Backfire and Flashback in Oxyfuel Processes

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Despite the development of new techniques, fuel gas processes like oxyfuel welding, cutting, heating and straightening have many industrial applications. This is partly because the equipment is versatile, easy to move around, and is relatively inexpensive, A point to remember when working with fuel gases is the risk of backfire and flashback, which can cause both material damage and personal injuries.

The purpose of this report is to increase the knowledge about how backfire and flashback can arise, and of how they can be avoided. Backfire or flashback is often caused defective or wrongly handled equipment. This emphasies the importance of education and training for increasing safety in places of work. It is also important to use safety equipment like check valves and flashback arrestors. In some countries the use of safety equipment is mandatory, while in others there are as yet only recommendations.

INTRODUCTION

Welding, cutting, heating and straightening are examples of processes which have been done with gas since the begining of this century (fuel gas and oxygen or air). There are many advantages in using gases for these processes. Among other things, the equipment is very versatile, it is easy to move around and it is relatively inexpensive. These advantages mean that even in the future the combustion processes will have many industrial applications.

A point to remember when working with fuel gases is the risk of backfire and flashback. These can damage equipment and other materials, and can even cause personal injuries. During the years, a lot has been done to design torches which are as backfire-safe as possible. This means that backfire is seldom due to incorrect torch design; it is more often due to worongly handled or faulty equipment. Training of operators and regular maintenance of equipment are therefore important measures for avoiding damage and injuries caused by backfire and flashback.

Another very important measure is to provide equipment with check valves and flashback arrestors. In several countries this is mandatory, while in other there are only recommendations.

The purpose of this report is to increase understanding about how backfire and flashback arise, and how to avoid them. Increased knowledge is the primary way of improving safety in places of work.

Background

Before we can understand what happens in a backfire of flashback, we must clarify certain concepts. Below is a brief description of the terms fuel gas, oxygen, decomposition, combustion, combustion velocity, gas exit velocity and detonation. There is also a description of the two types of torch used for welding, cutting and similar processes, namely the equal-pressure torch and the injector torch.

Fuel Gas

A fuel gas is with few exceptions a hydrocarbon or a mixture of hydrocarbons. Examples of fuel gasses are acetylene, methyl- acetylene mixtures, propylene, propane and natural gas.

For combustion to occur, there must also be an oxidizer, normally oxygen. Air can also be used, as it contains 21 percent oxygen. Combustion with air does not give such high temperatures as combustion with oxygen.

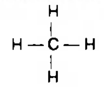
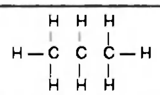
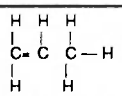
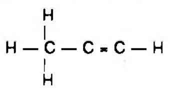
Decomposition and Combustion

The reactions which occur in a flame are that the fuel gas decomposes and is then combusted in oxygen or air. The reactions occur in several steps. The final products of total combustion are carbon dioxide and water. Combustion always generates heat.

In decomposition, a hydrocarbon is broken up into its constituents, carbon and hydrogen. Depending on the type of hydrocarbon, heat is either absorbed or generated. This heat is referred to as free enthalpy of formation (previously known as free heat of formation). Free enthalpy of formation with a positive value implies that heat is generated during decomposition. Acetylene is an example of a fuel gas which generates heat during decomposition, and thus has a positive enthalpy of formation (see Table 1). Examples of fuel gases which absorb heat during decomposition are propane and natural gas. These gases thus have a negative enthalpy of formation (see Table 1). The table also shows that the enthalpy of formation is related to the structural formula of the hydrocarbon. Double and triple bonds imply that heat is released during decomposition.

A condition for the above reactions to occur is that the decomposition and ignition temperatures respectively of the gas or gases are reached. The temperature does not necessarily have to be reached with the help of an open flame.

TABLE 1 : FREE ENTHALPY OF FORMATION AND STRUCTURAL FORMULATE OF SOME FUEL GASES.

