

# Gases, Gas Equipment and Processes

## Gases and properties

Because gases are mainly “invisible” they have a degree of mystery. Hazards often go unnoticed until fire, explosion, asphyxiation or poisoning take place. Like Electricity, gases are a good servant and a bad master. Gases, like solids and liquids, consist of molecules. In gases the distances between molecules are large compared with liquid and solids.

Gases can be compressed easily but liquids cannot be compressed. Gas assumes the shape and volume of its container. Gas confined within a closed container exerts a pressure - a result of molecular bombardment on the walls. Change of temperature and pressure may cause a change of state of matter.

## We are surrounded by gases

The Atmosphere or Air around us is a mixture of gases. The Atmosphere is about 150 km thick and the weight of air on a square foot is about

- 2100 pounds or
- 15 pounds per square inch or
- 10000 newtons per m<sup>2</sup> = 100kPa = 1 bar or
- 760 millimetres of mercury column or
- 10.34 metre of water column.

Living beings take in Oxygen which combines with Carbon and Hydrogen (Carbohydrates) in food, and releases CO<sub>2</sub> from lungs and H<sub>2</sub>O as water. Plants absorb CO<sub>2</sub> from the Atmosphere and give off Oxygen.

Air is a mixture of gases - % by volume

|                 |                |                 |
|-----------------|----------------|-----------------|
| N <sub>2</sub>  | Nitrogen       | <b>78.0</b>     |
| O <sub>2</sub>  | Oxygen         | <b>21.0</b>     |
| CO <sub>2</sub> | Carbon Dioxide | <b>0.03</b>     |
| Ar              | Argon          | <b>0.93</b>     |
| H <sub>2</sub>  | Hydrogen       | <b>0.01</b>     |
| Ne              | Neon           | <b>0.0015</b>   |
| Kr              | Krypton        | <b>0.000005</b> |
| He              | Helium         | <b>0.0005</b>   |
| O <sub>3</sub>  | Ozone          | <b>0.00006</b>  |
| Xe              | Xenon          | <b>0.000006</b> |

## Oxygen - the foundation of life

Oxygen is the most widely distributed chemical element. It is colourless, odourless, tasteless, slightly soluble in water. It is chemically very active, and combines with most elements by the process of Oxidation.

Apart from being 21 % of the air, it constitutes 90% by mass of water. Oxygen is essential to life and does not burn but promotes combustion. Oxygen was discovered in 1774 by Priestley & Scheele.

### Methods of making Oxygen

By heating compounds holding an excess of O<sub>2</sub>

|                    |                   |
|--------------------|-------------------|
| Mercuric Oxide     | HgO               |
| Lead Dioxide       | PbO <sub>2</sub>  |
| Barium Peroxide    | BaO <sub>2</sub>  |
| Potassium Chlorate | KClO <sub>3</sub> |

Heating Barium Peroxide BaO<sub>2</sub> gives off O<sub>2</sub> and BaO and this is the BRIN process (patented 1880) - the BRIN Oxygen company developed into BOC.

Under modern conditions O<sub>2</sub> is extracted from Air. There are some plants producing O<sub>2</sub> by electrolysis of water i.e. passing an electrical current through water giving O<sub>2</sub> at the anode (+) and H<sub>2</sub> at the Cathode (-)

Most Oxygen is produced by Liquefaction of Air at very low temperature and then splitting into O<sub>2</sub> and N<sub>2</sub>.

Inventors Linde, Hampson, Claude, Messer, Heylandt, Pictet, Hillebrand have contributed to this process. The O<sub>2</sub> is compressed in steel cylinders for supply to users or as liquid and vaporised on site.

Oxygen can also be separated from the nitrogen in air by means of Pressure Swing Adsorption (PSA). A vessel containing a carbon-based molecular sieve material called zeolite is filled with compressed air. The nitrogen molecules are adsorbed by the sieve material while the oxygen molecules drift past and are collected in an oxygen receiver tank. Pressure is then released from the vessel, and the nitrogen molecules are vented to the atmosphere. At the same time, the cycle is repeated in a second vessel to provide a constant flow of gas. Oxygen purities of 95 % and higher can be economically achieved using this technology.

A variant of this concept called Vacuum Swing Adsorption can also be used.

### Nitrogen - the chief constituent of the atmosphere

N<sub>2</sub> is 78% of Air

N<sub>2</sub> is colourless, odourless & tasteless

Chemically, it is relatively inert

Does not burn nor support combustion

An essential element of all animal & vegetable tissues.

### Nitrogen Oxides

Nitrogen forms a variety Oxides - N<sub>2</sub>O, Nitrous Oxide and NO, Nitric Oxide N<sub>2</sub>O.

Nitrogen oxides support combustion in the same way as Oxygen.

Nitrogen Monoxide or Nitrous Oxide N<sub>2</sub>O was discovered by Priestley in 1772 and in small quantities produces intoxication - "Laughing Gas". In large quantities, it produces unconsciousness and is used as an anaesthetic.

Nitrogen Trioxide (N<sub>2</sub>O<sub>3</sub>) and Nitrogen Pentoxide (N<sub>2</sub>O<sub>5</sub>) dissolve in water to form acids which give rise to Nitrates important for explosives and fertilisers.

Pressure Swing Adsorption (PSA) technology, as described above, can also economically generate nitrogen at a very high purity (up to 99.9999%).

Membrane separation technologies can also be used, by which a bundle of polymer fibers retain the oxygen, water vapour and carbon dioxide, while letting the nitrogen pass onwards. This can be economical for generating N<sub>2</sub> in the purity range 95 % to 99.5%

### Hydrogen is the lightest Fuel Gas

Hydrogen is the simplest and lightest chemical element.

H<sub>2</sub> is colourless, odourless and tasteless.

H<sub>2</sub> is very flammable.

H<sub>2</sub> was originally used to fill Airships but after several catastrophic fires Helium was used.

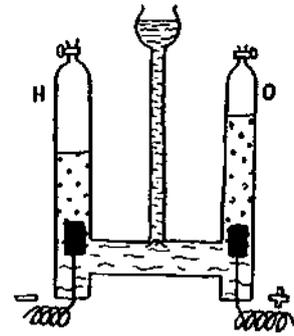
H<sub>2</sub> in combination with O<sub>2</sub> occurs in water (H<sub>2</sub>O) and in Carbohydrates and all organic compounds and acids.

H<sub>2</sub> readily combines with O<sub>2</sub> forming Oxides from compounds – this is called reduction.

H<sub>2</sub> was first produced in 1766 by Cavendish.

H<sub>2</sub> is usually produced by electrolysis of water - coming off at the cathode (-).

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## The inert gases of the Atmosphere

**Argon** - 0.932% is used for:

- Filling light bulbs.
- A shielding gas for welding.
- Filling Double glazed window cavities to increase thermal efficiency.

**Helium** - 0.0005% is used for:

- Filling Airships instead of H<sub>2</sub> because it is non-flammable.
- For leak detection.

**Neon** - 0.0015% is used for:

- Advertising signs and beacons.

**Xenon** – 0.00006% is used for:

- Filling light bulbs
- Some specialist anaesthetics.

