RIELLO
BURNERS

FORCED DRAUGHT BURNER HANDBOOK

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First Edition

September 2001

RIELLO S.p.A.
Legnago - Italy

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SUMMARY

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PREFACE

With these pages, there has been the intention of collecting, in an only volume, formulas, data and information useful for who faces problems whom solution involves understanding of combustion and systems which use forced draught burners for heating production.

The text is divided up into five sections, arranged in logical sequence that permits the reader to first of all achieve the theoretical fundamentals of the chemistry-physics of combustion and the manufacturing technique of burners and systems which are closely linked, such as fuel feeding circuits. Proceeding through the manual, the reader will find examples for the selection and dimensioning of different types of burners and procedures for measuring the combustion efficiency. The last section is dedicated to a collection of ready-use tables and diagrams concerning the specific themes of combustion.

The single chapters can be consulted separately in order to gain knowledge of the specific procedures and information required for the activities to be performed.

The topics dealt underlie, before legislation, technical-scientific laws; for this reason, legislation is quoted only in cases of strict necessity. Each reader must therefore check the consistency of the information contained herein with current legislation in his own country.

With this handbook, Riello wishes to make available an instrument practical and useful, without claiming to have completely dealt theoretical and installation apsects related to the argument of combustion systems.

Published from:
RIELLO S.p.A.
Legnago - Italy

1

FUNDAMENTAL COMBUSTION PRINCIPLES

1.1 BASIC REACTIONS

Combustion is the rapid oxidation of a fuel. The reaction is accompanied by that visible physical phenomenon which is called "flame" and by the generation of energy that is known as "heat".
Carbon combines with oxygen to form carbon dioxide, a non-toxic gas, and releases heat according to the following formula:

$$C + O_2 \rightarrow CO_2 + Heat$$

Likewise, hydrogen combines with oxygen to form water vapour, with the consequent production of heat, according to the following formula:

$$2H_2 + O_2 \rightarrow 2H_2O + Heat$$

It is important to note that fuel and oxygen combine in well-defined and specific proportions. The quantities of oxygen and fuels in the mixture are in perfect or "stoichiometric" proportion, when they enable complete oxidation of the fuel without any oxygen residue.
If there were excess fuel or insufficient oxygen, we would say the mixture was rich and the flame was reducing. This type of combustion is defined as incomplete because, although certain fuel particles are completely oxidised by the oxygen, others do not receive enough oxygen and consequently their combustion is only partial. As the following reaction formula indicates, partial or incomplete carbon combustion is accompanied by the formation of carbon monoxide, a highly toxic gas:

$$2C + O_2 \rightarrow 2CO + Heat$$

The amount of heat produced here is lower than that which accompanies perfect combustion.
Incomplete or reducing combustion is sometimes required in special industrial, thermal treatments, but these conditions must be avoided under any other circumstances.
If, on the other hand, excessive oxygen is

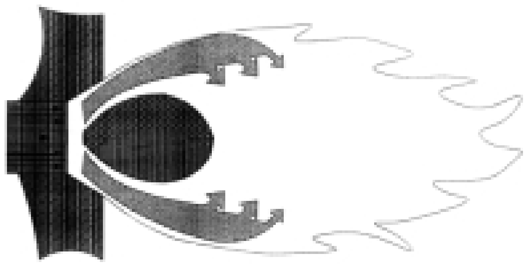


Diagram 1 *Elementary representation of a flame*

supplied to the mixture, we say the mixture is weak and combustion is oxidative.
Besides carbon dioxide and water vapour, other compounds are produced during combustion in smaller amounts, such as sulphur oxides, nitric oxides, carbon monoxide and metallic oxides, which are dealt with further on.

1.2 THE COMBUSTION SUPPORTER

The oxidative gas normally used is air, which is a gas mixture mainly made up of oxygen and nitrogen.
If we know the exact chemical composition of the fuel we can calculate the stoichiometric amount of oxygen and consequently the combustion supporter air required for combustion purposes.
The expression that provides the amount of stoichiometric air is as follows:

$$Wa = 11,51 \cdot C + 34,28 \cdot H + 4,31 \cdot S - 4,32 \cdot O \ [kg_{air}/kg_{fuel}];$$

oppure:

$$Wa = 8,88 \cdot C + 26,44 \cdot H + 3,33 \cdot S - 3,33 \cdot O \ [Nm^3_{air}/kg_{fuel}];$$

where C, H, S and O are respectively the mass percentages of carbon, hydrogen, sulphur and oxygen pertaining to the fuel composition.
In tables 2 and 3, the stoichiometric air amounts are illustrated of several fuels.
When "excess air" is used, i.e. an amount of oxygen higher than the stoichiometric amount, all the nitrogen and the portion of oxygen

Table 1	Principal fuels classification

Provenance / Phase	SOLID	LIQUID	GASEOUS
Natural	Wood, fossil carbons (pit coal)	Oil	Natural gas
Artificial (derivates)	Coke, charcoal	Petrol, kerosene, gasolio, feul oil	Methane, propane, butane, LPG, propane-air mix, town gas, bio-gas

which does not combine with the fuel, do not participate in the oxidation reaction.
Naturally, they absorb a certain amount of the heat produced during combustion, therefore the effective calorific energy is distributed over a greater volume of gas and the thermal level is lower (lower flame temperature).

The amount of oxygen contained in the air is around 21% in volume and approximately 23% in mass. However, these values are not fixed but vary in relation to altitude and temperature. The variations in oxygen concentrations in the air are due to the fact that heating the combustion supporter air and an increase in altitude produce the same effect, i.e. a reduction in air density. A decrease in air density corresponds to a decrease in the amount of oxygen.
At 1,000 metres above sea level, air density is nearly 10% lower than at 0 metres above sea level.
The change in air density and, consequently, in the amount of oxygen, due to a considerable change in altitude or temperature with respect to normal conditions (height equal to 100 metres above sea level and a combustion supporter air temperature of 15°C), is a parameter which should not be overlooked, as is better illustrated in section 2 in the paragraph relating to the examples for choosing the burner.

In certain conditions, for example when machinery is being used or other sources that create large amounts of humidity and steam, the amount of oxygen in the air could change, generally decreasing as relative humidity increases. The presence of dust, fibres in the intake combustion supporter air could also create problems with the combustion system.

1.3 THE FUELS

A fuel is a substance which reacts with the oxygen in the air and gives rise to a chemical reaction with the consequent development of thermal energy and a small amount of electromagnetic energy (light), mechanical energy (noise) and electrical energy (ions and free electrons).

Fuels can be classified on the basis of the physical state in which they are commonly found (solid, liquid or gaseous) and their nature (they are defined as natural or artificial fuels or derivatives).
The most commonly used fuels are classified in table 1 according to the above two criteria.

Natural fuels are concentrated in underground deposits from where they are extracted for

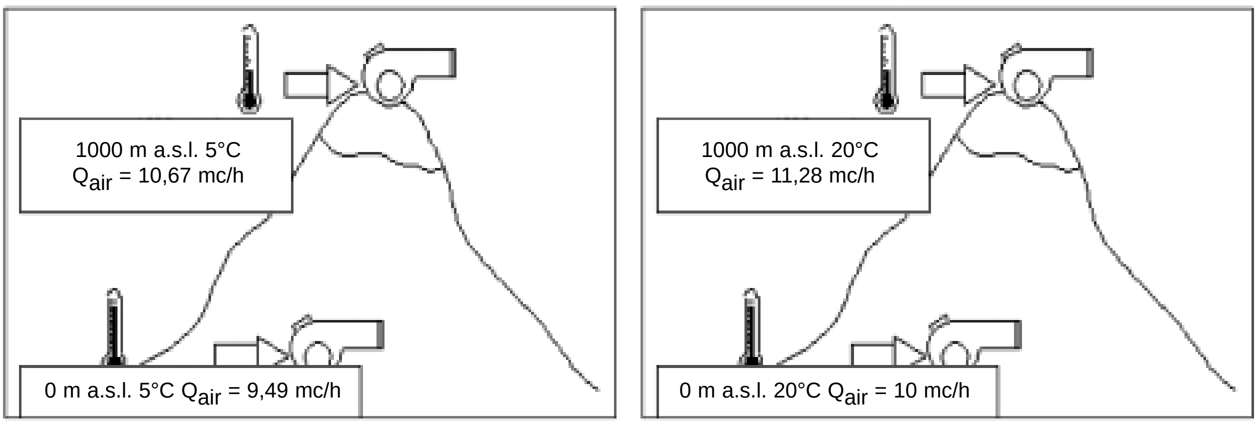


Diagram 2 Temperature and altitude influence on effective air delivery

processing; in fact, natural fuels are not directly utilisable as their composition is extremely variable and it is impossible to guarantee the safety and efficiency of the fuel beforehand.

Typical processing methods tend to transform natural fuels into artificial ones.
Charcoal is obtained from wood through slow and partial combustion inside a charcoal pit covered with earth.
Distilling low-grade fatty anthracite at a medium heat produces Coke.
Artificial gaseous fuels can be obtained from coal through synthesis processes such as dry distillation, partial oxidisation or reaction with water vapour.
All artificial liquid and gaseous fuels can be obtained by distilling oil.
Before natural gas can be used, the extremely pollutant fraction of H_2S must be removed, through desulphurisation, together with the inert fraction of CO_2.
All these processes are aimed at making the chemical composition of the fuels uniform, making them easier to use and more profitable.

In particular, liquid and gas fuels are easily transportable and can be finely proportioned to guarantee combustion efficiency. For these reasons, they are preferred in forced draught burners.
The characteristics that distinguish the fuels are:

• **Calorific value**
The definition of the calorific value of a fuel is the amount of heat developed during total combustion of the fuel mass unit.
The calorific value is measured in kJ/ Nm^3 (1) for gas and in kJ/kg for liquids and solids.
There are two calorific values:
- superior or gross calorific value (GCV) when all the water present at the end of combustion is in a liquid state;
- inferior or net calorific value (NCV) when all the water present at the end of conclusion is in a gaseous state.
The relationship that ties GCV to NCV is the following:
GCV=NCV+latent evaporation heat of the water produced by combustion
GCV therefore indicates the maximum theoretical amount of heat that can be extracted from the flue gases produced by combustion, using a user machine that condenses the discharge gases.
On the other hand, NCV indicates the maximum theoretical amount of heat that can be extracted from the flue gases produced by combustion using a user machine that does not condense the discharge gases.

• **Theoretical value**
This is the minimum quantity of combustion supporting air theoretically required to achieve ideal perfect stoichiometric combustion.
This is measured in Nm^3/Nm^3 for gaseous fuels or Nm^3/kg for liquid fuels.

The following principle physical characteristics are also important for gaseous fuels:

• **Air/relative density ratio**
This is the ratio of equal volume masses of dry air and gas measured under the same temperature and pressure conditions.

• **Dew point**
The water vapour in the flue gases condenses at this temperature. This temperature may vary considerably from the standard value of 100°C, as water vapour is mixed with other gases and is dependent on the flue gas acidity.
It is measured in degrees centigrade (°C).

• **Air explosive mixture**
This is the gas concentration range, expressed as a percentage, where the gas and air mixture is explosive.

• **Wobbe Index**
A parameter to define the heat released by a gas, obtained from the relationship between the gross caloric value and the square root of the density of the gas with respect to the air.

$$W = \frac{P.C.I.}{\sqrt{d}}$$

This index is extremely useful to evaluate the interchangeability of two different gaseous fuels: when a certain gas, even if it has different thermotechnical features from the basic gas, gives similar values to the Wobbe index, it can be used correctly in systems that had been originally designed to work with basic gas.

(1) A normal cubic meter (1 Nm^3) corresponds to a cubic meter of gas at atmospheric pressure (1,013 mbar) and a temperature of 0°C.

The parameter is also useful to calculate pressure drops (for gas train selection) when a different gas is used, included among those allowed as given in the instruction manual for the burner. Gas pressure drops can be expressed with the following formula:

$$\Delta P_2 = \Delta P_1 \cdot \left(\frac{W_1}{W_2}\right)^2$$

For liquid fuels, the following main physical features are also important:

• **Viscosity**
This is the intermolecular internal friction of a fluid, and therefore the macroscopic dimension that describes the level of resistance with which the fluid moves.
Dynamic viscosity (or absolute viscosity) is the tangential force per unit area of two parallel planes at unit distance apart when the space between them is filed with a fluid and one plane moves with unit velocity in its own plane relative to the other.
The SI unit of measure of dynamic or absolute viscosity is $N \cdot s/m^2$.
In practice, kinematic viscosity is used, defined by the absolute viscosity of a fluid divided by its density.
In the SI the kinematic viscosity is measured in m^2/s; in the technical system it is measured in cm^2/s; the unit is called "stoke" (St). Often, instead of the stoke its hundredth part is used, called centistoke (cSt) equal to mm^2/s.
To measure the liquid viscosity, various instruments have been perfected, called viscometers, which have induced numerous units of measure depending on the type of viscometer and measuring technique.

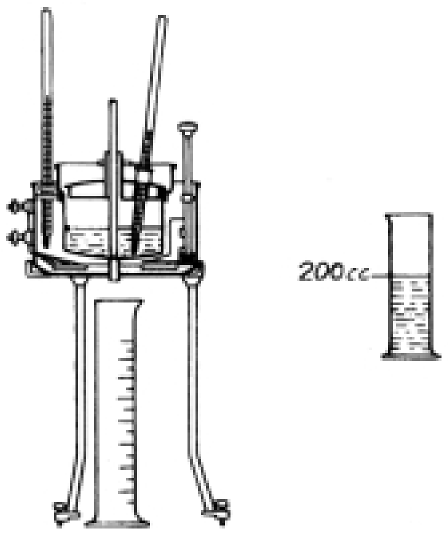


Diagram 3 *Example of a viscometer*

In Europe, the most common unit of measure besides the centistoke is the Engler degree (°E). The Engler viscometer is fundamentally a thermostatic container with a gauged hole, from which 200 cm^3 of the tested liquid flows out and the flow time is measured. The relationship between this time and the time for 200 cm^3 of water to flow out gives the °E viscosity.
Due to the large number of measuring instruments and units of measure that are available, it is difficult to convert the viscosity levels. Therefore, nomographs and approximate conversion tables are given in chapter 5.

• **Inflammability flash point**
This is the lowest temperature at which a mixture of air and vapours given off by a liquid fuel, in the specific conditions established by legislation and using an adequate primer, is inflammable. It is measured in degrees centigrade °C.

• **Self-igniting temperature**
This is the minimum temperature at which a mixture of fuel and combustion supporter spontaneously ignites without using a primer.
It is measured in degrees centigrade °C.

1.3.1 Gaseous fuels and their combustion

As we have seen in the opening paragraphs concerning combustion, in order to burn, a fuel it must be mixed with oxygen: the burners provide fuel gas and combustion supporter air in the right proportions, they mix them and give rise to their controlled combustion in a combustion chamber.
Gas burners can be classified according to two criteria. The first depends on the type of combustion supporter airflow into the burner and is classified as follows:

- Natural draught burners;
- Induced drauht burners;
- Forced draught burners.

Natural draught burners use the fuel gas supply pressure to pull the air through a Venturi system (normally performed by the nozzle) so that it is mixed with the fuel gas. As

a rule, with natural draught burners, the air flow rate generated by the Venturi effect on the gas flow (primary air) does not reach more than 50% of that required for perfect combustion, therefore a further airflow is required (secondary air) into the combustion chamber.
These burners can be extremely sensitive to combustion chamber depression (draught): greater is the depression, greater is the amount of air sucked in and mixed with the gaseous fuel, while, by contrast, a too low depression causes combustion without air, giving off extremely dangerous pollutants such as CO.
In order to guarantee consistent hygienically safe combustion, gas burning in induction burners usually takes place with high levels of excess air (100% and over).
In order to stabilise the operating conditions and be able to obtain combustion with lower excesses of air, induced draught burners are used, with a fan fitted up-stream (on the air side) or down-stream (to extract the combustion products) from the combustion chamber: in these conditions, primary air can reach 100% of that required for perfect combustion.
In forced draught burners, the air flow rate is guaranteed by elevated head pressure fans which make the draught operating conditions more or less independent of the burner operation. These can achieve high modulation ranges and can be combined with high-yield, and therefore "pressurised" heat generators, achieving optimum fuel and combustion air mixtures, making it possible to operate with low excesses of air and, therefore, increased combustion efficiency.
In this case, the fuel gas flows together in the air flow down-stream from the fan through several nozzles and usually requires greater delivery pressures than atmospheric burners, both due to the pressure drop by the nozzles and the need to control the air pressure.
A second criteria to classify burners depends on the percentage mixture of combustion air with respect to the fuel taken before stabilising the flame. The pre-mixing percentages can be classified as follows:

- Partial pre-mixed gas burners; (e.g. "premix" = 50%);
- Total pre-mixed gas burners ("premix" = 100%);
- Diffusion-flame burners.

In the first two cases, fuel-air mixing takes place partially or completely, before the mixture passes onto the combustion chamber: induction burners are therefore also pre-mix burners.
The pre-mixing allows rapid fuel oxidation reactions and therefore short flames; a consistent air-fuel mixture ratio also gives quieter combustion.
In diffusion-flame burners, the fuel-air mixing stage and the combustion stage are more or less simultaneous: to guarantee hygienically safe combustion with low excesses of air, increased turbulence is therefore necessary, thus also, producing high pressure drops on the air side.
Forced draught burners can be both pre-mixed or diffusion flame types.
Gaseous fuels can form explosive mixtures (2) with air. This happens when the fuel gas concentration is within a specific range and is variable for each individual fuel. To avoid any accumulation in the combustion chamber and in the flue pipe, legislation requires a minimum air only pre-purge time through the combustion chamber for induced draught burners.

Table 2 indicates the main gaseous fuels with their related thermo-technical characteristics.

(2) The explosion is nothing more than rapid combustion with a violent increase of pressure.

Table 2 Characteistics of gaseous fuels

THERMOTECHNICAL CHARACTERISTICS OF THE MOST COMMON GASEOUS FUELS

TYPE	NAME	EN 476 TYPE	CHEMICAL FORMULA OR COMPOSITION	BEHAVIOUR	DENSITY WITH RESPECT TO AIR at 15°C	AIR EXPLOSIVR MIXTURE %	INFERIOR CALORIFIC VALUE* MJ/Nm³	SUPERIOR CALORIFIC VALUE* MJ/Nm³	THEORETICAL AIR m³/Nm³	THEORETICAL HUMID FLUE GASES m³/Nm³	CO_2 MAX. IN VOL %	WATER VAPOUR IN FLUE GASES kg/Nm³	DEW POINT °C	WOBBE INDEX MJ/Nm³
PURE GAS	METHANE	G20	CH_4	Light gas	0,555	5÷15	34,02	37,78	9.56	10,44	11,65	1,61	58	45,87
	PROPANE	G31	C_3H_8	Heavy gas	1,555	2.4÷9.3	88	96,65	24,37	26,16	13,7	3,29	54	77,51
	BUTANE	G30	C_4H_{10}	Heavy gas	2,094	2÷7.6	116,09	125,81	32,37	34,66	14	4.20	53	80,22
MIXTURES	NATURAL GAS	G25	Example: CH_4 86% N_2 14%	Heavy gas			29,25	32,49						37,39
	LPG	-	Example: Propano 70% Butano 30%	Heavy gas	1,686	2.1÷9.5	101,6	110,4	26.32	28.23	13,74	3.51	54	78,25
	PROPANE AIR-MIX	-	Example: Gas 26.2% / Air 73.8% Gas composition: Propane 95% / Butane 5%	Light gas	1,149	7.5÷36	24,7	26,9	5,75	6,96	13,67	0,87	54	23,04
	TOWN GAS	-	Example: H_2 54.5% CO 5.5% CH_4 24.4% etc.	Light gas	0,397	5÷30	20,9	23,6	4,33	4,98	10,03	0,92	62	33,17
	BIOGAS	-	Example: Methane 64% Carbone dioxide 34.6% Nitrogen 1.2% Hydrogen 0.2%	Light gas	0,896	7.8÷23.4	23	25,5	6.12	7,05	16,85	1,03	57	24,3

* The calorific value refers to the normal cubic meter (Nm³), i.e. to 1m³ of gas at atmospheric pressure and at 0 °C. The m³ standard (stm³) of gas fitters on the other hand refers to 15 °C. 1stm³ gives 8200 kcal. In measurments made with gas counter it is advisable to refer to the standard m³.

Table 3 Names of liquid fuels in the main countries of use

	viscosity a 20°C		viscosity a 50°C																	
viscosity [cSt]	1,2	6,25	6,25	11,8	21	29	37	45	53	60	68	76	114	150	180	222	300	380	460	550
viscosity [°E]		**1,5**	**1,5**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**15**	**20**	**24**	**30**	**40**	**50**	**60**	**70**
ITALY	**kerosene**	**Gasolio**	**Olio combustibile fluidissimo**			**Olio combustibile fluido**		**Olio combustibile semifluido**		**Olio combustibile semidenso**						**Olio combustibile denso**				
U.K.	**kerosene**	**Gas Oil (D)**	**light fuel oil (E)**					**medium fuel oil (F)**						**heavy fuel-oil (G)**						
GERMANY		**heizol EL**	**heizol L**			**heizol M**		**heizol s**								**heizol ES**				
FRANCE	**kerosene**	**Fioul Domestique**	**Fioul moyen**			**Fioul Lourd No 1**										**Fioul Lourd No 2**				
HOLLAND	**Gasoil HBO I**	**Gasoil HBO II**	**Navy special**							**Middlezware stookolie**				**Zware stookolie**						
GREECE		**Light fuel oil**	**Mazoyt n°1**												**Mazoyt n°2**					
NORWAY		**Gasoil**	**Fyringsolje no 2**	**Fyringsolje no 5**										**Fyringsolje no 6**						
BELGIUM		**Gasoil / fuel-oil leger**	**fuel-oil moyen**			**fuel-oil lourd**								**fuel-oil extra-lourd**						
SPAIN		**Gas-oil**	**Fuel-ligero**			**Fuel-pesado no 1**										**Fuel-pesado no 2**				
DENMARK		**Fyringsgasolie**	**Fuel olie 1500"**													**Fuel olie 3500"**				
USA	**# 1**	**# 2**	**# 4**			**# 5**										**# 6**				
JAPAN	**keros**	**gasoil**	**light fuel oil**					**medium fuel oil**								**heavy fuel-oil**				
SOUTH AFRICA	**Paraffin**	**No 0 Diesel**	**LO 10**	**FO 150**										**HFF (HFO)**						
viscosity a 100°F [sec Saybolt univ.]	32	38	45	85	125	140	173	205	250	280	315	355	529	700	831	1080	1420	1780	2180	2500
viscosity a 100°F [sec Redwood 1]	28	35	41,5	76	110	120	155	185	220	250	280	320	466	625	733	925	1250	1600	1900	2200
	viscosity a 100°F (37,78°C)																			

Note: Table is to be considered as indicative

Table 4 Characteristics of liquid fuels

ITALIAN COMMERCIAL TRADE NAME	PHYSICAL ASPECT	DENSITY AT 15 °C RELATIVE TO WATER	VISCOSITY		CHEMICAL COMPOSITION				WATER AND DEPOSITS %max	INFERIOR CALORIFIC VALUE MJ/kg	SUPERIOR CALORIFIC VALUE MJ/kg	THEORETICAL AIR m_3/kg	THEORETICAL HUMID FLUE GASES m^3/kg	WATER VAPOUR kg/kg	DEW POINT °C	CO_2 MAX vol.%	PRE-HEATING FOR COMBUSTION
			at 38 °C E / c St	at 50 °C E	C %	H %	S %rnax	ASHES %max									
KEROSENE	Distilled liquid	0.81 (0.77-0.83)	1.6 c St at 20 °C	-	86.3	13.6	0.25	-	0.05	43,1	46,3	11.33	12.02	1.26	-	14.99	NO
GASOLIO	Distilled liquid	0.84 (0.815-0.875)	2-7.4 c St 1.12-1.6 °E	-	86.3	13.4	0.50* (0.30)	0.01	0.05	42,7	45,6	11.24	11.89	1.20	95	15.25	NO
GASOLIO PESANTE	Distilled liquid	0.86-0.875	6-12 c St at 20 °C 1.4-2 °E at 20 °C	-	-	-	-	-	-	-	-	-	-	-	-	-	YES** 70-80 °C
OLIO COMBUSTIBILE FLUIDO	Oily black residue of distillation + light oil	0.92	-	3-5	-	-	3	0.10	1	41	43,7	10.7	-	1.05	145	15.6	YES 100-110 °C
OLIO COMBUSTIBILE SEMIFLUIDO	Oily black residue of distillation + light oil	0.94	-	5-7	-	-	4	0.15	1	-	-	-	-	-	-	15.7	YES
OLIO COMBUSTIBILE DENSO ATZ (high S content)	Oily black residue of distillation	0.97	-	>7	85	11	4	0.20	2	40,2	42,7	10.57	11,14	0.99	150	15.8	YES 120-140 °C Also pre-heated for transport purposes
OLIO COMBUSTIBILE DENSO BTZ (low S content)	Oily black residue of distillation	0.97	-	>7	85	11	1	0.20	2	40,2	42,7	-	-	0.99	130	15.8	YES 120-140 °C Also pre-heated for transport purposes

* This limit is subject to the matters laid down by Presidential Decree No. 400 of 8/6/82. It is valid for zones A and B, established by Law 615 of 13/7/66 and subsequent amendments. As of 1/7/85 the limit in the zones A and B fell to 0.3% max.
** Pre-heating is at present not allowed by Circular No. 73 dated 29/7/71 of the Ministry of Industry

1.3.2 Liquid fuels and their combustion

Liquid fuels are made up of various types of hydrocarbons, i.e. molecules formed by carbon and hydrogen atoms. Unlike gaseous fuels, liquid fuels contain molecules of extremely long-chain hydrocarbons giving oils a liquid physical state.
Liquid fuels cannot be directly mixed with the oxygen in the air, but must be atomised in extremely small droplets that have a considerable reaction surface.
Inside the generator combustion chamber, the droplets of atomised liquid fuel heat up and evaporate releasing hydrocarbon vapours that ensure spontaneous fuel combustion.
For combustion to be perfect, the drops of liquid fuel must be oxidised within the body of the flame; if not, the drops form particles of particulate, as more fully illustrated in the next paragraph on pollutants.
Atomisation of liquid fuel is one of the main tasks performed by a burner. There are several atomisation methods for liquid fuels. The main ones are listed below:

- Mechanical atomisation;
- Pneumatic atomisation;
- Centrifugal atomisation;

The most common method is "mechanical atomisation" where liquid fuel atomisation is the result of the mechanical pressure exerted on the liquid, when it reaches the atomising nozzle, against the walls made up of small run channels and helicoidal holes in the nozzle. With this method, the fuel oil is split into a great deal of extremely small droplets due to brusque flow variations and impact against the walls due to high pressure (10-30 bar). The size of the droplets depends on the exerted pressure, the type of nozzle and the viscosity.
Another system is the "pneumatic system" where the droplets of liquid fuel are further atomised by a second high-pressure fluid (compressed air or vapour) when they come out from the mechanical nozzle. This system guarantees excellent fuel atomisation levels for dense fuel oils, but at the same time more complicated construction, with auxiliary liquid being present (working pressure 5-9 bar) and consequently higher installation cost compared to the classic mechanical method.
In rotary atomisation, the drops of fuel are formed by applying a centrifugal force to the liquid fuel with the aid of a rotating cup; this method is used for certain industrial-type burners.

On today's market, systems are available aimed at improving the mechanical-type atomisation system using modified fuels; basically, fuel oil and water emulsions are used. The individual drops of fuel oil are emulsified into water droplets that, within the body of the flame, become water vapour causing the fuel oil drops to explode. Therefore more efficient fuel atomisation results.
Independently from the type used for achieving a satisfactory atomisation degree, the liquid fuel must have a sufficiently low viscosity.
The viscosity of liquid fuel is strictly linked to the temperature; when the temperature increases the viscosity decreases. Therefore, certain liquid fuels must be pre-heated to achieve the desired viscosity.

As a rule, fuel oil viscosity required for achieving satisfactory atomisation is much lower than that requested by pumping systems, consequently a much higher temperature is required to achieve adequate atomisation than that requested for pumping the fluid. All these aspects translate into specific plant engineering choices that are fully covered in the section dedicated to plant engineering.
The viscosity required for obtaining sufficient fuel oil atomisation varies according to the type of burner and type of nozzle used. Generally, the nozzles require oil viscosity between 1.5 and 5 °E at 50°C in relation to the type of fuel. This viscosity value also determines the pre-heating temperature value. For example: supposing we use a fuel oil with viscosity of 22°E at 50°C to obtain a value of 3°E needed by the nozzle to obtain the right atomisation, the fuel must be pre-heated to a temperature between 90 and 100°C.

Table 3 gives the names used for liquid fuels in the main countries, while Table 4 shows the related thermotechnical characteristics.

1.4 POLLUTANT COMBUSTION EMISSIONS

The leading polluting agents to be considered in the combustion phenomenon are:

- sulphur oxides, generally indicated by SOx and mainly made up of sulphur dioxide SO_2 and sulphur trioxide SO_3;
- nitric oxides, generally indicated by NOx

and mainly made up of nitric oxide NO and nitrogen dioxide NO_2;

• carbon monoxide CO;

• total suspended particles indicated by TSP (PST).

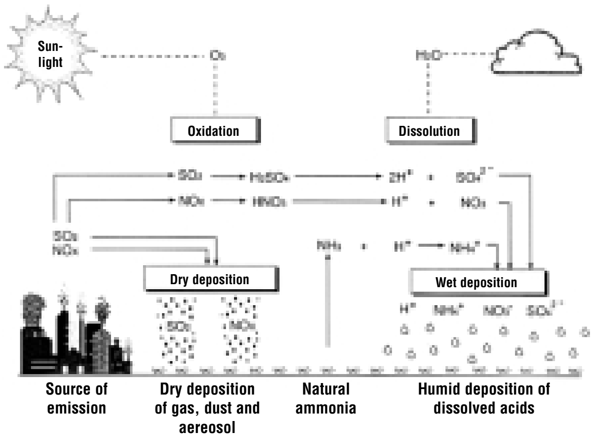


Diagram 4 *Acid rain formation process*

There are essentially three systems that can be adopted to reduce the pollutants:

• preventive systems, by acting on the fuel before subjecting it to combustion, trying to reduce the amount of polluting agents. A typical case is represented by liquid fuels (light oil and naphtha) where the sulphur content tends to be reduced;

• primary systems, by acting on the process and combustion equipment (burner), so that combustion takes place under the best conditions thus reducing the formation of pollutants;

• secondary system, by acting on the combustion gases, to break down the polluting components before they are expelled into the atmosphere.

During the design and the construction of civil engineering combustion plants, the first two systems should be used to reduce pollutants, therefore using "clean" fuels, gas, LPG, light oil and naphtha with a low sulphur (BTZ oil) and nitrogen content, and using special burners to minimise the polluting emissions of nitric oxides (Low-NOx burners);

The third system is recommended for use only in large industrial and thermoelectric plants, which mainly work with naphtha, where the large amount of burnt fuel and, consequently, emitted combusted gases justify the creation of specific breakdown plants.

1.4.1 Sulphur oxides

Sulphur oxides are considered toxic for man; especially sulphur dioxide SO_2 causes irritation of the eyes and lachrymation when the concentration exceeds 300 mg/Nm^3. The danger threshold is estimated at around 500 mg/Nm^3.

Moderate temperatures favour the formation of sulphur oxides. Under normal conditions of high combustion flame temperature and excess air around 20%, nearly all the sulphur present in the fuel oxidises into sulphur dioxide (SO_2).

Sulphur dioxide is a colourless gas with a density equal to nearly two and a half that of air, therefore it tends to stratify towards the ground in closed environments.

The percentage of sulphur trioxide SO_3 may become important for low combustion temperatures (400°C), for example in start-up phases of installations, or when the excess air is extremely high or even when pure oxygen is used.

Sulphur trioxide SO_3 reacts with water vapour, generating sulphuric acid H_2SO_4 that is corrosive even in the vaporous phase, thus damaging for heat generators, which are usually metallic.

Measures for controlling sulphur dioxide SO_2 and sulphur trioxide SO_3 emissions are first of all based on preventive action on fuels during their production, by using catalytic desulphurisation processes.

In large heavy oil-operated plants, the breakdown of nitric oxides is mainly by absorption using water-based solutions, which can achieve yields of around 90%.

1.4.2 Nitric oxides

Nitric monoxide NO is a colourless, odourless gas which is insoluble in water. It represents more than 90% of all nitric oxides formed during high-temperature combustion processes; it is not particularly toxic when its concentration ranges between 10 and 50 ppm. and it is non-irritant.

Nitrogen dioxide NO_2 is a visible gas even in low concentrations, with a browny-reddish colour and a particularly acrid smell; it is highly corrosive and an irritant to the nasal membranes and eyes when concentrated at 10 ppm, while causing bronchitis at concentrations of 150 ppm and pulmonary

oedema at 500 ppm, even if exposure lasts just a few minutes.
The nitric monoxide NO present in our city air can transform itself into nitrogen dioxide NO_2 by means of photochemical oxidation.
Three models of nitric oxide formation exist, which lead to the formation of different types of nitric oxide (different by type of origin but not by chemical composition); respectively they are:

- thermal nitric oxides (thermal NOx);
- prompt nitric oxides (prompt NOx);
- fuel nitric oxides (fuel NOx);

Thermal nitric oxides are formed by the oxidation of atmospheric nitrogen (contained in combustion supporter air) under high temperature (T>1500 K) and high oxygen concentration conditions, and represent the majority of nitric oxides in the case of gaseous fuels (methane and LPG) and in general in fuels which do not contain nitrogenous compounds.
Prompt nitric oxides are formed by means of the fixation of atmospheric nitrogen by hydrocarbon fragments (radicals) present in the flame area; this method of forming oxides is extremely rapid thus giving rise to the name prompt.
Their formation essentially depends on the concentration of radicals in the first stage of the flame; for oxidative flames (combustion with excess of oxygen), their contribution is negligible, while in the case of rich mixtures and for low-temperature combustion, their contribution may reach 25% of the full nitric oxides total.
Nitric oxides from fuel form by means of oxidation of the nitrogenous compounds contained in the fuel within the flame area, and their production is significant when the fuel's nitrogen content exceeds 0.1% in weight, essentially only for liquid and solid fuels.
Diagram 5 shows the contribution for each type of NOx depending on the type of fuel (under conditions of standard combustion):

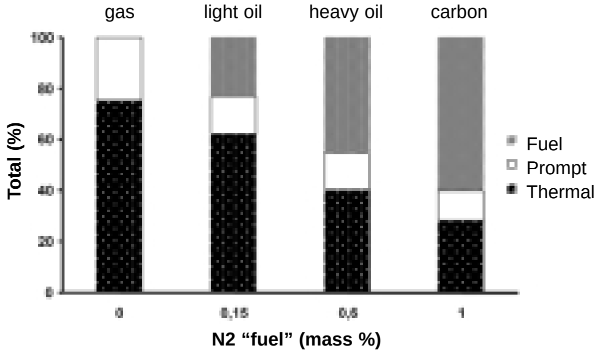


Diagram 5 *Type of NOx for certain fuels*

The portion of prompt nitric oxides remains more or less constant, whereas the portion of fuel nitric oxides grows and the portion of thermal nitric oxides decreases as we gradually pass to fuels with a higher molecular weight.

1.4.2.1 Reduction of the NOx in gaseous fuel combustion

The thermal nitric oxides in gaseous fuels represent up to 80% of total emissions; a drop in the combustion temperature achieves inhibition of the formation of these compounds.
The temperature drop may be carried out in various ways.
- specific thermal load reduction
An initial method involves decreasing the output burnt per unit of volume of the combustion chamber, resorting in fact to a "de-rating" of the boiler and thereby decreasing its nominal thermal capacity (if it is an existing boiler) or over-sizing the combustion chamber for new projects.
- combustion chamber architecture
Another solution that can be adopted involves the use of heat generators, which have combustion chamber architecture with three flue passes, in other words without inversion of the flame. In flame-inversion boilers, the combustion products re-ascend the combustion chamber during the flow inversion stage, confining the actual flame within an effectively smaller volume than that of the combustion chamber; a portion of the radiant energy possessed is also reflected towards the flame itself. These conditions lead to a flame temperature increase, with a consequent increase in the thermal nitric oxides. The same situation occurs in applications where the chamber wall temperatures are high, i.e. in furnaces or in boilers with fluid at high temperatures.
- air and gas pre-mixing
Under normal conditions the combustion systems are calibrated so that they can operate with excess air; this excess air establishes a lower effective combustion temperature than the adiabatic temperature and sometimes one that is lower than the limit which enables activation of the nitric oxide formation mechanism (1500 K).
Since the flame is a typically turbulent domain fed by two reactants that are difficult to mix perfectly, it is normal that zones with different

stoichiometry are formed therein. These will inevitably include zones with stoichiometric conditions or approximate to stoichiometric conditions: the temperatures in these regions will, without doubt, be so high that they will give rise to conditions suitable for thermal NOx formation.
These observations suggest action which could impede, or at least reduce, such situations: pre-mix the air and gas accurately before combustion and develop the latter without excessive turbulence, in such a way as to come close to the stoichiometric conditions which would result in the required excess air (and therefore come close to the theoretical combustion temperature which can be derived from the stoichiometric one) whatever the region effected by combustion.
An additional, positive contribution may be provided by uniform flame distribution- better still if this distribution covers wide surface areas - which also prevents the presence of small tongues of flame, inside which the temperatures would certainly be higher.
Examples of these techniques are represented by porous surface areas (in metallic or ceramic materials) or those comprising masses of fibres or characterised by the presence of tiny microscopic holes: up-stream from these surfaces, attempts are made to create an accurate as possible pre-mixing, while on the external surfaces the objective is to obtain a region of flame which is fairly uniformly extended and distributed.
This technique appears the most promising in absolute terms for Low NOx gas solutions, even if for now the high costs involved and certain constructive restrictions hinder its use, especially in the field of higher outputs.

- staged combustion

The nitric oxide formation speed is greater when in proximity to a ratio of fuel to combustion supporter, which is equal to the stoichiometric ratio. In order to obtain low nitric oxide formation speeds, it is possible to operate with a combustion system which on average operates with realistic excess air, but which presents internal zones with ratios between fuel and combustion supporter which are extremely different from the stoichiometric one, thereby resorting to a segregation of the fuel. As far as application is concerned, the aerodynamics of the flame and the fuel distribution can be adjusted, creating zones high in excess of air alternated with zones without, thus maintaining the global stoichiometry under correct operating conditions.

- combustion products blow-by

By diluting a portion of the burnt gases in the combustion supporter air, a decrease in the combustion supporter oxygen concentration is obtained together with a reduction of the flame temperature since part of the energy developed by combustion is immediately transferred to the inerts present in the fuel gas.
The breakdowns achievable by means of this technique are extremely high in the case of gaseous fuels, because of ensuring a sufficient mixing between the blown-by combustion products and the combustion supporter/fuel mixture.
It is relatively easy to active a blow-by of the combustion products in the flame directly within the chamber in the case of thermal generators, and therefore burners, with low outputs by resorting again to particular aerodynamics induced by the burner combustion head, As a rule these internal blow-bys are extremely high (around 50 %) because the fuel/combustion supporter reactants mixing is less effective and the flue gas temperature is relatively high (900 ÷ 1000 K).

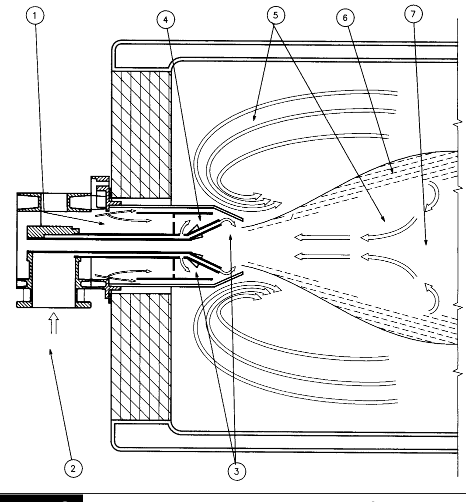


Diagram 6 *Functional layout of combustion process for a gas burner - Blue flame type.*
1 Comburent air - 2 Fuel gas intake - 3 Fuel gas jets- 4 Flame stabilization zone (combustion under stoichiometrics) - 5 Recirculed combustion products - 6 Over stoichiometrics combustion - mixture of fuel air, gas and recirculed combustion products - 7 "Cold" zone of the flame.

Sometimes, it is preferable to resort to an external blow-by of the combustion products for machines with a greater output due to the difficulties in obtaining this mixing, which only add to the aggravation of other problems (for example: the elevated combustion head load

Diagram 7 *Monobloc burner (light oil - Low NOx) of BGK series*

losses).
By means of an auxiliary fan, or by utilising the burner fan itself, a portion of the combustion products is withdrawn at the heat generator outlet and is re-conveyed up-stream from the combustion head, so as to pre-mix it with the combustion supporter air.

Even if in certain situations, a blow-by inside the combustion chamber may not be enough for extremely low NOx emission values (and this is the case now mentioned regarding high output burners), this technique may be applied in association with the staged combustion technique illustrated previously.

1.4.2.2 Reduction of the NOx in liquid fuel combustion

The substantial difference - within certain limits of the nitric oxides argument - between the combustion of gas and the combustion of liquid fuels, is the presence in the latter of nitrogen under the guise of nitrogenous compounds; this is at the origin of NOx production from fuels which, dependent on the nitrogen content in the oil, may also represent a significant portion of the total NOx.
As far as thermal and prompt nitric oxides are concerned, the same observations expressed in the case of gaseous fuels (discussed previously) apply.
With regard to nitric oxides from fuels, it has been observed that in reducing environments the nitrogen contained in the fuel may not produce the undesired NOx, but simple and harmless molecular nitrogen N_2.
The combustion chamber is an environment devoted to the oxidation of fuel; however, it is possible to create zones rich in fuel in certain regions of the flame and therefore form reducing situations for the purpose of producing molecular nitrogen N_2 in the place of nitric oxides.
For example, steps could be taken to supply the initial combustion region with 80 % of the total combustion supporter air together with 100 % of the fuel and, further on, supply the remaining 20 % of the combustion supporter air (over firing air).
These applications are still considered to be in the experimental stages for burners used in the sectors of standard heating systems. By contrast, these techniques are already a consolidated asset in the industrial systems of thermoelectric power stations.

1.4.3 Carbon monoxide (CO)

Carbon monoxide is a colourless, odourless and tasteless gas. Its relative density compared to air is 0.96, therefore it does not

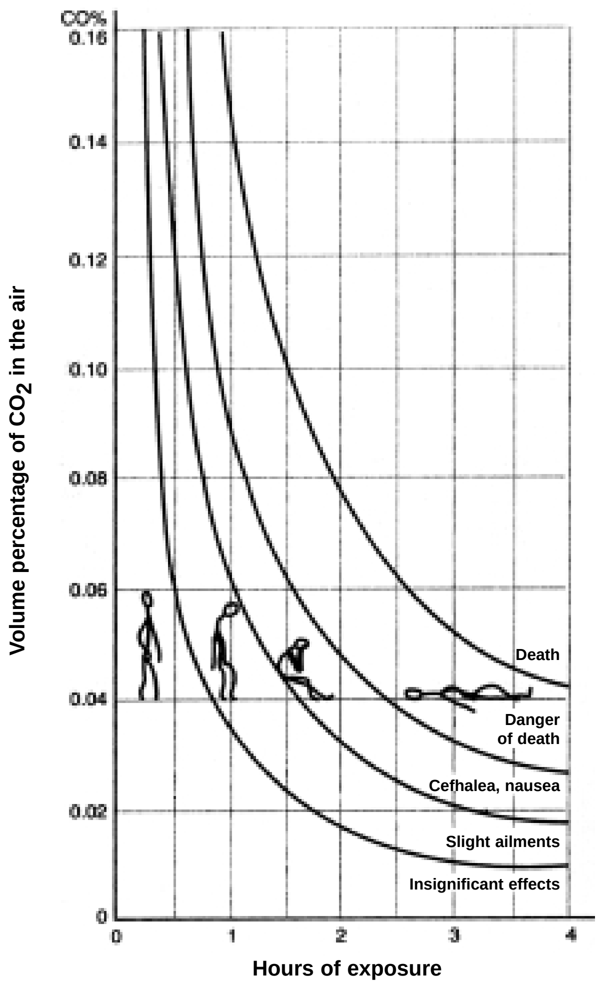


Diagram 8 *Effects of carbon monoxide*

disperse with ease.
Carbon monoxide is a toxic gas which, if inhaled, reacts extremely rapidly with the haemoglobin in the blood, preventing the regular oxygenation of the blood and, as a consequence, of the entire organism.
The physiological effects on the organism are the result of the concentration of the carbon monoxide in the air and the length of exposure of the person to said concentration.
The diagram 8 illustrates the effects of carbon monoxide in relation to the two previously mentioned parameters.

Carbon monoxide is present in combustion gas as the result of the partial oxidation of the carbon present in the fuel. Its presence in burnt gases is an indication of low combustion efficiency, because the carbon not perfectly oxidised to CO_2 corresponds to heat not produced.
Carbon monoxide is present in burnt gases when combustion is carried out with too little air than is required stoichiometrically and therefore the oxygen is insufficient for the purposes of completing the carbon oxidation reactions. Heating systems are responsible to a minimum extent for the presence of carbon monoxide in the atmosphere, since the combustion processes are usually conducted with excess air higher than the stoichiometric requirements.

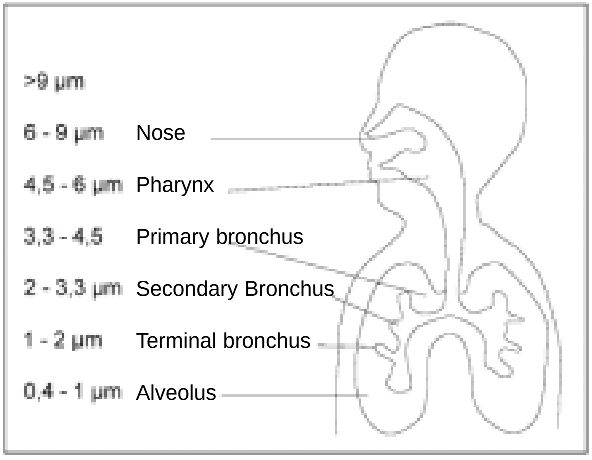
1.4.4 Total suspended particles

This category of polluting substances includes those emissions comprising particulates, inert solid substances and metallic components. The size of these particles varies from a minimum of 0.01 microns up to a maximum of 500 microns.
The particulate may be of an organic or inorganic nature; in more detail, three categories can be identified:

- Ashes, comprising inorganic, incombustible substances (metals, etc..), drawn into the combustion gases;
- Gas black, made up of the fuel residues which have evaporated but not oxidised;
- Cenopheres, comprising fuel residues that have been partially oxidised since they have been burnt before vaporising.

The finest portion of the particulate is called soot.
The danger of the particles is inversely proportionate to the size. Damage caused is

Diagram 9 *Penetration of the particles in the respiratory system*



mainly to the respiratory tracts and pulmonary system.
The diagram 9 indicates the depth these particles can penetrate the human body according to their size.

Furthermore, in the pulmonary alveolus the particulate acts as the vehicle transporting the metallic oxides (vanadium, nickel etc..) which may be produced during combustion and which are absorbed by the particles of the particulate.
Only the particles with an equivalent diameter smaller than 10 microns are sufficiently light to remain suspended in the air for several hours and therefore represent real danger of being inhaled by man.
Metal oxide emissions depend on the concentration of the respective metals in the fuel, therefore for civil installations the best solution for reducing emission essentially involves the utilisation of fuels with low heavy metals concentrations.
Gas black is usually produced in particular areas of the flame where there are insufficient oxygen or low temperature conditions; therefore, in order to avoid the formation of gas black it is necessary to guarantee the combustion process an adequate temperature, a sufficient quantity of oxygen and considerable turbulence in order to obtain a satisfactory mix between the fuel and the oxygen.
Cenospheres form when the nebulisation and volatilisation process of the liquid fuels in the combustion chamber is irregular or hindered by the elevated viscosity and low volatility of the fuel.
In order to reduce the production of these components, it is necessary to increase the

period spent in the combustion chamber and guarantee the fuel an adequate excess of oxygen.
The maximum concentration of the pollutants in the flue gases deriving from combustion, is a value fixed by national legislation and in certain cases differs in relation to particularly sensitive regions and/or metropolitan areas.

1.4.5 Comments on the emission of CO_2

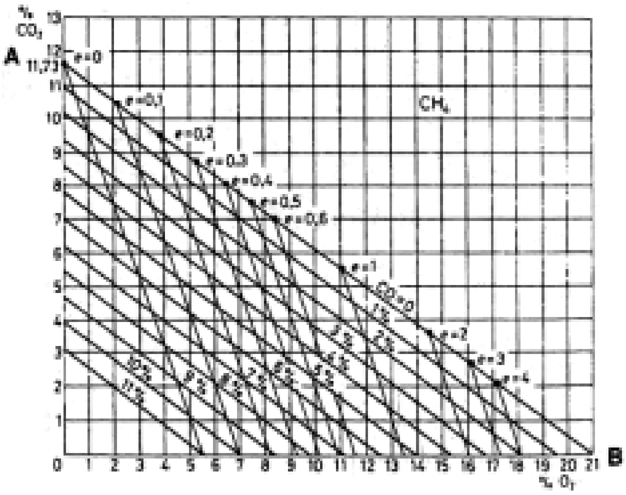
Carbon dioxide CO_2 was purposefully not included among the other pollutants mentioned since, together with water vapour, it is one of the main products of any hydrocarbon combustion process.
The accumulation of carbon dioxide in the atmosphere is the main culprit of the phenomenon known as the "greenhouse effect". Accumulated carbon dioxide absorbs part of the infrared radiation emitted by the earth towards the atmosphere, thus retaining the heat. The outcome of this phenomenon is the progressive increase in the Earth's average temperature with disastrous resulting consequences.
The absolute carbon dioxide quantity produced by combustion depends solely on the quantity of carbon C present originally in the burnt fuel. The greater the C/H ratio of the fuel, the greater the quantity of carbon dioxide produced will be.
As a rule, all energy produced being equal, liquid fuels produce more carbon dioxide than gaseous fuels.
As we will see in the next section concerning the control of combustion, the percentage of CO_2 in the flue gases must be as high as possible to achieve greater output.
All energy produced being equal, a lower CO_2 percentage in the combustion flue gases leads to the system being less efficient and, as a consequence, more fuel being oxidised.
This fact should not mislead the reader however, since even if we vary the percentage of CO_2 in the flue gases in relation to the dilution of the flue gases, the total quantity of CO_2 remains more or less unchanged.

1.5 COMBUSTION CONTROL

For combustion to be perfect, a quantity of air must be used greater than the theoretical quantity of air anticipated by the chemical reactions (stoichiometric air).
This increase is due to the need to oxidise all the available fuel, avoiding the possibility that fuel particles are only partially oxidised or completely unburnt.
The difference between the quantity of real air and stoichiometric air is defined as excess air.
As a rule, excess air varies between 5% and 50%, in excess of stoichiometric depending on the type of fuel and burner.
Generally, the more difficult the fuel is to oxidise, the greater the amount of excess air required to achieve perfect combustion.
The excess air cannot be too high because it influences combustion efficiency; an extremely large delivery of combustion supporter air dilutes the flue gases, which lowers the temperature and increases the thermal loss from the generator. In addition, beyond certain limits of excess air, the flame cools excessively with the consequent formation of CO and unburnt materials. Vice versa, an insufficient amount of air causes incomplete combustion with the previously mentioned problems. Therefore, the excess air must be correctly calibrated to guarantee perfect fuel combustion and ensure elevated combustion efficiency.

Complete and perfect combustion is verified by analysing the carbon monoxide CO in the burnt flue gases. If there is no CO, combustion is complete.
The excess air level can be indirectly obtained by measuring the uncombined oxygen O_2 or the carbon dioxide CO_2 present in the combustion flue gases.
The excess air will be equal to around 5 times the percentage, in terms of volume, of the oxygen measured.
When measuring CO_2, the amount present in the combustion flue gases depends solely on the carbon in the fuel and not on the excess air; it will be constant in absolute quantity and variable in volumetric percentage according to the greater or lesser dilution of the flue gases in the excess air. Without excess air, the volumetric percentage of CO_2 is maximum, with rising excess air, the volumetric percentage of CO_2 in the combustion flue gases decreases. Taking lower excesses of air, higher quantities of CO_2 correspond and vice versa, therefore combustion is more efficient when the quantity of CO_2 is near to the maximum CO_2.
The composition of the burnt gases can be represented in simple graphic form using the

Diagram 10 *Combustion triangle for methane gas*



"combustion triangle" or Ostwald triangle, diversified according to the fuel type.
Using this graph, (which is also included in chapter 5), we can obtain the CO content and the value of the excess air noting the percentages of CO_2 and O_2.
By way of example, the combustion triangle for methane gas is presented below.

The X-axis shows the percentage content of O_2, the ordinate axis shows the percentage content of CO_2. The hypotenuse is traced between point A corresponding to the maximum percentage of CO_2 (dependent on the fuel) with zero amount of O2 and point B corresponding to zero values of CO_2 and maximum values of O_2 (21%). Point A represents the stoichiometric combustion conditions, point B the absence of combustion. The hypotenuse is the position of the points representing perfect combustion without CO.

FUEL	CO_2 max in vol [%]	CO_2 advised[%]	Air excess [%]
METHANE	11,65	9,8 - 11	20 - 8
L.P.G.	13,74	11,5 - 12,8	20 - 10
TOWN GAS	10,03	8,2 - 9	20 - 10
LIGHT OIL	15,25	12 - 14	30 - 12
HEAVY OIL	15,6	11,8 - 13	35 - 20

Table 5 *Maximum recommended CO_2 values for the various fuels*

The straight lines corresponding to the various CO percentages are parallel to the hypotenuse.
Let us suppose that we have a system powered by methane gas whose measurements of burnt gas have given readings of 10% CO_2 and 3% O_2; from the triangle relating to methane gas we can obtain the CO value equal to 0 and an excess air value of 15%.

Table 5 shows the maximum CO_2 values achievable for the different types of fuel and those advised in practice in order to achieve perfect combustion. We should note that when the maximum levels are obtained in the central column, a control system must be provided for the emissions as described in chapter 4.

For liquid fuel powered systems, the flue gas index must also be measured, using the measurement method devised by Bacharach industries. The method involves sucking a specific volume of burnt gas with a small pump, and passing it through a filter of absorbent paper. The side of the filter fouled by the gas turns light grey-to-black in colour depending on the amount of soot present. The colour can be compared with a sample scale, made up of 10 shaded disks varying from 0 (white) to 9 (black). The sample scale number corresponding to the filter used determines the Bacharach number.
The limit value of this number is established by national anti-pollution legislation and depends on the type of liquid fuel.

To determine the particulate material contained in the combustion flue gases, there are two basic measurement concepts:

- graviometric;
- reflectometry.

Using the graviometric method, the particulate material suspended in the burnt flue gases is collected on special filters and subsequently weighed, to give the weight difference of the filter before and after the experiment was carried out.
The reflectometry principle determines a conventional index (equivalent black smoke) on the basis of the light absorption capacity, measured by reflectometry, of the particulate material collected on a filter after carrying out the experiment.

1.5.1 Combustion efficiency

Combustion efficiency is defined as the ratio between thermal energy supplied by combustion and the primary energy used for combustion

$$\eta = \frac{\text{energy supplied by combustion}}{\text{primary energy used}} \cdot 100\ (\%)$$

Primary energy is equal to the amount of fuel used for its calorific value; in paragraph 1.3 two calorific values have been defined: the superior value and the inferior value, therefore when we define the combustion efficiency, we must specify which of the two we are referring to.
The difference between the primary energy used and the energy supplied by combustion is equal to the thermal energy contained in the flue gases produced by combustion; the η combustion efficiency of a generator can therefore be calculated using the following formula:

$$\eta = 100 - P_S \quad [\%]$$

where:
η = efficiency of the heat generator;
P_S = thermal output lost through the flue pipe;

The conventional formulas used for determining losses through the flue pipe are:

$$P_s = \left(\frac{A_2}{CO_2} + B\right) \cdot (T_f - T_a)$$

if the concentration of available oxygen in the combustion flue gases is known, or:

$$P_s = \left(\frac{A_1}{21 - O_2} + B\right) \cdot (T_f - T_a)$$

if the concentration of carbon dioxide in the combustion flue gases is known.
where:
P_S = thermal output lost through the flue pipe [%];
T_f = flue gas temperature (°C);
T_a = combustion supporter air temperature (°C);
O_2 = oxygen concentration in the dry flue gases [%];
CO_2 = carbon dioxide concentration in the dry flue gases [%];
A1, A2 and B are empirical factors whose values, with reference to the N.C.V., are shown in table 6.

FUEL	A_1	A_2	B
METHANE	0,66	0,38	0,010
L.P.G.	0,63	0,42	0,008
LIGHT OIL	0,68	0,50	0,007
HEAVY OIL	0,68	0,52	0,007

Table 6 Factors for calculation of the combustion efficiency

1.5.2 Measurement units for combustion emissions

Legislation issued by various countries establishes certain limits expressed in various units of measurement, generally using ppm (parts per million), mg/Nm³ or mg/kWh with reference to 0% or to 3% of available oxygen present in combustion products.
The transformation from ppm to mg/Nm³ can be done using the equation of the perfect gases correctly modified:

$$1\,ppm = \frac{p}{R \cdot T} \cdot (PM) \quad [\text{mg/Nm}^3]$$

where:
p = pressure = 1 atm under normal conditions;
R = gas constant = 0.082;
T = temperature = 273 K under normal conditions;
PM = molecular weight;

The application of the previous equations for certain pollutants provides the following values:

COMPONENT	ppm	mg/Nm³
CO	1	1,25
NO	1	1,34
NO_2 (NO_X)	1	2,05
SO_2	1	2,86

Table 7 Equivalence in weight of ppm in the main polluting emissions

If the percentage of available oxygen in the flue gases differs from the usual reference values of 0% and 3%, the value of the E measured emissions can be converted - whatever their measurement unit is - to the equivalent referring to the reference percentages in the following ratios:

$$E_{3\%O_2} = E_{measured} \cdot \frac{18}{21 - \%O_{2\ flue\ gases}}$$

$$E_{0\%O_2} = E_{measured} \cdot \frac{21}{21 - \%O_{2\ flue\ gases}}$$

If the CO_2 percentage of the burnt flue gases is known, the following ratios can be used:

$$E_{3\%O_2} = E_{measured} \cdot \frac{\%CO_{2\ max\ at\ 0\%\ O_2}}{\%CO_{2\ flue\ gases}}$$

$$E_{0\%O_2} = E_{measured} \cdot \frac{\%CO_{2\ max\ at\ 0\%\ O_2}}{\%CO_{2\ flue\ gases}}$$

where the maximum concentration percentages of CO_2 are valid for the various fuels:

FUEL	CO_2 max at 0% of O_2 [%]	CO_2 max at 3% of O_2 [%]
METHANE	11,65	10
L.P.G.	13,74	11,77
TOWN GAS	10,03	8,6
LIGHT OIL	15,25	13,07
HEAVY OIL	15,6	13,37

Table 8 *Maximum values of CO_2 at 0% and at 3% of O_2 for the various fuels*

Therefore, from an operational point of view, having analysed the combustion products, we can proceed with converting the value measured from ppm to mg/Nm^3 and then relate this value to that referring to 0% or to 3% of oxygen.

The conversion from ppm to mg/kWh relates to the type of fuel used, with reasonably good approximation, the following equivalents can be used:

methane (G20 100% CH_4):

NO_x : ppm$_{3\%O2}$ = 2.052 mg/kWh
CO : 1 ppm$_{3\%O2}$ = 1.248 mg/kWh

light oil (PCI= 11.86 kWh/kg):

NO_x : 1 ppm$_{3\%O2}$ = 2.116 mg/kWh
CO : 1 ppm$_{3\%O2}$ = 1.286 mg/kWh

2

THE FORCED DRAUGHT BURNER

2.1 FOREWORD

The term "burners" describes a series of equipment for burning various types of fuel under suitable conditions for perfect combustion. The burner operates by sucking in the fuel and the combustion supporter air, mixes them thoroughly together and safely ignites them inside the heat generator furnace. The following are the parts that make up the burner and are analysed individually in the following paragraphs.

- The combustion head which mixes the fuel and the combustion supporter, and generates an optimum form of flame;
- The combustion air supply, comprising of the fan and any pipes for taking the air to the combustion head;
- Fuel supply, comprising components used for regulating the fuel flow and guaranteeing the safety of the combustion system;
- The electrical and control components required for firing the flame, the electricity supply to the motors and thermal output regulation developed by the burner.

Forced draught burners can control the combustion of all gaseous fuels (methane, LPG, town gas) and liquid fuels (diesel oil, heavy oil). Burners exist which use only one family of fuel (liquid or gaseous) and others that can use both called "DUAL FUEL" (double fuel) burners. Thus, three classes of burner are obtained:

- burners of gas fuels which use only gas fuels;
- burners of liquid fuels which use only liquid fuels;
- burners of liquid and gas fuels (DUAL FUEL) which use both gas and liquid fuels.

Forced draught burners can also be classified according to the type of construction, specifically:
- monobloc burners;
- separate fired burners or DUALBLOC.

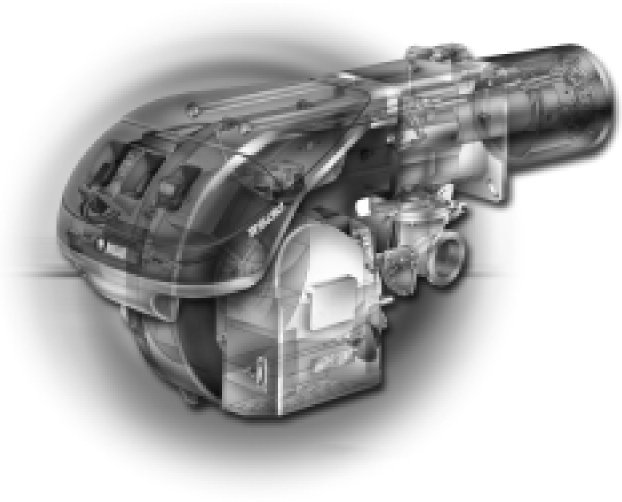
In monobloc burners, the fan and pump are an integral part of the burner forming a single body.
In DUALBLOC burners, the fan, pump and/or other fundamental parts of the burner are separate from the main body (head).
Monobloc burners are those most commonly used in output ranges varying from tens of kWs to several Mw output.
For higher outputs, or for special industrial processes, DUALBLOC burners are used.

Depending on output delivery type, we can classify forced draught burners according to the following distinctions:

- single-stage burners;
- multi-stage burners;
- modulating burners;

Single-stage burners operate with single-state delivery, fuel delivery is invariable and the burner can be switched on or off (ON-OFF).
Multi-stage burners, usually two-stage or three-stage, are set for running at one or more reduced output speeds or at maximum output (OFF-LOW-HIGH or OFF-LOW-MID-HIGH); switchover from one stage to another can be automatic or manual.
Two-stage burners also include versions called progressive two-stage, where changeover from one stage to another is through a gradual increase in output and not with sudden step increases.

Diagram 11 *Gas fired monobloc burner*



In modulating burners, the delivered output is automatically varied continuously between a minimum and maximum value, for optimum delivery of the thermal output in relation to system requirements.
Diagram 12 below shows the types of output delivery.

Forced draught burners now available on the market can function coupled with generators with a pressurised or unpressurised furnace or those with a slight negative draught condition.

The diagrams represent, respectively, an outline configuration of a monobloc two-stage diesel-fired burner, a monobloc modulating methane gas-fired burner and a DUALBLOC dual-fuel (gas and fuel oil) fired burner.
It is clear that in DUALBLOC burners, the fan and certain parts dedicated to treating the fuel are separate from the main body of the burner, but their function does not change. Therefore, in this manual, monobloc burners and those with separate fans are dealt with on an equivalent basis, except for certain technical characteristic aspects.

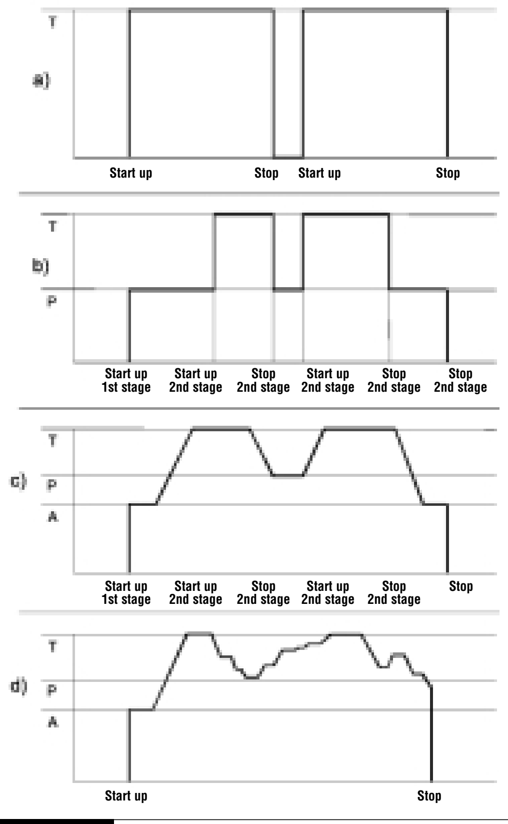


Diagram 12 *Burners operating chances: a) one-stage, b) two-stage, c) progressive two-stage, d) modulating*

2.2 THE FIRING RANGE OF A BURNER

The firing range of an Forced draught burner is a representation in the Cartesian plan of an area, showing the pressure of the combustion chamber on the Y axis and the thermal output on the X axis; this area indicates working conditions under which the burner guarantees combustion corresponding to the thermo-technical requirements. The firing range is obtained referring to data gained from experimental trials, which are correct in a prudent sense.
Diagram 14 shows the representation of the firing range of a series of diesel oil-fired burners.
Quite often, the firing range of just one burner is not illustrated, but rather a whole series, as in the diagram above.
The output can be expressed in kW or in kg/h of fuel burnt, while the pressure is expressed in either mbars or in Pa.

The firing range is obtained in special test boilers according to methods established by European legislation, in particular:

- EN 267 standard for liquid fuel burners;
- EN 676 standard for gaseous fuel burners;

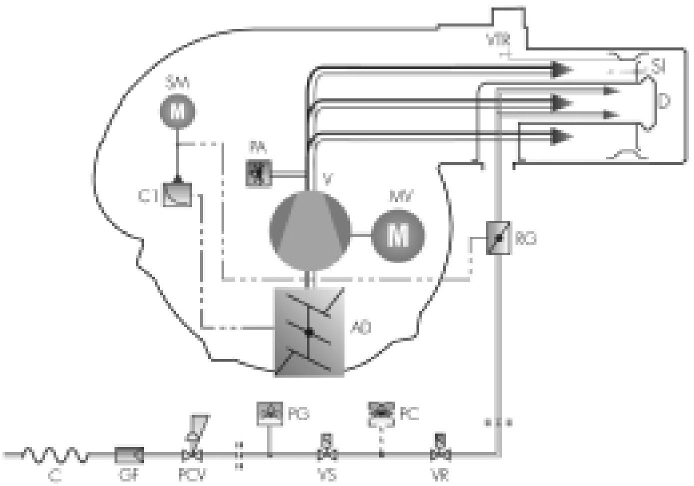
These standards establish the dimensions that the test combustion chamber must have. Diagram 15 shows the graph indicating the dimensions of the test furnace for forced draught burners powered by liquid or fuel gas. The graph represents the average dimensions of commercial boilers; if a burner is to operate in a combustion chamber with distinctly different dimensions, preliminary tests are advisable.

The firing range is determined experimentally under particular atmospheric pressure and combustion supporter air temperature test conditions. All the graphs showing the firing range for a forced draught burner must be accompanied by pressure and temperature indications, generally corresponding to a pressure of 1000 (3) mbar (100 m above sea level) and combustion supporter air temperature of 20°C.
If running conditions are considerably different from the test conditions, certain corrections must be made, as shown in chapter 3 of this manual.

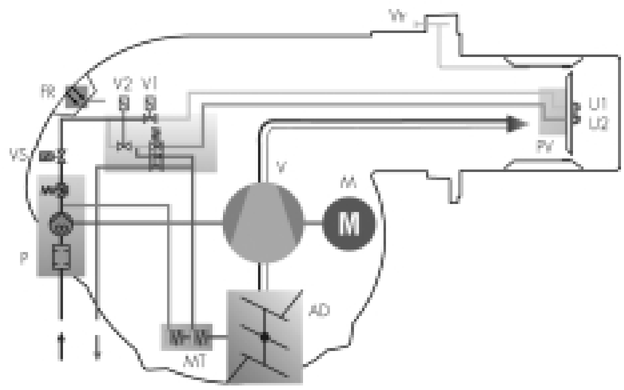
(3) Normal pressure at 100 m above sea level.

Diagram 13 *Layout of two monobloc (RL and RS series) burners and dual bloc (TI) burner*

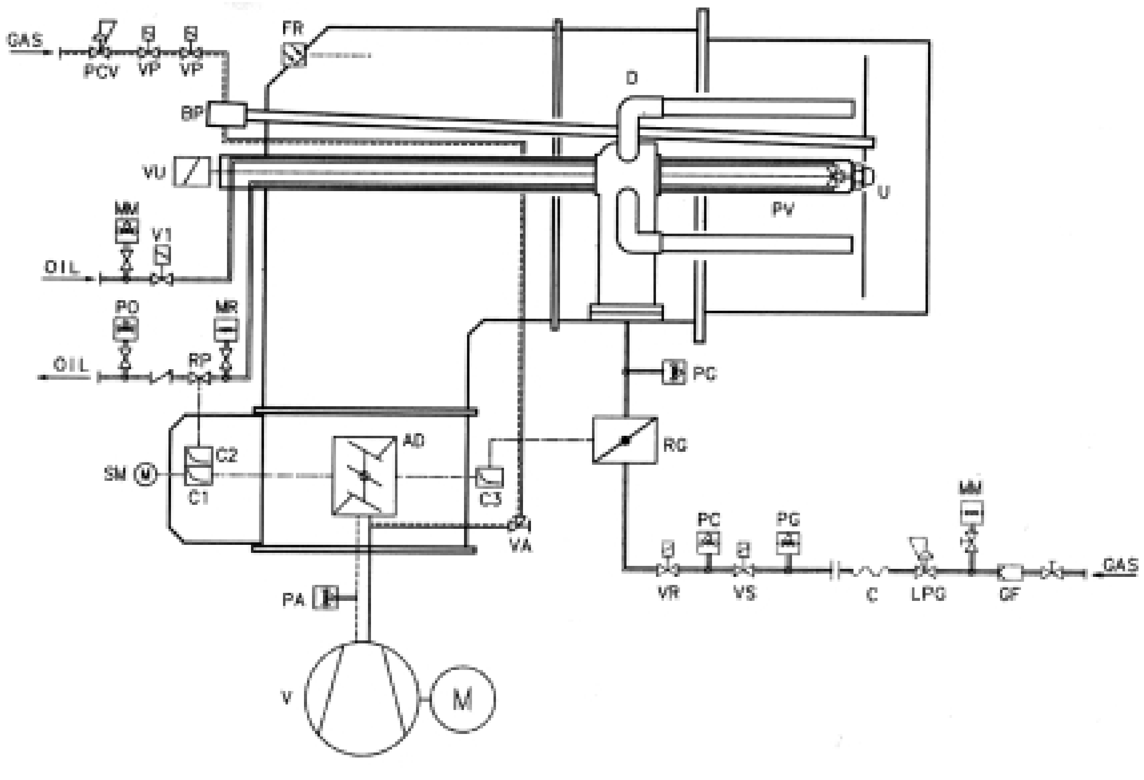
RS series



RL series



TI series



FR P.E. cell
V1,V2 Delivery oil valves
PV Nozzzle holder
AD Air damper
M Air fan and pump motor
P Pump with oil filter and pressure regulator
MT Two-stage hydraulic ram
V Supply air fan
VS Gas safety valve
VTR Combustion head regulation screw
U,U1,U2 Nozzles

GF Gas filter
PA Air pressure switch
PC Leak detection control device
C Anti-vibrant joint
PCV Gas pressure governor
PG Minimum gas pressure switch
PGM Maximum gas pressure switch
RG Gas flow regulator (butterfly valve)
C1 Air moudulating cam
SM Cam's servomotor
VR Gas regulation valve

BP Pilot burner
C2 Oil modulating cam
C3 Gas modulating cam
D Gas distributor
LPG Low pressure gas governor
MM Oil delivery gauge
MR Oil return gauge
PO Maximum oil pressure switch
SI Ionisation probe
VP Pilot vaves
VU Nozzle's safety valve

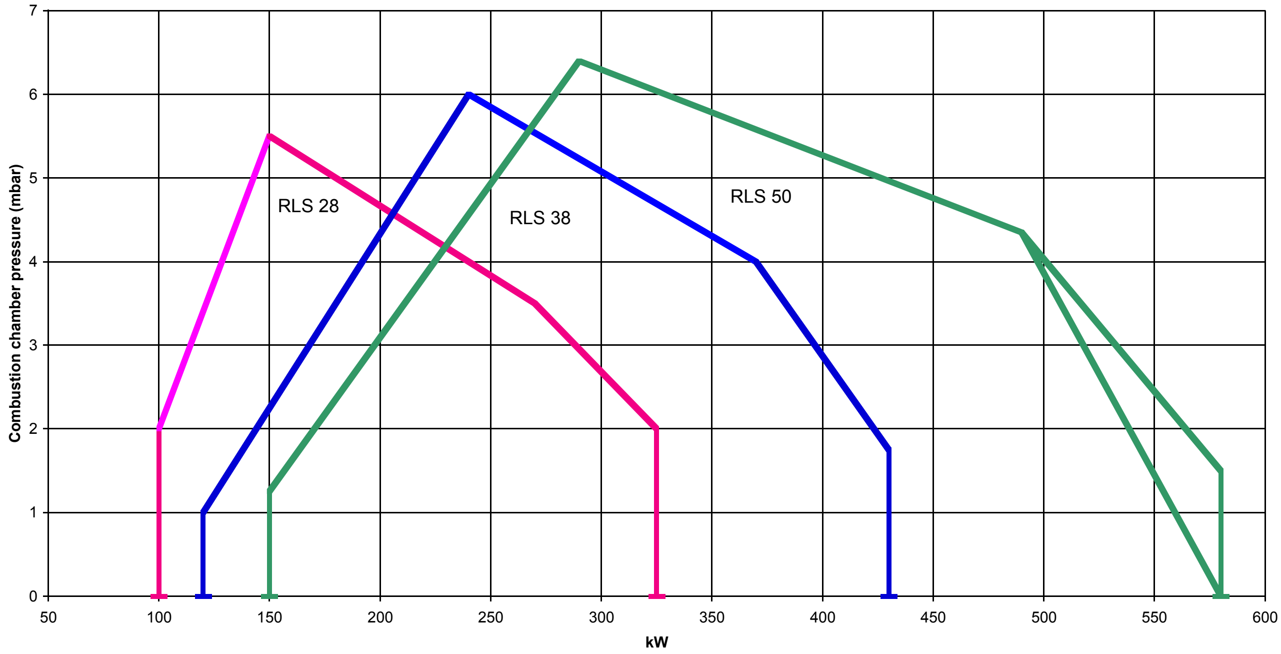
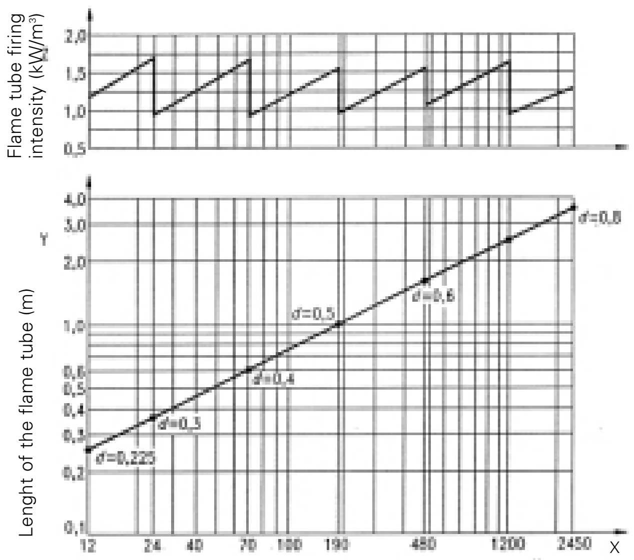


Diagram 14 *Firing ranges of Riello RLS series dual fuel burners*

The burner should be chosen so that maximum required load falls within the burner's firing range. The firing point is found by tracing a vertical line in correspondence with the required output value and a horizontal line in correspondence with the pressure in the combustion chamber; the intersection point between the two lines is the system firing point, including the burner and the heat generator.



d = diameter of the flame tube

Diagram 15 *Test combustion chamber for burners*

As far as the choice of single-stage burners is concerned, the firing point can be in any point of the burner's firing range.
For two-stage burners the firing range is ideally divided into two areas, left (zone A) and right (zone B) of the vertical line traced for the point corresponding to the maximum head available, as indicated in Diagram 16.
The firing point corresponding to the maximum output and, consequently, to operate in the 2nd stage, must be chosen within zone B. Zone B provides the maximum output of the burner in relation to the combustion chamber pressure.
The 1st stage output should be chosen within the minimum/maximum declared formula and normally falls within zone A. The absolute lower limit corresponds to the minimum value of zone A. However, in certain cases, for example where the use of two-stage burners is required in domestic hot water boilers, it is advisable not to go below 60-65% of maximum output in the first stage, and, due to condensation problems, to maintain flue temperature around 170-180°C at maximum load and at 140°C at 65% of load.
As far as progressive or modulating two-stage burners are concerned, the burner should be chosen in a similar manner to two-stage burners. In modulating burners, the nearer the firing point is to the maximum output values of the firing range, the higher the modulating formula of the burner. The modulating formula is defined as the turn down ratio between the maximum output and the minimum output expressed in proportion (e.g. 3:1 or 5:1).

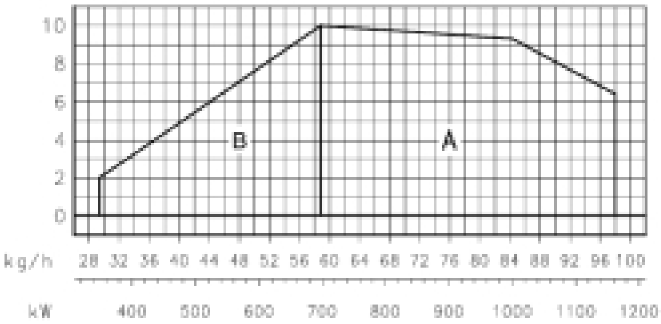


Diagram 16 *Firing range of Riello RLS100- two stage gas/light oil burner*

The firing range in cartesian format can only be determined for monobloc forced draught burners, where the coupling of the combustion head with the fan is defined by the burner manufacturer. The situation changes for dual bloc burners, as the combination of the combustion head and the fan is delegated to the design engineer. In this case, the firing range is characteristic only for the combustion head and determined in relation to the maximum and minimum fuel output allowed to the head itself.

For example Diagram 17 shows the firing ranges for combustion heads in the Riello TI Series Burners, where the darker area represents the range of optimum choice recommended by the manufacturer.

The choice regarding the size of the combustion heads should be made solely in relation to the output and the temperature of the combustion supporter air.

2.3 TYPICAL SYSTEM LAYOUT DIAGRAMS

The burner is just one of the components of a larger and more complex system for generating heat. Before passing on to the description of the individual parts of a combustion system, the following pages show the plant engineering diagrams for the various types of fuel, regulation of the thermal load and systems for optimising fuel control. By overlapping the diagrams of each of these layout classes, the entire combustion system can be designed.

