NOZZLES AND TIPS
CHAPTER 5

COMBUSTION AND NOZZLES

An air-gas mixture flowing out of a pipe expands and then its velocity gradually decreases.
The mixture particles on the outer surface of the flow cone leaving the pipe are slower than the ones in the centre of the flow. This is due to the friction the outer particles encounter on their way. For this reason the velocity of the mixture is maximum at the centre and gradually decreases towards the periphery.
If we wanted to detect the points in the flow where the mixture flows at equal speed, we would obtain some cones as the dashed line shows in figure 11A.
If the mixture were ignited, for instance by means of a pilot burner leaking the flow, the ignition would stabilize on that part of the cone where the flame propagation rate is the same as the flow speed.
If the flow speed at the outlet of the pipe is the same as the propagation rate of the flame, the latter stays attached or very close to the pipe and forms an ignition cone whose shape depends on the type of gas, the percentage of air in the mixture and the temperature of the mixture.

At low flow velocities, the edge of the flame lies quite close to the burner lip and is said to be attached. When the velocity is increased, the cone angle of the flame decreases and the edge of the flame is displaced a small distance downstream. With further increases in flow velocity, a critical velocity is reached where the flame edge jumps to a downstream position far from the burner lip. When the flame jumps to this position, it is said to be lifted. Increasing the velocity beyond the liftoff value results in increasing the liftoff distance until the flame abruptly blows off the tube altogether, an obviously undesirable condition. Flashback on the other hand occurs when the flame enters then propagates through the burner tube or port without quenching. This occurs when the local flame speed exceeds the local flow velocity. The phenomena of flashback and liftoff are both related to the correct calibration of the local laminar flame speed and the local flow velocity (V_P and V_F) which is not easy to obtain in this type of burners furthermore due to the phenomena mentioned above no capacity regulation is possible. That is why this type of burners is not used in industrial applications.

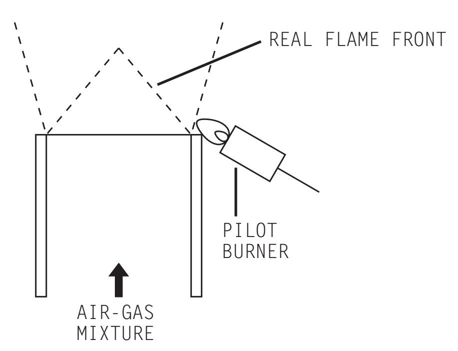

Fig. 11A

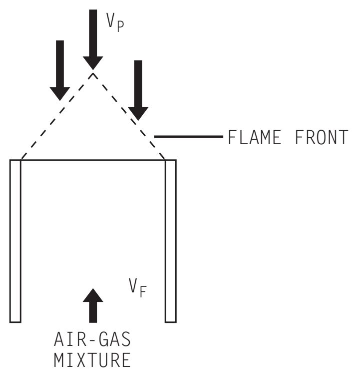

Fig. 11B

MULTI-HOLED BURNERS (ATMOSPHERIC BURNERS)

The phenomenon of flashback may be often reduced by using a very small diameter for the flow outlet. The larger the metal surface the quicker the mixture in the tube cools down. In standard conditions, when the local flame propagation rate exceeds the local flow veloctiy, we have a flashback. In this type of burners this does not occur because of the cooling effect of the metal surface which keeps the mixture temperature through the port, below 600 °C (ignition temperature). For this reason ignition starts right at the port.
In order to obtain a 5 to 1 capacity ratio, the port diameter must not exceed 3.25 mm; the thickness of the wall, where the port is, must be at least the same as the diameter.
Each port featuring this diameter delivers 100 kCal/h of natural gas.

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In this type of burners the total quantity of heat requested by the industrial process is hence distributed over a great number of ports which all feature the same diameter. The ignition of the mixture easily propagates from one port to the other if the distance from one port to the other does not exceed the diameter of the port by 4 times.
The quantity of air in the mixture in these burners does not exceed 30% of the theoretical value. Hence the remaining 70% of air necessary for the completion of combustion must be supplied as secondary air. Each flamelet obviously needs some air around it. For this reason, burners with three rows of ports cannot operate satisfactorily; as a matter of fact the central row does not receive enough air thus the flames of this row lift.
This type of burners cannot stand a capacity greater than the one mentioned above as the flame would lift from the port and then blow off.