Fuel Gas	Structural Formula	Free Entalphy of formation
Methane		— 75
Acetylene	H — C ≡ C — H	+ 228
Propane		— 105
Propylene		+ 20
Methyla-cetylene		= 111

Acetylene decomposition

Gases with a high positive enthalpy of formation generate a lot of heat during decomposition. Acetylene is an example. If supplied heat can caused an acetylene molecule to decompose, heat is generated which can in turn cause further decomposition. In some circumstances so much heat can be generated that the entire mass of gas explodes. So acetylene does not need oxygen to explode.

Whether or not an acetylene decomposition can propagate in a tube or pipe system will depend on the operating pressure and the internal diameter (Fig. 1). At normal acetylene pressures (0-1 bar (0-14.5 psi), i.e. 1-2 bar (14.5-29 psi) absolute pressure) and with the internal duct diameters which occur in welding and cutting torches we should, according to Figure 1, not have acetylene decomposition. However, investigations have shown that acetylene decomposition can be initiated if the torch is heated up. The heat generated by the initiated acetylene decomposition can raise the temperature to the ignition temperature of an oxyacetylene mixture, which is 300°C (572°F). A backfire will then occur.

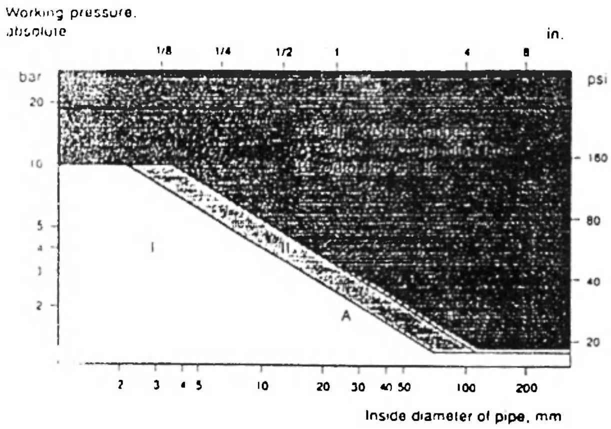


Fig. 1 : Working ranges for acetylene. I. Insignificant risk of decomposition. II. On initiation, decomposition can occur in the form of explosive combustion. III. On initiation the decomposition starts as an explosive combustion, in a long pipeline a transition to detonation can occur. (Due to the risk of decomposition acetylene can not be stored under pressure as many other gases. Instead, the acetylene cylinders are filled with a porous mass in which a solvent is absorbed. Acetylene dissolves in the liquid during filling. The porous mass effectively stops any decomposition which may start.)

Combustion velocity and gas exit velocity

The combustion velocity (flame propagation rate) is the rate at which a flame propagates in a pipe (Fig.2). The combustion velocity depends on variables such as :

- proportions of oxygen and fuel gas (Fig.3).
- temperature and pressure of the gas mixture.
- turbulence in the gas flow.

The gas exit velocity is the flow rate perpendicular to the flame front (Fig.2).

When a flame is burning stably at the nozzle opening there is in fact a complicated balance between the combustion velocity of the gas mixture and its gas exit velocity. This balance has a great influence on the development of a backfire. We will return to this later in the text.