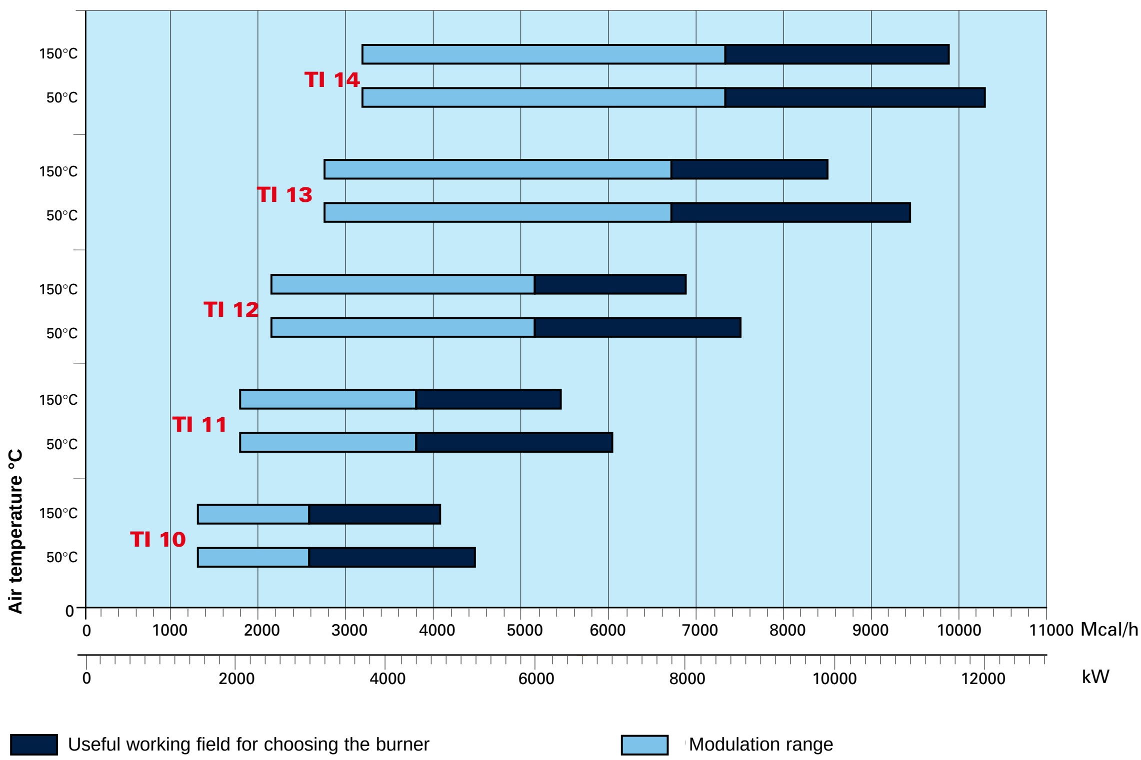


Diagram 17 *Firing range for Riello TI Series Burner combustion heads*

2.3.1 System engineering diagrams for gas fired burners

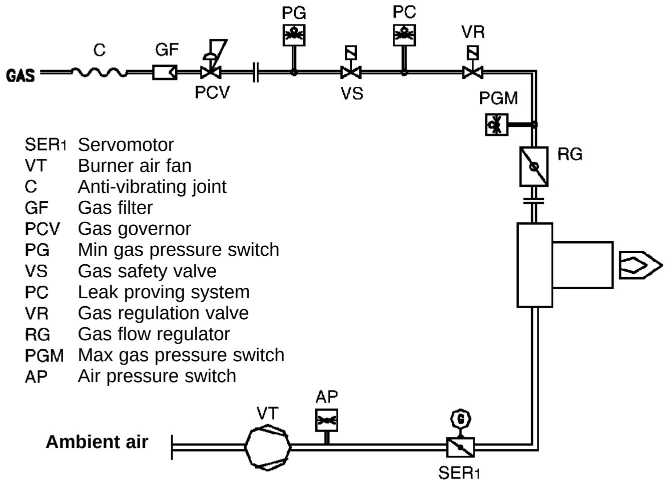


Diagram 18 *Gas supply - low pressure circuit*

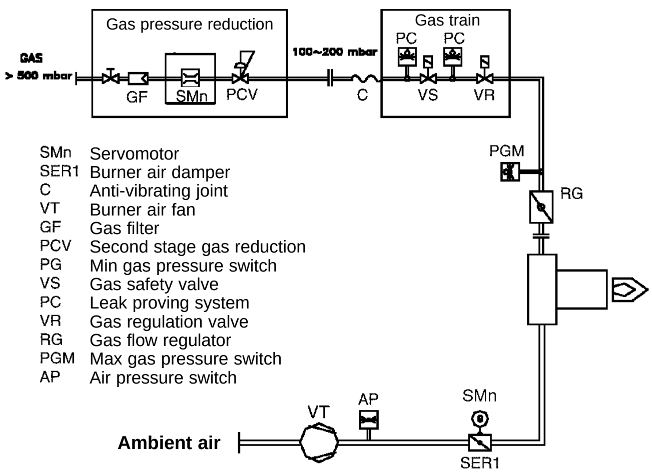


Diagram 19 *Gas supply - high pressure circuit*

2.3.2 System engineering diagrams for burners using low viscosity (< 6 cSt) liquid fuels - diesel oil / kerosene

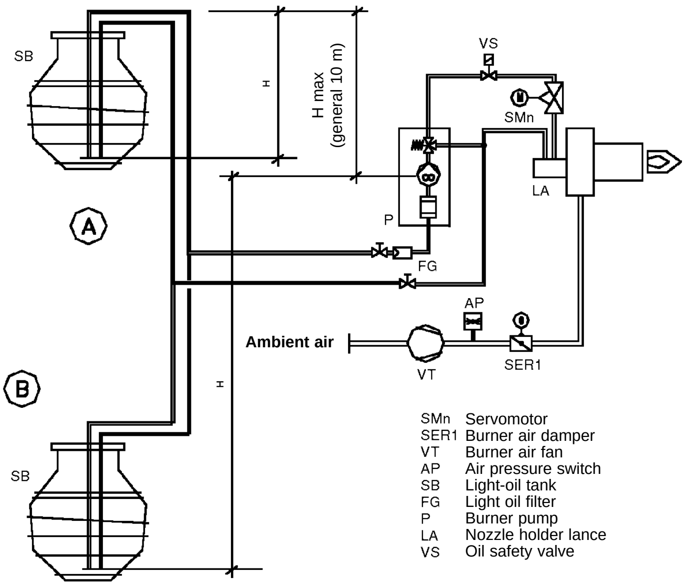


Diagram 20 *A = Drop-type plant with fedding from top; B = air intake system*

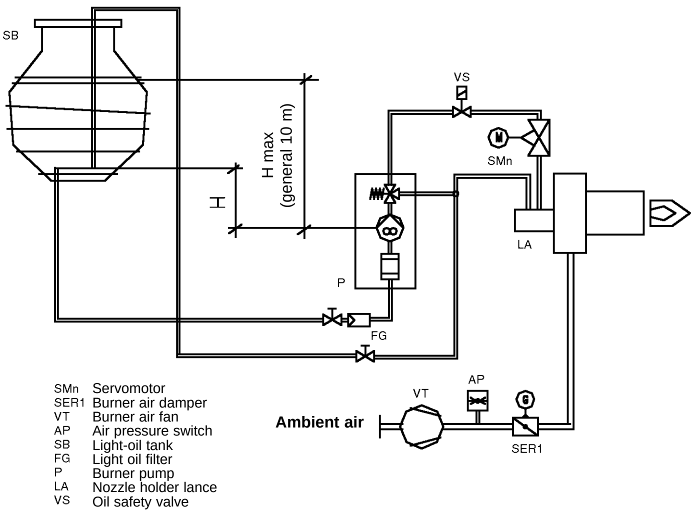


Diagram 21 *Drop-type plant with feeding from bottom*

SMn Servomotor
SER1 Burner air damper
VT Burner air fan
AP Air pressure switch
SB Light-oil tank
FG Light oil filter
P Burner pump
LA Nozzle holder lance
VS Oil safety valve
P2 Light-oil ring pump
MM Oil pressure gauge

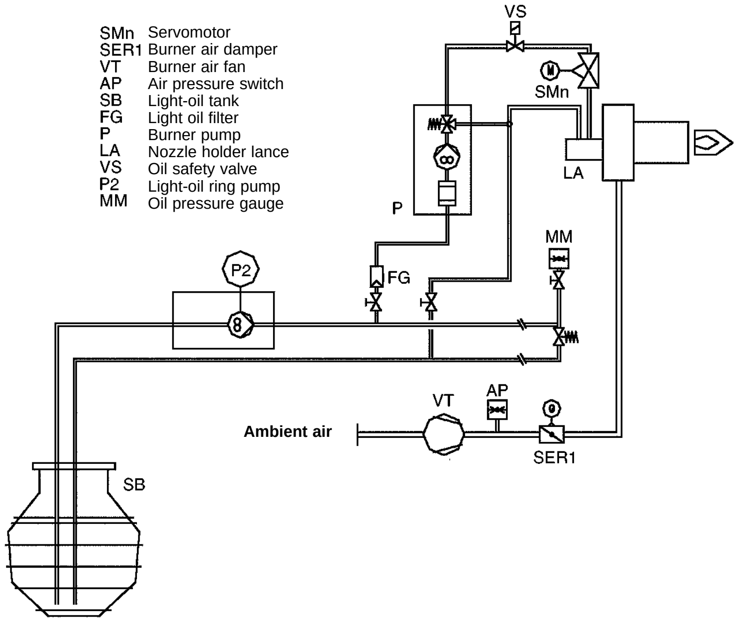


Diagram 22 *System with ring under pressure*

2.3.3 System engineering diagrams for burners using high viscosity (> 6 cSt) liquid fuels

BR Dualbloc burner
BR1 Monoblock burner
B Gas separator bottle
r Oil filter 300 microns degree
MM Oil delivery gauge
P(MP) Pumping group – transfer ring
P1(MP) Pumping group – burner circuit with filter and pressure regulator
P2(MP) Pumping group – main circuit with filter
PS Electrical oil preheater
RS1 Pump heater resistance
RS2 Oil tank heater resistance
SB Main oil tank
SB2 Service oil tank
T Thermometer
TC Temperature switch regulation

Tr Flexible oil line
Tr1 Flexible oil line pressure 25-30bar
TP Temperature probe
TM Max oil pressure switch
VC Vent valve
VG Supply air fan
VR1 Oil pressure regulator valve of the oil burner ring
VR2 Oil pressure regulator valve of the oil main ring
VS Preheater safety valve
VG7 Safety valve
VG Double valves
—∿— Heavy oil pipe with electrical preheater cable

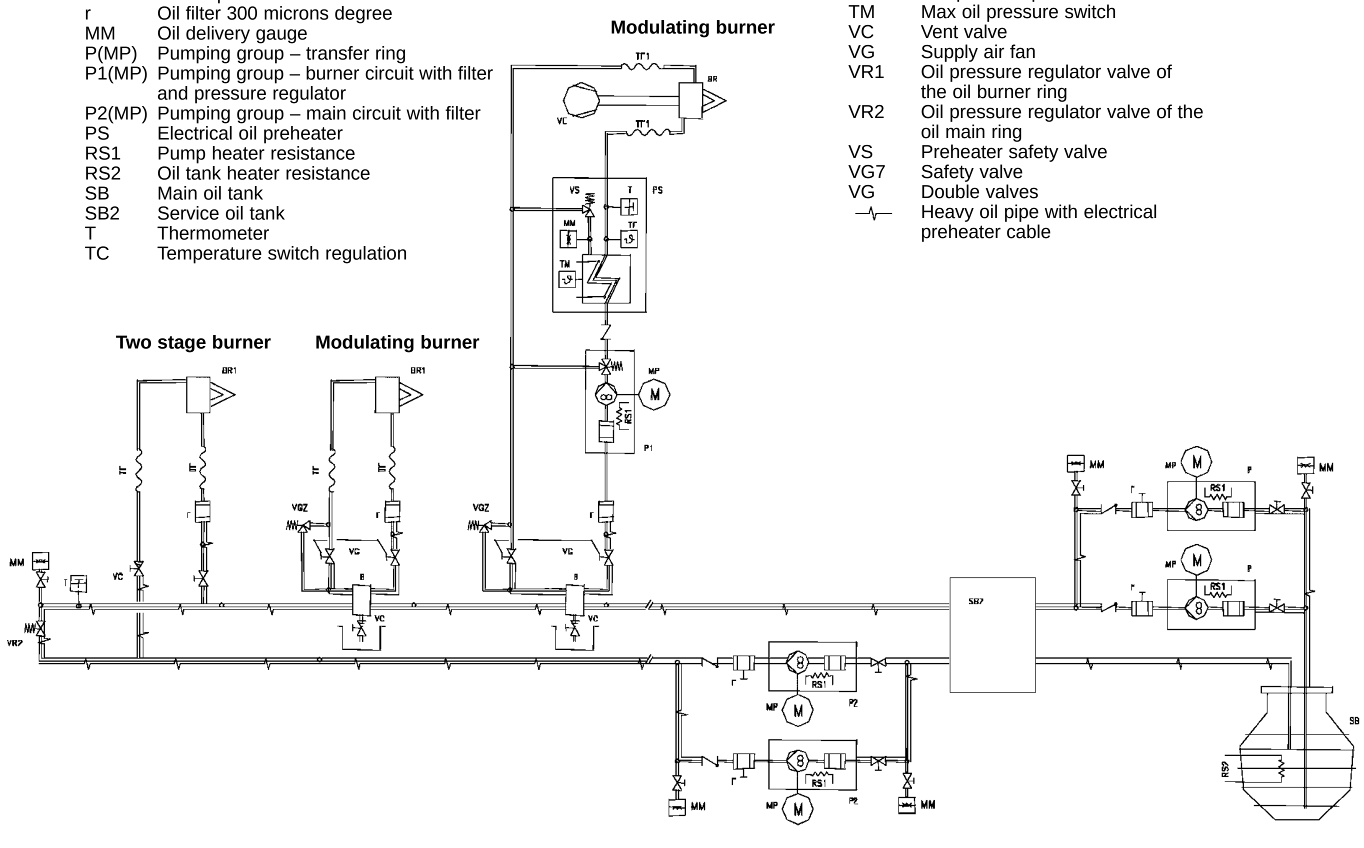


Diagram 23 *Ring-type system for multi-stage and modulating burners with service tank*

BR Dualbloc burner
BR1 Monoblock burner
B Oil burners gas separator
F Oil filter 300 microns degree
MM Oil delivery gauge
P(MP) Pumping group - main circuit with filter
P1(MP) Pumping group - burner circuit with filter and pressure regulator
PS Electrical oil preheater
RS1 Pump heater resistance
RS2 Oil tank heater resistance
SB Main oil tank
T Thermometer
TE Temperature switch regulation
TF Flexible oil line

TP Temperature probe
TM Max oil temperature switch
VC Control valve (3 way)
VE Supply air fan
VR1 Oil pressure regulator valve of the oil burner ring
VR2 Oil pressure regulator valve of the oil main ring
VS Preheater safety valve
VGZ Safety valve
VG Double valves
—⁄\/— Heavy oil pipe with electrical preheater cable

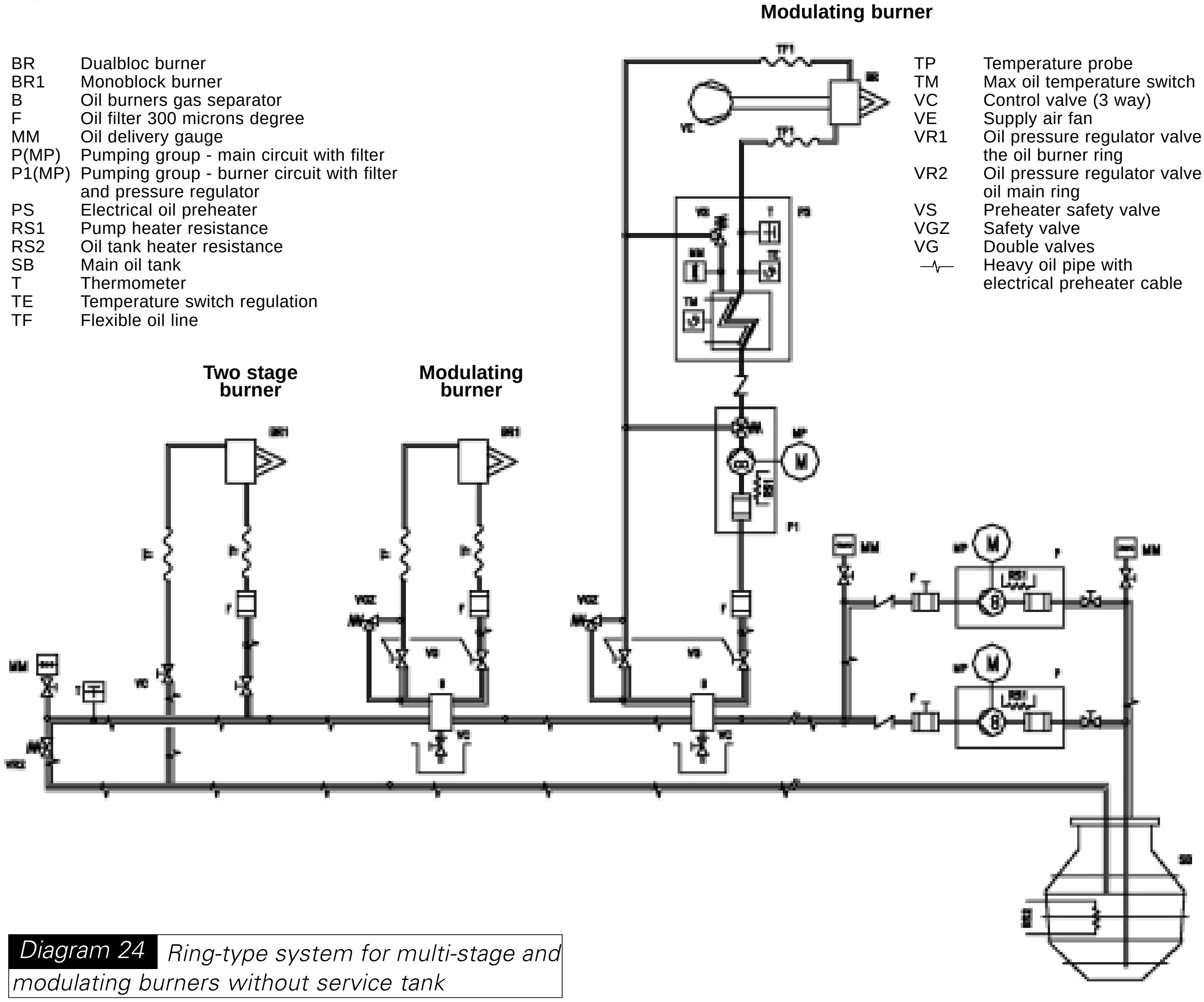
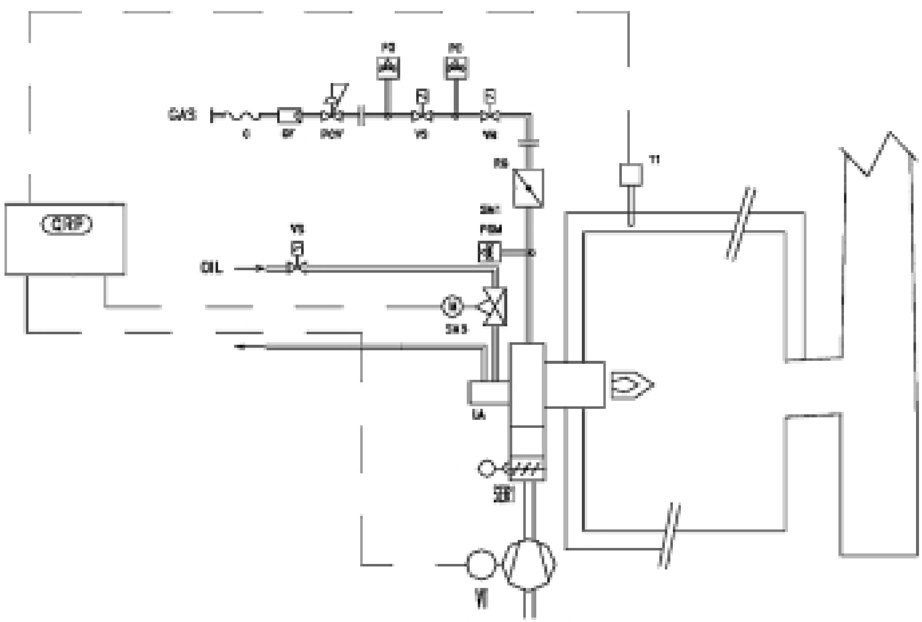


Diagram 24 *Ring-type system for multi-stage and modulating burners without service tank*

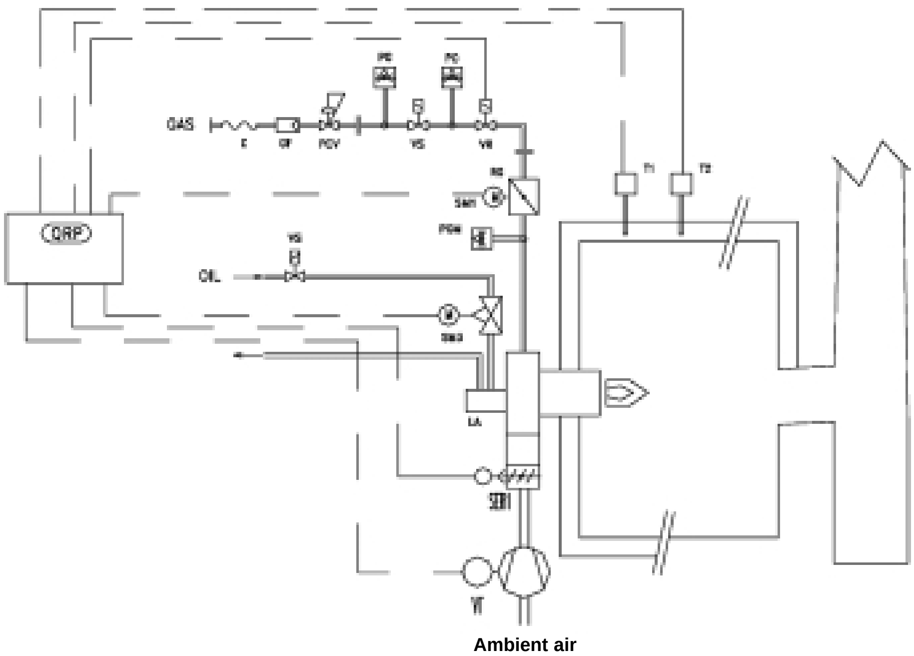
2.3.4 Diagrams for the calibration of single-stage burners



SER1 Burner air damper
VT Burner air fan
C Anti-vibrating joint
GF Gas filter
PCV Gas governor
PG Min gas pressure switch
VS Gas safety valve
PC Leak proving system
VR Gas regulation valve
RG Gas flow regulator
PGM Max gas pressure switch
T1 Thermostat
QRP Burner control panel
LA Nozzle holder lance
VS Oil safety valve

Diagram 25 *Layout of regulation components for a single-stage burner*

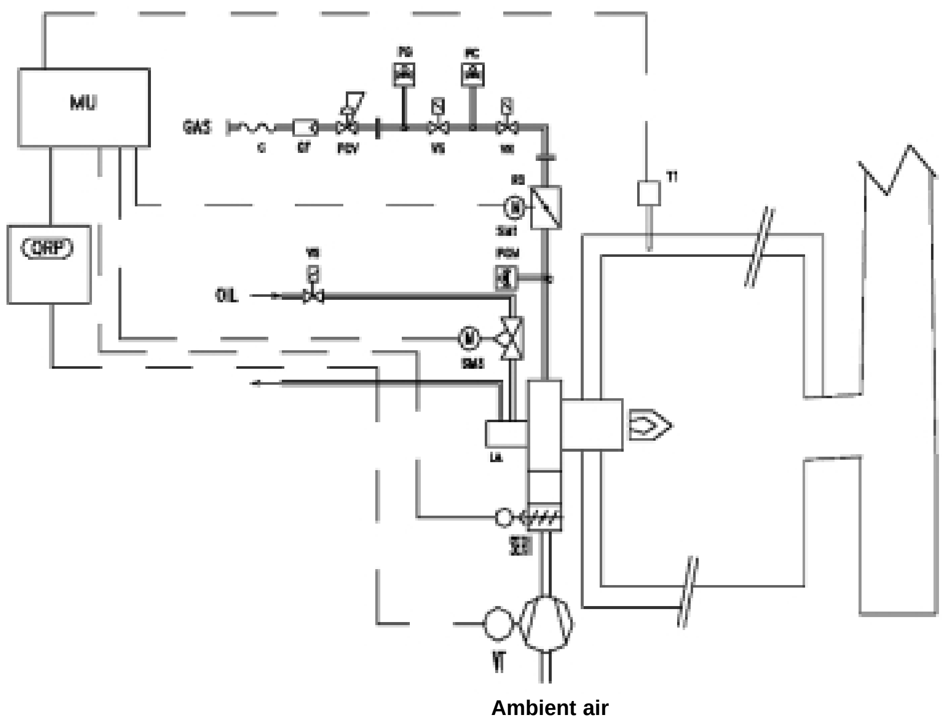
2.3.5 Diagrams for the calibration of multi-stage burners



SMn Servomotor
SER1 Burner air damper
VT Burner air fan
C Anti-vibrating joint
GF Gas filter
PCV Gas governor
PG Min gas pressure switch
VS Gas safety valve
PC Leak proving system
VR Gas regulation valve
RG Gas flow regulator
PGM Max gas pressure switch
T1 Thermostato/Pressure switch 1st stage
QRP Burner control panel
LA Nozzle holder lance
VS Oil safety valve
T2 Thermostato/Pressure switch 2nd stage

Diagram 26 *Layout of regulation components for a two-stage burner*

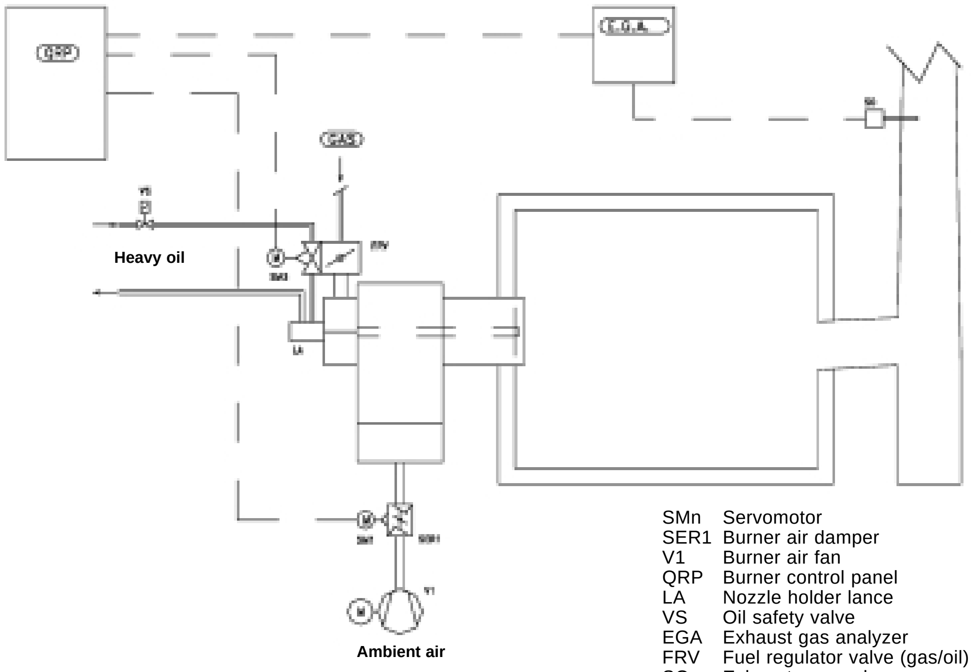
2.3.6 Diagrams for the calibration of modulating burners



SMn Servomotor
SER1 Burner air damper
VT Burner air fan
C Anti-vibrating joint
GF Gas filter
PCV Gas governor
PG Min gas pressure switch
VS Gas safety valve
PC Leak proving system
VR Gas regulation valve
RG Gas flow regulator
PGM Max gas pressure switch
T1 Temperature / pressure probe
QRP Burner control panel
LA Nozzle holder lance
MD Modulation device

Diagram 27 *Layout of regulation components for a modulating burner*

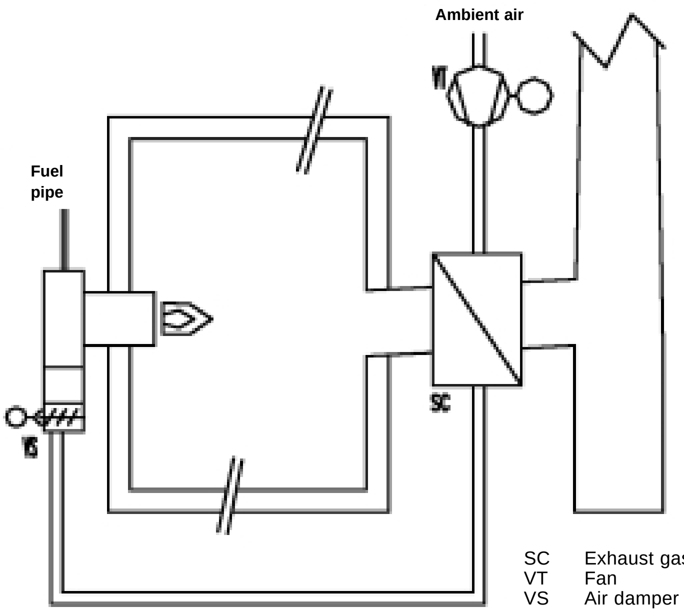
2.3.7 Diagram of burner with measurement and regulation of the percentage of O2 in the flue gases



SMn Servomotor
SER1 Burner air damper
V1 Burner air fan
QRP Burner control panel
LA Nozzle holder lance
VS Oil safety valve
EGA Exhaust gas analyzer
FRV Fuel regulator valve (gas/oil)
SO Exhaust gas probe

Diagram 28 *Layout of O_2 regulation system*

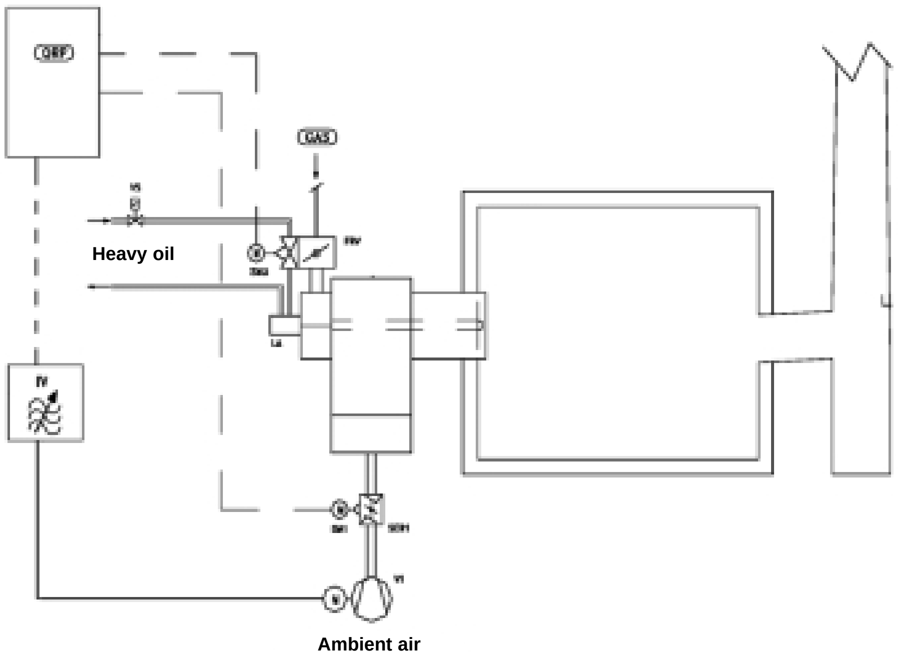
2.3.8 Diagram of burner with pre-heating of the combustion supporter air



SC Exhaust gas/air heat exchanger
VT Fan
VS Air damper

Diagram 29 *Layout of a system with pre-heating of comburent air*

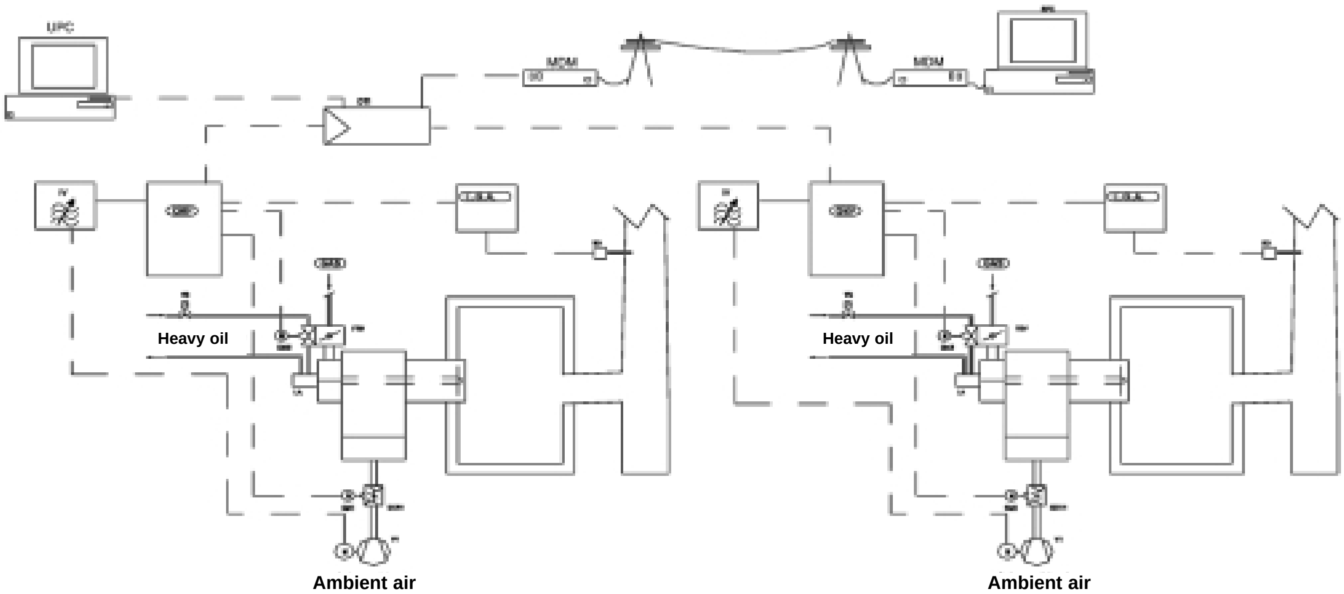
2.3.9 Diagram of burner with inverter controlled motors



SMn Servomotor
SER1 Burner air damper
V1 Burner air fan
QRP Burner control panel
LA Nozzle holder lance
VS Oil safety valve
IV Inverter
FRV Fuel regulator valve (gas/oil)
M Three phase induction motor

Diagram 30 *Layout of the fan speed rotation regulation with inverter*

2.3.10 Layout of the Burner Management -System



SMn Servomotor
SER1 Burner air damper
V1 Burner air fan
QRP Burner control panel
(i.e. micro modulation Autoflame)

LA Nozzle holder lance
VS Oil safety valve
IV Inverter
FRV Fuel regulator valve (gas/oil)
EGA Exhaust gas analyzer

SO Exhaust gas probe
DTI Data transfer interface
LPC Local computer
MDM Modem
RPC Remote computer

Diagram 31 *Layout of integrated management for supervising a combustion system*

2.4 THE COMBUSTION HEAD

The combustion head is the part of the burner that mixes the combustion supporting air with the fuel and stabilises the flame that is generated.
The combustion head essentially comprises the following components:

• The fuel metering device: nozzles for liquid fuels and orifices and distributors for gaseous fuels; oil nozzles are characterised by three parameters: output, spray angle and type of spray distribution (pattern).

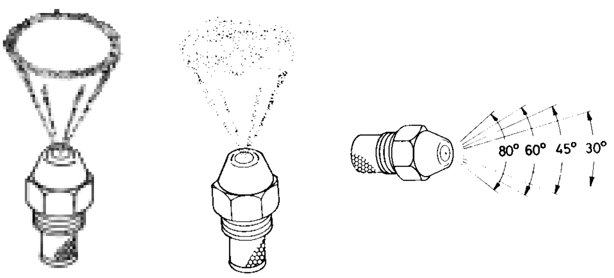


Diagram 32 *Nozzles: full cone and empty cone distribution; definition of spray angle*

• The turbulator diffuser disk, which mixes the fuel and the combustion air, and stabilises the flame to avoid it blowing back into the burner;

• The flame ignition system, uses electric arcs produced by high-voltage powered electrodes directly igniting the flame or coupled with a pilot burner;

• A flame sensor for motoring the flame;

• The flame tube comprising made of profiled metal cylinder which defines the output speed range.

The flame tube and the diffuser disk essentially determine the geometry of the flame developed by the burner. Especially the latter determines the rotational features of the fuel and combustion supporter mixture flow and, consequently, the flame dimensions. The rotational characteristic of the mixture flow is expressed in mathematical terms by the number of swirls defined as:

$$S = G_f / (G_x R)$$

where:
S = the number of swirls;
G_f = the angular momentum of the flow;
G_x = the axial force;
R = the radius of the nozzle outlet;

As a rule, an increase in the number of swirls causes an increase in the flame diameter and a decrease in the flame length.

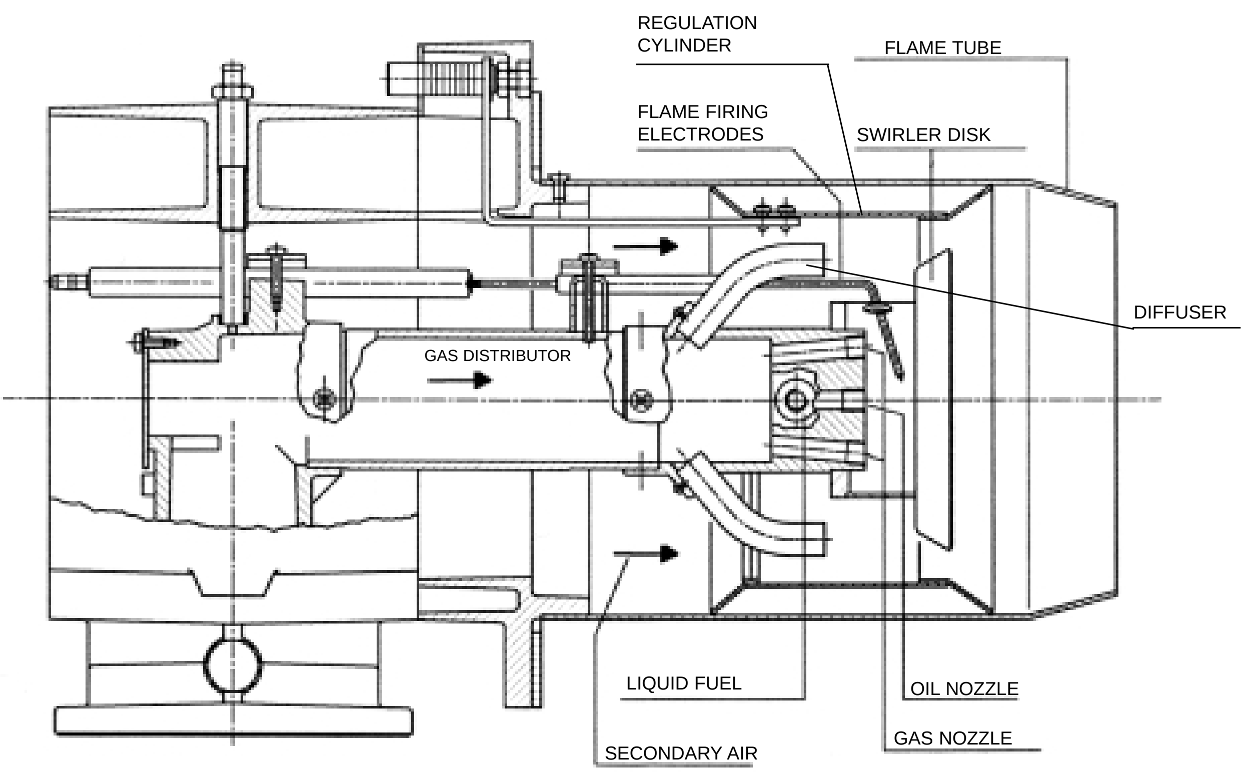


Diagram 33 *Drawing of composition of combustion head for gas/light oil Riello RLS100 burner*

The section between the sleeve and the diffuser disk determines the amount of secondary air available for the flame. This amount is zero when the disk is closer and in contact with sleeve. In certain burners it is possible to adjust the space between the disk and the turbulator diffuser changes the secondary air by changing the position of the disk itself.

Combustion heads can be classified according to the following layout:

- Non-adjustable fixed head, where the position of the combustion head is fixed by the manufacturer and cannot be changed;
- Adjustable head, where the position of the combustion head can be adjusted by the burner installer during commissioning;
- Variable-geometry head, where the position of the combustion head can be varied during the modulating burner operation.

Non-adjustable fixed head burners are generally burners used for industrial processes and dedicated to the generators they must be coupled to.
For adjustable head burners, regulation is pre-set in correspondence with the maximum output of the burner for the specific application. For easier start-up and configuration operations, a graph is provided for each burner indicating the position of the regulation mechanisms in relation to the required thermal output. This construction type makes the burner suitable for different requirements, which is why monobloc Forced draught burners with a low to medium output are predominantly adjustable head types.
Variable-geometry burners are generally high-output modulating burners.
The geometry of the head is also extremely important in reducing polluting emissions, especially Nox, as described in paragraph 1.4.2.

2.4.1 Pressure drop air side

The firing ranges of monobloc burners already take into account the air pressure drop of the combustion head. When choosing a dual bloc burner, for the purpose of choosing the correct fan, the pressure drop on the air side must be known in relation to the delivery; for easier reading, this information refers to a standard temperature and is supplied in relation to the thermal output developed.

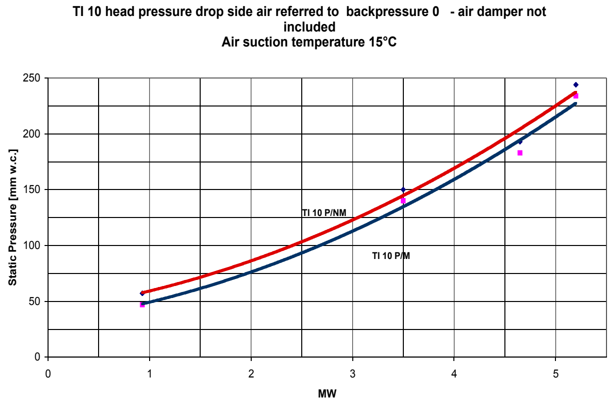


Diagram 34 Pressure drop air side in combustion head - dualbloc TI 10 burner

2.4.2 Pressure drop fuel side

To correctly select the fuel feed pipe for both monobloc and dual bloc burners, certain working information is required about the related circuits inside the combustion head.

In the case of gaseous fuels, tables or diagrams are provided, such as those presented in diagram 35, which provide the overall pressure drop of the gas pipe in the head, in relation to the thermal output developed.
For liquid fuels, the pressure value required by the nozzle for spill back nozzles (modulating), and the diagram of the minimum pressure to be guaranteed on the nozzle return pipe when the fuel delivery varies, are provided.

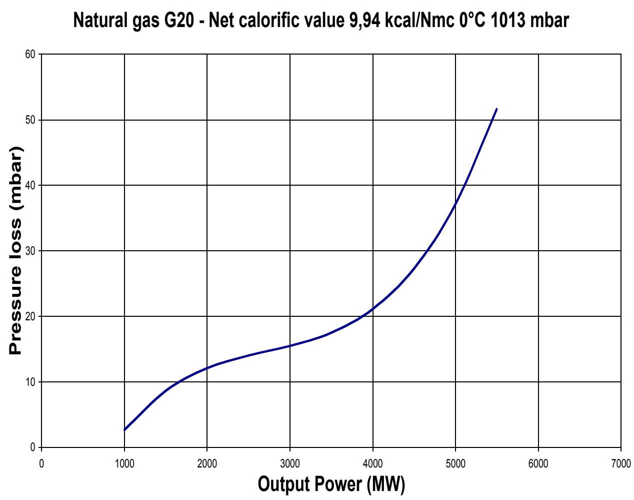


Diagram 35 Pressure drop gas side in combustion head - dualbloc TI 10 burner

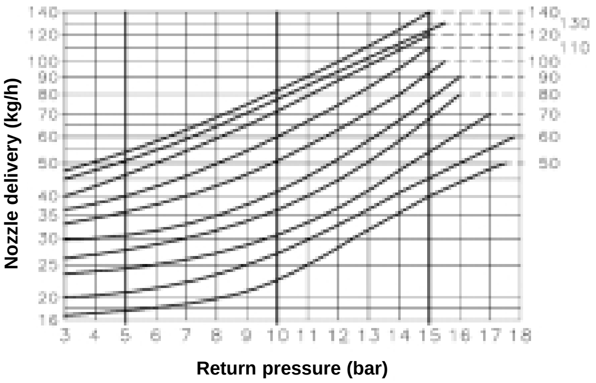


Diagram 36 Feed pressure of liquid fuel

2.5 THE FAN

Fans are machines capable of supplying energy to a fluid, by increasing pressure or speed, using a rotating element.
Depending on the air-flow direction the following types of fan can be used:

- centrifugal;
- axial;
- tangential.

In centrifugal fans, the air enters along the direction of the rotation axis and exits tangentially to the fan wheel. In axial fans, the air direction is parallel to the axis of the fan wheel. In tangential fans, the air enters and exists tangentially to the fan wheel.

The fans installed on monobloc burners and those used separately for dual bloc burners are generally centrifugal, such as that shown in the Diagram.
Centrifugal fans are made up of a box that contains a keyed fan wheel on a shaft supported by bearings. The shaft can be connected directly to the electric motor using joints or, indirectly, using belts and pulleys. The fan wheel positioned inside the box may have differing blade orientations/profiles and specifically:

- fan wheel with wing-shaped blades;
- fan wheel with reverse curved blades,
- fan wheel with radial blades;
- fan wheel with forward curved blades;

Diagram 37 shows the variation in absorbed output when fan delivery varies; the fan wheel with wing-shaped blades behaves similarly to the fan wheel with reverse curved blades.
The working characteristics of a fan, similar to those for pumps, are described by the characteristic curve. The characteristic curve

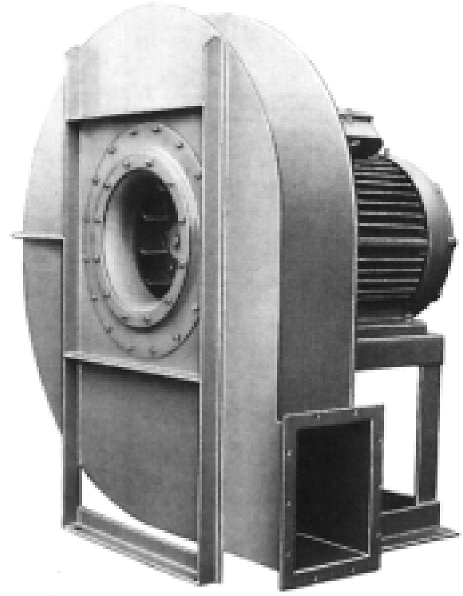


Diagram 37 Fan of a dualbloc burner

of a fan is represented in a Cartesian plan where the Y axis shows the pressure and the X axis shows the volumetric delivery (see Diagram 38).
The characteristic curves can be accompanied by other curves such as performance or yield curves and the absorbed output curve of the electric motor (see Diagram 39).

The number of characteristic curves for each fan depends on the number of rotation speeds, as shown in Diagram 40.
When a fan operates in a circuit, which also

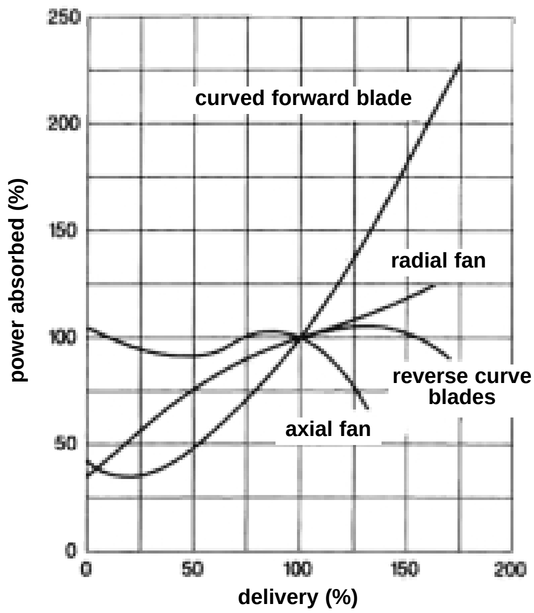


Diagram 38 Output absorbed from different types of fan varying delivery

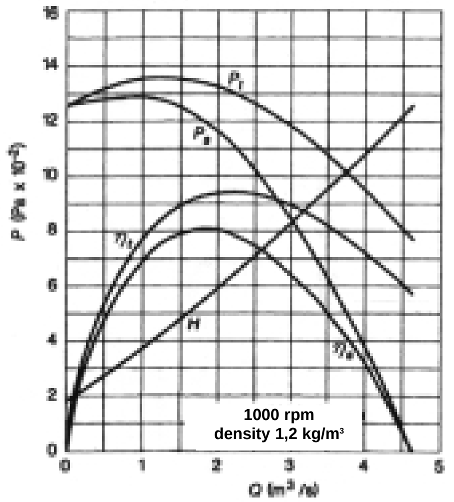


Diagram 39 *Typical performance graphs of a centrifugal fan*

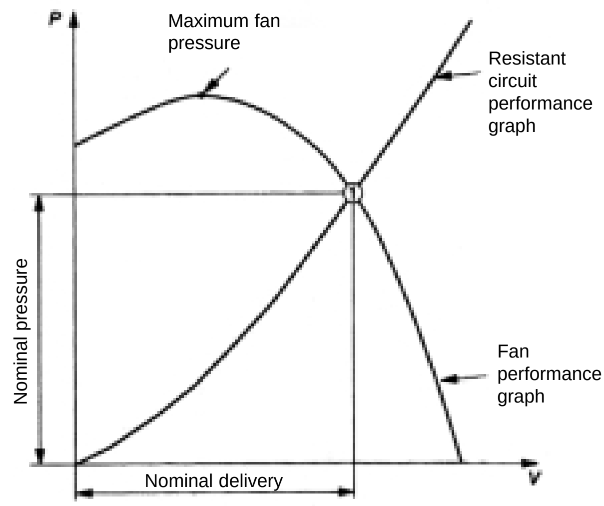


Diagram 41 *Performance graph of fan and resistant circuit with working point*

has a characteristic curve, delivery is supplied when total pressure developed is equal to the circuit pressure. This situation is represented by the intersection point between the characteristic fan curve and the characteristic circuit curve, as indicated in Diagram 41.
In the case of forced draught burners, the system characteristic curve varies in relation to the setting of the combustion head and opening degree of the air damper. To correctly choose the fan, the circuit curve must correspond to the load used.

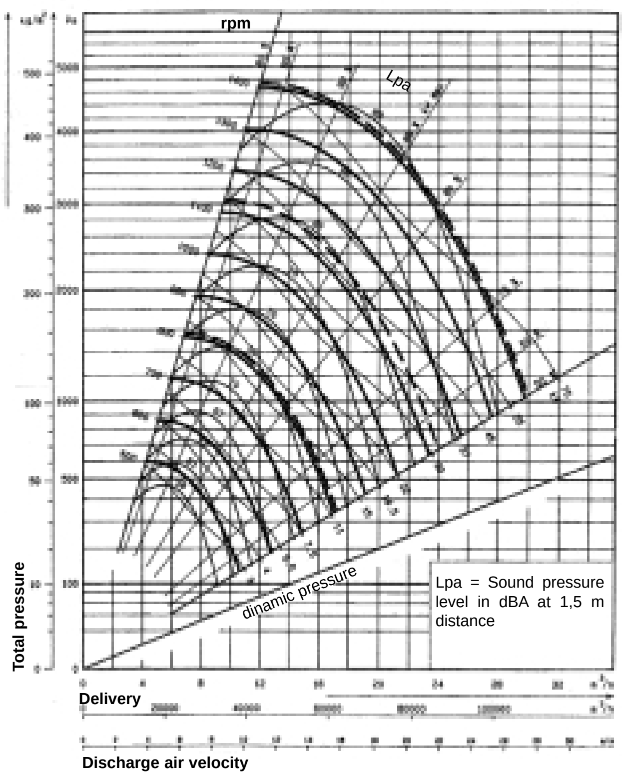


Diagram 40 *Fan performance graphs on varying motor speed rotation*

Therefore, in order to discover the delivery and the head of a fan, we need sufficiently precise information regarding the pressure drop induced by the circuit, including the air intake pipes, burner head feeding pipes and the accessories.
As already mentioned, circuit pressure drops have a parabolic flow with respect to fluid speed and, consequently, delivery.
Pressure drops in an areaulic system are determined by two components:

- concentrated pressure drops;
- distributed pressure drops.

Among the concentrated pressure drops, account must be taken of those introduced by the combustion head, where the air transits using a complex geometric route; furthermore, an air damper is fitted inside the burner for calibrating the delivery of combustion supporter air.
Burner manufacturers provide graphs that represent the trend of pressure drops in relation to air delivery, or, for easier consultation, in relation to the thermal output delivered by the burner.

Distributed pressure drops can be estimated by using the Darcy-Weisbach formula:

$$\Delta p_f = f \cdot \frac{L}{D} \cdot \frac{v^2}{2 \cdot g} \qquad \textbf{eq 2.5-1}$$

where:
Δp_f = pressure drop due to friction [m];
f = friction factor;

L = pipeline length [m];
D = pipeline diameter [m];
v = air speed inside the pipeline [m/s];
g = gravity acceleration 9.81 [m/s²];

The term $v^2/2g$ is called dynamic pressure.
The friction factor f can be determined using the MOODY abacus (Diagram 42) if the Reynolds number and related texture is known.
The Reynolds number is defined by the following formula:

$$N_{Re} = \frac{d \cdot V}{\gamma}$$

eq 2.5-2

where:
N_{Re} = Reynolds number;
d = internal pipeline diameter [m];
V = air speed [m/s];
g = kinematic air viscosity equal to 16.0 ·10-6 m²/s;
The related texture e/D is the formula between the absolute texture and the diameter of the pipeline both expressed in mm. Table 9 shows the absolute texture value of certain typical ducts.

For easier calculation, a series of abacuses exist to determine linear pressure drops, shown in section 5.
The formulas introduced always refer to certain circular sections, while in constructive practice rectangular pipelines are often used. To use the same formulas, an equivalent diameter De must be used, defined as:

$$D_e = 2 \cdot \frac{a \cdot b}{a + b}$$

eq 2.5-3

where:
D_e = equivalent diameter [m];
a, b = side dimensions of the rectangular pipeline [m];

Localised pressure drops, due to the presence of dampers, grids and any heat exchangers, must be calculated for the effective value of the drop introduced, which must be provided by the manufacturer of the mentioned devices.
Localised pressure drops, due to the presence of circuit peculiarities, such as curves, direction and section variations, can be calculated using the following equation:

$$\Delta p_w = \xi \cdot \rho \cdot \frac{v^2}{2}$$

eq 2.5-4

where:
Δpw = pressure drop [Pa];
ξ = non-dimensional drop factor;
ρ = volume mass [kg/m³];
v = average speed in the pipeline [m/s];

A series of tables exist in the technical literature, similar to those in Diagram 43 which show the ξ value for the various special pieces, some of which are illustrated in section 5 READY-TO-USE TABLES AND DIAGRAMS.

2.5.1 Regulating combustion air

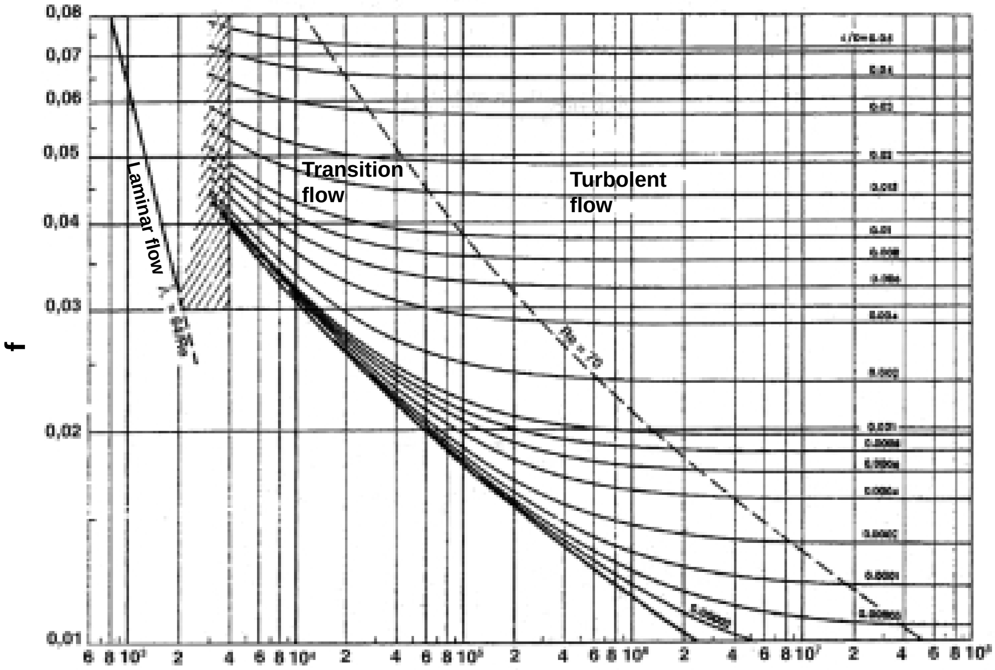
As already mentioned, the delivery of combustion supporter air is proportionate to the delivery of fuel burnt, which in turn is proportionate to the required output. For multi-stage and modulating burners, air provided by the fan must be changed in order to vary the delivery.

In Forced draught burners, delivery can be varied in two principal manners:

Table 9 *Non-dimensional drop factors for air pipelines*

Pipeline material	Absolut texture (mm)
Smooth iron plate duct	0,05
PVC duct	0,01 – 0,05
Aluminium plate duct	0,04 – 0,06
Galvanized sheet-iron duct with cross joints (1,2m step)	0,05 – 0,1
Galvanized sheet-iron circular duct, spiraliform with cross joints (3m step)	0,06 – 0,12
Galvanized sheet-iron duct with cross joints (0,8m step)	0,15
Glass fiber duct	0,09
Glass fiber (internal covering) duct	1,5
Protected glasswool (internal covering) duct	4,5
Flexible metal pipe	1,2 - 2,1
Flexible non-metal pipe	1 – 4,6
Cement duct	1,3 - 3

Diagram 42 *Moody's abacus*



Reynolds number Re = ρ Vd / μ

- Varying the fan firing point;
- Varying the number of fan revolutions;

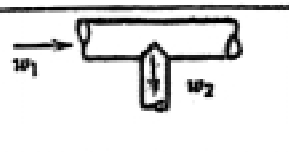
In the first regulation method, the fan firing point is moved, which remember can only be done along the characteristic curve, by varying the pressure drop of the areaulic circuit by introducing a servo-controlled damper (see Diagram 44). Depending on the opening degree of the damper, the various system curves are obtained. In our case, the regulation damper closing determines the variation of the characteristic system curve from curve 1 to curve 2; consequently, the fan firing point moves from A to B, with the consequent increase of the fan head from P_1 to P_2' and the decrease of the delivery from Q_1 to Q_2. The opening degree of the damper introduces the various characteristic system curves thus determining differing delivery values.
This system is rather effective, above all in centrifugal fans with forward curved blades, where a delivery drop corresponds to a drop in absorbed output. In centrifugal fans with reverse curved blades, the output curve has a virtually flat trend and therefore it is not possible to obtain optimum operating performances.

The variation of the number of fan revolutions is obtained by using specific electronic devices called "inverters".
These devices vary the frequency of the power supply voltage to the electric motor connected to the fan wheel. The number of electric motor revolutions is linked to the power supply frequency according to the following equation:

$$n = 120 \cdot \frac{f}{p}$$

where:
n = number of motor r.p.m.;
f = power supply voltage frequency [Hz];
p = number of poles;
By regulating the number of revolutions, maximum performance operating can be

Diagram 43 *Adimensional loss factors for air pipelines*

10


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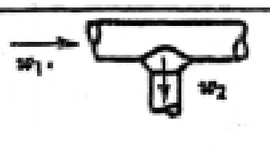

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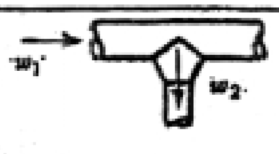


	10					11					12				
w_2/w_1 =	0,4	0,6	0,8	1,0	1,5	0,4	0,6	0,8	1,0	1,5	0,4	0,6	0,8	1,0	1,5
$\zeta_{2\,tot}$ =	7,0	3,4	2,0	1,5	0,9	5,0	2,2	1,2	0,9	0,5	4,7	1,9	0,9	0,6	0,4
$\zeta_{2\,st}$ =	1,5					0	0,3	0,7	0,9	1,0	0	0	0,3	0,6	0,9

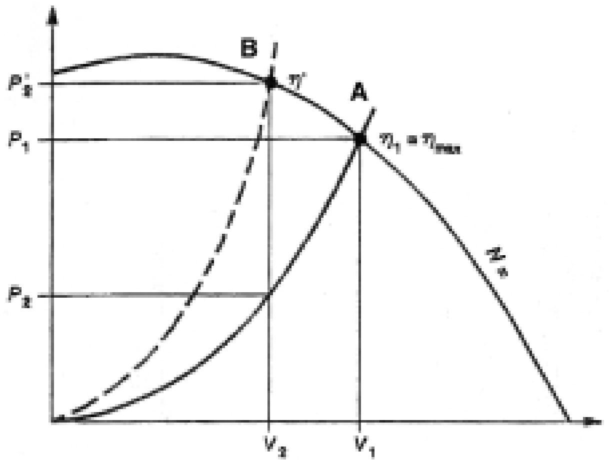


Diagram 44 *Change of delivery by varying pressure drops of the circuit*

obtained under the various working conditions, as the characteristic curve is translated until it coincides with the nominal firing point.
Diagram 45 shows the fan behaviour when the number of motor revs is varied.

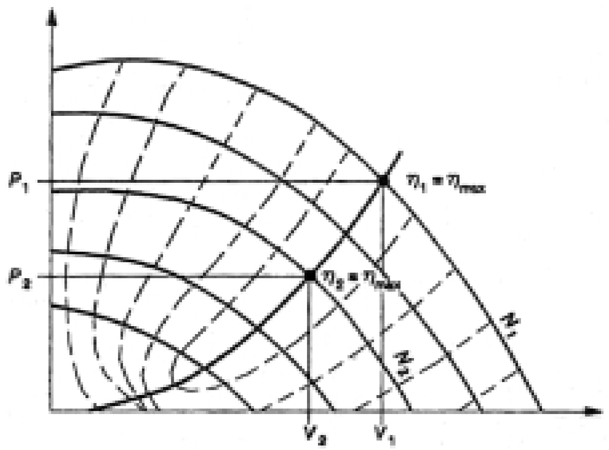


Diagram 45 *Example of delivery changing by motor speed variation*

2.6 FUEL SUPPLY

2.6.1 Gas supply

Gaseous fuel is usually transported from the point of storage/drawing to the user by a series of pipelines, which may be more or less branched (gas supply network). Inside the pipelines, the gas is at a pressure, which is variable by several tens of bars for main supply pipelines, and by several tens of mbars in final delivery pipelines of the gas to the user.
The main problem in distribution networks of gaseous fuels is the variation in feed pressure. Any pressure instability within the distribution network causes the burner to work incorrectly. In order to avoid such problems, fuel gas feed pressure to the combustion head must be:

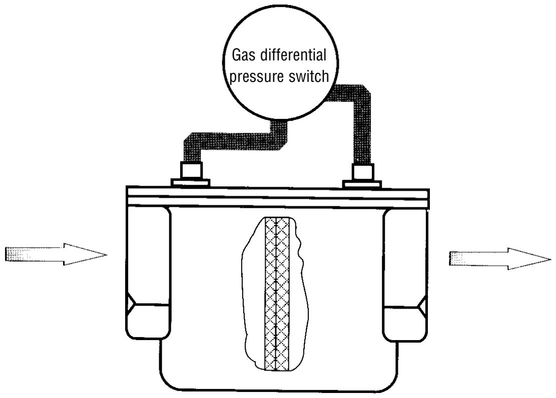
- Greater than a minimum value which can overcome the pressure drop due to the combustion head (see paragraph 2.4.2) and the back pressure in the heat generator combustion chamber;
- Lower than the permitted maximum pressure value declared by the manufacturer;
- Stable and repetitive with respect to the settings.

To guarantee these conditions, fuel gas supply to the burner is through a series of safety and control equipment that globally are called the "gas train".
Diagram 45 shows the functional layout of a gas train.

The connection module comprises a manual shut off valve and an anti-vibration connection joint so that any vibrations produced by the burner are not transmitted to the entire feed network of the fuel gas.
The filter is used to guarantee filtration of any particles that may be present in the gaseous fuel, particles that might damage the seal of the safety and shut off valve.
The task of the pressure reducer is to reduce the pressure of the mains gas and maintain constant the outgoing pressure, independently from the incoming pressure and delivery. Pressure reduction and stabilising is made through use of a membrane-type system loaded by a spring that controls the shutter opening using levers. The high pressure unit includes the lock out, safety and discharge valves as well as several gauges upstream and downstream for visually controlling pressure levels. The pressure reducer has a maximum incoming pressure and a series of outgoing

Diagram 46 *Functional layout of the gas train*

Diagram 47	Gas filter



pressure values that can be selected in relation to the spring and the effective rating. The pressure reducer and safety devices are necessary if network fuel gas pressure is greater than the maximum value established by the manufacturer for the downstream devices. (In this case, the function of stabiliser is included in the reducer).
If the gas network delivery pressure is lower than the maximum value permitted by the manufacturer, as a rule between 300 and 500 mbar, a pressure reducer is not needed, just the stabiliser.
The solenoid valve unit comprises a safety valve, a progressively opening regulating valve and a minimum pressure switch.

For burners with outputs greater than 1,200 kW, the EN676 standard establishes that the valve unit must be also equipped with a seal control device for the safety and regulation valve; this device is available and can also be used on burners with lower outputs.
The devices mentioned can be grouped into a

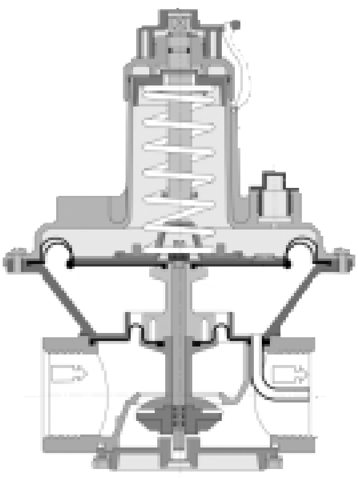
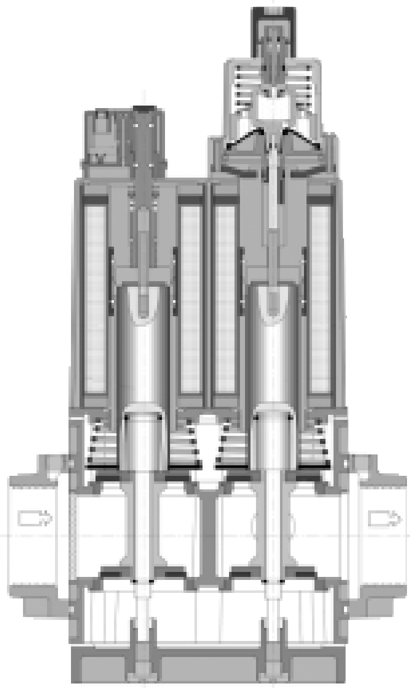


Diagram 48	Pressure Regulator

Diagram 49	Shut-off and safety valves



single body, which incorporates the functions of stabiliser, and safety shut off.

The valve units can be grouped into two categories, depending on the fuel shut off method:
- single flow;
- double flows.

The application of one of these two types depends on the thermal load regulation devices installed on the burner.

To attach the gas train to the burner, a connection adapter could be required.

Furthermore, a series of taps must be fitted in the gas train for measuring the pressure upstream from the filter, upstream from the

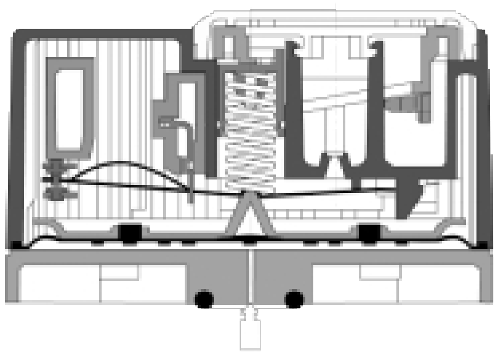
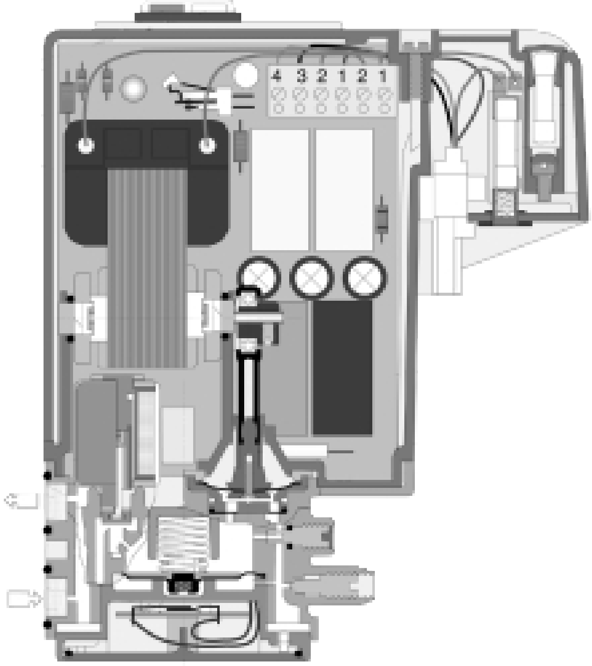


Diagram 50	Gas pressure switch

Diagram 51 | Seal control system



valve unit and in correspondence with the combustion head.
As already said, if the pressure upstream from the manual shut off valve is lower than a certain value established by the manufacturer, the pressure reducer is not required. In this case, the gas train supplied with the burner can be monobloc, i.e. with the filter, stabiliser and valve unit included inside a single component or else comprising individual components joined in series.
For domestic uses where the EEC 90/396 Gas Directive makes it compulsory for the manufacturer to type approve the whole system including the burners and the feed system, the complete gas train must be provided by the manufacturer and type approved together with the rest of the devices.
The choice of the gas train depends on the minimum pressure to be guaranteed to the burner head and, consequently, the maximum pressure drop determined by the latter, as illustrated in the subsequent paragraph and in the example in section 3.

A series of components are fitted to the

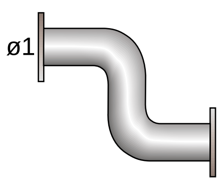


Diagram 52 | Connection adaptor

burner, which have a very important role during setting and regulating the entire system. In particular, gas or dual fuel burners have a butterfly valve to regulate fuel delivery, driven by a variable profile mechanical cam servomotor, or in the more sophisticated systems, controlled by the Burner management system (electronic cam). Generally, there is a maximum gas pressure switch to shut off burner functions if pressure is too high along the fuel supply line.

2.6.1.1 Calculating the fuel gas supply pipelines

The following formula is used for dimensioning the fuel gas supply pipelines:

$$\Delta P_{A\text{-}B} = \frac{\lambda \cdot V^2 \cdot \rho}{2 \cdot D_i} \cdot L_{TOT}$$

Eq. 2.6.1-1

where:
ΔPA-B = pressure drop between point A and point B [Pa];
I = friction factor;
V = the average gas speed [m/s];
r = the gas volume mass [kg/m3] referring to 15°C and 1,013 mbar;
LTOT = total pipeline length [m];
D_i = internal pipeline diameter [m];
The average gas speed inside the pipeline can be calculated using the following formula:

$$V = \frac{Q}{A} = \frac{Q}{2827.\ D_i^2} \quad [m/s]$$

Eq. 2.6.1-2

where:
Q = fuel gas delivery [m³/h];
D_i = internal pipeline diameter [m];

The fuel gas delivery must be established using the following formula:

$$Q = \frac{m}{H_i}$$

Eq. 2.6.1-3

where:
Q = fuel gas delivery [m³/h];
m = maximum burner output [kW];
H_i = inferior calorific value of the fuel gas [kWh/m³];
Remember that 1 kWh = 3,600 kJ.

The friction factor λ can be calculated using the following formula:

$$\lambda = 0{,}0072 + \frac{0{,}612}{R_e^{0{,}35}} + \frac{2{,}9 \cdot 10^{-5} \cdot R_e^{0{,}109}}{D_i}$$

Eq. 2.6.1-4

where:
D_i = internal pipeline diameter [m];
R_e = the Reynolds number which can be determined by using the following equation:

$$R_e = 354 \cdot \frac{Q}{D_i \cdot \gamma} \cdot 10^{-6}$$

Eq. 2.6.1-5

where:
D_i = internal pipeline diameter of the [m];
g = fuel gas kinematic viscosity [m²/s];
Q = fuel gas delivery [m³/h];

The viscosity of the gaseous fuel can be taken from the graph illustrated in diagram 53.
The graph shows the absolute viscosity expressed in micropoises. Remember that the kinematic viscosity is linked to the dynamic viscosity by the formula:

$$\gamma_{absolute} = \frac{\gamma}{\rho}$$

Eq. 2.6.1-6

where:
γabsolute= dynamic or absolute viscosity [kg/m·s];
γ = fuel gas kinematic viscosity [m²/s];
ρ = the volume mass of the gas [kg/m³] referring to 15°C and 1,013 mbar;
In technical practice, the absolute viscosity is measured in Poises (P) equating to:

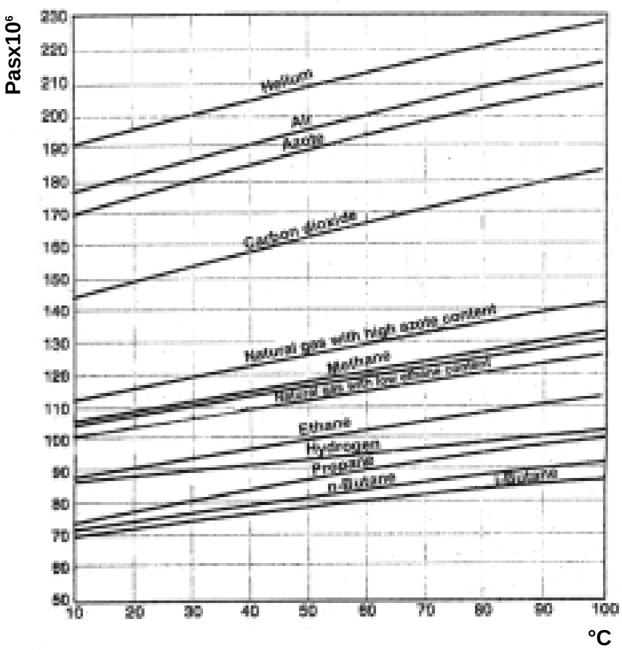


Diagram 53 *Absolute viscosity of certain gases*

$$1\,poise = 1\ \frac{g}{cm \cdot s} = 0{,}1\ \frac{Kg}{m \cdot s}$$

The pressure drops in feed pipelines between the fuel gas delivery point and the burner gas train must be kept within limits that guarantee correct functioning of any reducer units present. For low pressure systems (p ≤ 40 mbar), the pressure drops must be kept within the following values:

Gas	Pressure drop [mbar]
Town gas Natural gas and air mixtures	0,5
Natural gas Natural gas replacements L.P.G. and air mixtures	1,0
Liquid Petroleum Gas (G.P.L.)	2,0

Table 10 *Maximum pressure drops of gas pipelines*

The pressure drops in the pipelines are the sum of those distributed along the pipeline and those concentrated due to joints and hydraulic accessories (filters, valves, etc..).
The concentrated losses due to hydraulic accessories are calculated using the equivalent length method, in other words a concentrated loss is assimilated to a stretch of pipeline equal to the length of the related loss.
To correctly dimension the pipelines, we can define the following sizes:
L_{EFF} = effective pipeline length [m];
L_{EQUIV} = the sum of the equivalent lengths relating to concentrated pressure drops as a result of joints and hydraulic accessories[m];
L_{TOT} = total pipeline length, sum of the effective length and the equivalent length [m]:

$$L_{TOT} = L_{EFF} + L_{EQUIV}$$ **Eq. 2.6.1-7**

The equivalents lengths relating to the concentrated resistances of the components can be determined using the schedule shown in Table 11, which shows the reference equivalent lengths of the main concentrated resistances.

To determine the equivalent length, we must presume an initial pipeline diameter imposing a maximum fuel gas flow speed of approximately 1 m/s, taking care to correct the value of the equivalent lengths if a different

Table 11 *Maximum pressure drops of gas pipelines*

D_i (mm)	90° curve	T Connection	cross	Sharp bend	Cock
Natural gas - CH_4/air mixtures – Cracking gas					
<= 22,3	0,2	0,8	1,5	1	0,3
from 22,3 to 53,9	0,5	2	4	1,5	0,8
from 53,9 to 81,7	0,8	4	8	3	1,5
=> 81,7	1,5	6,5	13	4,5	2
Liquid Petroleum Gas – L.P.G. mixtures					
<= 22,3	0,2	1	2	1	0,3
from 22,3 to 53,9	0,5	2,5	5	2	0,8
from 53,9 to 81,7	0,8	4,5	9	3	1,5
=> 81,7	1,5	7,5	15	5	2

diameter should emerge from the calculation carried out using equation 2.6.1-1.

Section 5 contains some tables illustrating permissible gas delivery values in relation to the internal pipeline diameters and total lengths in steel and copper, for the gases in the first, second and third series; note that the total length and gas delivery is therefore essential to choose the pipeline diameter.

2.6.1.2 Choosing the gas train

For using burners in domestic and commercial spheres, the EEC 90/396 Gas Directive obliges burner manufacturers to provide the burner with a gas train complete with all the components.

The EEC 90/396 Gas Directive defines the essential requisites of the equipment that burns gaseous fuels. Self-certification of conformity by the manufacturer is not enough for all the aforementioned equipment, but certification is required which declares the compliance of the equipment with the provisions of the Gas Directive, issued by an Informed Body.

The gas train should be chosen from the manufacturer's catalogue, exclusively in relation to the pressure drop introduced by the same train.

To correctly choose the gas train to be combined with the burner, the sum of all the pressure drops suffered by the flow of the gaseous fuel from the delivery point up to the burner, must not exceed the available pressure at the delivery point.

Starting downstream, the drops to be considered are as follows:

H1: back pressure in the combustion chamber;
H2: the combustion head
H3: the gas train;
H4: the feeding system up to the delivery point, calculated as described in the previous section.

If we call H, the minimum pressure available at the delivery point for the gaseous fuel, the following conditions must be checked:

Thread	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3
D_i mm	13,2	16,7	22,3	27,9	36,6	42,5	53,9	69,7	81,7
Thickness mm	2,0	2,3	2,3	2,9	2,9	2,9	3,2	3,2	3,6
L m	Delivery (m³/h)								
2	1,69	3,23	7,13	13,18	27,72	41,75	80,04	161,62	246,99
4	1,14	2,18	4,81	8,89	18,70	28,16	53,96	109,03	166,37
6	0,91	1,73	3,82	7,06	14,85	22,36	42,83	86,53	133,62
8	0,77	1,47	3,25	6,00	12,61	18,98	36,36	73,44	113,38
10	0,68	1,30	2,86	5,28	11,10	16,71	32,01	64,66	99,82
15	0,54	1,03	2,27	4,19	8,81	13,26	26,40	51,30	79,19
20	0,46	0,87	1,93	3,56	7,48	11,26	21,56	43,52	67,18
25	0,40	0,77	1,70	3,14	6,59	9,91	18,98	38,31	59,14
30	0,36	0,69	1,53	2,83	5,94	8,93	17,10	34,52	53,28
40	0,31	0,59	1,30	2,40	5,04	7,58	14,51	29,29	45,20
50	0,27	0,52	1,14	2,11	4,43	6,67	12,77	25,78	39,78
75	0,22	0,41	0,91	1,67	3,52	5,29	10,13	20,44	31,54
100	0,18	0,36	0,77	1,42	2,98	4,49	8,59	17,34	26,75

Table 12 *Example for the tabular calculation of the diameter of the gas pipelines*

$$H \geq H_1 + H_2 + H_3 + H_4$$

For ease of calculation, certain manufacturers provide diagrams of the pressure drops in the gas trains as the sum of the gas train pressure drop and the combustion head (H_2+H_3).
Therefore, the choice of gas train must be satisfy the following equation:

Noting the maximum allowable value of H_2+H_3, using diagrams similar to those in Diagram 47, we can choose the gas train.

As shown in the diagram, the graph of the gas train characteristic curve is often accompanied by a graph showing the burner firing range to facilitate the choice.

2.6.1.3 The feeding of liquid petroleum gases (LPG)

Liquid petroleum gases are gases in a liquid state obtained by distilling crude oil or taken from natural gas and residual gases from refinery process. The composition of LPG is somewhat variable but generally comprises mixtures of propane and butane, which are generally considered fuels with a high level of purity.
LPG is produced and conserved in a liquid state, for storage and transporting large

Diagram 54 LPG tank

amounts in an economically viable manner. The volume formula between the gaseous stage and the liquid stage is variable and generally equates to 250 Nm^3/m^3; this means that during the transition from the gaseous state to the liquid state the mixture reduces its volume by over 250 times, so that even with tanks of limited dimensions it is possible to store considerable amounts of the fuel.
Therefore, to obtain a cubic metre of LPG in gaseous state, 4 litres of LPG in liquid state are needed.
The vapour tension of LPG is low making it possible to liquefy the gas with a pressure around 3 ÷ 5 bars. LPG can be distributed to an individual user or to a series of users. In the first case, the individual user can be guaranteed a sufficient stock of fuel using a series of cylinders weighing several tens of kilograms connected in series or by small tanks usually with a capacity of less than 5 m^3.
In the second case, a medium or low pressure distribution network linked to a single large

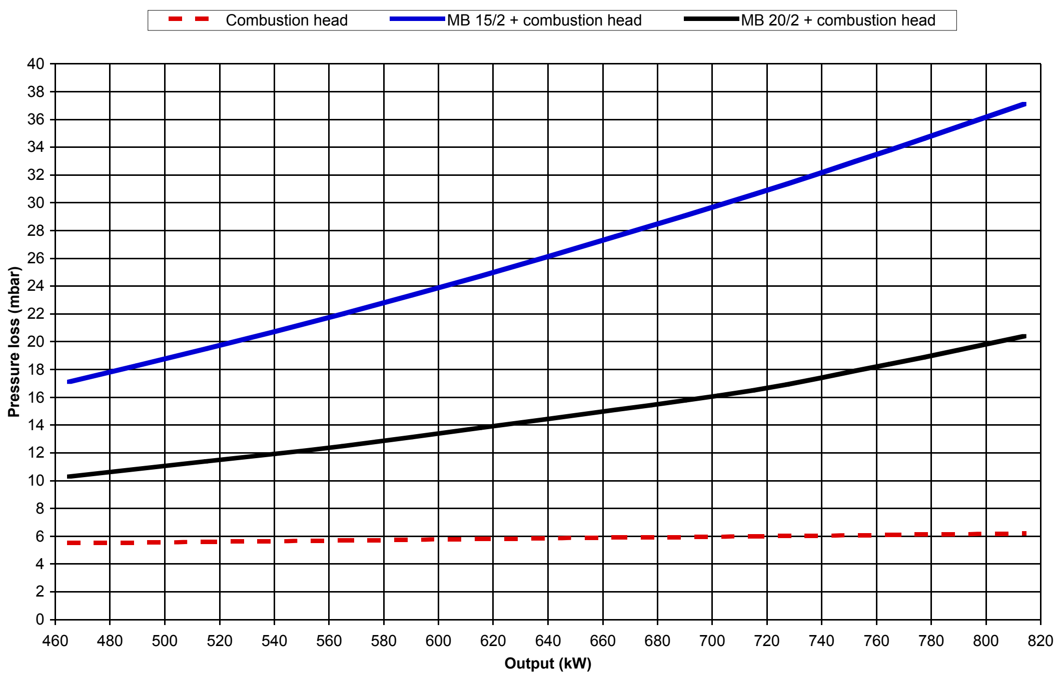


Diagram 55 *Graph for the detrmination of the gas train*

storage tank guarantees the supply to the individual user. The first solution is adopted to guarantee the gas supply to individual isolated users or those who have particular requirements, while the adoption of a distribution network is convenient for small communities or populated areas. With respect to the use of individual cylinders, installed in private property, the centralised system offers considerable advantages in terms of safety and continuity of running.

The LPG contained in a tank comprises a liquid state in the lower part and a gaseous state in the upper part. The tank cannot be filled completely in the liquid state, because should the temperature rise, the liquid, which cannot be compressed and is under pressure, would not be able to expand, with the consequent danger of the tank exploding. Therefore, a portion of volume free from the liquid state must be guaranteed, equal to at least 20% of the total volume.

LPG is used in burners and other equipment nearly always when the fuel is in a gaseous state.

LPG can be bled from the tank directly in its gaseous state from the top of the tank or can be drawn off in the liquid state from the bottom of the tank to then be transformed into gas in a special vaporiser.

When drawing off in the gaseous state, the delivery from the top of the tank causes a pressure drop inside the tank, thus modifying the balance between the liquid and the gaseous state, causing part of the liquid to evaporate in order to restore the initial pressure. LPG evaporation is an exothermic transformation, in other words it takes place by absorbing heat, subtracting it from the liquid mass of the LPG. The cooling of the liquid mass is proportionate to the amount of LPG drawn off in the gaseous state and determines a further pressure drop in the tank. If it is drawn off at a constant speed and within a certain limit, a balance will be established in which the heat required for transforming the state of the LPG is guaranteed by the heat exchange with the surrounding environment. It must be remembered that the heat exchange between the tank and the surrounding environment takes place exclusively through the portion of the external surface dampened by the liquid LPG.

If the gas is drawn off at a speed greater than the limit allowed, the temperature of the tank will fall considerably to the extent that a layer of ice forms on the surface of the tank, further decreasing the heat exchange with the surrounding environment until the fuel transformation is blocked, making drawing off impossible.

From the description of the process, we can see that the amount of gas that can be delivered from the tank depends on the heat transmission characteristics between the tank and the environment, which depend on the form, material and colour of the tank, as well as on the environmental conditions where the tank is installed. The tank manufacturers provide the maximum delivery capacity for the tank under standard working conditions, usually expressed in kg/h. This capacity may vary from 0.5 kg/h for small cylinders up to nearly 20 kg/h for tanks with a capacity of 5 m^3.

We should also remember that the delivery capacity of a tank depends on the filling level, decreasing as the fuel level decreases, due to the decrease in pressure and the heat exchange surface area. This means that not all the contents of the tank can be used, in order to guarantee a sufficient feed pressure. This minimum filling level, after which it should be topped up, is established by the tank manufacturer and is equal to around 25% of the tank's volume.

