BACKFIRE AND FLASHBACK IN GAS EQUIPMENT

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INTRODUCTION

Welding, cutting, heating and straightening are examples of processes which have been done with gas since the beginning 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 wrongly 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 others there are only recommendations. A summary of regulations and recommendations in different countries is given in Table 1.

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 or 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 torches 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 gases 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 combusttion with oxygen.

Decomposition & 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 or 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 (Table 2). Examples of fuel gases which absorb heat during decomposition are propane and natural gas. These gases thus have a negative enthalpy of formation (Table 2). 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.

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 cause 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. At normal acetylene pressures (0-1 bar e.g. 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 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. A backfire will then occur.

Combustion Velocity and Gas exit Velocity

The combustion velocity (flame propagation rate) is the rate at which flame propagates in a pipe (Fig. 1). The combustion velocity depends on variables such as : (a) proportions of oxygen and fuel gas (Fig. 2), (b) temperature and pressure of the gas mixture, and (c) turbulence in the gas flow.

The gas exit velocity is the flow rate at the orifice of the nozzle (Fig. 1).

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.

Combustion & Detonation

Combustion can either proceed as normal buring, deflagration, or as a detonation. A detonation 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 alter an acceleration process and lead to a detonation. A normal combustion or deflagration is characterized by combustion velocities of 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).

CAUSES OF BACKFIRE

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 :

a) Wrong pressure is set on the torch or regulator

b) Pressure drops depending on length and size of hoses

c) Cylinder gas pressure is running low

d) A hose has become constricted

e) Dirt is blocking or constricting the flow in the torch or hoses

f) 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 mix flow. Turbulence raises the combustion velocity, as the combustion becomes more effective, and can arise through :

a) Spatter in the nozzle orifice (common in piercing).

b) Damaged nozzle orifice.

c) uneven or scratched orifice walls (important to remember when manufacturing nozzles and tips).

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. 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.

Causes of Flashback

The cause of a **flashback** and hose explosions are that there is an explosive gas mixture **before** the mixing point due to the reverse flow, for example, 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.

Causes of reverse flow include the following :

a) Nozzle clogged by dirt, slag or damage. The gas with a higher pressure will then flow into the line with a lower pressure.

b) 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.

c) If both the 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.

d) 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.

e) 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.

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. 3), 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. Regulator-mounted flashback arrestors are mounted straight onto the regulator or outlet point (Fig. 4).

Table 1 : National Safety Regulations

Country		Check valve Leg.	Check valve Rec.	Torch-mounted flashback arrestor Leg.	Torch-mounted flashback arrestor Rec	Regulator mounted flashback arrestor Leg.	Regulator mounted flashback arrestor Rec.	Test required frequently
Austria	Ac					X		YES, every 2 years
	Ox					X		
Belgium	Ac					X		NO
	Ox					—		
Denmark	Ac					X[1]	X	YES, every year
	Ox					—	—	
Finland	Ac			X		X	—	NO. AGA recommends every 2 years
	Ox			X				
France	Ac							NO
	Ox							
Germany	Ac					X		YES once a year
	Ox					—		
Hungary	Ac	X		X		X		NO
	Ox	X		X		X		
Iceland	Ac							NO
	Ox							
Netherlands	Ac					X		YES
	Ox					—		
Norway	Ac		X				X	NO
	Ox		X				X	
Spain[2]	Ac							NO
	Ox							
Sweden	Ac	X				X		NO
	Ox	X					X	
Switzerland	Ac	X				X		NO
	Ox	X				X		
UK	Ac		X				X	NO
	Ox		X				X	

Leg = Legislation Rec. = Recommendation

Pipeline flame arrestor FR 63 for central acetylene systems

As an extra security FR 63 should be mounted in the pipes at all acetylene gas central installations. Fires and accidents occur very seldom when modern equipment is used. However, if an incident occures the FR 63 unit is constructed to limit the consequences in two ways : a) to stop the flame and b) to cut off further flow of gas.

The flame is stopped very effectively from passing the arrestor by a built-in sintered steel filter. If the flame is not quenched but is still burning at the outlet side of the arrestor, the temperature inside the arrestor will rise. At 95°C i.e. much below any temperature capable of destroying the filter, a soft soldering inside the arrestor will melt. A spring loaded valve will then close the outlet and further supply of acetylene will stop. It is to be noted that FR 63 works in one direction only.

ATTENTION !!!

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-- Editor, IWJ

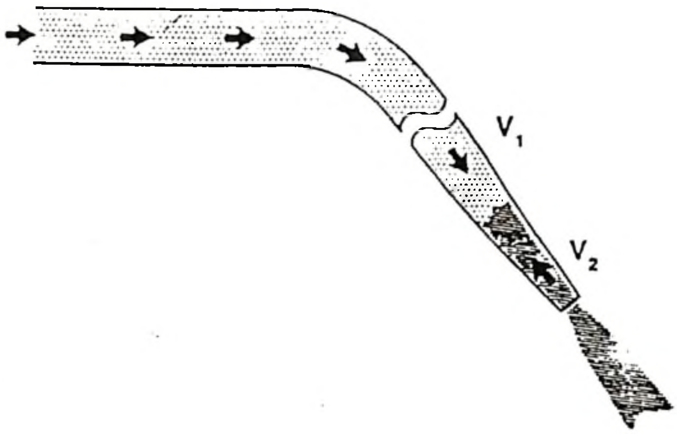

Fig. 1 : Gas exit velocity V - combustion velocity V_2 in this case the combustion velocity exceeds the gas velocity and a backfire will occur.