## Pressure management

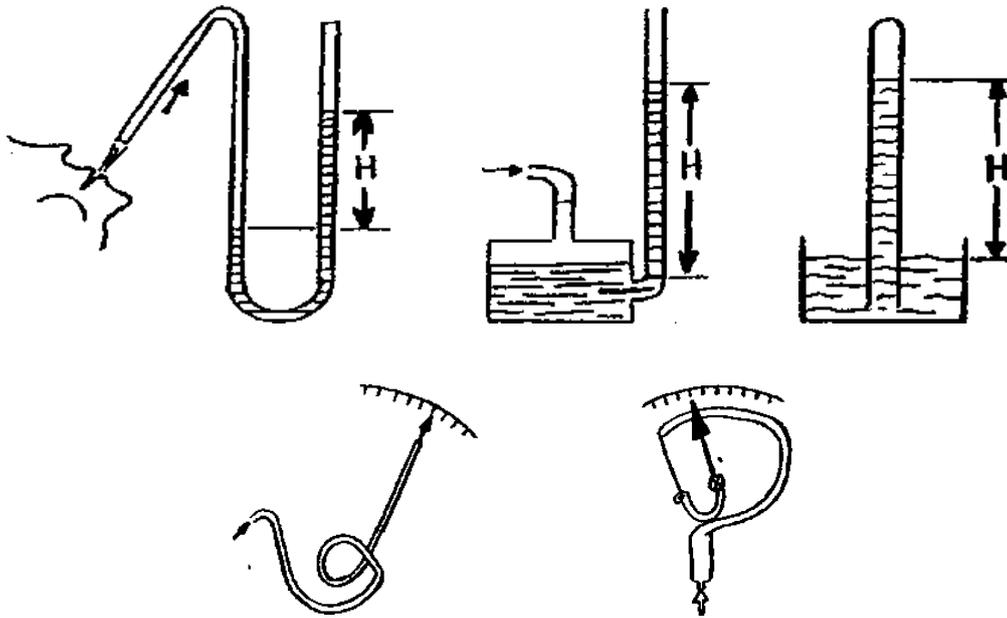
Pressure is expressed in force per unit area or as the elevation of a liquid column.

Common pressure measurement are:

|                                |                     |
|--------------------------------|---------------------|
| Pounds per square inch PSI or  | lb/sq in            |
| Kilogram per square centimetre | kg/cm <sup>2</sup>  |
| Newton per square metre        | (pascal)            |
| Multiple of Atmospheres        | Atu                 |
| Bar is 10000 Pa or             | 100 kPa             |
| Inches of water                | In H <sub>2</sub> O |
| Millimetre of Mercury          | mm Hg               |

|                |                                 |
|----------------|---------------------------------|
| 1 Atmosphere = | 14.7 PSI                        |
|                | 101325 Pa or 101.325 kPa        |
|                | 760 mm or 30" of Mercury column |
|                | 34 feet of water column         |

A simple way to measure pressure is to see how high a liquid is forced up one side of a 'U' tube when pressure is put on the other side.



Bourdon invented the Bourdon Pressure Gauge in 1770. A curved metal tube endeavours to straighten out as gas or liquid is forced into the tube.



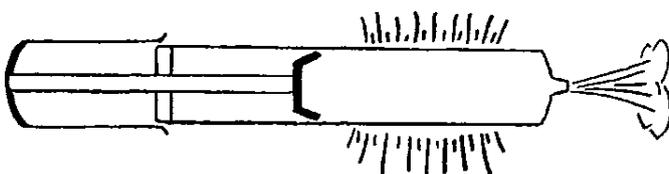
The Aneroid Barometer uses an evacuated thin metal box - the lid deflects in response to changes in Air pressure. A system of levers actuates a pointer.

### Gas compression and expansion

Compression allows more gas to be stored in a container. When gases are compressed, work is done and the temperature rises. According to Boyles law - Doubling pressure doubles the volume of gas contained. If the pressure halves, half the volume has been used.

When gases expand, work is done by the gas and the gas is cooled. This is the basis of refrigeration and known as the Joule-Thomson effect.

The 3 states of matter **Gas-Liquid-Solid** can be altered by lowering the temperature under the right conditions of pressure. If the temperature of a gas is lowered sufficiently, at constant pressure, it will condense into liquid. Alternatively, at constant temperature a high pressure should result in Liquefaction.



When gas is compressed without removing the heat of compression this is called **Adiabatic Compression**. Flammable materials may be raised to ignition temperature. If Oxygen is used and contaminants are present, violent burning may result with the possibility of explosion.

**Isothermal Compression** occurs when all the heat of compression is removed.

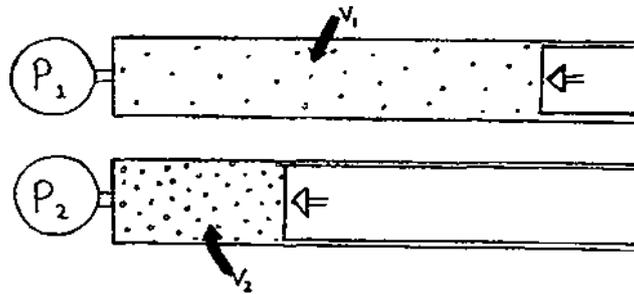
## Gas laws

### Effect of temperature

Most substances, including gases, increase in volume when heated.  
 In 1787 Charles showed that gases expand by  $1/273$  of the volume at  $0^{\circ}\text{C}$  for every  $1^{\circ}\text{C}$  rise under constant pressure.  
 Thus at  $-273^{\circ}\text{C}$  gas should be zero volume - this is called Absolute Zero.

### Effect of pressure

Applying pressure to a gas reduces volume.  
 In 1662 Boyle discovered volume is inversely proportional to pressure under constant temperature.



### Liquefaction of Gases

The cooling of gases to low temperatures under high pressures was thought to be the key to liquefaction of all gases but Faraday was unable to liquefy  $\text{H}_2$ ,  $\text{O}_2$ ,  $\text{N}_2$ ,  $\text{CH}_4$  and  $\text{CO}$  at  $-110^{\circ}\text{C}$  and called these **Permanent Gases**.

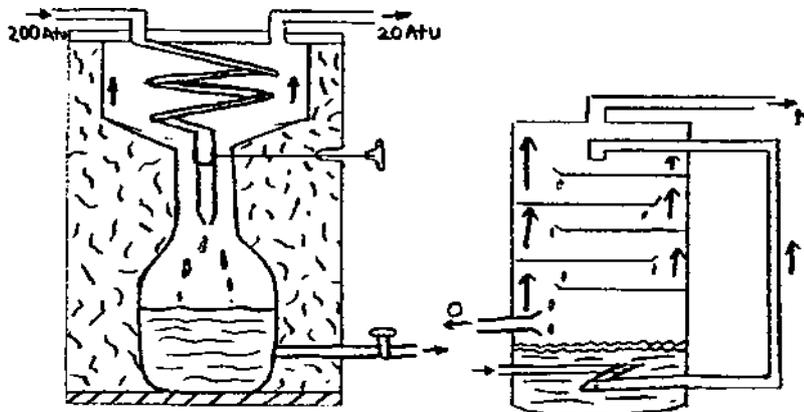
In 1863 Andrews established existence of a critical temperature for each gas - above which the gas could not be Liquefied no matter how high the pressure.

Critical Temperature for  $\text{O}_2$  is  $-119^{\circ}\text{C}$  and for  $\text{H}_2$  is  $-234^{\circ}\text{C}$

In 1874 Air was Liquefied by Dewar.

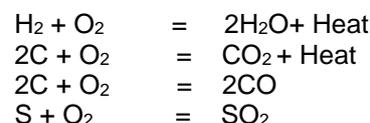
In 1895 practical machines for the liquefaction of Air were devised by Linde & Hampson. These depend upon expanding Air (at room temperature) at about 200 Atmospheres through an expansion valve. This expansion caused sufficiently low temperatures to allow the Air to liquefy.

Since the boiling points of  $\text{N}_2$  and  $\text{O}_2$  differ, the various gases are removed by evaporation -  $\text{N}_2$  evaporates first leaving a mixture of over 95%  $\text{O}_2$ .



Oxygen is supplied in Cylinders. At first, low pressure cylinders with  $\text{O}_2$  at about 20 bars were used but these were soon replaced by high pressure cylinders at 120-150 bar.