Therefore, the portion of the tank's volume that can be effectively used is equal to approximately 55% of the geometric volume of the tank.

To calculate the thermal capacity stored, we can use the following equations:

$$E_S = 0,55 \cdot V_G \cdot d \cdot PCI_{LPG}$$

Where:

E_S = energy stored by the tank [MJ];
V_G = the geometric volume of the tank [m^3];
d = LPG density equal to 0.52 kg/l [kg/l];
PCI_{LPG} = inferior calorific value of the LPG and equal to approximately 46 MJ/kg [MJ/kg];

The number of estimated annual refills is:

$$n = E_S / E_U$$

where:

n = number of annual refills;
E_S = energy stored by the tank [MJ];
E_U = energy consumed by the users [MJ];

Furthermore, we must always check that the total output installed does not exceed the maximum delivery capacity of the tank, in particular:

$$m_{tank} > m_{users} = P_U / PCI_{LPG}$$

where:
m_{tank}= maximum delivery capacity of the tank [kg/h];
m_{users} = maximum fuel delivery required by the users [kg/h];
P_U = output installed by the users [kW];
PCI_{LPG} = inferior calorific value of the LPG and equal to approximately 12.78 kWh/kg [kWh/kg]

When the delivery requested by the users exceeds the maximum delivery capacity of the available tanks, it must be drawn of in the liquid state. It is drawn off from the bottom of the tank with the fuel in a liquid state, and then cause the liquid to vaporise using a heat exchanger (vaporiser). This system guarantees the complete vaporisation of the LPG and permits the eventual pre-heating of the latter to avoid the formation of condensation on the pipeline. It is usually used where the cost of vaporisation is justified by the complexity of the system and is virtually compulsory if, for reasons of safety and space, the tanks are underground, as in this case the heat exchange between the tank and the outside environment is poor.

The pressure reduction from that inside the storage tank, (generally around 5 bars), to the working pressure (e.g. for small users around 30 mbars), is usually by a double-stage system. The first reducer reduces the pressure to 1.5 bars, while the second reducer reduces the pressure to 30 mbar (150 mbar for supplying industrial burners).
LPG in the gaseous form has a density more than 50% higher than that of air, and therefore in case of accidental leakage it tends to stratify low down and stagnate in pockets on the floor. In order to expel it, aeration is not always enough but the physical removal using appropriate means is often required. Any detectors and permanent aeration vents should be positioned flush with the floor.

2.6.2 Feeding diesel oil and kerosene

Hydraulic circuits on board liquid fuel burners or mixed burners, have different features and complexity, depending on the type of fuel, supplied output, load regulation logic (single-stage, multi-stage or modulating) and special standards in force. Generally the burners are fitted with a geared pump and a single or double fuel shut off solenoid system. Modulating burners also have shut off valves on the return circuit and a pressure regulator for varying output.

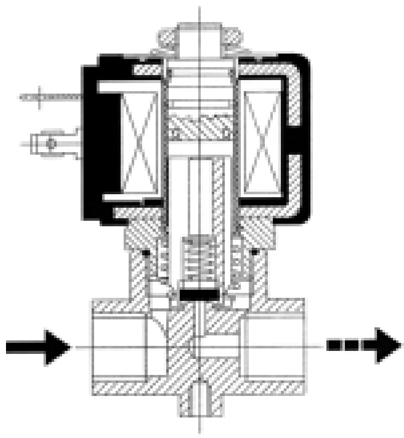


Diagram 56 *Shut-off solenoid valve on output circuit - close postition*

The fan motor drives the pump, or it is run independently, it can have special features for using kerosene. The following diagram shows the section of a typical geared pump fitted to the RL 190/M model, for example, on monobloc diesel oil burners (RL series).

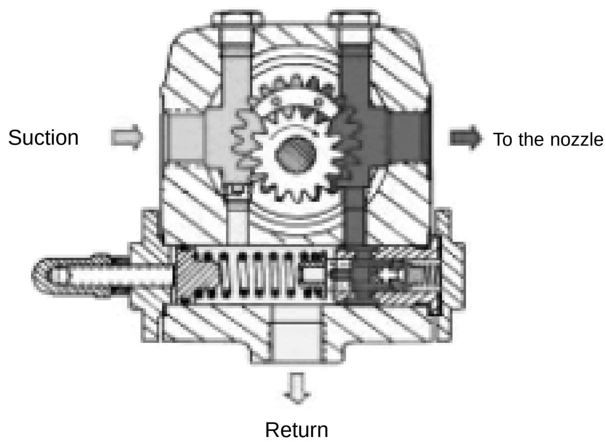


Diagram 57 *Gear pump for liquid fule monobloc burner*

In modulating burners, the modulating pressure regulator is activated in combination with the air damper, using mechanical lever systems or electronic systems that point by point supply fuel and combustion air in the correct proportions to obtain the required output.
For adaptation to specific standards, pressure control devices can be fitted, such as minimum and maximum oil pressure switches.

The table below shows the commercial

Table 13 *Summary of liquid fuels*

	Viscosity	-					+
Name	I	Kerosene	Gasolio	Olio combustibile fluido	Olio combustibile semidenso	Olio combustibile denso	Catrami
	UK	kerosene	Gas oil	Light fuel oil	Medium fuel oil	Heavy fuel oil	Tars
	D		Heizol EL	Heizol M	Heizol S	Heizol S	Teer
	F	kerosene	Domestique	Lourd n°1		Lourd n°2	Bitume
	USA			6			Incombustible
Feeding circuit	Air intake system	yes	yes	no	no	no	
	Drop-type system	yes	yes	yes (unwary)	no	no	
	Ring under pressure	yes	yes	yes	yes	yes	
	Pipelines heating	no	no	optional	advised	yes	

wording for the various liquid fuels, highlighting the typical plant engineering types for diesel oil and kerosene.
The diesel oil feed systems covered in this section are a "bi-pipeline" type and namely those comprising a delivery pipeline from the tank to the burners and a return pipeline from the burner to the tank.

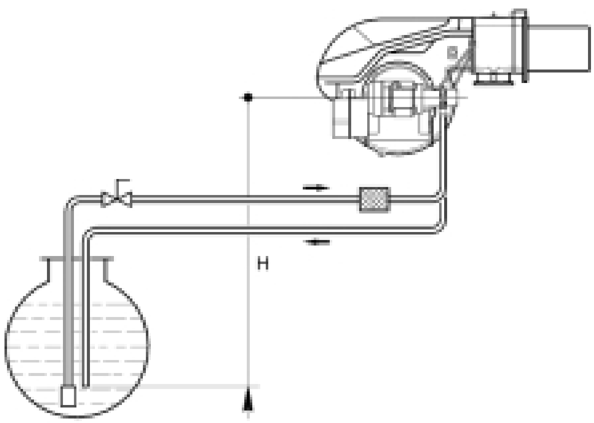


Diagram 58 *Light oil burner feeding*

Systems also exist with single diesel oil feeding pipelines, without a return line to the storage tank, where re-circulation of the unburned diesel oil takes place in proximity to the burner itself using specific accessory components.

By varying the tank position with respect to the burner position, we have the following plant engineering examples:

1. drop-type systems with supply from bottom;
2. drop-type systems with supply from summit;
3. in-take type systems;
4. systems with ring under pressure.

The first three plant engineering types do not require the use of an additional pump, but entrust diesel oil circulation to the pump installed on the burner.
In the system with the ring under pressure, an additional pump is required with the task of guaranteeing the fuel flow in the main ring. Due to the long distance between storage tank and burner, the burner pump normally has to guarantee the feed pressure.
The minimum temperature that diesel oil can reach in underground or insulated pipelines, can be assumed as +2°C.

The first three plant engineering types are discussed together as they are subject to the same criticality.

2.6.2.1 Drop-type system with supply from bottom / drop-type system with supply from summit / intake type system

As already mentioned, these three plant engineering types are related by the fact that the burner pump must guarantee fuel transport from the storage tank to the burner nozzles.

In drop-type systems with supply from the bottom (Diagram 21) the difference in height between the maximum level reachable in the storage tank and the centre of gravity of the pump must be lower than the value established by the burner manufacturer (generally between 4 and 10 meters) so as not to over-stress the pump seal mechanism.
For drop-type systems with supply from the summit (Diagram 20A), it is advisable that the height P, vertical distance between the centre of gravity of the burner pump and the highest point in the circuit, does not exceed a certain value established by the burner manufacturer (generally between 4 and 10 meters) so as not to over-stress the pump seal mechanism. Furthermore, to allow self-priming the pump, the height V must be no greater than 4 meters.
In the intake-type system (Diagram 20B), a pump depression of 50,000 Pa (0.50 bar) must not be exceeded, so that gas is not released from the fuel, sending the pump into cavitation.
These pipelines can be dimensioned using the ready-to-use tables supplied by the burner manufacturer, where on the basis of the plant engineering type, the difference in height between the intake mouth and the pump's centre of gravity, and the pipeline diameter, the maximum realisable distance from the system is provided.
This distance should be taken as the total length of the delivery pipeline. One of these tables is presented below by way of example:

+H -H (m)	Pipeline length (m)					
	RL 70 Ø (mm)			RL 100 - 130 - 190 Ø (mm)		
	10	12	14	12	14	16
+ 4,0	51	112	150	71	138	150
+ 3,0	45	99	150	62	122	150
+ 2,0	39	86	150	53	106	150
+ 1,0	32	73	144	44	90	150
+ 0,5	29	66	132	40	82	150
0	26	60	120	36	74	137
- 0,5	23	54	108	32	66	123
- 1,0	20	47	96	28	58	109
- 2,0	13	34	71	19	42	81
- 3,0	7	21	46	10	26	53
- 4,0	-	8	21	-	10	25

Table 14 Schedule for the tabular scaling of the light oil feed pipelines

If we require an analytical calculation of the pipelines, we can use the procedure indicated in the following paragraph for systems with pressurised ring.

Whatever the plant engineering type chosen, a diesel oil filter must be fitted on the delivery pipeline for separating water and impurities present in the fuel, and a standard valve at the end of the delivery pipeline in the fuel storage tank.
The diesel oil storage tank must also be equipped with all the devices required by current local legislation (breather pipes, shut off valves, etc..).

2.6.2.2 Systems with pressurised ring

If the burner pump cannot self-feed because the distance and/or the difference in height of the tank are greater than the values supplied by the burner manufacturer, a pressurised ring circuit must be adopted.
The ring-type circuit comprises a pipeline, which departs from and returns to the storage tank, with an auxiliary pump to make the fuel flow under pressure.

Pumping unit P (main ring)
This pumping unit must have a delivery equal to at least twice the sum of the maximum drawing capacities of the burners and comprise a couple of pumps and filters with the possibility of switchover in by-pass:

$$Q_{p2} = 2 \cdot (\Sigma M_i) \quad \textbf{eq 2.6.2-1}$$

where M_i is the pump delivery of the individual burner.
This over-dimensioning is necessary to guarantee stable pressure in the ring independently from the possible burner functioning combinations.
This pumping unit must have a line filter with a metal net cartridge for diesel oil, to separate the impurities and water that may be present in the fuel.
The pumping unit head should be calculated on the basis of the residual pressure which must be guaranteed to the ring and the pipeline pressure drops calculated as specified below.
In the absence of certain information from the burner manufacturer concerning the pump delivery on the machine, the following typical values can be used:

- for multi-stage burners: $M = 1.3 \div 1.5 \cdot m$
- for modulating burners: $M = 2.0 \div 2.5 \cdot m$

where m is the delivery of fuel equivalent to the maximum output of the burner.

Pipelines

The pipelines are dimensioned considering the flow inside the pipes under turbulent conditions, as diesel oil has low viscosity.

The pipeline pressure drops are the sum of those distributed along the pipeline and those concentrated due to connecting elements and hydraulic accessories (filters, valves, etc..).

The concentrated drops due to hydraulic accessories are reckoned using the equivalent lengths method, i.e. a concentrated loss is assimilated to a section of pipeline equivalent to the length of the related loss.

To correctly dimension the pipelines the following sizes are defined:

L_{EFF} = effective length of the pipeline [m];

L_{EQUIV} = sum of equivalent lengths relative to concentrated pressure drops as a result of connecting elements and hydraulic accessories [m];

L_{TOT} = total length of the pipeline, sum of the effective and equivalent lengths [m]:

$$L_{TOT} = L_{EFF} + L_{EQUIV} \quad [m]$$ **Eq 2.6.2 -2**

The equivalent lengths relative to the concentrated resistances of the components must be taken from the technical specifications supplied by the manufacturer. If these values are not available, some tables exist, shown in section 5, which contain the equivalent lengths referring to the main concentrated resistances.

Any filters must be calculated using the effective pressure drop procured by their presence provided by the manufacturer. If the exact pressure drop value is not available, the filter can be assimilated to an open valve.

The calculation delivery is, obviously, equal to that of the pumping unit on the main ring.

As far as the delivery pipeline is concerned, the diameter should be chosen in relation to the maximum permitted speed equating to 1÷2 m/s using the following equation:

$$A = \frac{Q}{V} \Rightarrow \pi \cdot \frac{d^2}{4} = \frac{Q}{V} \Rightarrow d = \sqrt{\frac{4 \cdot Q}{\pi \cdot V}}$$

eq 2.6.2 -3

where:

d = internal pipeline diameter [m];

Q = delivery in terms of liquid fuel volume [m^3/s] equal to m/ρ where ρ is the diesel oil volume mass as calculated below and m is the delivery in terms of diesel oil mass;

V = liquid fuel flow speed equal to 1.5 m/s;

The chosen pipeline corresponds to the commercially available diameter immediately above that determined using the equation 2.6.2-3.

After establishing the pipeline diameter, the exact fluid speed inside the pipeline must be calculated using the equation 2.6.2-3 to establish the effective hydraulic status of the system, calculating the Reynolds Number using the following formula:

$$N_{Re} = \frac{d \cdot V}{\gamma}$$ **Eq 2.6.2 -4**

where:

N_{Re} = Reynolds Number;

d = internal pipeline diameter [m];

V = liquid fuel flow speed;

γ = kinematic viscosity at the transfer temperature of the liquid fuel [m^2/s];

If N_{Re} > 2,320, the flow is defined as turbulent; otherwise we have a laminar flow.

The intake pipeline, i.e. the length upstream from the pump, between the pump itself and the storage tank, must be dimensioned in relation to the maximum permissible project-related drop.

The maximum project-related pressure drop is equal to:

$$\Delta P_{prog} = \Delta P_{amn} - \Delta h_{asp} - \Delta P_{acc} \quad [Pa]$$

Eq 2.6.2 -5

where:

ΔP_{amn}= the absolute pressure allowed at intake (NPSH) indicated by the pump manufacturer; otherwise, this pressure must not be less than 50,660 Pa (0.5 bar);

Δh_{asp} = intake height [Pa];

ΔP_{acc} = head loss due to the presence of hydraulic accessories not calculated in determining the equivalent lengths on the intake pipeline (filters, etc..) [Pa]

The intake height is equal to:

$$\Delta h_{asp} = \Delta h_{geom} \cdot \rho \cdot 9,81 \quad [Pa]$$ **eq 2.6.2 -6**

where:

Δh_{geom} = the difference in height between the fuel test point in the tank and the centre of the delivery pump [m];

ρ = diesel oil volume mass [kg/m^3];

The value of Δh_{geom} is positive if the tank test point is lower than the centre of the pump, negative if the tank test point is higher than the centre of the pump.

The liquid fuel volume mass depends on the temperature according to the following formula:

$$\rho = \frac{\rho_{15}}{1 + \beta \cdot (t - 15)} \qquad \textbf{eq 2.6.2 -7}$$

where:
ρ = liquid fuel volume mass [kg/m³];
ρ_{15} = liquid fuel volume mass at the reference temperature of 15°C equal to 865 kg/m³;
t = transfer temperature of the diesel oil equal to 2°C [°C];
β = expansion formula equal to 0.00064°C^{-1};

If the flow is laminar, the pipelines should be dimensioned according to the following formula:

$$d = \sqrt{42 \cdot \frac{\gamma \cdot L_{TOT} \cdot m}{\Delta P_{prog}}} \qquad \textbf{eq 2.6.2 -8}$$

where:
d = internal pipeline diameter [m];
γ = kinematic viscosity of the liquid fuel transfer temperature [m²/s];
L_{TOT} = total pipeline length, sum of the effective and equivalent lengths [m];
m = mass-related delivery of the pumping unit [kg/s];
ΔP_{prog} = maximum project-related pressure drop (depression) [Pa];

In technical practice the kinematic viscosity is expressed either in cSt or in a unit of measure depending on the type of viscometer used to measure the viscosity (Engler, Saybolt universal, Redwood degrees, etc…); therefore, before using the previous formula the kinematic viscosity must be transformed into cSt using the tables and alignment charts indicated in section 5, remembering that:

$$1 \text{ cSt} = 1 \text{ mm}^2/\text{s} = 10^{-6} \text{ m}^2/\text{s}; \qquad \textbf{eq. 2.6.2 -9}$$

If the flow is turbulent, the pipelines should be dimensioned according to the following formula:

$$d = \sqrt[5]{0{,}00084 \cdot \frac{\gamma \cdot L_{TOT} \cdot m^2}{\Delta P_{prog}}}$$

where:
d = internal pipeline diameter [m];
γ = the friction factor to be estimated in the diagram shown below in relation to the N_{Re} and the relative texture e/D, where e represents the absolute texture in mm;
L_{TOT} = the total pipeline length, sum of the effective and equivalent lengths [m];
m = mass-related delivery of the pumping unit [kg/s];
ΔP_{prog} = maximum project-related pressure drop (depression) [Pa];

The table 15 shows the value of the absolute texture of certain types of pipelines:

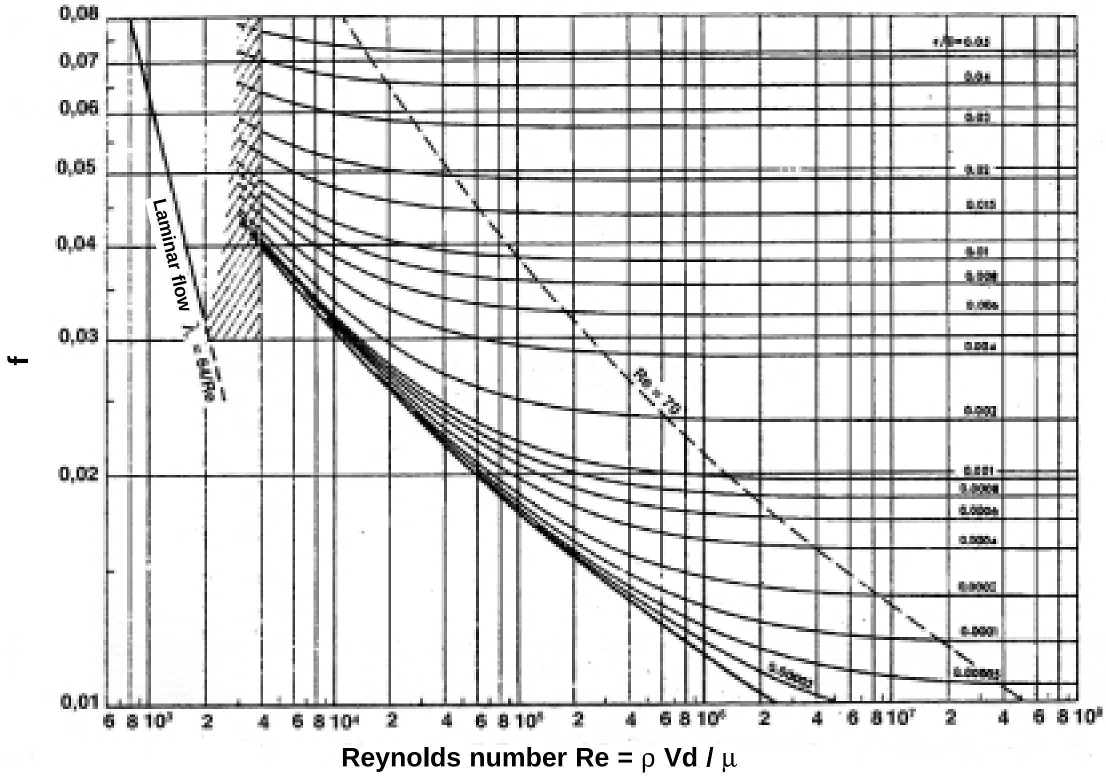
The graph 59 shows the friction factor value *f* in relation to the Reynolds Number NRe and the relative texture e/D.

The diameter calculated in this manner must not, in any case, be less than 6 mm.
Once the above-mentioned diameter has been calculated, it is necessary to check that the speed is not lower than 0.15 m/s using the equation (2.6.2-3), specifically:

Material	**Wall status**	**Absolute texture (mm)**
Wire-drawing pipes, new (copper, brass, bronze, light alloy) Synthetic material pipes, new	technically smooth	0,001 3 ÷ 0,001 5
Non-welded pipes, new	rolled film	0,02 ÷ 0,06
	pickled	0,03 ÷ 0,04
	zinc-plated	0,07 ÷ 0,16
Longitudinal welded pipes, new	rolled film	0,04 ÷ 0,1
	tarred	0,01 ÷ 0,05
	galvanized	0,008
Stell pipes after long employ	moderately rusted or lightly encrusted	0,15 ÷ 0,2
	heavily encrusted	up to 3

Table 15 *Absolute texture of the pipelines*

Diagram 59 *Moody's abacus*



$$V = \frac{Q}{A} = \frac{Q}{\pi \cdot \frac{d^2}{4}} \quad [m/s] \qquad \textbf{eq. 2.6.2 -10}$$

where:
d = internal pipeline diameter [m];
Q = liquid fuel delivery in volume [m^3/s];
If the transfer speed is less than the limit value of 0.15 m/s, proceed as follows:

- the pipeline diameter that guarantees this minimum speed should be chosen using the formula:

$$A = \frac{Q}{V} \Rightarrow \pi \cdot \frac{d^2}{4} = \frac{Q}{V} \Rightarrow d = \sqrt{\frac{4 \cdot Q}{\pi \cdot 0{,}15}}$$

eq. 2.6.2 -11

- the total maximum pipeline length (effective + equivalent) connecting the tank and the pump is determined so as not to exceed the project-related pressure drop using the following formula:

for the laminar flow

$$L_{TOT} = \frac{d^4 \cdot \Delta P_{prog}}{42 \cdot \gamma \cdot m} \qquad \textbf{eq. 2.6.2 -12}$$

for the turbulent flow

$$L_{TOT} = \frac{d^5 \cdot \Delta P_{prog}}{0{,}00084 \cdot \gamma \cdot m} \qquad \textbf{eq. 2.6.2 -13}$$

The pump is situated at a distance from the tank, which should not exceed L_{TOT}, considered as the sum of the effective and equivalent lengths.
If the resulting diameter were less than 6 mm, a pipeline with an internal diameter of 6 mm should be chosen taking care to up-rate the delivery of the pump so that the fluid speed is greater than 0.15 m/s.

Pressure regulating valves
The pressure regulating valves are required to maintain the pressure in specific parts of the circuit and therefore the desired delivery. They

Diagram 60 *Pressure regulating valve*

are installed in the main ring, normally between the intake and return pipelines from the burner pump and essentially comprise a valve body in cast iron with hydraulic couplings for high and low pressure and a by-pass regulator piston with a related spring and rating organ.
Their function is such that, even under a large delivery variation, the established pressure is maintained within a certain tolerance range.
These valves are chosen on the basis of the following project data:

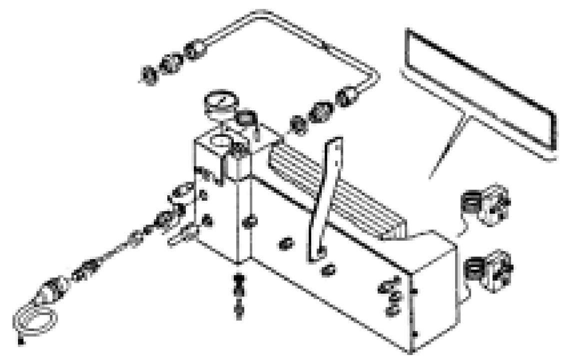
- delivery equal to that of the pumping unit in the related circuit;
- pressure range typically between 100,000 and 400,000 Pa (1÷4 bar).

2.6.3 Feeding of heavy oil (fuel oil)

For the hydraulic circuits on board these burners, the same is valid as for diesel oil and kerosene, the only difference being a pre-heater is fitted (electric or fluid) for the fuel oil, like the one shown in the following figure.

The basic characteristic of heavy oil or fuel oil that determines the plant engineering typology, is its viscosity. The viscosity of a liquid depends on its temperature
Table 16 gives the commercial names of the various fuel oils together with the related plant engineering implications determined by viscosity.

Diagram 61 *Heavy oil preheating unit*



The supply systems in burners powered by high viscosity liquid fuel can be divided into two types:

- drop-type systems;
- pressurised ring systems.

The first plant engineering type, applicable solely for multi-stage burners and not for modulating burners, is advisable only for extremely fluid fuel oil (viscosity < 3°E to 50°C) and usable only if the burner pump is guaranteed an adequate hydraulic head under all running conditions. These are used very little at present.
This paragraph analyses the second plant engineering type, with pressurised ring, which offers a greater guarantee of satisfactory running.
Basically, this supply system comprises two ring circuits plus a transfer circuit; the main one for circulating the heavy oil from the service tank, the secondary one for circulating the oil from the primary circuit to the burner

	Viscosity	-					+
Name	I	Kerosene	Gasolio	Olio combustibile fluido	Olio combustibile semidenso	Olio combustibile denso	Catrami
	UK	kerosene	Gas oil	Light fuel oil	Medium fuel oil	Heavy fuel oil	Tars
	D		Heizol EL	Heizol M	Heizol S	Heizol S	Teer
	F	kerosene	Domestique	Lourd n°1		Lourd n°2	Bitume
	USA			6			
Feeding circuit	Air intake system	yes	yes	no	no	no	Incombustible
	Drop-type system	yes	yes	yes (unwary)	no	no	
	Ring under pressure	yes	yes	yes	yes	yes	
	Pipelines heating	no	no	optional	advised	yes	

Table 16 *Summary of liquid fuels*

and the transfer one for transferring the fuel oil from the storage tank to the service tank. All the circuits are controlled by their own pump; the pump for the primary and transfer circuits should be chosen by the design engineer, while those for the secondary circuit are provided as standard fittings with the burner.
The possible variants depend on whether the burner is multi-stage or modulating. In summary, the plant engineering diagrams under analysis are the following:

1. ring-type system for multi-stage burners with service tank;
2. ring-type system for modulating burners with service tank;
3. ring-type system for multi-stage burners without service tank;
4. ring-type system for modulating burners without service tank;

2.6.3.1 Ring-type systems for multi-stage burners with or without service tanks (type 1-3)

The functional layout is illustrated in Diagrams 23 and 24.
In this paragraph, we will analyse the dimensioning of the main circuit components.

Storage tank
The storage volume should be determined in relation to the fuel oil delivery method and derives from a compromise between the supply transport cost, delivery guarantee and installation cost for the tank.
As a general indication, the following minimum types can be considered:

- two tanks of 45,000 kg;
- three tanks of 25,000 kg;

Pumping unit P1 (transfer ring)
This component is only present in plant engineering types with service tanks.
This pumping unit, denominated transfer, must have a capacity equal to 1.2-1.5 times the peak maximum consumption, and comprise a pair of pumps and filters with the possibility of switchover in by-pass. They are :
m i = maximum fuel consumption of the Nth burner;
Mi = pump delivery of the Nth burner;
The pumping unit delivery is equal to:

$$Q_{p1} = 1,2 \div 1,5 \cdot (\Sigma m_i) \qquad \textbf{eq. 2.6.2 -14}$$

Diagram 62 | Pumps for fuel oil

This pumping unit must have a self-cleaning blade filter or similar, equipped with a heater, with meshes with a dimension between 400 and 600 μm.

Fuel oil pumps can be monobloc or with separate gear or screw motors. The number of revs is normally low (900÷1,400 g/1'), and as a rule the more viscous the oil, the lower the number of revs must be.
Pumping units already complete with filter, pumps, pressure regulating valve, gauge, check valve and shut off valve are available on the market.
The head ensured by these pumps normally ranges between 100.00÷600,000 Pa (1÷6 bar).

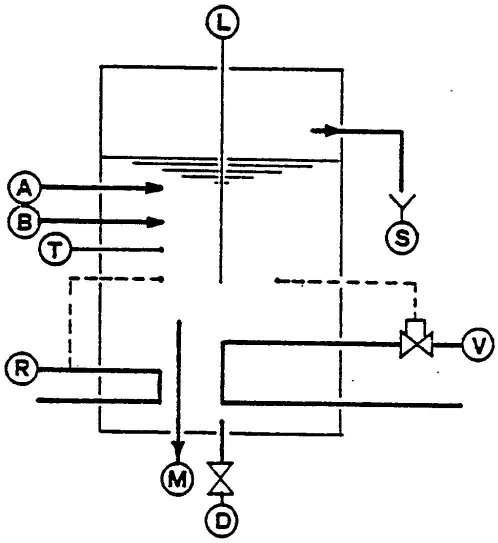
Service tank S
This component is only present in plant engineering types with service tank.
The service tank acts as a communication element between the transfer section and the ring section for final fuel oil pre-heating. This allows accumulating a certain amount of liquid fuel between the cistern and the burner. The tank must have the following characteristics:
- tank capacity equal to 2-3 times the sum of the maximum hourly drawing capacities of the burners:

$$V_S = 2 \div 3 \cdot (M_i) \cdot 1 \text{ [kg]} \qquad \textbf{eq. 2.6.2 -15}$$

- entry of the fuel oil from the end plate;
- double fluid/electrical pre-heater; the fluid pre-heater (warm water or vapour) to be positioned immediately above the arrival point for the liquid fuel; the electrical pre-heater above the fluid pre-heater with integration and emergency functions;
- drawing off the liquid fuel above the pre-heaters.

The tank must be equipped with the following devices:

Diagram 63 *Service tank*



A – oil from reservoir
B – return oil from the burner
D – tank drainage
L – tank gage
M – oil to the burner
R – electrical heater
V – steam heater
S – overflow discharge

- end plate outlet for water and sediment;
- level control with minimum and maximum alarm equipped with self-checking systems;
- atmosphere breather pipe;
- "over full" device with return line to storage tank;

Pumping unit P2 (main ring)
This pumping unit must have a delivery equal to at least 3 times the sum of the maximum drawing capacities of the burners and comprise a couple of pumps and filters with the possibility of switchover in by-pass:

$$Q_{p2} = 3 \cdot (M_i) \qquad \textbf{eq. 2.6.2 -16}$$

This over-dimensioning is due to the need to maintain a stable pressure independently from the possible combinations of the various burner running stages.
This pumping unit must have a self-cleaning blade filter or similar, equipped with heater and with meshes measuring between 200 and 300 μm.
The head of the pumping unit should be calculated on the basis of the ring pressure to be guaranteed, as a rule greater than 100,000 Pa (1 bar), and the pipeline pressure drops calculated as specified below.
Remember that in the absence of definite information from the burner manufacturer concerning the pump delivery on board the machine, the following characteristic values can be used:

- for multi-stage burners: M = 1.3÷1.5 ·m
- for modulating burners: M = 2.0÷2.5 ·m

Pressure regulating valves
The pressure regulating valves are required to maintain the pressure in specific parts of the circuit and therefore the delivery desired. They are installed on the main ring and essentially comprise a valve body in cast iron with hydraulic couplings for high and low pressure and a by-pass regulator piston with a related spring and rating organ.
Their function is such that, even under large delivery variations, the required pressure is maintained within a certain tolerance range.
The choice of these valves is made on the basis of project data:

- delivery equal to that of the pumping unit in the related circuit;
- pressure range between 50,000 Pa (0.5 bar) and 500,000 Pa (5 bar), typically between 100,000 and 400,000 Pa (1÷4 bar).

Calculating the pipelines
The pressure drops in the pipelines are the sum of those distributed along the pipeline and those concentrated due to connecting elements and hydraulic accessories (filters, valves, etc…).
To correctly dimension the pipelines the following sizes are defined:
L_{EFF} = effective pipeline length [m];
L_{EQUIV} = sum of the equivalent lengths relative to concentrated pressure drops as a result of the connecting elements and hydraulic accessories [m];
L_{TOT} = total pipeline length, sum of the effective and equivalent lengths [m]:

$$L_{TOT} = L_{EFF} + L_{EQUIV} \quad [m] \qquad \textbf{eq. 2.6.2 -17}$$

The equivalent lengths relative to the concentrated elements of the components must be gained from the manufacturer's technical specifications. If these values are not available, some tables exist, as illustrated in section 5, which contain the equivalent lengths referring to the main concentrated resistances.
Any filters must be calculated with the effective head loss procured by their presence. If the exact pressure drop value is not available, it is possible to assimilate the filter to an open valve.
The following procedure can be used both for

the transfer and the primary circuits.
To correctly dimension the pipelines, the system must be divided into two parts:

- intake pipelines;
- delivery pipelines.

This division is justified by the fact that while the pump performances on the delivery pipeline do not create any problems given the high heads that can be achieved, in the range of 300,000÷500,000 Pa (3÷5 bar), on the intake pipeline there are some maximum depression limits which must not be exceeded to avoid gasification problems with the fuel oil with consequent problems of pump cavitation. This value (NPSH) is supplied by the pump manufacturer and in any case cannot be any lower than 50,000 Pa (0.5 bar).

The intake pipeline is dimensioned in relation to the following parameters:

- maximum project-related pressure drop (depression) ΔP_{prog} [Pa];
- minimum speed V_{min} equal to 0.15 m/s;
- minimum internal diameter D_{min} no less than 0.008 m

The maximum project-related pressure drop is equal to:

$$\Delta P_{prog} = \Delta P_{amn} - \Delta h_{asp} - \Delta P_{acc} \text{ [Pa]}$$

eq. 2.6.2 -18

where:

ΔP_{amn} = the absolute pressure allowed at intake (NPSH) indicated by the pump manufacturer; otherwise, this pressure must not be less than 50,660 Pa (0.5 bar);
Δh_{asp} = intake height;
ΔP_{acc} = head loss due to the presence of any hydraulic accessories not calculated in the determining the equivalent lengths present on the intake pipeline (filters, etc…)
The intake height is equal to:

$$\Delta h_{asp} = \Delta h_{geom} \cdot \rho \cdot 9{,}81 \quad \text{[Pa]}$$ **eq. 2.6.2 -19**

where:
Δh_{geom} = the difference in height between the fuel test point in the tank and the centre of the delivery pump [m];
ρ = heavy fuel oil volume mass [kg/m^3];
The value of Δh_{geom} is positive if the tank test point is lower than the centre of the pump, negative if the tank test point is higher than the centre of the pump.

The liquid fuel volume mass depends on the temperature according to the following formula:

$$\rho = \frac{\rho_{15}}{1 + \beta \cdot (t - 15)}$$ **eq. 2.6.2 -20**

where:
ρ = liquid fuel volume mass [kg/m^3];
ρ_{15} = liquid fuel volume mass at the reference temperature of 15°C equal to 990 kg/m^3;
t = liquid fuel transfer temperature [°C];
β = expansion formula equal to 0.00063°C^{-1};

The liquid fuel transfer temperature is determined with reference to the constructive limits of the pumping unit, which in fact determine the maximum viscosity of the liquid that can be pumped and its temperature. As a general rule, the viscosity limit ranges between 30°E and 50 °E (228÷380 cSt) which determines a liquid fuel transfer temperature around 50÷60°C. There are some pumping units capable of pumping liquids with a viscosity greater than 100°E. In any event, it is good practice to keep the viscosity values below 50°E.
The pipelines are dimensioned according to the following formula:

$$d = \sqrt{42 \cdot \frac{\gamma \cdot L_{TOT} \cdot m}{\Delta P_{prog}}}$$ **eq. 2.6.2 -21**

where:
d = internal pipeline diameter [m];
γ = kinematic viscosity of the liquid fuel transfer temperature [m^2/s];
L_{TOT} = total pipeline length, sum of the effective and equivalent lengths [m];
m = mass-related delivery of the pumping unit [kg/s];
ΔP_{prog} = maximum project-related pressure drop (depression) [Pa];

It should be pointed out that, in technical practice kinematic viscosity is expressed either in cSt or in a unit of measure depending on the type of viscometer used to measure the viscosity (Engler, Saybolt universal, Redwood, etc…); therefore, before using the previous formula the kinematic viscosity must be transformed into cSt using the tables and alignment charts indicated in section 5, remembering that:

$$1 \text{ cSt} = 1 \text{ mm}^2/\text{s} = 10^{-6} \text{ m}^2/\text{s}$$ **eq. 2.6.2 -22**

To determine the minimum internal diameter of the pipeline, the total length of the pipeline

must be determined and consequently the equivalent length that, in turn, depends on the internal diameter of the pipeline. We must therefore presume an initial provisional diameter for estimating the equivalent lengths. An initial diameter estimate can be made by presuming a liquid fuel flow speed, pre-determining the diameter with the following formula:

$$A = \frac{Q}{V} \Rightarrow \pi \cdot \frac{d^2}{4} = \frac{Q}{V} \Rightarrow d = \sqrt{\frac{4 \cdot Q}{\pi \cdot V}}$$

eq. 2.6.2 -23

where:
d = internal pipeline diameter [m];
Q = liquid fuel delivery in volume [m^3/s];
V = liquid fuel flow speed as equal to 0.15÷0.20 m/s;
Once the equivalent length and, consequently, the total length have been determined, it is possible to use the equation (2.6.2-21) to determine the minimum internal diameter of the pipeline.
If the diameter calculated in this manner is significantly different to that presumed for calculating the equivalent lengths, the equivalent lengths must be re-calculated with the new diameter using the equation (2.6.2-23) and subsequently repeat the diameter calculation using the equation 2.6.2-21.
The pipeline will correspond to the commercially available diameter immediately above that determined using the equation (2.6.2-21).
At this point, the speed in the pipeline must be checked using the following formula:

$$V = \frac{Q}{A} = \frac{Q}{\pi \cdot \frac{d^2}{4}} \quad [m/s]$$ **eq. 2.6.2 -24**

where:
d = internal pipeline diameter [m];
Q = liquid fuel delivery in volume [m^3/s];
If the transfer speed is lower than the limit value of 0.15 m/s, proceed as follows:

- the pipeline diameter that guarantees this certain minimum speed should be chosen using the formula:

$$A = \frac{Q}{V} \Rightarrow \pi \cdot \frac{d^2}{4} = \frac{Q}{V} \Rightarrow d = \sqrt{\frac{4 \cdot Q}{\pi \cdot 0{,}15}}$$

eq. 2.6.2 -25

- the total maximum pipeline length (effective + equivalent) connecting the tank and the pump is determined so as not to exceed the project pressure drop using the following formula:

$$L_{TOT} = \frac{d^4 \cdot \Delta P_{prog}}{42 \cdot \gamma \cdot m}$$ **eq. 2.6.2 -26**

The pump will be connected at a distance from the tank, which should not exceed L_{TOT} considered as the sum of the effective and equivalent lengths.
If the resulting diameter were less than 0.008 m, a pipeline with an internal diameter of 0.008 m should be chosen taking care to up-rate the pump delivery so that the fluid speed is greater than 0.15 m/s.

As far as the delivery pipeline is concerned, the diameter should be chosen in relation to the maximum allowed speed equating to 0.6 m/s using the equation (2.6.2-23), more precisely:

$$A = \frac{Q}{V} \Rightarrow \pi \cdot \frac{d^2}{4} = \frac{Q}{V} \Rightarrow d = \sqrt{\frac{4 \cdot Q}{\pi \cdot V}}$$

eq. 2.6.2 -27

where:
d = internal pipeline diameter [m];
Q = liquid fuel delivery in terms of volume [m^3/s];
V = liquid fuel flow speed equal to 0.6 m/s;
The pipeline will correspond to the commercially available diameter immediately above that is determined using the equation (2.6.2-23). After which, proceed calculating the pressure drop of the entire circuit (transfer or primary ring) using the following equation:

$$\Delta P_{prog} = \frac{42 \cdot \gamma \cdot L_{TOT} \cdot m}{d^4}$$ **eq. 2.6.2 -28**

where:
d = internal pipeline diameter [m];
γ = kinematic viscosity at the liquid fuel transfer temperature [m^2/s];
L_{TOT} = total pipeline length, sum of the effective and equivalent lengths [m];
m = mass-related delivery of the pumping unit [kg/s];
ΔP_{prog} = calculation pressure drop [Pa];

The calculation pressure drop must be added to the loss due to any hydraulic accessories (filters, etc…) present on the delivery pipeline, the loss present on the delivery pipeline and

the difference in height between the intake pipeline and the delivery pipeline:

$$\Delta P_{tot} = \Delta P_{calc} + \Delta P_{acc} + 9,81 + \frac{\Delta H_{pipelines}}{\rho} \quad [Pa]$$

eq. 2.6.2 -29

where:
ΔP_{tot} = total pressure drop [Pa];
ΔP_{calc} = calculation pressure drop of the delivery pipeline [Pa];
ΔP_{acc} = head loss due to the presence of any hydraulic accessories not calculated in determining the equivalent length, present on the delivery pipeline (filters, etc…) [Pa];
$\Delta H_{pipelines}$ = difference in height between the intake pipeline and the delivery pipeline [m];
ρ = liquid fuel volume mass [kg/m^3];

The value calculated in this manner added to the residual head that must be guaranteed the ring, must be inferior to the head guaranteed by the pump; specifically:

$$P_{pump} \geq P_{ring} + \Delta P_{tot} \quad [Pa]$$ **eq. 2.6.2 -30**

where:
P_{pump} = the head guaranteed by the pumping unit [Pa];
P_{ring} = the pressure to be guaranteed the ring >100,000 Pa (>1 bar) [Pa];
ΔP_{tot} = total pressure drop in the pipelines [Pa];
In case of negative results, one of the following actions can be taken:

- decrease the delivery pipeline length so as to reduce the pressure drops;
- increase the delivery pipeline diameter so as to reduce the pressure drops;
- choose a different pumping unit to guarantee the required head.

The pipelines are mainly made in steel without welding.

2.6.3.2 Ring-type systems for modulating burners with or without service tanks

Diagrams 23 and 24 illustrate the reference plant engineering layout for modulating burners.
The system is similar to the previous one, except for the connection of the secondary burner circuit to the primary feed circuit. This connection be made via an outgas tank. This device is necessary to recover the heat discharged by the modulating burner when it is running at minimum.
In fact, while in multi-stage burners the excess pump delivery is discharged by the pump control device, and therefore is not a burden for the heater, this does not happen in modulating burners, since practically the entire delivery of the burner pump passes through the heater and the return flow is more or less the atomisation temperature for the liquid fuel. Note that this temperature depends on the viscosity of the liquid fuel and may also be considerably higher than 100°C, therefore much higher than the fuel oil transfer temperature equal to approximately 50-60°C.
During the modulation phase, the majority of the fuel oil delivery is discharged on the return line and this, first of all, represents a useless waste of energy and, in addition, a burden for the burner as the pre-heater may not be adequate for heating all the delivery, thus causing a consequent drop in temperature and deterioration of the atomisation, possibly extinguishing the flame. For these motives, correct connection of the modulating burner is achieved using the outgas tank which, thanks to its particular construction, enables almost total recovery of the heat contained in the return line, whilst also allowing the gases to be discharged.
This outgas tank can also be conveniently used with multi-stage burners, as in this pre-heating phase there is a complete blow-by in the burner heater.

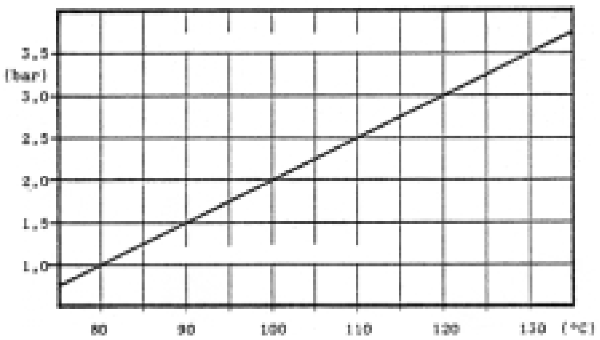
To dimension the pipelines and system components, please refer to references illustrated previously for multi-stage burners. In this paragraph, attention is focused on just the pumping unit and the gas separator bottle.

Pumping unit P2 (main ring)
This pumping unit must have a delivery at least 3 times the sum of the maximum burner drawing capacities and comprise a couple of pumps and filters with the possibility of switchover in by-pass:

$$Q_{p2} = 3 \ (\Sigma M_i)$$ **eq. 2.6.2 -31**

This over-dimensioning is required to maintain a stable pressure independently from the possible combinations of the various burner running stages.
This pumping unit must have a self-cleaning blade filter or similar, equipped with heater and with meshes measuring between 200 e 300 µm.

Diagram 64 *Ring pressure - advised values*



The ring pressure to the regulator should be chosen with reference to the fuel oil temperature in the outgas device and, for reasons of safety, be equal to the atomisation temperature, to prevent the development of gas from the hot oil and ensure the burner pump runs correctly without the danger of pump cavitation.
The ring pressure Pring, which the pumping unit must guarantee, should be calculated referring to the following graph:

Gas separator bottle
This device essentially comprises a vertical barrel divided horizontally by a circular sector. The oil circulating in the ring delivery pipeline runs through the upper portion. Two overlapping couplings are present in the lower portion for connecting the burner hoses; the upper of the two is the return line, while the lower one should be connected to the intake; the coupling of the return line is extended nearly as far as the opposite wall, to prevent the by-pass of hot oil to the upper chamber through the split made in the dividing sector. In this manner, the intake pipeline recovers nearly all the hot oil from the return pipeline and, because of the low descent speed of the oil taken in by the pump, it is possible the development and separation of gas bubbles which may have formed.
The lower bottom of the tank must be equipped with an outlet and threaded coupling for inserting the electrical heating element. A breather pipe must be positioned in the upper part for discharging the gases that may have accumulated in the tank.

2.6.3.3 Heating the pipelines

For all the plant engineering variations mentioned, the pipelines must be marked for heating the fuel oil. The following is the dimensioning method:

The heat to be supplied to the transport pipelines takes into account two factors:
- initial pipeline heating and normal setting;
- compensation of the heat loss when running;

To calculate the energy required for normal setting, the following formula can be used, which takes into account the oil mass to be heated and that of the steel pipeline under ideal conditions with no heat loss. The formula is as follows:

$$e_1 = (q \cdot \rho \cdot c_e + M \cdot c_f) \cdot \Delta T$$ **eq. 2.6.2 -32**

where:
e_1 = specific energy per metre of length to supply to the pipeline [kJ/m];
q = oil content per metre of pipe [m^3/m];
ρ = fuel oil volume mass [kg/m^3];
c_e = fuel oil specific heat (equal to approximately 1.88 kJ/kg°C) [kJ/kg°C];
M = weight of the steel pipelines per linear metre of pipeline [kg/m];
c_f = specific heat of the steel (equal to approximately 0.46 kJ/kg°C) [kJ/kg°C];
ΔT = thermal head of the pipeline and the fuel oil between the system stand-by status and steady running status (approximately 50°C) [°C];

The total energy to be supplied is given by:

$$E_1 = e_1 \cdot L$$ **eq. 2.6.2 -33**

where:
E_1 = total energy to be supplied to the pipelines [kJ];
e_1 =specific energy per metre of length to be supplied to the pipelines [kJ/m];
L = effective length of the pipeline [m];

The total power required to guarantee the energy depends on the time taken to achieve the steady running state:

$$P_1 = \frac{E_1}{t \cdot 3600}$$ **eq. 2.6.2 -34**

where:
E_1 = energy to be supplied to the pipelines [kJ];
P_1 = system power for obtaining steady running state in the pipelines [kW];
t = time taken to obtain steady running state conditions [hours];
The specific power per unit of length is:

$$p_1 = \frac{P_1}{L} \cdot 100 \qquad \textbf{eq. 2.6.2 -35}$$

where:
p_1 = the specific power per unit of length for reaching the steady running state of the pipelines [W/m];
P_1 = system power for reaching the steady running state of the pipelines [kW];
L = effective length of the pipeline [m];

To calculate the energy that needs to be supplied to compensate the heat loss during steady running state, the following simplified formula can be used which only takes into account the resistance of the pipeline's insulation without taking into account the scant resistance provided by the metal pipeline:

$$p_2 = \frac{2 \cdot \pi \cdot \lambda \cdot \Delta T}{ln\left(\frac{D_{tot}}{D_{est}}\right)} \qquad \textbf{eq. 2.6.2 -36}$$

where:
p_2 = specific power per unit of length for heat losses from the pipelines [W/m];
λ = thermal conductivity of the pipeline insulation [W/m°C];
D_e = external diameter of the steel pipeline [mm];
D_{tot} = total diameter equal to D_e +2·s where s is the thickness of the insulation [mm];
ΔT = thermal head between the pipeline and fuel oil temperatures and the external temperature [°C];

The total power to be installed will be equal to:

$$P_2 = \frac{p_2 \cdot L}{1000} \qquad \textbf{eq. 2.6.2 -37}$$

where:
P_2 = total system power for heat losses from the pipelines [kW];
p_2 = specific power per unit of length for heat losses from the pipelines [W/m];
L = effective length of the pipeline [m];

The heating system for heating the pipelines must be dimensioned to overcome the heat losses and provide the pre-heating heat. While heat losses are always present, pre-heating during start-up is only necessary when the system is primed or after long periods in stand-by, for example, for maintenance work.
Increasing the thickness of the insulation can reduce heat loss, while the pre-heating heat may be deferred over time but not eliminated.

If we presume rather short times for achieving steady running status (0.5÷1 hour), the load level due to heat loss is only a small fraction of the total which is nearly all absorbed by the pre-heating power.
Given the high cost for heating the pipelines and the desultory nature of the operations for achieving steady running status, it is advisable to adopt fairly long pre-heating times, around 4 to 5 hours, so as to rationally make the best of the power employed, provided it is compatible with the type of system and its running requirements.
To calculate the total power to be installed, the commitment required to satisfy the heat losses of the pipeline at steady running state is calculated by half:

$$P_{tot} = P_1 + \frac{P_2}{2} \qquad \textbf{eq. 2.6.2 -38}$$

where:
P_{tot} = total system power for reaching steady running state and for the heat loss from the pipelines [kW];
P_1 = system power for the reaching steady running state for the pipelines [kW];
P_2 = system power for the heat loss from the pipelines [kW];

The pipelines can be heated in two different ways:

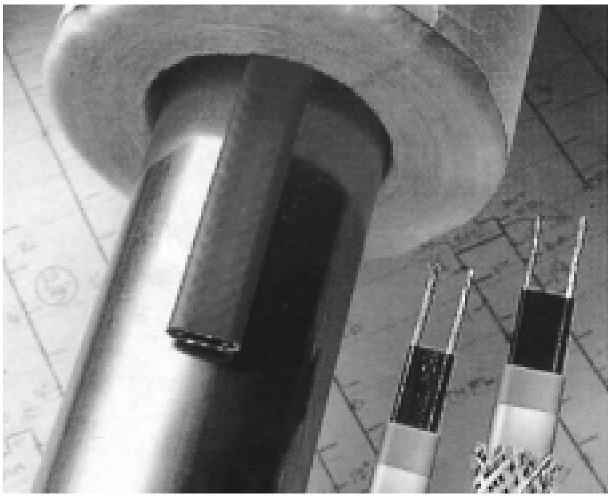
- using electrical heating element;
- using warm or overheated water;
- using vapour

In this manual we only touch upon electrical-type heating which permits simple and fast marking that can be easily modified if required.
The pipes can be electrically heated by thermal bands or heating wires.
The thermal bands are flexible polyester bands, which contain electrical elements insulated individually by PVC sheaths supplied either in rolls of a pre-cut length or in reels that must be cut by the user.
The efficiency of the electrical heating systems is always less than 100% both because of imperfect contact with the pipe, and due to the inevitable heat loss outwards despite the insulation.
Generally, the efficiency yields can reach the following value:

- thermal bands and thermal covers η = 85%;
- heating wires η = 70%;

The total power to be supplied is equal to:

Diagram 65 *Self-regulating heating band*



$$P_{eff} = \frac{P_{tot}}{\eta}$$

where:
P_{eff} = the total power which the electrical heating system must provide [kW];
P_{tot} = total system power for reaching steady running state and for the heat loss from the pipelines [kW];

The choice of the heating bands should be made according to the maximum temperature achievable by the pipeline (for example 65°C). The heating bands can be self-regulating, where the power issued decreases with the increase in temperature until it stops at a certain value (60÷80°C), or else non-self-regulating in which case a limit thermostat must be provided to control the temperature.
The non-self-regulating heating bands have a constant power emitting ability which is independent from the temperature and they should be chosen according to the power required as calculated using the above procedures, in particular:

$$p_{eff} = \frac{P_{eff}}{L} \cdot 1000$$

where:
p_{eff} = specific power per pipeline length which the electrical system must supply [W/m];
P_{eff} = total power which the electrical heating system must supply [kW];
L = effective pipeline length [m];

If P_{band} is the specific heating power of the non-self-regulating band; we will obtain the length of the heating band per meter of pipeline as:

$$l_{band} = \frac{p_{eff}}{p_{band}}$$

where:
l_{band} = the length of the heating band per metre of pipeline;
p_{eff} = specific power per length of pipeline which the electrical system must provide [W/m];
p_{band} = specific heating power per metre of band [W/m];

The specific power outputs of the bands can be varied by a few W/m units to several hundreds of W/m; as a rule this can be done using heating bands with a specific power between 20 and 40 W/m.
Once the length of the belt has been obtained, the pitch of the turns can be obtained using which the oil fuel pipeline will coil, using the diagrams provided by the band manufacturers, such as those shown in diagram 66.

The X axis shows the length of the heating band per metre of pipeline; the Y axis shows the pitch of the turn. This diagram should be used in the following manner:

- from the point corresponding to the value lband on the X axis, trace a vertical line until you meet the curve corresponding to the diameter of the pipeline;
- in relation to the point found, read the value of the turns required to obtain the power desired.

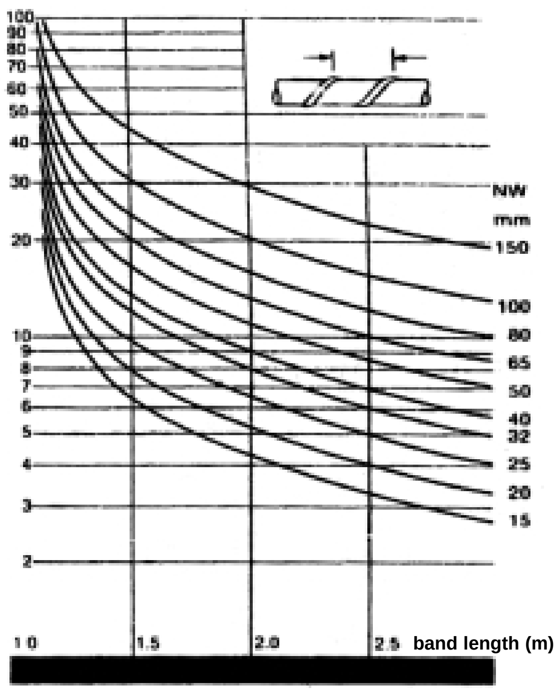


Diagram 66 *Turns' step for heating bands*

If the number of the turns obtained in this manner is too high, it can be reduced by increasing the specific power of the heating band.

In the event that self-regulating heating bands are chosen, their specific power P_{band} must be chosen in relation to a reference temperature, which is equivalent to the minimum achievable by the fuel oil, normally equal to 10°C; then the procedure is similar to that developed for non-self-regulating heating bands.

Heating wires comprise a coated multi-wired conductor. When the heating wire is powered it produces heat using the "Joule" effect. The power dissipated depends on the conductor strength and the power supply potential. As a rule, manufacturers give the strength of the wire as the benchmark; the specific power should be calculated according to the law of Joule expressed for constant voltages:

$$p_{wire} = \frac{V^2}{r_{wire} \cdot L^2_{wire}}$$

where:

p_{wire} = specific heating power per metre of heating wire [W/m];

V = power supply voltage of the heating wire [V];

r_{wire} = specific strength per length of the heating wire [Ω/m];

L_{wire} = heating wire length [m];

The heating wire should have a specific power between 20÷40 w/m².

The power supply pipeline can be marked with a copper tube with a small diameter, through which the heating wire can be passed for making installation and/or replacement easier.

To connect the main ring and the secondary ring of the burner pump, there are several flexible heated and insulated pipes equipped with a specific thermostat. These pipes are shown as accessories in the burner-related catalogues, and they are equipped with a very powerful fixed element, to minimise waiting times for pre-heating the pipe after the burner has been in stand-by.

2.6.3.4 Heating the storage tanks

As already mentioned, heavy oil at room temperature is usually solid and therefore not suitable for pumping purposes. To obtain viscosity values that are suitable for pumping, the oil must be pre-heated in the tanks. The heating system must be able to compensate the inevitable heat loss from the tank and provide the heat requirements for the oil being used.

The heat loss takes place through the outside surface area of the tank and is due to the difference in temperature between the fuel contained in the tank and the environment.

The calculation of the heat loss from a tank should be made according to the methods and the hypothesis of heat transmission, which is not always rapid or immediate as in the case of underground tanks.

Section 5 contains a diagram for pre-dimensioning heating systems for full and completely heated tanks.

The status of the tank completely full with hot oil is an ideal condition which rarely occurs, as the heating area is limited to the portion of volume involved in pumping, therefore the part of the tank heated is extremely small and thus an output equal to 1/3 of the nominal one found using the graph can be considered adequate.

The heat requirement for pumped oil is calculated using the following equation:

$$Q = \frac{m_c \cdot c_e \cdot \Delta T}{3600}$$

where:

Q = power for heating the pumped oil [kW];

m_c = correct fuel oil delivery [kg/h];

c_e = specific fuel oil heat (equal to approximately 1.88 kJ/kg°C) [kJ/kg°C];

ΔT = the difference between the temperature of the delivery oil and the external temperature (50÷60°C) [°C];

For safety reasons, a corrected delivery value is used rather than the real value.

If the transfer pump works non-stop with a ring equipped with a return line to the tank, the correct delivery will be equal to 1.5 times the burnt delivery.

If the transfer pump feeds a service tank without a return line, running will be intermittent and regulated by the level switch in the service tank; in this case, the correct delivery will be equal to that of the transfer pump.

The tanks can be heated by:

- electrical systems;
- warm or over-heated water systems;
- vapour systems;

In this section, we will analyse the electrical type of heating.
The tanks can be electrically heated either by band-type heaters outside the surface area or by internal heaters.
For heating with bands, the reader should refer to previous chapters for this type of heater, bearing in mind however that in this case the overall heat loss of the tank should be considered.
The internal heater can essentially be classified in two types:

- for upright tanks;
- for horizontal tanks;

Those for upright tanks are similar to water/vapour tube nest heaters and comprise an element battery welded to a tube plate.
The specific thermal load must be as low as possible, at the most 2 W/m^2 and possibly around 0.8 w/m^2, in order to reduce the formation of cracking products to a minimum.
To exploit the features of these heaters to the utmost, they should not be attached directly to the tank, but rather equipped with a series of devices to make them work as out and out rapid exchangers.
The heaters for horizontal tanks comprise a submersed bell-shaped container that contains the heating elements; the bell is laid vertically on the bottom of the tank and held up by a spacer.
The great advantage of these heaters is the ease with which they can be installed, permitting rapid maintenance by extracting the heater via the manhole without having to empty the tank.
However, the heaters are limited to a practical output value no greater than 36 kW.

2.7 ELECTRICAL SUPPLY AND BURNER CONTROL

As we have seen in the previous paragraphs, components are installed on the burner which require an electricity power supply:

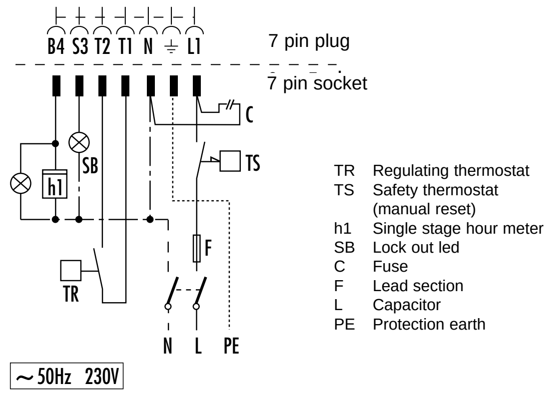
- Fan;
- Liquid fuel pre-heater;
- Liquid fuel suction pump.

As well as other components which require a low voltage power supply:

- Auxiliary systems for regulating and controlling combustion.

For small monobloc burners powered by single-phase current, the two classes of users

Diagram 67 *Electrical layout of a monobloc burner with single-phase electrical power supply*



are electrically powered with a single line.
In the case of monobloc burners with an average to high output and separately powered burners, the power supply is separate from the auxiliary supply; in the case of monobloc burners, the electrical equipment is generally mounted on the machine, while for dualbloc burners, the electrical panels are separate from the frame of the combustion head.
For monobloc burners, the electricity power supply data is clearly shown in the technical charts for the burner. The definition of the electrical energy requirement for a dualbloc burner, on the other hand, requires the design of the whole combustion system as certain components are separate from the combustion head and should be chosen in relation to the performance required from the system.

Combustion regulation and control requires an electricity power supply to perform the

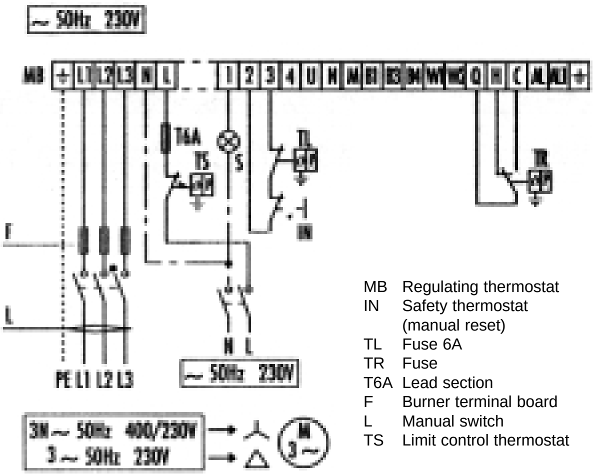
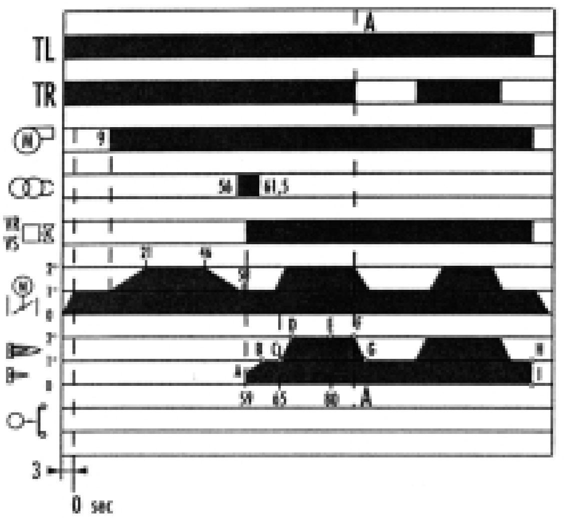


Diagram 68 *Electrical layout of a monobloc burner with three phase power supply*

Diagram 69 *Firing sequence of a methane gas burner*



following functions:

- Handling of the firing and flame safety sequence;
- Regulating the thermal load.

Observance of the safety instructions requires the use of special devices for supervising the burners. Legislation establishes, with reference to the type of burner, the control measures that must be adopted. However, the following principles are always valid:

1. The flame must be present within a limited period of time from when the fuel is made available to the nozzle and subsequently it must burn uninterruptedly;
2. Depending on the type of burner, the maximum margin of time must be indicated during which the fuel can be discharged without the flame forming. This period of time, which is sufficiently short, is called safety time;
3. In absence of flame detection within safety time, a system lock-out takes place and fuel flow is stopped;
4. For oil burners, if during working flame goes out due to a temporary problem, it may be re-established by a new firing;
5. Failure of burner devices that compromise safety, control and formation of the flame, must automatically interrupt the burner operations. This lock out, called a safety lock out, is indicated by a warning light and can only be released manually.

The equipment required to perform these functions is as follows:

1. An on/off fuel system, for example an electromagnetic valve;
2. An electrical firing device;
3. A flame detection system which ascertains with safety the presence or absence of the flame and determines the corresponding control orders. For gas burners, the detection sensor is generally an ionisation type, while for liquid fuel or mixed fuel burners the sensor is usually a photocell type;
4. A timing circuit which establishes the safety time;
5. A lock out circuit in case of failure.

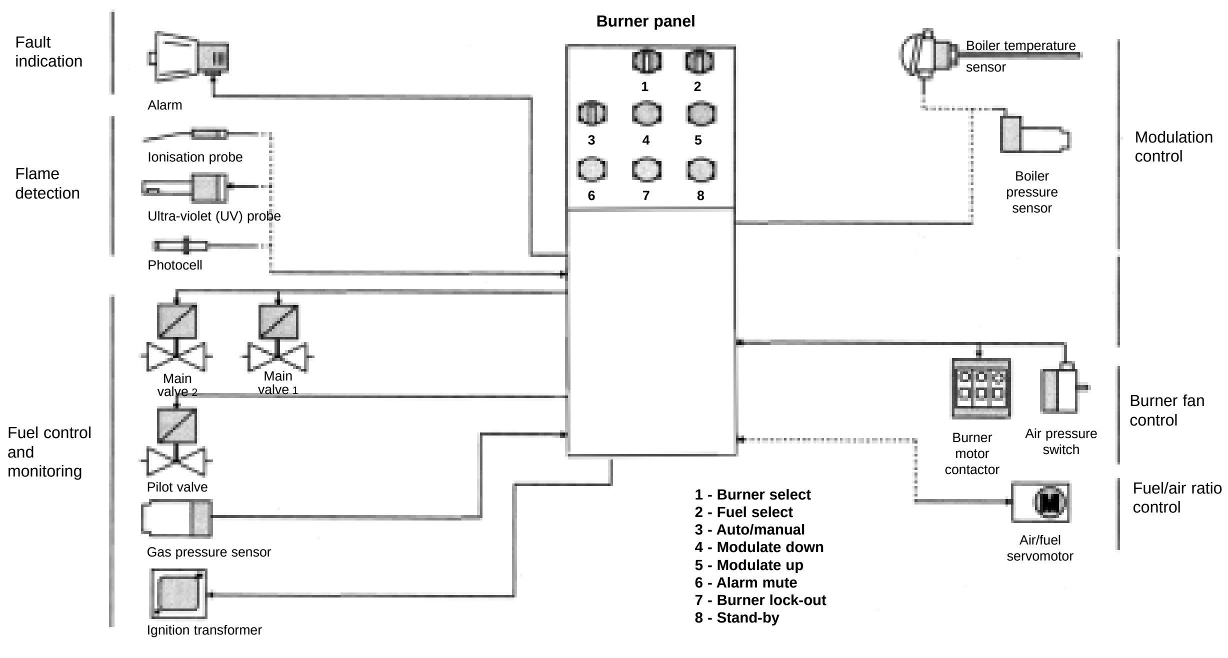


Diagram 70 *Diagram of the main components required for combustion control and regulation*

Diagram 69 illustrates the firing sequence of a methane gas burner, while figure 70 shows the layout of the main components required for controlling the flame and regulating the load.

According to the size, the fuel type and the requirements linked to the application, the air and fuel can be regulated as follows (see section 2.1):

- Single-stage
- Multi-stage (two-stage or three-stage)
- Progressive two-stage
- Modulating

In the case of single-stage regulation, in order to start-up or stop the burner all that is needed is a device that activates the heat regulation handling system. As a rule, it is represented by the contact of a thermostat with two settings, which regulates, for example, the water temperature of a boiler. When the temperature decreases with respect to the value prescribed, the thermostat requests heat, therefore it closes the contact and starts up the burner; vice versa for an increase in temperature the contact opens and the burner is stopped. The control panel, which differs in relation to the output and the type of burner, having received the heat request signal, establishes the running sequence of the various devices.
If, during the programme, firing does not occur during the safety time, the continuation of the programme is interrupted and the problem is signalled (safety lock out).

If it becomes necessary to supply the thermal output on two levels, one can use a two-stage type regulation. In this case, two separate thermostats called first flame and second flame control the firings. Each of the two thermostats behaves like the single thermostat in the single-stage burner, activating/deactivating the release devices of the fuel and combustion supporter air.
The two thermostats function at different temperature levels. The thermostat that controls the first stage must be calibrated to a higher temperature than that of the second thermostat.
As the differentials of the two thermostats are not always immediately available, as given in diagram 60, this type of regulation can be done more accurately and effectively using double threshold thermostats (with fixed differential).
Furthermore, for domestic boilers, which for a certain period of the year are only used to supply hot water, there is the so-called summer deactivation of the second threshold, where the second stage functions are cut off.
Regulating the thermal load in the single-stage and two-stage type is defined as “rapid”, as the activating devices are instantaneous. For some applications, where a more gradual thermal load variation is required, progressive and modulating stage regulations are used.
In progressive two-stage starting up, the fuel

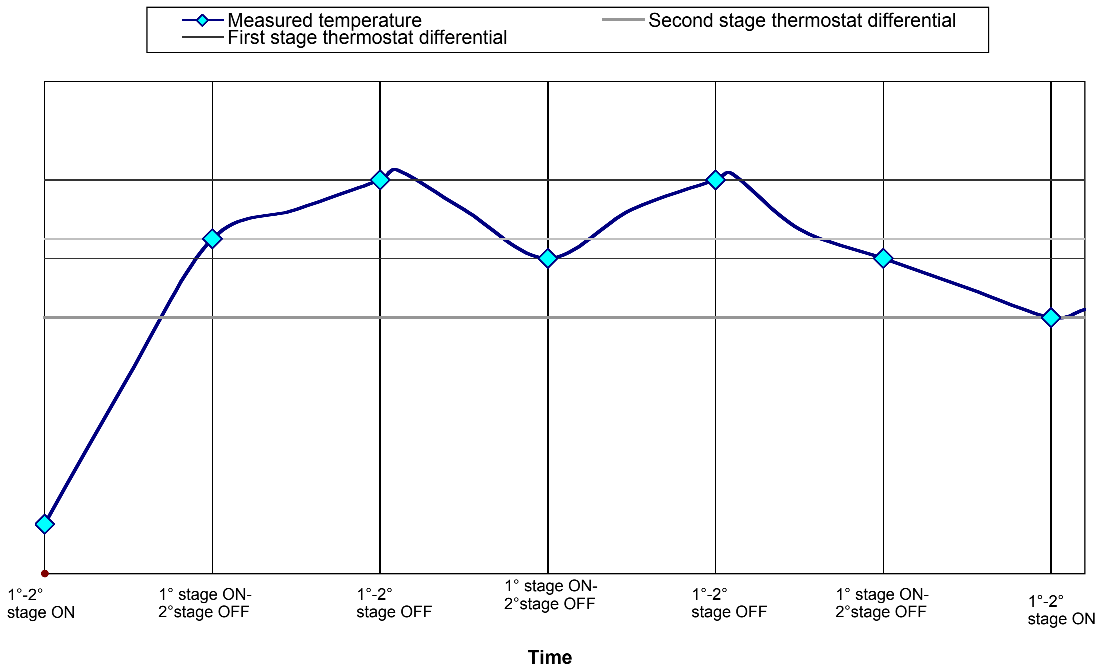
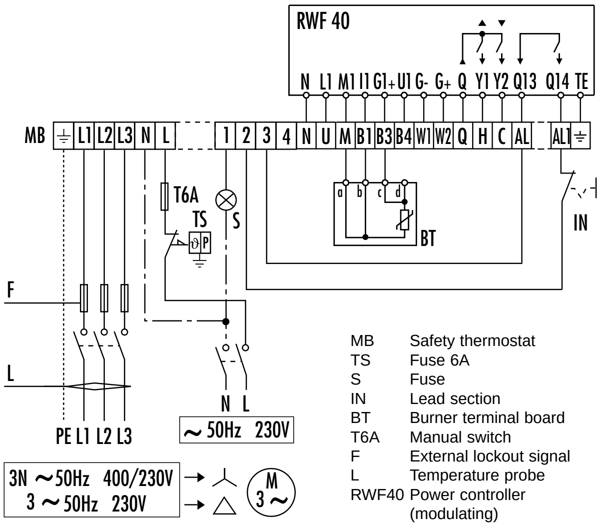


Diagram 71 *Programming of the regulation temperatures for a two-stage burner*

Diagram 72 *Electrical layout of a modulating burner with control devices*



regulator is taken to the firing load position. The servomotor for the combined fuel/combustion supporter regulation with slow opening, varies the delivery up to maximum load. The servomotor then controls the capacity of the burner at maximum or at minimum load values.

The difference between this mode and the modulating mode is the possibility of the latter to take intermediate regulation positions between maximum and minimum. To obtain satisfactory modulation, the servomotor can have slower stroke than the progressive two-stage burner; furthermore, an out and out electronic regulator must be provided with PI or PID regulation action complete with temperature probes or pressure probes. For monobloc burners, this device can usually be applied directly to the burner.

2.8 NOISE LEVELS IN FORCED DRAUGHT BURNERS

Noise is defined as an undesired sound which, within the range of audible frequencies between 20 and 20,000 Hz, disturbs, provokes irritation and/or damages health.
Sound is a collection of particle oscillations within a flexible medium.
The emission of a sound by a source implies the emission of energy which, referring to a unit of time, represents the sonorous power measured in watts. The level of sonorous power is defined by the following equation:

$$L_W = 10 \log (W/W_0) \ \text{(dB)} \qquad \textbf{eq. 2.8 -1}$$

where W0 is the reference power equal to 10^{-12} W.
Furthermore, the difference between pressure in the presence of sound and pressure in a point in space in the absence of sound is defined as sonorous pressure in the same point in space; this is measured in Pascals. The level of sonorous pressure is expressed using the following equation:

$$L_p = 20 \log (P/P_0) \ \text{(dB)} \qquad \textbf{eq. 2.8 -2}$$

where P is the reference pressure equal to $20 \cdot 10^{-6}$ Pa, which represents the minimum pressure perceivable by the human ear.
For ease of calculation, power and pressure levels have been introduced which are expressed in decibels (dB); the decibel reflects the logarithmic response of the ear to the variations in sonorous intensity.
The table below shows some of the power values of certain sources and some sonorous pressure values in certain environments.

Sound power [W]	Sound power level [dB]	Source type
$25 \div 40\ 10^6$	195	Lead missile
10^5	170	Turbojet engine
10^3	150	Commercial aircraft
10	130	Large orchestra
1	120	Pneumatic hammer
10^{-1}	110	20000 m^3/h centrifugal fan
10^{-2}	100	Motor vehicle on motrorway
10^{-3}	90	2500 m^3/h axial fan
10^{-4}	80	Conversation
10^{-9}	30	Whisper

Table 17 *Typical values of sound power*

Table 18 | *Average values of sound pressure*

Sound pressure [Pa]	Sound pressure level [dB]	Condition
200	140	Aircraft taking off at 30 m
63	130	Pneumatic machine operator
20	120	Large thermal power plant
6.3	110	Automatic press operator
0.63	90	Lathe operator Heavy truck at 6 m distance
0.2	80	Roadside with big traffic
0.002	60	Restaurant

It is necessary to completely understand the difference between sonorous power and sonorous pressure; the power is an absolute magnitude referring to the emitting source. The pressure is a measurement relating to a point in space and consequently the emission of a sound by a source. The pressure measured in a point in space depends both on the sonorous source, the distance of the measurement point of the source and the conditions surrounding the system. Therefore, the sonorous pressure data is always accompanied by test conditions: distance of the measurement point and type of room in which the test was carried out.
The sonorous power cannot be measured directly but is calculated using the measurements of sonorous pressure, in particular acoustic measuring laboratories.
By virtue of the definition of the level using the equations indicated above, we can conclude that a doubling of the sonorous power is equivalent to an increase of 3 dB of the level of power, while a doubling of the sonorous pressure is equivalent to an increase of 6 dB of the level of pressure.

In order to add or subtract different levels of pressure, it is possible to use the following equation:

$$L_{ptot} = 10 \cdot \log \left[\sum 10^{(0,1 L_i)} \right] \text{ [dB]} \quad \textbf{eq. 2.8 -3}$$

bearing in mind that in case of level differences, the summation must be carried out with relative values.

Each noise comprises a collection of sounds with different frequencies. The sounds that can be heard by the human ear are those with a frequency ranging between 20 Hz and 20,000 Hz. However, the human ear does not assign the same sensitivity to sounds with different frequencies. Therefore, on an experimental basis, several isophonic curves were created, in other words curves of equal loudness measured in “phons” The number of phons is equal to the level of sonorous

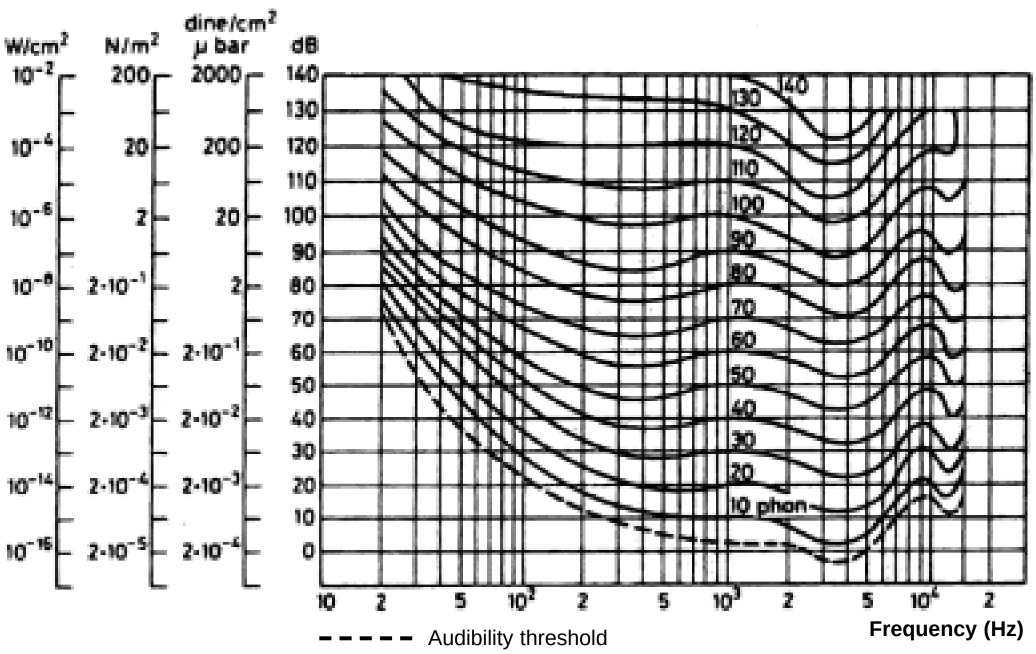


Diagram 73 | *Isophonic curves*

pressure corresponding to the reference frequency of 1000 Hz.
The Diagram shows these curves in which the X axis shows the frequencies in Hz and the Y axis the level of sonorous pressure in dB; from an analysis of these curves, we can conclude how sounds of different frequencies produce the same loudness (same value of phons) despite having different values of sonorous pressure.

Table 19 *Octave frequency band spectrum*

Central band frequency [Hz]	63	125	250	500	1000	2000	4000	8000
Level [dB]	72	80	67	60	62	55	51	45

By examining the curves, we can see that the lower the frequency, the higher the level of sonorous pressure can be, loudness being equal.
Therefore, if we wish to obtain measurements that are, as far as possible, in accordance with the auditory sensations of the ear, a damping of the lowest frequencies is necessary in order to gain a weighted measurement. Various weighted curves have been normalised, the most commonly used is called the "A" curve; these curves are shown in Diagram 74. The instruments for measuring sonorous pressure, called sound-level meters or phonometers, already have the possibility to carry out measurements using the weighted curve "A" within them.

If the measurement is made using a linear weighted scale, the level of sonorous pressure

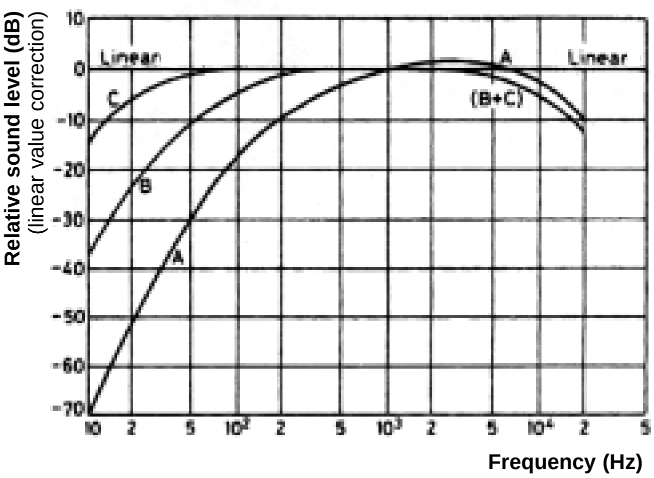


Diagram 74 *Weighted curves*

is measured in dB; if, on the other hand, the measurement is made using the "A" weighted scale, the level is expressed in dB(A).

When, for a determinate noise, the level divided into the various frequencies is known (for example: in octave band), the overall noise level is obtained by making the summation using the equation (2.6.3).
In particular, for the following spectrum in octave band:

the level of overall pressure will be equal to:

$$L_p = 10 \cdot \log \left[10^{7.2} + 10^{8.0} + 10^{6.7} + 10^{6.0} + 10^{6.2} + 10^{5.5} + 10^{5.1} + 10^{4.5}\right] = 80.9$$

As already estimated, it is not possible to directly measure the sonorous power of a machine, but it is necessary to read off the sonorous pressure in a given point in order to then arrive at the power. In free field, i.e. where the sound waves move away from the source in all directions, the equation that ties the level of sonorous power to the level of sonorous pressure is:

$$L_W = L_P + 20 \cdot \log(r) + 11 \quad [\text{dB}] \qquad \textbf{eq. 2.8 -4}$$

This equation is also used for the measurements made in the "free-field" chambers of the acoustic measurement laboratories. The free-field chambers are special measurement chambers, where the walls that enclose the physical space are made of material with an elevated absorption factor, in order to simulate ideal open field conditions.
The above equation reveals, as already mentioned, that the level of sonorous pressure decreases as it moves away from the emitting source; this decrease is equal to 6 dB for each doubling of the distance between the measurement point and the source of emission.
If you wish to determine the theoretical level of sonorous pressure within a room in which a machine is placed, such as a burner within a power station, the following equation should

be applied:

$$L_p = L_w + 10 \cdot \log\left(\frac{Q}{2 \cdot \pi \cdot r^2} + \frac{4}{R}\right) + 0,5 \quad [dB]$$

eq. 2.8 -5

where:
L_p = the level of sonorous pressure in dB;
L_W = the level of sonorous power in dB;
r = the distance from the source [m];
Q = the directional factors of the source equal to:
= 1 for sources near the centre of the room;
= 2 if the source is at the centre of a wall or floor;
= 4 if the source of noise is positioned at the intersection of two walls.
R = the constant of the room [m^2];

The constant of the room can be determined using the following equation:

$$R = \frac{S \cdot \alpha_m}{(1 - \alpha_m)} \quad [m^2]$$

eq. 2.8 -6

where:
S = the total surface area of the walls of the room;
α_m = the average absorption factor of the room equal to:

$$\alpha_m = \frac{\sum_i S_i \cdot \alpha_i}{S} \quad [m^2]$$

eq. 2.8 -7

where:
S_i = the surface area of the Nth wall;
α_i = the absorption factor of the Nth wall;

The absorption factor varies in relation to the wave frequency of the incident sound, therefore the analysis using the equation 2.8.5 should be carried out for frequencies to then calculate the total value using the method previously described.
Table 20 shows the absorption factors of certain materials.