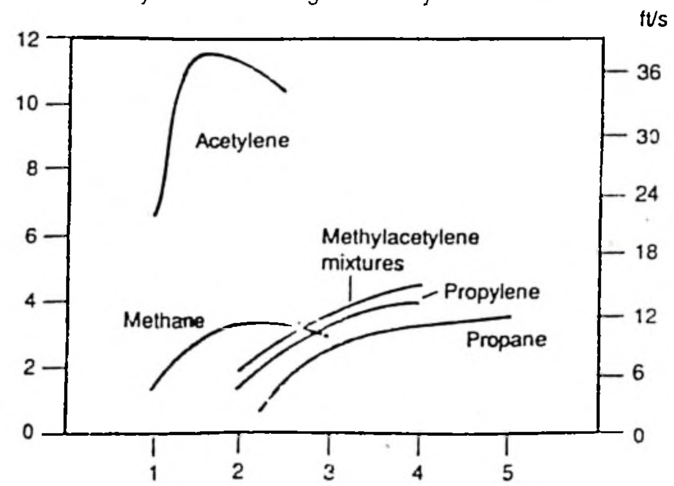

Fig. 2 : Relation between combustion velocity and mixing proportions for some common fuel gases.

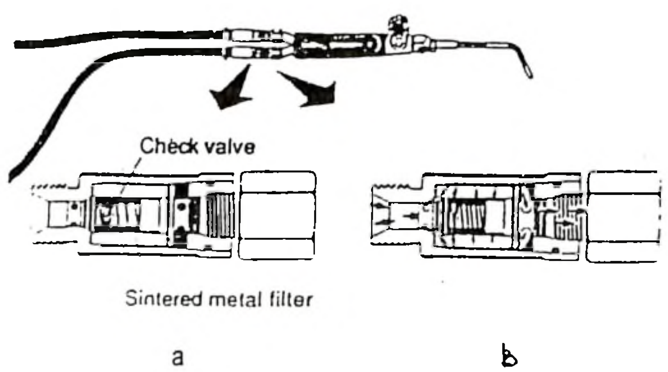

Fig. 3 : Torch-mounted flashback arrestor.
(a) Check valve closed (b) Normal flow-check valve open

Table 2 : Free enthalpy of formation and structural formulae of some fuel gases

<table>
<tr><th>FUEL GAS</th><th>STRUCTURAL FORMULA</th><th>FREE ENTHALPY OF FORMATION (kJ/mole)</th></tr>
<tr><td>Methane</td><td>H
I
H— C — H
I
H</td><td>-75</td></tr>
<tr><td>Acetylene</td><td>H—C=C—H</td><td>+228</td></tr>
<tr><td>Propane</td><td>H H H
I I I
H-C-C-C-H
I I I
H H H</td><td>-105</td></tr>
<tr><td>Propylene</td><td>H H H
I I I
C-C- C -H
I I
H H</td><td>+20</td></tr>
<tr><td>Methyl-acetylene</td><td>H
I
H-C-C- C-H
I
H</td><td>+111</td></tr>
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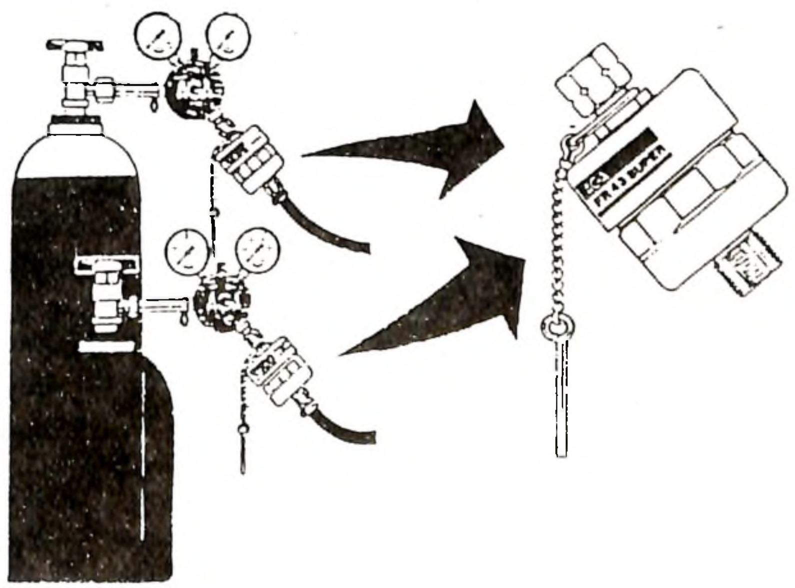

Fig. 4 : Regulator-mounted flashback arrestor