These generally held about 100-200 cubic feet of gas (3-6 cubic metre). Over the years, pressures have increased and most gases are supplied at 230 bar with 300 bar cylinders coming into service. 300 bar cylinders will be fitted with NEVOC valves, per the New European Valve Outlet Connections.



## Combustion or burning

Materials on heating combine with Oxygen in Air to form Oxides. Often these Oxides are gases and “disappear” as the process proceeds. This is chemical union accompanied by heat and light.

Every chemical reaction involves a change in the substances - Some of the chemical energy is released or degraded with evolution or absorption of heat. The speed of a chemical reaction is affected by temperature. In gases higher temperatures increase mobility of molecules and increase the rate of reaction.

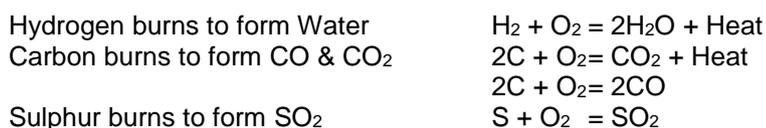
For combustion to occur, 3 factors are necessary: a Fuel, Oxygen to support combustion and an ignition source.

It may be necessary to heat the materials to start combustion. This temperature is called **Ignition Temperature** or flash point.

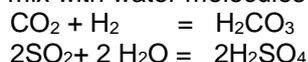
Once combustion commences, heat is evolved to keep temperature above ignition temperature and combustion (burning) continues as long as Fuel and Oxygen remain.

Fuels are composed of the elements **Carbon & Hydrogen - The Hydrocarbons**. The proportions determine the ease of ignition and the speed of burning.

## Basic fuels and their combustion



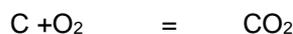
The products of combustion generally mix with water molecules to form acids.



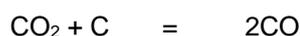
## The Fuel gases

### Carbon

Carbon combines fairly readily with Oxygen to form Oxides of CO & CO<sub>2</sub>. At the bottom of the fire there is an abundant supply of O<sub>2</sub>.



But as CO<sub>2</sub> gas passes upward through coal or coke it is reduced to Carbon Monoxide and burns with a hot blue flame.



This formation of CO as a result of insufficient ventilation can be fatal because CO readily displaces Haemoglobin in blood to prevent it from carrying Oxygen to the lungs. CO<sub>2</sub> forms naturally by exhalation and decay of matter. And large amounts are formed in fermentation of alcoholic beverages.

If Calcium Carbonate (Chalk, Limestone) is heated  $\text{CaCO}_3 = \text{CaO} + \text{CO}_2$

CO<sub>2</sub> liquefies at -78°C.

If released through a nozzle the cooling as it expands results in solid “snow”.

One volume of solid CO<sub>2</sub> will give 835 volumes of gas subject to temperature at atmospheric pressure whilst one volume of liquid will produce 435 volumes at the same temperature. As it warms it passes from solid to gaseous state without producing liquid on melting – hence the name “Dry ice”.

CO<sub>2</sub> is a colourless gas, heavier than Air, no appreciable smell, soluble in water, it does not support combustion.

CO<sub>2</sub> regulates breathing and if the concentration increases there will be an increased need to breathe. This may not be noticed before unconsciousness occurs. High levels of CO<sub>2</sub> will deplete oxygen levels in the blood and unconsciousness and death can follow quickly. Areas with a possible risk of CO<sub>2</sub> leakage eg. pub cellars, should be fitted with monitors.

CO<sub>2</sub> is compressed in cylinders and used for aerating drinks and in fire extinguishers for electrical fires. At ambient conditions the CO<sub>2</sub> is in the form of liquid with some gas above. The pressure is about 70 bar (1000 PSI) at 20°C.

As the vapour is drawn off more liquid vaporises. During vaporisation, the CO<sub>2</sub> absorbs heat and frost may form on the valve.

Apart from the standard vapour withdrawal cylinder, cylinders with a dip tube are available and these use the pressure of vaporised gas to force liquid up the tube and out of the cylinder. The need for a CO<sub>2</sub> heater is more marked with these.

CO in cylinders is a gas in the same manner as Oxygen and Nitrogen. It is very poisonous. The main use of CO is a reducing agent.

## Hydrocarbons C + H

A unique property of Carbon is that it combines with atoms to an almost unlimited extent - the Hydrocarbons.

The Hydrocarbon Fuel gases are in 3 classes:

**The Paraffins** - Methane & Ethane Propane, Butane & Pentane

**The Olefins** – Ethylene

**The Acetylenes**

Methane CH<sub>4</sub> & Ethane C<sub>2</sub>H<sub>6</sub> are colourless gases which are the principal components of Natural gas. Methane, Marsh gas or Water gas is produced from decomposing vegetables. They burn with a pale blue non-luminous flame.

Propane C<sub>2</sub>H<sub>8</sub> Butane C<sub>4</sub>H<sub>10</sub>, Pentane C<sub>5</sub>H<sub>12</sub> are colourless liquids at ambient temperatures. They are odourless in the natural state, but Methyl Mercaptan is added to give an odour that is detectable before danger develops.

They are all much heavier than Air and will collect in low lying areas. Trenches can be a particular hazard. The liquid petroleum gas cylinders have about 80% volume of liquid with gas vapour above.

The pressure of the gas vapour varies with temperature:

At 20°C Propane pressure is 7.50 bar (110 PSI)

Butane pressure is about 1.0 bar (14.5 PSI)

Ethylene C<sub>2</sub>H<sub>4</sub> is a colourless gas with a sweet smell, a luminous flame and is highly explosive in Air and Oxygen. Ethylene crosses the boundary of liquefied and compressed gas - above 10°C it is a compressed gas at about 80.0 bar (1200 PSI) and below 10°C is a liquid gas.

## Acetylene C<sub>2</sub>H<sub>2</sub>

Is lighter than air, a colourless gas with a garlic smell due to impurities in the carbide used in the manufacture of the gas.

It is highly flammable and burns with a hot smoky flame due to the large percentage of Carbon it contains.

With suitable burners, the flame is dazzlingly white and found wide use as an illuminant. It produces copper and silver Acetylides with Cuprous Chloride (red) and Silver Nitrate (white) which are violently explosive and detonate when rubbed. Explosions in pipes of Acetylene generators have been attributed to Acetylides.

It was discovered by Davy in 1836.

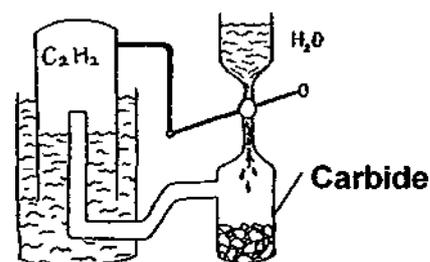
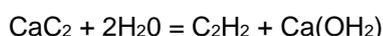
In 1862 Woehler found Acetylene could be produced from Calcium Carbide. But not until 1892 Wilson discovered a means of producing Carbide that made commercial production of Acetylene feasible.

The intense white light made Acetylene useful for Lighthouses and in 1895 Le Chatelier discovered that the Acetylene-Oxygen flame had the highest temperature of any gas at 3100°C.

In addition, the reducing action of the flame prevents the formation of oxides in the weld.

Commercial production of Carbide together with the practical methods to make Oxygen (1895) and the development of high temperature blowpipes meant the use of Acetylene for welding grew rapidly.

The practical way to produce Acetylene is to add water to react upon Carbide.



## Acetylene - the dangerous made safe

Under low pressure Acetylene is a stable compound but when mixed with Air and Oxygen it becomes explosive. The flammability range of 3 - 97% is very wide.

If generated or compressed above 1.5 bar (22 PSI) it acquires explosive properties.

If a spark or sudden shock is introduced, the dissociation of the gas will travel rapidly through the gas. No Air is required to produce an explosion. For this reason, all generators are constructed to limit pressure to 1.0 bar.