When measuring noise in an environment, it is necessary to remember that besides the noise produced by the machine, noise deriving from other sources is always present. The collection of extraneous signals is defined as background noise. The measurements made must therefore be cleansed of this value.
The valuation of the cleansing is made by measuring the sonorous pressure level when the machine is on and when it is off, to measure the level of background noise.
By then applying the equation (2.8.3.), the pressure value due only to the machine when running can be reached. We can presume, for example, that we have taken the measurement under the two conditions indicated with the following values:
machine on Lp = 80 dB;
machine off Lp = 76 dB;
the sonorous pressure value corresponding to the machine alone will be equal to:

2.8.1 Deadening noise made by forced draught burners

The noise produced by the burner essentially

Materials	**Central band frequency**					
	125	**250**	**500**	**1000**	**2000**	**4000**
Crude wall	0,02	0,02	0,03	0,04	0,05	0,07
Finished wall	0,01	0,01	0,02	0,02	0,02	0,02
Plaster	0,02	0,03	0,03	0,04	0,02	0,03
Pine wood	0,01	0,01	0,01	0,09	0,1	0,12
Glass	0,03	0,03	0,03	0,03	0,02	0,02
Strained velvet tent situated at 20cm	0,08	0,289	0,44	0,5	0,4	0,35
Non-strained velvet tent situated at 20cm	0,14	0,35	0,55	0,75	0,7	0,6
Felt	0,09	0,14	0,29	0,5	0,62	0,56
Rock-wool (thick.=2,5cm)	0,26	0,45	0,61	0,72	0,75	0,85
Rock-wool (thick.=5cm)	0,38	0,54	0,65	0,76	0,78	0,86
Glasswool (thick 2,5 cm)	0,16	0,43	0,87	0,99	0,93	0,86
PU1	0,09	0,1	0,11	0,21	0,35	0,45
PU2	0,1	0,2	0,35	0,55	0,45	0,53
PU3	0,25	0,35	0,6	0,55	0,51	0,7
PU4	0,19	0,3	0,43	0,45	0,52	0,58
PU5	0,19	0,45	0,57	0,43	0,42	0,65

Legend: PU means flexible expanded polyurethane with 30kg/m^3 density.
PU1: thickenss 10mm; PU2: thickness 30mm; PU3: thickness 50mm; PU4: thickness 70mm of which 20mm basic and 50mm pyramids; PU4: thickness 50mm of which 30mm basic and 20mm ashlar.

Table 20 *Absorption factors of certain materials*

Diagram 75 *Blimp for air blown burners*

derives from these three sources:

- Pumps in the pumping groups;
- Fan;
- Flame

In order to limit the noise level, soundproofing devices can be fitted which should be installed on the burners and mount any pumps outside the burner on flexible supports.
The blimps are articles that are available as optionals in burner manufacturers' catalogues and are made in sound-absorbent material (light materials tend to absorb high frequence noises, while heavy materials absorb better low frequence noises). They can reduce the noise level made by the fan, the pump installed on the machine and, in part, that made by the flame.
Diagram 75 shows a blimp.

In dual bloc burners, where the fan is outside the machine, the primary source of noise is still the fan, but the pressure waves which it produces are transmitted via the air in-take pipelines and the combustion head delivery pipelines.
In order to reduce the noise emitted by external fans, it is necessary to choose those offer high performances at low speed, and with a running point positioned in the stable section of its characteristic curve. The installation of the machine must take place using anti-vibration supports. The connection of the fan with the pipelines must be made with anti-vibration joints. The connection pipelines must have a possible variation of the section, near to the fan, made with an inclination angle no greater than 15°; furthermore, any accessories must be installed at a distance of at least 3 equivalent diameters from the fan.
In cases where a heavy noise reduction of the aeraulic system is required, special silencers can be installed comprising baffle plates in sound-absorbing material inside the intake pipeline section. The introduction of these silencers determines an increase in the pressure drops of the aeraulic system and therefore they should only be inserted in cases of effective need.
Another technical solution used in order to limit the sound emissions, involves the installation of fans closed in special soundproofing devices.
When one of the above mentioned systems is installed in an Forced draught burner (blimp, silencer or box) to dampen noise, the correct functions of the system should be tested with these devices fitted, to check that any head drops caused by them fall within acceptable levels.
In certain countries legislation exists which fixes the limits for sound emission within the various application fields.

2.9 OPTIMISING COMBUSTION WITH FORCED DRAUGHT BURNERS

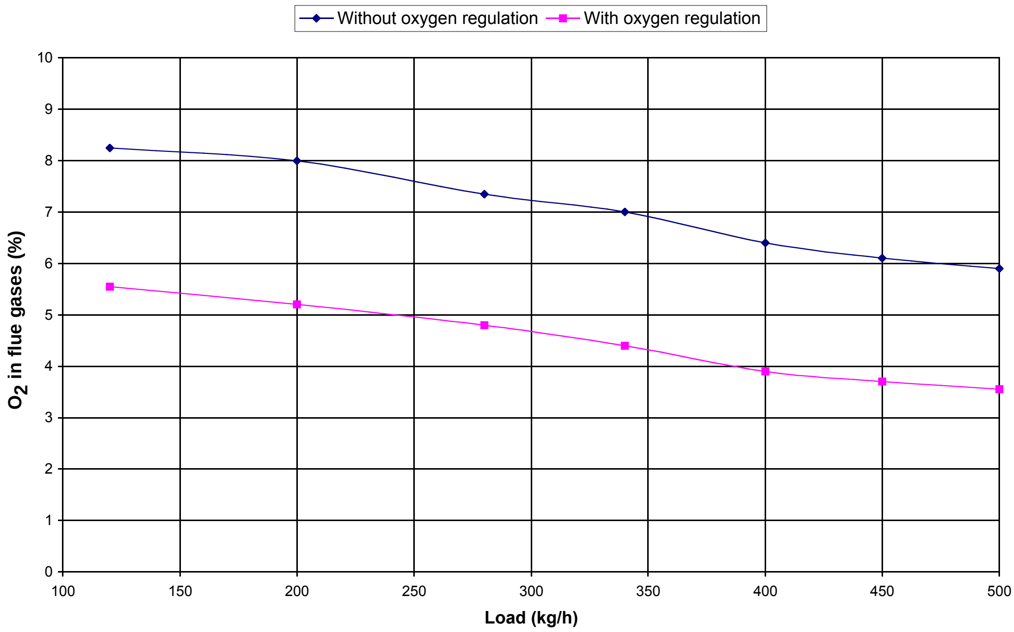
In this section, we will analyse certain technologies capable of forcibly optimising the combustion process developed using an Forced draught burner. As can be seen, these techniques require the application of plant engineering subsystems, which allow accurate combustion monitoring and regulation, such as:

- Systems for regulating combustion O_2;
- Pre-heating combustion supporter air;
- Regulating the number of fan revolutions.
- Burner Management System.

2.9.1 Regulating the O_2

As anticipated in section 1, to avoid the presence of unburned combustion particles in the flue gases and therefore obtain total fuel oxidation, a degree of air in excess with respect to the stoichiometric value must be present, which cannot however be too high or the efficiency will suffer.
The excess air is determined and established when the burner is set in relation to the average running parameters for the burner, and measured in relation to the amount of oxygen or carbon dioxide present in the discharge flue gases. The optimum value of the excess air however is variable when the burner is running, in relation to the amount of

Diagram 76 *Reference values of the oxygen content in flue gases for a gas burner*

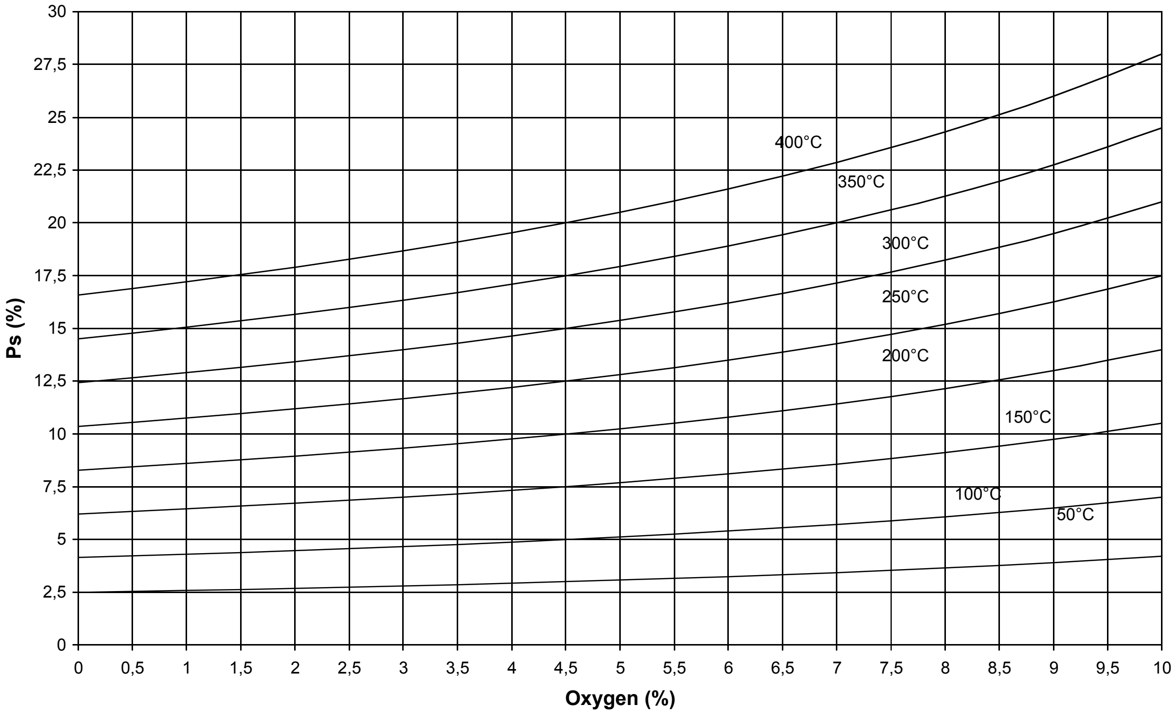


oxygen required for perfect fuel oxidation. Therefore the exact amount of air to be supplied to the burner depends on the oxygen content in the air and the characteristics of the fuel; in particular, the parameters that have most influence on the amount of air required are:

- Combustion supporter air temperature: an increase of 10°C in the combustion supporter air temperature corresponds to a decrease in air density of around 3% with the consequent decrease of the oxygen in the air by approximately 0.6%;
- Barometric air pressure: a decrease in the barometric pressure of 10 mbars causes a drop in the air density by approximately 1% with a consequent decrease in the oxygen present in the air of around 0.2%;
- Calorific value of the fuel: an increase of 5% in the calorific value of the fuel corresponds to an increase in the oxygen requirement of 1%;
- Fuel delivery, temperature and pressure;
- Draught of the flue and back pressure of the furnace;

All the variables mentioned above influence combustion thus determining the amount of oxygen required and, consequently, the excess air. For the best control of the combustion process, the amount of air must be continually modified so that the amount of oxygen in the flue gases emerges as optimum. This system denominated "regulation of O_2 in flue gases" involves a probe for measuring the oxygen in the flue gases, which is installed in the flue gas pipe in the generator, and an electronic control unit.
The probe is linked to the electronic control unit and reads the oxygen value present in the combustion flue gases. The probes used are generally zircon (ZrO_2) in type or electrochemical, as they are reliable, accurate and equipped with a more or less instantaneous response.
The control unit determines the change between the oxygen value measured by the probe and the nominal value set, to determine the exact amount of air to feed to the burner. By positioning/correction of the burner air regulation damper, controlled by a servomotor, the control unit can guarantee the right contribution of combustion supporter air, and therefore of oxygen, in relation to the output supplied by the burner.
The control of the oxygen in the combustion flue gases makes it possible to set the excess air to the value corresponding to the maximum technical combustion efficiency. In fact, while without the control of the O_2 excesses of air must be guaranteed that are greater than the optimum ones for safety reasons, in order to take into account the variable working conditions, with the O_2 regulation system, it is possible to set minimum oxygen values in the flue gases, to determine the minimum excess of air to obtain complete fuel oxidation without the need for increasing safety.
In this way, NOx emissions are reduced, due to the smaller amount of oxygen present during combustion.
Minimisation of excess air involves a decrease in the delivery of the burnt gases and, consequently, their temperature. The result is

Diagram 77 *Loss of the flue gases for different % of O2*



a further increase in technical combustion efficiency.
Diagram 77 clearly shows, for a given temperature of the flue gases, variation in efficiency by varying the percentage of oxygen.
An additional advantage deriving from applying this system is the continual fuel monitoring, making it possible to immediately highlight any malfunctions which can be compensated until an allowed threshold is reached, beyond which it is possible, if necessary, to shut the system down.

2.9.2 Pre-heating the combustion supporter air

This technical solution is adopted to recover the heat contained in the flue gases. The sphere of application is limited to high-temperature heat producing systems, such as diathermic oil systems. In such cases, in fact, the exchange fluid must be heated to a temperature of more than 300°C and, consequently, the flue gases exit the boiler at a high temperature. Generally, the pre-heating temperature of the combustion supporter air that is achieved is around 150°C.
Heat recovery is achieved using an air/flue gas heat exchanger installed inside the flue gases discharge pipe. The amount of heat recovered is proportionate to the mass-related delivery of the air for the temperature change caused by the passage through the exchanger. On average, this technique makes it possible to obtain an improvement in efficiency up to 8 %.

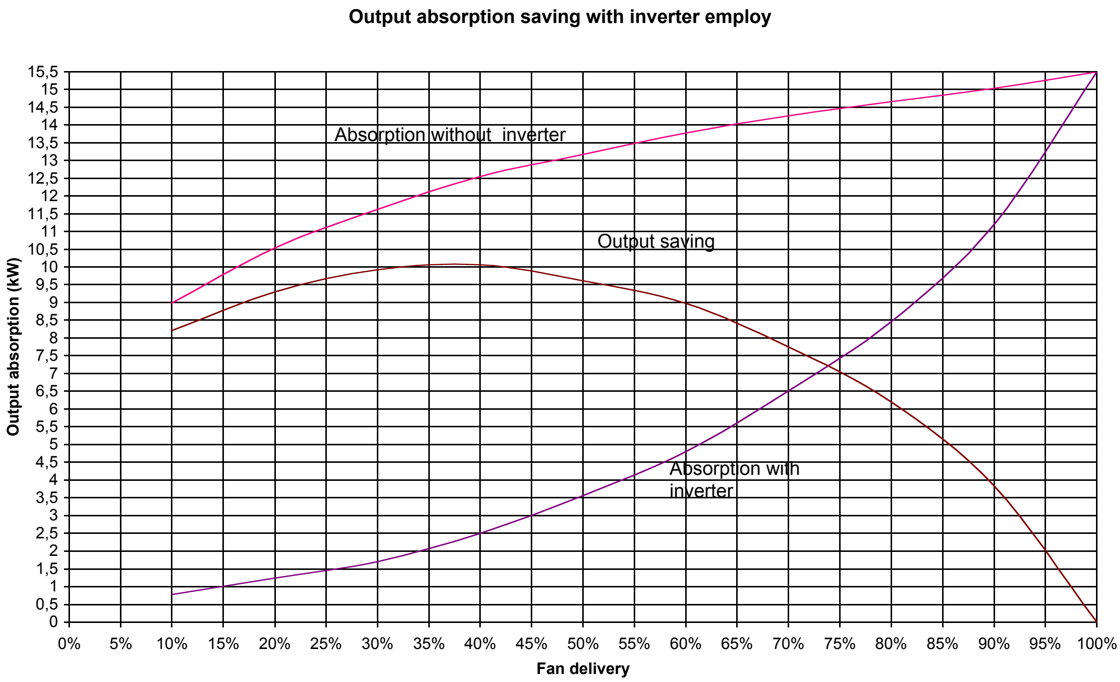
It is good practice to install the combustion supporter air thrust fan upstream from the heat exchanger.
When calculating the pressure drops, the real conditions of air use must be taken into account, using the application of the correction factors shown in table 23.

2.9.3 Regulating the fan speed

In section 2.5.1 concerning the fans, we saw how combustion supporter air regulation can be done using a variation in the system characteristic curve or using the fan characteristic curve: the first can be done using the variation in pressure drop introduced by a servo-controlled damper, while the second can be done varying the rotation frequency of the fan motor.
The fan rotation frequency is changed using particular frequency and tension converters called inverters, capable of regulating the fan rotation speed and, consequently, the delivery of the combustion supporter air. The following advantages can be obtained with this:

- reduction in electrical power absorbed by the fan;

Diagram 78 *Diagram for the evaluation of the energy saving by means of the inverter*



- reduction in noise levels;

The electrical power absorbed by the fan is directly proportionate to the number of revs, therefore a decrease in the number of revs corresponds to a decrease in the power absorbed.

The reduction in the noise level is obtained both at fan level and with regard to any dampers that are passed by an air flow that has a lower speed.

For these advantages to be effective, the frequency converter (inverter) must guarantee the exact observance of the descent and ascent ramps. This is necessary to maintain the correct fuel/air formula; to obtain the latter the motor must precisely follow the value of the number of nominal revs programmed without any delays.

The saving which can be obtained by introducing the rev converter is equal to approximately 40% of the electrical energy absorbed by the fan. A precise evaluation of the energy saving can be calculated using the graph in Diagram 78.

2.9.4 The Burner Management System

To achieve an improvement in technical combustion efficiency, as well as guarantee an efficient supervision of the combustion system, the system can be supplemented by a burner supervision system called Burner Management System, a concept layout of which is shown in Diagram 79.

Using this system, it is possible to unite and supervise all burner regulations and exploit them simultaneously. For example, it is possible to integrate oxygen regulation with the fan rotation speed, thus obtaining a saving in terms of electrical power absorbed as described in the following diagram, or handle the functioning of several burners at the same time.

Diagram 79 Conceptual representation of a Burner Management System

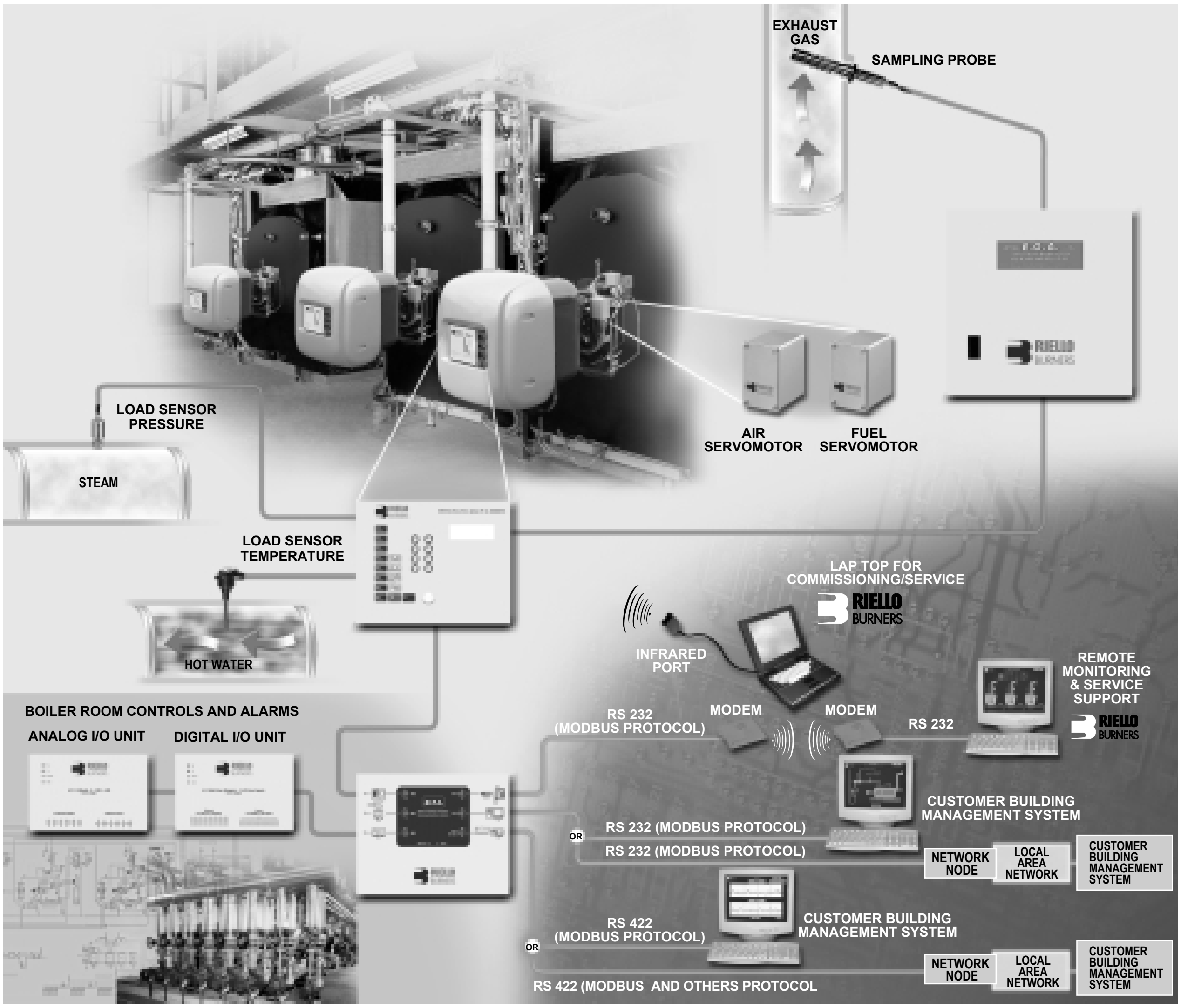
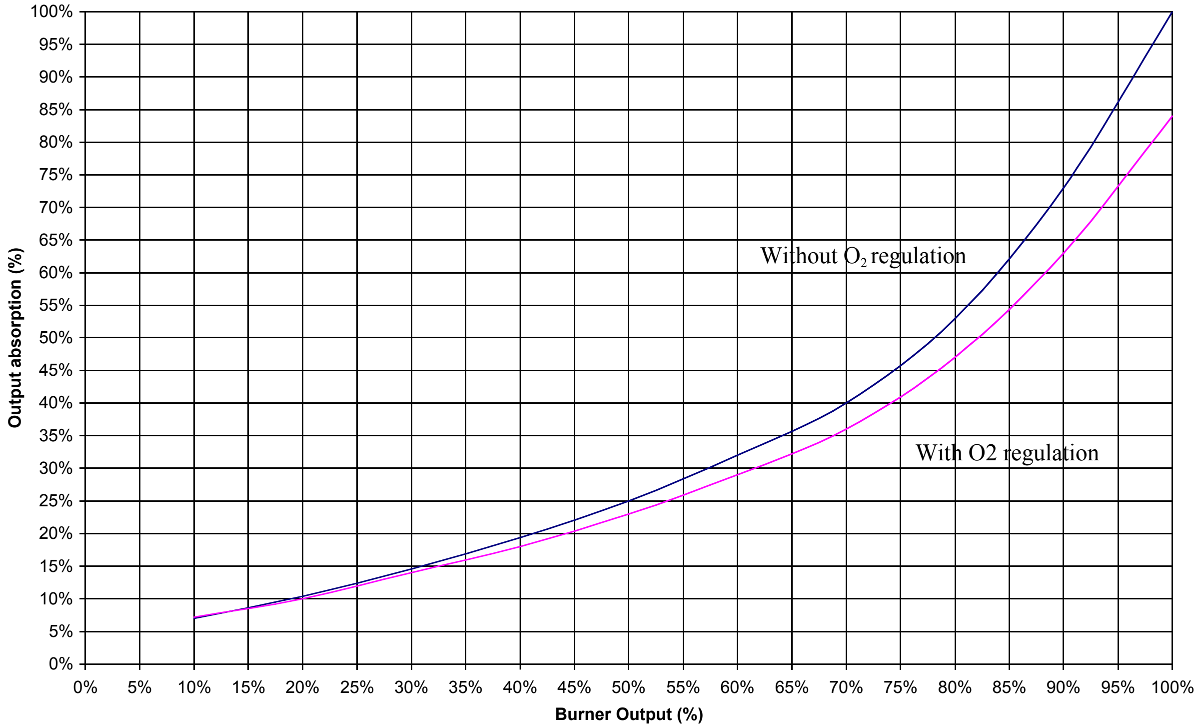


Diagram 80 Electrical power absorption with O2 regulation and inverter



SELECTION OF A FORCED DRAUGHT BURNER

3.1 GENERAL CRITERIA

In order to choose the correct burner, certain characteristic data must be known; a list of the main points is illustrated as follows:

1. thermal capacity at the furnace of the heat generator or thermal discharge Pfoc [kW];
2. back pressure in the combustion chamber, or flue gas side pressure drop DP [Pa];
3. type of boiler;
4. fuel;
5. regulation method for the installed power capacity;
6. minimum feed pressure of methane gas;
7. altitude of the system [m above sea level] and average air temperature;
8. special installation characteristics.

The first three parameters are characteristic data of the boiler and must be supplied by the manufacturer; parameters 4 and 5 are technical choices that the design engineer must make, while parameters 6, 7 and 8 are a constraint of the heat generation system.

For an organised and complete collation of the data required for correctly choosing a burner, a checklist can be used similar to Table 21.

3.1.1 Thermal capacity at the heat generator furnace

The thermal capacity at the heat generator furnace constitutes the characteristic data of the generator and represents the energy that must be supplied to the generator by burning the fuel in the burner to obtain the effective boiler output, which must be no lower than hat required by the system. Sometimes this value is called the boiler thermal discharge and is expressed in either kW or in kcal/h. The difference between the value of the furnace thermal capacity and the effective output constitutes the portion of energy which will be lost, mainly via the flue gases and the boiler shell.
Their ratio represents the effective boiler efficiency at maximum capacity:

$$\eta_{100\%} = \frac{Q_{useful}}{Q_{furnace}}$$

For pressurised boilers, this efficiency is generally between 90% and 93% and it can be calculated by considerating the fuel efficiency (described in section 1.5.1) and the loss through the shell (which generally are 1÷2%). Preliminarily, if we only have the effective capacity of the boiler, the capacity at the boiler furnace can be calculated by dividing the effective capacity by 0.9:

$$Q_{furnace} = \frac{Q_{useful}}{0.90}$$

If the only data available is the delivery of vapour produced, generally expressed in kg-h or t/h, the furnace thermal output can be calculate using the following equation

$$Q_{furnace} = [\, G_v \; C_P \; (T^{vapour} - T^{water}) + G_v \; C_{LAT\ VAP}] \,/\, \eta$$

Where:
G_V = mass-related vapour delivery [kg/s]
C_p = specific heat at constant pressure [kW/kg °C]
T_{vapour} = vapour temperature [°C]
T_{water} = water temperature entering the boiler [°C]
$C_{LAT\ VAP}$ = latent vaporisation heat [kW/kg]
η = efficiency of the vapour generator.

Table 21 *Absorption factors of certain materials*

CHART OF THE DATA REQUIRED FOR A COMBUSTION SYSTEM SELECTION

Boiler model ________ **Manufacturer** ________ **Year of prod.** ________

Fluid type
☐ Hot water ☐ Superheated water ☐ Diathermic oil ☐ Hot air (indirect exch.)
☐ High pressure vapour ☐ Low pressure vapour ☐ Superheated vapour ☐ Hot air (direct exchange)

Max firing pressure ______ [bar] Max firing temp. ______ [°C] Vapour prod. ______ [kg/h]

Boiler type
Flue gas pipes ☐ 3-turns ☐ Reverse flame chamber ☐ Double combustion chamber
Water pipes ☐ D-shape ☐ Coiled/rapid ☐ Vertical

Nominal boiler output ______ [KW] ______ [Kcal/h] Boiler efficiency ______ %
Boiler furnace output ______ [KW] ______ [Kcal/h] Existing burner type (trademark): ________

Combustion chamber data

Backpressure / Furnace depression ______ [mbar] ______ [mm W.C.]

Length ______ [mm] Height ______ [mm] Projection of burner head ______ [mm]
Diameter ______ [mm] Breadth ______ [mm]

Fuel
☐ Light oil ☐ Heavy oil ☐ Kerosene
☐ Methane gas ☐ LPG ☐ City gas ☐ Biogas

Gas supply data Net calor. value ______ [kWh/Nmc] ______ [Kcal/Nmc]

Delivery pressure ______ [mbar] ______ [bar] ______ [mm W.C.]

Oil supply data

Viscosity
Gas oil ☐ 6 cSt at 20°C
Light fuel oil ☐ 3°E at 50°C
Medium fuel oil ☐ 20°E at 50°C
Heavy fuel oil ☐ 50°E at 50°C

Net calorific value ______ [kJ/Kg] ______ [kWh/Kg] ______ [kcal/Kg]

Installation place Country (abroad) ______ Town ______ Company ______

Altitude ______ [m a.s.l.] ☐ Indoor ☐ Outdoor Tmin/max ______ [°C]

Electrical data 3-phase voltage supply/Control voltage/frequency

☐ 400/230/50 ☐ 400/110/50 ☐ 440/220/60 ☐ 210/120/60 ☐ / /

Burner control options ☐ Modulating regulation ☐ Continuos self-checking ☐ Oxygen regulation

Dual block burner pumpibg unit (options) ☐ Pre-mounted ☐ Only components

Pump/Filter ☐ Single pump ☐ Double pump ☐ Single filter ☐ Double filter

Preheater ☐ Electrical ☐ Steam ☐ Doble (steam/electrical) ☐ Oil delivery measure

Gas train ☐ Train regulation ☐ Safety train ☐ Leakage control ☐ Gas delivery measure

Other requirments (norms, spcs, notes) ________

3.1.2 Back pressure in the combustion chamber

Depending on the backpressure in the combustion chamber, the heat generators can be divided in two large families:

1. Boilers in slight depression;
2. Pressurised boilers;

In depression-type boilers, the flow of combustion supporter air and combustion products depends on the draught effect of the flue, which is established as a result of the difference in temperature between the flue gases and external air, and/or the presence of balanced-draught systems.

In both types of boiler, combustion supporter air is taken in by force by the fan, which in monobloc burners is incorporated in the burner itself.
The thermal yield of the boiler is heavily influenced by the pressure value which is created in the combustion chamber by the turbulence of the flue gases; theoretically, by increasing the pressure drops on the flue gas side, the boiler heat exchange efficiency can be increased. Currently, boiler manufacturers have achieved a standardisation level of backpressure with values proportionate to the thermal discharge from the boiler.

If the manufacturer does not supply precise information, an indicative value can be obtained from the graph below:

The data presented is valid for recently produced boilers and for Western countries. It is therefore possible that, for older boilers or those manufactured in countries using methods greatly different from western technological culture, these values will also be considerably different.

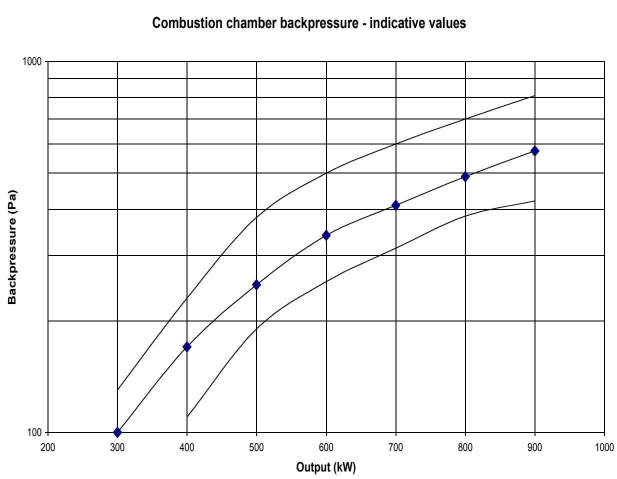


Diagram 81 *Combustion chamber backpressure in relation to thermal output*

3.1.3 Type of heat generator

The boiler construction type is extremely important when choosing the burner, especially regarding the length of the combustion head. In fact, the various boilers mentioned above have combustion chambers and, consequently, flame form requirements that vary somewhat from one another. The combustion chambers can be divided in two categories:
- with direct route of flue gases (e.g. boilers with three flue gas turns or serpentine boilers)
- with inversion route of the flue gases in the chamber (e.g. boilers with two flue gas turns)

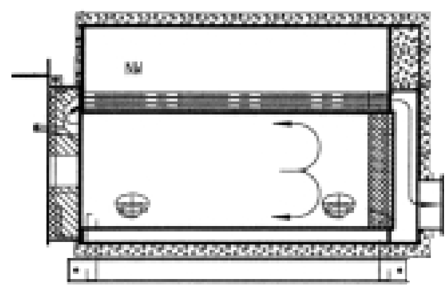


Diagram 82 *Reverse flame boiler*

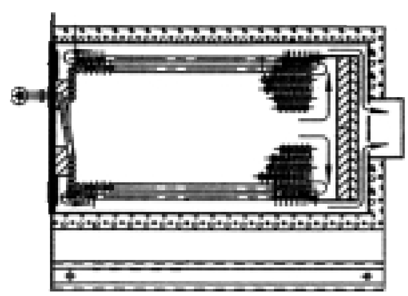


Diagram 83 *Serpentine boiler*

for both types, the manufacturer must supply the length of the blast tube required by the burner, to create optimum combustion conditions; this value is determined on an experimental basis by laboratory tests.
In the absence of such data, it is possible to form hypothesis and general considerations, which help in choosing the most appropriate length of blast tube; in detail:
For cast iron component boilers and those in

steel with three flue gas turns, the blast tube can jut out only from the internal edge of the front door; for boilers with two flue gas turns and flame inversion, the blast tube must penetrate the combustion chamber beyond the second flue gas turn entry, to avoid any by-pass of burnt gas directly into the second turn. The head penetration inside the combustion chamber can be modified by adjusting one of the mobile flanges or by adopting of an extension and/or spacer placed between the burner connection plate and the front of the boiler.
The complete definition of flue route is greatly influenced by the type of flue pipe and the hot or cold running setting.

For burners with three flue gas turns or flame inversion chambers, protective heatproof insulating material (11 in the following diagram) should be fitted between the boiler refractory and the blast tube, and the flange should be fixed to the boiler plate with a gasket placed in-between (8 in the diagram 84).

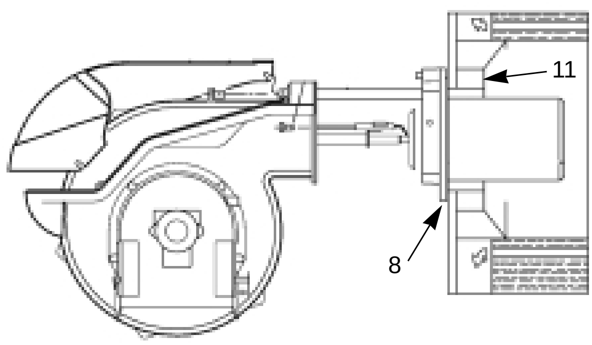


Diagram 84 *Fixing of the blast tube to the boiler port*

For boilers with combustion chambers in refractory walls, besides the above considerations regarding flue gas routes, the irradiation effect must also be considered directly on the combustion head, which is thermally stressed due to the elevated wall temperature.
Precautional measures have to be evaluated singularly consulting boiler manufacturer.

3.1.4 Fuel

The type of fuel is usually a system limit and is rarely a choice that the design engineer may make in relation to the cheapness of the fuel, yield and complexity of the fuel feed system.

3.1.5 Burner operation mode

The operation mode of the mono-stage, two or three-stage or modulating burner is a choice made by the system design engineer, in relation to the variability of the system thermal load and the generator heat inertia characteristics.

3.1.6 Minimum feed pressure of gaseous fuel

The minimum feed pressure value of gaseous fuel is required to choose the gas train. The value is provided and guaranteed with reasonable certainty by the fuel supply board and completes the supply contract. For independent installations with storage tanks, the data is represented by the pressure guaranteed by such equipment.

3.1.7 Installation altitude and average combustion air temperature

The burner firing range refers to certain standardised barometric pressure values equating to 1000 mbar (average atmospheric pressure value at an altitude of 100 m above sea level) and combustion supporter air temperature values equating to 20°C, subject to different indication shown at the bottom of the firing ranges.
If the burner has to function at a different altitude and/or at a combustion supporter air temperature that is different to the standard values, the performance variations must be taken into account both in terms of power/output and head guaranteed by the fan. These variations are due to the fact that heating the combustion supporter air and increasing altitude produce the same effect, i.e. a reduction in air density. A decrease in air density is matched by a decrease in the amount of oxygen and, consequently, a decrease in the maximum amount of fuel burnable with variations of the maximum output that can be achieved by the burner.
Furthermore, the total head developed by the fan also undergoes a reduction which is directly proportionate to the decrease in density; in particular, by the law of fans, if the specific air weight varies following changes in its temperature and/or its pressure, all fans

being equal, the fan volumetric delivery will not vary, but the pressure developed and the output absorbed vary according to the following law:

$$P_1 = P_2 \cdot \frac{\delta_1}{\delta_2}$$

$$N_1 = N_2 \cdot \frac{\delta_1}{\delta_2}$$

where:
P_1= total pressure developed with a fluid density of δ_1;
P_2= total pressure developed with a fluid density of δ_2;
N_1= output absorbed with a fluid density of δ_1;
N_2= output absorbed with a fluid density of δ_2;

To choose the burner, it is necessary to check that the system firing point remains inside the burner firing range, even under different temperature and altitude conditions.
Therefore, to choose a burner for a system to be installed at an altitude and/or temperature which is different from the standard burner test values, we must create a virtual firing point, which has an increased output value with respect to the real firing point.
The increase is made by dividing the effective output by factor F function of the temperature and the barometric pressure.

$$Q_{burner} = \frac{Q_{foc}}{F}$$

This output value corresponds to a maximum head value of the burner fan Pmax which can be obtained from the firing range as the intersection between the curve of the firing range and the vertical line traced for the value Qburner. As mentioned previously, this value should be taken as valid for standard burner test conditions and must therefore be correct in relation to the variations in fan performances, in particular:

$$P_{burner} = P_{max} \cdot F$$

If the head Pburner is greater than the backpressure to be overcome in the combustion chamber, the burner can satisfy the system requirements.
If not, there are two possible actions:
• choose the burner from the next class up and repeat the verification procedure described above;
• reduce the burner fuel delivery, and consequently, the output, so as to reduce the pressure drops in the combustion chamber, to achieve the maximum pressure available;
The pressure drops are a quadratic function of the flue gas delivery, equivalent to fuel delivery and consequently burner output. The equation that links the two magnitudes is as follows:

$$P_{reduced} = P_{furnace} \cdot \left(\frac{Q_{reduced}}{Q_{furnace}}\right)^2$$

In correspondence to every value of $Q_{reduced}$, the above verification procedure should be repeated until the maximum correct head available is greater than the back pressure reduced in the combustion chamber.
The procedure is indicated in the following example, where the F factor value can be taken from table 22.
Tables exist, such as 30, showing the F inverse value.

3.1.8 Special installation features

If the burner is to be fitted to the heat generator with special limits, such as installation direction, extreme temperatures or other factors, the manufacturer must be consulted to verify in each single case, if the family of burners chosen for the application is correct.

3.2 SELECTION OF A MONOBLOC BURNER - NUMERIC EXAMPLE

Various information is required to correctly choose a burner. For this reason, the first step suggested is a correct and complete collation of the data, which can be drawn up on the basis of schedule 24.

It is also necessary to outline the complete fuel feeding combustion system.

3.2.1 Selection of the burner model

The series of double-powered burners (dual fuel) which satisfies the fuel requirement to be used (gas G20 + diesel oil) is the RLS with two-stage operating.
The choice must be made with an identified virtual firing range starting from the correct output value at the furnace in relation to the height.

s. l. m. 0 d. m. a. d. n. m. a. s. l.	Atmospheric pressure / Pressione atmosferica	F ARIA / LUFT / AIR / AIR °C							
m	mbar	0	5	10	15	20	25	30	40
0	1013	1,087	1,068	1,049	1,030	1,013	0,996	0,979	0,948
100	1000	1,073	1,054	1,035	1,017	1,000	0,983	0,967	0,936
200	989	1,061	1,042	1,024	1,006	0,989	0,972	0,956	0,926
300	978	1,049	1,031	1,012	0,995	0,978	0,961	0,946	0,915
400	966	1,037	1,018	1,000	0,983	0,966	0,950	0,934	0,904
500	955	1,025	1,006	0,989	0,971	0,955	0,939	0,923	0,894
600	944	1,013	0,995	0,977	0,960	0,944	0,928	0,913	0,884
700	932	1,000	0,982	0,965	0,948	0,932	0,916	0,901	0,872
800	921	0,988	0,971	0,953	0,937	0,921	0,905	0,891	0,862
900	910	0,977	0,959	0,942	0,926	0,910	0,895	0,880	0,852
1000	898	0,964	0,946	0,930	0,913	0,898	0,883	0,868	0,841
1200	878	0,942	0,925	0,909	0,893	0,878	0,863	0,849	0,822
1400	856	0,919	0,902	0,886	0,871	0,856	0,842	0,828	0,801
1600	836	0,897	0,881	0,865	0,850	0,836	0,822	0,808	0,783
1800	815	0,875	0,859	0,844	0,829	0,815	0,801	0,788	0,763
2000	794	0,852	0,837	0,822	0,808	0,794	0,781	0,768	0,743

Table 22 *F - correction factor of discharge head and delivery in relation to temperature and altitude*

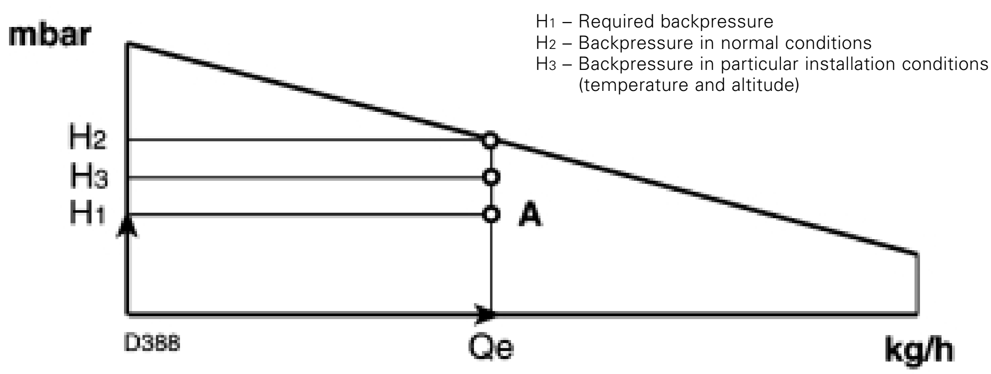


Table 23 *Example of backpressure reduction for a burner*

Using table 22, for a height of 1,000 m and a temperature of 20°C, an F factor value is obtained equal to 0.898; the correct output will be equal to:

$$Q_{burner} = \frac{Q_{foc}}{F} = \frac{450}{0,898} = 501,1\ kW$$

The burner models that satisfy the parameter Q_{burner} equal to 501.1 kW, taking the data from the tables in the catalogue or from the choice index.

From table 25, we can see that there are two burners that satisfy the required capacity: the RLS 50 and the RLS 70.
The choice between these two models of burner should be made in relation to the backpressure within the combustion chamber. This verification must be carried out with the help of the firing ranges.
On the diagram of the chosen burners, a vertical line should be traced in correspondence to the maximum output required of 501.1 kW, and thus the maximum back pressure value which can be overcome, supplied by the burner fan, is gained.
We can obtain the following maximum heads

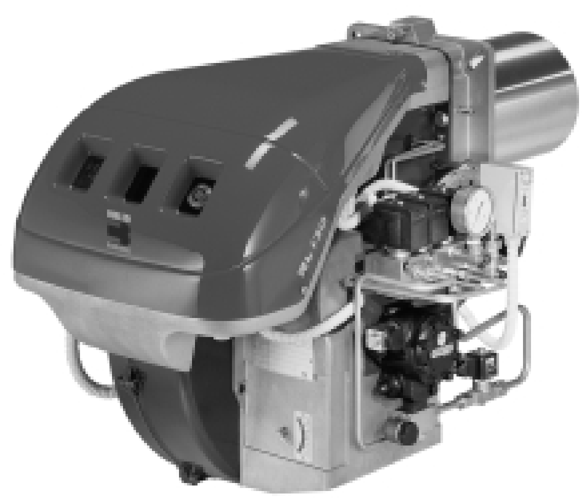


Diagram 85 *Dual fuel (light oil-gas) burner of RLS series*

CHART OF THE DATA REQUIRED FOR A COMBUSTION SYSTEM SELECTION

Boiler model ____________ **Manufacturer** ____________ **Year of prod.** ____________

Fluid type
☑ Hot water ☐ Superheated water ☐ Diathermic oil ☐ Hot air (indirect exch.)
☐ High pressure vapour ☐ Low pressure vapour ☐ Superheated vapour ☐ Hot air (direct exchange)

Max firing pressure 5 [bar] Max firing temp. 95 [°C] Vapour prod. ______ [kg/h]

Boiler type
Flue gas pipes ☐ 3-turns ☑ Reverse flame chamber ☐ Double combustion chamber
Water pipes ☐ D-shape ☐ Coiled/rapid ☐ Vertical

Nominal boiler output ______ [KW] ______ [Kcal/h] Boiler efficiency ______ %
Boiler furnace output 450 [KW] ______ [Kcal/h] Existing burner type (trademark): ____________

Combustion chamber data

Backpressure / Furnace depression 4,5 [mbar] ______ [mm W.C.]

Length 1800 [mm] Height ______ [mm] Projection of burner head ______ [mm]
Diameter 510 [mm] Breadth ______ [mm]

Fuel
☑ Light oil ☐ Heavy oil ☐ Kerosene
☑ Methane gas ☐ LPG ☐ City gas ☐ Biogas

Gas supply data Net calor. value 10 [kWh/Nmc] ______ [Kcal/Nmc]

Delivery pressure 28 [mbar] ______ [bar] ______ [mm W.C.]

Oil supply data

Viscosity
Gas oil ☑ 6 cSt at 20°C
Light fuel oil ☐ 3°E at 50°C
Medium fuel oil ☐ 20°E at 50°C
Heavy fuel oil ☐ 50°E at 50°C

Net calorific value ______ [kJ/Kg] 11,86 [kWh/Kg] ______ [kcal/Kg]

Installation place Country (abroad) ITALIA Town ______ Company ____________

Altitude 1000 [m a.s.l.] ☑ Indoor ☐ Outdoor Tmin/max 15/25 [°C]

Electrical data 3-phase voltage supply/Control voltage/frequency

☐ 400/230/50 ☑ 400/110/50 ☐ 440/220/60 ☐ 210/120/60 ☐ / /

Burner control options ☐ Modulating regulation ☐ Continuos self-checking ☐ Oxygen regulation

Dual block burner pumpibg unit (options) ☐ Pre-mounted ☐ Only components

Pump/Filter ☐ Single pump ☐ Double pump ☐ Single filter ☐ Double filter

Preheater ☐ Electrical ☐ Steam ☐ Doble (steam/electrical) ☐ Oil delivery measure

Gas train ☐ Train regulation ☐ Safety train ☐ Leakage control ☐ Gas delivery measure

Other requirments (norms, spcs, notes) ____________

Table 24 *Chart of the data required for a combustion system selection - example*

Table 25 *Technical data of RLS series of monoblock burners*

Model		RLS 28	RLS 38	RLS 50	RLS 70	RLS 100	RLS 130
HEAT OUTPUT(*) (2nd stage)	kW	163-325	232-442	290-581	465-814	698-1163	930-1395
	Mcal/h	192-378	270-513	337-676	541-947	812-1352	1081-1622
Fuel delivery (2nd stage)	kg/h	13,7-27,4	19,6-37,3	24,5-49	39-69	59-98	78-118
HEAT OUTPUT(*) (min. 1st stage)	kW	100	116	145	232	349	465
	Mcal/h	116	135	169	270	406	541
Fuel delivery (min. 1st stage)	kg/h	8,5	9,8	12,3	19	29,5	39
FUELS	Light oil, viscosity at 20°C: $6 mm^2/s$ max (1,5°E - 6cst)						
	Natural gas: G20 (methane) - G21 - G22 - G23 - G25						
	GPL - G30 (propane) - G31 (butane)						
Gas pressure at maximum delivery: G20/G25/G31	mbar	11/16,2/9,5	13/19,2/12	14/20,8/10,5	6,2/7,5/7,8	10/13/12	11,5/14,4/15
Ambient temperature	°C	0-40					
Max combustion air temperature	°C	60					
ELECTRICAL SUPPLY	Phase - Hz - V	1 - 50 -230		3 N - 50 - 400/230			
ELECTRICAL MOTORS	rpm	2800					
Fan motor	W	250	420	650	1100	1500	2200
	A	2,1	2,9	3-1,7	4,8-2,8	5,9-3,4	8,8-5,1
Pump motor	W	90			370		
	A	0,8			2,4		
PUMP							
delivery (at 12 bar)	kg/h	67			164		
pressure range	bar	4-18			10-20		
max fuel temperature	°C	60					
ELECTRICAL POWER CONSUMPTION	W max	530	760	910	1800	2200	3000
ELECTRICAL PROTECTION		IP44					
APPROVAL	CE	0063AR4637			0063AS4863		
	DIN	-			5G835/97M		
NOISE LEVELS (**)	dBA	68	70	72	74	77,5	80
CONFORMITY TO EEC DIRECTIVES		90/396 - 89/336 - 73/23 - 92/42			90/396 - 89/336 - 73/24		

(*) Reference conditions: Ambient temperature 20°C - Barometric pressure 1000 mbar - Altitude 1000 m a.s.l.
(**) Sound pressure measured in manufacturer's combustion laboratory, with burner operating on test boiler and at maximum rated output.

from the firing ranges:

- RLS 50. Pmax = 4 mbar
- RLS 70. Pmax = 9 mbar

The maximum head taken from the graph must be corrected in relation to the installation height by using the F factor, obtaining the following values:
for the RLS 50 burner:

$$P_{burner} = P_{max} \cdot F = 4 \cdot 0{,}898 = 3{,}6 \text{ mbar}$$

for the RLS 70 burner:

$$P_{burner} = P_{max} \cdot F = 9 \cdot 0{,}898 = 8{,}1 \text{ mbar}$$

The backpressure in the combustion chamber is equal to 4.5 mbar (450 Pa), greater than that which can be supplied by the RLS 50 series and lower than that which can be supplied by the RLS 70 series.
Two solutions can be adopted:

1. the RLS 50 can be used, with a consequent reduction in the maximum output that can be supplied in relation to the maximum head available;

2. the RLS 70 burner can be used;

In the first case, we can calculate the reduction in thermal output by using the iterative procedure summarised in the table below.

The maximum output which can be supplied can be taken from the following table and is that corresponding to the line in which the effective head of the burner overcomes the back pressure in the combustion chamber:

$Q_{furnace}$ [kW] (1)	R [%] (2)	$Q_{reduced}$ [kW] (3)	$P_{reduced}$ [mbar] (4)	Q_{burner} [kW] (5)	P_{max} [mbar] (6)	P_{burner} [mbar] (7)
450	1%	446	4,41	496	4,1	3,68
450	2 %	441	4,32	491	4,2	3,77
450	3 %	437	4,23	486	4,3	3,86
450	4 %	432	4,15	481	4,4	3,95
450	5 %	428	4,06	476	4,5	4,04
450	**6 %**	**423**	**3,98**	**471**	**4,6**	**4,13**
450	7 %	419	3,89	466	4,7	4,22

Table 26 *Iterative process table*

The values in the columns have the following meaning:

(1) original furnace output $Q_{furnace}$;
(2) reduction percentage of furnace output r;
(3) reduced furnace output

$$Q_{reduced} = r \cdot Q_{furnace}$$

(4) boiler head at reduced output;

$$P_{reduced} = P_{furnace} \cdot \left(\frac{Q_{reduced}}{Q_{furnace}}\right)^2$$

(5) required output at the burner

$$Q_{burner} = Q_{reduced} / F;$$

(6) maximum head available corresponding to Q_{burner} P_{max};
(7) effective burner head

$$P_{burner} = P_{max} \cdot F$$

A 6% reduction of output is required so that the fan head is greater than the backpressure in the combustion chamber of the boiler.
If the system can cope with a 6% reduction of

the maximum output, the RLS 50 series burner can be used.

In the diagram representing the firing ranges, the burner firing point (indicated in yellow) has also been indicated in the event that installation is carried out at a height corresponding to the burner test value (100 m above sea level and 20°C), and thus with no need to correct the chosen parameters.
As can be seen in this last hypothetical example, the maximum output required is possible with the inferior RLS 50 series, without a reduction in output. This demonstrates the importance of evaluating the geodetic installation height and of its weighting in reference to the output and pressure parameters.

Continuing the example, we can hypothesise using the RLS70 burner.

3.2.2 Selection of the combustion head length

The combustion head of the RLS 70 series burner is 250 mm long.

The boiler in question is a flue gas pipe-type boiler with flame inversion. The constructive diagram of the boiler is shown in the illustration below.

For this boiler, the distance C between the burner fastening plate and the entrance of the second flue gas turn after flame inversion is equal to approximately 200 mm.
Considering the indications given previously, optimum conditions could be the protrusion of the combustion head beyond this section of at least 20-25% with respect to the distance between the fastening plate and the second flue gas turn entrance.

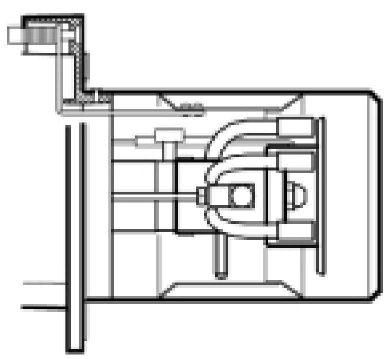
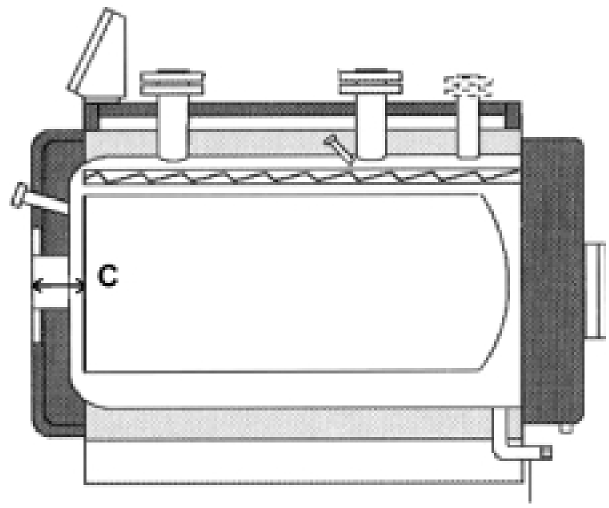


Diagram 86 *Combustion head*

Diagram 87 *Hot water boiler constructive layout*



The combustion head penetrates by around 50 mm into the combustion chamber. For the RLS70 series burner, the length of the combustion head is in fact equal to 250 mm, optimum value for the use in question.

If this length were much greater than that requested, certain accessories would be needed to decrease the penetration inside the combustion chamber; these accessories are called spacers and are positioned between the burner coupling flange and the boiler shell.
If the head were shorter, extensions would be used.

In certain cases, the length of the burner combustion head is clearly declared by the boiler manufacturer.

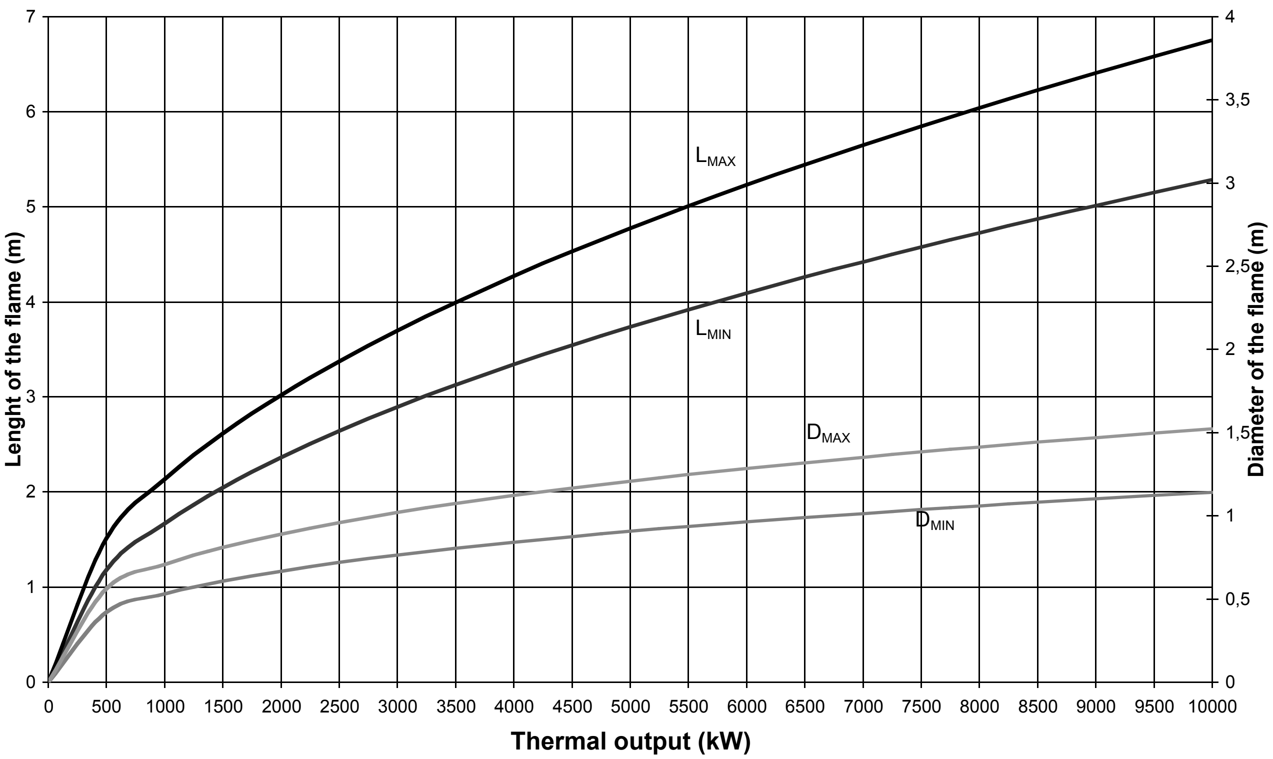
3.2.3 Verifying the flame length

Before choosing the fuel feed, the dimensions of the combustion chamber must be checked, which is to be combined with the chosen burner, to ensure they are similar to those of the test boiler used to test the burners.

For this check, the diagram below should be used, in which by entering the thermal output or the fuel delivery on the X axis, we can read off the diameter of the combustion chamber on the upper axis and the length of the chamber on the Y axis. The choice is confirmed if the boiler the burner will be coupled to, falls within the tolerance range.

In our case, the combustion chamber has a

Diagram 88 *Lenght and diameter of the flame in relation to burner output*



diameter of 700 mm and a length of 1,600 mm, therefore the combination with the RLS 70 burner is confirmed.

If the dimensions were very different to those of the test boiler, we could obtain a flame geometry (length and width) which is not optimised for the application; when the combustion chamber is too short, physical damage may be caused to the body of the boiler due to heat stress caused by the contact of the flame with the bottom wall.

3.2.4 Selection of the gas train

The choice of the gas train to combine with the burner must be made, bearing in mind that the sum of all the pressure drops suffered by the gaseous fuel must not exceed the available pressure.
Starting downstream, the following drops must be taken into consideration:
1. H_1: back pressure in the combustion chamber;
2. H_2: combustion head;
3. H_3: gas train;
4. H_4: feed system up to the delivery point delivery;

The minimum pressure available at the delivery point for the gaseous fuel being H, the following condition must be verified:

$$H \geq H_1 + H_2 + H_3 + H_4$$

For ease of calculation, the graphs of gas train pressure drops have been estimated and represented graphically under the form of graphs and tables already inclusive of the portion lost due to the combustion head (H_2+H_3). However, to give complete information, these graphs also illustrate the pressure drop of the combustion head alone (H_2). In order to obtain the pressure drop of just the gas train (H_3), just calculate the difference between the two values.
Therefore, the choice of the gas train must be made to satisfy the following equation:

$$H_2 + H_3 \leq H - (H_1 + H_4)$$

In the case, the values are as follows:
H=2,800 Pa (28 mbar);
H_1=450 Pa (4.5 mbar);
H_4=1.000 Pa (10 mbar)

The pressure drop of the gas train and the combustion head must not exceed the following value:

$$H_2 + H_3 \leq 2.800 - (450 + 1000) = 1.350 \text{ Pa} = 13{,}5 \text{ mbar}$$

The fluid pressure drops in a pressurised system are proportionate to the delivery of the fluid itself. In the case of methane gas, delivery can be calculated by using the following formula:

$$m = \frac{Q_{fur}}{I.C.V.} \left[\frac{Nm^3}{h}\right]$$

where:
Q_{fur}= boiler output at the furnace [kW];
I.C.V. = inferior fuel calorific value [kWh/m³];

In the case, the delivery of gaseous fuel is equal to:

$$m = \frac{450}{10{,}0} = 45{,}0 \left[\frac{Nm^3}{h}\right]$$

The delivery used for choosing the gas train is the effective delivery at the boiler furnace.
The choice of the gas train should be made using the graphs provided for two-stage gas flow trains. Specifically a vertical line should be drawn corresponding to the output at the furnace or corresponding to the fuel delivery according to the graph; the intersection of this line with the specific curves for each train provides the respective pressure drop inclusive of the portion due to the combustion head.

The pressure losses for the various gas trains that can be used are as follows:
combustion head + train MB15/2:
1650 Pa (16.5 mbar);
combustion head + train MB 20/2:
1250 Pa (12.50 mbar);
pressure drop for combustion head:
600 Pa (6 mbar);

The gas train that satisfies the maximum pressure drop requirement that can be supported by our system is therefore the MB 20/2 model.

In this case, the train does not require any adapter for connection to the burner, but as a rule, the appropriate accessories for correct coupling must be chosen.

3.2.5 Selection of the components for the diesel oil feed circuit

The diesel oil feed circuit considered is that which involves direct intake from a tank installed at a height of 3 metres below the burner.

The pipes are dimensioned using the following table supplied by the manufacturer, where the length of the pipelines is the extension to be taken as a sum of the total length of the pipes and the equivalent lengths of the devices introduced into the circuit.
The circuit is 25 m long, and contains the

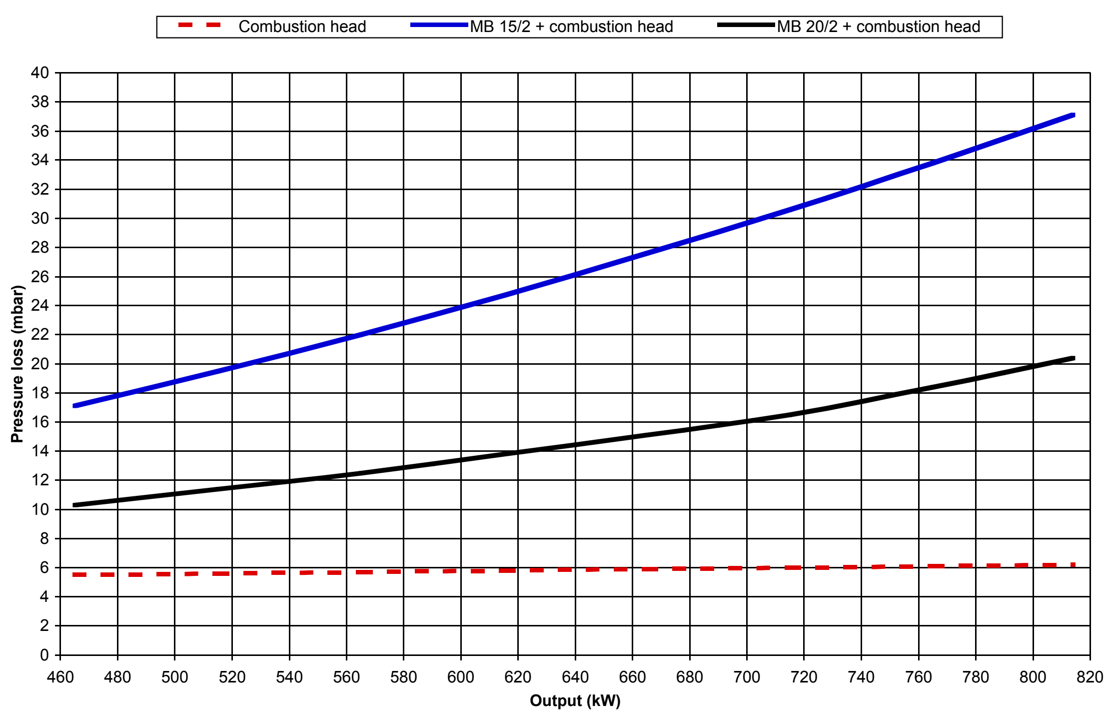
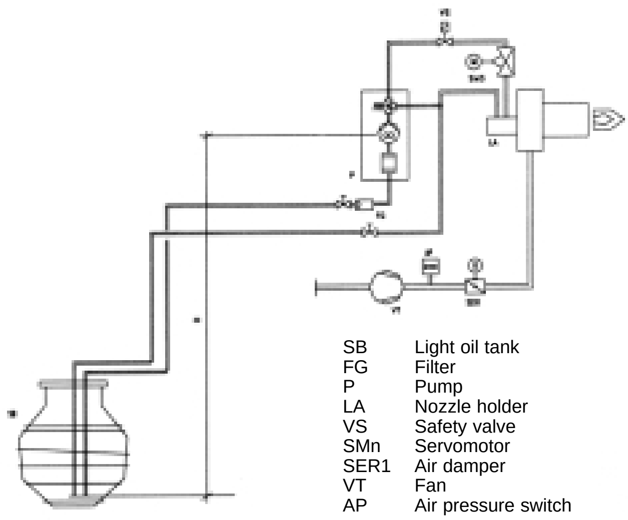


Diagram 89 *Diagram for selection of gas trains*

Diagram 90 *Layout of a light oil feeding circuit*



following components that correspond to the equivalent lengths; the following diagram was used for the calculation, presuming an internal pipeline diameter of 14 mm

- 4 curves of 90°
  L_{eq} curve = 0.1 m
- 1 filter
  L_{eq} filter = L_{eq} valve (open) = 0.045 m
- 2 shut-off valves.
  L_{eq} valve (open) = 0.045 m

The total equivalent length is therefore:

$$L_{tot\ eq} = L_{there+back} + \Sigma L_{eq} = 25 + 4x0.1 + 0.045 + 2x0.045 = 25.535 \text{ m}$$

Entering the table in the line relating to H = -3, a 26 metres length of pipeline corresponds to an internal diameter of the pipeline equal to 14 mm. Therefore, the hypothesis initially made for determining the equivalent lengths is correct; if the difference in height between the burner and the tank had been – 4 m, a pipeline with an internal diameter of 16 mm would have been used, and in this case the equivalent lengths of the curves, the valves and the filter would have to be recalculated.

3.3 SELECTION OF A DUALBLOC BURNER - NUMERIC EXAMPLE

The previous paragraph shows the numerousness of the information required to make a pondered choice of the possible combustion system. It is also indispensable to gather all the data using the same method for separately powered burners.

The DUALBLOC burner that we choose using this process must satisfy the following project-related data:

The diagram below shows the plant-engineering layout of this application.

The following diagram shows and industrial TI series burner.

3.3.1 Selection of the burner model

The combustion requirement with pre-heated air, typical of diathermic oil generators, makes it necessary to adopt a separate ventilation burner.

+H / -H (m)	Pipeline length (m)					
	RL 70 Ø (mm)			RL 100 - 130 - 190 Ø (mm)		
	10	12	14	12	14	16
+ 4,0	51	112	150	71	138	150
+ 3,0	45	99	150	62	122	150
+ 2,0	39	86	150	53	108	150
+ 1,0	32	73	144	44	90	150
+ 0,5	29	66	132	40	82	150
0	26	60	120	36	74	137
- 0,5	23	54	108	32	65	123
- 1,0	20	47	96	28	58	109
- 2,0	13	34	71	19	42	81
- 3,0	7	21	46	10	26	53
- 4,0	-	8	21	-	10	25

Table 27 *Schedule for the tabular scaling of the light oil feed pipelines*

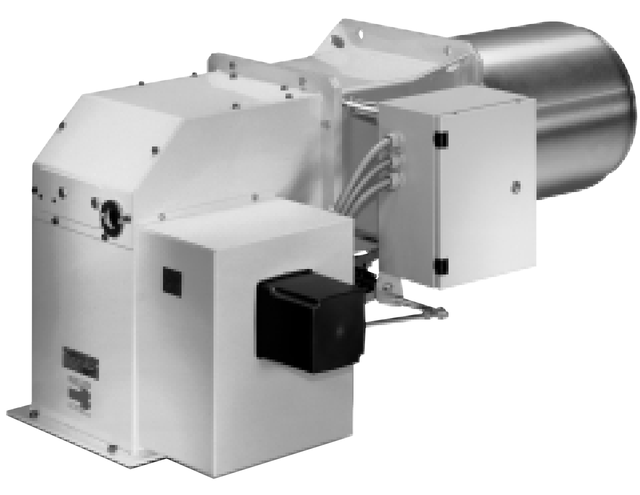


Diagram 91 *Dualbloc burner of TI series*

The Riello Burners TI series of DUALBLOC burners satisfies the requirement of the double fuel to be used (gas + fuel oil), which has a characteristic regulation of the modulating thermal output.

The burner must be chosen in relation to the requested furnace output: as a rule, this is indicated on the name plate of heat generator for existing installations and can be found in the manufacturer's catalogue for new installations. In this case, taking the nominal or effective output as the only data available, the thermal output at the furnace can be gained by using the simplified formula indicated in section 3.1.1.

$$Q_{furnace} = \frac{Q_{effective}}{0{,}90} = \frac{5814}{0{,}9} = 6460\ kW$$

The installation height equating to 50 metres does not require any correction to this output value, therefore from the following technical data table we can learn that the first model to satisfy said requirements is the TI11.

CHART OF THE DATA REQUIRED FOR A COMBUSTION SYSTEM SELECTION

Boiler model ________ **Manufacturer** ________ **Year of prod.** ________

Fluid type
☐ Hot water ☐ Superheated water ☑ Diathermic oil ☐ Hot air (indirect exch.)
☐ High pressure vapour ☐ Low pressure vapour ☐ Superheated vapour ☐ Hot air (direct exchange)

Max firing pressure 10 [bar] Max firing temp. 300 [°C] Vapour prod. ____ [kg/h]

Boiler type
Flue gas pipes ☑ 3-turns ☐ Reverse flame chamber ☐ Double combustion chamber
Water pipes ☐ D-shape ☑ Coiled/rapid ☐ Vertical

Nominal boiler output 5814 [KW] ____ [Kcal/h] Boiler efficiency 90 %
Boiler furnace output ____ [KW] ____ [Kcal/h] Existing burner type (trademark): ________

Combustion chamber data

Backpressure / Furnace depression 15 [mbar] ____ [mm W.C.]

Length 5800 [mm] Height ____ [mm] Projection of burner head ____ [mm]
Diameter 2500 [mm] Breadth ____ [mm]

Fuel
☐ Light oil ☑ Heavy oil ☐ Kerosene
☑ Methane gas ☐ LPG ☐ City gas ☐ Biogas

Gas supply data Net calor. value 10 [kWh/Nmc] ____ [Kcal/Nmc]

Delivery pressure ____ [mbar] 2 [bar] ____ [mm W.C.]

Oil supply data

	Gas oil	Light fuel oil	Medium fuel oil	Heavy fuel oil
Viscosity	☐ 6 cSt at 20°C	☐ 3°E at 50°C	☐ 20°E at 50°C	☑ 50°E at 50°C

Net calorific value ____ [kJ/Kg] 11,86 [kWh/Kg] 10,67 [kcal/Kg]

Installation place Country (abroad) ITALIA Town ____ Company ________

Altitude 1000 [m a.s.l.] ☑ Indoor ☐ Outdoor Tmin/max 15/25 [°C]

Electrical data 3-phase voltage supply/Control voltage/frequency

☐ 400/230/50 ☑ 400/110/50 ☐ 440/220/60 ☐ 210/120/60 ☐ / /

Burner control options ☑ Modulating regulation ☐ Continuos self-checking ☐ Oxygen regulation

Dual block burner pumpibg unit (options) ☐ Pre-mounted ☐ Only components

Pump/Filter ☐ Single pump ☐ Double pump ☐ Single filter ☐ Double filter

Preheater ☐ Electrical ☐ Steam ☐ Doble (steam/electrical) ☐ Oil delivery measure

Gas train ☐ Train regulation ☐ Safety train ☐ Leakage control ☐ Gas delivery measure

Other requirments (norms, spcs, notes) ________

Table 28 *Chart of the data required for a combustion system selection - example*

Table 29	Chart of the data required for a combustion system selection - example

	Model			▼ TI 10	▼ TI 11	▼ TI 12	▼ TI 13	▼ TI 14
	Setting type			modulating				
	Modulation ratio at max output		natural gas	1 : 6	1 : 6	1 : 6	1 : 6	1 : 5
			LPG	1 : 5	1 : 5	1 : 5	1 : 5	1 : 4
			light oil	1 : 4	1 : 4	1 : 4	1 : 4	1 : 3,5
			heavy oil	1 : 3	1 : 3	1 : 3	1 : 3	1 : 3
	Servo-motor	type		SQM10				
		run time	s	42				
	Heat Output	natural gas	kW	870/3000÷5200	1160/4200÷7000	1450/6000÷8700	1830/7800÷11000	2400/8500÷12000
			Mcal/h	748/2580÷4472	998/3612÷6020	1247/5160÷7482	1574/6708÷9460	2064/7310÷10320
		LPG	kW	1040/3000÷5200	1400/4200÷7000	1740/6000÷5700	2200/7800÷11000	3000/8500÷12000
			Mcal/h	894/2580÷4472	1204/3612÷6020	1496/5160÷7482	1892/6708÷9460	2580/7310÷10320
		light oil	kW	1300/3000÷5200	1750/4200÷7000	2170/6000÷8700	2750/7800÷11000	3400/8500÷12000
			Mcal/h	1118/2580÷4472	1505/3612÷6020	1866/5160÷7482	2365/6708÷9460	2924/7310÷10320
		heavy oil	kW	1700/3000÷5200	2330/4200÷7000	2900/6000÷8700	3660/7800÷11000	4000/8500÷12000
			Mcal/h	1462/2580÷4472	2004/3612÷6020	2494/5160÷7482	3148/6708÷9460	3440/7310÷10320
	Working temperature		°C min./max.	-15/60				
Fuel/Air Data	Light oil	net calorific value	kWh/kg	11,8				
			Kcal/kg	10200				
		viscosity at 20°C	mm²/s (cSt)	4 ÷ 6				
		Output	Kg/h	111/253÷438	148/354÷590	183/506÷734	232/658÷927	287/717÷1012
		max temperature	°C	50				
	Heavy oil	net calorific value	kWh/kg	11,1÷11,3				
			Kcal/kg	9545÷9720				
		viscosity at 20°C	mm²/s (cSt)	500				
		Output	Kg/h	152/268÷464	208/375÷625	259/536÷777	326/696÷982	357/759÷1071
		max temperature	°C	140				
	Atomised pressure		bar	25÷28				
	G20	net calorific value	kWh/Nmc	10				
		Density	kg/Nmc	0,71				
		Output	Nmc/h	87/300÷520	116/420÷700	145/600÷870	183/780÷1100	240/850÷1200
	G25	net calorific value	kWh/Nmc	8,6				
		Density	kg/Nmc	0,78				
		Output	Nmc/h	101/349÷605	135/488÷814	169/698÷1012	213/907÷1279	279/988÷1395
	LPG	net calorific value	kWh/Nmc	25,8				
		Density	kg/Nmc	2,02				
		Output	Nmc/h	40/116÷202	54/163÷271	67/233÷337	85/302÷426	116/329÷465
	Fan		type	Centrifugal with reverse curve blades				
	Air temperature		°C max.	150				
Electrical Data	Electrical supply		Ph/Hz/V	1/50-60/230 - (1/50-60/110 on request)				
	Control box		type	LFL 1.333 - LFL 1.335 (Intermittent working) - LGK 16 (Continuos working)				
	Auxiliary electrical power		VA	630				
	Total current		A	2,7 - 5,7				
	Protection level		IP	54				
	Ignition transformer		V1 - V2	230 V - 1x8 KV				
			I1 - I2	1,4A - 30 mA				
	Operation			Intermittent (at least one stop every 24 h) - Continuos (at least one stop every 72 h)				
Emissions	Sound pressure		dBA	--				
	Sound output		W	--				
	Light oil	CO emission	mg/kWh	< 110				
		Grade of smoke indicator	N° Bach.	< 1				
		NOx emission	mg/kWh	< 250				
	Heavy oil	CO emission	mg/kWh	Depending on the fuel amount				
		Grade of smoke indicator	N° Bach.	Depending on the fuel amount				
		NOx emission	mg/kWh	Depending on the fuel amount				
	G20	CO emission	mg/kWh	< 100				
		NOx emission	mg/kWh	< 170				
Approval	Reference directive			89/336 - 73/23 - 98/37 - 90/396 CEE				
	Reference norms			EN 267 - EN 676				
	Certifications			--				

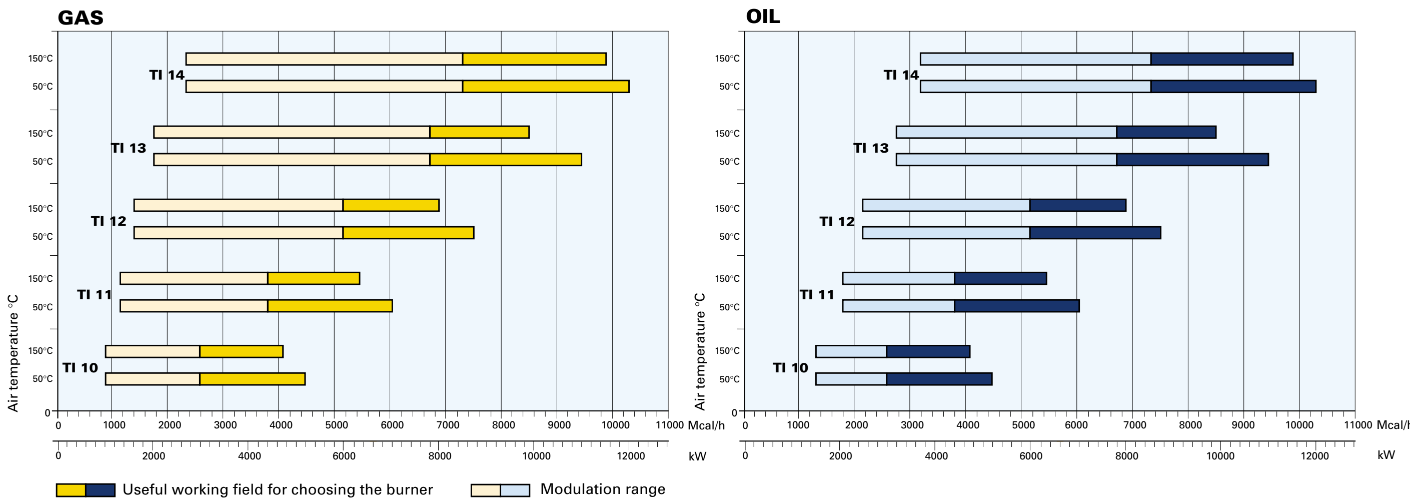
Reference conditions:
Temperature: 20°C - Pressure: 1013.5 mbar - Altitude: 100 meters a.s.l. - Noise measured at a distance of 1 meter.

After this preliminary choice, a check must be made on the firing range.
The firing range for separately powered burners is represented by a histogram that identifies the minimum and maximum outputs that can be developed by the burner.
The TI firing ranges are shown below both for methane gas and fuel oil (naphtha) feeding. These diagrams illustrate the firing ranges relating to the two usual temperature values. 50°C in the case of combustion supporter air not reheated and 150 °C for processes where the combustion supporter air is pre-heated.
Looking at the diagrams with furnace output equal to 6,460 kW, it is evident how the TI11 model, which develops a thermal output of 7 MW with combustion supporter air at 50 °C is not applicable with pre-heated air at a temperature of 150 °C. The choice therefore falls on the TI12 model.

3.3.2 Selection of the fan

The information required to choose the fan includes air delivery and the head required to guarantee that the combustion supporter air participates correctly in the combustion process.

Diagram 92	*Firing ranges for Riello TI Series of burner combustion heads*



Calculating the combustion supporter air delivery

The combustion supporter air delivery is proportionate to the delivery of burnt fuel, therefore

$$G_{air}^{G\,20} = \frac{Q_{foc}}{PCI_{G\,20}} \times g_{theoretical\ air}^{G\,20} \times e^{G\,20} = \frac{6460}{10,0} \times$$

$$\times\ 9,56 \times 1,20 = 7410\ mc/h$$

$$G_{air}^{fuel\ oil} = \frac{Q_{foc}}{PCI_{fuel\ oil}} \times g_{theoretical\ air}^{fuel\ oil} \times e_{fuel\ oil} =$$

$$\frac{6460}{10,67} \times 10,37 \times 1,25 = 7848\ mc/h$$

The fan must therefore satisfy the additional air delivery from among those requested by the various fuels, in this case it is therefore G_{air} = 7848 mc/h.

Since the installation is at a height of 1,000 metres above sea level and at a temperature of 40 °C, to guarantee an equal number of moles of oxygen, this delivery must be corrected using the F factor obtaining:

$$G_{air}^{corretta\ (H,T)} = \frac{G_{air}}{F} = \frac{7848}{0,841} = 9331\ kW$$

If the manufacturer provides the characteristic data and curves of the fans already corrected to the intake temperature, the correction must be realised solely in function of the height obtaining:

$$G_{air}^{corrected\ (H,T)} = \frac{G_{air}}{F} = \frac{7848}{0,898} = 8739\ kW$$

Calculating the fan head

The fan head is the sum of the head at combustion head exit and the induced pressure drops in the air pipelines and from the combustion head.

Called Hfan, the effective head of the fan, the following conditions must be checked:

$$H_{fan} \geq H_1 + H_2 + H_3 + H_4$$

where,

H_1 = back pressure in the combustion chamber;

H_2 = pressure drop in the combustion head;

H_3 = pressure drop in the air pipelines;

H_4 = pressure drop in the heat exchangers;

The pressure drops must all refer to the effective air temperature and heights.

Combustion chamber

The backpressure in the combustion chamber is project-related data and is equal to H_1 = 1,500 Pa.

Combustion head

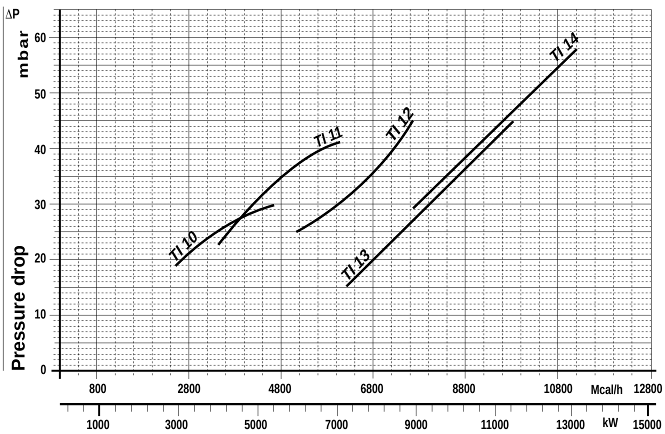
The pressure drop in the combustion head is taken from the diagrams supplied by the burner manufacturer.

For burners with a movable head, we must consider the characteristic curve obtained in the laboratory for the same layout of the head set for actual functioning .