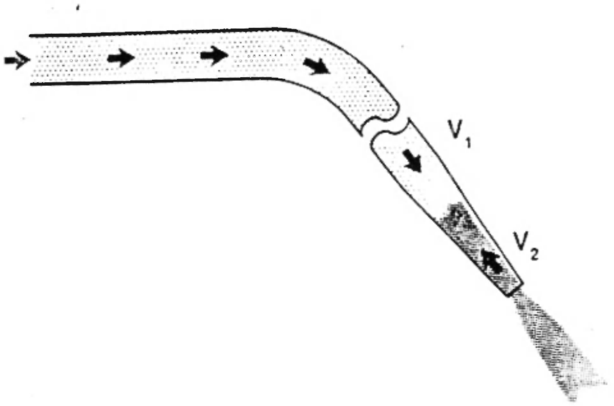


Fig. 2 : Gas exit velocity V_1, and combustion velocity V_2

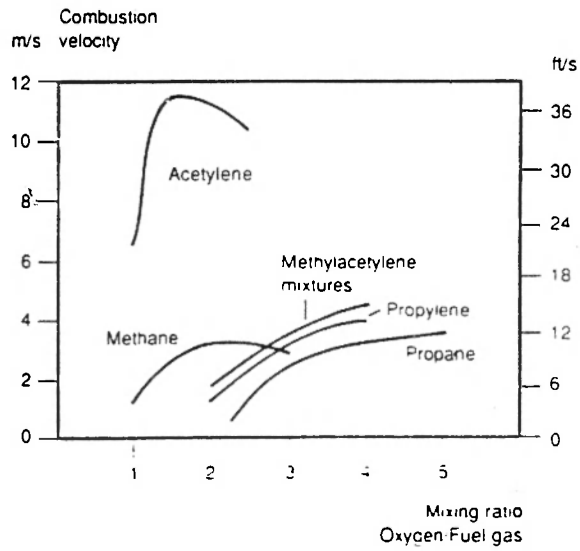


Fig. 3 : Relation between combustion velocity and mixing propertions for some common fuel gases.

Combustion and Detonation

Combustion can either proceed as normal burning, deflagration, or as a denotation. A denotation starts as an ordinary combustion which propagates at a relatively low speed. From the flame front a pressure wave spreads which heats up the gas mixture. This heating raises the combustion velocity. New pressure waves further raise the temperature, and the combustion velocity again rises. This chain reaction can after an acceleration process lead to a denotation. A normal combustion or deflagration is characterized by combustion velocities or some meters per second, whereas a detonation propagates at supersonic speed, i.e. up to several thousand meters per second (several thousand feet per second).

Different types of torches

To understand what happens in backfire and flashback we must know how the torch is constructed. Depending on the mixing principle, we distinguish between injector torches and equal-pressure torches. The principles are shown in Figures 4 and 5.

In an injector torch, a type of low-pressure torch, the fuel gas pressure is always considerably lower than the oxygen pressure. The gases are mixed by letting the oxygen flow suck in the fuel gas through the injector nozzle. According to ISO, injector torches must always be marked with the symbol I.

In an equal-pressure torch the pressures of the fuel gas and oxygen are equal on the inlet side. According to ISO, equal- pressure torches must always be marked with the symbol II

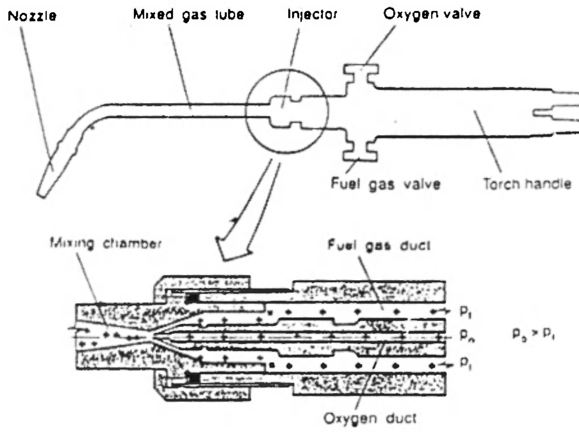


Fig. 4 : Principle of an injector torch.

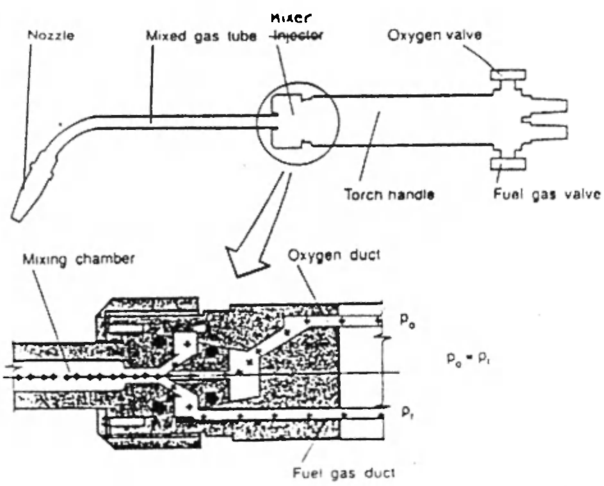


Fig. 5 : Principle of an equal-pressure torch

Backfire, Sustained Backfire and Flashback Definitions

A backfire implies that the flame burns back info the torch with a sharp bang. Either the flame is extinguished, or it is reignited at the nozzle opening. A backfire is fairly harmless in itself, but it can be a sign of some fault in the equipment of gas supply.