During the early development, very little was known about the chemical and physical properties of Acetylene and gas was compressed into cylinders with few precautions.

Continued accidents caused restriction and prohibitions and in the UK a limit of 100 inches WG (3.6 PSI) was proclaimed in an 1875 act of parliament. This was raised to 250 inches WG (9 PSI) or 0.62 bar during the First World War. Today a limit of 22 PSI (1.5 bar) applies.

Then Claude & Hess established that Acetylene could be stored above 25 PSI if the container was sub-divided into minute cells and this led to the development of a porous mass. Early porous masses were Charcoal, Asbestos and now mixtures of Charcoal, Clay, Asbestos and Cement.

Simultaneously it was found Acetone was able to absorb up to 25 volumes of Acetylene. Each increase in pressure of 1 Atmosphere allows additional 25 volumes to be absorbed. At pressure of 15 Atmosphere (220 PSI) 15.0 bar some 400 volumes are stored.

Dissolved Acetylene (DA) being stored by the combination of porous mass and absorption solved the storage of Acetylene with safety.

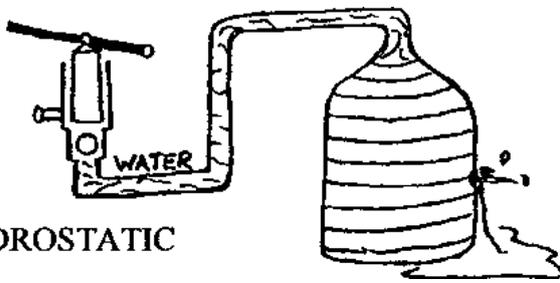
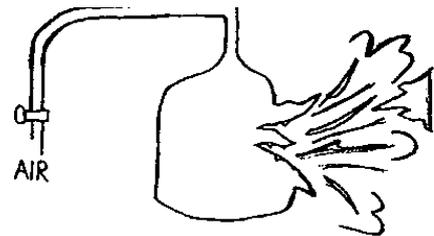
DA does not allow a measure of content by pressure - it is determined by weight.

When the cylinder is discharged, Acetone vapour is drawn out with the gas. If the flow rate is kept below the rate that the cylinder was charged -7 hours, the Acetone loss is negligible.

If Acetone is withdrawn the flame exhibits a green tinge. Withdrawal of Acetone will also occur if cylinders are not upright.

## Compressed gases and safety

When gas is compressed the energy of compression is stored within. If the release of gas is uncontrolled the stored energy will be released violently.



HYDROSTATIC

When liquid in a container is compressed, a small addition of energy causes rapid increase in pressure. If the container fails in any way, the water will leak in an almost harmless way through any tiny crack.

It is for this reason testing of most pressure vessels is done first using water. Note any trapped Air will violently escape.

Any pressure testing whether Hydrostatic or Pneumatic should have proper cover to prevent ejection of pieces or the reaction of elastic items upon failure.

Whenever pressurisation is to be done from a compressed gas supply, always open the valve very, very slowly in to allow the pressure to rise slowly - watch the pressure gauges!

A rubber welding hose will burst at about 70 bar (1000 PSI) so connecting to 200 bar will produce a violent and dangerous result. Always control the pressure with a regulator which has a maximum outlet pressure lower than the burst pressure of the vessel being tested.

## Compressed gas cylinders

Oxygen, Nitrogen, Argon, Hydrogen, Carbon Monoxide, Carbon Dioxide, Ethylene are stored in solid steel or extruded aluminium cylinders at pressures from 150 to 300 Atmospheres (150-300 bar). They are manufactured and tested to very exacting codes and standards.

Acetylene (DA), LPG (Propane & Butane) are stored in welded steel cylinders manufactured for lower service pressures.

DA cylinders are filled with a porous clay-cement mixture plus Acetone to absorb the Acetylene.

LPG cylinders contain about 80% volume liquid and 20% gas. This is to ensure that at higher temperatures the cylinder does not become occupied completely by liquid - when a small increase in volume of incompressible liquid would exert Hydraulic pressure on the container.

As pressure vessels, all cylinders must be regularly inspected and tested for damage, internal corrosion and overheating which may have reduced their pressure rating.

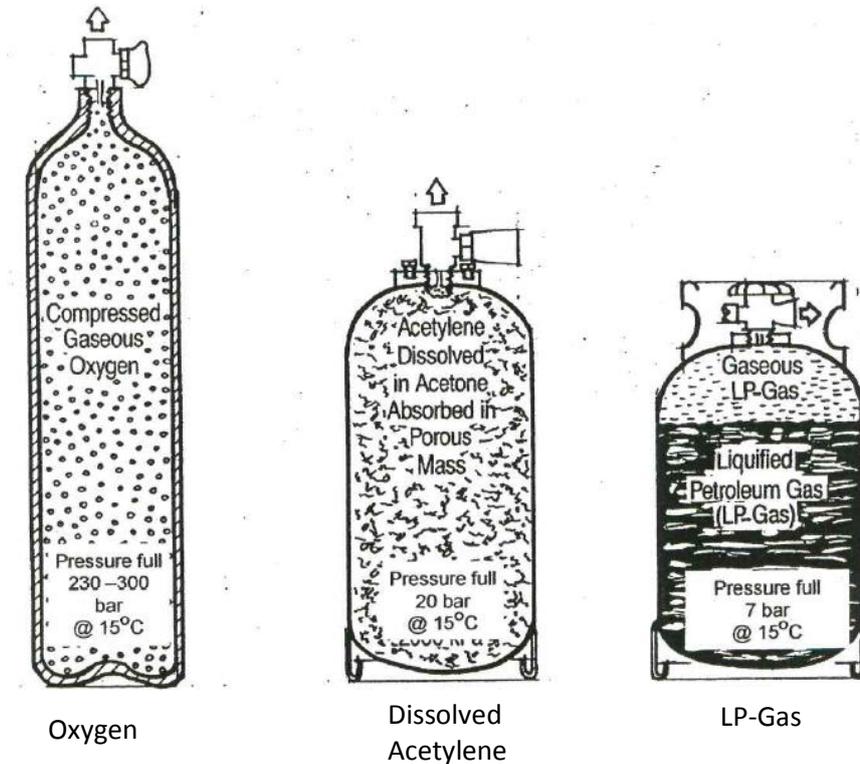
As the pressure of the contained gas increases with temperature most cylinders are designed to safely contain the gas at the pressure developed at 65°C. This pressure is approximately 20% greater than the filled pressure at 15°C. It is also the Hydraulic test pressure used for regular tests.

In the event of a cylinder being involved in a fire, higher temperatures will occur and the metal of the cylinder will be annealed - as a result explosive rupture may occur. The mode of cylinder rupture varies from ductile split and opening like a banana to shattering and throwing shrapnel. Higher tensile materials are more likely to not have a ductile failure.

The cylinder, valve, safety device and contents must, as a system, fail safe when conditions arise that may cause the cylinder pressure to rise to the test pressure.

The simplest and safest test is a Hydrostatic test in which any failure will be leakage of water whereas Air pressure would result in violent release of high energy expanding Air.

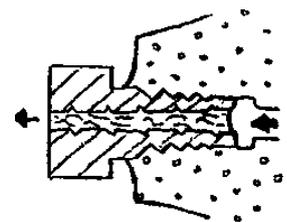
### COMPRESSED GAS CYLINDERS



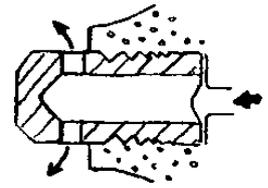
### Gas cylinder Safety devices

To prevent violent injury to property and people, cylinders have a device to release excessive pressure at a rate which avoids explosive failure.