In this case, the drop in the burner head is therefore equal to H_2 = 27 mbar = 2,700 Pa.

This value refers to a test temperature equal to

Diagram 93 *Combustion head pressure drops for TI series - air side*



20°C, therefore the value obtained will be corrected with the following Kc [(4)] factor relating to a temperature of 150 °C, taken from the law of perfect gases (see section 2.5).

The correct pressure drop will therefore be equal to

$$H_2 = 27 \times 1.44 = 38{,}8 \text{ mbar} = 3898 \text{ Pa}$$

The air which arrives at the head is taken in at a height greater than the standard laboratory test height; for this reason, the pressure drop must be further corrected by dividing H2 by the F factor relating to a height of 1,000 metres above sea level.

The effective pressure drop of the head will therefore be equal to

$$H_2 = 38.98 \times 1{,}114 = 43.43 \text{ mbar} = 4343 \text{ Pa}$$

The distribution ducts

The calculations of the dimensions of the air delivery duct section must satisfy various requirements:

- limit the head requested at the fan;
- limit the internal air speed;
- respect the available dimensions.

In this case, since there are no dimension limits, a maximum speed of 20 m/s is fixed and at the end of the calculation we will check that the loss induced by the duct does not exceed the value of 500 Pa. From the following diagram, for a speed of 20 m/s and a delivery of 2,586 l/s (9,331 mc/h) the diameter of the section of the ducts is equal to 450 mm.

Again on the diagram, we can read the related distributed pressure drop equating to e = 9 Pa/m.

The duct also presents two gentle 90° curves, which have a non-dimensional loss factor equal to $\xi = 1$, thus we can calculate the related pressure drops with the known formula

$$\Delta p_w = \xi \cdot \rho \cdot \frac{v^2}{2} = 1 \cdot 1{,}1 \cdot 20^2 / 2 = 220 \text{ Pa}$$

with a hypothetical duct length of 20 m, the H_3 pressure drop is therefore

$$H_3 = \varepsilon \cdot L + 2 \cdot \Delta_{pw} = 9 \cdot 20 + 2 \cdot 220 = 620 \text{ Pa.}$$

The air in the ducts or pipelines is however taken in under temperature and height conditions that are different from standard ones; this leads to a variation in air density and therefore a variation in the pressure drops. The value of H_3 obtained as above must therefore be corrected by using the Kc = 1,19 factor relating to the intake conditions [(5)] of the fan (40 °C, 1,000 metres above sea level).

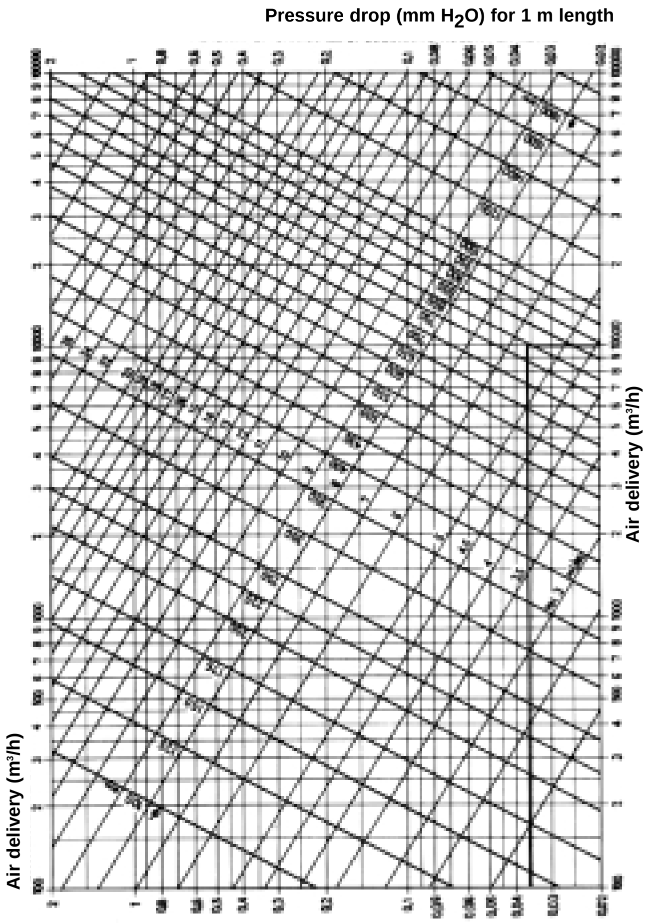
s. l. m. 0 d. m. a. d. n. m. a. s. l.	Kc ARIA / LUFT / AIR / AIR °C												
m	0	20	30	40	50	60	70	80	90	100	120	140	150
0	0,920	0,987	1,021	1,055	1,088	1,122	1,156	1,189	1,223	1,257	1,324	1,391	1,425
100	0,932	1,000	1,034	1,068	1,102	1,136	1,171	1,205	1,239	1,273	1,341	1,409	1,443
500	0,976	1,047	1,083	1,119	1,154	1,190	1,226	1,261	1,297	1,333	1,404	1,476	1,511
750	1,006	1,079	1,116	1,153	1,190	1,227	1,263	1,300	1,337	1,374	1,448	1,521	1,558
1000	1,038	1,114	1,152	1,190	1,228	1,266	1,304	1,342	1,379	1,417	1,493	1,569	1,607
1250	1,067	1,145	1,184	1,223	1,262	1,301	1,340	1,379	1,418	1,457	1,535	1,613	1,653
1500	1,101	1,182	1,222	1,263	1,303	1,343	1,384	1,424	1,464	1,505	1,585	1,666	1,706
1750	1,136	1,220	1,261	1,303	1,344	1,386	1,428	1,469	1,511	1,552	1,636	1,719	1,760
2000	1,174	1,259	1,302	1,345	1,388	1,431	1,474	1,517	1,560	1,603	1,689	1,775	1,818
2250	1,206	1,294	1,339	1,383	1,427	1,471	1,515	1,559	1,604	1,648	1,736	1,824	1,869
2500	1,251	1,342	1,388	1,434	1,480	1,525	1,571	1,617	1,663	1,709	1,800	1,892	1,938
2750	1,284	1,378	1,425	1,472	1,519	1,566	1,613	1,660	1,707	1,755	1,849	1,943	1,990
3000	1,321	1,417	1,466	1,514	1,562	1,611	1,659	1,708	1,756	1,804	1,901	1,998	2,046

Table 30 *Kc - correction factor of discharge head and delivery in relation to temperature and altitude*

(4) The Kc correction factor is the inverse of the F correction factor.

(5) The increase transformation of the temperature which takes place in the exchanger is isochor (volume=constant) therefore the density remains constant and the specific pressure drops do not change.

Diagram 94 *Pressure drops in circular pipelines*



$$H_3 = K_c \cdot H_3 = 1{,}19 \cdot 620 = 737.8 \text{ Pa}$$

The heat exchanger

The heat exchanger should be chosen in relation to the air, the nominal flue gas delivery and the related increase in temperature of the combustion supporter air.

Two effects cause the pressure variation in the heat exchanger:

- the isochor transformation (at constant volume), where the flue gases release heat into the air;
- the mechanical resistor of the tube nest.

Heat exchanger manufacturers supply the characteristic curve for each heat exchanger taken from given input and output height and temperature conditions.

This value must be corrected as a result of the different input/output temperatures and the various installation heights.

The exchanger introduced into this system has a pressure drop, corresponding to the delivery of 9331 mc/h and a temperature increase of 110 °C (from 40°C to 150 °C), equal to

$$H_4 = 500 \text{ Pa}$$

The exchanger is however installed at 1,000 metres above sea level, therefore this drop must be corrected by using the parameter Kc, thereby obtaining

$$H_4 = 500 \cdot 1.114 = 557 \text{ Pa}$$

The effective fan head

The effective head that the fan must provide is therefore equal to

$$H_{fan} = H_1 + H_2 + H_3 + H_4 = 1.000 + 4.343 + 620 + 300 = 6{,}320 \text{ Pa} = 63{,}20 \text{ mbar}$$

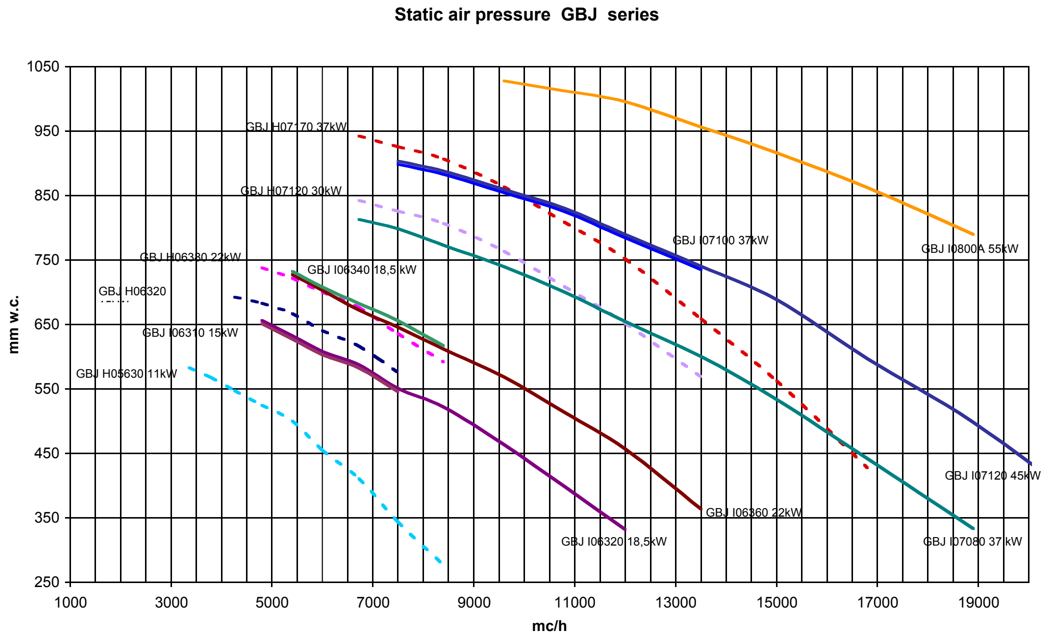
From the tables provided by the manufacturer, similar to those below, we can choose the model of fan.

In this case, the manufacturer provides the characteristic running values with air at 40 °C, therefore entering the table relating to effective heads of around 600 mm (6000 Pa) with a value of the corrected air delivery Gcorrected(H) of 8739 mc/h, we can obtain the fan model: GBJI06360, for which we must also indicate the orientation of the pressure

	Delivery (m^3/h)																	
	3000	4000	5000	6000	7000	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000
Fan model	Static air pressure (mmH_2O)																	
GBJH05630	600	550	500	450	400	300												
GBJI06310	650	625	600	550	525	500												
GBJH06320	710	700	675	650	600	550												
GBJH06380			760	710	680	640												
GBJI06340			700	675	650	630												
GBJI06320			650	600	575	535	490	450	390	330								
GBJI06360			740	700	660	625	590	550	500	450	400							
GBJH07120					840	810	790	750	700	650	600							
GBJI07100					830	875	850	825	800	770	740							
GBJH07170					940	910	880	850	800	750	700	625	560	490	410			
GBJI07080					810	780	755	725	695	650	610	585	530	490	425	390	330	
GBJI07120						895	875	850	820	790	750	720	690	640	585	545	495	440
GBJI0800A								1025	1005	990	875	845	910	885	855	815	790	750

Table 31 *Fans selection table*

Diagram 95 *Performence graphs of GBJ fan series*



inlet in relation to the intake inlet.
The effective firing point of the fan must be verified on the real characteristic curve.

As we can see from the diagram, the firing point falls halfway through the characteristic curve of the fan, which is thus verified.
A further check can be carried out, when working at high altitudes, by declassing the motor, which gives a reduction in nominal output as the temperature and altitude increase. From graphs and tables similar to the following, supplied by the electric motor or fan manufacturers, the reduction factor is obtained for the motor nominal output; this must always be greater than the power absorbed by the fan at the effective working output. It is important to remember that the absorbed power by the fan is reduced by the F correction factor previously used for elevated altitudes and temperatures.

	ALTITUDE (m a.s.l.)			
Temperature (°C)	4000	3000	2000	0-1000
0	1,98	1,2	1,3	1,3
10	1	1,1	1,2	1,3
20	0,9	1	1,1	1,2
30	0,8	0,9	1	1,1
40	0,7	0,8	0,9	1
50	0,6	0,7	0,8	0,9
60	0,5	0,6	0,7	0,8

Table 32 *Nominal output declassing factor in relation to temperature and altitude*

3.3.3 Selection of the gas train

Generally, the gas train comprises two groups of components:

- The safety and regulating valves;
- The pressure reduction unit.

The safety unit is chosen in relation to the combustion head pressure drops on the gas side; for the Riello Burner the characteristic curves from the gas side of the TI burner series for G20 natural gas are shown below.

For a furnace output of 6,410 kW, the sum of the drops of the gas butterfly valve and the head is equal to 24+6=30 mbar (3,000 Pa).

Using the diagram 97, we can choose the size of the safety value unit (6) DMV100/1, which has pressure drops equal to approximately 30 mbar (3,000 Pa).

The sum of the pressure drops in the head and the valve unit is therefore:

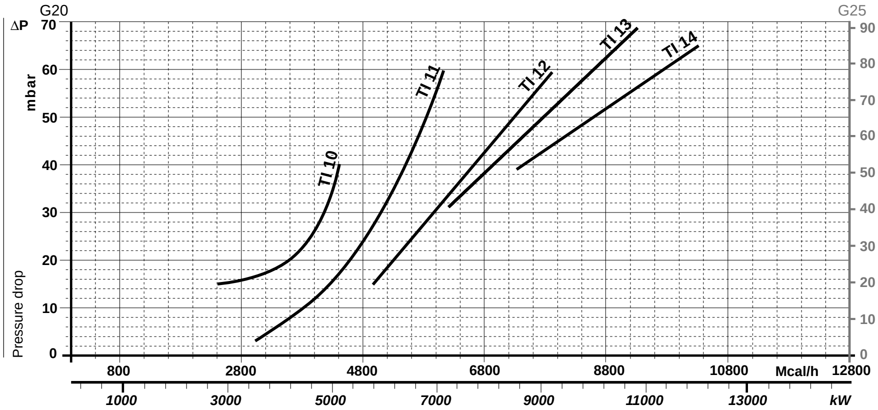
$$H_{gas} = (H_{head} + H_{butterfly}) + H_{valve} = 30+30 = 60 \text{ mbar}$$

The feed pressure of the gas is equal to 2 bar, therefore a reducer unit is necessary to guarantee an outgoing pressure equal to 60 mbar and a gas delivery equal to

$$G_{gas} = Q_{foc} / PCI_{gas} = 6,410 / 10 = 641 \text{ Nm}^3 / \text{h}$$

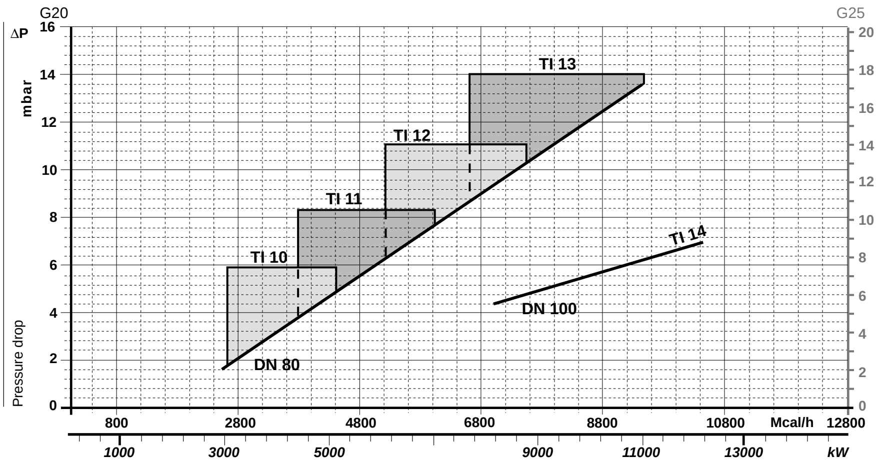
(6) The safety and regulating value unit comprises: a double automatic shut off valve and a low point pressure switch.

Diagram 96 Combustion head and butterfly valve pressure drops for TI series - gas side



Combustion head losses

Reference conditions:
Temperature: 15°C
Pressure: 1013.5 mbar



Butterfly valve losses

Reference conditions:
Temperature: 15°C
Pressure: 1013.5 mbar

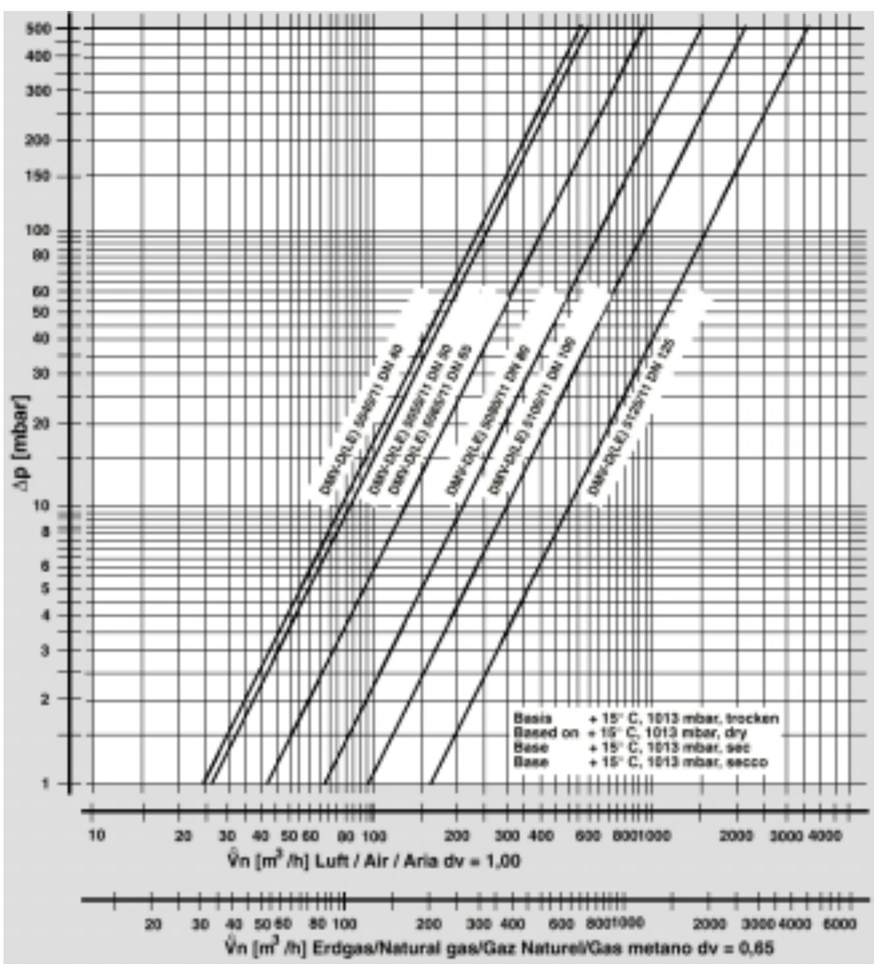


Diagram 97 Pressure drops in DMV safety valves

Table 33 — *High pressure regulating/reducing units selection table*

High pressure regulating train (Pi > 500 mbar - max 4 bar)									
Model type	**Version**	**Outlet pressure**	**DN in**	**Reg Valve**	**DN out**	**Max Press. [bar]**	**Inlet Press. [bar]**	**Max delivery G 20 [Nmc/h]**	**Max delivery LPG [Nmc/h]**
HPRT	80	27-60	1"1/2	D 50	1"1/2	4	1,5	70	45
HPRT	160	27-60	1"1/2	D 100	2"	4	1,5	140	90
HPRT	250	65-120	2"	D 160/32	65	4	1,5	225	144
HPRT	500	100-200	65	D 250/40	65	4	1,5	422	270
HPRT	750	100-200	80	D 250/50	80	4	1,5	765	490
HPRT	1000	155-230	100	N 50	100	4	1,5	1150	736
HPRT	1500	150-220	100	N 65	100	4	1,5	1350	864
HPRT	2000	150-220	125	N80	125	4	1,5	2360	1510

From the table of pressure reducers for high pressure Riello Burners (>500 mbar - max 4 bar) we can choose the reducer unit [7] HPRT 750 with the BP type spring, which guarantees outgoing pressure regulation ranging from 60 to 110 mbar.

3.3.4 Selection of the thrust unit for liquid fuel and the nozzles

In separate feed burners, the pre-heating and liquid fuel thrust components are separate from the burner body mounted on the heat generator.
To complete the burner, a suitable thrust unit must therefore be chosen, both with regards type and nominal running characteristics.

First, the functioning philosophy must be determined, which in this case we can presume is the type with a single pumping unit with electrical pre-heating.

We must then take the pressure values of the combustion head fuel oil P_{head} and fuel oil delivery $m_{pumping}$.

The first can be gained from the technical data table for the TI12 burner

$$P_{head} = 25 \div 28 \text{ bar.}$$

The delivery of the pumping unit must be approximately double the nominal delivery required for combustion:

$$m_{pumping} = 2 \cdot m_{burner} = \frac{Qfoc}{PCI_{fuel\ oil}} =$$

$$2 \cdot \frac{6460}{10,67} = 1210,8 \text{ kg / h}$$

taking the fuel oil density as d =0.97 kg/l we obtain:

$$m_{pumping} / \delta = 1210.8 / 0.97 = 1248.2 \text{ l/h}$$

Heavy oil electrical heating/pumping unit skid - single pumping unit										3/400/50 3/440/60
Model type	**Version**	**Heating type**	**Electrical heaters**	**PH/V/HZ**	**Port size**	**Delivery [l/h] @15 bar**	**Delivery [l/h] @30 bar**	**Motor power [KW] - 50 Hz**	**Max output kg/h**	**Heating power KW**
SN	250	EP	1EP14	3/400/50 3/440/60	1/2"	580	540	1,1	265	14
SN	320	EP	1EP20	3/400/50 3/440/60	3/4"	950	700	1,5	350	20
SN	400	EP	2EP14	3/400/50 3/440/60	3/4"	1400	1200	2,2	540	28
SN	500	EP	2EP20	3/400/50 3/440/60	3/4"	1400	1200	2,2	590	40
SN	650	EP	2EP20	3/400/50 3/440/60	3/4"	1900	1700	3	775	40
SN	800	EP	3EP14	3/400/50 3/440/60	3/4"	1900	1700	3	835	42
SN	1000	EP	3EP20	3/400/50 3/440/60	1"	2700	2200	5,5	1085	60
SN	1500	EP	4EP20	3/400/50 3/440/60	1"	5400	3600	7,5	1550	80

Table 34 — *Pumping unit skids selection table*

(7) The reduction unit comprises: a manual shut off valve, a filter, a pressure regulator with safety valve, an anti-vibration joint and two pressure probes.

Spill back nozzles for mechanical atomizing				
2-Stages - Progressive modulating				
Model type	**Note**	**Spry angle**	**Max capacity [kg/h]**	**Part.n°**
B5-45-AA	TI 10 - TI 11 - TI12 - TI 13	45	250	3009802
B5-45-AA	TI 10 - TI 11 - TI12 - TI 13	45	275	3009803
B5-45-AA	TI 10 - TI 11 - TI12 - TI 13	45	300	3009804
B5-45-AA	TI 10 - TI 11 - TI12 - TI 13	45	325	3009805
B5-45-AA	TI 10 - TI 11 - TI12 - TI 13	45	350	3009806
B5-45-AA	TI 10 - TI 11 - TI12 - TI 13	45	375	3009807
B5-45-AA	TI 10 - TI 11 - TI12 - TI 13	45	400	3009808
B5-45-AA	TI 10 - TI 11 - TI12 - TI 13	45	425	3009809
B5-45-AA	TI 10 - TI 11 - TI12 - TI 13	45	450	3009810
B5-45-AA	TI 10 - TI 11 - TI12 - TI 13	45	475	3009811
B5-45-AA	TI 11 - TI 12 - TI 13	45	500	3009812
B5-45-AA	TI 11 - TI 12 - TI 13	45	525	3009813
B5-45-AA	TI 11 - TI 12 - TI 13	45	550	3009814
B5-45-AA	TI 11 - TI 12 - TI 13	45	575	3009815
B5-45-AA	TI 11 - TI 12 - TI 13	45	600	3009816
B5-45-AA	TI 11 - TI 12 - TI 13	45	650	3009817
B5-45-AA	TI 12 - TI 13	45	700	3009818
B5-45-AA	TI 12 - TI 13	45	750	3009819
B5-45-AA	TI 12 - TI 13	45	800	3009820
B5-45-AA	TI 13	45	850	3009821
B5-45-AA	TI 13	45	900	3009822
B5-45-AA	TI 13	45	950	3009823

Table 35 *Pumping unit skids selection table*

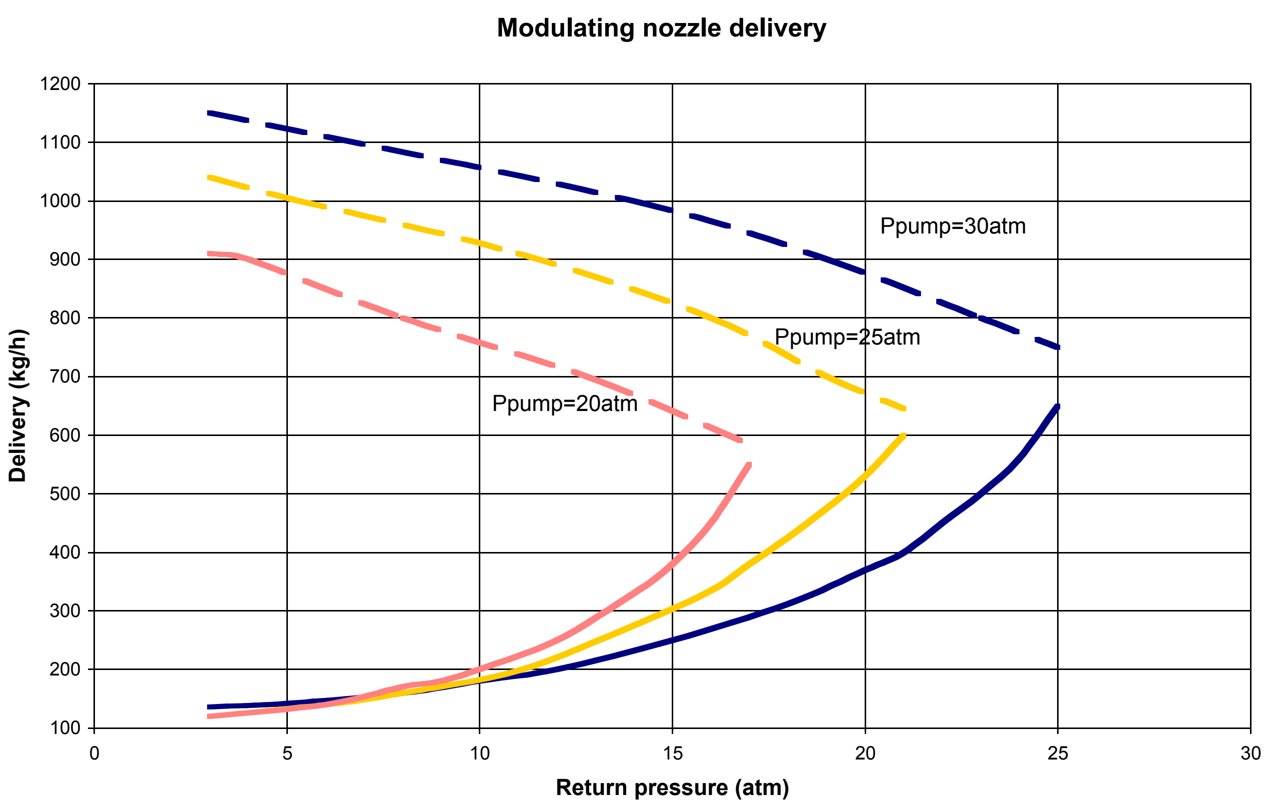


Diagram 98 *Nozzles delivery for modulating burners*

Looking at the fuel oil delivery column at a pressure of 30 bar, from the table for choosing the electrical pre-heating and thrust units with single pumping unit in Riello Burners, we can obtain the thrust unit model, which is the SN500

Selection the nozzles

The nozzles must be chosen in relation to the type of fuel atomisation, the thermal load regulation type and the combustion chamber dimensions. In this case, atomisation is mechanical, load regulation is modulating and the combustion chamber has a standard length/diameter ratio.

Looking at the maximum delivery column of the mechanical atomisation nozzles with a spray angle of 45° , we can choose the nozzle which has a nominal fuel delivery slightly greater than the theoretical one requested by the burner.

$$m_{burner} = \frac{Qfoc}{PCI_{fuel\ oil}} = \frac{6460}{10,67} = 605,4\ kg/h$$

The correct nozzle is therefore the B3-45-AA 650 kg/h code No. 3009817.

Verification of the correct load modulating ratio requested of 1:5 must be made on the diagram provided by the nozzle manufacturer, in relation to the maximum and minimum fuel pressure in the return circuit. In this case, we have 650/130=5 mad therefore the requested modulating ratio is possible.

3.3.5 Selection of the components in the liquid fuel feed circuit

The liquid fuel feed circuit taken into consideration is the following:

The circuit shown in the diagram is the most appropriate when using heavy oil with a viscosity between 7°E and 65 °E measured at 50°C.

This feed system comprises two ring circuits plus a transfer circuit; the principal one for circulating the heavy oil from the service tank, the secondary one for circulating the oil from the primary circuit to the burner and the transfer one for transferring fuel oil from the storage tank to the service tank. All the circuits are controlled by their own pump, those for the primary circuit and transfer circuit should be chosen by the design engineer, while those for the secondary circuit are provided as standard fittings with the burner.

As far as the primary ring and transfer ring are concerned, the viscosity pumping limit is usually around 70°E at 50°C. Therefore, for these circuits a temperature of 50-60°C can be considered as more than sufficient to avoid blocking the pipelines.

The heavy oil must therefore be taken to a certain temperature for it to be adequately atomised and subsequently burnt in the combustion chamber. To obtain an adequate

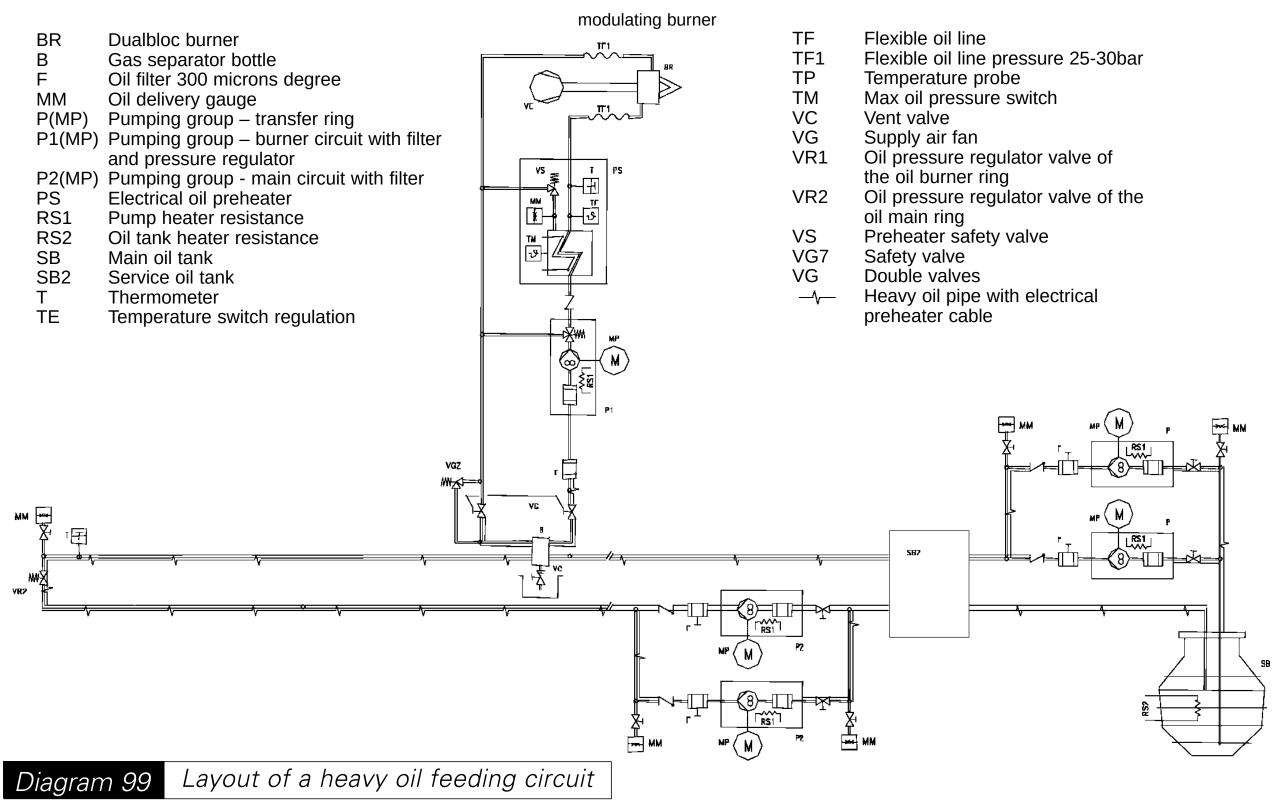


Diagram 99 *Layout of a heavy oil feeding circuit*

atomisation of the fluid oil, the range of viscosity goes from 2°E to 5°E at 50°C. To obtain this viscosity value, the heaviest fuel oils must be pre-heated up to 130°C.
Naphtha burners in the Riello Burners range are equipped with electrical modulating pre-heaters regulated by a series of regulating and safety thermostats capable of reaching the temperatures required for atomising the fuel.
Furthermore, for the heaviest fuel oil special kits for heavy oil must be used, comprising a series of electrical elements for the secondary feed circuit pump.

For dimensioning the circuit equipment, the following initial data is take for reference purposes:
Effective length of intake pipelines L_{eff}= 15 m;
Equivalent length of intake pipelines L_{equiv}=10 m;
Effective length of delivery pipeline L_{eff}= 30 m;
Equivalent length of delivery pipeline L_{equiv}=20 m;
pump tank height difference Δh_{geom} = 1 m;
project-related temperature t = 60°C;
volume mass of heavy fuel oil at the reference temperature (15°C) = 990 kg/m^3;
viscosity γ at 50°C = 50°E (approx.. 400·10-6 m^2/s);
viscosity γ at 60°C = 40°E (approx. 200·10-6 m^2/s);
fuel oil thrust unit delivery 1,200 kg/h = 20.7 l/min.

3.3.5.1 Transfer pump between the storage tank and the service tank

The transfer circuit pumping plant must comprise a couple of pumps equipped with their own filters and with the possibility of switchover in by-pass.
Both the pumps, suitable for heavy fuel oil (with gears), must be chosen with a delivery equal to 1.2-1.5 times the maximum peak consumption of the system, in this case:

m_{pump1} = (1,2 → 1,5) · m_{pumping} = (1,2 → 1,5) · 1200 = 2400 *kg / h*

These pumps must be equipped with a self-cleaning blade filter (comb-type) with mesh dimension ranging between 400 and 600 mm and pre-heated to 50-60°C.

It is well to the remember that to avoid problems on the intake pipelines, the pumping plant should be positioned as near as possible to the storage tank.

3.3.5.2 Service tank

The service tank, which also acts as an outgas device, is a hydraulic disconnection element between the transfer stretch and that of the main ring. This tank must have the following characteristics:

- fuel oil entry from the base;
- double pre-heater, one fluid heater (water or vapour) to be positioned immediately above the arrival point of the heavy fuel oil and an electrical pre-heater above the fluid pre-heater with integration and emergency functions;
- drawing of the heavy fuel oil above the two pre-heaters;
- tank capacity equal to at least 2-3 times the sum of the maximum hourly drawing capacities of the burners;

In this case, the tank has a capacity equal to:

V = (2 → 3) ·m_{pumping} = (2 → 3) · 20,74 l /min · 60 min = 2488 → 3733 l

This volume should be taken as effective, entirely occupied by the heavy fuel oil; a quota must be calculated equal to 10% of additional volume for the gases and vapours emitted by the oil.
In addition, the service tank must be equipped with the following devices:
- end plate outlet for water and sediment;
- level control with minimum and maximum alarm equipped with self-checking systems;
- atmosphere breather pipe;
- "over full" device with return line to storage tank;

3.3.5.3 Pump in the main ring

The pumping plant in the main ring must comprise a couple of pumps with their own filters and the possibility of switchover in by-pass.
Both the pumps in the main ring should be chosen on the basis of the fluid delivery and viscosity at the temperature of the circulation fluid. The pumps in the main rings must be dimensioned for a minimum delivery equal to

at least 3-5 times the sum of the maximum drawing capacities of the burners.

$m_{pump} = (3 \rightarrow 5) \cdot m_{\text{pumping}} = (3 \rightarrow 5) \cdot 1200 = 3600 \rightarrow 3733\ kg/h$

These pumps must be equipped with a self-cleaning blade filter (comb-type) with mesh dimension ranging between 200 and 300 mm and pre-heated to 50-60°C, the pumping plant should be positioned as near as possible to the storage tank.
We can presume using a pump with the following characteristics:
Q = 4,000 kg/h (1,11 kg/s);
H = 30 m approx.
and a self-cleaning filter with meshes of 250 mm which, for delivery of approximately 4,000 kg/h introduces a pressure drop of 3,000 Pa.
The ring circuit must be equipped with a pressure-regulating valve, with a regulating interval ranging between 1 and 4 bar and with a nominal delivery greater than that of the circuit corresponding to a pump delivery.

3.3.5.4 Dimensioning the main ring pipelines

The pipelines must be made from black steel tubes without welding joints. The pipelines must be marked using an electrical heating wire with an output between 20 and 40 W/m or using heating fluid. For easier installation and maintenance operations, the pipeline can be marked with a copper tube (diameter 12x1-20x1) within which the heating wire can run. The pipelines must be insulated in closed-cell foam.

The diameter of the circuit pipeline must be dimensioned on the basis of the following considerations:
minimum speed in the intake pipelines (upstream from the pumps): 0.15 m/s;
maximum speed in the delivery pipelines (downstream from the pumps): 0.6 m/s;

The heavy fuel oil volume mass at a temperature of 60°C is equal to:

$$\rho = \frac{\rho_{15}}{1 + \beta \cdot (t - 15)} = \frac{990}{1 + 0{,}00063 \cdot (60 - 15)} = 963\ [\text{kg/m}^3]$$

The intake pipeline must be dimensioned so that the pressure drop in that stretch does not exceed the following value:

$$\Delta P_{\text{prog}} = \Delta P_{\text{amn}} - \Delta h_{\text{asp}} - \Delta P_{\text{acc}}\ [Pa]$$

where:
ΔP_{amn} = absolute pressure allowed at intake (NPSH) indicated by the pump manufacturer; otherwise, this pressure must not be less than 50,660 Pa (0.5 ata);
Δh_{asp} = intake height;
ΔP_{acc} = head loss due to the presence of accessories (filters, etc…)
The intake height is equal to:

$$\Delta h_{\text{asp}} = \Delta h_{\text{geom}} \cdot \rho \cdot 9{,}81\ [Pa]$$

where:
Δh_{geom}= difference in height between the fuel test point in the tank and the centre of the feed pump [m];
ρ = volume mass of the heavy fuel oil [kg/m³];
The value is positive if the tank is lower than the burner, and negative if the tank is higher.
In this case, we have the following values:

$$\Delta h_{\text{asp}} = \Delta h_{\text{geom}} \cdot \rho \cdot 9{,}81 = 1 \cdot 963 \cdot 9{,}81 = 9.447\ [Pa]$$

therefore, the maximum pressure drop allowed along the pipeline will be equal to:

$$\Delta P_{\text{prog}} = \Delta P_{\text{amn}} - \Delta h_{\text{asp}} - \Delta P_{\text{acc}} = 50.660 - 9.447 - 3.000 = 38.213\ [Pa]$$

The minimum internal diameter of the pipeline is obtained using the following formula:

$$d = \sqrt[4]{42 \cdot \frac{\gamma \cdot L_{TOT} \cdot m}{\Delta P_{prog}}} = \sqrt[4]{42 \cdot \frac{200 \cdot 10^{-6} \cdot 25 \cdot 1{,}11}{39.713}} = 0{,}276\ \text{m}$$

If we presume using an iron DN100 (4") pipeline with an internal diameter of 101.6 m, the transfer speed is equal to:

$$V = \frac{Q}{A} = \frac{Q}{\pi \cdot \frac{d^2}{4}} = \frac{0{,}278 / 963}{0{,}00087} = 0{,}356\ \text{m/s}$$

which is greater than the minimum allowed safety value of 0.15 m/s.
If the transfer speed is lower than the limit value of 0.15 m/s, we should proceed as follows:

choose the pipeline diameter that guarantees the minimum speed using the formula:

$$A = \frac{Q}{V} \Rightarrow \pi \cdot \frac{d^2}{4} = \frac{Q}{V} \Rightarrow d = \sqrt{\frac{4 \cdot Q}{\pi \cdot 0{,}15}}$$

the total maximum length (effective + equivalent) of the connection pipeline between the tanks and the pump is determined, so as not to exceed the project-related pressure drops using the following formula:

$$L_{TOT} = \frac{d^4 \cdot \Delta P_{prog}}{42 \cdot \gamma \cdot m}$$

In the pressurised stretches, i.e. the pipeline downstream from the pump, the fluid speed can reach 0.6 m/s, which in our case gives a pipeline with the following diameter:

$$d = \sqrt{\frac{4 \cdot Q}{\pi \cdot 0{,}15}} = \sqrt{\frac{4 \cdot \frac{0{,}278}{963}}{\pi \cdot 0{,}6}} = 0{,}0248 \text{ m}$$

therefore, we will choose a DN25 (1”) iron pipeline that has an internal diameter equal to 0.0278 metres.
The pressure drops distributed along the pipeline will be equal to:

$$\Delta P_{prog} = \frac{42 \cdot \gamma \cdot L_{TOT} \cdot m}{d^4} = \frac{42 \cdot 200 \cdot 10^{-6} \cdot 50 \cdot 0{,}278}{0{,}0278^4} =$$

$$= 195.486 \text{ Pa } (\cong 20 \text{ m approximately})$$

This value added to the concentrated pressure drops introduced by the special components (filters, valves, etc.) not calculated in the equivalent lengths, must be less than the head supplied by the pumping system.

3.3.6 Selection of the electrical control panel

The types of electrical power supply and control signals for a DUALBLOC burner depend on the size of the components that make up the combustion system and the type of regulation of the thermal load.
The manufacturers have tables for choosing the electrical power supply and control panels in relation to the type of burner, its maximum developed output and the type of regulation.
In this case, the electrical panel will be chosen from the table relating to TI dual-fuel (heavy oil

Table 36 Nozzles selection table

Heavy oil/Natural gas dualbloc burners control panel					
Model type	Burner output [kW]	Fan Absorbed Power [KW]	Heating Absorbed power [KW]	Pump Absorbed power [KW]	Heating type
QA 10 PNM - 1A	TI 10 max 3900	11	20	1,5	EP
QA 10 PNM - 1B	TI 10 max 3900	11	15	1,5	EV
QA 10 PNM - 2A	TI 10 max 4600	11	28	2,2	EP
QA 10 PNM - 2B	TI 10 max 5000	11	15	2,2	EV
QA 11 PNM - 1A	TI 11 max 5400	15	28	2,2	EP
QA 11 PNM - 1B	TI 11 max 5400	15	15	2,2	EV
QA 11 PNM - 2A	TI 11 max 6200	15	40	2,2	EP
QA 11 PNM - 2B	TI 11 max 6200	15	20	2,2	EV
QA 11 PNM - 3A	TI 11 max 7000	22	40	3	EP
QA 11 PNM - 3B	TI 11 max 7000	22	25	3	EV
QA 12 PNM - 1A	TI 12 max 7700	22	40	3	EP
QA 12 PNM - 1B	TI 12 max 7700	22	25	3	EV
QA 12 PNM - 2A	TI 12 max 8500	30	42	3	EP
QA 12 PNM -2B	TI 12 max 8500	30	30	3	EV
QA 13 PNM - 1A	TI 13 max 9300	30	42	3	EP
QA 13 PNM - 1B	TI 13 max 9300	30	30	3	EV
QA 13 PNM - 2A	TI 13 max 10800	37	60	5,5	EP
QA 13 PNM - 2B	TI 13 max 10800	37	40	5,5	EV
QA 14 PNM - 1A	TI 14 max 11600	55	60	5,5	EP
QA 14 PNM - 1B	TI 14 max 11600	55	40	5,5	EV
QA 14 PNM - 2A	TI 14 max 12400	55	80	7,5	EP
QA 14 PNM - 2B	TI 14 max 12400	55	50	7,5	EV

and natural gas) burners looking at the developed output column, in correspondence with the maximum value of 7,800 kW for a TI12 burner, we can read the initials of the electrical panel required QA12 NM and the related absorbed electrical output, corresponding to an electrical power supply with three-phase current.
This latter information must be provided by the design engineer of the heating plant electrical systems where the heavy oil generator in question will be installed.

MEASURING COMBUSTION EFFICIENCY

4.1 INSTRUMENTS

The following instruments are required to correctly measure combustion efficiency:

1. Carbon dioxide CO_2 analyser / or Oxygen O_2 analyser;
2. Carbon monoxide CO analyser (gas only);
3. Measuring instruments for the "Bacharach" smoke grade index (liquid fuels only);
4. Thermometer for measuring combustion supporter air temperature;
5. Thermometer for measuring the temperature of combustion products;
6. Thermometer for measuring the temperature of the boiler fluid;
7. Chronometer.

The instruments listed in points 1, 2, 3, 4 and 5 can be replaced by a single multi-function device similar to that illustrated in diagram 87;

4.2 PRELIMINARY OPERATIONS

Before proceeding with calculating combustion efficiency, the effective capacity at the furnace where the measurement will be taken must be gauged; this can be determined by measuring the fuel delivery and multiplying it by the related inferior calorific value.

Diagram 100 *Example of analyzer for measuring combustion efficiency*

Since it is not possible to determine the fuel delivery effectively burnt using the following methods; we will take the value declared by the manufacturer as the reference thermal output.

The reference capacity at the furnace must be equal to or lower than the maximum output at the furnace.

The measurement methods for both liquid and gaseous fuels, of the delivery of fuel burnt are illustrated as follows.

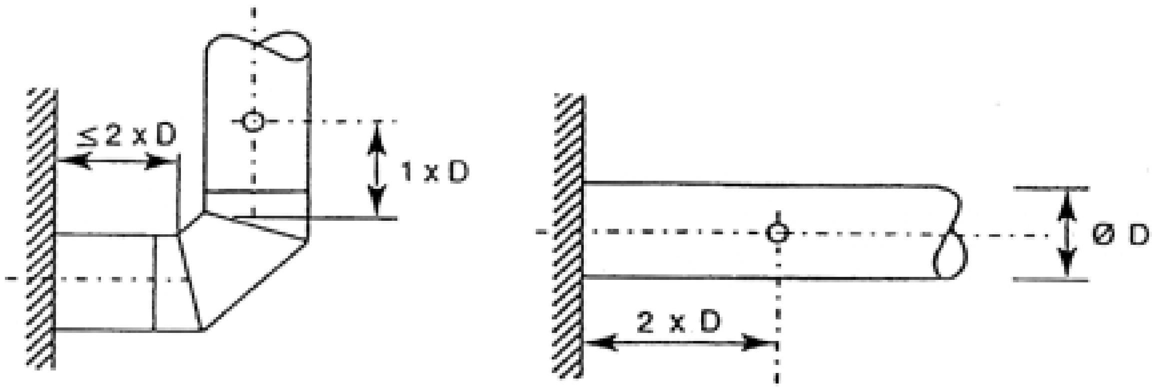
4.2.1 Systems fired by liquid fuel

We proceed with the weighing method, with a tank filled with a known volume of fuel which is sucked in by the burner for a determinate period. The volume of fuel consumed divided by the test time provides the fuel delivery value.
A simplified method, with an error margin up to 10%, involves verifying the size of the nozzle(s), and taking the atomisation pressure of the nozzle; referring to the tables of the nozzles mounted on the burner we can obtain the fuel delivery value (usually expressed in kg/h). This data should be multiplied by the corresponding inferior calorific value, thus obtaining the capacity effectively burnt.
Ready-to-use tables exist, which in relation to the nozzle delivery and the pump pressure provide the delivery of the liquid fuel.

4.2.2 Systems fired by gaseous fuel

In systems powered by mains gas, fuel delivery is taken by reading the meter; to calculate the output effectively burnt, the above methods are valid.
We recommend paying great attention when reading the meter in that, if it is placed on a high pressure gas feed line, account must be taken of the gas compressibility; in fact by

Diagram 101 *Gas flow characteristics measuring points*



compressing a gas, its is reduced volume but the number of molecules remains constant, i.e. density increases following the subsequent law. In this case, the reading, which is volumetric, will be lower than the effective mass-related delivery,

$$P_1 = P_2 \cdot \frac{\delta_1}{\delta_2}$$

Where:
P_1= gas pressure at a density of δ_1;
P_2= gas pressure at a density of δ_2;

A simplified formula (valid only for meter pressure greater than 40 mbar) for correcting the delivery values read in relation to the pressure, is illustrated as follows:

$$V_{vc} = V_{vi} \frac{1013 + P}{1013}$$

Where
V_{VC} = correct delivery of gas [Nm^3/h]
V_{Vi}= measured delivery in terms of volume [Nm^3/h]
P = gas pressure at the meter [mbar]

Another simple method for calculating the effective gas delivery is represented by using the correction factors in the table, in relation to the pressure and the temperature read off the meter. Several of these tables are illustrated in section 5 of this manual.

In systems without meters, a calibrated diaphragm must be fitted to the feed pipeline, or alternatively, the combustion head pressure can be used as an indication.

4.3 MEASUREMENT CONDITIONS AND OPERATING METHODS

The measurements must be carried out when the heat generator is in a steady running state (for example: at around 70 ° C for hot water generators) and at the maximum output at the furnace for such measurements.
To correctly take these measurements, the following must be performed:

1. Make a hole with a sufficient diameter for inserting the probes used for the measurements (approximately 10 mm.), in the flue gas connector, boiler/flue, two diameters in distance from the generator outlet, if available, use the specific hole provided by the heat generator manufacturer;
2. Ensure that there is no seepage of air prior to the hole for drawing off the combustion products (seal any holes, slits, etc…), because secondary air would alter the measured values, thereby discrediting the test;
3. Bring the heat generator to steady running state (for example: around 70° C for hot water heat generators);
4. For each single parameter take at least three measurements, at equal intervals during the test period deemed necessary by the operator, and each time at least 120 seconds after beginning the sample;
5. Seal the hole made for the measurements;
6. Transcribe the measured data, where the value measured of each individual parameter is obtained from the arithmetic mean of the first three significant measurements (any anomalous measurements must not be taken into account).

4.4 CALCULATING THE COMBUSTION EFFICIENCY

The fuel efficiency _ of a generator can be calculated by using the following formula, with the drop at the generator shell considered as nil.

$$\eta = 100 - P_s \quad \pm 2\%$$

Where:
η heat generator efficiency;
P_S is the thermal output lost via the flue;
and ±2% is the tolerance linked to uncertainties relating to the measuring instruments and the reading of the parameters measured.

As has already been seen in paragraph 1.5.1, the conventional formulas used for determining losses via the flue are:

$$P_s = \left(\frac{A_1}{21 - O_2} + B \right) \cdot (T_f - T_a)$$

if the concentration of oxygen free in the combustion flue gases is known, or:

$$P_s = \left(\frac{A_2}{CO_2} + B \right) \cdot (T_f - T_a)$$

if the concentration of carbon dioxide in the combustion flue gases is known.

where:
P_S = thermal output lost via the flue [%];
T_f = temperature of the flue gases (°C);
T_a = temperature of the combustion supporter air (°C);
O_2 = concentration of oxygen in the dry flue gases [%];
CO_2 = concentration of carbon dioxide in the dry flue gases [%];

A1, A2 and B are some empirical factors whose values are shown in the table below.

Fuel	A_1	A_2	B
METHANE	0,66	0,38	0,010
L.P.G.	0,63	0,42	0,008
LIGHT OIL	0,68	0,50	0,007
HEAVY OIL	0,68	0,52	0,007

Table 37 *Coefficients for calculation of combustion efficiency*

Leaving aside the measured value of fuel efficiency, to consider combustion satisfactory the concentration of CO must be checked referred to the condition of dry combustion products and without air at lower than 0.1% (1000 ppm).
The concentration of CO dry flue gases without air is provided by the equation:

$$CO_{dry\ flue\ gases\ without\ air} = CO_m \times \frac{CO_{2\ theoretical}}{CO_{2\ measured}}$$

where:
CO_m is the amount of carbon monoxide measured
$CO_{2theoretical}$ is the theoretical CO_2
$CO_{2measured}$ is the measured CO_2
The values of CO_2 theoretical are illustrated in Table 5 of section 1 - Maximum and recommended CO_2 levels for various fuels.

The same can be said, for heat generators powered by liquid fuel, if the smoke grade index referred to the Bacharach (8) scale, is greater than 2 for diesel oil and greater than 6 for fuel oil.

4.1.1 Example for calculating combustion efficiency

Let us examine the following measured values:
Fuel: natural gas
Measurement of CO_2: 9.6%
Temperature of flue gases T_f: 170 ° C
Temperature of combustion supporter air T_a: 30°C
Measurement of CO: 80 ppm
Theoretical CO_2: 11,7%

Since we know the value of CO_2 present in the flue gases, we can obtain the following thermal output value lost at the flue:

$$P_s = \left(\frac{0,38}{9,6} + 0,010 \right) \cdot (170 - 30) = 6,94$$

The fuel efficiency of the generator referred to the thermal output of the furnace for which the measurement was carried out, is given by:

$$\eta = 100 - 6,94 = 993,06 \quad \pm 2\%$$

To conclude, the concentration of CO must be checked referred to the condition of dry combustion products without air:

$$CO_{dry\ flue\ gases\ without\ air} = 88 \times \frac{11,7}{9,6} = 107,25\ ppm$$

equal to 0.0107 % < 0.1 %

(8) The Bacharach measurement method has already been described in section 1.

READY-TO-USE TABLES AND DIAGRAMS

5.1 MEASURING UNITS AND CONVERSION FACTORS
1.1 Units of International system SI and main conversion factors

UNITA' DEL SISTEMA INTERNAZIONALE SI E PRINCIPALI FATTORI DI CONVERSIONE
Units of International system SI and main conversion factors

GRANDEZZA *Physical quantity*	UNITA' SI *SI unit*	Unità di altri sistemi - *Units of other systems* (5)					
		ST (TECNICO) *Metric*	Fattori - *Factors*		I - P *Inch - Pound*	Fattori - *Factors*	
			K	1/K		K	1/K
LUNGHEZZA *Length*	m (metro) *(metre)*	m	1	1	in (inch)	39,37	0,0254
					ft (foot)	3,281	0,3048
AREA *Area*	m^2 (metro quadro) *(square metre)*	m^2	1	1	in^2 (square inch)	1550	0,000645
					ft^2 (square foot)	10,764	0,0929
VOLUME *Volume*	m^3 (metro cubo) *(cubic metre)*	m^3	1	1	ft^3 (cubic foot)	35,315	0,02832
TEMPO *Time*	s (secondo) *(second)*	s *h (ora - hour)*	1 *0,0002778*	1 *3600*	sec (second) *hr (hour)*	1 *0,0002778*	1 *3600*
VELOCITA' DI ROTAZIONE *Rotational speed*	giro/s *rev/s*	giro/min *rev/min*	60	0,01667	rpm (rev/min)	60	0,01667
VELOCITA' *Velocity*	m/s	m/s	1	1	fpm (foot/min)	196,85	0,00508
FREQUENZA *Frequency*	Hz (hertz)	Hz (periodi/s)	1	1	Hz (cycle/sec)	1	1
MASSA *Mass*	kg (kilogrammo) *(kilogramme)*	—	—	—	lb(pound)	2,2046	0,4536
	g (grammo) *(gramme)*	—	—	—	gr (grain)	15,4324	0,0648
MASSA VOLUMICA *Mass per unit volume*	kg/m^3	(2)	—	—	lb/ft^3	0,06243	16,0167
PORTATA IN MASSA *Mass flow rate*	kg/s	(2)	—	—	—	—	—
FORZA, PESO (1) *Force, weight*	N (newton)	kgf (kg forza) *(kg force)*	0,102	9,807	lbf (pound force)	0,2248	4,4482
PESO SPECIFICO *Specific gravity*	(2)	kgf/m^3	—	—	lbf/ft^3	–	–
PORTATA IN PESO *Flow rate in weight*	(2)	kgf/s	—	—	lbf/sec	—	—
PORTATA IN VOLUME *Flow rate in volume*	m^3/s *L/h*	m^3/h *L/h*	3600 *1*	0,000278 *1*	cfm (cu • ft/min) *gpm (gal/min)*	2118,88 *0,0044*	0,000472 *227,12*
MOMENTO DI UNA FORZA *Moment of a force (1)*	N · m	kgf · m	0,102	9,807	lbf · ft	0,7375	1,356
MOMENTO D'INERZIA *Moment of inertia (1)*	kg · m^2	kgf · s^2 · m (3)	0,102	9,807	lb · ft^2 (3)	23,73	0,0421

1.2 Units used for heat transfer calculations

GRANDEZZA	SISTEMA SI *SI system*		SISTEMA ST *ST system (metric)*				SISTEMA I-P *I-P system*			
	simb. *symb.*	Unità di misura *Units*	simb. *symb.*	Unità di misura *Units*	Fattori di conversione *Conversion factors*		simb. *symb.*	Unità di misura *Units*	Fattori di conversione *Conversion factors*	
					K	1/K			K	1/K
Quantità di calore *Quantity of heat*	Q	**joule (J)**	Q	kilocaloria (kcal) *kilocalorie*	$0{,}2388 \times 10^{-3}$	4186,8	Q	British thermal unit *BTU*	$0{,}9478 \times 10^{-3}$	1055,06
Spessore *Thickness*	s	**metro (m)** *metre*	s	metro (m) *metre*	1	1	s	pollice (in) *inch*	39,37	0,0254
Superficie *Surface*	S	**metro qd. (m^2)** *sq. metre*	S	metro qd. (m^2) *sq.metre*	1	1	A	piede qd (ft^2) *square foot*	10,764	0,0929
Differenza di temper. *Temp. difference*	Δt	**kelvin (K)**	Δt	gr. centigrado (°C) *deg.centigrade*	1	1	Δt	gr. Fahrenheit (°F) *deg. Fahrenheit*	9/5	5/9
Calore specifico *Specific heat*	c	**J/kg · K**	c	$kcal/kg_f \cdot °C$	$0{,}2388 \times 10^{-3}$	4186,8	c	$BTU/lb_f \cdot °F$	$0{,}2388 \times 10^{-3}$	4186,8
Conducibilità termica *Thermal conductivity*	L	**W/m · K**	L	kcal/m · h · °C	0,8605	1,1628	k	BTU/ft · hr · °F	0,578	1,730
Coeff. di trasmissione di una parete *Heat transfer coefficient of a wall*	K	**W/m^2 · K**	K	kcal/m^2 · h · °C	0,8605	1,1628	U	BTU/ft^2 · hr · °F	0,176	5,677
Coefficiente parziale di trasmissione *Partial heat transfer coefficient*	α	**W/m^2 · K**	α	kcal/m^2 · h · °C	0,8605	1,1628	h	BTU/ft^2 · hr · °F	0,176	5,677
interno - *internal*	α_i		α_i				h_i			
esterno - *external*	α_e		α_e				h_e			
Fattore di sporcamento *Fouling factor*	f	**m^2 · K/W**	f	m^2 · h · °C/kcal	1,1628	0,8605	r	ft^2 · hr · °F/BTU	5,677	0,176

Nota - Per passare dalle unità SI a quelle di altri sistemi, moltiplicare per K; inversamente moltiplicare per 1/K.
Note - For changing from SI units to those of other system, multiply by K; inversely multiply by 1/K.

1.3 Conversion factors among the units of measurment

1.3.1 Lenght

Unità base del sistema SI: metro (m)
Basic unit of SI system: metre (m)

Unità di misura *Measuring unit*	Simbolo *Symbol*	m	cm	mm	in	hd	ft	yd	fm	rod	link
metro *metre*	**m**	1	10^2	10^3	39,3701	9,8425	3,2808	1,0936	0,5468	0,1988	4,9710
centimetro *centimetre*	**cm**	10^{-2}	1	10	0,3937	0,0984	0,0328	0,0109	0,0055	0,0020	$4{,}97 \times 10^{-2}$
millimetro *millimetre*	**mm**	10^{-3}	10^{-1}	1	0,0394	$9{,}84 \times 10^{-3}$	3.28×10^{-3}	$1{,}09 \times 10^{-3}$	$0{,}55 \times 10^{-3}$	$0{,}20 \times 10^{-3}$	$4{,}97 \times 10^{-3}$
pollice *inch*	**in**	$2{,}54 \times 10^{-2}$	2,54	25,4	1	0,25	0,0833	0,0278	0,0139	$0{,}51 \times 10^{-2}$	0,1263
mano *hand*	**hd**	0,1016	10,16	101,60	4	1	0,3333	0,1111	0,0556	$2{,}02 \times 10^{-2}$	0,5051
piede *foot*	**ft**	0,3048	30.48	304,80	12	3	1	0,3333	0,1667	0,0606	1,5152
iarda *yard*	**yd**	0,9144	91,44	914,40	36	9	3	1	0,5	0,1818	4,5455
braccio *fathom*	**fm**	1,8288	182,88	1828,80	72	18	6	2	1	0,3636	9,0909
pertica *rod*	**rod**	5,0292	502,92	5029,20	198	49,5	16,5	5,5	2,75	1	25
link	**link**	0,2012	20,12	201,168	7,9177	1,9800	0,6600	0,2200	0,1100	0,04	1

1.3.2 Area

Unità base del sistema SI: metro quadro (m^2)
Basic unit of SI system: square metre (m^2)

Unità di misura *Measuring unit*	Simbolo *Symbol*	m^2	cm^2	in^2	ft^2	yd^2	rd^2	rood	ac
metro quadro *square metre*	m^2	1	10^4	1550,0	10,7639	1,1960	0,0395	$0{,}988 \times 10^{-3}$	$0{,}247 \times 10^{-3}$
centimetro quadro *square centimetre*	cm^2	10^{-4}	1	0,1550	$10{,}764 \times 10^{-4}$	$1{,}196 \times 10^{-4}$	$3{,}954 \times 10^{-6}$	$98{,}846 \times 10^{-9}$	$24{,}710 \times 10^{-9}$
pollice quadro *square inch*	in^2	$6{,}452 \times 10^{-4}$	6,4516	1	$6{,}944 \times 10^{-3}$	$7{,}716 \times 10^{-4}$	$25{,}508 \times 10^{-6}$	$0{,}638 \times 10^{-6}$	$0{,}1594 \times 10^{-6}$
piede quadro *square foot*	ft^2	$9{,}290 \times 10^{-2}$	928,030	144	1	0,1111	$3{,}673 \times 10^{-3}$	$0{,}9183 \times 10^{-4}$	$2{,}2957 \times 10^{-5}$
iarda quadra *square yard*	yd^2	0,8361	8361,274	1296	9	1	0,0031	$0{,}8264 \times 10^{-3}$	$0{,}2066 \times 10^{-3}$
pertica *perch (square rod)*	rd^2	25,2929	$25{,}293 \times 10^4$	$39{,}204 \times 10^3$	272,2505	30,25	1	0,025	$0{,}625 \times 10^{-2}$
rood	rood	1011,714	$1011{,}71 \times 10^4$	$1{,}568 \times 10^6$	10890,00	1210,00	40	1	0,25
acro *acre*	ac	4046,856	$4046{,}86 \times 10^4$	$627{,}264 \times 10^4$	43560,0	4840,0	160	4	1

1.3.3 Volume

Unità base del sistema SI: metro cubo (m^3)
Basic unit of SI system: cubic metre (m^3)

Unità di misura *Measuring unit*	Simbol *Symbol*	m^3	L	in^3	ft^3	yd^3	gl(UK)	pn(UK)	qt(UK)	gal(UK)
metro cubo *cubic metre*	m^3	1	10^3	$61,024 \times 10^3$	35,3147	1,3080	7039,03	1759,63	879,88	219,969
dm cubo o litro *cubic dcm or liter*	dm^3=L	10^{-3}	1	61,0238	0,353	$1,308 \times 10^{-3}$	7,0390	1,7596	0,8799	0,2200
pollice cubo *cubic inch*	in^3	$0,0164 \times 10^{-3}$	0,01639	1	$5,787 \times 10^{-4}$	$2,143 \times 10^{-5}$	0,1153	0,0288	0,0144	$3,6045 \times 10^{-3}$
piede cubo *cubic foot*	ft^3	0,02832	28,317	1728	1	0,0370	199,323	49,831	24,915	6,2288
iarda cubica *cubic yard*	yd^3	0,7646	764,555	46656	27	1	5381,73	1345,43	672,716	168,179
gill (UK)	gl	$0,142 \times 10^{-3}$	0,1421	8,6693	$5,017 \times 10^{-3}$	$0,186 \times 10^{-3}$	1	0,25	0,125	0,03125
pinta *pint (UK)*	pn	$0,568 \times 10^{-3}$	0,5683	34,677	0,0201	$0,743 \times 10^{-3}$	4	1	0,5	0,125
quarto *quart (UK)*	qt	$1,136 \times 10^{-3}$	1,1365	69,355	0,0401	$1,486 \times 10^{-3}$	8	2	1	0,25
gallone *gallon (UK)*	gal	$4,546 \times 10^{-3}$	4,5461	277,419	0,1605	$5,946 \times 10^{-3}$	32	8	4	1

Unità di misura *Measuring unit*	Simbolo *Symbol*	m^3	L	brl (US)	brl (oil)	gl (US)	pn (US)	qt (US)	gal (US)
metro cubo *cubic metre*	m^3	1	10^3	8,3864	6,2898	8453,51	2113,38	1056,69	264,172
dm cubo o litro *cubic dm or litre*	L	10^{-3}	1	$8,386 \times 10^{-3}$	$6,290 \times 10^{-3}$	8,4535	2,1134	1,0567	0,2642
barile barrel *(US liquid)*	brl	0,1192	119,240	1	0,75	1008,00	252	126	31,5
barile *barrel (US oil)*	brl	0,1590	158,987	1,3333	1	1344	336	168	42
gill (US)	gl	$0,118 \times 10^{-3}$	0,1183	$0,992 \times 10^{-3}$	$0,774 \times 10^{-3}$	1	0,25	0,125	0,03125
pinta *pint (US)*	pn	$0,473 \times 10^{-3}$	0,4732	$3,968 \times 10^{-3}$	$2,976 \times 10^{-3}$	4	1	0,5	0,125
quarto *quart (US)*	qt	$0,946 \times 10^{-3}$	0,9463	$7,936 \times 10^{-3}$	$5,952 \times 10^{-3}$	8	2	1	0,25
gallone *gallon (US)*	gal	$3,785 \times 10^{-3}$	3,7854	0,0317	0,0238	32	8	4	1

1.3.4 Mass

Unità base del sistema SI: chilogrammo (kg)
Basic unit of SI system: kilogramme (kg)

Unità di misura *Measuring unit*	Simbolo *Symbol*	kg	lb	lb *(troy)*	st	hw *(UK)*	hw *(US)*	t	ton *(US)*	ton *(UK)*
chilogrammo *kilogramme*	kg	1	2,2046	2,6792	0,1575	0,0197	0,0220	10^{-3}	$1,1023 \times 10^{-3}$	$0,9842 \times 10^{-3}$
libbra *pound*	lb	0,4536	1	1,2153	0,0714	$0,893 \times 10^{-2}$	10^{-2}	$0,454 \times 10^{-3}$	$0,500 \times 10^{-3}$	$0,446 \times 10^{-3}$
libbra *pound (troy)*	lb	0,3732	0,8229	1	0,0588	$0,735 \times 10^{-2}$	$0,823 \times 10^{-2}$	$0,373 \times 10^{-3}$	$0,411 \times 10^{-3}$	$0,367 \times 10^{-3}$
stone (UK)	st	6,3503	14	17,014	1	0,1250	0,1400	$6,350 \times 10^{-3}$	7×10^{-3}	$6,247 \times 10^{-3}$
hundredweight (UK)	hw	50,8024	112	136,11	8	1	1,1200	$50,80 \times 10^{-3}$	56×10^{-3}	$44,64 \times 10^{-3}$
hundred weight (US)	hw	45,3592	100	121,53	7,1429	0,8929	1	$45,36 \times 10^{-3}$	50×10^{-3}	$44,64 \times 10^{-3}$
tonnellata *ton (metric)*	t	10^3	2204,62	2679,23	157,47	19,684	22,046	1	1,1023	0,9842
tonnellata *ton short (US)*	ton	907,1847	2000	2430,56	142,86	17,857	20	0,9072	1	0,8929
tonnellata *ton long (UK)*	ton	1016,047	2240	2722,22	160	20	22,400	1,0160	1,1200	1

1.3.5 Pressure

Unità base del sistema SI: pascal (Pa) = N/m²
Basic unit of SI system: pascal (Pa) = N/m²

Unita di misura *Measurig unit*	Simbolo *Symbol*	Pa	bar	at	mm Hg	kg_f/m^2	psi	lb_f/ft^2	in w.	in Hg	ft w.
pascal	Pa	1	10^{-5}	$1,0197 \times 10^{-5}$	0,0075	0,10197	$0,145 \times 10^{-3}$	0,02088	0,00401	$0,295 \times 10^{-3}$	$0,335 \times 10^{-3}$
bar	bar	10^5	1	1,0197	750,07	10197	14,505	2088	401,46	29,530	33,456
atmosfera=kg_f/cm^2 *atmosphere*	at	98070	0,9807	1	735,56	10000	14,223	2048,16	393,71	28,960	32,808
millimetri di Hg *millimetre of mercury*	mm Hg	133,32	$1,3332 \times 10^{-3}$	$1,3595 \times 10^{-3}$	1	13,595	0,0193	1,392	0,5353	0,0394	0,0446
chilogrammi per m² *kilogramme per sq. m*	kg_f/m^2	9,807	$9,807 \times 10^{-5}$	10^{-4}	0,0735	1	0,00142	0,205	0,0394	0,0029	0,0033
libbre per pollice quadro *pounds per sq. inch*	psi	6894,14	0,06894	0,0703	51,719	703,07	1	144	27,683	2,0362	2,3069
libbre per piede quadro *pounds per sqare foot*	lb_f/ft^2	47,876	$4,7876 \times 10^{-4}$	$4,8824 \times 10^{-4}$	0,7183	4,8824	0,00694	1	0,1922	0,01414	0,01602
pollici di c.a *inches of water*	in w.	249,09	0,00249	0,00254	1,868	25,4	0,03614	5,203	1	0,07355	0,0833
pollici di mercurio *inches of mercury*	in Hg	3386,36	0,03386	0,03453	25,4	345,34	0,4912	70,731	13,595	1	1,1329
piedi di c.a *feet of water*	ft w.	2989	0,02989	0,03048	22,42	304,8	0,4334	62,43	12	0,8827	1

1.3.6 Work, energy, heat, enthalpy

Unità base del sistema SI: joule (J=Nm)
Basic unit of SI system: joule (J=Nm)

Unità di misura *Measuring unit*	Simbolo *Symbol*	J	kg_f m	Cal *(kcal)*	Wh	CVh	ft.lb_f	Btu	CHU
joule	J	1	0,10197	$0,2388 \times 10^{-3}$	$0,2778 \times 10^{-3}$	$0,378 \times 10^{-6}$	0,7375	$0,9478 \times 10^{-3}$	$0,5266 \times 10^{-3}$
chilogrammetro *kilogramme metre*	kg_fm	9,807	1	$2,342 \times 10^{-3}$	$2,724 \times 10^{-3}$	$0,370 \times 10^{-5}$	7,233	$9,295 \times 10^{-3}$	$5,164 \times 10^{-3}$
chilocaloria *kilocalorie*	Cal *(kcal)*	4186,80	426,92	1	1,163	$1,581 \times 10^{-3}$	3087,6	3,9683	2,2046
wattora *watt hour*	Wh	3600	367,08	0,8605	1	$1,360 \times 10^{-3}$	2654,87	3,413	1,8956
cavallo vapore ora *horsepower hour (metric)*	CVh	$2647,8 \times 10^{3}$	$269,91 \times 10^{3}$	632,53	735,5	1	$1952,92 \times 10^{3}$	2512,2	1394,23
libbra piede *foot pound*	ft. lb_f	1,356	0,1383	$0,3238 \times 10^{-3}$	$0,3767 \times 10^{-3}$	$0,512 \times 10^{-6}$	1	$1,2853 \times 10^{-3}$	$5,2656 \times 10^{-3}$
BTU (IST) *British thermal unit*	Btu	1055,06	107,58	0,2520	0,2930	$0,398 \times 10^{-3}$	778,03	1	0,5556
CHU	CHU	1899,11	193,65	0,4536	0,5275	$0,717 \times 10^{-3}$	1400,52	1,8	1

1.3.7 Power (mechanical, electric and thermal)

Unità base del sistema SI : watt (W)
Basic unit of SI system : watt (W)

Unita di misura *Measuring unit*	Simbolo *Symbol*	W	kcal/h	kgm/s	Btu/h	ft lb/s	BHP	CV	ton (UK)	ton (US)
watt	W	1	0.8605	0,102	3,413	0,7375	$1,341 \times 10^{-3}$	$1,360 \times 10^{-3}$	$0,284 \times 10^{-3}$	$0,318 \times 10^{-3}$
chilocaloria/ora *kilocalorie/hour*	kcal/h	1,1628	1	0,1186	3,9683	0,8576	$1,559 \times 10^{-3}$	$1,581 \times 10^{-3}$	$0,331 \times 10^{-3}$	$0,370 \times 10^{-3}$
chilogrammetro/secondo *kilogramme metre/second*	kgm/s	9,807	8,434	1	33,47	7,233	$1,315 \times 10^{-2}$	$1,333 \times 10^{-2}$	$2,788 \times 10^{-3}$	$3,123 \times 10^{-3}$
British thermal unit/hour	BTU/h	0,2930	0,2520	0,02988	1	0,2161	$0,393 \times 10^{-3}$	$0,398 \times 10^{-3}$	$0,833 \times 10^{-4}$	$0,933 \times 10^{-4}$
libbra piede/secondo *foot pound/second*	ft lb/s	1,356	1,166	0,1383	4,627	1	$1,818 \times 10^{-3}$	$1,844 \times 10^{-3}$	$0,386 \times 10^{-3}$	$0,432 \times 10^{-3}$
cavallo vapore *brake horsepower*	BHP (UK)	745,7	641,3	76,04	2547,0	550	1	1,0139	0,2120	0,2375
cavallo vapore *horsepower (metric)*	CV	735,5	632,53	75,0	2512,2	542,4	0,986	1	0,2091	0,2342
ton (raffreddamento UK) *ton (refrigeration UK)*	ton (UK)	3516,85	3024,5	358,6	12000	2593,7	4,716	4,782	1	1,120
ton (raffreddamento US) *ton (refrigeration US)*	ton (US)	3140,05	2700,44	320,18	10717	2315,8	4,211	4,269	0,893	1

1.3.8 Velocity

Unità base del sistema SI: metro al secondo (m/s)
Basic unit of SI system: metre per second

Unita di misura *Measuring unit*	Simbolo *Symbol*	m/s	m/min	cm/s	ft/s	ft/min	km/h	Mi/h *(statute)*	Mi/h *(naut.UK)*	knt
metro al secondo *metre per second*	m/s	1	60	10^2	3,2808	196,85	3,60	2,237	1,943	1,944
metro al minuto *metre per minute*	m/min	0,01667	1	1,667	0,05468	3,2808	0,06	$3,728 \times 10^{-2}$	$3,238 \times 10^{-2}$	$3,240 \times 10^{-2}$
centimetro al secondo *centimetre per second*	cm/s	10^{-2}	0,6	1	0,03281	1,9685	0,036	0,0224	0,0194	0,0194
piede al secondo *foot per second*	ft/s	0,3048	18,288	30,48	1	60	1,0973	0,6818	0,5921	0,5925
piede al minuto *foot per minute*	ft/min	$0,508 \times 10^{-2}$	0,3048	0,508	0,01667	1	$1,829 \times 10^{-2}$	$1,136 \times 10^{-2}$	$0,987 \times 10^{-2}$	$0,987 \times 10^{-2}$
chilometro all'ora *kilometre per hour*	km/h	0,2778	16,667	27,78	0,9113	54,678	1	0,6214	0,5396	0,5400
miglio all'ora *mile per hour (statute)*	Mi/h	0,4470	26,822	44,70	1,467	88,028	1,609	1	0,8684	0,8690
miglio all'ora *mile per hour (naut.UK)*	Mi/h	0,5148	30,886	51,48	1,689	101,333	1,853	1,1515	1	1,00064
nodo *knot*	knt	0,5144	30,867	51,44	1,688	101,268	1,852	1,1508	0,9994	1

1.3.9 Flow rate in volume

Unità base del sistema SI: metro cubo al secondo (m^3/s)
Basic unit of SI system: cubic metre per second

Unità di misura *Measurig unit*	Simbolo *Symbol*	m^3/s	m^3/h	L/s	cm^3/s	cfm	cfh	gpm	gph	y^3/min
metro cubo al secondo *cubic metre per second*	m^3/s	1	3600	10^3	10^6	2118,88	127133	15850	$951,02 \times 10^3$	78,477
metro cubo all'ora *cubic metre per hour*	m^3/h	$0,2778 \times 10^{-3}$	1	0,2778	277,778	0,5886	35,315	4,4029	264,17	0.0218
litro al secondo *litre per second*	L/s	10^{-3}	3,6	1	10^3	2,1189	127,134	15,850	951,02	0,0785
centimetro cubo al sec. *cubic centimetre per second*	cm^3/s	10^{-6}	0,0036	10^{-3}	1	0,0212	0,1271	0,0158	0,951	$0,785 \times 10^{-4}$
piede cubo al minuto *cubic foot per minute*	cfm	$0,4719 \times 10^{-3}$	1,6990	0,4719	471,95	1	60	7,480	448,83	0,0370
piede cubo all'ora *cubic foot per hour*	cfh	$0,7866 \times 10^{-5}$	0,02832	$0,7866 \times 10^{-2}$	7,866	0,01667	1	0,1247	7,480	$0,6173 \times 10^{-3}$
gallone al minuto *gallon per minute (US)*	gpm	$0,6309 \times 10^{-4}$	0,2271	0,06309	63,090	0,1337	8,0208	1	60	$4,951 \times 10^{-3}$
gallone all'ora *gallon per hour*	gph	$0,1052 \times 10^{-5}$	$3,785 \times 10^{-3}$	$0,1052 \times 10^{-2}$	1,0515	$2,228 \times 10^{-3}$	0,1337	0,01667	1	$8,252 \times 10^{-4}$
iarda cubica al minuto *cubic yard per minute*	y^3/min	0,01274	45,873	12,743	12742,6	27	1620	201,97	12118,44	1

1.3.10 Other conversion factors for non SI units

MASSA VOLUMICA E SOLUZIONI LIQUIDE
MASS PER UNIT VOLUME AND LIQUID SOLUTIONS

grain/gallone (gr/gal) - *grain/gallon (UK)*	**parti per milione (p.p.m.)** - *parts per million*	**14,254**	7,016 × 10^{-2}
grain/gallone (gr/gal) - *grain/gallon (US)*	**grammi/litro (g/L = g/dm^3)** - *grammes/litre*	**1,7118 × 10^{-2}**	58,417
grain/gallone (gr/gal) - *grain/gallon (US)*	**parti per milione (p.p.m.)** - *parts per million*	**17,118**	5,842 × 10^{-2}
grain/libbra (gr/lb) - *grain/pound*	**grammo/chilogrammo (g/kg)** - *gramme/kilogramme*	**0,1428**	7,003
libbra/gallone (lb/gal) - *pound/gallon (UK)*	**chilogrammo/litro (kg/L)** - *kilogramme/litre*	**0,0998**	10,02
libbra/gallone (lb/gal) - *pound/gallon (US)*	**chilogrammo/litro (kg/L)** - *kilogramme/litre*	**0,11983**	8,345
libbra/piede cubo (lb/ft^3) - *pound/cubic foot*	**chilogrammo/metro cubo (kg/m^3)** - *kilogramme/cubic metre*	**16,018**	6,2428 × 10^{-2}
libbra/piede cubo (lb/ft^3) - *pound/cubic foot*	**grammo/litro (g/L)** - *gramme/litre*	**16,018**	6,2428 × 10^{-2}
libbra/piede cubo (lb/ft^3) - *pound/cubic foot*	**libbra/pollice cubo (lb/in^3)** - *pound/cubic inch*	**5,787 × 10^{-4}**	1728
libbra/pollice cubo (lb/in^3) - *pound/cubic inch*	**chilogrammo/metro cubo (kg/m^3)** - *kilogramme/cubic metre*	**27,68 × 10^{3}**	3,6127 × 10^{-5}
libbra/pollice cubo (lb/in^3) - *pound/cubic inch*	**grammo/centimetro cubo (g/cm^3)** - *gramme/cubic centimetre*	**27,678**	0,03613
oncia/gallone (oz/gal) - *ounce/gallon (UK)*	**grammo/litro (g/L)** - *gramme/litre*	**6,236**	0,1604
oncia/gallone (oz/gal) - *ounce/gallon (US)*	**grammo/litro (g/L)** - *gramme/litre*	**7,489**	0,1335
parti per milione (p.p.m) - *parts per million*	**grammo/litro (g/L)** - *gramme/litre*	**10^{-3}**	10^{3}
parti per milione (p.p.m) - *parts per million*	**milligrammo/litro (mg/L)** - *milligramme/litre*	**1**	1
tonnellata/iarda cubica (ton/yd^3) - *ton/cubic yard (UK)*	**chilogrammo/metro cubo (kg/m^3)** - *kilogramme/cubic metre*	**1328,94**	7,525 × 10^{-4}
tonnellata/iarda cubica (ton/yd^3) - *ton/cubic yard (US)*	**chilogrammo/metro cubo (kg/m^3)** - *kilogramme/cubic metre*	**1186,55**	8,428 × 10^{-4}

CALORE E TRASMISSIONE DEL CALORE
Heat and heat transfer

Btu / libbra (Btu/lb) - *Btu / pound*	**chilojoule / chilogrammo (kJ/kg)** - *kilojoule / kilogramme*	**2,326**
Btu / piede cubo (Btu/ft^3) - *Btu / cubic foot*	**chilojoule / metro cubo (kJ/m^3)** - *kilojoule / cubic metre*	**37,259**
Btu / piede cubo · grado F (Btu/ft^3 · F) *Btu / cubic foot · degree F*	**chilojoule / metro cubo · grado C (kJ/m^3 · C)** *kilojoule/ cubic metre · degree C*	**67,066**
Btu / piede quadro · minnuto (Btu/ft^2 · min) *Btu / square foot -minute*	**watt / centimetro quadro (W/cm^2)** *watt / square centimetre*	**0,0189**
Btu / piede quadro · ora (Btu/ft^2 · h) *Btu / square foot · hour*	**watt / metro quadro (W/m^2)** *watt / square metre*	**3,155**
Btu · pollice/piede quadro · ora · F (Btu · in/ft^2 · h · F) *Btu · inch / square foot · hour · F*	**watt / metro · grado C (W/m · C)** *watt / metre·degree C*	**0,1442**
Btu · pollice/piede quadro · sec · F (Btu · in/ft^2· s · F) *Btu · nch/square foot · sec · F*	**watt / metro · grado C (W/m · C)** *watt / metre · degree C*	**519,22**
caloria/centimetro · sec · grado C (cal/cm · s · C) *calorie/centimetre · sec · degree C*	**watt / metro · grado C (W/m · C)** *watt / metre · degree C*	**418,68**
therm / gallone UK (therm/gal) - *therm / UK gallon*	**gigajoule / metro cubo (GJ/m^3)** - *gigajoule / cubic metre*	**23,208**
therm / gallone US (therm/gal) - *therm / US gallon*	**gigajoule / metro cubo (GJ/m^3)** - *gigajoule / cubic metre*	**27,872**

PORTATA IN MASSA
FLOWRATE IN MASS

libbra/minuto (lb/min) - *pound/minute*	**chilogrammo/secondo (kg/s)** - *kilogramme/second*
libbra/ora (lb/hr) - *pound/hour*	**chilogrammo/ora (kg/h)** - *kilogramme/hour*
libbra/ora (lb/hr) - *pound/hour*	**chilogrammo/secondo (kg/s)** - *kilogramme/second*
libbra/secondo (lb/sec) - *pound/second*	**chilogrammo/ora (kg/h)** - *kilogramme/hour*
libbra/secondo (lb/sec) - *pound/second*	**chilogrammo/secondo (kg/s)** - *kilogramme/second*
oncia/minuto (oz/min) - *ounce(avdp)/minute*	**chilogrammo/ora (kg/h)** - *kilogramme/hour*
oncia/minuto (oz/min) - *ounce(avdp)/minute*	**chilogrammo/secondo (kg/s)** - *kilogramme/second*
oncia/secondo (oz/sec) - *ounce(avdp)/second*	**chilogrammo/ora (kg/h)** - *kilogramme/hour*
oncia/secondo (oz/sec) - *ounce(avdp)/second*	**chilogrammo/secondo (kg/s)** - *kilogramme/second*
tonnellata UK/ora (ton/hr) - *UK ton/hour*	**chilogrammo/secondo (kg/s)** - *kilogramme/second*
tonnellata US/ora (ton/hr) - *US ton/hour*	**chilogrammo/secondo (kg/s)** - *kilogramme/second*

1.4 Conversion of inches and fractions of inch in millimetres

	0"	1"	2"	3"	4"	5"	6"	7"	8"	9"	10"
0"	0,000	25,400	50,800	76,200	101,600	127,000	152,400	177,800	203,200	228,600	254,000
1/64"	0,397	25,797	51,197	76,597	101,997	127,397	152,797	178,197	203,597	228,997	254,397
1/32"	0,794	26,194	51,594	76,994	102,394	127,794	153,194	178,594	203,994	229,394	254,794
3/64"	1,191	26,591	51,991	77,391	102,791	128,191	153,591	178,991	204,391	229,791	255,191
1/16"	1,588	26,988	52,388	77,788	103,188	128,588	153,988	179,388	204,788	230,188	255,588
5/64"	1,984	27,384	52,784	78,184	103,584	128,984	154,384	179,784	205,184	230,584	255,984
3/32"	2,381	27,781	53,181	78,581	103,981	129,381	154,781	180,181	205,581	230,981	256,381
7/64"	2,778	28,178	53,578	78,978	104,378	129,778	155,178	180,578	205,978	231,378	256,778
1/8"	3,175	28,575	58,975	79,375	104,775	130,175	155,575	180,975	206,375	231,775	257,175
9/64"	3,572	28,972	54,372	79,772	105,172	130,572	155,972	181,372	206,772	232,172	257,572
5/32"	3,969	29,369	54,769	80,169	105,569	130,969	156,369	181,769	207,169	232,569	257,969
11/64"	4,366	29,766	55,166	80,566	105,966	131,366	156,766	182,166	207,566	232,966	258,366
3/16"	4,763	30,163	55,563	80,963	106,363	131,763	157,163	182,563	207,963	233,363	258,763
13/64"	5,159	30,559	55,959	81,359	106,759	132,159	157,559	182,959	208,359	233,759	259,159
7/32"	5,556	30,956	56,356	81,756	107,156	132,556	157,956	183,356	208,756	234,156	259,556
15/64"	5,953	31,353	56,753	82,153	107,553	132,953	158,353	183,753	209,153	234,553	259,953
1/4"	6,350	31,750	57,150	82,550	107,950	133,350	158,750	184,150	209,550	234,950	260,350
17/64"	6,747	32,147	57,547	82,947	108,347	133,747	159,147	184,547	209,947	235,347	260,747
9/32"	7,144	32,544	57,944	83,344	108,744	134,144	159,544	184,944	210,344	235,744	261,144
19/64"	7,541	32,941	58,341	83,741	109,141	134,541	159,941	185,341	210,741	236,141	261,541
5/16"	7,938	33,338	58,738	84,138	109,538	134,938	160,338	185,738	211,138	236,538	261,938
21/64"	8,334	33,734	59,134	84,534	109,934	135,334	160,734	186,134	211,534	236,934	262,334
11/32"	8,731	34,131	59,531	84,931	110,331	135,731	161,131	186,531	211,931	237,331	262,731
23/64"	9,128	34,528	59,928	85,328	110,728	136,128	161,528	186,928	212,328	237,728	263,128
3/8"	9,525	34,925	60,325	85,725	111,125	136,525	161,925	187,325	212,725	238,125	263,525
25/64"	9,922	35,322	60,722	86,122	111,522	136,922	162,322	187,722	213,122	238,522	263,922
13/32"	10,319	35,719	61,119	86,519	111,919	137,319	162,719	188,119	213,519	238,919	264,319
27/64"	10,716	36,116	61,516	86,916	112,316	137,716	163,116	188,516	213,916	239,316	264,716
7/16"	11,113	36,513	61,913	87,313	112,713	138,113	163,513	188,913	214,313	239,713	265,113
29/64"	11,509	36,909	62,309	87,709	113,109	138,509	163,909	189,309	214,709	240,109	265,509
15/32"	11,906	37,306	62,706	88,106	113,506	138,906	164,306	189,706	215,106	240,506	265,906
31/64"	12,303	37,703	63,103	88,503	113,903	139,303	164,703	190,103	215,503	240,903	266,303
1/2"	12,700	38,100	63,500	88,900	114,300	139,700	165,100	190,500	215,900	241,300	266,700
33/64"	13,097	38,497	63,897	89,297	114,697	140,097	165,497	190,897	216,297	241,697	267,097
17/32"	13,494	38,894	64,294	89,694	115,094	140,494	165,894	191,294	216,694	242,094	267,494
35/64"	13,891	39,291	64,691	90,091	115,491	140,891	166,291	191,691	217,091	242,491	267,891
9/16"	14,288	39,688	65,088	90,488	115,888	141,288	166,688	192,088	217,488	242,888	268,288
37/64"	14,684	40,084	65,484	90,884	116,284	141,684	167,084	192,484	217,884	243,284	268,684
19/32"	15,081	40,481	65,881	91,281	116,681	142,081	167,481	192,881	218,281	243,681	269,081
39/64"	15,478	40,878	66,278	91,678	117,078	142,478	167,878	193,278	218,678	244,078	269,478
5/8"	15,875	41,275	66,675	92,075	117,475	142,875	168,275	193,675	219,075	244,475	269,875
41/64"	16,272	41,672	67,072	92,472	117,872	143,272	168,672	194,072	219,472	244,872	270,272
21/32"	16,669	42,069	67,469	92,869	118,269	143,669	169,069	194,469	219,869	245,269	270,669
43/64"	17,066	42,466	67,866	93,266	118,666	144,066	169,466	194,866	220,266	245,666	271,066
11/16"	17,463	42,863	68,263	93,663	119,063	144,463	169,863	195,263	220,663	246,063	271,463
45/64"	17,859	43,259	68,659	94,059	119,459	144,859	170,259	195,659	221,059	246,459	271,859
23/32"	18,256	43,656	69,056	94,456	119,856	145,256	170,656	196,056	221,456	246,856	272,256
47/64"	18,653	44,053	69,453	94,853	120,253	145,653	171,053	196,453	221,853	247,253	272,653
3/4"	19,050	44,450	69,850	95,250	120,650	146,050	171,450	196,850	222,250	247,650	273,050
49/64"	19,447	44,847	70,247	95,647	121,047	146,447	171,847	197,247	222,647	248,047	273,447
25/32"	19,844	45,244	70,644	96,044	121,444	146,844	172,244	197,644	223,044	248,444	273,844
51/64"	20,241	45,641	71,041	96,441	121,841	147,241	172,641	198,041	223,441	248,841	274,241
13/16"	20,638	46,038	71,438	96,838	122,238	147,638	173,038	198,438	223,838	249,238	274,638
53/64"	21,034	46,434	71,834	97,234	122,634	148,034	173,434	198,834	224,234	249,634	275,034
27/32"	21,431	46,831	72,231	97,631	123,031	148,431	173,831	199,231	224,631	250,031	275,431
55/64"	21,828	47,228	72,628	98,028	123,428	148,828	174,228	199,628	225,028	250,428	275,828
7/8"	22,225	47,625	73,025	98,425	123,825	149,225	174,625	200,025	225,425	250,825	276,225
57/64"	22,622	48,022	73,422	98,822	124,222	149,622	175,022	200,422	225,822	251,222	276,622
29/32"	23,019	48,419	73,819	99,219	124,619	150,019	175,419	200,819	226,219	251,619	277,019
59/64"	23,416	48,816	74,216	99,616	125,016	150,416	175,816	201,216	226,616	252,016	277,416
15/16"	23,813	49,213	74,613	100,013	125,413	150,813	176,213	201,613	227,013	252,413	277,813
61/64"	24,209	49,609	75,009	100,409	125,809	151,209	176,609	202,009	227,409	252,809	278,209
31/32"	24,606	50,006	75,406	100,806	126,206	151,606	177,006	202,406	227,806	253,206	278,606
63/64"	25,003	50,403	75,803	101,203	126,603	152,003	177,403	202,803	228,203	253,603	279,003

1.5 Temperature conversion tables

Tabella di conversione della temperatura
Temperature conversion table

Nota - Trovare la temperatura nota da convertire nella colonna centrale - Quindi leggere la conversione in °C a sinistra e quella in °F a destra.
Note - Find the known temperature to be converted in the centre column. Then read the centigrade conversion to left and Fahrenheit to right.