In a sustained backfire the flame burns back into the torch with continued burning in the mixer, often al the mixing point itself. A sustained backfire is characterized by an initial bang (backfire) followed by a whistling or screeching sound from the continued combustion. If the sustained backfire is not quickly interrupted, melting will occur in the torch, and escaping combustion products can cause injuries.

Reverse flow (bacflow) occurs when gas at higher pressure flows into the gas line with a lower gas pressure.

Flashback implies that the flame burns back through the torch and into the gas supply system, i.e. the hoses and in the worst cases even the regulators. If a flashback reaches an acetylene cylinder which lacks the necessary safety equipment a serious accident can occur. Flashback is mostly caused by reverse flow, e.g. flow of oxygen into the acetylene hose, so that an explosive mixture is present in the hose. This mixture can then be ignited by a backfire which occurs when the torch is lit. The hose will then explode.

Causes of backfire

The actual cause of a backfire is that the combustion velocity exceeds the exit velocity of the gas mixture (Fig. 5). If the situation is the reverse the flame will instead be blown out-a so-called blow-off occurs. When there is a balance between the combustion velocity of the gas mixture and its exit velocity, the flame burns stably (Fig. 6)

In practice the gas mixture's exit velocity in a cutting nozzle is about ten times the combustion velocity. So how can there be a balance between flow and combustion with such a big difference in velocity? The answer is that there is not a balance across the entire nozzle orifice, but only adjacent to the orifice wall where the gas velocity is reduced by reduction by friction against the wall. Figure 7 shows schematically the profile of the gas velocity with laminar flow in a pipe.

The same figure also shows how the combustion velocity varies across the duct diameter. Note that the combustion velocity against the wall is zero. This is among other things because the combustion reactions have been prevented by heat conduction to the wall. When the flame is in balance the flow is adjusted so that the gas exit velocity and combustion velocity are equal at points adjacent to the pipe wall. These points determine the whole flame and serve as a pilot flame across the entire gas flow.

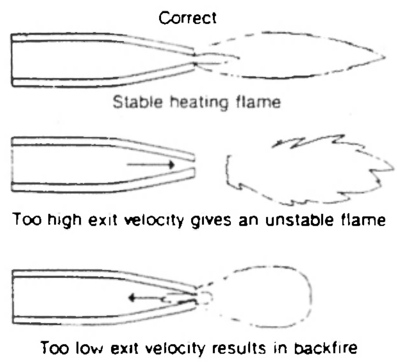


Fig. 6 : The character of the flame depends on the relation between the gas exit velocity and the combustion velocity.

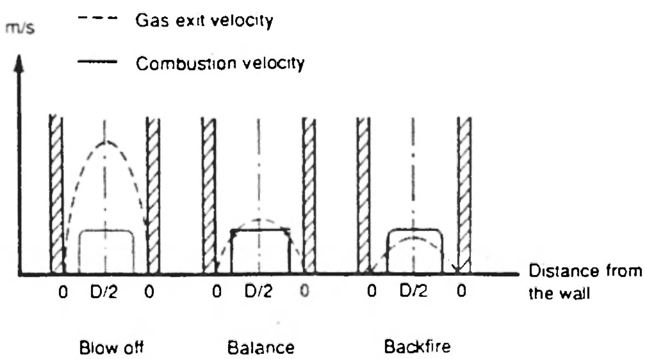


Fig. 7 : Flame stability in a pipe. D = pipe diameter. The figure shows the absolute values of the velocities

As a backfire occurs either when the gas exit velocity is too low or when the combustion velocity is too high, it is important to find out which factors influence these velocities. Common causes of too low gas exit velocity are :

- Wrong pressure is set on the torch or regulator.
- Pressure drops depending on length and size of hoses.