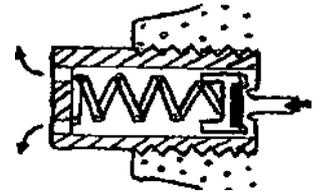
In Europe “high pressure” cylinders such as O<sub>2</sub>, N<sub>2</sub> do not have safety devices but with CO<sub>2</sub>, a thin metal bursting disc will fracture when the gas pressure rises because the temperature has risen to 60-65°C.



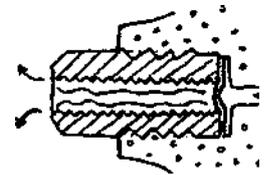
DA - some use a bursting disc rated at 1000 PSI (7000kPa), but most employ fusible metal in plugs located in the cylinder neck and base. These melt when the temperature rises to 100°C and allow the gas to escape. They are simple and rugged devices that are more resistant to corrosion than the very thin device. The overall safety of a charged Acetylene cylinder and its safety devices are checked by actual bonfire tests carried out at munition test ranges.



LP-gas cylinders have a spring-loaded pressure relief valve which opens to bleed excessive pressure irrespective of whether it occurs due to increased temperature or over-filling of liquid. The valve is designed to release gas and liquid so that the pressure within does not exceed the test pressure. Typically, this test pressure is 33 bar (480 PSI).



Hydrogen cylinders are fitted with a combined bursting disc and fusible plug. The fusible plug supports the bursting disc until a temperature of 75°C occurs. The unsupported disc then fails due to excessive pressure.



## The advantages and problems of the various safety devices

A spring loaded relief valve will open to vent excess pressure and then re-seat.

A spring loaded valve has to be loaded to a seating stress at least equal to the opening pressure. This causes the seating material to bond by vulcanising to the metal orifice.

Also being a mechanical device it may jam closed or weep if the housing is deformed.

The bursting disc is simple but involves a high level of quality control to achieve a narrow pressure rating. It is usually leak tight but corrosion may weaken the material.

The fusible plug is simple and generally reliable but weeping may occur because full bond has not been achieved between the fusible metal and the plug. They are not suitable for higher pressure because fusible metal extrudes easily.

## Precautions in handling compressed gases

### Oxygen

Accelerates combustion often violently.

Do not contaminate with oil, grease or particles of low ignition temperature.

Do not open valves rapidly because adiabatic compression may ignite particles.

Materials recommended for use with high pressure Oxygen are Copper, PTFE and PTCFE. Avoid Steels, Rubbers, and Nylon. Chloroprene (Neoprene) has precedents for use. Do not cause Oxygen concentration in any enclosed space or clothing because any ignition would be accelerated violently.

### Nitrogen

Is generally Inert. Avoid displacement of Oxygen in enclosed area, as Asphyxiation will occur.

### Nitrous Oxide

Like Oxygen, accelerates combustion. Its release will cause Intoxication and unconsciousness.

Follow same safety procedures as for Oxygen.

### Carbon Dioxide

It's generally inert. Avoid displacement of Oxygen, as Asphyxiation will occur.

Large discharge results in freezing and frostbite.

### Carbon Monoxide

Is highly poisonous. Ensure adequate ventilation. It can be the by-product of combustion where Oxygen is restricted.

### Hydrogen

Is highly combustible in Air and Oxygen.

Small leaks can ignite because expansion is Exothermic rather than Endothermic with most other gases.

### Dissolved Acetylene

Is highly combustible and explosive with Air and Oxygen - a wide range of flammability. Do not use at pressures above 1.5 bar. Do not use under pressure with Copper alloys exceeding 70%.

Cylinders must be vertical to avoid draining of Acetone. Withdrawal from cylinders should not exceed a rate of 1/7 contents per hour.

### Ethylene

Is highly explosive with Air and Oxygen. Do not use copper alloys.

### LP-gas (liquefied Petroleum gas)

Combustible and explosive but has narrower limits of flammability than DA and Hydrogen. Heavier than Air - flows into hollows and remains in pools - Adequately ventilate. High flows can cause freezing and frostbite. Any leak that can be smelled is a potential danger.

Vaporisation rate is dependent on both air temperature and the area of the cylinder in contact with the liquid gas. As the cylinder empties this area reduces and thus the vaporisation rate drops. The liquid level is often marked by the frost line during periods of high consumption.

Vaporisation rate (cft per hour) of a 100-lb Propane cylinder

Propane (lb) in cylinder

|     | -18C | -12C | -7   | -1C  | +4.5C | +10C | +15.5C | +21C  |
|-----|------|------|------|------|-------|------|--------|-------|
| 100 | 45.5 | 55.7 | 67.0 | 77.3 | 85.5  | 94.5 | 111.0  | 120.0 |
| 90  | 42.0 | 51.5 | 60.9 | 70.0 | 80.0  | 85.8 | 103.0  | 111.0 |
| 80  | 37.8 | 46.4 | 54.9 | 63.5 | 72.0  | 80.6 | 85.8   | 94.5  |
| 70  | 33.5 | 41.3 | 48.9 | 56.6 | 64.0  | 72.0 | 79.6   | 85.8  |
| 60  | 30.0 | 36.9 | 43.6 | 50.0 | 56.0  | 63.5 | 70.4   | 77.0  |
| 50  | 25.8 | 31.8 | 37.8 | 43.6 | 50.0  | 55.8 | 61.7   | 67.0  |
| 40  | 22.3 | 26.8 | 31.7 | 36.9 | 42.0  | 47.4 | 52.4   | 56.6  |
| 30  | 18.0 | 22.3 | 26.6 | 30.9 | 34.0  | 38.6 | 43.0   | 47.2  |
| 20  | 14.6 | 17.3 | 20.6 | 24.0 | 27.5  | 30.0 | 33.4   | 36.9  |
| 10  | 11.3 | 12.9 | 15.4 | 17.3 | 19.7  | 22.3 | 24.0   | 26.6  |

### Joining metals

Joining can be accomplished by either soldering, brazing or welding.

#### Soldering

When 2 metals are heated (not melted) and are joined by a different metal with a melting point below 450°C. The adhesion is achieved by molecular attraction.

**Brazing**

When the joining metal melts above 450°C, the parent metal is raised to a temperature to allow “wetting” of the joint faces. A brazed joint is stronger than a soldered joint because stronger alloys are used. It is distributed by capillary action.

**Welding**

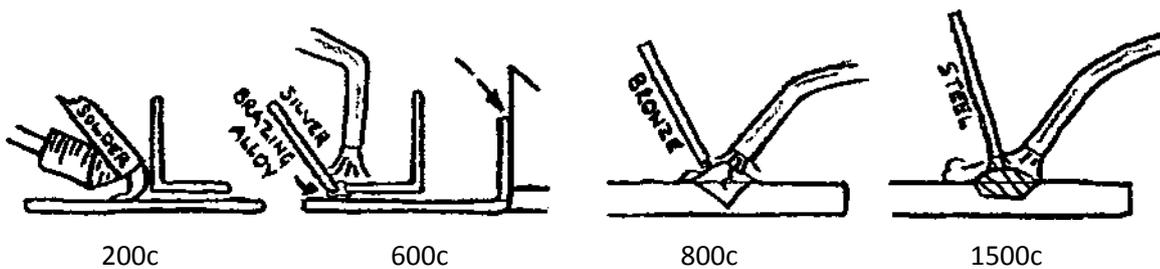
Joins metal by melting the joint faces with or without application of pressure. When similar metals are joined by melting, the edges actual alloying of the metal occurs. This produces a joint of high strength.

**Braze welding**

Is a special distinction of brazing whereby the filler metal is not spread by capillary action but by thick layers as in welding. As dissimilar metals are used to form the junction, adhesion is formed without alloying occurring.

**Failure of adhesion**

Dirt and Oxide film on surfaces is the main hindrance to effective alloying or bonding. The usual method to break down Oxide film is to use a chemical flux to dissolve Oxides which floats in the form of a slag.