Es. / *e.g.* 21,1 **70** *158,0* — quindi 70°F = 21,1°C / *thus 70°C = 158,0°F*

°C		°F
-272,8	**-459**	
-267,8	**-450**	
-262,2	**-440**	
-256,7	**-430**	
-251,1	**-420**	
-245,6	**-410**	
-240,0	**-400**	
-234,4	**-390**	
-228,9	**-380**	
-223,3	**-370**	
-217,8	**-360**	
-212,2	**-350**	
-206,7	**-340**	
-201,1	**-330**	
-195,6	**-320**	
-190,0	**-310**	
-184,4	**-300**	
-178,9	**-290**	
-173,3	**-280**	
-169,4	**-273**	*-459,4*
-167,8	**-270**	*-454,0*
-162,2	**-260**	*-436,0*
-156,7	**-250**	*-418,0*
-151,1	**-240**	*-400,0*
-145,6	**-230**	*-382,0*
-140,0	**-220**	*-364,0*
-134,4	**-210**	*-346,0*
-128,9	**-200**	*-328,0*
-123,3	**-190**	*-310,0*
-117,8	**-180**	*-292,0*
-112,2	**-170**	*-274,0*
-106,7	**-160**	*-256,0*
-101,1	**-150**	*-238,0*
-95,6	**-140**	*-220,0*
-90,0	**-130**	*-202,0*
-84,4	**-120**	*-184,0*
-78,9	**-110**	*-166,0*
-73,3	**-100**	*-148,0*
-67,8	**-90**	*-130,0*
-62,2	**-80**	*-112,0*
-56,7	**-70**	*-94,0*
-51,1	**-60**	*-76,0*
-45,6	**-50**	*-58,0*
-45,0	**-49**	*-56,2*
-44,4	**-48**	*-54,4*
-43,9	**-47**	*-52,6*
-43,3	**-46**	*-50,8*
-42,8	**-45**	*-49,0*
-42,2	**-44**	*-47,2*
-41,7	**-43**	*-45,4*
-41,1	**-42**	*-43,6*
-40,6	**-41**	*-41,8*
-40,0	**-40**	*-40,0*
-39,4	**-39**	*-38,2*
-38,9	**-38**	*-36,4*
-38,3	**-37**	*-34,6*
-37,8	**-36**	*-32,8*
-37,2	**-35**	*-31,0*
-36,7	**-34**	*-29,2*
-36,1	**-33**	*-27,4*
-35,6	**-32**	*-25,6*
-35,0	**-31**	*-23,8*
-34,4	**-30**	*-22,0*
-33,9	**-29**	*-20,2*
-33,3	**-28**	*-18,4*
-32,8	**-27**	*-16,6*

°C		°F
-32,2	**-26**	*-14,8*
-31,7	**-25**	*-13,0*
-31,1	**-24**	*-11,2*
-30,6	**-23**	*-9,4*
-30,0	**-22**	*-7,6*
-29,4	**-21**	*-5,8*
-28,9	**-20**	*-4,0*
-28,3	**-19**	*-2,2*
-27,8	**-18**	*-0,4*
-27,2	**-17**	*1,4*
-26,7	**-16**	*3,2*
-26,1	**-15**	*5,0*
-25,6	**-14**	*6,8*
-25,0	**-13**	*8,6*
-24,4	**-12**	*10,4*
-23,9	**-11**	*12,2*
-23,3	**-10**	*14,0*
-22,8	**-9**	*15,8*
-22,2	**-8**	*17,6*
-21,7	**-7**	*19,4*
-21,1	**-6**	*21,2*
-20,6	**-5**	*23,0*
-20,0	**-4**	*24,8*
-19,4	**-3**	*26,6*
-18,9	**-2**	*28,4*
-18,3	**-1**	*30,2*
-17,8	**0**	*32,0*
-17,2	**1**	*33,8*
-16,7	**2**	*35,6*
-16,1	**3**	*37,4*
-15,6	**4**	*39,2*
-15,0	**5**	*41,0*
-14,4	**6**	*42,8*
-13,9	**7**	*44,6*
-13,3	**8**	*46,4*
-12,8	**9**	*48,2*
-12,2	**10**	*50,0*
-11,7	**11**	*51,8*
-11,1	**12**	*53,6*
-10,6	**13**	*55,4*
-10,0	**14**	*57,2*
-9,4	**15**	*59,0*
-8,9	**16**	*60,8*
-8,3	**17**	*62,6*
-7,8	**18**	*64,4*
-7,2	**19**	*66,2*
-6,7	**20**	*68,0*
-6,1	**21**	*69,8*
-5,6	**22**	*71,6*
-5,0	**23**	*73,4*
-4,4	**24**	*75,2*
-3,9	**25**	*77,0*
-3,3	**26**	*78,8*
-2,8	**27**	*80,6*
-2,2	**28**	*82,4*
-1,7	**29**	*84,2*
-1,1	**30**	*86,0*
-0,6	**31**	*87,8*
0,0	**32**	*89,6*
0,6	**33**	*91,4*
1,1	**34**	*93,2*
1,7	**35**	*95,0*
2,2	**36**	*96,8*
2,8	**37**	*98,6*
3,3	**38**	*100,4*
3,9	**39**	*102,2*
4,4	**40**	*104,0*
5,0	**41**	*105,8*
5,6	**42**	*107,6*

°C		°F
6,1	**43**	*109,4*
6,7	**44**	*111,2*
7,2	**45**	*113,0*
7,8	**46**	*114,8*
8,3	**47**	*116,6*
8,9	**48**	*118,4*
9,4	**49**	*120,2*
10,0	**50**	*122,0*
10,6	**51**	*123,8*
11,1	**52**	*125,6*
11,7	**53**	*127,4*
12,2	**54**	*129,2*
12,8	**55**	*131,0*
13,3	**56**	*132,8*
13,9	**57**	*134,6*
14,4	**58**	*136,4*
15,0	**59**	*138,2*
15,6	**60**	*140,0*
16,1	**61**	*141,8*
16,7	**62**	*143,6*
17,2	**63**	*145,4*
17,8	**64**	*147,2*
18,3	**65**	*149,0*
18,9	**66**	*150,8*
19,4	**67**	*152,6*
20,0	**68**	*154,4*
20,6	**69**	*156,2*
21,1	**70**	*158,0*
21,7	**71**	*159,8*
22,2	**72**	*161,6*
22,8	**73**	*163,4*
23,3	**74**	*165,2*
23,9	**75**	*167,0*
24,4	**76**	*168,8*
25,0	**77**	*170,6*
25,6	**78**	*172,4*
26,1	**79**	*174,2*
26,7	**80**	*176,0*
27,2	**81**	*177,8*
27,8	**82**	*179,6*
28,3	**83**	*181,4*
28,9	**84**	*183,2*
29,4	**85**	*185,0*
30,0	**86**	*186,8*
30,6	**87**	*188,6*
31,1	**88**	*190,4*
31,7	**89**	*192,2*
32,2	**90**	*194,0*
32,8	**91**	*195,8*
33,3	**92**	*197,6*
33,9	**93**	*199,4*
34,4	**94**	*201,2*
35,0	**95**	*203,0*
35,6	**96**	*204,8*
36,1	**97**	*206,6*
36,7	**98**	*208,4*
37,2	**99**	*210,2*
37,8	**100**	*212,0*
38,3	**101**	*213,8*
38,9	**102**	*215,6*
39,4	**103**	*217,4*
40,0	**104**	*219,2*
40,6	**105**	*221,0*
41,1	**106**	*222,8*
41,7	**107**	*224,6*
42,2	**108**	*226,4*
42,8	**109**	*228,2*
43,3	**110**	*230,0*
43,9	**111**	*231,8*

°C		°F
44,4	**112**	*233,6*
45,0	**113**	*235,4*
45,6	**114**	*237,2*
46,1	**115**	*239,0*
46,7	**116**	*240,8*
47,2	**117**	*242,6*
47,8	**118**	*244,4*
48,3	**119**	*246,2*
48,9	**120**	*248,0*
49,4	**121**	*249,8*
50,0	**122**	*251,6*
50,6	**123**	*253,4*
51,1	**124**	*255,2*
51,7	**125**	*257,0*
52,2	**126**	*258,8*
52,8	**127**	*260,6*
53,3	**128**	*262,4*
53,9	**129**	*264,2*
54,4	**130**	*266,0*
55,0	**131**	*267,8*
55,6	**132**	*269,6*
56,1	**133**	*271,4*
56,7	**134**	*273,2*
57,2	**135**	*275,0*
57,8	**136**	*276,8*
58,3	**137**	*278,6*
58,9	**138**	*280,4*
59,4	**139**	*282,2*
60,0	**140**	*284,0*
60,6	**141**	*285,8*
61,1	**142**	*287,6*
61,7	**143**	*289,4*
62,2	**144**	*291,2*
62,8	**145**	*293,0*
63,3	**146**	*294,8*
63,9	**147**	*296,6*
64,4	**148**	*298,4*
65,0	**149**	*300,2*
65,6	**150**	*302,0*
66,1	**151**	*303,8*
66,7	**152**	*305,6*
67,2	**153**	*307,4*
67,8	**154**	*309,2*
68,3	**155**	*311,0*
68,9	**156**	*312,8*
69,4	**157**	*314,6*
70,0	**158**	*316,4*
70,6	**159**	*318,2*
71,1	**160**	*320,0*
71,7	**161**	*321,8*
72,2	**162**	*323,6*
72,8	**163**	*325,4*
73,3	**164**	*327,2*
73,9	**165**	*329,0*
74,4	**166**	*330,8*
75,0	**167**	*332,6*
75,6	**168**	*334,4*
76,1	**169**	*336,2*
76,7	**170**	*338,0*
77,2	**171**	*339,8*
77,8	**172**	*341,6*
78,3	**173**	*343,4*
78,9	**174**	*345,2*
79,4	**175**	*347,0*
80,0	**176**	*348,8*
80,6	**177**	*350,6*
81,1	**178**	*352,4*
81,7	**179**	*354,2*
82,2	**180**	*356,0*
82,8	**181**	*357,8*

°C		°F
83,3	**182**	*359,6*
83,9	**183**	*361,4*
84,4	**184**	*363,2*
85,0	**185**	*365,0*
85,6	**186**	*366,8*
86,1	**187**	*368,6*
86,7	**188**	*370,4*
87,2	**189**	*372,2*
87,8	**190**	*374,0*
88,3	**191**	*375,8*
88,9	**192**	*377,6*
89,4	**193**	*379,4*
90,0	**194**	*381,2*
90,6	**195**	*383,0*
91,1	**196**	*384,8*
91,7	**197**	*386,6*
92,2	**198**	*388,4*
92,8	**199**	*390,2*
93,3	**200**	*392,0*
93,9	**201**	*393,8*
94,4	**202**	*395,6*
95,0	**203**	*397,4*
95,6	**204**	*399,2*
96,1	**205**	*401,0*
96,7	**206**	*402,8*
97,2	**207**	*404,6*
97,8	**208**	*406,4*
98,3	**209**	*408,2*
98,9	**210**	*410,0*
99,4	**211**	*411,8*
100,0	**212**	*413,6*
100,6	**213**	*415,4*
101,1	**214**	*417,2*
101,7	**215**	*419,0*
102,2	**216**	*420,8*
102,8	**217**	*422,6*
103,3	**218**	*424,4*
103,9	**219**	*426,2*
104,4	**220**	*428,0*
105,0	**221**	*429,8*
105,6	**222**	*431,6*
106,1	**223**	*433,4*
106,7	**224**	*435,2*
107,2	**225**	*437,0*
107,8	**226**	*438,8*
108,3	**227**	*440,6*
108,9	**228**	*442,4*
109,4	**229**	*444,2*
110,0	**230**	*446,0*
110,6	**231**	*447,8*
111,1	**232**	*449,6*
111,7	**233**	*451,4*
112,2	**234**	*453,2*
112,8	**235**	*455,0*
113,3	**236**	*456,8*
113,9	**237**	*458,6*
114,4	**238**	*460,4*
115,0	**239**	*462,2*
115,6	**240**	*464,0*
116,1	**241**	*465,8*
116,7	**242**	*467,6*
117,2	**243**	*469,4*
117,8	**244**	*471,2*
118,3	**245**	*473,0*
118,9	**246**	*474,8*
119,4	**247**	*476,6*
120,0	**248**	*478,4*
120,6	**249**	*480,2*
121,1	**250**	*482,0*

°C		°F
121,7	251	483,8
122,2	252	485,6
122,8	253	487,4
123,3	254	489,2
123,9	255	491,0
124,4	256	492,8
125,0	257	494,6
125,6	258	496,4
126,1	259	498,2
126,7	260	500,0
127,2	261	501,8
127,8	262	503,6
128,3	263	505,4
128,9	264	507,2
129,4	265	509,0
130,0	266	510,8
130,6	267	512,6
131,1	268	514,4
131,7	269	516,2
132,2	270	518,0
132,8	271	519,8
133,3	272	521,6
133,9	273	523,4
134,4	274	525,2
135,0	275	527,0
135,6	276	528,8
136,1	277	530,6
136,7	278	532,4
137,2	279	534,2
137,8	280	536,0
138,3	281	537,8
138,9	282	539,6
139,4	283	541,4
140,0	284	543,2
140,6	285	545,0
141,1	286	546,8
141,7	287	548,6
142,2	288	550,4
142,8	289	552,2
143,3	290	554,0
143,9	291	555,8
144,4	292	557,6
145,0	293	559,4
145,6	294	561,2
146,1	295	563,0
146,7	296	564,8
147,2	297	566,6
147,8	298	568,4
148,3	299	570,2
148,9	300	572,0
149,4	301	573,8
150,0	302	575,6
150,6	303	577,4
151,1	304	579,2
151,7	305	581,0
152,2	306	582,8
152,8	307	584,6
153,3	308	586,4
153,9	309	588,2
154,4	310	590,0
155,0	311	591,8
155,6	312	593,6
156,1	313	595,4
156,7	314	597,2
157,2	315	599,0
157,8	316	600,8
158,3	317	602,6
158,9	318	604,4
159,4	319	606,2
160,0	320	608,0
160,6	321	609,8
161,1	322	611,6
161,7	323	613,4
162,2	324	615,2
162,8	325	617,0
163,3	326	618,8
163,9	327	620,6
164,4	328	622,4
165,0	329	624,2

°C		°F
165,6	330	626,0
166,1	331	627,8
166,7	332	629,6
167,2	333	631,4
167,8	334	633,2
168,3	335	635,0
168,9	336	636,8
169,4	337	638,6
170,0	338	640,4
170,6	339	42,2
171,1	340	644,0
171,7	341	45,8
172,2	342	647,6
172,8	343	649,4
173,3	344	651,2
173,9	345	53,0
174,4	346	654,8
175,0	347	656,6
175,6	348	658,4
176,1	349	660,2
176,7	350	662,0
177,2	351	663,8
177,8	352	665,6
178,3	353	667,4
178,9	354	669,2
179,4	355	671,0
180,0	356	672,8
180,6	357	674,6
181,1	358	676,4
181,7	359	678,2
182,2	360	680,0
182,8	361	681,8
183,3	362	683,6
183,9	363	685,4
184,4	364	687,2
185,0	365	689,0
185,6	366	690,8
186,1	367	692,6
186,7	368	694,4
187,2	369	696,2
187,8	370	698,0
188,3	371	699,8
188,9	372	701,6
189,4	373	703,4
190,0	374	705,2
190,6	375	707,0
191,1	376	708,8
191,7	377	710,6
192,2	378	712,4
192,8	379	714,2
193,3	380	716,0
193,9	381	717,8
194,4	382	719,6
195,0	383	721,4
195,6	384	723,2
196,1	385	725,0
196,7	386	726,8
197,2	387	728,6
197,8	388	730,4
198,3	389	732,2
198,9	390	734,0
199,4	391	735,8
200,0	392	737,6
200,6	393	739,4
201,1	394	741,2
201,7	395	743,0
202,2	396	744,8
202,8	397	746,6
203,3	398	748,4
203,9	399	750,2
204,4	400	752,0
205,0	401	753,8
205,6	402	755,6
206,1	403	757,4
206,7	404	759,2
207,2	405	761,0
207,8	406	762,8
208,3	407	764,6
208,9	408	766,4

°C		°F
209,4	409	768,2
210,0	410	770,0
210,6	411	771,8
211,1	412	773,6
211,7	413	775,4
212,2	414	777,2
212,8	415	779,0
213,3	416	780,8
213,9	417	782,6
214,4	418	784,4
215,0	419	786,2
215,6	420	788,0
216,1	421	789,8
216,7	422	791,6
217,2	423	793,4
217,8	424	795,2
218,3	425	797,0
218,9	426	798,8
219,4	427	800,6
220,0	428	802,4
220,6	429	804,2
221,1	430	806,0
221,7	431	807,8
222,2	432	809,6
222,8	433	811,4
223,3	434	813,2
223,9	435	815,0
224,4	436	816,8
225,0	437	818,6
225,6	438	820,4
226,1	439	822,2
226,7	440	824,0
227,2	441	825,8
227,8	442	827,6
228,3	443	829,4
228,9	444	831,2
229,4	445	833,0
230,0	446	834,8
230,6	447	836,6
231,1	448	838,4
231,7	449	840,2
232,2	450	842,0
232,8	451	843,8
233,3	452	845,6
233,9	453	847,4
234,4	454	849,2
235,0	455	851,0
235,6	456	852,8
236,1	457	854,6
236,7	458	856,4
237,2	459	858,2
237,8	460	860,0
238,3	461	861,8
238,9	462	863,6
239,4	463	865,4
240,0	464	867,2
240,6	465	869,0
241,1	466	870,8
241,7	467	872,6
242,2	468	874,4
242,8	469	876,2
243,3	470	878,0
243,9	471	879,8
244,4	472	881,6
245,0	473	883,4
245,6	474	885,2
246,1	475	887,0
246,7	476	888,8
247,2	477	890,6
247,8	478	892,4
248,3	479	894,2
248,9	480	896,0
249,4	481	897,8
250,0	482	899,6
250,6	483	901,4
251,1	484	903,2
251,7	485	905,0
252,2	486	906,8
252,8	487	908,6
253,3	488	910,4

°C		°F
253,9	489	912,2
254,4	490	914,0
255,0	491	915,8
255,6	492	917,6
256,1	493	919,4
256,7	494	921,2
257,2	495	923,0
257,8	496	924,8
258,3	497	926,6
258,9	498	928,4
259,4	499	930,2
260,0	500	932,0
262,8	505	941,0
265,6	510	950,0
268,3	515	959,0
271,1	520	968,0
273,9	525	977,0
276,7	530	986,0
279,4	535	995,0
282,2	540	1004,0
285,0	545	1013,0
287,8	550	1022,0
290,6	555	1031,0
293,3	560	1040,0
296,1	565	1049,0
298,9	570	1058,0
301,7	575	1067,0
304,4	580	1076,0
307,2	585	1085,0
310,0	590	1094,0
312,8	595	1103,0
315,6	600	1112,0
321,1	610	1130,0
326,7	620	1148,0
332,2	630	1166,0
337,8	640	1184,0
343,3	650	1202,0
348,9	660	1220,0
354,4	670	1238,0
360,0	680	1256,0
366,0	690	1274,0
371,0	700	1292,0
377,0	710	1310,0
382,0	720	1328,0
388,0	730	1346,0
393,0	740	1364,0
399,0	750	1382,0
404,0	760	1400,0
410,0	770	1418,0
415,6	780	1436,0
421,1	790	1454,0
426,7	800	1472,0
432,2	810	1490,0
437,8	820	1508,0
443,3	830	1526,0
448,9	840	1544,0
454,4	850	1562,0
460,0	860	1580,0
465,6	870	1598,0
471,1	880	1616,0
476,7	890	1634,0
482,2	900	1652,0

°C		°F
487,8	910	1670,0
493,3	920	1688,0
498,9	930	1706,0
504,4	940	1724,0
510,0	950	1742,0
515,6	960	1760,0
521,1	970	1778,0
526,7	980	1796,0
532,2	990	1814,0
537,8	1000	1832,0
543,3	1010	1850,0
548,9	1020	1868,0
554,4	1030	1886,0
560,0	1040	1904,0
565,6	1050	1922,0
571,1	1060	1940,0
576,7	1070	1958,0
582,2	1080	1976,0
587,8	1090	1994,0
593,3	1100	2012,0
598,9	1110	2030,0
604,4	1120	2048,0
610,0	1130	2066,0
615,6	1140	2084,0
621,1	1150	2102,0
626,7	1160	2120,0
632,2	1170	2138,0
637,8	1180	2156,0
643,3	1190	2174,0
648,9	1200	2192,0
654,4	1210	2210,0
660,0	1220	2228,0
665,6	1230	2246,0
671,1	1240	2264,0
676,7	1250	2282,0
682,2	1260	2300,0
687,8	1270	2318,0
693,3	1280	2336,0
698,9	1290	2354,0
704,4	1300	2372,0
710,0	1310	2390,0
715,6	1320	2408,0
721,1	1330	2426,0
726,7	1340	2444,0
732,2	1350	2462,0
737,8	1360	2480,0
743,3	1370	2498,0
748,9	1380	2516,0
754,4	1390	2534,0
760,0	1400	2552,0
765,6	1410	2570,0
771,1	1420	2588,0
776,7	1430	2606,0
782,2	1440	2624,0
787,8	1450	2642,0
793,3	1460	2660,0
798,9	1470	2678,0
804,4	1480	2696,0
810,0	1490	2714,0
815,6	1500	2732,0

Valori dei gradi singoli — *Values of single degrees*

°C	°F	°F	°C
1	1,8	1	0,56
2	3,6	2	1,11
3	5,4	3	1,67
4	7,2	4	2,22
5	9,0	5	2,78
6	10,8	6	3,33
7	12,6	7	3,89
8	14,4	8	4,44
9	16,2	9	5,0
°C = 5/9 (°F-32°)		F = (9/5°C) + 32°	

1.6 Standard voltages and frequencies in different countries

Country	Frequency (Hz)	Voltage/s (V)	Country	Frequency (Hz)	Voltage/s (V)
Afghanistan	50	220/380	Dominican republic	60	110/220
Algeria	50	127/220	Ecuador	60	120/208
	50	220/380		60	127/220
American samoa	60	240/480		60	120/240
Angola	50	220/380	Egypt	50	220/380
Antigua	60	230/400	El salvador	60	115/230
Argentina	50	220/380	England (and Wales)	50	240/480
Australia (East zone)	50	240/415		50	240/415
(West zone)	50	254/440	Equatorial guyana	50	220
Austria	50	220/380	Ethiopia	50	220/380
Azorse	50	220/380	ex - U.S.S.R.	50	220/380
Bahamas	60	120/208	ex-Yugoslavia	50	220/380
	60	115/200	Far Oer	50	220/380
	60	120/240	Fiji	50	240/415
Bahrain	50	230/400	Finland	50	220/380
	60	230/400	France	50	220/380
Bangladesh	50	220/380		50	110/220
	50	230/400		50	115/230
Barbados	50	110/190		50	127/220
	50	120/208		50	500
	50	115/200	French guyana	50	220/380
	50	115/230	Gabon	50	220/380
Belgium	50	127/220	Gambia	50	220/380
	50	220/380	Germany	50	220/380
	50	220	Ghana	50	220/380
Belize	60	110/220	Gibraltar	50	240/415
	60	220/440	Greece	50	220/380
Benin	50	220/380	Grenada	50	2307400
Bermuda	60	120/240	Guadeloupe	50	220/380
	60	120/208	Guam	60	120/208
Bolivia	50	110/220		60	110/220
	50	220/380	Guatemala	60	120/240
	50	115/230		60	120/208
	60	220/380	Guinea	50	220/380
Botswana	50	220/380	Guinea bissau	50	220/380
Brazil	60	110/220	Guyana	50	110/220
	60	220/440		60	110/220
	60	127/220	Haiti	50	220/380
	60	220/380		60	110/220
	60	115/220	Honduras	60	110/220
	60	125/216	Honk kong	50	200/346
	60	230/400	Iceland	50	220/380
	50	220/440	India	50	220/380
Bulgaria	50	220/380		50	230/400
Burundi	50	220/380	Indonesia	50	220/380
Cambodia	50	220/380		50	127/220
	50	120/208	Iran	50	220/380
Camerun	50	127/220	Iraq	50	220/380
	50	220/360	Ireland	50	220/380
	50	230/400	Isle of Man	50	240/415
Canada	60	120/240	Israel	50	230/400
	60	575	Italy	50	220/380
Canarie	50	127/220		50	127/220
	50	220/380	Ivory coast	50	220/380
Cape Verde	50	220/380	Jamaica	50	110/220
Cayman Islands	50	220/380	Japan	50	100/200
Central african republic	50	220/380		60	100/200
Chile	50	220/380	Jerusalem	50	220/380
China	50	220/380	Jordan	50	220/380
Ciad	50	220/380	Kenya	50	240/415
Colombia	60	110/220	Korea	60	100/200
	60	150/260		0	220/380
	60	440	Kuwait	50	240/415
Congo	50	220/380	Laos	50	220/380
Costarica	60	120/240	Lebanon	50	110/190
Cuba	60	120/240		50	220/380
Cyprus	50	240/415	Lesotho	50	220/380
Czech republic	50	220/380			
Denmark	50	220/380			

Country	Frequency (Hz)	Voltage/s (V)
Liberia	60	120/208
	60	120/240
Libya	50	127/220
	50	220/380
Luxembourg	50	220/380
	50	120/208
Macao	50	220/380
Madagascar	50	220/380
	50	127/220
Majorca	50	220/380
	50	127/220
Malawi	50	220/380
Malaysia	50	240/415
Maldives	50	230/400
Mali	50	220/380
Malta	50	220/380
Martinique	50	220/380
Mauritius	50	240/415
Mexico	60	127/220
Monaco	50	220/380
	50	127/220
Monzambique	50	220/380
Morocco	50	127/220
	60	220/380
Nepal	50	220/440
Netherland antilles	60	220/380
	60	115/230
	50	120/208
	50	127/220
Netherlands	60	220/380
New Zeland	50	230/400
Niacaragua	60	120/240
Niger	50	220/380
Nigeria	50	240/415
Northern Ireland	50	230/400
	50	230
Norway	60	220/380
Oman	50	220/380
Pakistan	50	220/380
	50	230/400
Panama	60	110/220
	60	115/230
	60	120/208
Papua Nuova Guinea	50	240/415
Paraguay	50	220/380
Perù	60	110/220
	50	220
Philippines	60	110/220
Poland	50	220/380
Portorico	60	120/208
Portugal	50	220/380
Qatar	50	240/415
Romania	50	220/380
Ruanda	50	220/380
Saudi Arabia	60	127/220
	50	220/380
Scotland	50	240/415
Senegal	50	127/220
Seychelles	50	240
Sierra Leone	50	220/380
Singapore	50	230/400
Slovakia	50	220/380
Somalia	50	110/220
	50	220/440
	50	220/380
South Africa	50	220/380
Spain	50	220/380
	50	127/220
Sri Lanka	50	230/400
St. Kitts & Nevis	60	230/400
St. Lucia	50	240/416
St. Vincent	50	230/400
Sudan	50	240/415
Suriname	60	115/230
	50	127/220
Swatziland	50	230/400
Sweden	50	220/380
Switzerland	50	220/380
Syria	50	220/380
Tahiland	50	220/380
Tahiti	60	127/220
Taiwan	60	110/220
Tanzania	50	230/400
Togo	50	127/220
	50	220/380
Tonga	50	240/415
Trinidad & Tobago	60	115/230
	60	230/400
Tunisia	50	127/220
	50	220/380
Turkey	50	220/380
Uganda	50	240/415
United Arab Emirates	50	220/380
Uruguay	50	220
USA	60	600
	60	120/240
	60	460
	60	575
Venezuela	60	120/208
Vietnam	50	120/208
	50	127/220
	50	220/380
Virgin islands	60	120/240
Yemen	50	220/380
	50	230/400
Zaire	50	220/380
Zambia	50	220/380
Zimbawe	50	220/380

In case the higher value is double than lower, there is a single phase system with three conductors with two main conductors and an intermediate conductor.

In case the higher value is 1,73 times more then lower, there is a three phase system with 4 conductors with 3 main conductors and a conductor connected to the star-centre.220/380V voltage are being replaced from 230/400V.

In case of a single value, there is a three phase system with three main conductors.

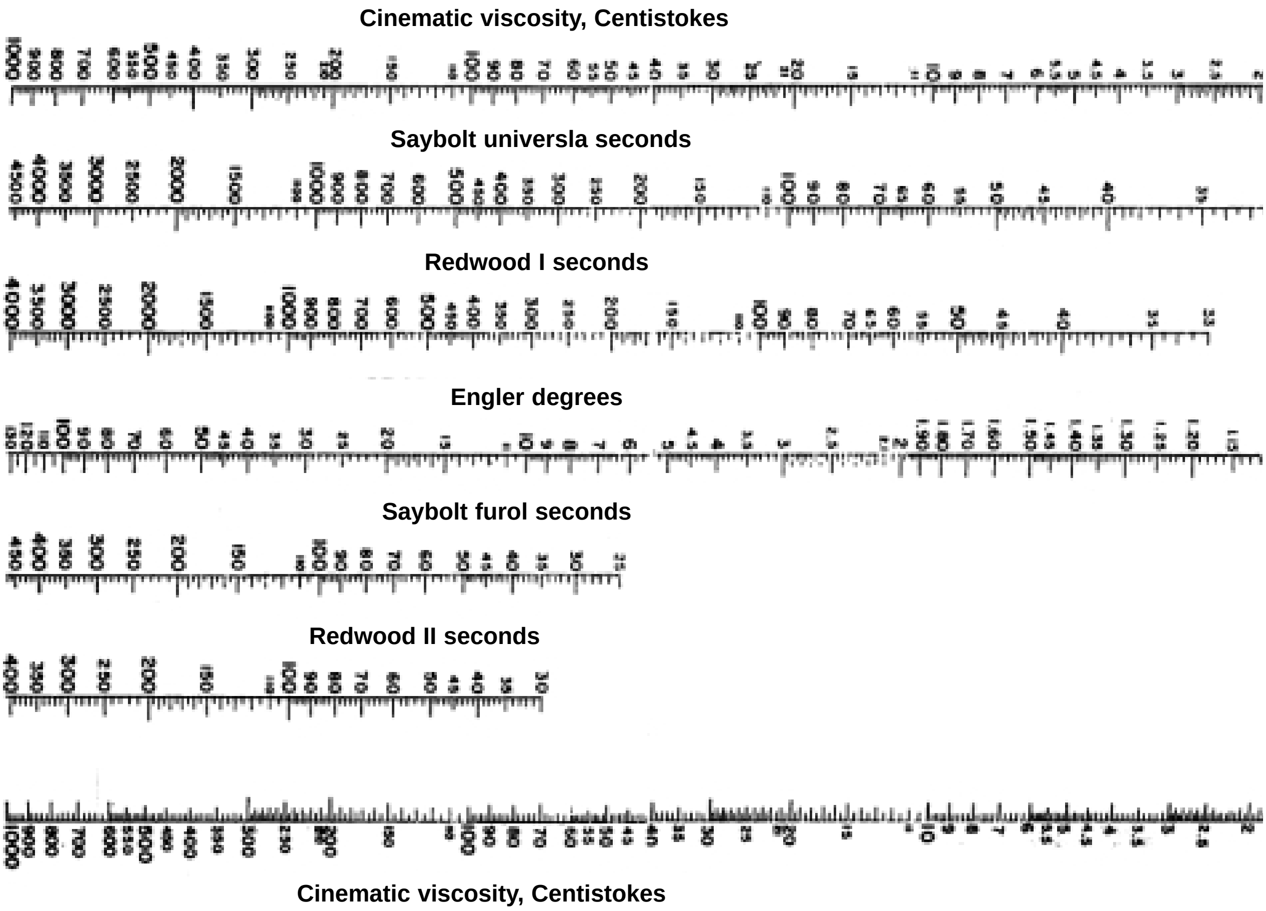
1.7 Personal units of measurment and conversion factors

5.2 TABLES AND DIAGRAMS ABOUT FUEL VISCOSITY

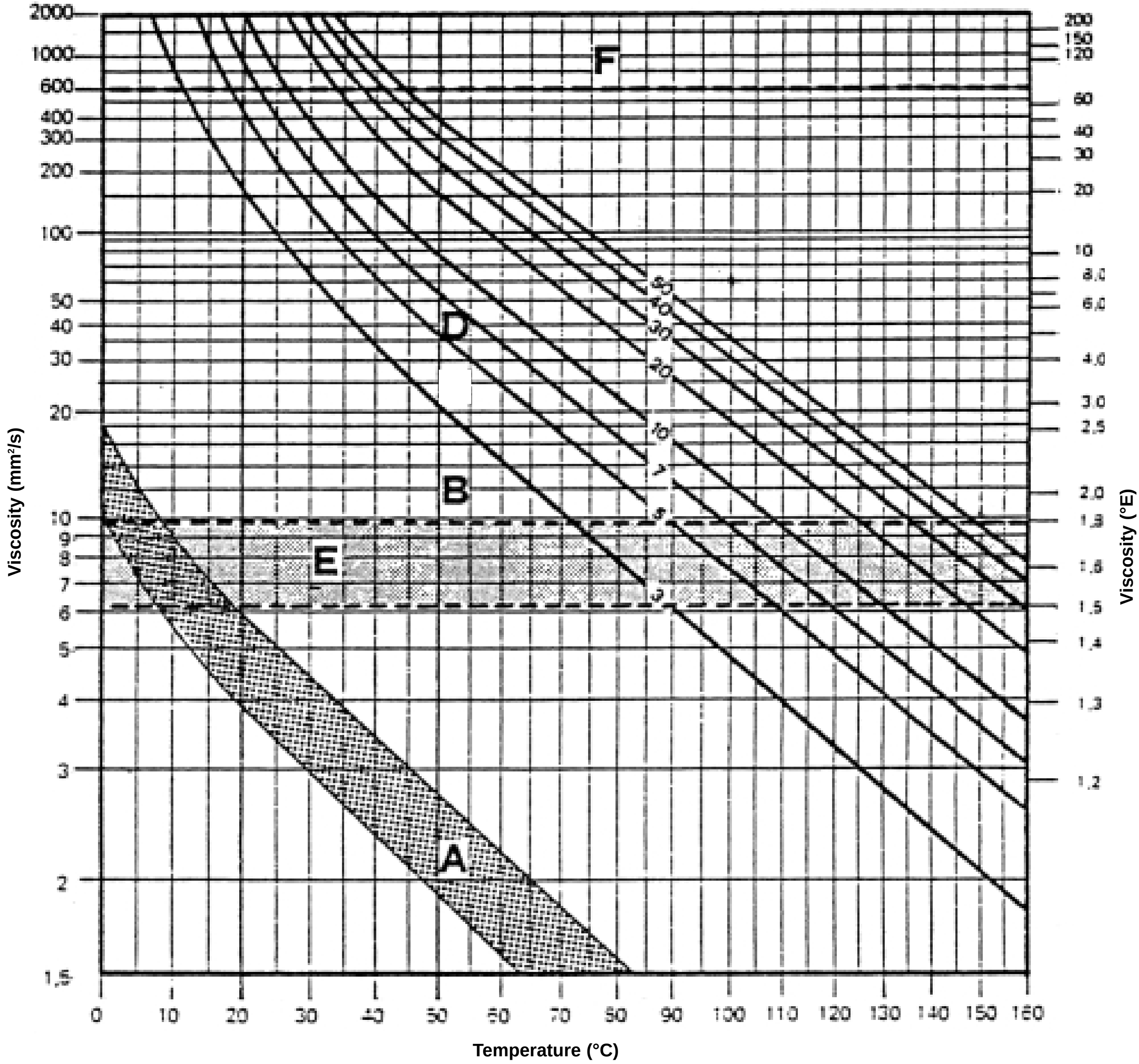
1.8 Approximated equivalence table between viscosity measurements at the same temperature

Cinematica (Centistokes)	Engler (gradi - *degrees*)	Saybolt Universal (secondi - *seconds*)	Saybolt Furol (secondi - *seconds*)	Redwood N°1 (secondi - *seconds*)	Redwood N°2 (secondi - *seconds*)
2,69	1,18	35		32,2	
4,28	1,32	40		36,2	
5,84	1,46	45		40,6	
7,39	1,60	50		44,9	
8,88	1,75	55		49,1	
10,34	1,88	60		53,5	
11,75	2,02	65		57,9	
13,11	2,15	70		62,3	
14,42	2,31	75		67,6	
15,72	2,42	80		71,0	
16,98	2,55	85		75,1	
18,20	2,68	90		79,6	
19,40	2,81	95		84,2	
20,60	2,95	100		88,4	
23,00	3,21	110		97,1	
25,3	3,49	120		105,9	
27,5	3,77	130		114,8	
29,8	4,04	140		123,6	
32,1	4,32	150		132,4	
34,3	4,59	160		141,1	
36,5	4,88	170		150,0	
38,7	5,15	180		158,8	
41,0	5,44	190		167,5	
43,2	5,72	200	23,0	176,4	
47,5	6,28	220	25,3	194,0	
51,9	6,85	240	27,0	212	
56,2	7,38	260	28,7	229	
60,6	7,95	280	30,5	247	
64,9	8,51	300	32,5	265	
70,4	9,24	325	35,0	287	
75,8	9,95	350	37,2	309	
81,2	10,7	375	39,5	331	
86,6	11,4	400	42,0	353	
92,0	12,1	425	44,2	375	
97,4	12,8	450	47,0	397	
102,8	13,5	475	49	419	
108,2	14,2	500	51	441	
119,2	15,6	550	56	485	
120,9	17,0	600	61	529	
140,7	18,5	650	66	573	
151,3	19,9	700	71	617	
162,3	21,3	750	76	661	
173,2	22,7	800	81	705	
184,0	24,2	850	86	749	
194,8	25,6	900	91	793	
206	27,0	950	96	837	
216	28,4	1000	100	882	
260	34,1	1200	121	1058	104
303	39,8	1400	141	1234	122
346	45,5	1600	160	1411	138
390	51	1800	180	1587	153
433	57	2000	200	1703	170
541	71	2500	250	2204	215
650	85	3000	300	2646	255
758	99	3500	350	3087	300
866	114	4000	400	3526	345
974	128	4500	450	3976	390
1082	142	5000	500	4408	435
1190	156	5500	550	4849	475
1300	170	6000	600	5290	515
1405	185	6500	650	5730	560
1515	199	7000	700	6171	600
1625	213	7500	750	6612	645
1730	227	8000	800	7053	690
1840	242	8500	850	7494	730
1950	256	9000	900	7934	770
2055	270	9500	950	8375	815
2165	284	10000	1000	8816	855

1.9 Nomograph for viscosity units conversions



1.10 Viscosity variations in relation to temperature for different fuels



A – MAX and MIN limits of Gas oil (D) range
B – light fuel oil (E) range
D – medium fuel oil (F) range
E – adviced limits of nozzle viscosity
F – economical limit value for pumpability of fuel oil

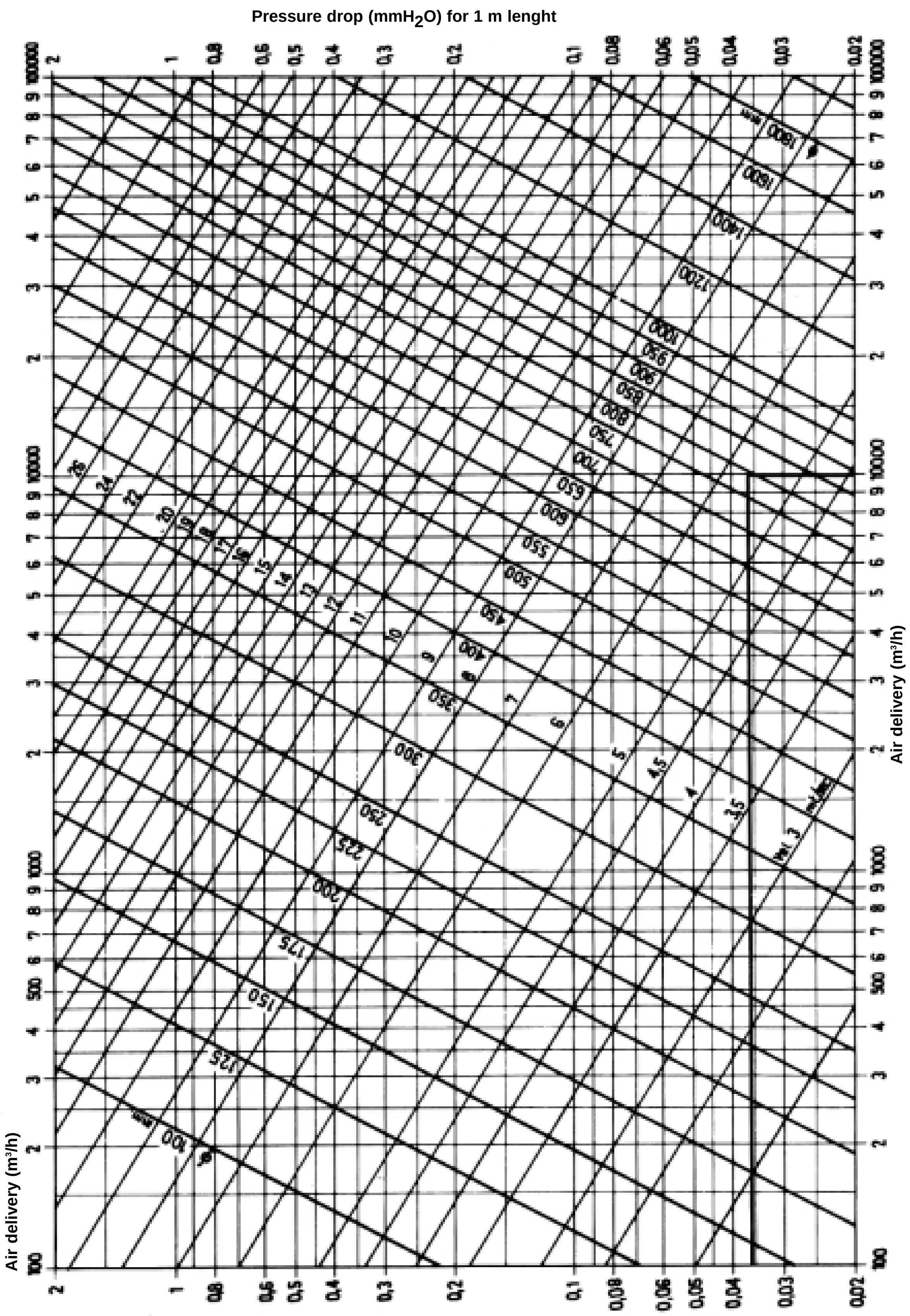
1.11 Gas dynamic viscosity

FLUIDO - *Fluid*	0°C		25°C		50°C		75°C		100°C		125°C	
	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$
Acetilene - *Acetylene*	9,541	0,9728	10,250	1,0451	10,945	1,1160	11,629	1,1857	12,304	1,2545	12,974	1,3228
Acetone - *Acetone*	7,183	0,7324	7,798	0,7951	8,407	0,8572	9,011	0,9187	9,612	0,9800	10,213	1,0413
Acido cloridrico *Hydrochloric acid*	12,973	1,3227	14,101	1,4377	15,218	1,5517	16,328	1,6648	17,435	1,7776	18,542	1,8905
Alcool etilico *Ethyl alcohol*	8,398	0,8563	9,085	0,9263	9,762	0,9953	10,431	1,0636	11,096	1,1314	11,759	1,1990
Alcool metilico *Methyl alcohol*	9,082	0,9260	9,909	1,0103	10,731	1,0941	11,550	1,1776	12,369	1,2612	13,191	1,3450
Ammoniaca - *Ammonia*	9,390	0,9574	10,258	1,0459	11,122	1,1340	11,984	1,2218	12,846	1,3098	13,713	1,3982
Anidride carbonica *Carbon dioxide*	13,660	1,3928	14,725	1,5014	15,772	1,6081	16,805	1,7134	17,827	1,8177	18,844	1,9213
Anidride solforosa *Sulphur dioxide*	11,585	1,1812	12,475	1,2719	13,348	1,3610	14,208	1,4487	15,059	1,5355	15,905	1,6217
Aria - *Air*	17,260	1,760	18,490	1,885	19,671	2,006	20,808	2,122	21,905	2,234	22,965	2,342
Argo - *Argon*	20,864	2,1273	22,251	2,2687	23,599	2,4062	24,916	2,5405	26,209	2,6723	27,485	2,8024
Azoto - *Nitrogen*	16,653	1,6979	17,741	1,8089	18,799	1,9167	19,831	2,0220	20,843	2,1252	21,841	2,2269
Benzolo - *Benzole*	7,017	0,7155	7,656	0,7806	8,291	0,8454	8,924	0,9099	9,557	0,9744	10,192	1,0392
Bromo - *Bromine*	13,777	1,4047	14,957	1,5250	16,124	1,6440	17,282	1,7621	18,435	1,8797	19,589	1,9972
Cloro - *Chlorine*	12,765	1,3015	13,841	1,4112	14,904	1,5197	15,959	1,6272	17,008	1,7341	18,055	1,8409
Elio - *Helium*	17,752	1,8099	18,855	1,9225	19,925	2,0315	20,966	2,1377	21,985	2,2416	22,987	2,3437
Etano - *Ethane*	8,578	0,8747	9,290	0,9472	9,993	1,0189	10,689	1,0899	11,381	1,1604	12,072	1,2309
Etere etilico - *Ethyl ether*	7,183	0,7324	7,798	0,7951	8,407	0,8572	9,011	0,9187	9,612	0,9800	10,213	1,0413
Etilene - *Ethylene*	9,476	0,9661	10,215	1,0415	10,941	1,1155	11,657	1,1886	12,367	1,2609	13,072	1,3328
Fluoro - *Fluorine*	20,620	2,1024	22,868	2,3316	25,139	2,5632	27,435	2,7973	29,762	3,0346	32,127	3,2757
Freon 12	11,781	1,2012	12,489	1,2734	13,175	1,3433	13,840	1,4112	14,491	1,4775	15,129	1,5426
Freon 22	12,042	1,2278	12,896	1,3149	13,730	1,3999	14,547	1,4832	15,352	1,5653	16,149	1,6466
Idrogeno - *Hydrogen*	8,492	0,8658	8,994	0,9170	9,479	0,9665	9,950	1,0145	10,410	1,0614	10,861	1,1074
Idrogeno solforato *Hydrogen sulphide*	11,853	1,2085	12,915	1,3169	13,971	1,4244	15,021	1,5315	16,070	1,6385	17,122	1,7458
Metano - *Methane*	10,217	1,0417	10,965	1,1180	11,697	1,1926	12,416	1,2659	13,126	1,3383	13,829	1,4100
Ossido di carbonio *Carbon monoxide*	17,026	1,7360	18,067	1,8421	19,075	1,9449	20,055	2,0449	21,014	2,1426	21,956	2,2386
Ossigeno - *Oxygen*	19,236	1,9613	20,413	2,0813	21,551	2,1974	22,659	2,3103	23,742	2,4207	24,806	2,5292
Pentano - *Pentane*	5,556	0,5665	6,189	0,6311	6,832	0,6966	7,484	0,7631	8,148	0,8308	8,825	0,8997
Propano - *Propane*	7,734	0,7886	8,318	0,8481	8,892	0,9066	9,456	0,9641	10,013	1,0210	10,567	1,0774
Propilene - *Propylene*	7,895	0,8050	8,560	0,8728	9,218	0,9399	9,870	1,0064	10,519	1,0725	11,167	1,1386
Solfuro di carbonio *Carbon sulphide*	9,024	0,9200	9,909	1,0104	10,796	1,1007	11,684	1,1913	12,578	1,2824	13,479	1,3743
Toluolo - *Toluol*	6,516	0,6643	7,100	0,7239	7,680	0,7830	8,257	0,8419	8,834	0,9007	9,412	0,9597

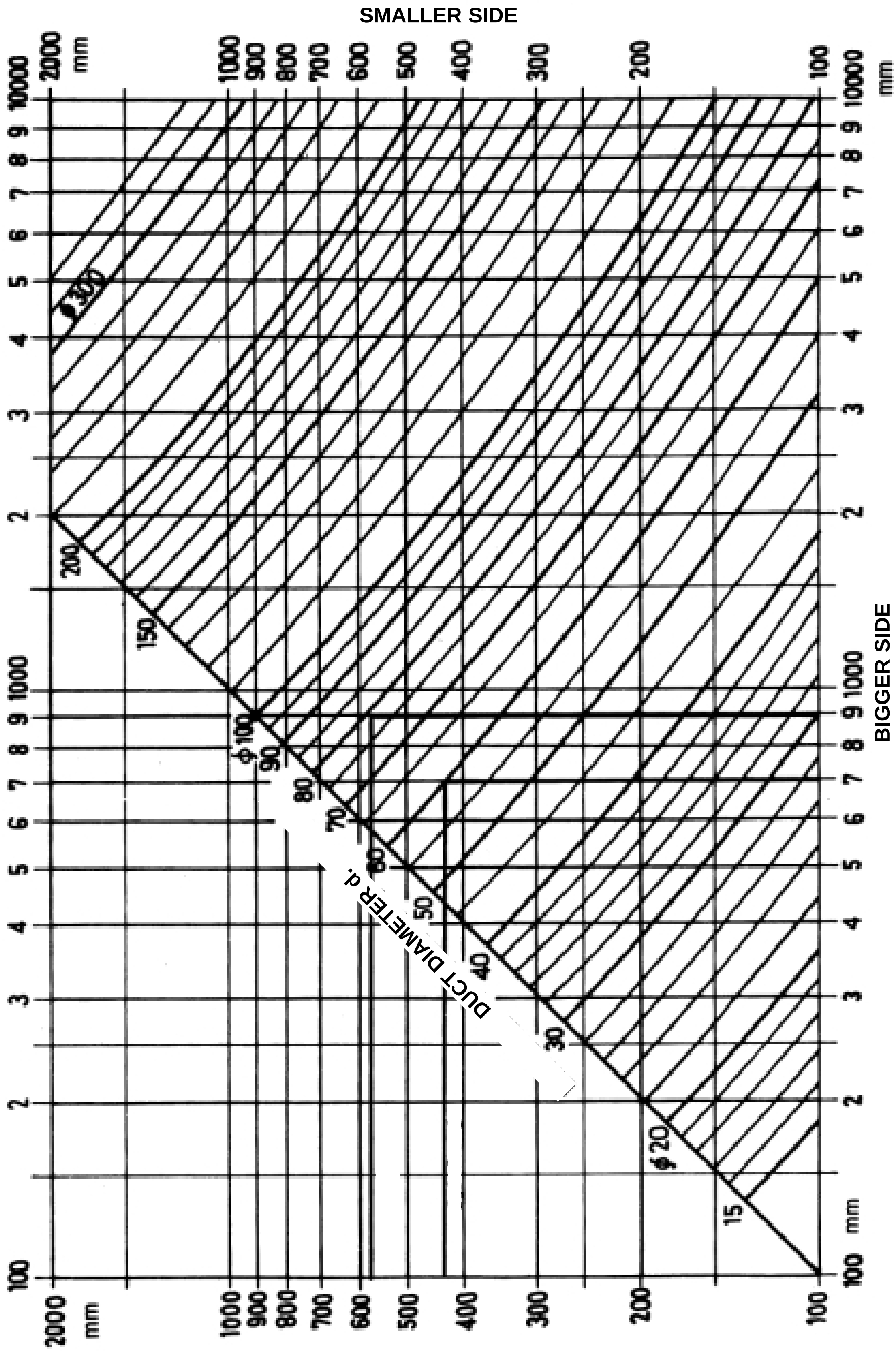
150°C		175°C		200°C		225°C		250°C		275°C		300°C	
Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$	Pa·s $\times 10^6$	kg·s/m² $\times 10^6$
13,640	1,3908	14,305	1,4585	14,966	1,5260	15,622	1,5929	16,267	1,6585	16,890	1,7221	17,479	1,7821
10,816	1,1028	11,422	1,1645	12,029	1,2264	12,634	1,2882	13,232	1,3492	13,814	1,4085	14,367	1,4649
19,653	2,0039	20,770	2,1177	21,891	2,2320	23,009	2,3460	24,116	2,4588	25,193	2,5686	26,216	2,6730
12,422	1,2666	13,086	1,3343	13,751	1,4020	14,412	1,4694	15,064	1,5359	15,697	1,6005	16,297	1,6617
14,018	1,4293	14,852	1,5143	15,690	1,5998	16,529	1,6853	17,360	1,7701	18,171	1,8527	18,943	1,9315
14,586	1,4872	15,466	1,5770	16,353	1,6673	17,240	1,7578	18,120	1,8475	18,979	1,9351	19,798	2,0186
19,858	2,0248	20,872	2,1281	21,884	2,2313	22,889	2,3337	23,878	2,4346	24,836	2,5323	25,743	2,6248
16,748	1,7076	17,590	1,7935	18,429	1,8790	19,263	1,9640	20,082	2,0476	20,876	2,1285	21,626	2,2050
23,991	2,446	24,986	2,548	25,952	2,646	26,891	2,742	27,805	2,835	28,696	2,926	29,566	3,015
28,747	2,9311	30,000	3,0588	31,241	3,1854	32,466	3,3103	33,664	3,4324	34,818	3,5501	35,905	3,6608
22,828	2,3276	23,807	2,4273	24,776	2,5262	25,732	2,6236	26,666	2,7189	27,566	2,8106	28,412	2,8969
10,831	1,1044	11,475	1,1700	12,123	1,2361	12,771	1,3021	13,413	1,3676	14,040	1,4315	14,636	1,4923
20,745	2,1152	21,906	2,2335	23,070	2,3522	24,231	2,4706	25,379	2,5876	26,495	2,7015	27,555	2,8096
19,105	1,9480	20,158	2,0553	21,213	2,1629	22,265	2,2702	23,304	2,3761	24,313	2,4790	25,272	2,5767
23,976	2,4445	24,954	2,5443	25,921	2,6429	26,873	2,7400	27,802	2,8347	28,695	2,9257	29,533	3,0112
12,763	1,3013	13,456	1,3720	14,150	1,4427	14,841	1,5131	15,522	1,5827	16,185	1,6502	16,813	1,7143
10,816	1,1028	11,422	1,1645	12,029	1,2264	12,634	1,2882	13,232	1,3492	13,814	1,4085	14,367	1,4649
13,776	1,4046	14,479	1,4763	15,181	1,5478	15,878	1,6189	16,564	1,6888	17,229	1,7566	17,858	1,8208
34,535	3,5212	36,988	3,7713	39,482	4,0256	42,003	4,2826	44,524	4,5397	47,006	4,7927	49,388	5,0356
15,759	1,6068	16,381	1,6702	16,995	1,7328	17,598	1,7943	18,187	1,8543	18,752	1,9119	19,282	1,9660
16,940	1,7272	17,727	1,8075	18,509	1,8872	19,283	1,9661	20,042	2,0435	20,774	2,1181	21,465	2,1886
11,305	1,1527	11,744	1,1974	12,177	1,2415	12,602	1,2849	13,016	1,3271	13,414	1,3677	13,787	1,4057
18,180	1,8536	19,245	1,9622	20,315	2,0713	21,385	2,1804	22,444	2,2884	23,477	2,3937	24,460	2,4939
14,528	1,4813	15,225	1,5523	15,918	1,6230	16,605	1,6930	17,279	1,7618	17,931	1,8282	18,546	1,8909
22,884	2,3333	23,803	2,4269	24,710	2,5194	25,603	2,6104	26,473	2,6992	27,309	2,7845	28,094	2,8645
25,855	2,6362	26,893	2,7420	27,918	2,8465	28,926	2,9493	29,910	3,0496	30,854	3,1459	31,742	3,2364
9,516	0,9702	10,222	1,0422	10,942	1,1156	11,672	1,1901	12,404	1,2647	13,126	1,3383	13,821	1,4092
11,118	1,1336	11,668	1,1897	12,217	1,2456	12,761	1,3011	13,295	1,3556	13,812	1,4083	14,302	1,4582
11,816	1,2048	12,468	1,2712	13,120	1,3377	13,771	1,4041	14,413	1,4696	15,038	1,5332	15,630	1,5937
14,389	1,4671	15,311	1,5611	16,242	1,6561	17,178	1,7515	18,108	1,8463	19,019	1,9392	19,890	2,0279
9,994	1,0189	10,579	1,0786	11,167	1,1386	11,755	1,1986	12,338	1,2580	12,905	1,3158	13,446	1,3709

5.3 TABLES AND DIAGRAMS FOR CIRCUITS DIMENSIONING

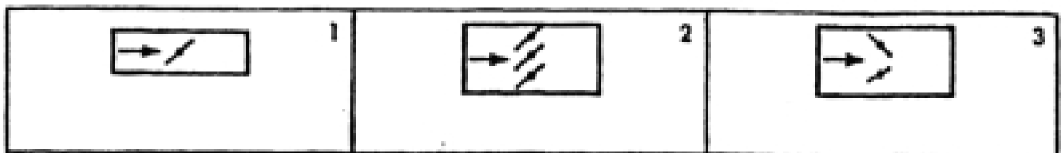
1.12 Distributed pressure drops in air circular ducts



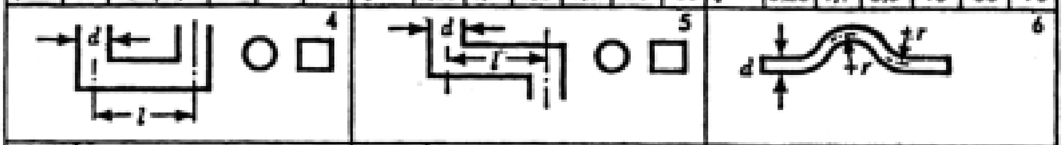
1.13 Equivalence between circular and rectangulare sections of air ducts



1.14 Air ducts dimensioning: loss coefficients for special pieces in circular and rectangular pieces



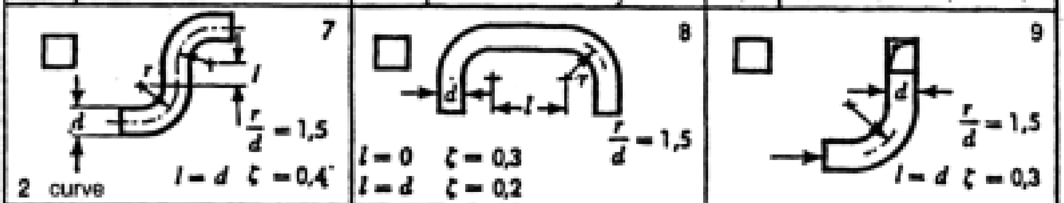
	1						2						3					
$\alpha°$ =	0	15	30	45	60	75	0	15	30	45	60	75	0	15	30	45	60	75
ζ =	0,25	0,6	3,5	17	95	600	0,25	0,7	2,2	6,5	20	60	0,25	1,1	3,3	10	30	90



4: l/d	1	2	3	4
ζ	3,5	1,7	1,6	1,7

5: l/d	0	0,5	1	2
ζ	0	1,6	1,9	2,1

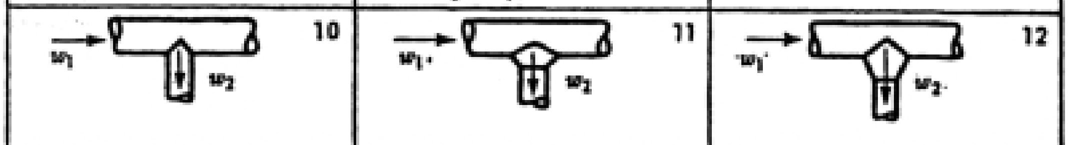
6: r/d	2	4	6	8
ζ	0,6	0,4	0,2	0,1



7: 2 curve; $\frac{r}{d} = 1,5$; $l = d$ $\zeta = 0,4$

8: $\frac{r}{d} = 1,5$; $l = 0$ $\zeta = 0,3$; $l = d$ $\zeta = 0,2$

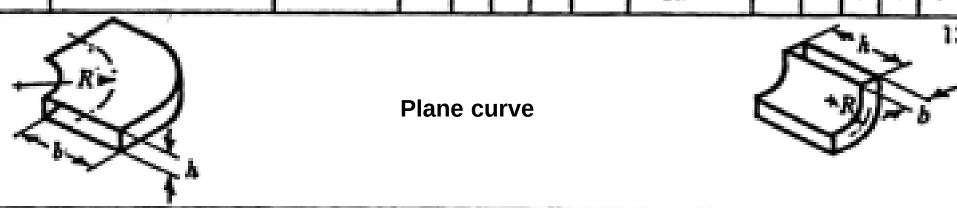
9: $\frac{r}{d} = 1,5$; $l = d$ $\zeta = 0,3$



10: w_2/w_1 =	0,4	0,6	0,8	1,0	1,5
ζ_{2st} =	7,0	3,4	2,0	1,5	0,9
ζ_{2d} =	1,5				

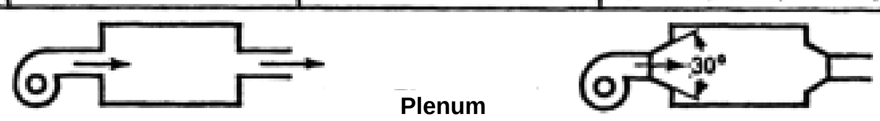
11: w_2/w_1 =	0,4	0,6	0,8	1,0	1,5
ζ_{2st} =	5,0	2,2	1,2	0,9	0,5
ζ_{2d} =	0	0,3	0,7	0,9	1,0

12: w_2/w_1 =	0,4	0,6	0,8	1,0	1,5
ζ_{2st} =	4,7	1,9	0,9	0,6	0,4
ζ_{2d} =	0	0	0,3	0,6	0,9



13: Plane curve

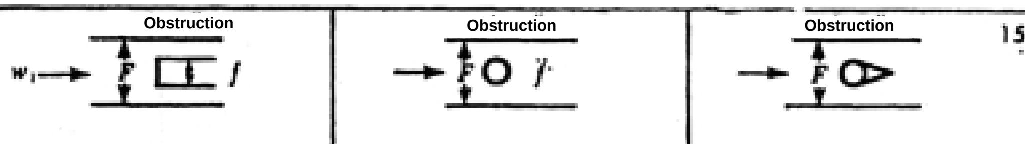
h/b =	0,25				0,50				0,75 … 3,0			
R/b =	0,75	1,0	1,5	2,0	0,75	1,0	1,5	2,0	0,75	1,0	1,5	2,0…3,0
ζ =	0,55	0,45	0,3	0,2	0,45	0,3	0,2	0,15	0,4	0,2	0,15	0,10



14: Plenum

$\zeta = 0,7 + 0,6 = 1,3$

$\zeta = 0,4 + 0,2 = 0,6$



15: Obstruction

f/F	0,1	0,2	0,3	0,4	0,5	0,1	0,2	0,3	0,4	0,5	0,1	0,2	0,3	0,4	0,5
ζ_1	0,7	1,0	1,8	2,9	4,0	0,2	0,4	0,75	1,3	2,0	0,07	0,15	0,35	0,6	0,9

1 — Cuve

R/D =	0,5	0,75	1,0	1,5	2	3	4
ζ =	0,9	0,43	0,33	0,24	0,19	0,17	0,15

2

R/D =	0,5	0,75	1,0	1,5	2
3 élém. ζ =	1,3	0,8	0,5	0,3	0,25
5 élém. ζ =	1,1	0,6	0,4	0,25	0,2

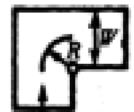
3 — Guiding fin

	R/W =	0,5	0,75	1	2
W1/W 0,25	ζ =	0,4	0,25	0,2	0,1
W1/W 0,5	ζ =	0,5	0,3	0,2	0,1

4

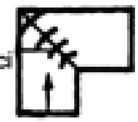
h/b =	0,25	0,5	1,0	2,0
ζ =	2,1	1,7	1,2	0,6

5



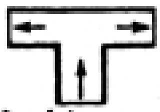
R/W =	0	0,2	0,4	0,6	0,8
ζ =	1,4	0,7	0,6	0,7	1,1

6



without fins	with fins
ζ = 0,35	0,1

7 — Bifurcation

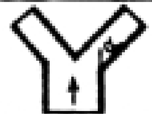


ζ = 1,4

8

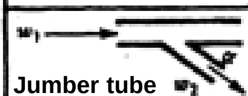
R/W =	0,5	0,75	1	1,5	2
○ ζ =	1,1	0,6	0,4	0,25	0,2
□ ζ =	1,0	0,5	0,25	0,15	0,1

9



α =	10	30	45	60	90°
○□ ζ =	0,1	0,3	0,7	1,0	1,4

10 — Jumber tube

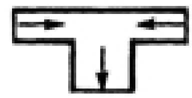


w_2/w_1 =	0,4	0,6	0,8	1,0	2,0	3,0
α = 60°	5,0	2,2	1,3	0,8	0,5	0,6
α = 45°	3,5	1,3	0,7	0,4	0,4	0,5

11

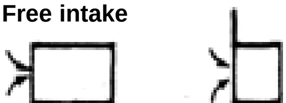
R/D =	0,5	0,75	1	1,5	2
ζ =	1,3	0,9	0,8	0,6	0,5

12



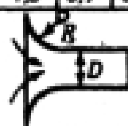
ζ = 1,4

13 — Free intake



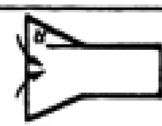
○ ζ =	0,9	0,6
□ ζ =	1,25	0,7

14



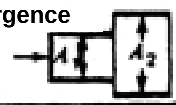
R/D =	0,25	0,5	0,75	1,0
ζ =	0,2	0,1	0,05	0,05

15



α =	15	30	45	60	90°
○□ ζ =	0,5	0,3	0,3	0,4	0,7

16 — Divergence

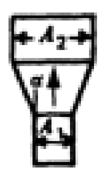


A_1/A_2 =	0	0,2	0,4	0,6	0,8	1,0
ζ_1 = (rapportato a F_1)	1,0	0,7	0,4	0,2	0,1	0

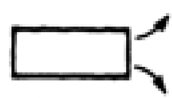
17

valori di ζ_1

A_1/A_2	α = 5°	7,5	10	15	20	>30
f = 0,5	0,07	0,09	0,13	0,21	0,27	0,28
0,33	0,11	0,16	0,22	0,36	0,48	0,50
0,25	0,13	0,20	0,28	0,46	0,62	0,63

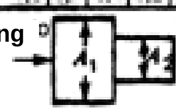


18



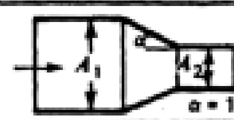
ζ = 1,0

19 — Narrowing



A_2/A_1 =	0	0,2	0,4	0,6	0,8	1,0
ζ_2 =	0,6	0,45	0,3	0,2	0,1	0

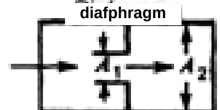
20



α = 10 ... 45°

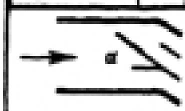
A_2/A_1 =	0,2	0,4	0,6	0,8	1,0
ζ_2 =	0,08	0,08	0,06	0,02	0

21 — diafphragm



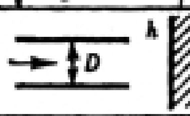
A_1/A_2 =	0,9	0,8	0,7	0,6	0,5	0,4
ζ =	0,06	0,28	0,78	1,82	3,8	8,1