- Cylinder gas pressure is running low.
- A hose has been become constricted.
- Dirt is blocking or constricting the flow in the torch or hoses
- Design faults in the equipment such as too large area of nozzle orifice(s).

As mentioned earlier, the combustion velocity is dependent on the mixing proportions, temperature of gas mixture and any turbulence in the gas mixflow. Turbulence raises the combustion velocity, as the combustion becomes more effective, and can arise through :

- Spatter in the nozzle orifice (common in piercing)
- Damaged nozzle orifice.
- Orifice walls are uneven or scratched (important to remember when manufacturing nozzles and tips).

The heating up of a nozzle means raised gas mix temperature, which in turn raises the combustion velocity. An increased gas mix temperature also raises the pressure in the mixer. In injector torches this means that the suction power of the injector is decreased, so that the flame received excess oxygen. Excess oxygen raises the combustion velocity (see Fig. 3) and increases the risk of backfire.

Heating up of the nozzle can also initiate acetylene decomposition, which in turn leads to backfire.

The fact above show that it is important to avoid heating the nozzle. By making nozzles of copper, dissipation of heat will be good. Water cooling of the torch and nozzle can also improve the protection against backfire.

Causes of sustained backfire

Sustained backfire normally starts with a backfire. The backfire moves through the torch as a detonation with a shock wave in front of the flame front. When the detonation front reaches the injector or mixing point this part is heated up at the same time as the pressure from the shock wave causes the oxygen and fuel gas to be pressed back into their ducts. When the oxygen and fuel gas once again flow forwards after a backfire, a sustained backfire can arise at the mixing point if the temperature has reached the ignition temperature of the gas mixture.

One way of improving safety from sustained backfire is by reducing the risk of backfire (see section above).

The safety from sustained backfire can also be improved by various design measures, for example.

- Cooling mixing chamber and mixed gas tube.
- Avoiding turbulence in mixed gas tube and nozzle orifice.
- Small mixing volume in mixed gas tube.
- Flow resistor in the fuel gas and heating oxygen ducts before the mixing point. In the event of backfire the major part of the burning gas mixture will flow out through the nozzle orifice instead of forcing its way into the fuel gas and oxygen ducts.

In most torch designs the above principles have already been taken into consideration. Besides these measures there are quite a number of theories about how to avoid sustained backfire, of which some are given below.

1. Delayed return of oxygen flow. This would mean partly that fuel gas containing glowing carbon particles would have time to pass the mixing point before the oxygen flows out, and partly that the mixture would have a deficiency of oxygen, which would reduce the combustion velocity momentarily.

2. Damping the resonance. The shock wave in a detonation gives rise to pressure resonance which raises the temperature. If this resonance is not damped before the gas mix once again flows forwards, the mix can be reignited by the high temperature.

   AGA's spiral injector, which is installed in the torch JETSTREAM (see Fig. 8) is an example of a design feature based on both the above theories.

3. Quenching. For a flame to propagate through a tube the duct must have a certain diameter. If the diameter is smaller than the "quenching diameter" the flame will not pass. Flame arrestors are partly based on the theory of "quenching".

Causes of Flashback

The cause of a flushbacks and hose explosions are that there is an explosive gas mixture before the mixing point due to the reverse flow, for example of oxygen into the fuel gas hose. If flashback occurs on ignition, and if there is a sufficient quantity of gas mix, there is such a violent explosion in the hose that it bursts.

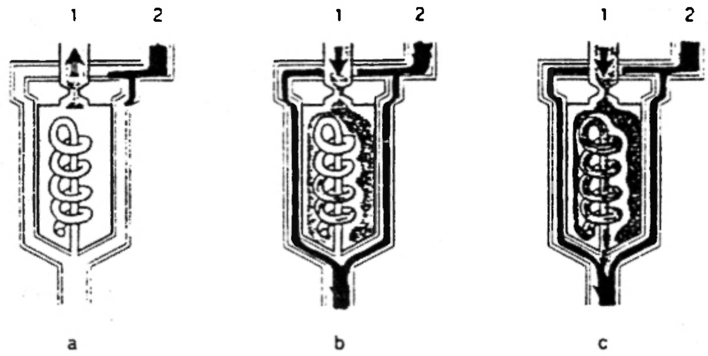


Fig. 8 : Spiral Injector. 1. Oxygen 2. Fuel gas. a. Bacjfire. b. and c. After the backfire