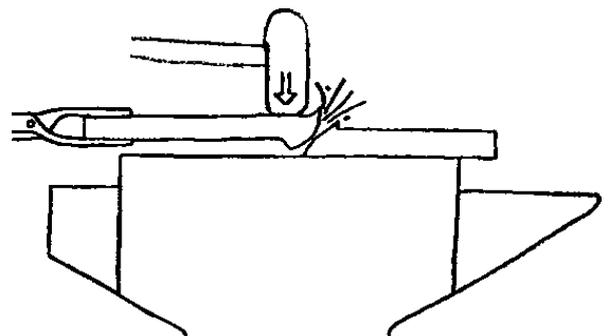


**Pressure welding**

The oldest form of heating metal is the Blacksmiths Charcoal Forge.

Two pieces of metal are heated to a plastic temperature then joined by firmly hammering together.

A scarf joint is employed to increase area of contact and strength. Hammering ensures close contact of the joint and drives out some of the Oxide to the outside of the joint. Later water-gas (Methane) was used to heat the edges to be joined.



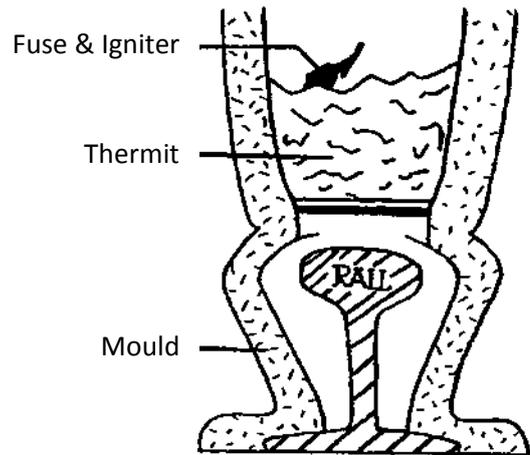
**Fusion welding**

Is basically a casting process.

The simplest method is by pouring molten metal around the joint.

**Thermit welding**

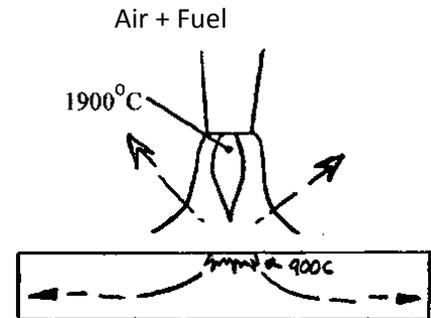
A crucible of Iron Oxide and powdered Aluminium-Thermit is ignited and 3000°C obtained. The molten Iron then flows into a mould around the joint and melts the edges to be joined. The process is used chiefly for welding rails and thick sections.



**To achieve a satisfactory weld**

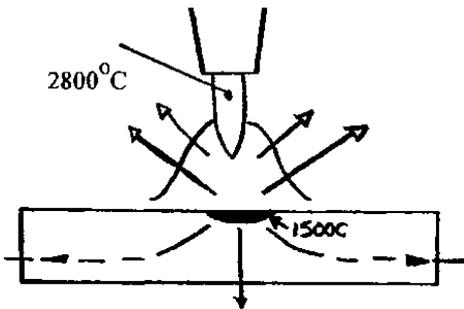
In addition to sufficient heat to melt metals, the flame must not Oxidise (burn) or contaminate the metal and flame products must not be toxic.

Air-Fuel gas flames of 1500-2000°C are adequate for heating metals to 500-1000°C but are useless for melting metals at 1500°C. In Air-Fuel gas mixtures, the Nitrogen present in Air absorbs a large part of the reaction heat and lowers the flame temperature and heat available.



Heat in = heat loss

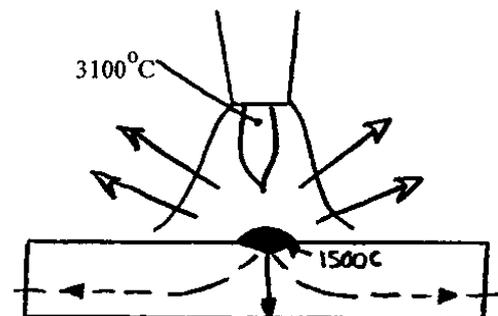
Oxy + Propane



Heat in = heat loss

Oxygen with the Fuel gas boosts the flame temperature and the heat released. Air-Fuel as produces sufficient heat for soldering and brazing.

Oxy + Acetylene



Heat in = heat loss

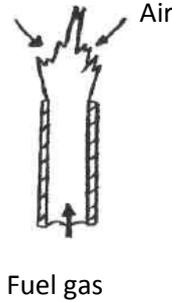
Only Oxy-Acetylene provides a high enough temperature (3100°C) to exceed heat losses with sufficient margin of extra heat to melt steel.

The amount of heat generated depends upon the amount of Fuel gas mixture consumed. This is determined by the size of the flame orifice (tip size).

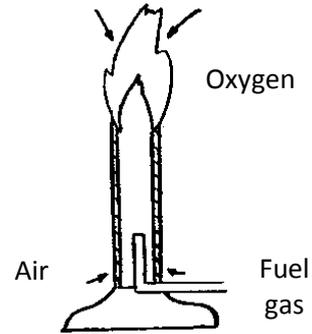
## Oxygen-Fuel Gas Combustion

When a Fuel gas burns, it may receive Oxygen in 4 ways:

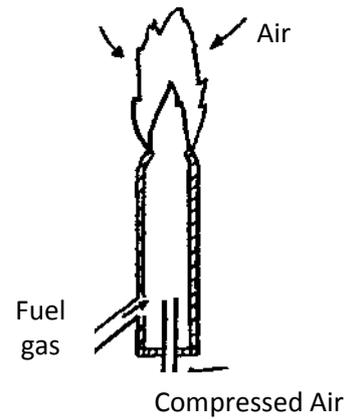
1. From the surrounding air.



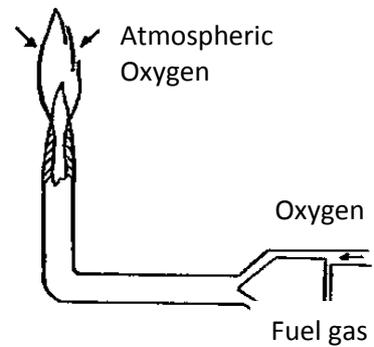
2. From Air drawn into the Fuel gas and mixed before the flame.



3. From pressurised Air mixed with Fuel gas before they burn.



From pressurised Oxygen mixed with Fuel gas before they burn.

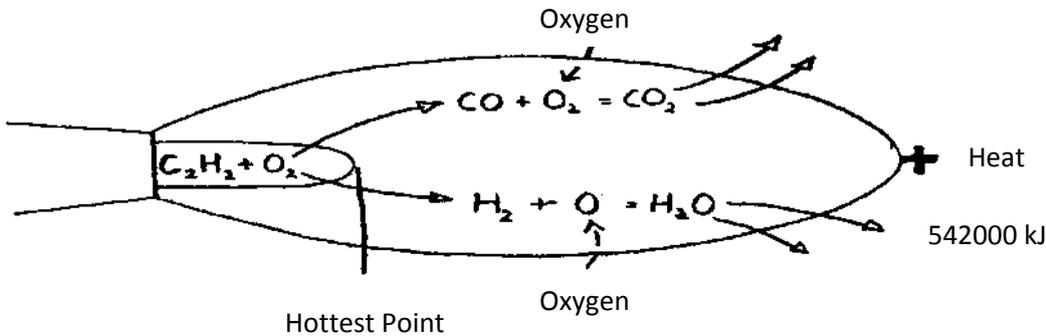


Each of these methods adds more Oxygen to the gas mixture and increases the flame temperature and the heat. Air-Fuel gas flames produce sufficient heat for soldering and brazing but not for fusion welding.