FLAME HOLDING

Most burners for industrial use, however, need a thermal capacity, per outlet orifice area, much greater than the one needed by the burners mentioned above. In order to avoid liftoff, an annular row of flamelets is provided for around the outlet orifice of the burner featuring the same characteristics as the ones mentioned above. The flamelets are designed to keep the main flame constantly ignited and avoid any liftoff even when the main orifice load is 100 times greater than the limit load mentioned above.

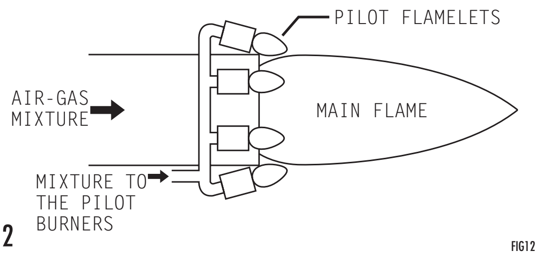

Fig. 12

In some sophisticated, expensive industrial processes, the mixture is supplied to the flamelets, called "pilot" flamelets, by a mixer and a conduit which are completely separated from those of the main burner (fig. 12).
Most burners used in industrial processes on the other hand are "self-piloted" and feature one mixer only.
In atmospheric, multi-holed burners (plate or tube annular burners) the mixture pressure to the burner is 0.8 ÷2 mm H_2O. Industrial one-torch burners may work with a mixture pressure above 1,500 mm H_2O. This value is one thousand times higher than the limit one, that is before liftoff takes place. Obviously in these conditions the flame must be piloted by means of a number of flamelets placed all around the boundary of the mixture flow. All self-piloted burners feature many small ports around the outlet orifice of the main flame through which, due to the pressure drop, the mixture velocity (flowing at high speed from the main orifice) decreases. The number, diameter and position of these small ports depend on the mixture velocity and aeration.

NOZZLES FOR LOW-PRESSURE TORCH BURNERS

The nozzles suitable for mixture pressures up to 65 mm H_2O and 60% pre-mixing are those shown in fig. 13.
The mixture, when it arrives at the nozzle, partly directs to the main (central) orifice and partly directs to the orifices around it where it is subject to a pressure drop and decrease in velocity. Pilot orifices feature the same combustion characteristics as multi-holed burners. The great flame stability of the pilot ports allow to keep the flame of the main port ignited. The nozzle lips extend beyond the ignition point to protect the flames from potential air flows.
The mixture pressure limit mentioned above (65 mm H_2O) must be considered as a total pressure drop limit through the nozzle.
In order to find out the total pressure drop through the nozzle, the

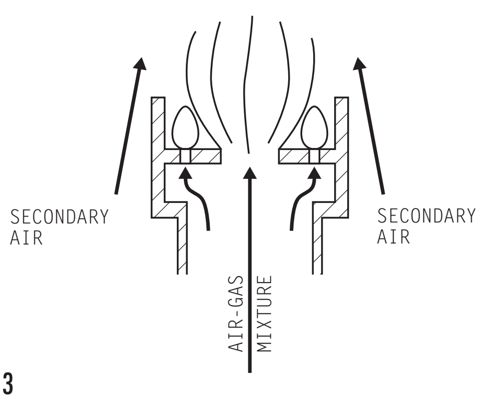

Fig. 13

component in the combustion chamber must be added to the value of DP at the nozzle. When operating with 20÷60% pre-mixing, it is necessary to add great quantities of secondary air around the nozzle to complete combustion.
Naturally these nozzles must be fed by mixers which are suitable for reaching the pre-mixing value mentioned above. What we said in Chapter 3, in the section about the "influence of draft on the working of atmospheric mixers" is true of this type of nozzles,too. Clearly enough, moreover, as a consequence of the weak mixture pressures and the need to entrain great quantities of secondary air, these burners cannot work in pressurized combustion chambers even though by few hundredths of millimetre of column of water.
Self-piloted nozzles for low-pressure mixture feature a big central orifice. When operating at gas pressures ranging from 100 to 200 mm H_2O very little flow reductions are possible (2 to 1 maximum) due to the frequency of flashback problems in this type of burners, particularly in conditions of medium-high draft. Usually an "on-off" regulation is performed on these equipments.