22



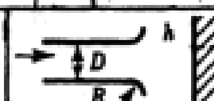
α =	0°	30°	45°	60°
ζ =	1	1,5	3,5	8

23



h/D =	0,2	0,4	0,6	0,8	1,0
ζ =	-	1,6	1,2	1,05	1,0

24



R/D = 0,5

h/D =	0,1	0,2	0,4	0,6	0,8	1,0
ζ =	0,7	0,4	0,7	0,8	0,8	0,8

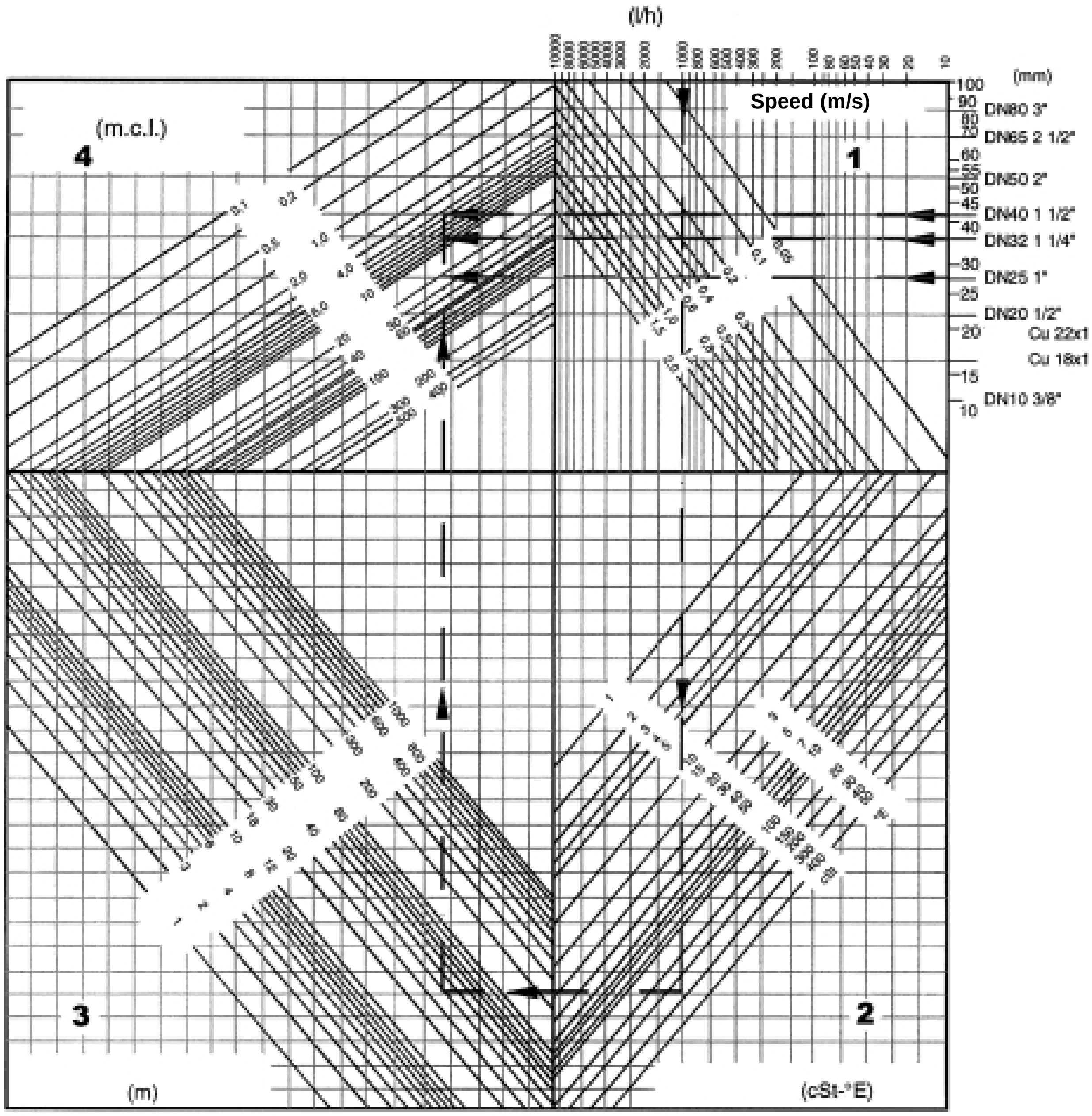
25 — Drilled metal sheets

free section in %	10	20	30	40	50	60	70	80
ζ for w = 0,5 m/s	110	30	12	6	3,6	2,3	1,8	1,4
1,0	120	33	13	6,8	4,1	2,7	2,1	1,6
1,5	128	36	14,5	7,4	4,6	3,0	2,3	1,8
2,0	134	39	15,5	7,8	4,9	3,2	2,5	1,9
2,5	140	40	16,5	8,3	5,2	3,4	2,6	2,0
3,0	146	41	17,5	8,6	5,5	3,7	2,8	2,1

w is referred to the total section

for net grilles ζ values are about a half

1.15 Distributed pressure drops in air pipelines for liquid and gaseous fuels

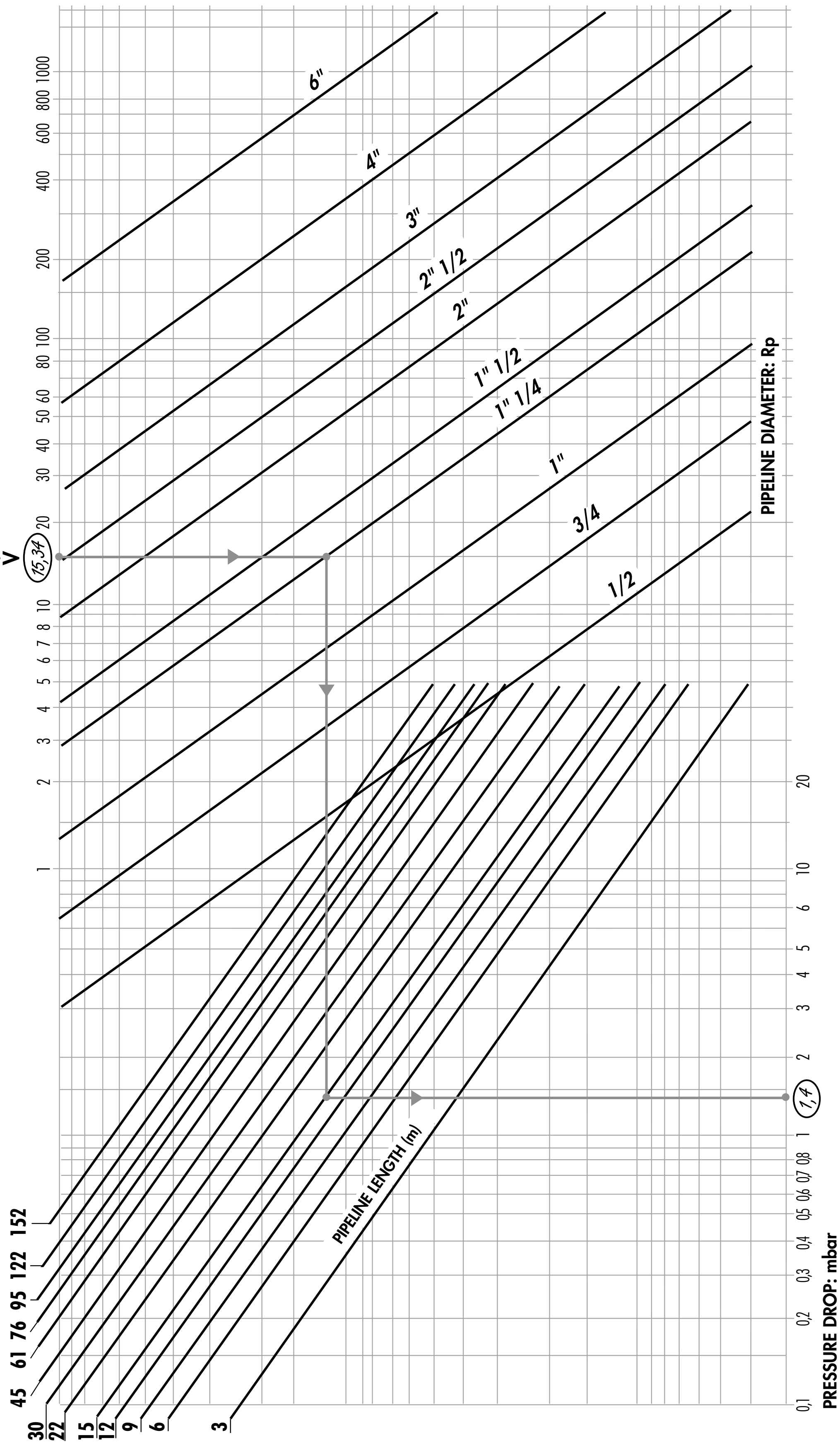


PROCEDURE

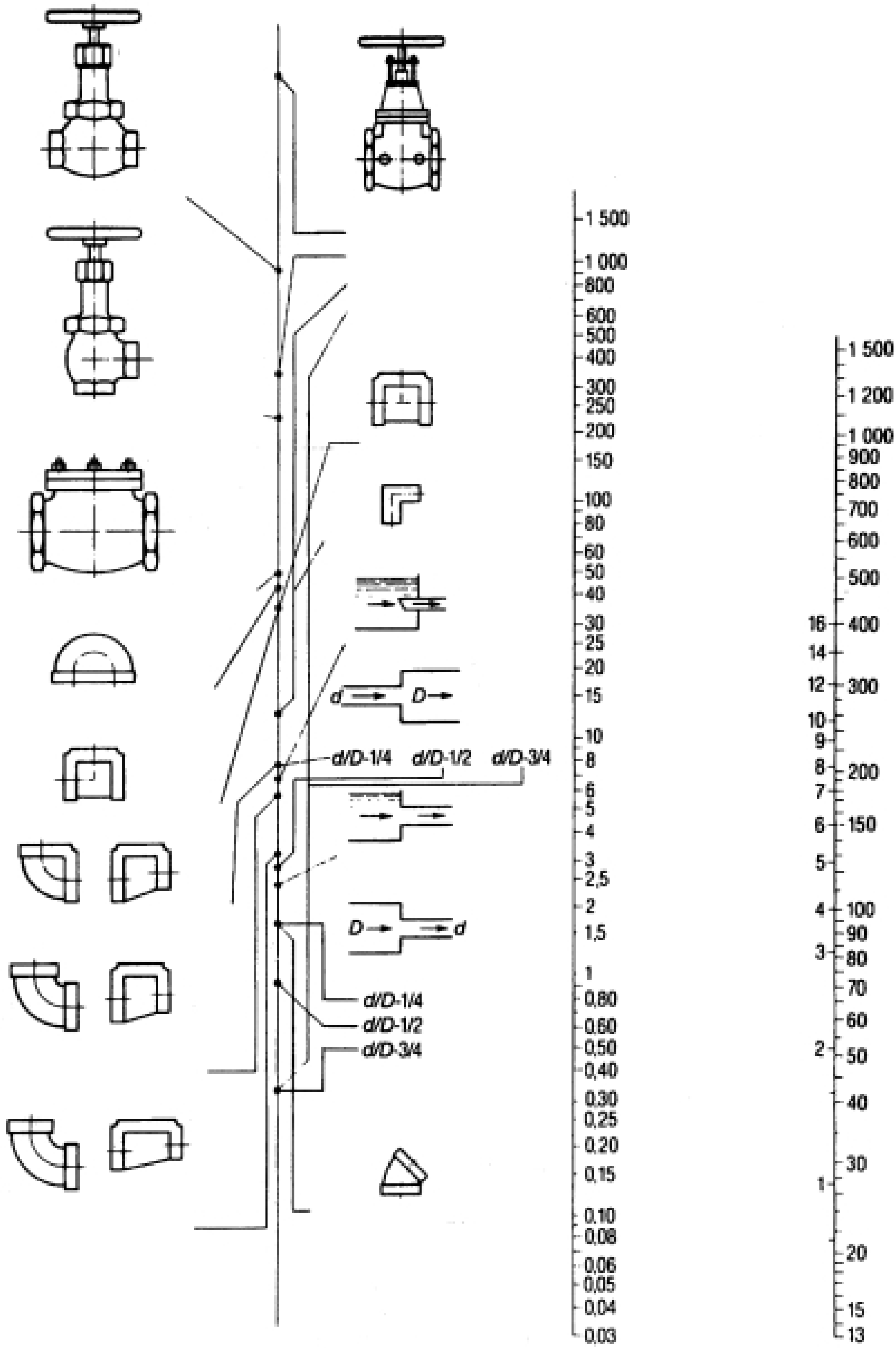
1) Individuate on the horizontal axis at the top of square "1" fuel oil delivery required
2) Go down vertically until intersecating in square "2" the oblique line corresponding to oil viscosity at ref. temperature: two scales, in cSt and °E, are reported.
3) From intersection point proceed horizontally in the left direction until intersecating in square "3" the oblique line corresponding to pipeline lenght
4) From intersection point proceed upwards until intersecating in square "4" the oblique lines corresponding to different pressure drops in m c. H_2O
5) At this point it is possible to procced in two ways: or it is prefixed max. pressure drop; then from intersection point with oblique line proceed horizontally in the right direction and on vertical axis of square "1" read pipeline diameter (mm and inches are reported). Otherwise from pipeline diameter, pressure drops are obtained with opposite procedure.

$$\dot{V} = \frac{\text{Gas delivery } [Nm^3/h]}{f}$$

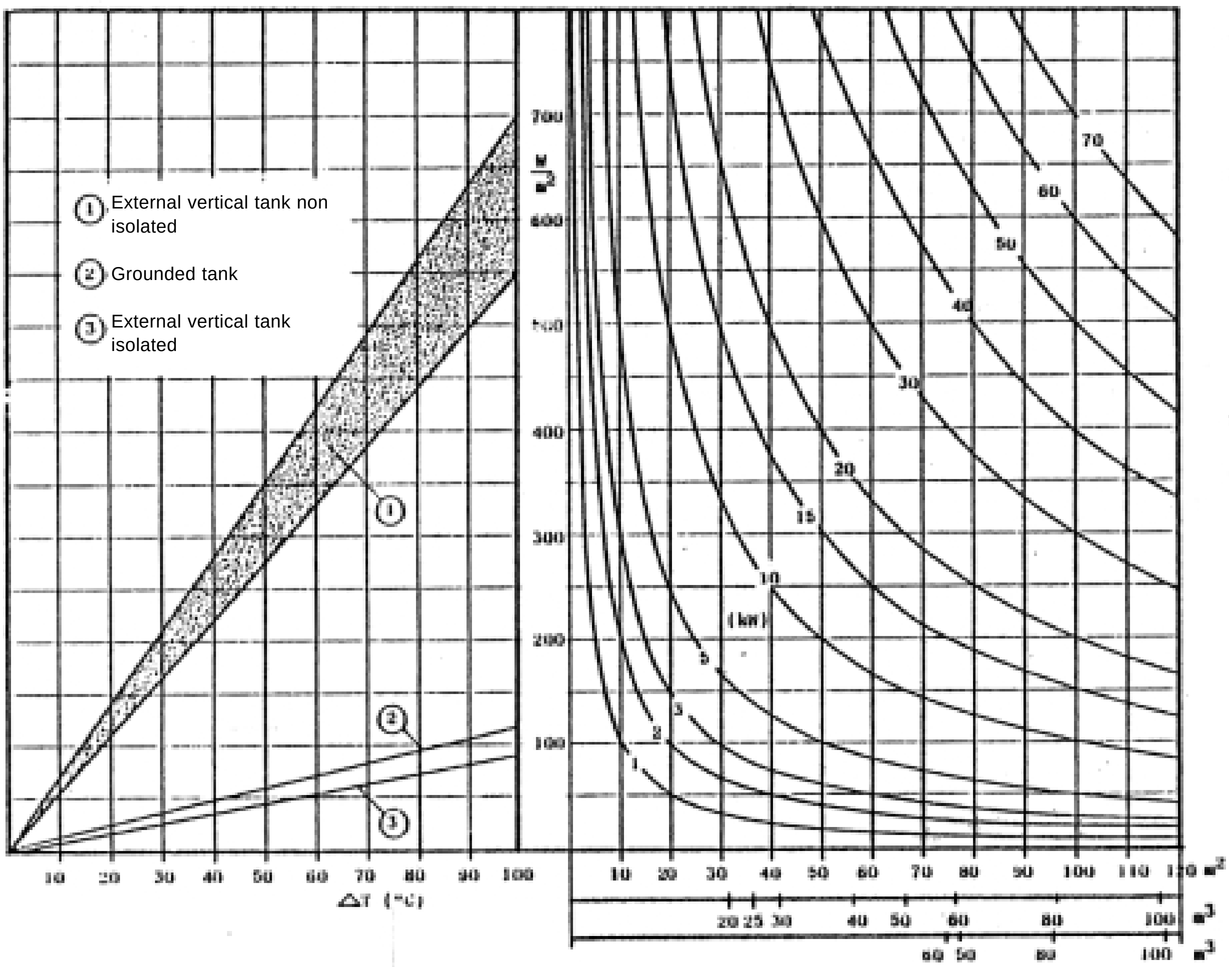
$$f = \begin{cases} 1 & \text{- G20} \\ 0{,}62 & \text{- G25} \\ 1{,}18 & \text{- G31} \end{cases}$$



1.16 Liquid fuel feeding circuit dimensioning: equivalent lenght of main concentrated resistances



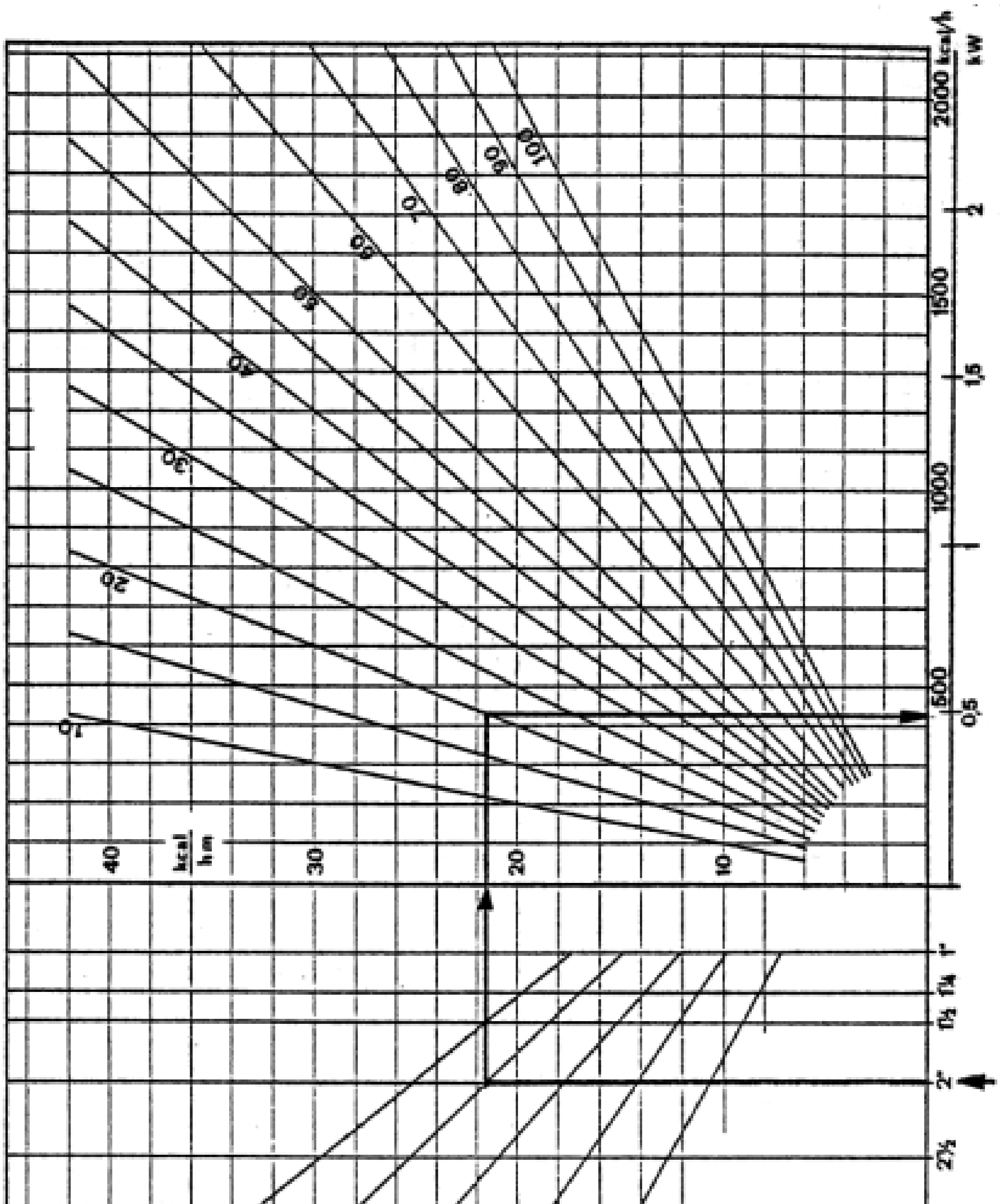
1.17 Dispersion of heavy oil tanks



PROCEDURE

1) Individuated on the left horizontal axis project ΔT (difference between heavy oil temperature and min. external), trace a vertical line until intersecating line relative to the specific tank. Zone 1 correspond to non isolated vertical tanks, line 2 is relative to horizontal grounded tanks and line 3 to vertical isolated tanks,
2) From intersection point proceed horizontally in the right direction and individuate on vertical axis the dispersion for m^2 of tank external surface;
3) Evaluated external surface of tank, individuate the value on right horizontal axis; if this value is missing, make use of bottom axis where volume of vertical and horizontal tanks is reported (typical commercial values);
4) Trace vertical until intersecating previous horizontal line relative to dispersion for m2 of tank;
5) The line correspondant to intersection point represents dispersions of tank when it is completely full of preheated heavy oil.

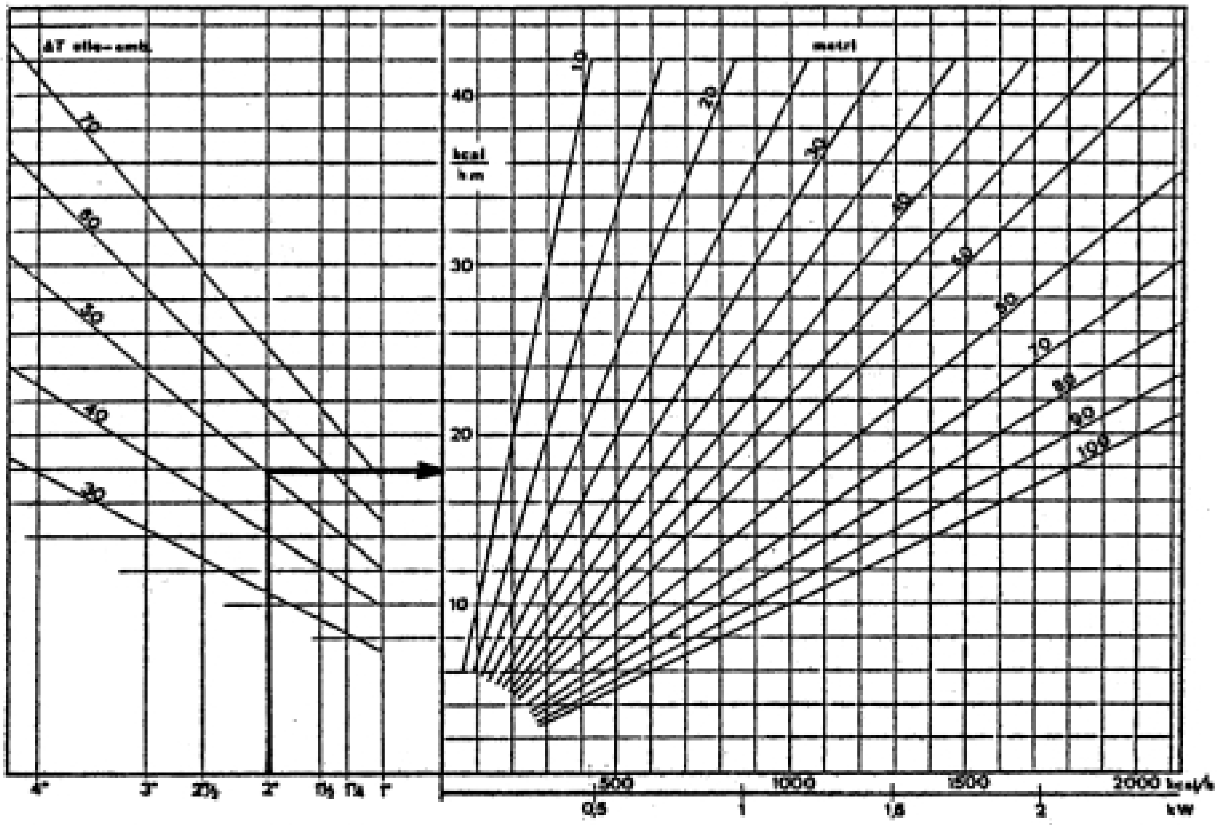
1.18 Compensation of thermal dispersions in steady condition

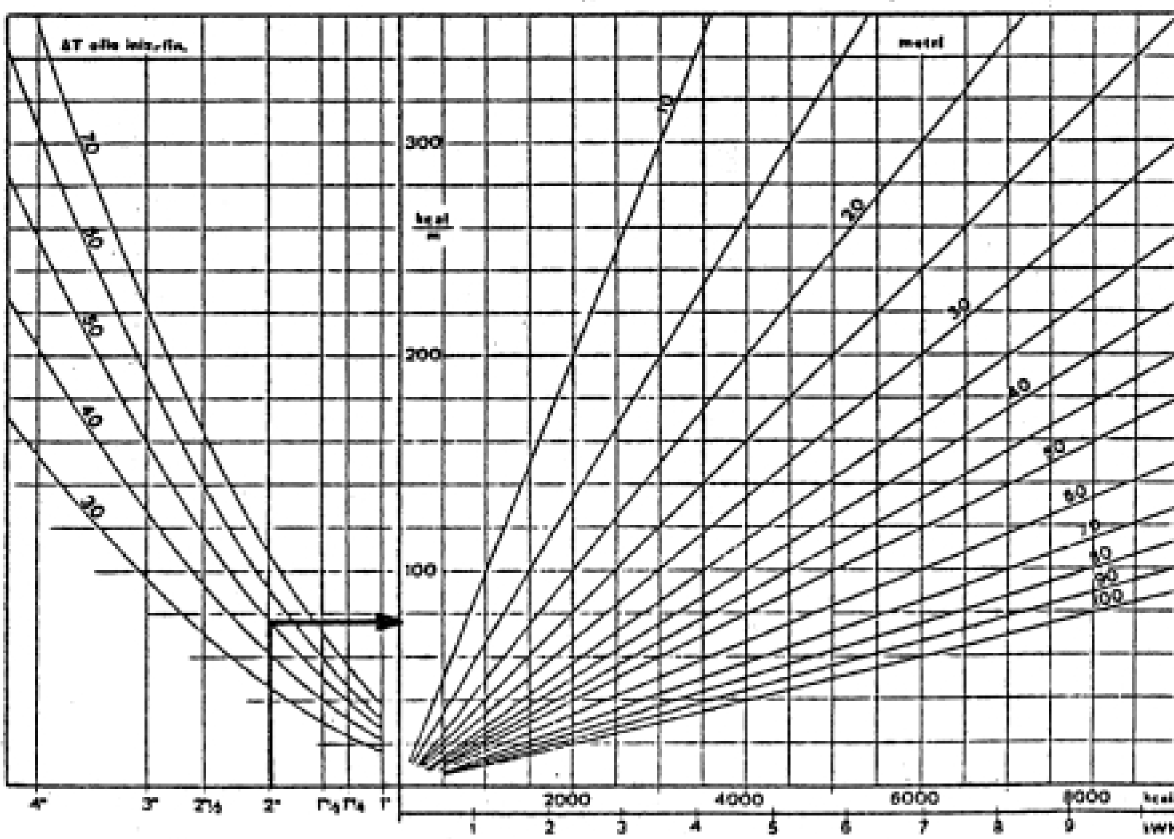


PROCEDURE

1) Individuate on the left horizontal axis pipeline diameter,
2) Trace vertical until intersecating oblique line correspondant to project ΔT between heavy oil and external temperature;
3) Trace from intersection point an horizontal line in the right direction and evaluate on vertical axis dispersion for 1 m of pipeline;
4) Extend horizontal line until intersecating oblique line relative to pipeline lenght;
5) Trace vertical and read on the right horizontal axis the total output required.

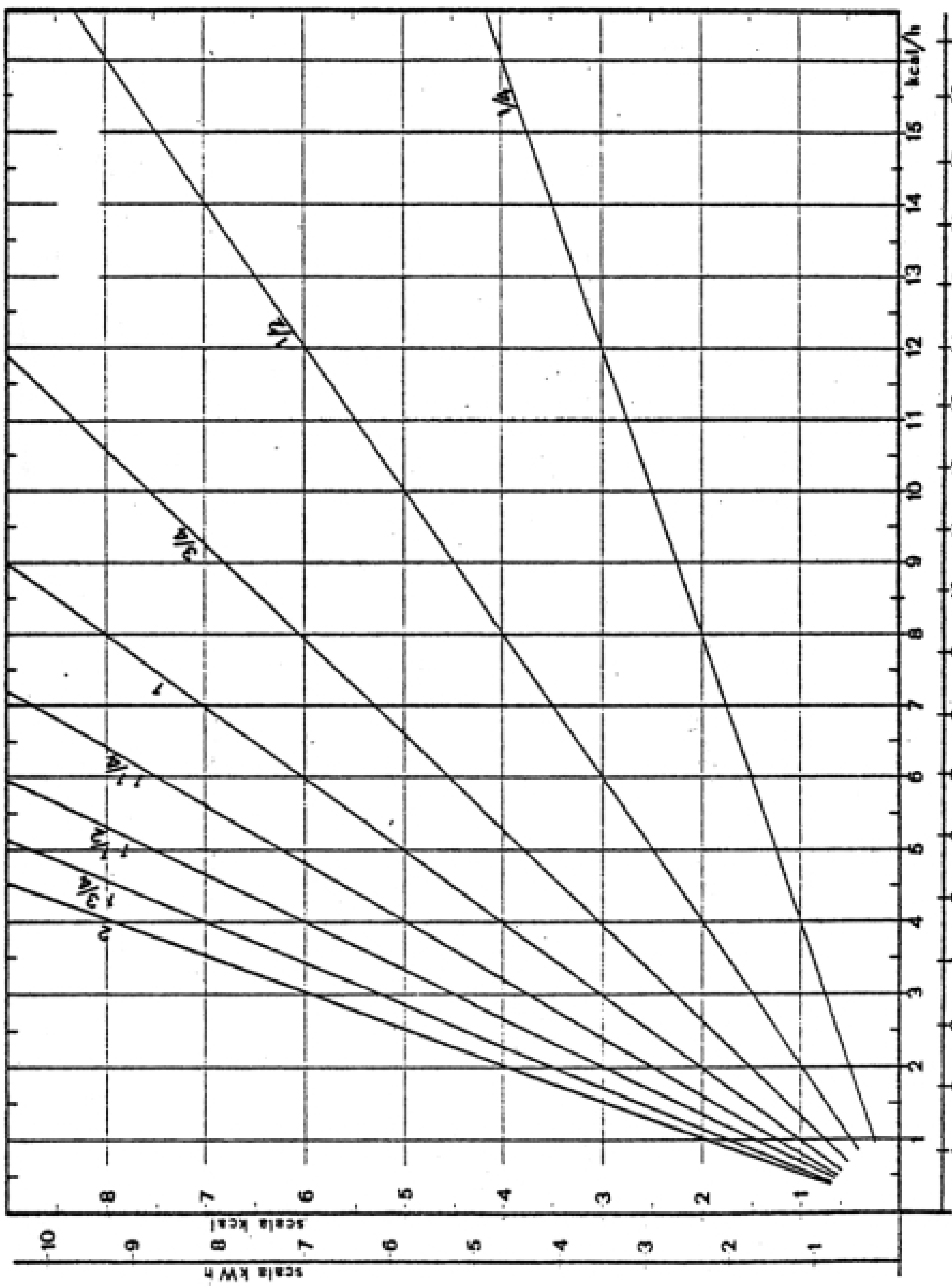
1.19 Calculation of total needed output





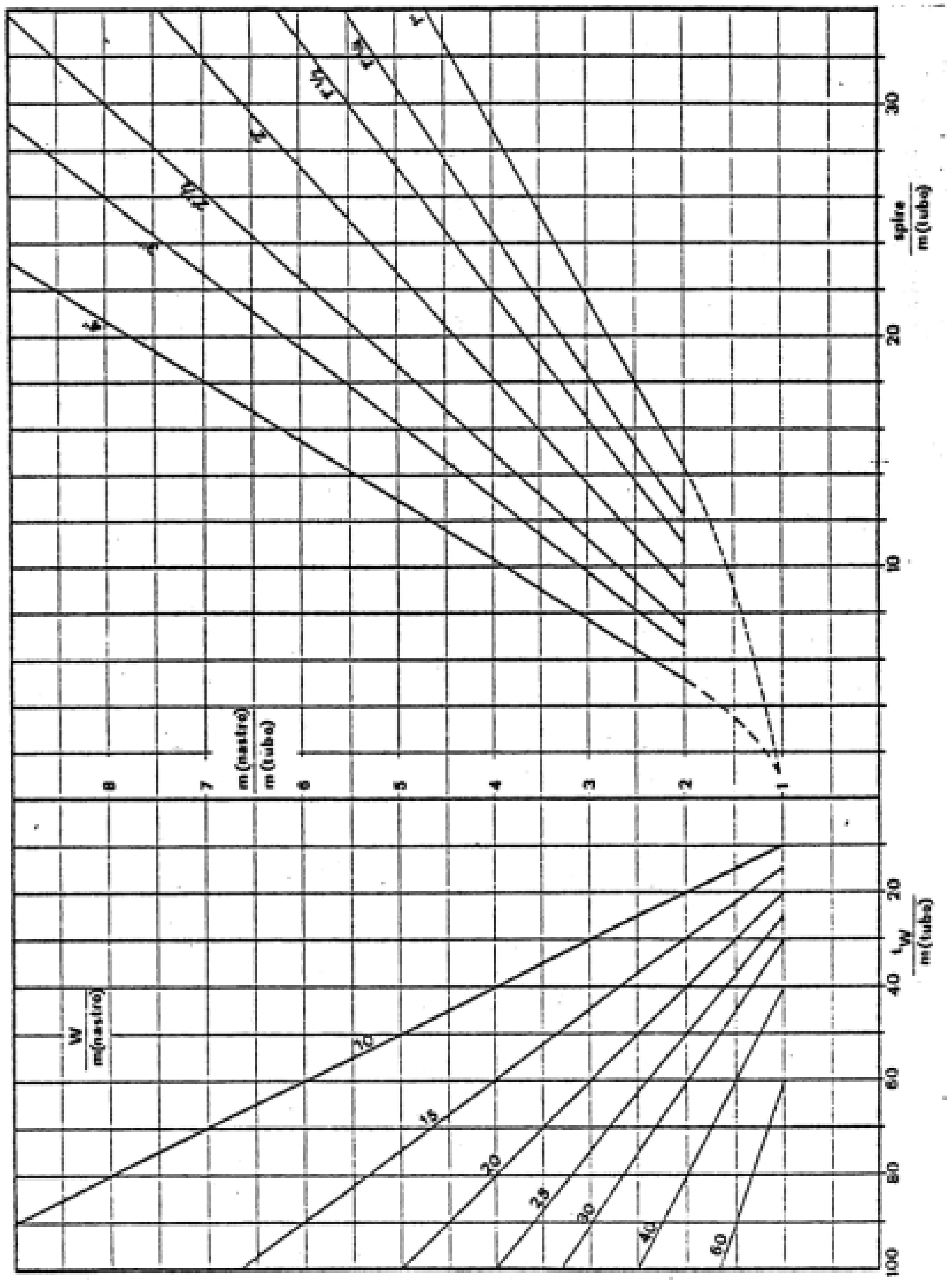
NOTE: The diagram at the bottom, similar to the previous one from a functional point of view, allows to calculate the energy required from a system with oil preheating to reach the steady state.

1.20 Diagram for passing from energy to output



NOTE: The diagram allows, once knew energy to reach steady state, to calculate output, which depends from warm-up time (represented in hours from oblique lines).

1.21 Diagram for pipelines tracing with heating bands



PROCEDURE

1) Individuate on the left horizontal axis necessary output for 1 m of pipekine
2) Trace a vertical line until intersecating oblique line relative to linear output dispersed from the band;
3) From intersection point proceed horizontally in the right direction and individuate on vertical axis the band lenght for 1 m of pipeline;
4) Extend horizontal line until intersecating oblique line relative to pipeline diameter;
5) Trace vertical and on the right horizontal axis read approximatively the number of turns for 1 m of pipeline.

1.22 Nozzle delivery with liquid fuels

Effective delivery (kg/h) of nozzles for light oil at 25°C						
	Fuel atomization pressure (bar)					
Nozzle nominal delivery (GPH)	10	11	12	13	14	15
0,4	1,41	1,48	1,55	1,62	1,69	1,75
0,5	1,76	1,85	1,94	2,02	2,11	2,19
0,55	1,93	2,03	2,13	2,23	2,32	2,41
0,6	2,11	2,22	2,33	2,43	2,53	2,62
0,65	2,28	2,40	2,52	2,63	2,74	2,84
0,75	2,64	2,77	2,91	3,04	3,16	3,28
0,85	2,99	3,14	3,30	3,44	3,58	3,72
1	3,51	3,70	3,88	4,05	4,21	4,37
1,1	3,87	4,07	4,27	4,45	4,64	4,81
1,25	4,39	4,62	4,85	5,06	5,27	5,47
1,35	4,74	4,99	5,24	5,47	5,69	5,91
1,5	5,27	5,55	5,82	6,07	6,32	6,56
1,65	5,80	6,10	6,40	6,68	6,95	7,22
1,75	6,15	6,47	6,79	7,09	7,38	7,66
2	7,03	7,40	7,76	8,10	8,43	8,75
2,25	7,91	8,32	8,73	9,11	9,48	9,84
2,5	8,79	9,25	9,69	10,12	10,54	10,94
2,75	9,66	10,17	10,66	11,14	11,59	12,03
3	10,54	11,10	11,63	12,15	12,64	13,12
3,25	11,42	12,02	12,60	13,16	13,70	14,22
3,5	12,30	12,95	13,57	14,17	14,75	15,31
4	14,06	14,80	15,51	16,20	16,86	17,50
4,5	15,81	16,65	17,45	18,22	18,96	19,68
5	17,57	18,50	19,39	20,25	21,07	21,87
5,5	19,33	20,35	21,33	22,27	23,18	24,06
6	21,09	22,20	23,27	24,29	25,29	26,25
6,5	22,84	24,05	25,21	26,32	27,39	28,43
7	24,60	25,90	27,14	28,34	29,50	30,62
7,5	26,36	27,75	29,08	30,37	31,61	32,81
8	28,11	29,60	31,02	32,39	33,72	35,00
8,5	29,87	31,45	32,96	34,42	35,82	37,18
9	31,63	33,30	34,90	36,44	37,93	39,37
9,5	33,39	35,15	36,84	38,47	40,04	41,56
10	35,14	37,00	38,78	40,49	42,14	43,74
10,5	36,90	38,85	40,72	42,52	44,25	45,93
11	38,66	40,70	42,66	44,54	46,36	48,12
11,5	40,41	42,55	44,59	46,56	48,47	50,31
12	42,17	44,40	46,53	48,59	50,57	52,49
13	45,68	48,10	50,41	52,64	54,79	56,87
13,5	47,44	49,95	52,35	54,66	56,89	59,05
14	49,20	51,80	54,29	56,69	59,00	61,24
15	52,71	55,50	58,17	60,74	63,22	65,62
15,5	54,47	57,35	60,11	62,76	65,32	67,80
16	56,23	59,20	62,05	64,79	67,43	69,99
17	59,74	62,90	65,92	68,83	71,65	74,36
17,5	61,50	64,75	67,86	70,86	73,75	76,55
18	63,26	66,60	69,80	72,88	75,86	78,74
19	66,77	70,30	73,68	76,93	80,07	83,11
19,5	68,53	72,15	75,62	78,96	82,18	85,30
20	70,28	74,00	77,56	80,98	84,29	87,49
21,5	75,56	79,55	83,37	87,06	90,61	94,05
22	77,31	81,40	85,31	89,08	92,72	96,24
24	84,34	88,80	93,07	97,18	101,15	104,99
26	91,37	96,20	100,82	105,28	109,58	113,73
28	98,40	103,60	108,58	113,37	118,00	122,48
30	105,43	110,99	116,33	121,47	126,43	131,23
32	112,46	118,39	124,09	129,57	134,86	139,98
33	115,97	122,09	127,97	133,62	139,08	144,36
35	123,00	129,49	135,72	141,72	147,50	153,10
36	126,51	133,19	139,60	145,77	151,72	157,48
40	140,57	147,99	155,11	161,96	168,58	174,98
45	158,14	166,49	174,50	182,21	189,65	196,85
50	175,71	184,99	193,89	202,46	210,72	218,72

Effective delivery (kg/h) of nozzles for Heavy oil (3-5°E at 50°C) at 120°C						
	Fuel atomization pressure (bar)					
Nozzle nominal delivery (GPH)	**18**	**19,5**	**21**	**22,5**	**24**	**25,5**
0,4	1,99	2,08	2,17	2,25	2,33	2,41
0,5	2,49	2,60	2,71	2,81	2,91	3,01
0,55	2,74	2,86	2,98	3,09	3,20	3,31
0,6	2,99	3,12	3,25	3,37	3,49	3,61
0,65	3,24	3,38	3,52	3,65	3,78	3,91
0,75	3,74	3,90	4,06	4,22	4,37	4,51
0,85	4,24	4,42	4,60	4,78	4,95	5,11
1	4,98	5,20	5,42	5,62	5,82	6,02
1,1	5,48	5,73	5,96	6,19	6,40	6,62
1,25	6,23	6,51	6,77	7,03	7,28	7,52
1,35	6,73	7,03	7,31	7,59	7,86	8,12
1,5	7,48	7,81	8,13	8,43	8,73	9,02
1,65	8,22	8,59	8,94	9,28	9,61	9,93
1,75	8,72	9,11	9,48	9,84	10,19	10,53
2	9,97	10,41	10,83	11,25	11,64	12,03
2,25	11,22	11,71	12,19	12,65	13,10	13,54
2,5	12,46	13,01	13,54	14,06	14,56	15,04
2,75	13,71	14,31	14,90	15,46	16,01	16,54
3	14,95	15,61	16,25	16,87	17,47	18,05
3,25	16,20	16,92	17,61	18,27	18,92	19,55
3,5	17,45	18,22	18,96	19,68	20,38	21,06
4	19,94	20,82	21,67	22,49	23,29	24,06
4,5	22,43	23,42	24,38	25,30	26,20	27,07
5	24,92	26,02	27,09	28,11	29,11	30,08
5,5	27,42	28,63	29,80	30,93	32,02	33,09
6	29,91	31,23	32,50	33,74	34,93	36,10
6,5	32,40	33,83	35,21	36,55	37,85	39,11
7	34,89	36,43	37,92	39,36	40,76	42,11
7,5	37,38	39,04	40,63	42,17	43,67	45,12
8	39,88	41,64	43,34	44,98	46,58	48,13
8,5	42,37	44,24	46,05	47,80	49,49	51,14
9	44,86	46,84	48,76	50,61	52,40	54,15
9,5	47,35	49,45	51,46	53,42	55,31	57,15
10	49,85	52,05	54,17	56,23	58,22	60,16
10,5	52,34	54,65	56,88	59,04	61,14	63,17
11	54,83	57,25	59,59	61,85	64,05	66,18
11,5	57,32	59,86	62,30	64,66	66,96	69,19
12	59,82	62,46	65,01	67,48	69,87	72,19
13	64,80	67,66	70,43	73,10	75,69	78,21
13,5	67,29	70,27	73,13	75,91	78,60	81,22
14	69,79	72,87	75,84	78,72	81,51	84,23
15	74,77	78,07	81,26	84,34	87,34	90,24
15,5	77,26	80,67	83,97	87,16	90,25	93,25
16	79,75	83,28	86,68	89,97	93,16	96,26
17	84,74	88,48	92,09	95,59	98,98	102,27
17,5	87,23	91,08	94,80	98,40	101,89	105,28
18	89,72	93,69	97,51	101,21	104,80	108,29
19	94,71	98,89	102,93	106,84	110,63	114,31
19,5	97,20	101,49	105,64	109,65	113,54	117,32
20	99,69	104,10	108,35	112,46	116,45	120,32
21,5	107,17	111,90	116,47	120,89	125,18	129,35
22	109,66	114,51	119,18	123,71	128,09	132,36
24	119,63	124,92	130,02	134,95	139,74	144,39
26	129,60	135,33	140,85	146,20	151,38	156,42
28	139,57	145,74	151,69	157,44	163,03	168,45
30	149,54	156,14	162,52	168,69	174,67	180,48
32	159,51	166,55	173,35	179,94	186,32	192,52
33	164,49	171,76	178,77	185,56	192,14	198,53
35	174,46	182,17	189,61	196,80	203,78	210,57
36	179,45	187,37	195,02	202,43	209,61	216,58
40	199,39	208,19	216,69	224,92	232,90	240,65
45	224,31	234,22	243,78	253,03	262,01	270,73
50	249,23	260,24	270,87	281,15	291,12	300,81

Effective delivery (kg/h) of nozzles for kerosene at 25°C					
	Fuel atomization pressure (bar)				
Nozzle nominal delivery (GPH)	**8**	**9**	**10**	**11**	**12**
0,4	1,17	1,25	1,32	1,39	1,46
0,5	1,46	1,56	1,65	1,74	1,82
0,55	1,61	1,71	1,81	1,91	2,00
0,6	1,75	1,87	1,98	2,08	2,18
0,65	1,90	2,03	2,14	2,26	2,37
0,75	2,19	2,34	2,47	2,61	2,73
0,85	2,49	2,65	2,80	2,95	3,09
1	2,92	3,12	3,30	3,47	3,64
1,1	3,22	3,43	3,63	3,82	4,00
1,25	3,66	3,90	4,12	4,34	4,55
1,35	3,95	4,21	4,45	4,69	4,91
1,5	4,39	4,68	4,95	5,21	5,46
1,65	4,83	5,14	5,44	5,73	6,01
1,75	5,12	5,45	5,77	6,08	6,37
2	5,85	6,23	6,60	6,95	7,28
2,25	6,58	7,01	7,42	7,82	8,19
2,5	7,31	7,79	8,25	8,68	9,10
2,75	8,04	8,57	9,07	9,55	10,01
3	8,77	9,35	9,90	10,42	10,92
3,25	9,51	10,13	10,72	11,29	11,83
3,5	10,24	10,91	11,55	12,16	12,74
4	11,70	12,47	13,20	13,89	14,56
4,5	13,16	14,03	14,85	15,63	16,38
5	14,62	15,58	16,50	17,37	18,20
5,5	16,09	17,14	18,15	19,10	20,02
6	17,55	18,70	19,80	20,84	21,84
6,5	19,01	20,26	21,44	22,58	23,66
7	20,47	21,82	23,09	24,31	25,48
7,5	21,94	23,38	24,74	26,05	27,30
8	23,40	24,93	26,39	27,79	29,12
8,5	24,86	26,49	28,04	29,52	30,94
9	26,32	28,05	29,69	31,26	32,77
9,5	27,78	29,61	31,34	33,00	34,59
10	29,25	31,17	32,99	34,73	36,41
10,5	30,71	32,73	34,64	36,47	38,23
11	32,17	34,28	36,29	38,21	40,05
11,5	33,63	35,84	37,94	39,94	41,87
12	35,10	37,40	39,59	41,68	43,69
13	38,02	40,52	42,89	45,15	47,33
13,5	39,48	42,08	44,54	46,89	49,15
14	40,95	43,63	46,19	48,63	50,97
15	43,87	46,75	49,49	52,10	54,61
15,5	45,33	48,31	51,14	53,84	56,43
16	46,79	49,87	52,79	55,58	58,25
17	49,72	52,98	56,09	59,05	61,89
17,5	51,18	54,54	57,74	60,79	63,71
18	52,64	56,10	59,39	62,52	65,53
19	55,57	59,22	62,69	66,00	69,17
19,5	57,03	60,78	64,33	67,73	70,99
20	58,49	62,33	65,98	69,47	72,81
21,5	62,88	67,01	70,93	74,68	78,27
22	64,34	68,57	72,58	76,42	80,09
24	70,19	74,80	79,18	83,36	87,37
26	76,04	81,04	85,78	90,31	94,65
28	81,89	87,27	92,38	97,26	101,94
30	87,74	93,50	98,98	104,20	109,22
32	93,59	99,74	105,57	111,15	116,50
33	96,51	102,85	108,87	114,62	120,14
35	102,36	109,09	115,47	121,57	127,42
36	105,29	112,20	118,77	125,04	131,06
40	116,99	124,67	131,97	138,94	145,62
45	131,61	140,25	148,46	156,31	163,83
50	146,23	155,84	164,96	173,67	182,03

Effective delivery (kg/h) of nozzles for BioDiesel at 25°C						
	Fuel atomization pressure (bar)					
Nozzle nominal delivery (GPH)	10	11	12	13	14	15
0,4	1,58	1,66	1,74	1,82	1,89	1,97
0,5	1,97	2,08	2,18	2,27	2,37	2,46
0,55	2,17	2,29	2,40	2,50	2,60	2,70
0,6	2,37	2,49	2,61	2,73	2,84	2,95
0,65	2,57	2,70	2,83	2,96	3,08	3,19
0,75	2,96	3,12	3,27	3,41	3,55	3,69
0,85	3,36	3,53	3,70	3,87	4,02	4,18
1	3,95	4,16	4,36	4,55	4,73	4,91
1,1	4,34	4,57	4,79	5,00	5,21	5,40
1,25	4,93	5,19	5,44	5,69	5,92	6,14
1,35	5,33	5,61	5,88	6,14	6,39	6,63
1,5	5,92	6,23	6,53	6,82	7,10	7,37
1,65	6,51	6,86	7,19	7,50	7,81	8,11
1,75	6,91	7,27	7,62	7,96	8,28	8,60
2	7,89	8,31	8,71	9,10	9,47	9,83
2,25	8,88	9,35	9,80	10,23	10,65	11,06
2,5	9,87	10,39	10,89	11,37	11,83	12,28
2,75	10,86	11,43	11,98	12,51	13,02	13,51
3	11,84	12,47	13,07	13,64	14,20	14,74
3,25	12,83	13,51	14,16	14,78	15,39	15,97
3,5	13,82	14,55	15,25	15,92	16,57	17,20
4	15,79	16,62	17,42	18,19	18,94	19,65
4,5	17,76	18,70	19,60	20,47	21,30	22,11
5	19,74	20,78	21,78	22,74	23,67	24,57
5,5	21,71	22,86	23,96	25,01	26,04	27,02
6	23,68	24,94	26,13	27,29	28,40	29,48
6,5	25,66	27,01	28,31	29,56	30,77	31,94
7	27,63	29,09	30,49	31,84	33,14	34,40
7,5	29,61	31,17	32,67	34,11	35,50	36,85
8	31,58	33,25	34,85	36,39	37,87	39,31
8,5	33,55	35,32	37,02	38,66	40,24	41,77
9	35,53	37,40	39,20	40,93	42,60	44,22
9,5	37,50	39,48	41,38	43,21	44,97	46,68
10	39,47	41,56	43,56	45,48	47,34	49,14
10,5	41,45	43,64	45,74	47,76	49,71	51,59
11	43,42	45,71	47,91	50,03	52,07	54,05
11,5	45,39	47,79	50,09	52,30	54,44	56,51
12	47,37	49,87	52,27	54,58	56,81	58,96
13	51,32	54,03	56,63	59,13	61,54	63,88
13,5	53,29	56,10	58,80	61,40	63,91	66,33
14	55,26	58,18	60,98	63,67	66,27	68,79
15	59,21	62,34	65,34	68,22	71,01	73,70
15,5	61,18	64,42	67,51	70,50	73,38	76,16
16	63,16	66,49	69,69	72,77	75,74	78,62
17	67,11	70,65	74,05	77,32	80,48	83,53
17,5	69,08	72,73	76,23	79,59	82,84	85,99
18	71,05	74,81	78,40	81,87	85,21	88,44
19	75,00	78,96	82,76	86,42	89,94	93,36
19,5	76,97	81,04	84,94	88,69	92,31	95,81
20	78,95	83,12	87,12	90,96	94,68	98,27
21,5	84,87	89,35	93,65	97,79	101,78	105,64
22	86,84	91,43	95,83	100,06	104,15	108,10
24	94,74	99,74	104,54	109,16	113,61	117,93
26	102,63	108,05	113,25	118,25	123,08	127,75
28	110,53	116,36	121,96	127,35	132,55	137,58
30	118,42	124,68	130,67	136,45	142,02	147,41
32	126,32	132,99	139,38	145,54	151,48	157,23
33	130,26	137,14	143,74	150,09	156,22	162,15
35	138,16	145,45	152,45	159,19	165,69	171,98
36	142,11	149,61	156,81	163,73	170,42	176,89
40	157,89	166,23	174,23	181,93	189,36	196,54
45	177,63	187,01	196,01	204,67	213,02	221,11
50	197,37	207,79	217,79	227,41	236,69	245,68

1.23 Commercial features of steel and copper pipelines

							SECTION (cm²)			Length for	Length for
	DN	Weight mm	SP mm	DINT mm	Weight kg/m	Vol. ext. l/m	VOL. INT. (l/m)	SUP. EST m²/m	SUP. INT. m²/m	SUP. EST. m/m²	SUP. INT. m/m²
	100	108	**3,6**	100,8	9,26	9,16	7,98	0,34	0,3165	2,95	3,16
			4	100	10,25		7,85		0,314		3,18
			4,5	99	11,48		7,69		0,3109		3,22
4"	100	114,3	**3,6**	107,1	9,82	10,26	9,00	0,36	0,3363	2,79	2,97
			4	106,3	10,88		8,87		0,3338		3,00
			4,5	105,3	12,18		8,70		0,3306		3,02
			5	104,3	13,47		8,54		0,3275		3,05
	125	133	3,6	125,8	11,48	13,89	12,42	0,42	0,395	2,39	2,53
			4	125	12,72		12,27		0,3925		2,55
			4,5	124	14,25		12,07		0,3894		2,57
			5	123	15,78		11,88		0,3862		2,59
5"	125	139,7	3,6	132,5	12,08	15,32	13,78	0,44	0,4161	2,28	2,40
			4	131,7	13,38		13,62		0,4135		2,42
			4,5	130,7	15,00		13,41		0,4104		2,44
			5	129,7	16,60		13,21		0,4073		2,46
	150	159	3,6	151,8	13,79	19,85	18,09	0,50	0,4767	2,00	2,10
			4	151	15,28		17,90		0,4741		2,11
			4,5	150	17,14		17,66		0,471		2,12
			5	149	18,98		17,43		0,4679		2,14
6"	150	168,3	3,6	161,1	14,61	22,24	20,37	0,53	0,5059	1,89	1,98
			4	160,3	16,20		20,17		0,5033		1,99
			4,5	159,3	18,17		19,92		0,5002		2,00
			5	158,3	20,13		19,67		0,4971		2,01
	175	193,7	4,5	184,7	20,99	29,45	26,78	0,61	0,58	1,64	1,72
			5,4	182,9	25,06		26,26		0,5743		1,74
	200	219,1	5	209,1	26,39	37,68	34,32	0,69	0,6566	1,45	1,52
			5,9	207,3	31,01		33,73		0,6509		1,54
	250	273	5,4	262,2	35,62	58,51	53,97	0,86	0,8233	1,17	1,21
			5,9	261,2	38,84		53,56		0,8202		1,22
			6,3	260,4	41,42		53,23		0,8177		1,22
	300	323,9	5,9	312,1	46,25	82,36	76,46	1,02	0,98	0,98	1,02
			6,3	311,3	49,32		76,07		0,9775		1,02
			7,1	309,7	55,44		75,29		0,9725		1,03

Ø External	Non-welded pipelines				Welded pipes Fretz Moon		Welded pipes ERW (normal series)	
	Ø internal	Normal thickness	Weight	Flow section	Thickness	Weight	Thickness	Weight
mm	mm	mm	kg/m	cm²	mm	kg/m	mm	kg/m
30	25,4	2,3	1,59	5,07	2,3	1,59	—	—
33,7	29,1	2,3	1,79	6,65	2,3	1,79	—	—
33	32,8	2,6	2,29	8,45	2,6	2,29	—	—
42,4	37,2	2,6	2,57	10,90	2,6	2,57	—	—
44,5	39,3	2,6	2,70	12,1	2,6	2,70	—	—
48,3	43.1	2,6	2,95	14,6	2,6	2,95	2,6	2,95
54	48,8	2,6	3,32	18,7	2,6	3,32	—	—
57	51,2	2,9	3,90	20,6	2,9	3,90	—	—
60,3	54,5	2,9	4,14	23,3	2,9	4,14	2,9	4,14
70	64,2	2,9	4,83	32,4	2,9	4,83	—	—
76,1	70,3	2,9	5,28	38,8	2,9	5,28	2,9	5,28
88,9	82,5	3,2	6,81	53,5	2,9	6,20	2,9	6,20
101,6	94,4	3,6	8,76	70,0	—	—	—	—
108	100,8	3,6	9,33	79,8	—	—	—	—
114,3	107,1	3,6	9,90	90,1	—	—	3,2	8,83
133	125	4	12,80	123	—	—	—	—
139,7	131,7	4	13,50	136	—	—	3,6	12,2
159	150	4,5	17,10	177	—	—	—	—
168,3	159,3	4,5	18,1	199	—	—	4	16,3
193,7	182,9	5,4	25,0	263	—	—	—	—
219,1	207,3	5,9	31,0	338	—	—	5	26,4
244,5	231,9	6,3	37,0	422	—	—	—	—
273	260,4	6,3	41,6	533	—	—	5,6	36,8
323,9	309,7	7,1	55,6	753	—	—	5,9	46,2
355,6	339,6	8	68,3	906	—	—	6,3	54,5
368	352	8	70,8	973	—	—	—	—
406,4	388,8	8,8	85,9	1187	—	—	6,3	62,4
419	401,4	8,8	88,7	1265	—	—	—	—

Conventional designation	Internal nominal Ø	External nominal Ø	Thickness	Conventional weights			Flow section	Execution type
				Non-threaded black	Threaded with sleeve			
					Black	Zinc-plated		
Pollici	mm	mm	mm	kg/m	kg/m	kg/m	cm²	
3/8	13,2	17,2	2	0,747	0,753	0,807	1,37	s.s. o F.M.
1/2	16,6	21,3	2,35	1,10	1,11	1,18	2,16	
3/4	22,2	26,9	2,35	1,41	1,42	1,50	3,87	
1	27,9	33,7	2,9	2,21	2,23	2,34	6,11	
1 1/4	36,6	42,4	2,9	2,84	2,87	3,00	10,5	
1 1/2	42,5	48,3	2,9	3,26	3,30	3,45	14,2	
2	53,8	60,3	3,25	4,56	4,63	4,82	22,7	
2 1/2	69,6	76,1	3,25	5,81	5,93	6,17	38,1	
3	81,6	88,9	3,65	7,65	7,82	8,10	52,3	
4	106,2	114,3	4,05	11,00	11,30	11,70	88,6	s.s. ERW

1.24 Correction factors for lecture of gas delivery from gas meters

Corrective factor for lecture of gas delivery from gas meter (barometric pressure1013 mbar)																
	Gas temperature (°C)															
P_{gas} (*)	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
0	1,0000	0,9927	0,9856	0,9785	0,9715	0,9647	0,9579	0,9512	0,9447	0,9382	0,9318	0,9255	0,9192	0,9131	0,9070	0,9010
10	1,0099	1,0025	0,9953	0,9882	0,9811	0,9742	0,9674	0,9606	0,9540	0,9474	0,9410	0,9346	0,9283	0,9221	0,9160	0,9099
20	1,0197	1,0123	1,0050	0,9978	0,9907	0,9837	0,9768	0,9700	0,9633	0,9567	0,9502	0,9437	0,9374	0,9311	0,9249	0,9188
30	1,0296	1,0221	1,0148	1,0075	1,0003	0,9933	0,9863	0,9794	0,9726	0,9660	0,9594	0,9529	0,9465	0,9401	0,9339	0,9277
40	1,0395	1,0319	1,0245	1,0171	1,0099	1,0028	0,9957	0,9888	0,9820	0,9752	0,9686	0,9620	0,9555	0,9491	0,9428	0,9366
50	1,0494	1,0417	1,0342	1,0268	1,0195	1,0123	1,0052	0,9982	0,9913	0,9845	0,9778	0,9711	0,9646	0,9582	0,9518	0,9455
60	1,0592	1,0515	1,0439	1,0365	1,0291	1,0218	1,0147	1,0076	1,0006	0,9937	0,9870	0,9803	0,9737	0,9672	0,9607	0,9544
70	1,0691	1,0613	1,0537	1,0461	1,0387	1,0313	1,0241	1,0170	1,0099	1,0030	0,9962	0,9894	0,9828	0,9762	0,9697	0,9633
80	1,0790	1,0711	1,0634	1,0558	1,0483	1,0409	1,0336	1,0264	1,0193	1,0123	1,0054	0,9985	0,9918	0,9852	0,9787	0,9722
90	1,0888	1,0809	1,0731	1,0654	1,0579	1,0504	1,0430	1,0358	1,0286	1,0215	1,0146	1,0077	1,0009	0,9942	0,9876	0,9811
100	1,0987	1,0907	1,0829	1,0751	1,0675	1,0599	1,0525	1,0451	1,0379	1,0308	1,0238	1,0168	1,0100	1,0032	0,9966	0,9900
110	1,1086	1,1005	1,0926	1,0848	1,0770	1,0694	1,0619	1,0545	1,0472	1,0401	1,0330	1,0260	1,0191	1,0122	1,0055	0,9989
120	1,1185	1,1103	1,1023	1,0944	1,0866	1,0790	1,0714	1,0639	1,0566	1,0493	1,0422	1,0351	1,0281	1,0213	1,0145	1,0078
130	1,1283	1,1201	1,1120	1,1041	1,0962	1,0885	1,0808	1,0733	1,0659	1,0586	1,0514	1,0442	1,0372	1,0303	1,0234	1,0167
140	1,1382	1,1299	1,1218	1,1137	1,1058	1,0980	1,0903	1,0827	1,0752	1,0678	1,0606	1,0534	1,0463	1,0393	1,0324	1,0256
150	1,1481	1,1397	1,1315	1,1234	1,1154	1,1075	1,0998	1,0921	1,0845	1,0771	1,0697	1,0625	1,0553	1,0483	1,0413	1,0345
160	1,1579	1,1495	1,1412	1,1331	1,1250	1,1171	1,1092	1,1015	1,0939	1,0864	1,0789	1,0716	1,0644	1,0573	1,0503	1,0434
170	1,1678	1,1593	1,1510	1,1427	1,1346	1,1266	1,1187	1,1109	1,1032	1,0956	1,0881	1,0808	1,0735	1,0663	1,0592	1,0522
180	1,1777	1,1691	1,1607	1,1524	1,1442	1,1361	1,1281	1,1203	1,1125	1,1049	1,0973	1,0899	1,0826	1,0753	1,0682	1,0611
190	1,1876	1,1789	1,1704	1,1620	1,1538	1,1456	1,1376	1,1297	1,1218	1,1141	1,1065	1,0990	1,0916	1,0843	1,0771	1,0700
200	1,1974	1,1887	1,1802	1,1717	1,1634	1,1551	1,1470	1,1391	1,1312	1,1234	1,1157	1,1082	1,1007	1,0934	1,0861	1,0789
210	1,2073	1,1985	1,1899	1,1814	1,1730	1,1647	1,1565	1,1484	1,1405	1,1327	1,1249	1,1173	1,1098	1,1024	1,0951	1,0878
220	1,2172	1,2083	1,1996	1,1910	1,1825	1,1742	1,1660	1,1578	1,1498	1,1419	1,1341	1,1265	1,1189	1,1114	1,1040	1,0967
230	1,2270	1,2181	1,2093	1,2007	1,1921	1,1837	1,1754	1,1672	1,1592	1,1512	1,1433	1,1356	1,1279	1,1204	1,1130	1,1056
240	1,2369	1,2279	1,2191	1,2103	1,2017	1,1932	1,1849	1,1766	1,1685	1,1604	1,1525	1,1447	1,1370	1,1294	1,1219	1,1145
250	1,2468	1,2377	1,2288	1,2200	1,2113	1,2028	1,1943	1,1860	1,1778	1,1697	1,1617	1,1539	1,1461	1,1384	1,1309	1,1234
260	1,2567	1,2475	1,2385	1,2297	1,2209	1,2123	1,2038	1,1954	1,1871	1,1790	1,1709	1,1630	1,1552	1,1474	1,1398	1,1323
270	1,2665	1,2573	1,2483	1,2393	1,2305	1,2218	1,2132	1,2048	1,1965	1,1882	1,1801	1,1721	1,1642	1,1565	1,1488	1,1412
280	1,2764	1,2671	1,2580	1,2490	1,2401	1,2313	1,2227	1,2142	1,2058	1,1975	1,1893	1,1813	1,1733	1,1655	1,1577	1,1501
290	1,2863	1,2769	1,2677	1,2586	1,2497	1,2409	1,2321	1,2236	1,2151	1,2068	1,1985	1,1904	1,1824	1,1745	1,1667	1,1590
300	1,2962	1,2867	1,2774	1,2683	1,2593	1,2504	1,2416	1,2330	1,2244	1,2160	1,2077	1,1995	1,1915	1,1835	1,1756	1,1679
310	1,3060	1,2965	1,2872	1,2780	1,2689	1,2599	1,2511	1,2423	1,2338	1,2253	1,2169	1,2087	1,2005	1,1925	1,1846	1,1768
320	1,3159	1,3063	1,2969	1,2876	1,2785	1,2694	1,2605	1,2517	1,2431	1,2345	1,2261	1,2178	1,2096	1,2015	1,1935	1,1857
330	1,3258	1,3161	1,3066	1,2973	1,2880	1,2789	1,2700	1,2611	1,2524	1,2438	1,2353	1,2269	1,2187	1,2105	1,2025	1,1946
340	1,3356	1,3259	1,3164	1,3069	1,2976	1,2885	1,2794	1,2705	1,2617	1,2531	1,2445	1,2361	1,2278	1,2196	1,2115	1,2035
350	1,3455	1,3357	1,3261	1,3166	1,3072	1,2980	1,2889	1,2799	1,2711	1,2623	1,2537	1,2452	1,2368	1,2286	1,2204	1,2124
360	1,3554	1,3455	1,3358	1,3262	1,3168	1,3075	1,2983	1,2893	1,2804	1,2716	1,2629	1,2544	1,2459	1,2376	1,2294	1,2213
370	1,3653	1,3553	1,3455	1,3359	1,3264	1,3170	1,3078	1,2987	1,2897	1,2808	1,2721	1,2635	1,2550	1,2466	1,2383	1,2301
380	1,3751	1,3651	1,3553	1,3456	1,3360	1,3266	1,3173	1,3081	1,2990	1,2901	1,2813	1,2726	1,2641	1,2556	1,2473	1,2390
390	1,3850	1,3749	1,3650	1,3552	1,3456	1,3361	1,3267	1,3175	1,3084	1,2994	1,2905	1,2818	1,2731	1,2646	1,2562	1,2479
400	1,3949	1,3847	1,3747	1,3649	1,3552	1,3456	1,3362	1,3269	1,3177	1,3086	1,2997	1,2909	1,2822	1,2736	1,2652	1,2568
410	1,4047	1,3945	1,3845	1,3745	1,3648	1,3551	1,3456	1,3363	1,3270	1,3179	1,3089	1,3000	1,2913	1,2826	1,2741	1,2657
420	1,4146	1,4043	1,3942	1,3842	1,3744	1,3647	1,3551	1,3456	1,3363	1,3272	1,3181	1,3092	1,3004	1,2917	1,2831	1,2746
430	1,4245	1,4141	1,4039	1,3939	1,3839	1,3742	1,3645	1,3550	1,3457	1,3364	1,3273	1,3183	1,3094	1,3007	1,2920	1,2835
440	1,4344	1,4239	1,4137	1,4035	1,3935	1,3837	1,3740	1,3644	1,3550	1,3457	1,3365	1,3274	1,3185	1,3097	1,3010	1,2924
450	1,4442	1,4337	1,4234	1,4132	1,4031	1,3932	1,3834	1,3738	1,3643	1,3549	1,3457	1,3366	1,3276	1,3187	1,3099	1,3013
460	1,4541	1,4435	1,4331	1,4228	1,4127	1,4027	1,3929	1,3832	1,3736	1,3642	1,3549	1,3457	1,3367	1,3277	1,3189	1,3102
470	1,4640	1,4533	1,4428	1,4325	1,4223	1,4123	1,4024	1,3926	1,3830	1,3735	1,3641	1,3548	1,3457	1,3367	1,3279	1,3191
480	1,4738	1,4631	1,4526	1,4422	1,4319	1,4218	1,4118	1,4020	1,3923	1,3827	1,3733	1,3640	1,3548	1,3457	1,3368	1,3280
490	1,4837	1,4729	1,4623	1,4518	1,4415	1,4313	1,4213	1,4114	1,4016	1,3920	1,3825	1,3731	1,3639	1,3548	1,3458	1,3369
500	1,4936	1,4827	1,4720	1,4615	1,4511	1,4408	1,4307	1,4208	1,4109	1,4012	1,3917	1,3823	1,3730	1,3638	1,3547	1,3458
510	1,5035	1,4925	1,4818	1,4711	1,4607	1,4504	1,4402	1,4302	1,4203	1,4105	1,4009	1,3914	1,3820	1,3728	1,3637	1,3547
520	1,5133	1,5023	1,4915	1,4808	1,4703	1,4599	1,4496	1,4395	1,4296	1,4198	1,4101	1,4005	1,3911	1,3818	1,3726	1,3636
530	1,5232	1,5121	1,5012	1,4905	1,4799	1,4694	1,4591	1,4489	1,4389	1,4290	1,4193	1,4097	1,4002	1,3908	1,3816	1,3725
540	1,5331	1,5219	1,5109	1,5001	1,4894	1,4789	1,4686	1,4583	1,4482	1,4383	1,4285	1,4188	1,4092	1,3998	1,3905	1,3814
550	1,5429	1,5317	1,5207	1,5098	1,4990	1,4884	1,4780	1,4677	1,4576	1,4476	1,4377	1,4279	1,4183	1,4088	1,3995	1,3903
560	1,5528	1,5415	1,5304	1,5194	1,5086	1,4980	1,4875	1,4771	1,4669	1,4568	1,4469	1,4371	1,4274	1,4179	1,4084	1,3991
570	1,5627	1,5513	1,5401	1,5291	1,5182	1,5075	1,4969	1,4865	1,4762	1,4661	1,4561	1,4462	1,4365	1,4269	1,4174	1,4080
580	1,5726	1,5611	1,5499	1,5388	1,5278	1,5170	1,5064	1,4959	1,4855	1,4753	1,4653	1,4553	1,4455	1,4359	1,4263	1,4169
590	1,5824	1,5709	1,5596	1,5484	1,5374	1,5265	1,5158	1,5053	1,4949	1,4846	1,4745	1,4645	1,4546	1,4449	1,4353	1,4258
600	1,5923	1,5807	1,5693	1,5581	1,5470	1,5361	1,5253	1,5147	1,5042	1,4939	1,4837	1,4736	1,4637	1,4539	1,4443	1,4347
610	1,6022	1,5905	1,5790	1,5677	1,5566	1,5456	1,5347	1,5241	1,5135	1,5031	1,4929	1,4827	1,4728	1,4629	1,4532	1,4436
620	1,6120	1,6003	1,5888	1,5774	1,5662	1,5551	1,5442	1,5334	1,5228	1,5124	1,5021	1,4919	1,4818	1,4719	1,4622	1,4525
630	1,6219	1,6101	1,5985	1,5871	1,5758	1,5646	1,5537	1,5428	1,5322	1,5216	1,5113	1,5010	1,4909	1,4809	1,4711	1,4614
640	1,6318	1,6199	1,6082	1,5967	1,5854	1,5742	1,5631	1,5522	1,5415	1,5309	1,5205	1,5102	1,5000	1,4900	1,4801	1,4703
650	1,6417	1,6297	1,6180	1,6064	1,5949	1,5837	1,5726	1,5616	1,5508	1,5402	1,5297	1,5193	1,5091	1,4990	1,4890	1,4792

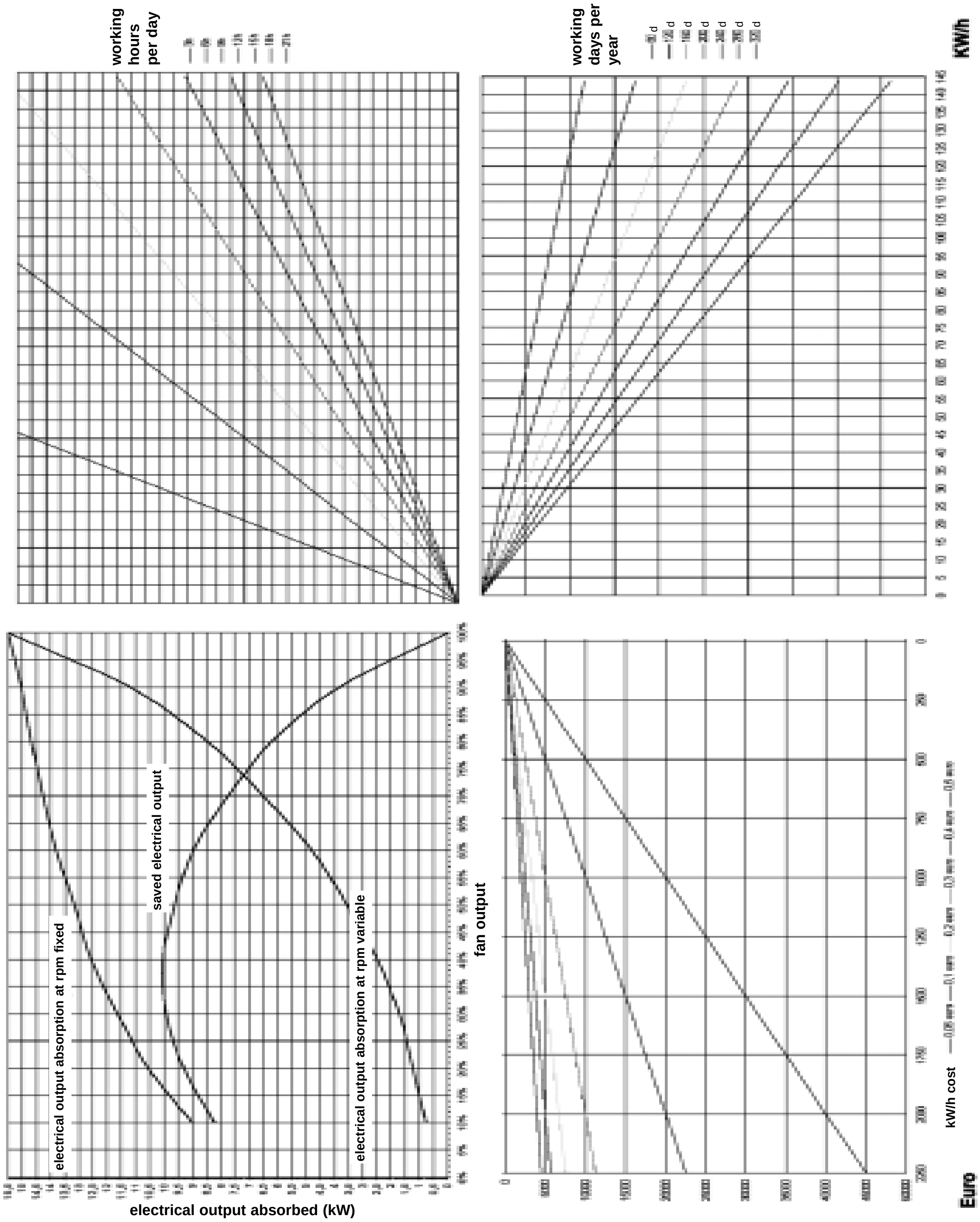
(*) Gas is read in mbar and it is relative to the atmospheric one

Corrective factor for lecture of gas delivery from gas meter (barometric pressure1013 mbar)																
	Gas temperature (°C)															
P_{gas} (*)	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**
650	1,6417	1,6297	1,6180	1,6064	1,5949	1,5837	1,5726	1,5616	1,5508	1,5402	1,5297	1,5193	1,5091	1,4990	1,4890	1,4792
660	1,6515	1,6395	1,6277	1,6160	1,6045	1,5932	1,5820	1,5710	1,5601	1,5494	1,5389	1,5284	1,5181	1,5080	1,4980	1,4881
670	1,6614	1,6493	1,6374	1,6257	1,6141	1,6027	1,5915	1,5804	1,5695	1,5587	1,5481	1,5376	1,5272	1,5170	1,5069	1,4970
680	1,6713	1,6591	1,6472	1,6354	1,6237	1,6122	1,6009	1,5898	1,5788	1,5679	1,5573	1,5467	1,5363	1,5260	1,5159	1,5059
690	1,6811	1,6689	1,6569	1,6450	1,6333	1,6218	1,6104	1,5992	1,5881	1,5772	1,5664	1,5558	1,5454	1,5350	1,5248	1,5148
700	1,6910	1,6787	1,6666	1,6547	1,6429	1,6313	1,6199	1,6086	1,5974	1,5865	1,5756	1,5650	1,5544	1,5440	1,5338	1,5237
710	1,7009	1,6885	1,6763	1,6643	1,6525	1,6408	1,6293	1,6180	1,6068	1,5957	1,5848	1,5741	1,5635	1,5531	1,5427	1,5326
720	1,7108	1,6983	1,6861	1,6740	1,6621	1,6503	1,6388	1,6274	1,6161	1,6050	1,5940	1,5832	1,5726	1,5621	1,5517	1,5415
730	1,7206	1,7081	1,6958	1,6836	1,6717	1,6599	1,6482	1,6367	1,6254	1,6143	1,6032	1,5924	1,5817	1,5711	1,5607	1,5504
740	1,7305	1,7179	1,7055	1,6933	1,6813	1,6694	1,6577	1,6461	1,6347	1,6235	1,6124	1,6015	1,5907	1,5801	1,5696	1,5593
750	1,7404	1,7277	1,7153	1,7030	1,6909	1,6789	1,6671	1,6555	1,6441	1,6328	1,6216	1,6107	1,5998	1,5891	1,5786	1,5681
760	1,7502	1,7375	1,7250	1,7126	1,7004	1,6884	1,6766	1,6649	1,6534	1,6420	1,6308	1,6198	1,6089	1,5981	1,5875	1,5770
770	1,7601	1,7473	1,7347	1,7223	1,7100	1,6980	1,6860	1,6743	1,6627	1,6513	1,6400	1,6289	1,6180	1,6071	1,5965	1,5859
780	1,7700	1,7571	1,7444	1,7319	1,7196	1,7075	1,6955	1,6837	1,6720	1,6606	1,6492	1,6381	1,6270	1,6162	1,6054	1,5948
790	1,7799	1,7669	1,7542	1,7416	1,7292	1,7170	1,7050	1,6931	1,6814	1,6698	1,6584	1,6472	1,6361	1,6252	1,6144	1,6037
800	1,7897	1,7767	1,7639	1,7513	1,7388	1,7265	1,7144	1,7025	1,6907	1,6791	1,6676	1,6563	1,6452	1,6342	1,6233	1,6126
810	1,7996	1,7865	1,7736	1,7609	1,7484	1,7360	1,7239	1,7119	1,7000	1,6883	1,6768	1,6655	1,6543	1,6432	1,6323	1,6215
820	1,8095	1,7963	1,7834	1,7706	1,7580	1,7456	1,7333	1,7213	1,7094	1,6976	1,6860	1,6746	1,6633	1,6522	1,6412	1,6304
830	1,8193	1,8061	1,7931	1,7802	1,7676	1,7551	1,7428	1,7306	1,7187	1,7069	1,6952	1,6837	1,6724	1,6612	1,6502	1,6393
840	1,8292	1,8159	1,8028	1,7899	1,7772	1,7646	1,7522	1,7400	1,7280	1,7161	1,7044	1,6929	1,6815	1,6702	1,6591	1,6482
850	1,8391	1,8257	1,8125	1,7996	1,7868	1,7741	1,7617	1,7494	1,7373	1,7254	1,7136	1,7020	1,6906	1,6793	1,6681	1,6571
860	1,8490	1,8355	1,8223	1,8092	1,7964	1,7837	1,7712	1,7588	1,7467	1,7347	1,7228	1,7111	1,6996	1,6883	1,6771	1,6660
870	1,8588	1,8453	1,8320	1,8189	1,8059	1,7932	1,7806	1,7682	1,7560	1,7439	1,7320	1,7203	1,7087	1,6973	1,6860	1,6749
880	1,8687	1,8551	1,8417	1,8285	1,8155	1,8027	1,7901	1,7776	1,7653	1,7532	1,7412	1,7294	1,7178	1,7063	1,6950	1,6838
890	1,8786	1,8649	1,8515	1,8382	1,8251	1,8122	1,7995	1,7870	1,7746	1,7624	1,7504	1,7386	1,7269	1,7153	1,7039	1,6927
900	1,8885	1,8747	1,8612	1,8479	1,8347	1,8218	1,8090	1,7964	1,7840	1,7717	1,7596	1,7477	1,7359	1,7243	1,7129	1,7016
910	1,8983	1,8845	1,8709	1,8575	1,8443	1,8313	1,8184	1,8058	1,7933	1,7810	1,7688	1,7568	1,7450	1,7333	1,7218	1,7105
920	1,9082	1,8943	1,8807	1,8672	1,8539	1,8408	1,8279	1,8152	1,8026	1,7902	1,7780	1,7660	1,7541	1,7423	1,7308	1,7194
930	1,9181	1,9041	1,8904	1,8768	1,8635	1,8503	1,8373	1,8245	1,8119	1,7995	1,7872	1,7751	1,7631	1,7514	1,7397	1,7283
940	1,9279	1,9139	1,9001	1,8865	1,8731	1,8598	1,8468	1,8339	1,8213	1,8087	1,7964	1,7842	1,7722	1,7604	1,7487	1,7371
950	1,9378	1,9237	1,9098	1,8962	1,8827	1,8694	1,8563	1,8433	1,8306	1,8180	1,8056	1,7934	1,7813	1,7694	1,7576	1,7460
960	1,9477	1,9335	1,9196	1,9058	1,8923	1,8789	1,8657	1,8527	1,8399	1,8273	1,8148	1,8025	1,7904	1,7784	1,7666	1,7549
970	1,9576	1,9433	1,9293	1,9155	1,9019	1,8884	1,8752	1,8621	1,8492	1,8365	1,8240	1,8116	1,7994	1,7874	1,7755	1,7638
980	1,9674	1,9531	1,9390	1,9251	1,9114	1,8979	1,8846	1,8715	1,8586	1,8458	1,8332	1,8208	1,8085	1,7964	1,7845	1,7727
990	1,9773	1,9629	1,9488	1,9348	1,9210	1,9075	1,8941	1,8809	1,8679	1,8551	1,8424	1,8299	1,8176	1,8054	1,7935	1,7816
1000	1,9872	1,9727	1,9585	1,9445	1,9306	1,9170	1,9035	1,8903	1,8772	1,8643	1,8516	1,8390	1,8267	1,8145	1,8024	1,7905
1010	1,9970	1,9825	1,9682	1,9541	1,9402	1,9265	1,9130	1,8997	1,8865	1,8736	1,8608	1,8482	1,8357	1,8235	1,8114	1,7994
1020	2,0069	1,9923	1,9779	1,9638	1,9498	1,9360	1,9225	1,9091	1,8959	1,8828	1,8700	1,8573	1,8448	1,8325	1,8203	1,8083
1030	2,0168	2,0021	1,9877	1,9734	1,9594	1,9456	1,9319	1,9185	1,9052	1,8921	1,8792	1,8665	1,8539	1,8415	1,8293	1,8172
1040	2,0267	2,0119	1,9974	1,9831	1,9690	1,9551	1,9414	1,9278	1,9145	1,9014	1,8884	1,8756	1,8630	1,8505	1,8382	1,8261
1050	2,0365	2,0217	2,0071	1,9928	1,9786	1,9646	1,9508	1,9372	1,9238	1,9106	1,8976	1,8847	1,8720	1,8595	1,8472	1,8350
1060	2,0464	2,0315	2,0169	2,0024	1,9882	1,9741	1,9603	1,9466	1,9332	1,9199	1,9068	1,8939	1,8811	1,8685	1,8561	1,8439
1070	2,0563	2,0413	2,0266	2,0121	1,9978	1,9836	1,9697	1,9560	1,9425	1,9291	1,9160	1,9030	1,8902	1,8776	1,8651	1,8528
1080	2,0661	2,0511	2,0363	2,0217	2,0073	1,9932	1,9792	1,9654	1,9518	1,9384	1,9252	1,9121	1,8993	1,8866	1,8740	1,8617
1090	2,0760	2,0609	2,0460	2,0314	2,0169	2,0027	1,9886	1,9748	1,9611	1,9477	1,9344	1,9213	1,9083	1,8956	1,8830	1,8706
1100	2,0859	2,0707	2,0558	2,0410	2,0265	2,0122	1,9981	1,9842	1,9705	1,9569	1,9436	1,9304	1,9174	1,9046	1,8919	1,8795
1110	2,0958	2,0805	2,0655	2,0507	2,0361	2,0217	2,0076	1,9936	1,9798	1,9662	1,9528	1,9395	1,9265	1,9136	1,9009	1,8884
1120	2,1056	2,0903	2,0752	2,0604	2,0457	2,0313	2,0170	2,0030	1,9891	1,9754	1,9620	1,9487	1,9356	1,9226	1,9099	1,8973
1130	2,1155	2,1001	2,0850	2,0700	2,0553	2,0408	2,0265	2,0124	1,9984	1,9847	1,9712	1,9578	1,9446	1,9316	1,9188	1,9061
1140	2,1254	2,1099	2,0947	2,0797	2,0649	2,0503	2,0359	2,0217	2,0078	1,9940	1,9804	1,9669	1,9537	1,9406	1,9278	1,9150
1150	2,1352	2,1197	2,1044	2,0893	2,0745	2,0598	2,0454	2,0311	2,0171	2,0032	1,9896	1,9761	1,9628	1,9497	1,9367	1,9239
1160	2,1451	2,1295	2,1142	2,0990	2,0841	2,0694	2,0548	2,0405	2,0264	2,0125	1,9988	1,9852	1,9719	1,9587	1,9457	1,9328
1170	2,1550	2,1393	2,1239	2,1087	2,0937	2,0789	2,0643	2,0499	2,0357	2,0218	2,0080	1,9944	1,9809	1,9677	1,9546	1,9417
1180	2,1649	2,1491	2,1336	2,1183	2,1033	2,0884	2,0738	2,0593	2,0451	2,0310	2,0172	2,0035	1,9900	1,9767	1,9636	1,9506
1190	2,1747	2,1589	2,1433	2,1280	2,1128	2,0979	2,0832	2,0687	2,0544	2,0403	2,0264	2,0126	1,9991	1,9857	1,9725	1,9595
1200	2,1846	2,1687	2,1531	2,1376	2,1224	2,1074	2,0927	2,0781	2,0637	2,0495	2,0356	2,0218	2,0082	1,9947	1,9815	1,9684
1210	2,1945	2,1785	2,1628	2,1473	2,1320	2,1170	2,1021	2,0875	2,0730	2,0588	2,0448	2,0309	2,0172	2,0037	1,9904	1,9773
1220	2,2043	2,1883	2,1725	2,1570	2,1416	2,1265	2,1116	2,0969	2,0824	2,0681	2,0540	2,0400	2,0263	2,0128	1,9994	1,9862
1230	2,2142	2,1981	2,1823	2,1666	2,1512	2,1360	2,1210	2,1063	2,0917	2,0773	2,0632	2,0492	2,0354	2,0218	2,0083	1,9951
1240	2,2241	2,2079	2,1920	2,1763	2,1608	2,1455	2,1305	2,1157	2,1010	2,0866	2,0723	2,0583	2,0445	2,0308	2,0173	2,0040
1250	2,2340	2,2177	2,2017	2,1859	2,1704	2,1551	2,1399	2,1250	2,1103	2,0958	2,0815	2,0674	2,0535	2,0398	2,0263	2,0129
1260	2,2438	2,2275	2,2114	2,1956	2,1800	2,1646	2,1494	2,1344	2,1197	2,1051	2,0907	2,0766	2,0626	2,0488	2,0352	2,0218
1270	2,2537	2,2373	2,2212	2,2053	2,1896	2,1741	2,1589	2,1438	2,1290	2,1144	2,0999	2,0857	2,0717	2,0578	2,0442	2,0307
1280	2,2636	2,2471	2,2309	2,2149	2,1992	2,1836	2,1683	2,1532	2,1383	2,1236	2,1091	2,0949	2,0808	2,0668	2,0531	2,0396
1290	2,2734	2,2569	2,2406	2,2246	2,2088	2,1932	2,1778	2,1626	2,1476	2,1329	2,1183	2,1040	2,0898	2,0759	2,0621	2,0485
1300	2,2833	2,2667	2,2504	2,2342	2,2183	2,2027	2,1872	2,1720	2,1570	2,1422	2,1275	2,1131	2,0989	2,0849	2,0710	2,0574
(*) Gas is read in mbar and it is relative to the atmospheric one																