## The Oxygen Acetylene flame

In 1895 Le Chatelier discovered the special feature of the Oxy-Acet flame, the highest flame temperature and the reducing nature of the flame envelope.

In 1901 the first Oxy-Acetylene blowpipes were made by Pouche and Picard.



|            |         |         |            |           |
|------------|---------|---------|------------|-----------|
| $C_2H_2 +$ | $O_2 =$ | $H_2 +$ | $2CO +$    | 195000 kJ |
| $H_2 +$    | $O =$   | $H_2O$  | $+ 104000$ | kJ        |
| $2CO +$    | $O_2 =$ | $2CO_2$ | $+ 243000$ | kJ        |
| Total      |         |         |            | 542000 kJ |

1 volume  $C_2H_2$  combines with  $2\frac{1}{2}$  volumes  $O_2$  - 2 volumes  $CO_2$  & 1 volume  $H_2O$  + Heat  
 $2\frac{1}{2}$  volumes Oxygen – 1 volume through blowpipe –  $1\frac{1}{2}$  volumes from Air

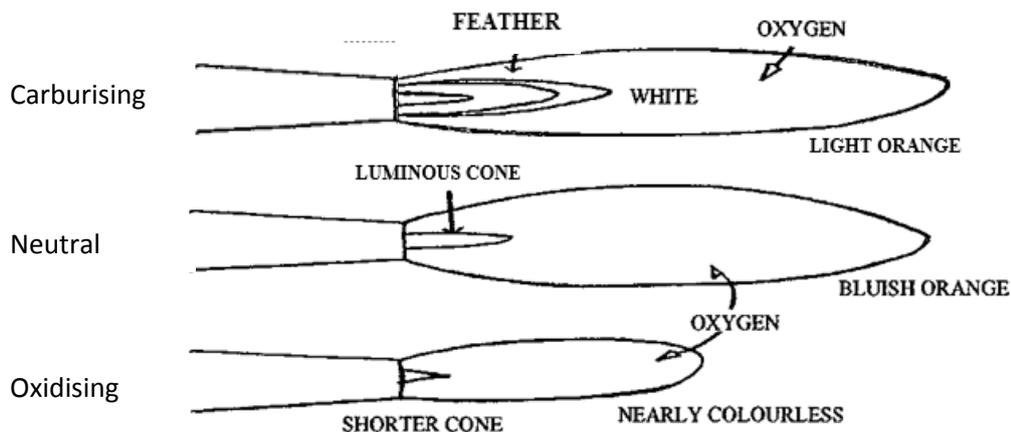
## The Oxygen - Fuel gas flame

The correct proportions of Oxygen and Fuel gas must be used to avoid the defects caused by Oxidising and carburising flames.

Excess Oxygen will oxidise (burn) the molten metal. Excess Carbon will add harmful Carbon.

A **Neutral flame** is the correct normal flame for most welding. There are specific uses for oxidising and carburising flames.

The **Oxy-Acetylene flame** permits these various flames to be easily recognised.



Acetylene is the gas preferred for welding. Propane and Natural gas are used for heating, soldering, brazing and braze welding. Hydrogen is used for welding non-ferrous metals and brazing.

## Gas cutting is a chemical process

Most metals Oxidise slowly with Oxygen - forming metal oxides. Oxidisation is more rapid as the temperature increases.

If the tip of a steel wire is heated to red heat, then plunged into a jar of Oxygen, the Iron burns rapidly in contact with the Oxygen.

In 1899 Fletcher of Warrington found that after heating an Iron plate to incandescence that an extra supply of Oxygen could melt holes in the plate.

In **Gas cutting** Iron (steel) burns vigorously in a jet of Oxygen, if first brought to ignition temperature - this is a chemical process.

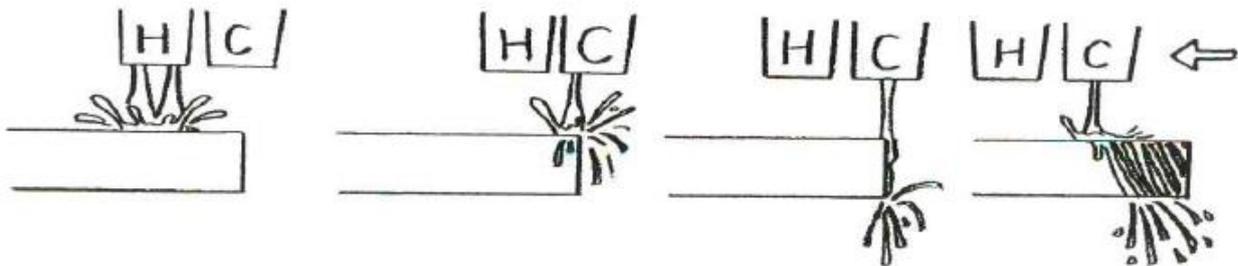
Oxygen cutting has 3 phases:

- Heating of Iron to ignition temperature (800-1000°C).
- Burning (rapid oxidising) of Iron in a jet of Oxygen directed on it.
- Removal of "burnt" particles by the jet of Oxygen.

This achieved by separate heating and cutting Oxygen jets.

Control of the cut is possible because the high velocity Oxygen produces a narrow stream which confines the burning action to narrow slot (Kerf). In practice the metal is not consumed entirely by the Oxygen - part of the molten metal is blown away by the jet.

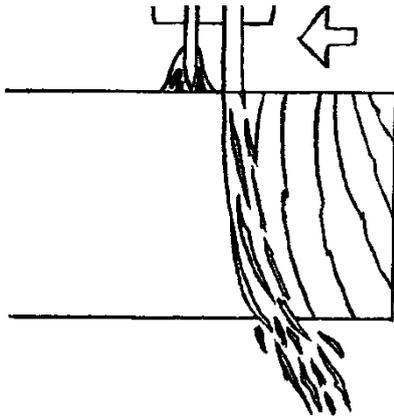
Theoretically preheating should not be necessary beyond starting the cut - in practice it is maintained throughout as extra heat is necessary to melt the oxide formed so that it can be blown away by the Cutting Oxygen jet. Heat is lost in the Oxides and metal blown out of the Kerf, and conductance by the adjacent metal.



## The cutting process

In cutting the preheat is provided in similar way to a welding blowpipe and a separate jet is provided for cutting. Combustion in the preheat flame occurs as for welding and when cutting starts a considerable amount of heat is released.

The purity of the Oxygen has an important influence on cutting. Oxygen should be 97-99%. Oxygen 95% purity is satisfactory for welding but the inferiority for cutting is evident and with 90% cutting blowpipes do not work normally.



The thickness that can be cut is limited by the amount of cutting Oxygen. 100 Litre Oxygen oxidises 44 cm<sup>3</sup> pure Iron.

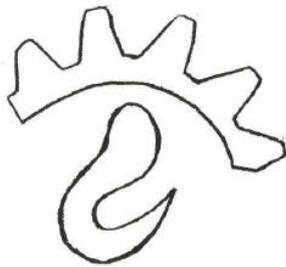
Since the preheat flame has only to achieve ignition temperature fuel gases with lower flame temperatures than Oxy-Acetylene are suitable - such as Propane, Natural gas, Coal gas and Petrol vapour. The cutting process is a chemical reaction with Oxygen so higher temperature fuel gases do not increase the speed of cutting but will shorten the preheat time.

### The economic significance of flame cutting

Prior to Oxy-Fuel cutting, even for cutting moderate thickness, heavy machinery was necessary to shear, saw, tum, plane, mill or nibble. Flame cutting does not mechanically engage or touch the work so heavy clamps are not necessary to resist cutting forces.



Only low power is required to propel cutting heads.