Causes of reverse flow include the following :

- Nozzle clogged by dirt, slag of damage. The gas with a higher pressure will then flow into the line with a lower pressure.
- The oxygen pressure is dropping to less than the fuel gas pressure. Unless the oxygen valve on the torch is closed, fuel gas will flow over into the oxygen line.
- If both regulators are closed and the torch valves are left open when the operator leaves the job, the fuel gas with its lower pressure will be evacuated first. Oxygen can then flow into the fuel gas line.
- Too high oxygen pressure when igniting the torch. If the operator opens both torch valves and tries to ignite with the oxygen flowing, oxygen can flow backwards into the fuel gas line.
- A small nozzle in relation to the valve opening on the torch forces the gas at higher pressure over to the gas duct with the lower pressure, as all the gas cannot escape through the nozzle.

Besides by correct handling of equipment, reverse flow and flashback can be avoided by using check valves on the torch handle. If a flashback should occur despite this, it is prevented from reaching regulators and gas cylinders by the use of a flashback arrestor on the regulator and/or torch.

Preventive measures

In the previous chapter we discussed the causes of backfire and flashback, and how the risks can be reduced by design improvements. Still, the most common causes of backfire and flashback are incorrectly handled or defective equipment. So in this chapter we will describe what the operator himself can do to avoid backfire and flashback.

Correct handling of equipment

To avoid reverse flow and the formation of an explosive mixture somewhere in the system, all component parts must be correctly assembled. Seals and gaskets must not be damaged. Also, the various parts should all be of the same make to give the best guarantee of a leak-proof system.

- Set the correct pressure according to the manufacturer's welding or cutting table.
- Use the correct nozzle size, and remember to reset the pressure when changing nozzles.
- Make sure that the nozzle is not blocked by dirt or slag.
- Damaged nozzles must be replaced.
- When cleaning, use the correct size of cleaning needle.
- Do not have the nozzle too close to the work. The gas exit velocity can then be impaired so that the nozzle heats up and can cause a backfire.
- Before lighting the flame, purge the fuel gas and oxygen hoses for a few seconds with the respective gas to avoid the risk of having mixed gases in a hose when igniting. The hoses must be purged one at a time.

Lighting the torch

Correct lighting of the torch is important to avoid backfire and flashback. The ignition process differs in injector torches and equal-pressure torches. However, in both cases the hoses must be purged first. This must be done for one gas at a time. The torch valve for the other gas must then be closed.

Lighting an injector torch

- Open the oxygen valve.
- Open the fuel gas valve.
- Light the flame.
- Adjust the flame character.

Lighting an equal-pressure torch

- Open the fuel gas valve all the way
- Light the flame.
- Open the oxygen valve
- Adjust the flame character with the oxygen valve.

Check valves and flashback arrestors

By using safety devices the risk of backfire, flashback can in most cases be avoided. The most common types of safety equipment are check valves and flashback arrestors. In some countries check valves and flashback arrestors are mandatory, while in others there are only recommendations.

Check valves

Check valves are installed on the torch on both fuel gas and oxygen connection (Fig.9). In many cases the torch is already provided with check valves from the start. Checkvalves effectively prevent reverse flow of gas. As already described, reverse flow is the most common cause of flashback. On the other hand check valves will not stop a backfire that occurs for other reasons. For a check valve to be really efficient, it must be functionally checked at regular intervals, suitably every sixth month.

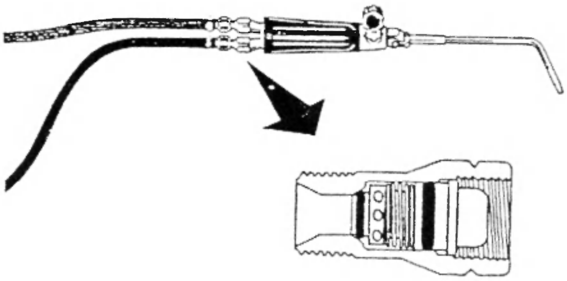


Fig. 9 : check valves installed on a torch.