LOW-PRESSURE TORCH BURNERS WITH A WIDE CAPACITY RATIO

Another type of burner is similar to the previous one as for the design. This one though allows for a greater capacity ratio thanks to a steel disc placed at the level of the central orifice of the nozzle which may reduce the nozzle area by 80% in case of a decreased need for heat (fig. 14).
The disk is connected via a metal rod to the diaphragm of a pneumatic regulator placed on the back of the burner. A spring between the diaphragm and the body of the burner in normal conditions, keeps the disc in a backward position, which corresponds to the nozzle section completely closed. The upper chamber of the diaphragm regulator is loaded with the gas line pressure between the capacity regulator and the jet nozzle. As long as the gas pressure has not reached the value of 40 mm H_2O, the disc does not move from the back position. In this position no flashback can occur because the mixture velocity at the nozzle outlet is the highest.
When the capacity that is the gas pressure P_1 is increased, the diaphragm is loaded by a greater static pressure hence the disc will

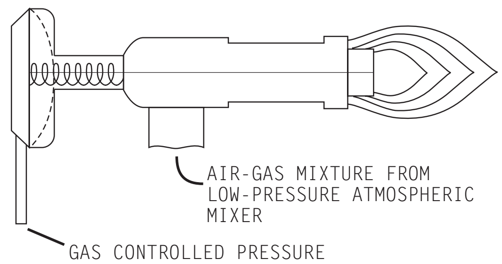

Fig. 14

move forward. In this way the free section of the central port of the nozzle will be be increased. The disc is free to run for up to 40 mm.
From its maximum forward position, the disc will run the whole way back entrained by the spring tension as the gas boost decreases.
Burners equipped with this device may reach capacity ratios higher than 10/1 even with maximum gas pressures of 150 mm H_2O and in medium draft conditions. With higher gas pressures higher capacity ratios may be obtained.

NOZZLES FOR HIGH-PRESSURE TORCH BURNERS

Operating with rich mixtures (from 65 to 95% premixing) and pressures exceeding 50 mm H_2O, the ports of the pilot flamelets of a low-pressure nozzle do not work properly. As a matter of fact in these working conditions it is difficult if not impossible to create a pressure drop through the pilot ports capable of stabilizing the pilot flamelets. In this case the combination of two effects is very useful:
1) the pressure drop through the pilot ports;
2) the expansion of the mixture in an annular chamber placed before the combustion area, to slow down the mixture velocity and stabilize the pilot flames. Fig. 15a shows this system.

This type of nozzle is usually used for small burners. In great burners pilot ports would find themselves too far away from the central orifice to obtain good ignition results. In these cases it is advisable to use the system shown in fig. 15b where the pilot flamelets bump into the nozzle lips which are folded on themselves towards the centre. In this case too, the aim is to reduce the speed of the mixture flowing out of the pilot ports. At the same time the effect deriving from the increase in the propagation rate is exploited which is caused by the temperature of the metal of the nozzle. Another stabilizing effect is due to the sudden change of direction of the pilot flames which bump into the nozzle lips.
The immediate expansion of the mixture as soon as it leaves the central orifice of the nozzle, creates some depression around it. Thanks to this some secondary air is entrained which is necessary both for stabilizing the pilot flame and complete the combustion of gas. Therefore it is necessary that some secondary air flows around the

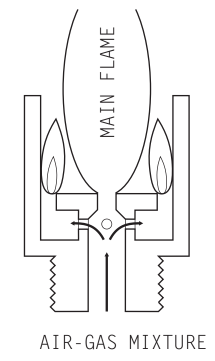

Fig. 15a
FIG15A

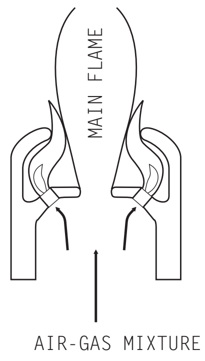

Fig. 15b
FIG15B

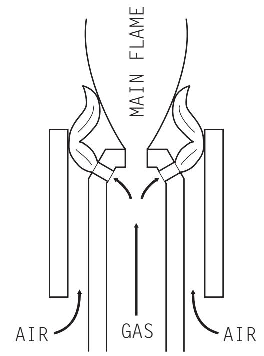

Fig. 15c
FIG15C

nozzle; otherwise the pilot flamelets will blowoff and the effect of flame holding would disappear.
The system shown in fig.15c allows for the adequate aeration of the nozzle. This type of sytem is more suitable for the so-called "linear burners" or "laminar-flame burners". In this case the two outer metallic walls are made up of two inox steel rails and are expresely separated from the central body of the burner to allow for some air flowing. The combined effect of the pressure drop through the pilot ports and the impact of the flamelets on the outer rails acts as a stabilizer on the flame. This type of construction prevents the burner from overheating thanks to the cooling effect of the air flowing between the burner body and the rails.
In the burners shown in figs. 15, the higher the mixture pressure the wider the ratio of the maximum capacity to the minimum capacity which can be obtained.
With mixture pressures of 200÷250 mm H_2O capacity ratios of 5 to 1 can be obtained.