Corrective factor for lecture of gas delivery from gas meter (barometric pressure1013 mbar)																
	Gas temperature (°C)															
P_{gas} (*)	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
1300	2,2833	2,2667	2,2504	2,2342	2,2183	2,2027	2,1872	2,1720	2,1570	2,1422	2,1275	2,1131	2,0989	2,0849	2,0710	2,0574
1310	2,2932	2,2765	2,2601	2,2439	2,2279	2,2122	2,1967	2,1814	2,1663	2,1514	2,1367	2,1223	2,1080	2,0939	2,0800	2,0663
1320	2,3031	2,2863	2,2698	2,2536	2,2375	2,2217	2,2061	2,1908	2,1756	2,1607	2,1459	2,1314	2,1170	2,1029	2,0889	2,0751
1330	2,3129	2,2961	2,2796	2,2632	2,2471	2,2312	2,2156	2,2002	2,1849	2,1699	2,1551	2,1405	2,1261	2,1119	2,0979	2,0840
1340	2,3228	2,3059	2,2893	2,2729	2,2567	2,2408	2,2251	2,2096	2,1943	2,1792	2,1643	2,1497	2,1352	2,1209	2,1068	2,0929
1350	2,3327	2,3157	2,2990	2,2825	2,2663	2,2503	2,2345	2,2189	2,2036	2,1885	2,1735	2,1588	2,1443	2,1299	2,1158	2,1018
1360	2,3425	2,3255	2,3087	2,2922	2,2759	2,2598	2,2440	2,2283	2,2129	2,1977	2,1827	2,1679	2,1533	2,1389	2,1247	2,1107
1370	2,3524	2,3353	2,3185	2,3019	2,2855	2,2693	2,2534	2,2377	2,2222	2,2070	2,1919	2,1771	2,1624	2,1480	2,1337	2,1196
1380	2,3623	2,3451	2,3282	2,3115	2,2951	2,2789	2,2629	2,2471	2,2316	2,2162	2,2011	2,1862	2,1715	2,1570	2,1427	2,1285
1390	2,3722	2,3549	2,3379	2,3212	2,3047	2,2884	2,2723	2,2565	2,2409	2,2255	2,2103	2,1953	2,1806	2,1660	2,1516	2,1374
1400	2,3820	2,3647	2,3477	2,3308	2,3143	2,2979	2,2818	2,2659	2,2502	2,2348	2,2195	2,2045	2,1896	2,1750	2,1606	2,1463
1410	2,3919	2,3745	2,3574	2,3405	2,3238	2,3074	2,2912	2,2753	2,2596	2,2440	2,2287	2,2136	2,1987	2,1840	2,1695	2,1552
1420	2,4018	2,3843	2,3671	2,3502	2,3334	2,3170	2,3007	2,2847	2,2689	2,2533	2,2379	2,2228	2,2078	2,1930	2,1785	2,1641
1430	2,4116	2,3941	2,3768	2,3598	2,3430	2,3265	2,3102	2,2941	2,2782	2,2626	2,2471	2,2319	2,2169	2,2020	2,1874	2,1730
1440	2,4215	2,4039	2,3866	2,3695	2,3526	2,3360	2,3196	2,3035	2,2875	2,2718	2,2563	2,2410	2,2259	2,2111	2,1964	2,1819
1450	2,4314	2,4137	2,3963	2,3791	2,3622	2,3455	2,3291	2,3128	2,2969	2,2811	2,2655	2,2502	2,2350	2,2201	2,2053	2,1908
1460	2,4413	2,4235	2,4060	2,3888	2,3718	2,3550	2,3385	2,3222	2,3062	2,2903	2,2747	2,2593	2,2441	2,2291	2,2143	2,1997
1470	2,4511	2,4333	2,4158	2,3985	2,3814	2,3646	2,3480	2,3316	2,3155	2,2996	2,2839	2,2684	2,2532	2,2381	2,2232	2,2086
1480	2,4610	2,4431	2,4255	2,4081	2,3910	2,3741	2,3574	2,3410	2,3248	2,3089	2,2931	2,2776	2,2622	2,2471	2,2322	2,2175
1490	2,4709	2,4529	2,4352	2,4178	2,4006	2,3836	2,3669	2,3504	2,3342	2,3181	2,3023	2,2867	2,2713	2,2561	2,2411	2,2264
1500	2,4808	2,4627	2,4449	2,4274	2,4102	2,3931	2,3764	2,3598	2,3435	2,3274	2,3115	2,2958	2,2804	2,2651	2,2501	2,2353
1510	2,4906	2,4725	2,4547	2,4371	2,4198	2,4027	2,3858	2,3692	2,3528	2,3366	2,3207	2,3050	2,2895	2,2742	2,2591	2,2441
1520	2,5005	2,4823	2,4644	2,4467	2,4293	2,4122	2,3953	2,3786	2,3621	2,3459	2,3299	2,3141	2,2985	2,2832	2,2680	2,2530
1530	2,5104	2,4921	2,4741	2,4564	2,4389	2,4217	2,4047	2,3880	2,3715	2,3552	2,3391	2,3232	2,3076	2,2922	2,2770	2,2619
1540	2,5202	2,5019	2,4839	2,4661	2,4485	2,4312	2,4142	2,3974	2,3808	2,3644	2,3483	2,3324	2,3167	2,3012	2,2859	2,2708
1550	2,5301	2,5117	2,4936	2,4757	2,4581	2,4408	2,4236	2,4068	2,3901	2,3737	2,3575	2,3415	2,3258	2,3102	2,2949	2,2797
1560	2,5400	2,5215	2,5033	2,4854	2,4677	2,4503	2,4331	2,4161	2,3994	2,3829	2,3667	2,3507	2,3348	2,3192	2,3038	2,2886
1570	2,5499	2,5313	2,5131	2,4950	2,4773	2,4598	2,4425	2,4255	2,4088	2,3922	2,3759	2,3598	2,3439	2,3282	2,3128	2,2975
1580	2,5597	2,5411	2,5228	2,5047	2,4869	2,4693	2,4520	2,4349	2,4181	2,4015	2,3851	2,3689	2,3530	2,3373	2,3217	2,3064
1590	2,5696	2,5509	2,5325	2,5144	2,4965	2,4788	2,4615	2,4443	2,4274	2,4107	2,3943	2,3781	2,3621	2,3463	2,3307	2,3153
1600	2,5795	2,5607	2,5422	2,5240	2,5061	2,4884	2,4709	2,4537	2,4367	2,4200	2,4035	2,3872	2,3711	2,3553	2,3396	2,3242
1610	2,5893	2,5705	2,5520	2,5337	2,5157	2,4979	2,4804	2,4631	2,4461	2,4293	2,4127	2,3963	2,3802	2,3643	2,3486	2,3331
1620	2,5992	2,5803	2,5617	2,5433	2,5253	2,5074	2,4898	2,4725	2,4554	2,4385	2,4219	2,4055	2,3893	2,3733	2,3575	2,3420
1630	2,6091	2,5901	2,5714	2,5530	2,5348	2,5169	2,4993	2,4819	2,4647	2,4478	2,4311	2,4146	2,3984	2,3823	2,3665	2,3509
1640	2,6190	2,5999	2,5812	2,5627	2,5444	2,5265	2,5087	2,4913	2,4740	2,4570	2,4403	2,4237	2,4074	2,3913	2,3755	2,3598
1650	2,6288	2,6097	2,5909	2,5723	2,5540	2,5360	2,5182	2,5007	2,4834	2,4663	2,4495	2,4329	2,4165	2,4003	2,3844	2,3687
1660	2,6387	2,6195	2,6006	2,5820	2,5636	2,5455	2,5277	2,5100	2,4927	2,4756	2,4587	2,4420	2,4256	2,4094	2,3934	2,3776
1670	2,6486	2,6293	2,6103	2,5916	2,5732	2,5550	2,5371	2,5194	2,5020	2,4848	2,4679	2,4511	2,4347	2,4184	2,4023	2,3865
1680	2,6584	2,6391	2,6201	2,6013	2,5828	2,5646	2,5466	2,5288	2,5113	2,4941	2,4771	2,4603	2,4437	2,4274	2,4113	2,3954
1690	2,6683	2,6489	2,6298	2,6110	2,5924	2,5741	2,5560	2,5382	2,5207	2,5033	2,4863	2,4694	2,4528	2,4364	2,4202	2,4043
1700	2,6782	2,6587	2,6395	2,6206	2,6020	2,5836	2,5655	2,5476	2,5300	2,5126	2,4955	2,4786	2,4619	2,4454	2,4292	2,4131
1710	2,6881	2,6685	2,6493	2,6303	2,6116	2,5931	2,5749	2,5570	2,5393	2,5219	2,5047	2,4877	2,4709	2,4544	2,4381	2,4220
1720	2,6979	2,6783	2,6590	2,6399	2,6212	2,6026	2,5844	2,5664	2,5486	2,5311	2,5139	2,4968	2,4800	2,4634	2,4471	2,4309
1730	2,7078	2,6881	2,6687	2,6496	2,6307	2,6122	2,5938	2,5758	2,5580	2,5404	2,5231	2,5060	2,4891	2,4725	2,4560	2,4398
1740	2,7177	2,6979	2,6784	2,6593	2,6403	2,6217	2,6033	2,5852	2,5673	2,5497	2,5323	2,5151	2,4982	2,4815	2,4650	2,4487
1750	2,7275	2,7077	2,6882	2,6689	2,6499	2,6312	2,6128	2,5946	2,5766	2,5589	2,5415	2,5242	2,5072	2,4905	2,4739	2,4576
1760	2,7374	2,7175	2,6979	2,6786	2,6595	2,6407	2,6222	2,6040	2,5859	2,5682	2,5507	2,5334	2,5163	2,4995	2,4829	2,4665
1770	2,7473	2,7273	2,7076	2,6882	2,6691	2,6503	2,6317	2,6133	2,5953	2,5774	2,5599	2,5425	2,5254	2,5085	2,4919	2,4754
1780	2,7572	2,7371	2,7174	2,6979	2,6787	2,6598	2,6411	2,6227	2,6046	2,5867	2,5691	2,5516	2,5345	2,5175	2,5008	2,4843
1790	2,7670	2,7469	2,7271	2,7076	2,6883	2,6693	2,6506	2,6321	2,6139	2,5960	2,5782	2,5608	2,5435	2,5265	2,5098	2,4932
1800	2,7769	2,7567	2,7368	2,7172	2,6979	2,6788	2,6600	2,6415	2,6232	2,6052	2,5874	2,5699	2,5526	2,5356	2,5187	2,5021
1810	2,7868	2,7665	2,7466	2,7269	2,7075	2,6884	2,6695	2,6509	2,6326	2,6145	2,5966	2,5791	2,5617	2,5446	2,5277	2,5110
1820	2,7966	2,7763	2,7563	2,7365	2,7171	2,6979	2,6790	2,6603	2,6419	2,6237	2,6058	2,5882	2,5708	2,5536	2,5366	2,5199
1830	2,8065	2,7861	2,7660	2,7462	2,7267	2,7074	2,6884	2,6697	2,6512	2,6330	2,6150	2,5973	2,5798	2,5626	2,5456	2,5288
1840	2,8164	2,7959	2,7757	2,7559	2,7362	2,7169	2,6979	2,6791	2,6605	2,6423	2,6242	2,6065	2,5889	2,5716	2,5545	2,5377
1850	2,8263	2,8057	2,7855	2,7655	2,7458	2,7264	2,7073	2,6885	2,6699	2,6515	2,6334	2,6156	2,5980	2,5806	2,5635	2,5466
1860	2,8361	2,8155	2,7952	2,7752	2,7554	2,7360	2,7168	2,6979	2,6792	2,6608	2,6426	2,6247	2,6071	2,5896	2,5724	2,5555
1870	2,8460	2,8253	2,8049	2,7848	2,7650	2,7455	2,7262	2,7072	2,6885	2,6701	2,6518	2,6339	2,6161	2,5986	2,5814	2,5644
1880	2,8559	2,8351	2,8147	2,7945	2,7746	2,7550	2,7357	2,7166	2,6978	2,6793	2,6610	2,6430	2,6252	2,6077	2,5903	2,5733
1890	2,8657	2,8449	2,8244	2,8041	2,7842	2,7645	2,7451	2,7260	2,7072	2,6886	2,6702	2,6521	2,6343	2,6167	2,5993	2,5821
1900	2,8756	2,8547	2,8341	2,8138	2,7938	2,7741	2,7546	2,7354	2,7165	2,6978	2,6794	2,6613	2,6434	2,6257	2,6083	2,5910
1910	2,8855	2,8645	2,8438	2,8235	2,8034	2,7836	2,7641	2,7448	2,7258	2,7071	2,6886	2,6704	2,6524	2,6347	2,6172	2,5999
1920	2,8954	2,8743	2,8536	2,8331	2,8130	2,7931	2,7735	2,7542	2,7351	2,7164	2,6978	2,6795	2,6615	2,6437	2,6262	2,6088
1930	2,9052	2,8841	2,8633	2,8428	2,8226	2,8026	2,7830	2,7636	2,7445	2,7256	2,7070	2,6887	2,6706	2,6527	2,6351	2,6177
1940	2,9151	2,8939	2,8730	2,8524	2,8322	2,8122	2,7924	2,7730	2,7538	2,7349	2,7162	2,6978	2,6797	2,6617	2,6441	2,6266
1950	2,9250	2,9037	2,8828	2,8621	2,8417	2,8217	2,8019	2,7824	2,7631	2,7441	2,7254	2,7070	2,6887	2,6708	2,6530	2,6355

(*) Gas is read in mbar and it is relative to the atmospheric one

1.25 Graphical method for determining energy saving by use of inverter

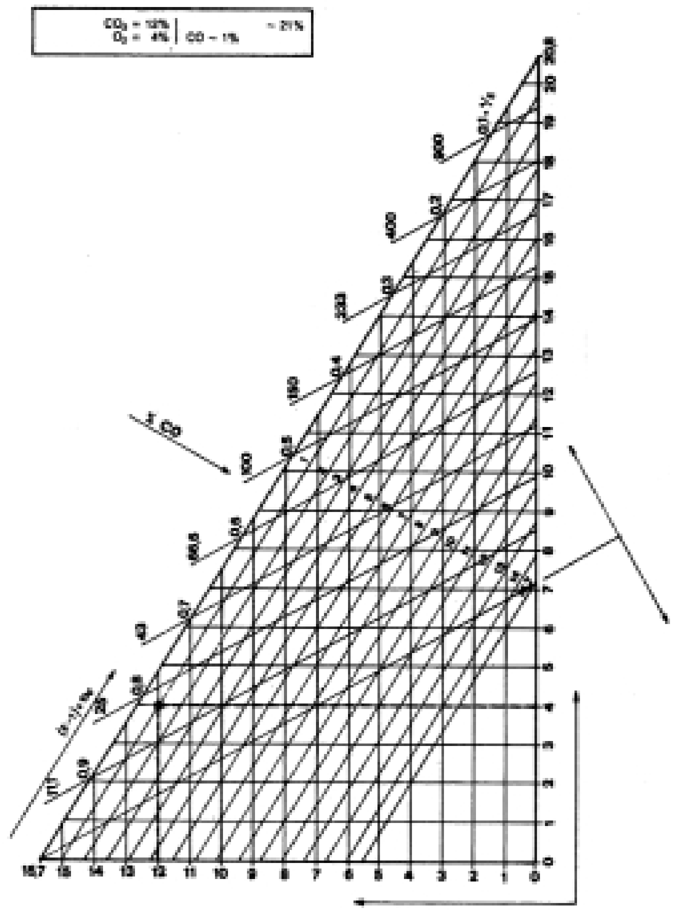


PROCEDURE

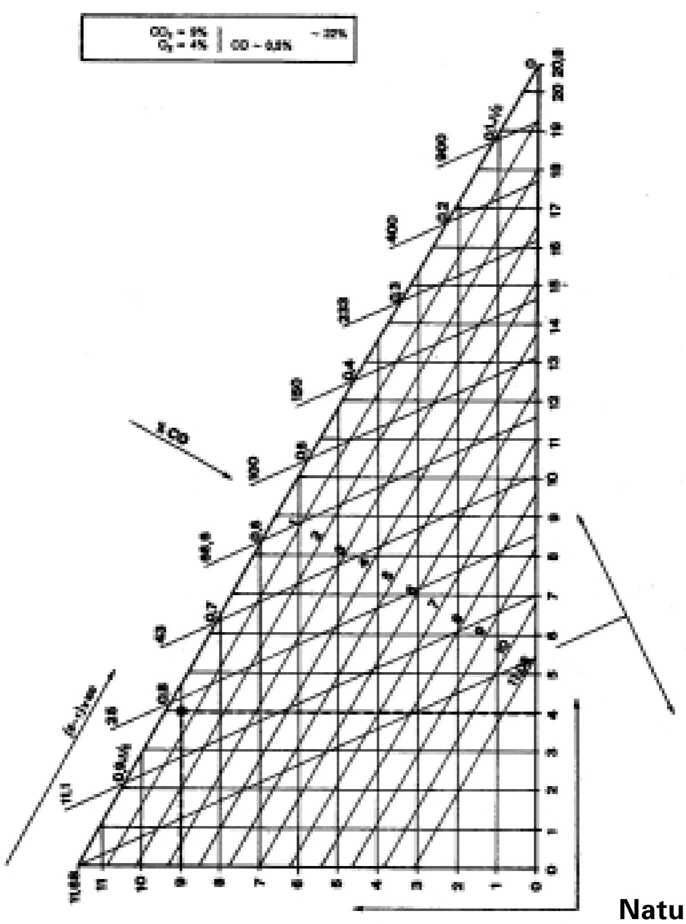
7- On horizontal axis of the 1st diagram at the top from left individuate fan output (as percentage of max. output).
8- Trace vertical upwards and intersecate line representing saved electrical ouput.
9- From intersection point trace horizontal in the right direction until intersecating, on the 2nd diagram at the top from left, line representing the hours of working per day.
10- From intersection point trace vertical downwards until intersecating, on the 2nd diagram at the bottom from left, line representing the days of working per year.
11- From intersection point trace horizontal in the left direction until intersecating, on the 1st diagram at the bottom from left, line representing 1 kWh cost in euro.
12- From intersection point trace vertical downwards until reading on horizontal axis the money saved in a year by using an inverter.

5.4 TABLES AND DIAGRAMS ABOUT COMBUSTION

1.26 Combustion triangle for natural gas and light/heavy oil

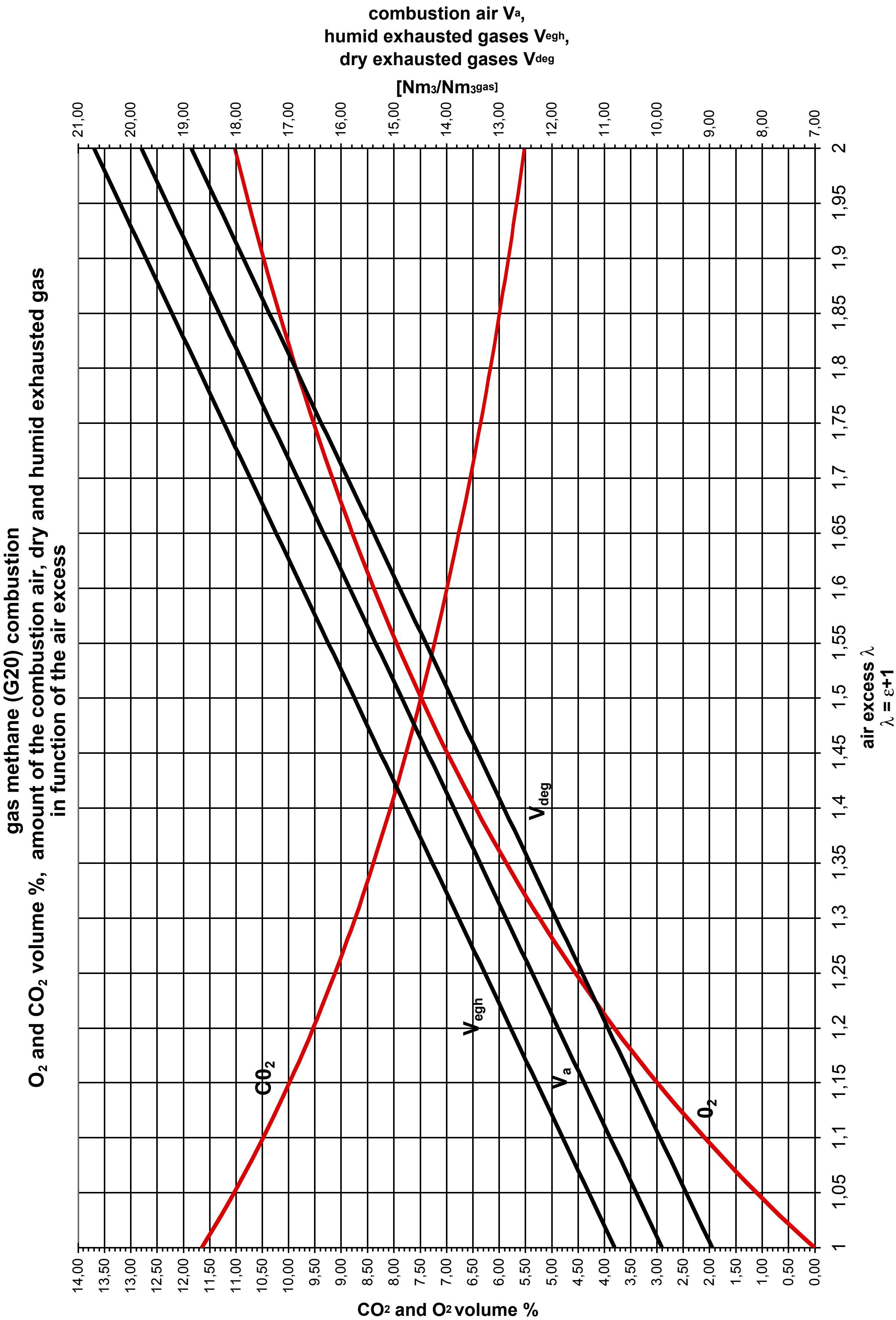


Light/Heavy oil

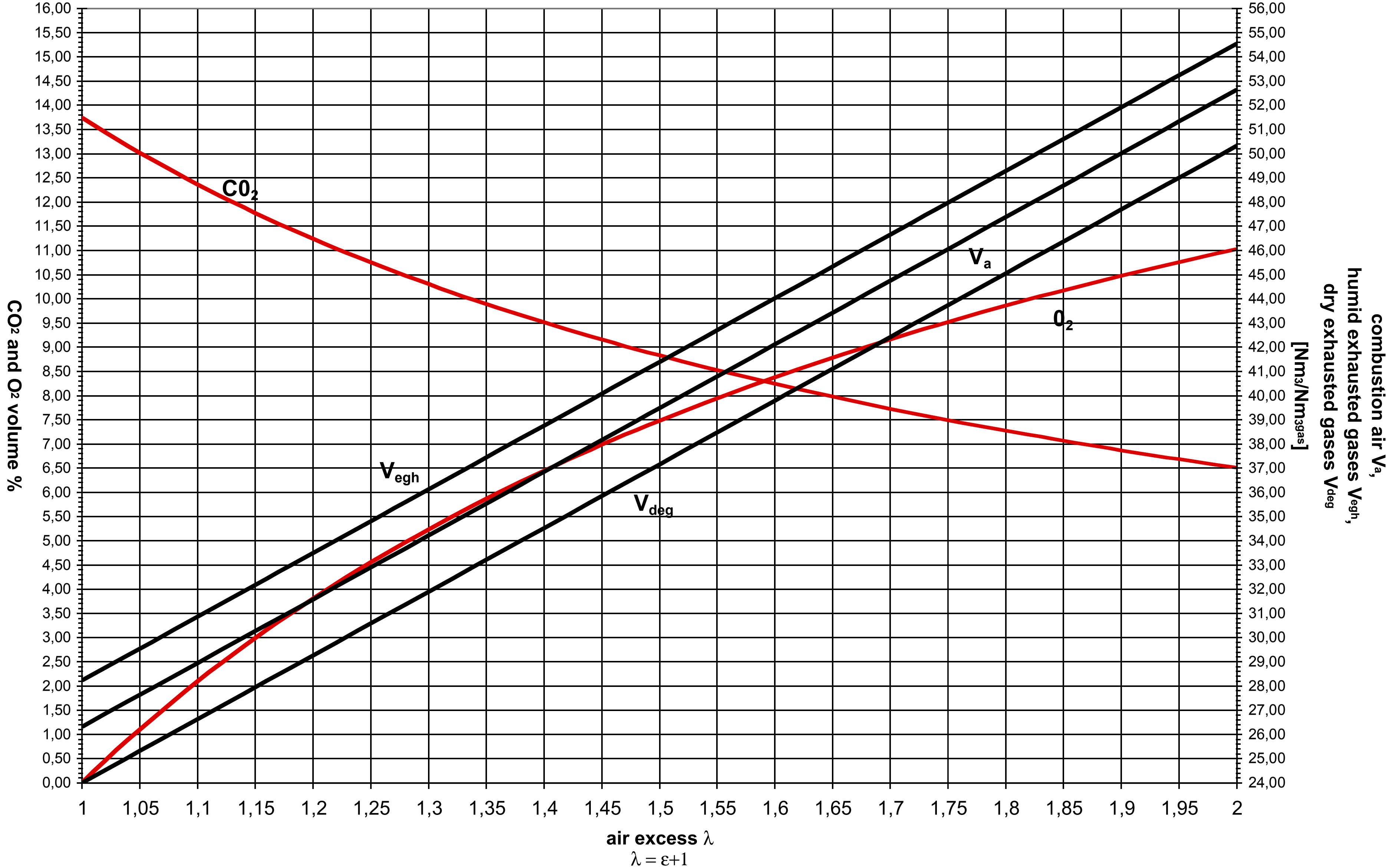


Natural gas

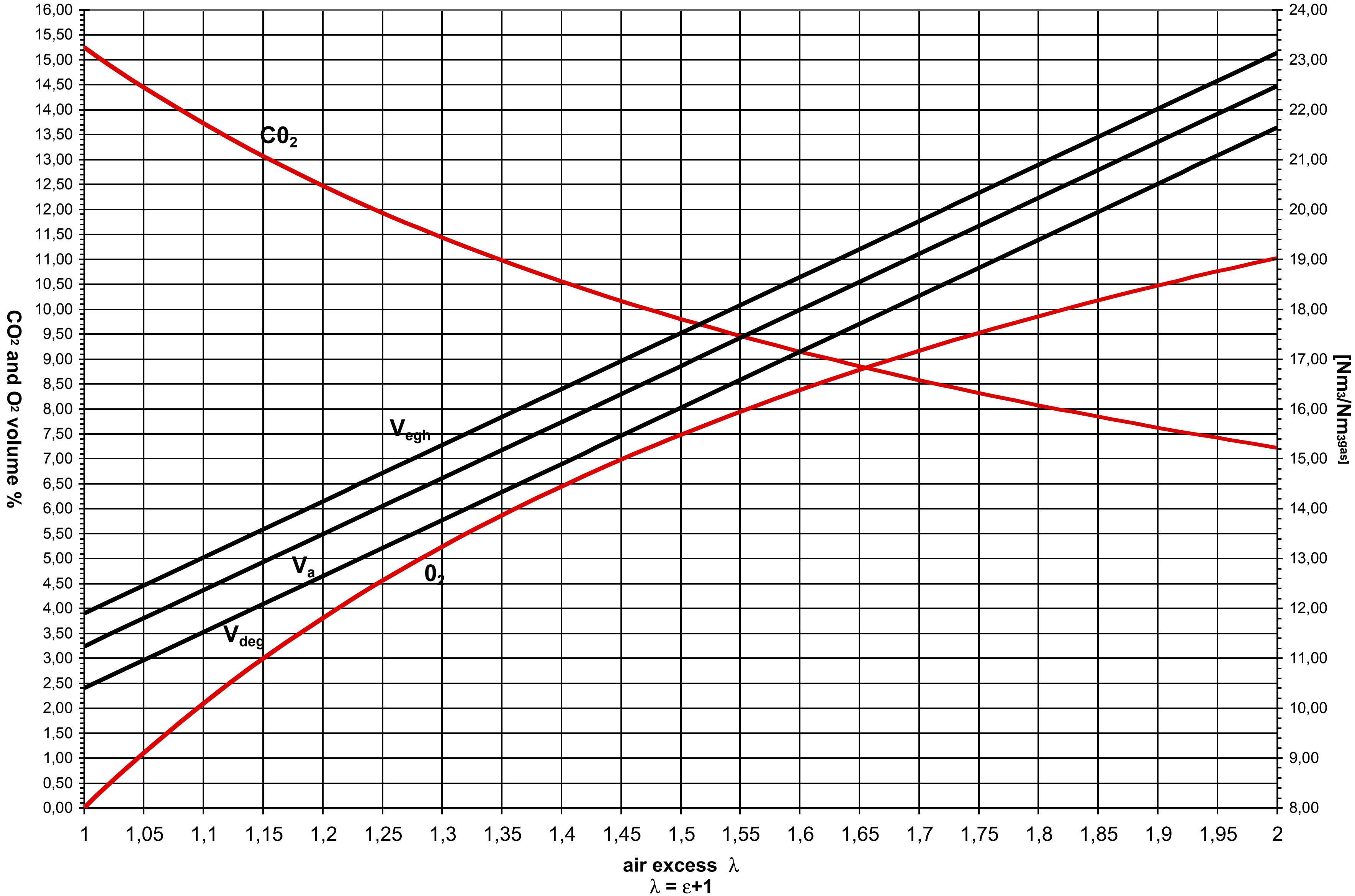
1.27 Combustion air and gas burnt quantities in relation to air excess for different fuels: G20, LPG, light oil and heavy oil



LPG combustion (LPG: 70% propane 30% butane)
O_2 and CO_2 volume %, amount of the combustion air, dry and humid exhausted gas in function of the air excess

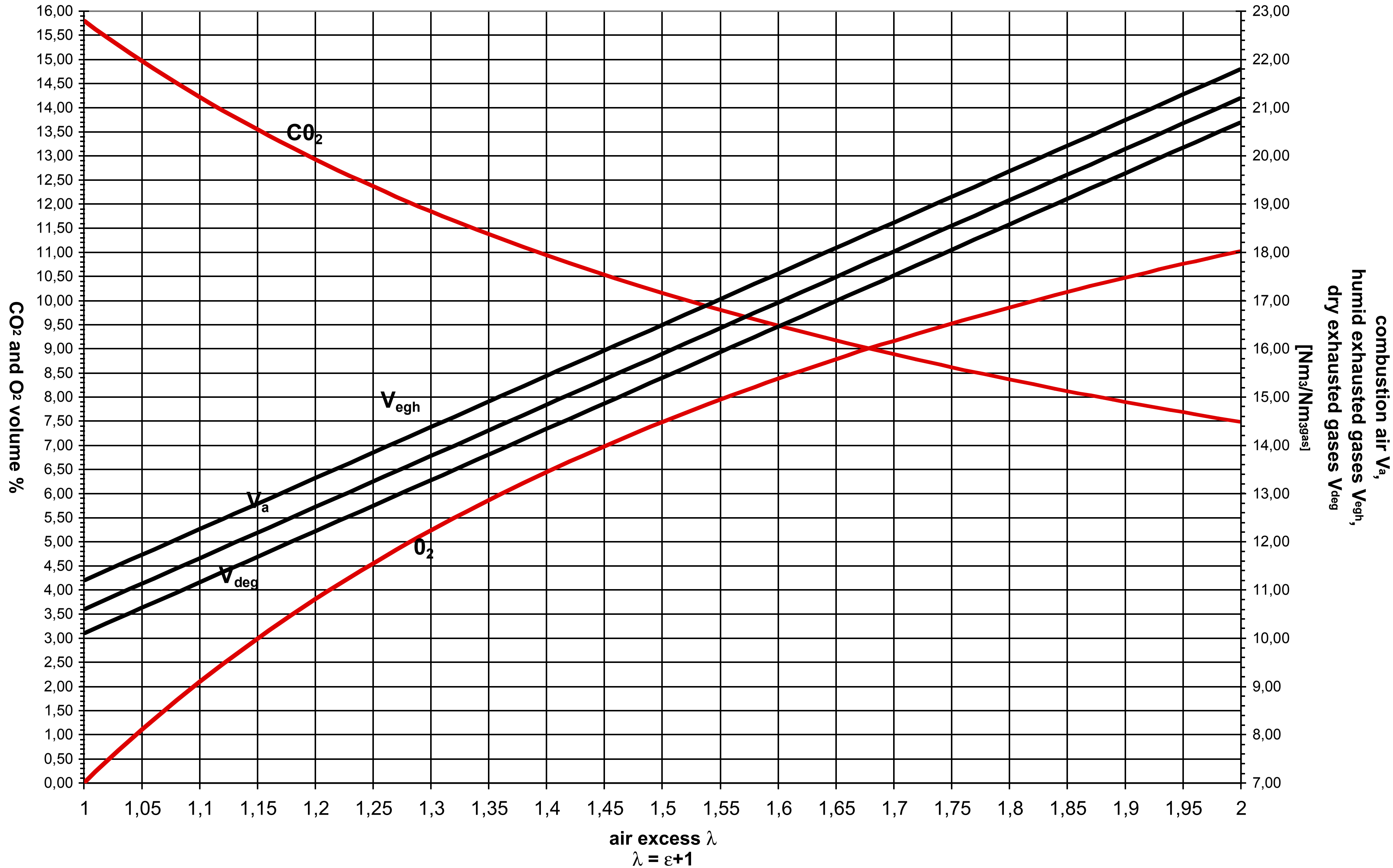


light oil combustion
O_2 and CO_2 volume %, amount of the combustion air, dry and humid exhausted gas in function of the air excess

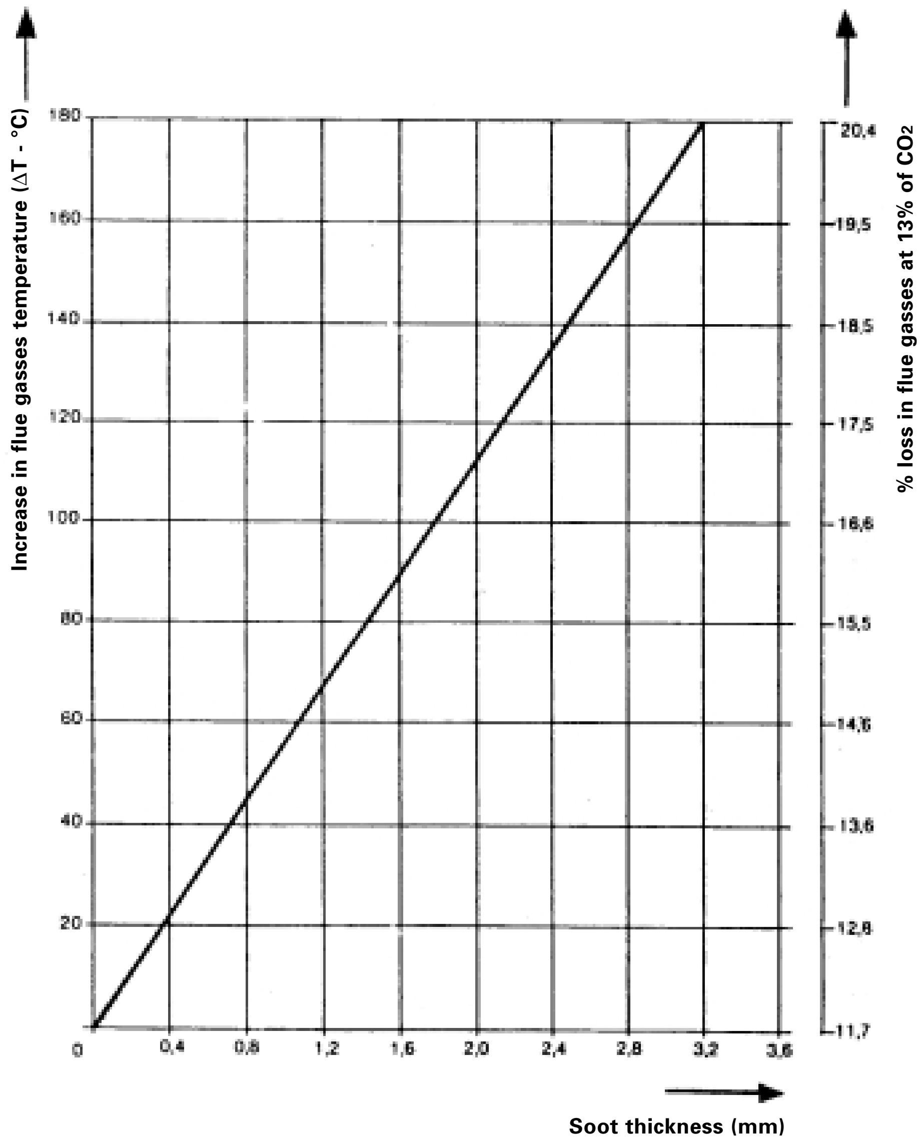


heavy fuel oil combustion (20°E a 50°C)

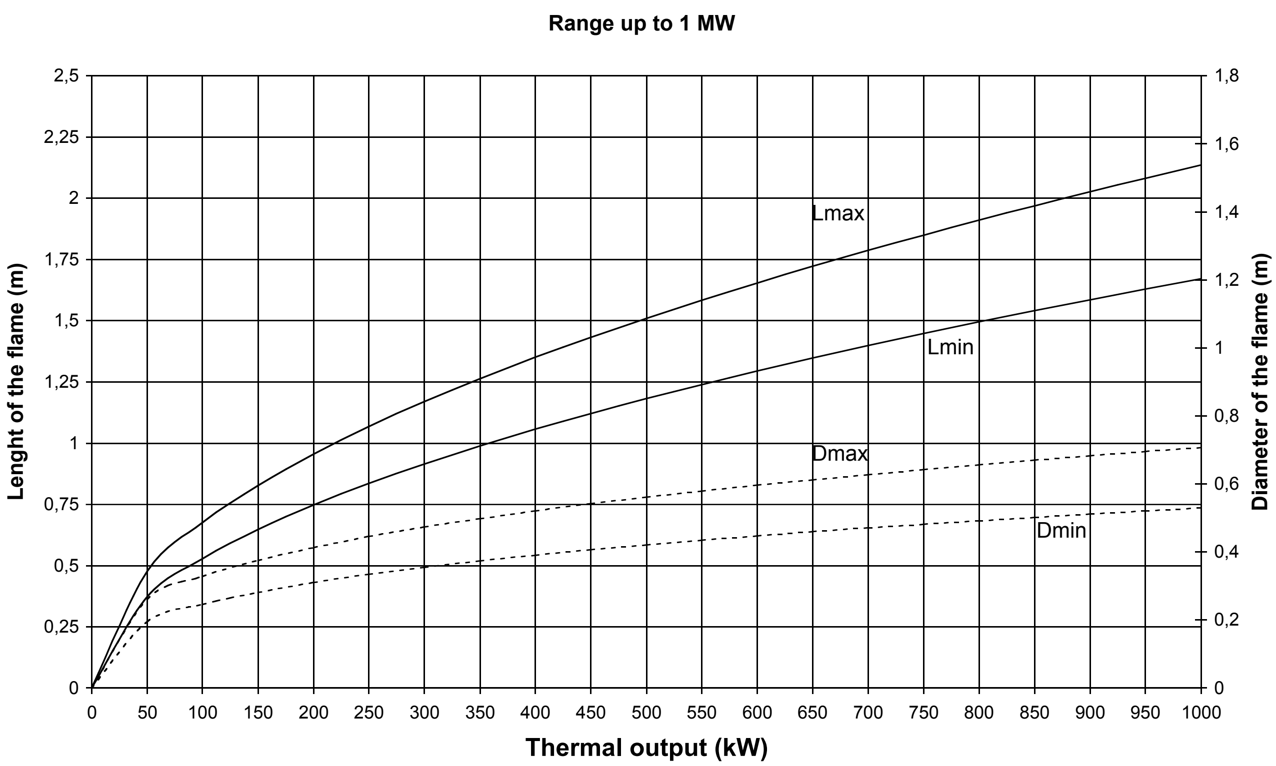
O_2 and CO_2 volume %, amount of the combustion air, dry and humid exhausted gas in function of the air excess

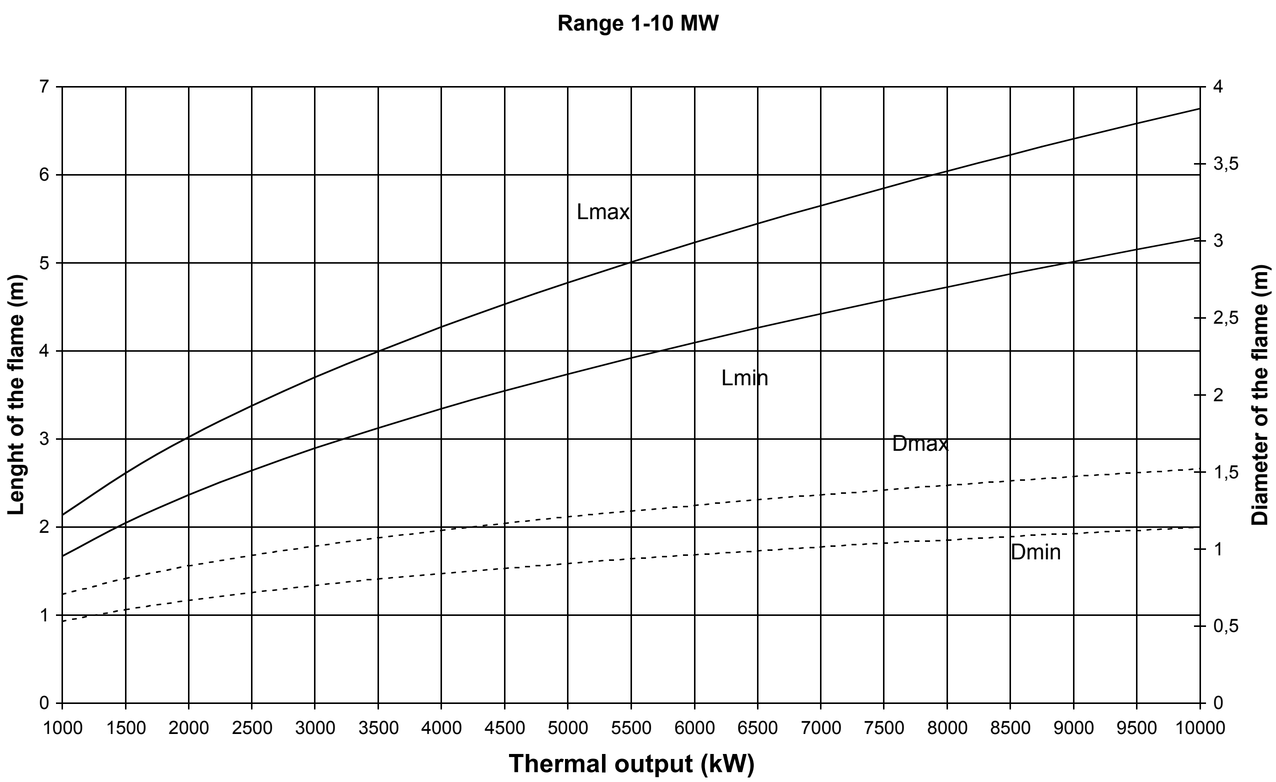


1.28 Increase of temperature in exhausted gas in relation to soot thickness

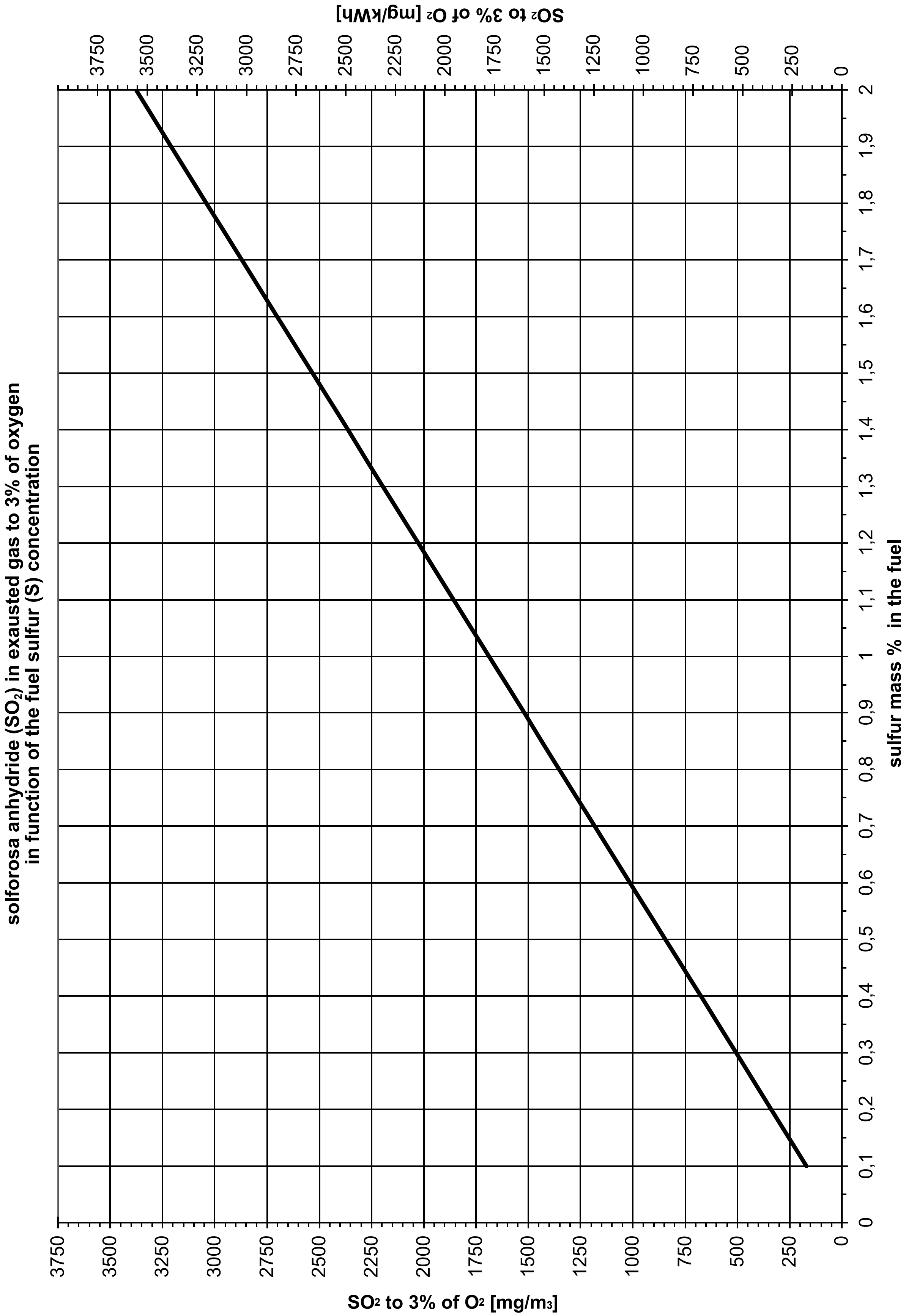


1.29 Lenght and diameter of the flame in relation to burner output

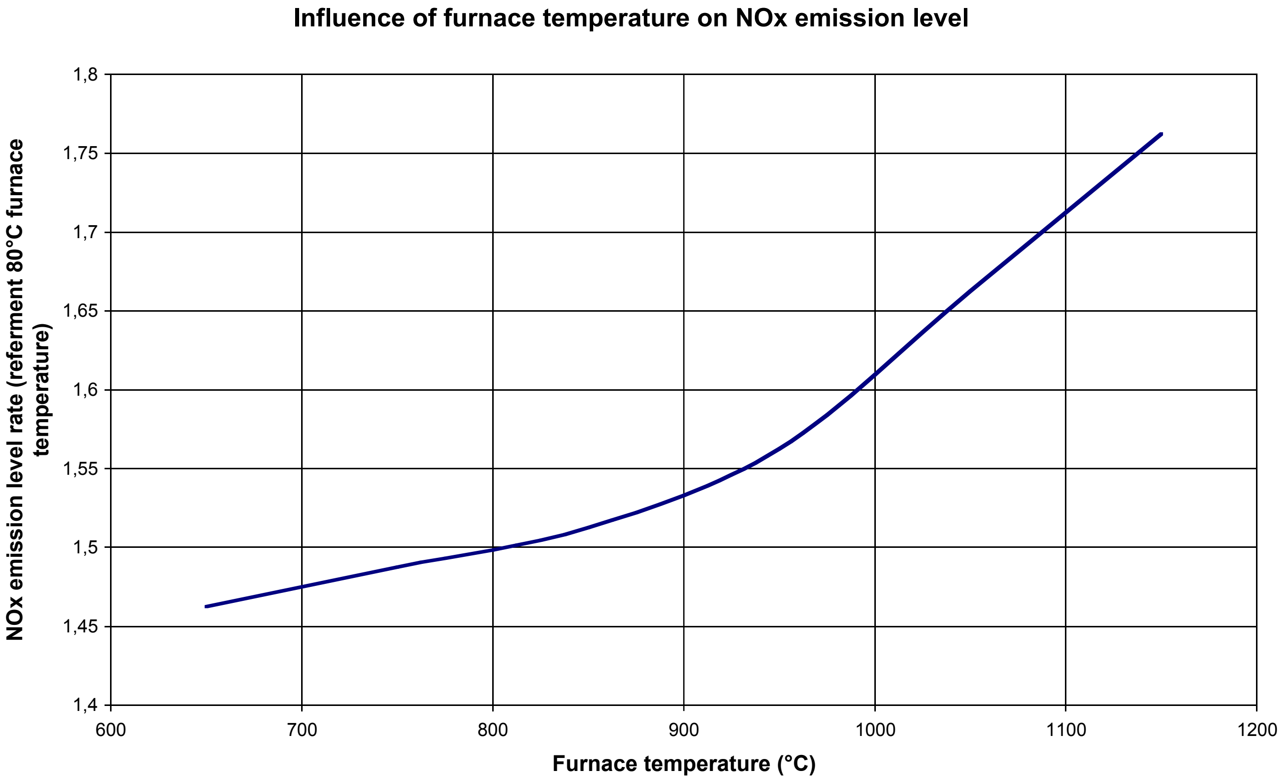


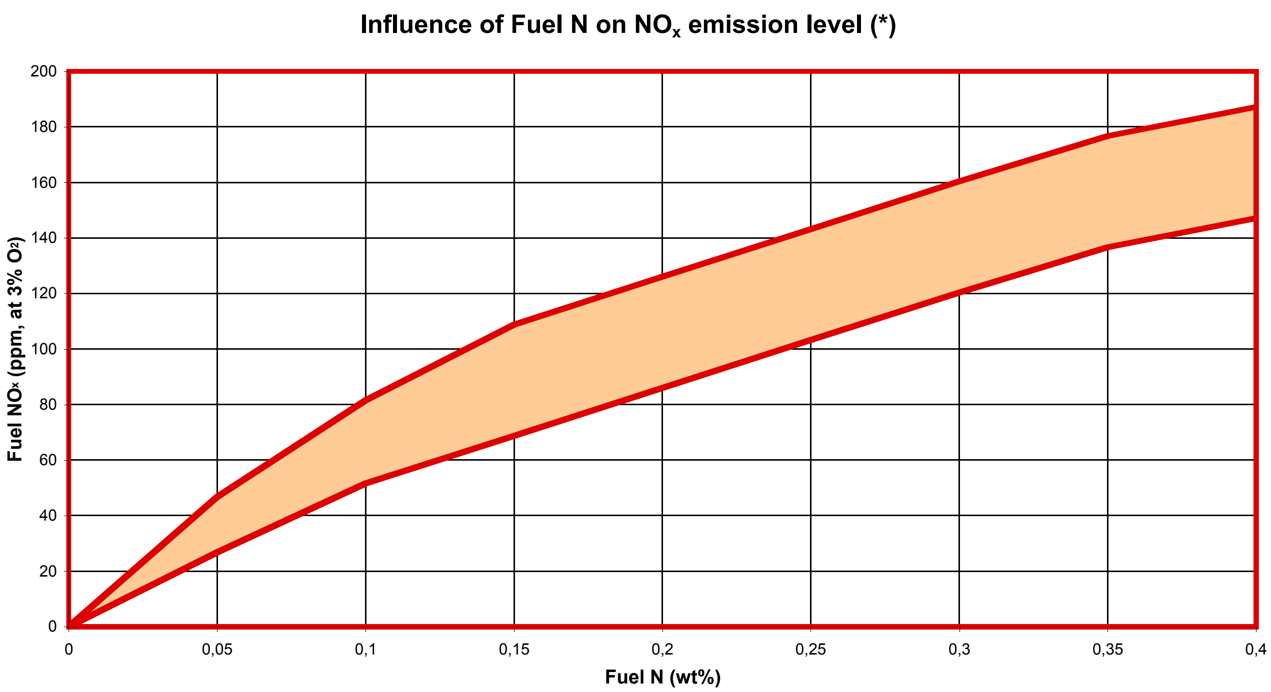


1.30 SO_2 emissions (mg/m3 e mg/kWh) in oil combustion in relation of S content (%) in the fuel at 3% of O_2



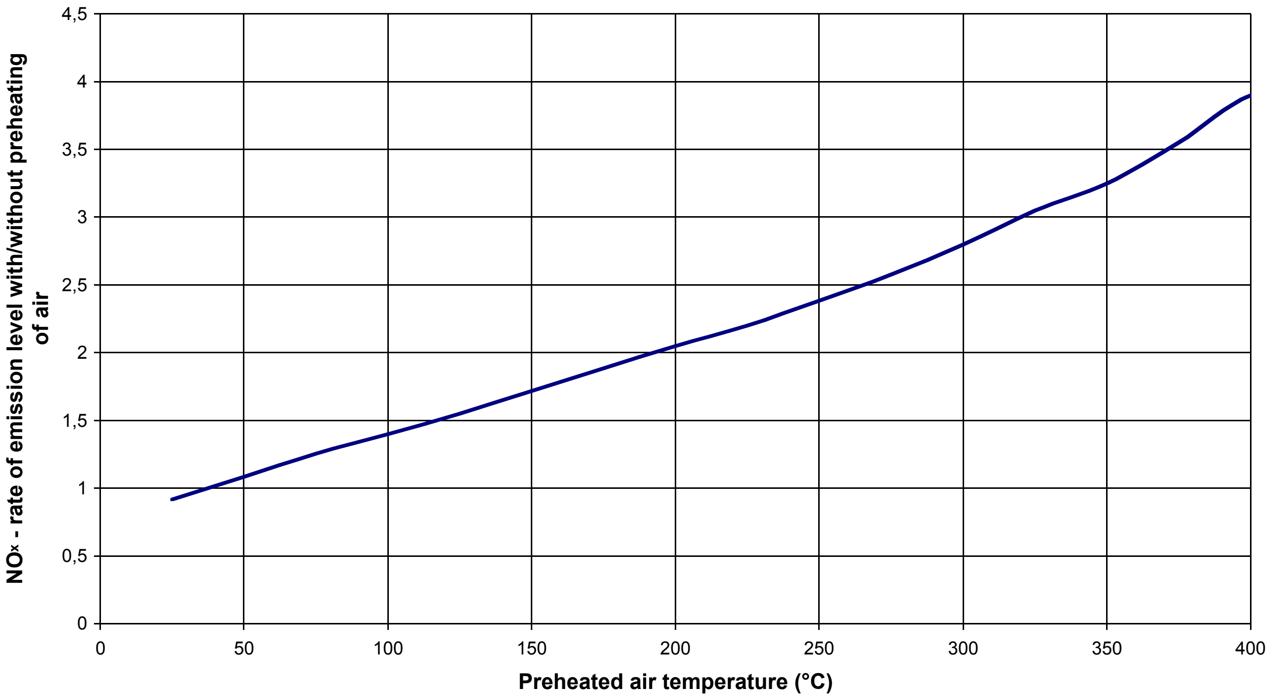
1.31 NOx emissions in relation to the different parameters of influence





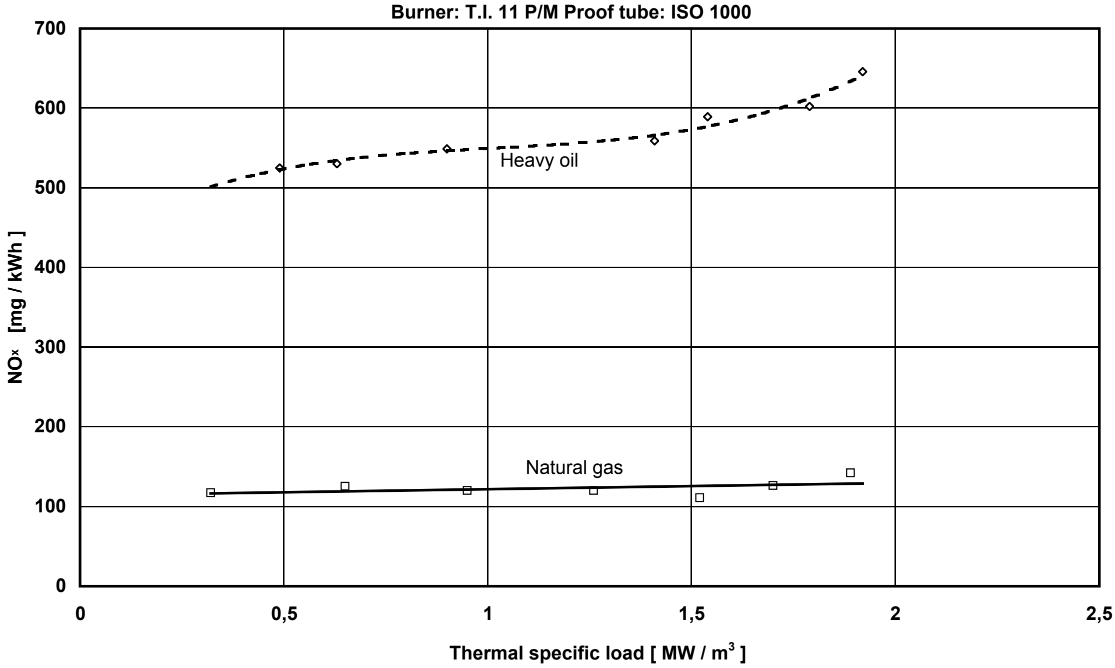
(*) The range of values shows the dispersion due to different burners

Influence of combustion air temperature on NO_x emission level



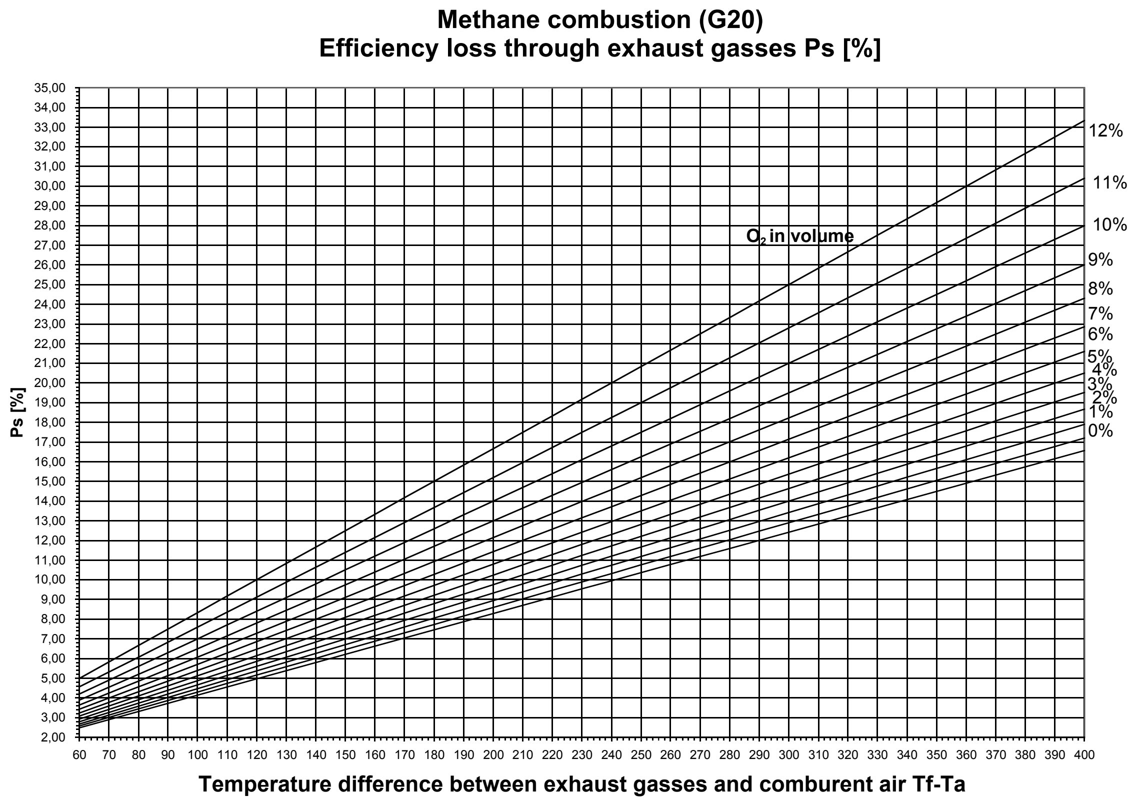
Load-ING Grafico 1

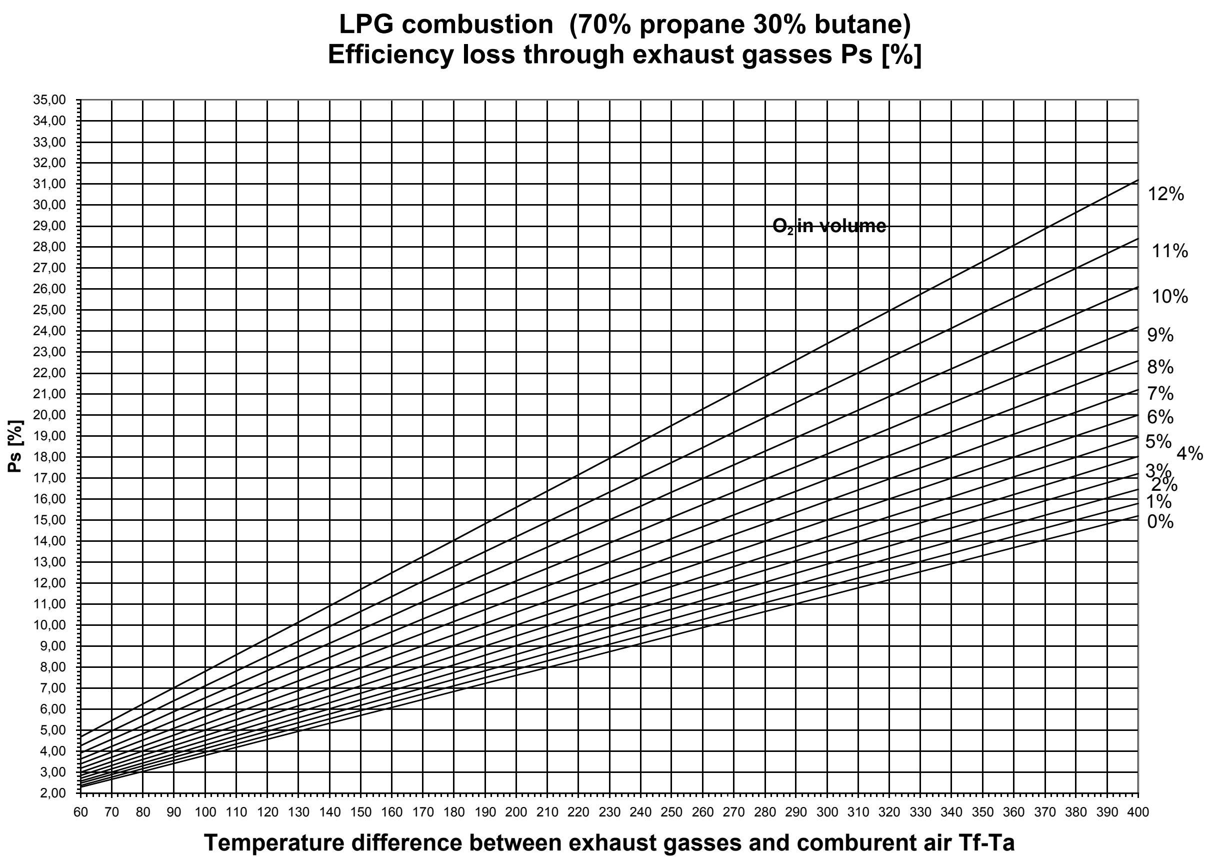
Influence of thermal load on NOx emisison level
Burner: T.I. 11 P/M Proof tube: ISO 1000



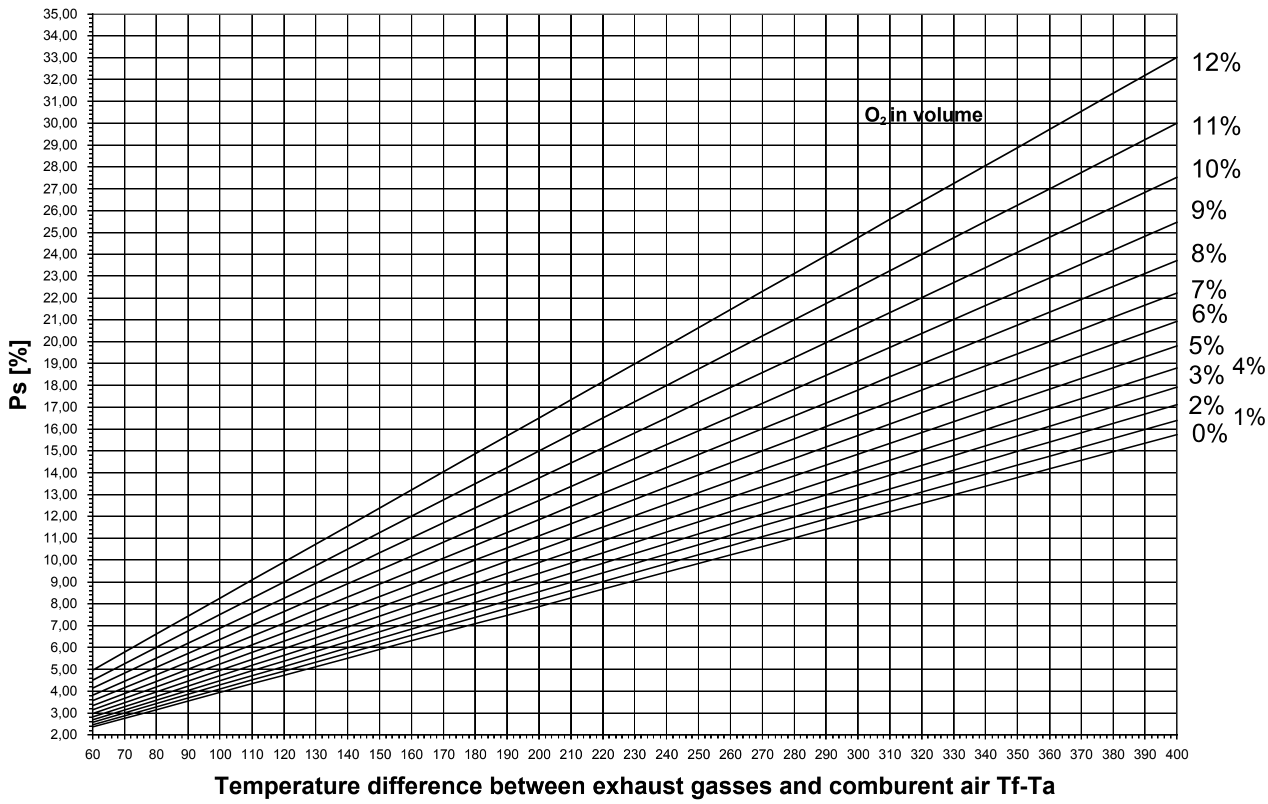
Pagina 1

1.32 Efficiency loss in exhausted gasses in relation to O_2 content for different fuels

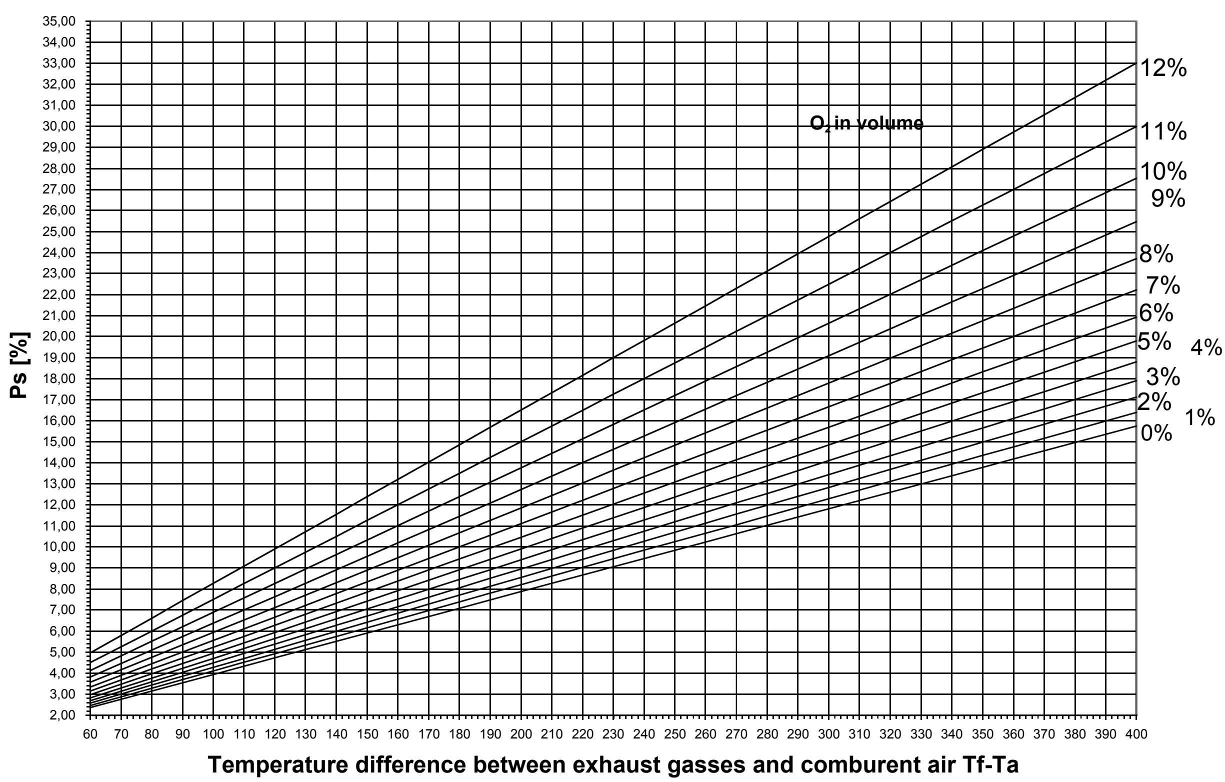




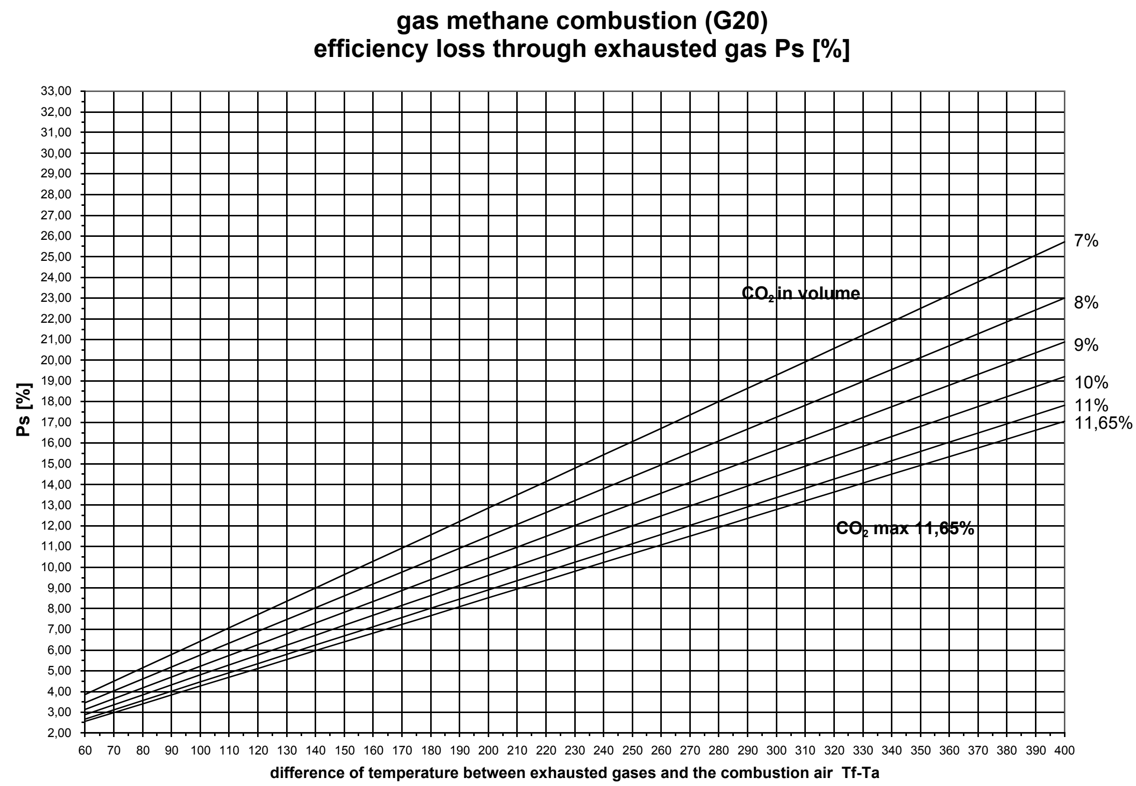
Light oil combustion
Efficiency loss through exhaust gasses Ps [%]

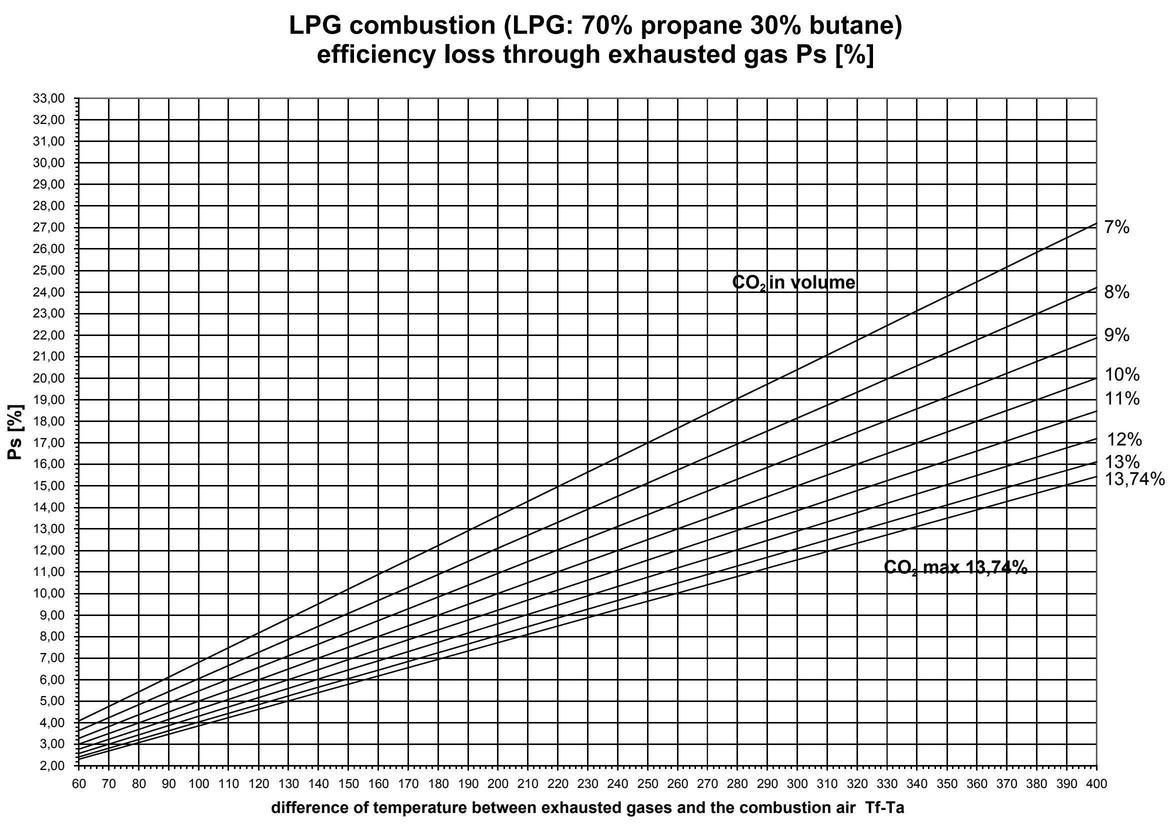


Heavy oil combustion (20°E a 50°C)
Efficiency loss through exhaust gasses Ps [%]

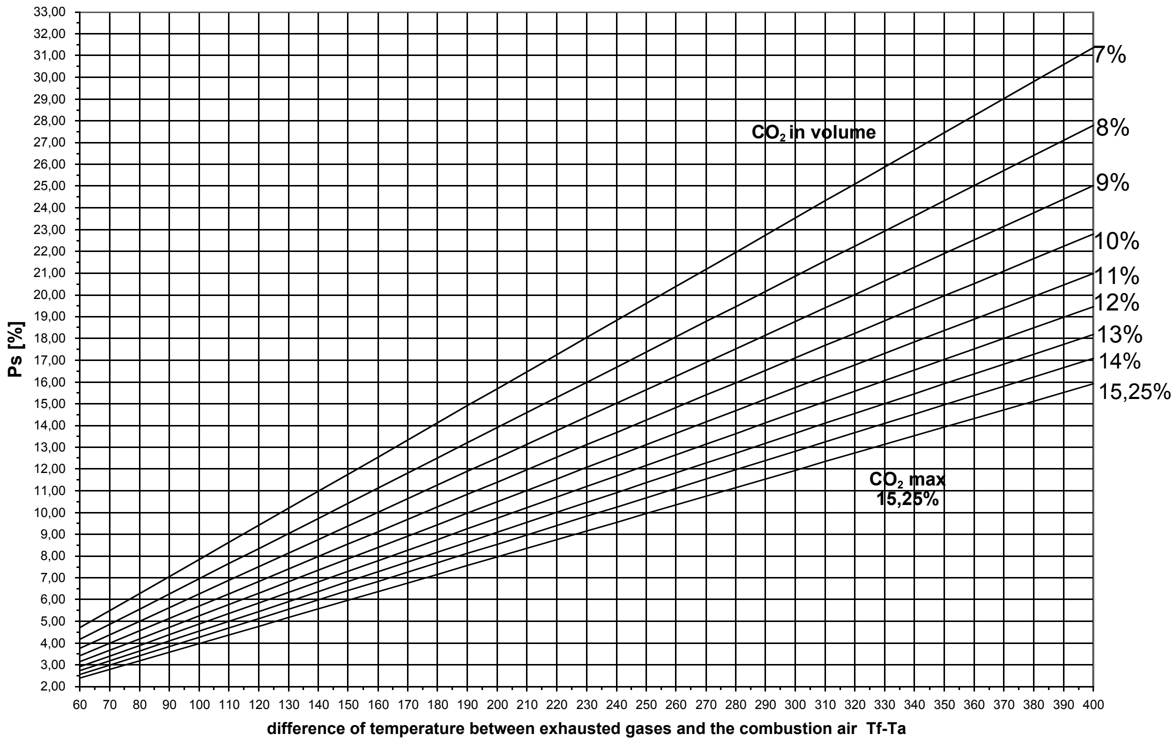


1.33 Efficiency loss in exhausted gasses in relation to CO_2 content for different fuels

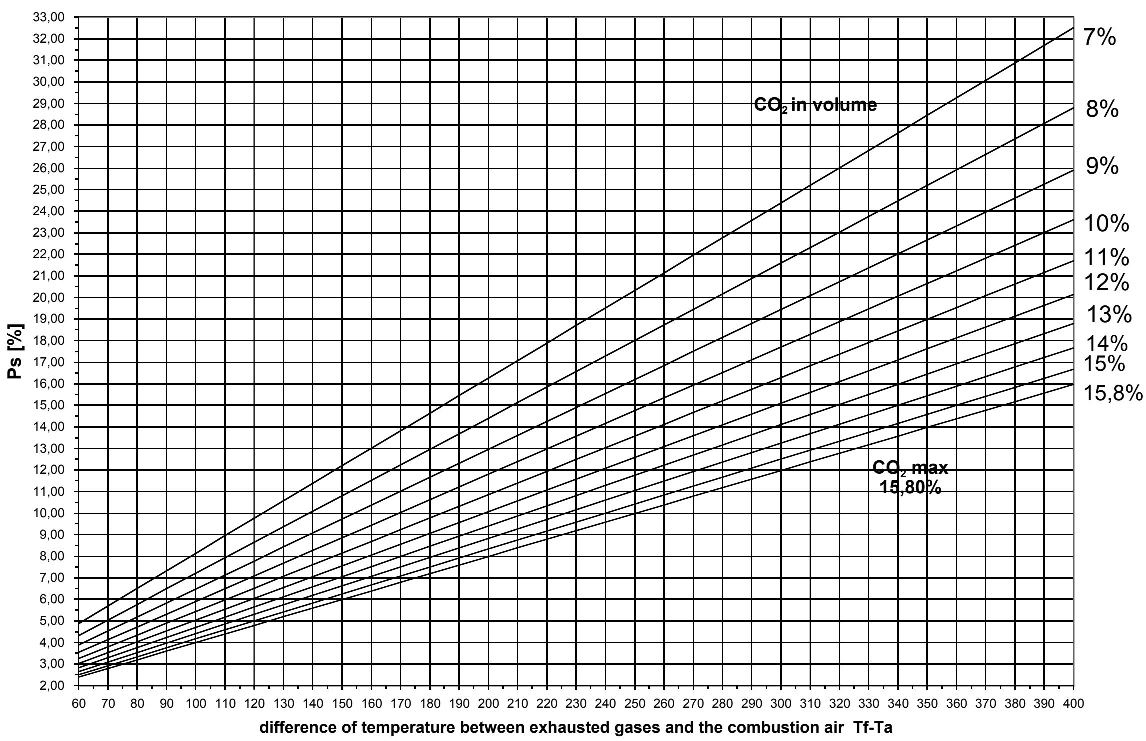




Light oil combustion
efficiency loss through exhausted gas Ps [%]



Heavy oil combustion (20°E a 50°C)
efficiency loss through exhausted gas Ps [%]



1.34 Conversion factors for pollutant emissions

Conversion from ppm to mg/Nm^3 and from mg/Nm^3 to ppm

Gas		
CO	1 ppm = 1,25 mg/Nm^3	1 mg/Nm^3 = 0,8 ppm
NO	1 ppm = 1,34 mg/Nm^3	1 mg/Nm^3 = 0,746 ppm
NOx	1 ppm = 2,05 mg/Nm^3	1 mg/Nm^3 = 0,488 ppm
SO_2	1 ppm = 2,86 mg/Nm^3	1 mg/Nm^3 = 0,35 ppm
C_3H_8	1 ppm = 1,98 mg/Nm^3	1 mg/Nm^3 = 0,505 ppm

Conversion from ppm to mg/kWh and from mg/Nm^3 to mg/kWh at 3% of O_2

Metane G20	
NOx	1 ppm = 2,052 mg/kWh
NOx	1 mg/Nm^3 = 1,032 mg/kWh
CO	1 ppm = 1,248 mg/kWh
CO	1 mg/Nm^3 = 0,99 mg/kWh
Light oil	
NOx	1 ppm = 2,116 mg/kWh
NOx	1 mg/Nm^3 = 1,032 mg/kWh
CO	1 ppm = 1,286 mg/kWh
CO	1 mg/Nm^3 = 1,0288 mg/kWh

Lineagrafica

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