Flashback arrestors

A flashback arrestor will effectively prevent a flashback from entering the cylinder or supply system, which could cause a serious accident. Flashback arrestors are available in the form of torch-mounted and regulator-mounted arrestors.

Torch-mounted flashback arrestors are, as the name implies, mounted straight onto the torch (Fig. 10), and have two functions. They stop the flame in the event of a backfire with the help of a flame arrestor, and they prevent reverse flow with the help of a built-in check valve. The flame arrestor consists of a sintered metal filter, normally of stainless steel. Gas can flow through, but a flame is extinguished due to the cooling effect.

The thing to bear in mind when using torch-mounted flashback arrestors is that the flame arrestor causes a pressure drop and thus reduces the flow capacity. So first check what flow the application demands.

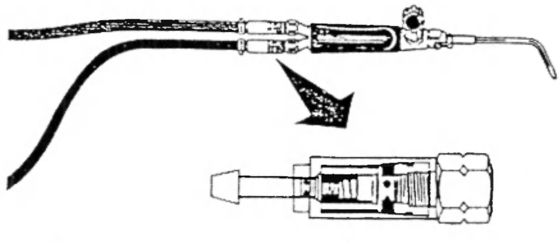


Fig. 10 : Torch-mounted flashback arrestor

Regulator-mounted flashback arrestors are mounted straight onto the regualtor or outlet point (Fig. 11).

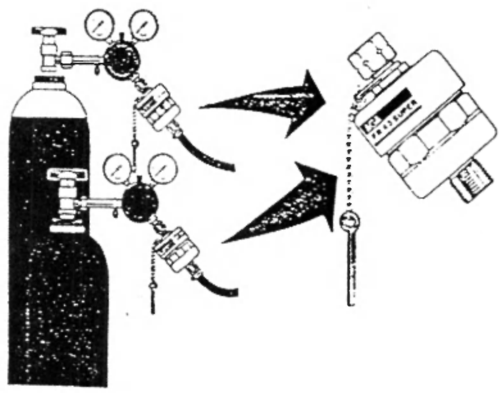


Fig. 11 : Regulator-mounted flashback arrestor

Besides preventing reverse flow with the help of a checkvalve and extinguishing the flame after a flashback with the help of a flame arrestor, regulator-mounted flashback arrestors can also have the following functions :

- Shuts off continued supply of gas in the event of a flashback. The pressure shock wave accompanying a flashback activates a shut-off valve. This must be reset after a flashback. Different manufacturers have solved this in different ways. The resetting can either be done with some type of button, lever or pin. It is important to be able to reset the regulator-mounted flashback arrestor, but it must not be too easy to do. The operator must consider what caused the flashback, and correct any defects.
- Thermally activated shut-off prevents gas from flowing out from the cylinder in the event of a

fire. If this function has been activated, the flashback arrestor cannot be reset; it must be replaced.

The (principles of the) different functions are shown in Fig. 12.

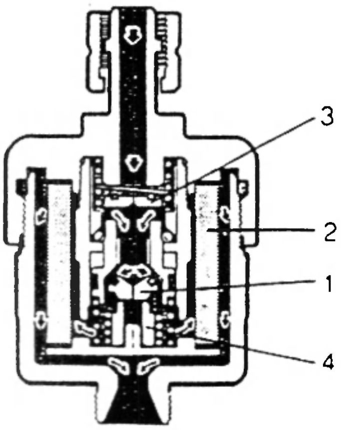


Fig. 12 : Regulator-mounted flashback arrestor with four different functions : 1. Check valve prevents reserve flow. 2. Flame arrestor extinguishes the flame in case of flashback. 3. Pressure-sensitive shut-off valve cuts off further gas supply after a flashback. 4. Temperature-sensitive shut-off device cuts off continued gas supply in case of fire

The advantage of a flashback arrestor mounted on the regulator or outlet point is that it can have a much greater flow capacity than one mounted on the torch. The latter has to be small and light, so that the flame arrestor cannot be made too large. The pressure drop across the flame arrestor is therefore greater. The disadvantage of a flashback arrestor on the regulator is that it does not prevent hose explosions. The best safety level is therefore achieved if one can have a flashback arrestor on the regulator and a flashback arrestor on the torch shank. This is possible if the required flows are not too high. For higher flows one has to be content with check valves on the torch and flashback arrestors on the regulators.