COMPLETELY CLOSED BURNERS

The burners which work with primary air in stoichiometric ratio with gas (100% premixing) usually have a head (or block) in some refractory material in the place of the metallic nozzle. The metallic parts of the burner which are exposed to high temperatures are adequately protected. These burners must operate with no secondary air so as to perfectly control the oxygen excess or deficiency in the combustion chamber. They allow for the best combustion rating and are used for special industrial heat processes where working temperatures exceeding 500 °C up to 1,900 °C are necessary.
Obviously, flame holding is obtained in a different way as compared to the way mentioned above being secondary air and metallic parts not available.
The mixture flowing from a tube into a refractory block gradually expands in the diverging section of the block itself. The last tract of the tube and the conic block behave as a standard venturi. In fig. 16 P_1 is the mixture pressure at the outlet tube and P_3 is the atmospheric pressure beyond the outlet mouth of the block (see the acronyms given to the pressures in the description of the venturis, Ch. 2).
In these conditions, in each steps obtained in the cone of the refractory block some negative pressure P_2 is created. As a matter of fact, when the cone section is increased right in those points, the mixture speed decreases and then increases again. According to the capacity of the burner, in one of these points lies the equilibrium between the mixture outflow velocity and the flame propagation rate. The turbulent currents forming in the depression areas P_2 work as pilot. As a matter of fact around the steps of the block some flame rings form which burn constantly and keep the high-speed mixture flowing centrally burning.
The pilot burners for the initial automatic ignition of the main flame are usually placed on the steps of the block so as to exploit, for the stability of the pilot flame, the draft existing in those points.

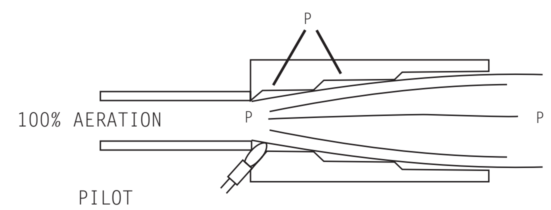

Fig. 16
FIG16

Completely closed burners with not well-designed refractory blocks must be ignited at a low regime of capacity. It is advisable to shift to the maximum capacity only after that the refractory block becomes incandescent. Flame holding in these burners is only due to the increase in the flame propagation rate caused by the heat radiating from the refractory. Well-designed burners with stepped refractory block may, on the contrary, be immediately started at the maximum capacity without problems.

Generally speaking total pre-mix burners are responsible for the maximum flame propagation rate. For this reason, flashback in the inlet mixture manifold is quite frequent, particularly during the phase of capacity reduction. With some proper change in the burner head (see fig. 17) such hazard can be greatly reduced. A metallic piece is placed in the middle of the mixture pipe, where the mixture flows into the refractory block. This metallic piece must be protected frontally by means of the so-called refractory ceramic "nose". In this way the area of the mixture outflow is reduced and the outelt velocity increased. Furthermore, the metallic piece absorbs much of the heat released to the mixture by the combustion chamber, cooling the mixture to below 600 °C.

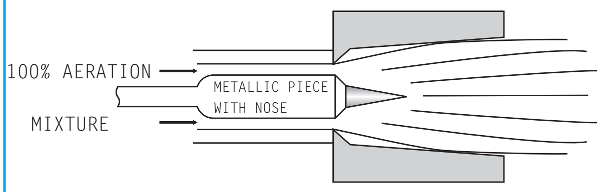

Fig. 17

In this type of burners capacity ratios of 10/1 may be easily exceeded without problems with mixture pressures of 250 mm H_2O at the maximum capacity.

The kind of burners shown in figure 17 only needs one step in the refractory block in order to obtain good flame holding.

A remarkable draft area is created by the combination of this step and the "nose". The turbulence of the mixture in the block is very high and consequently the flame is short.