It is important to equip not only the fuel gas side but also the oxygen side with flashback arrestors. A flashback arrestor on the oxygen regulator can for example prevent oxygen from continuing to flow out in case of fire. This is important, as additional oxygen raises the combustion velocity.

Maintenance of equipment

One important measure for avoiding backfire and flashback is to keep the equipment in good condition. The nozzle can be regarded as the most exposed part of the equipment. It is important to keep the nozzle clean and undamaged. Dirt and slag spatter cause turbulent gas flow which in turn increases the risk of backfire. A clogged nozzle can cause reverse flow, with a risk of flashback. Nozzles can be cleaned chemically or mechanically. In mechanical cleaning with needles it is important to select the correct size for the nozzle orifice. The orifice must not be enlarged, as this would reduce the gas exit velocity and thus increase the risk of backfire.

Other points to consider regarding equipment are :

- Use undamaged hoses with the correct connections to torch and regulator.
- See to it that no gas leakage occurs. For example, check that the seal between torch handled and welding or cutting attachment is intact.
- Do not combine different brands of equipment.
- Check valves and flashback arrestors have to be functionally checked at regular intervals.

Education and training

Backfire and flashback always mean more or less extended interruptions of production. Equipment can be damaged, and personnel can be injured. So it is very important that the operator understands why backfire and flashback occur, and what he can do to avoid them. He must also know what to do if a sustained backfire of flashback do occur. This means that education and training of operators are very important for reducing risks.

In Sweden the insurance companies have begun to stipulate that welders and others engaged in "hot work" on temporary work sites, must attend a special training, resulting in a certificate. The reason is that fires, damage and injuries every year in connection with welding and other jobs involving heating cost the insurance companies a lot of money. The insurance companies hope that training will reduce these costs.

What to do in case of backfire and flashback

In case of backfire you hear a sound resembling machine-gun fire. Repeated backfire can mean that equipment is defective or is not being handled correctly. Try to find out the cause.

In case of sustained backfire, which gives a whistling sound, the gas supply must be shut off immediately on the torch and the regulators. The oxygen must be shut off first. The torch may have to be cooled with water. Before the equipment is put back into operation check the nozzle and seal, as they may have been damaged.

In case of flashback, decomposition can start in the acetylene cylinder if there is no flashback arrestor mounted on the regulator. Decomposition can also be initiated if the cylinder is exposed to heat, so that the temperature of the cylinder wall exceeds 300°C (572oF). In case of flashback, the following measures must be taken :

- Immediately close the cylinder valves, both fuel gas oxygen. Use fire-resistant gloves. The flame goes out as soon as the fuel gas is shut off.
- Check that the acetylene cylinder is not hot-which can be a sign of decomposition. If the cylinder is hot, check that the valve is properly closed. In a closed and gas-tight cylinder the continued decomposition in the porous mass will be stopped.

EVACUATE AND IMMEDIATELY ROPE OFF THE AREA !

CALL THE FIRE DEPARTMENT !

If docomposition continues at the same time as the acetylene cylinder is leaking (for example through a leaking sylinder valve) there is a great risk that the docomposition zone will spread and the cylinder will explode. The decomposition continues because new acetylene is continually fed to the decomposition zone. The explosion can occur within anything from a few minutes to 24 hours. If it is suspected that decomposition is in progress while at the same time the cylinder is leaking the rules are :

- Evacuate and rope off area!
- Call the fire department!
- Do not approach the cylinder!
- Cool the cylinder for 24 hours!