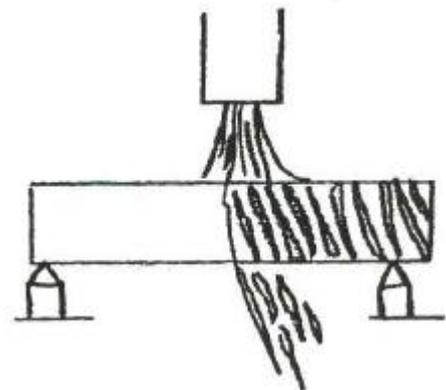


Thickness from 1.5mm to 1.5 metres can be cut. Equipment has low initial cost and is really portable. Flame cutting made possible the metal fabrication industry by providing an easy method to produce a wide variety of simple components that are built into a complex unit by welding.

Flame cutting carried out by an unguided hand torch does not give a smooth cut edge but with proper guiding cuts can be produced that equal machined surfaces.

Straight cuts can be made with shears and saws on plate and sections but cutting out circles and shapes cannot be made with this equipment - it is easy to carry this out with the cutting torch.

Thus a great economic advance in technology was afforded by the invention of the cutting torch.



## Laser cutting and Plasma cutting

**Laser cutting** is a thermal cutting process, using a laser beam directed through computer-controlled optics to direct the beam at the material to be cut. The material then either melts, burns, vaporises away, or is blown away by a jet of “assist gas”, leaving an edge with a high-quality surface finish.

Industrial laser cutters are highly accurate, and are used to cut flat-sheet material, as well as boring and engraving of many materials including mild steel, aluminum, stainless steel, and titanium. They can also be used for welding. The laser beam itself is generated by ionising a gas in a device called a resonator. The principal resonator gases are helium, nitrogen, and carbon dioxide, or blends thereof. Each of these gases when ionized emit at different wavelengths. High purities, typically 5.0 (99.999 %) are used, because moisture, hydrocarbons and other impurities adversely affect the laser performance.

The “assist gas” blasted from the nozzle protect the optics from fumes and spatter, and cool and clean the edges of the kerf. If O<sub>2</sub> is used as an assist gas, it also contributes to the cutting process by reacting with the metal to be cut. The additional heat input from the oxidisation enables mild steel and low-alloyed steels to be cut faster or thicker.

Main assist gases used:

- Carbon and low alloy steels – oxygen or nitrogen (high pressure)
- Stainless steels, aluminium & alloys – nitrogen (high pressure)
- Magnesium, titanium & other reactive materials – argon (high pressure)

Laser Welding is a fast-growing industrial application. Because the beam is high energy, laser welding is a low heat input process compared to conventional arc welding, giving deep penetration and low distortion welds. Generally, no filler is required (autogenous). Often CO<sub>2</sub> is used as the resonator gas, with He as a shielding gas. For some specialised applications, shielding gas mixtures are used.

**Plasma cutting**, also known as Plasma Arc Cutting (PAC) is used for cutting electrically conductive materials using accelerated jet of hot plasma. Typical materials cut are steel, stainless steel, aluminium, brass and copper.

The plasma is formed from superheated, electrically ionised gas, typically O<sub>2</sub> or N<sub>2</sub> or Ar or blends thereof, depending on the material to be cut. The plasma is blown through a nozzle at high speed, and an electrical arc is formed within the gas, between an electrode in the nozzle, and the electrically conductive metal. The electrical arc ionises some of the gas, thereby creating an electrically conductive channel of plasma. As electricity from the cutter torch travels down this plasma it delivers sufficient heat to melt through the metal, and the high velocity gas and plasma blow the molten metal away – thereby cutting the metal.

In addition to the plasma gases, shielding gases such as air, CO<sub>2</sub> or N<sub>2</sub> are used, again depending on the material to be cut.

Plasma cutting can cut non-ferrous metals if they are electrically conductive. It is typically faster than oxy-fuel cutting, particularly with metals less than 7 cm thick, and is often the most economic solution.

### Purity and control of gases used in laser cutting and plasma cutting

For optimal performance, resonator and plasma gas purities of 99.999% (5.0) or better are required, Typically, these would contain < 0.5 ppm hydrocarbons, and < 2 ppm moisture. In some specialised applications, very specific gas mixtures are used.

Laser assist gases of purity greater than 99.95 % (3.5) are used. Pressure and flow control also key to optimal performance.

With O<sub>2</sub> as an assist gas, the pressure used depends on the material thickness. For cutting thin material, pressures over 20 barg are used, where the contribution of the combustion process is insignificant and the melt-shear removal process does all the work. For thick sheets however, the maximum applicable oxygen pressure drops rapidly.

## Oxy-Fuel gas blowpipe for welding

Blowpipes (or torches) are simple devices for mixing Oxygen and Fuel Gas to burn at the burner outlet (tip or nozzle).

They are derived from blowpipes used by Jewellers, metal workers, chemists and glassworkers used to intensify a flame by using a current of Air projected through a small orifice.

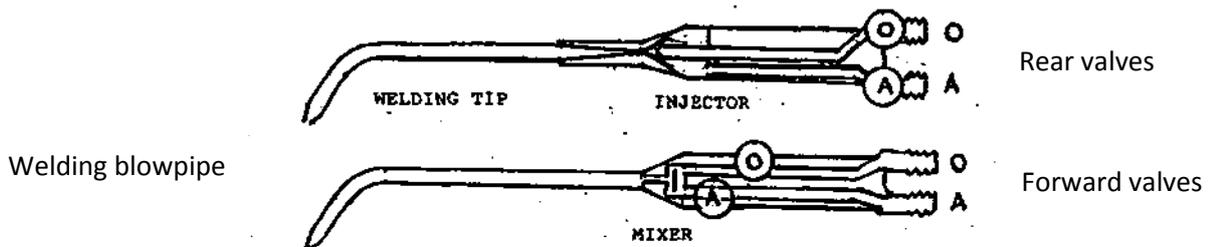
Gases were first mixed in desired proportions by dynamic control using one gas at high velocity from a small orifice to aspirate another at lower pressure into the mixing tube: The simplest is the Bunsen burner and gas stove which use gas under pressure to aspirate Air into the mixing tube.

Next compressed Air was used to aspirate low pressure Fuel gas into a mixing chamber.

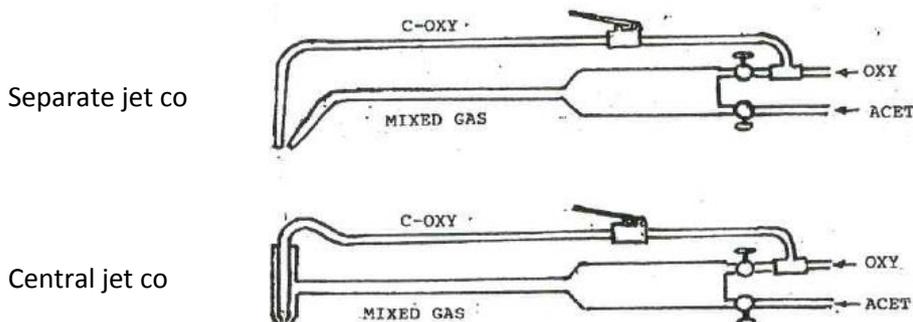
Later compressed Oxygen was used to aspirate low pressure coal gas or Acetylene into a diffuser mixing chamber.

When Fuel gases were compressed at higher pressures, mixing by mechanical means was used (by fixed orifices) to set the volumes of the gases supplied at equal pressures.

### BASIC WELDING BLOWPIPE – CUTTING BLOWPIPE – CUTTING ATTACHMENT



The cutting blowpipe is essentially a welding blowpipe with an additional supply of Oxygen to a cutting jet or nozzle.



Early models had a single co jet following the heating tip - but limited to continuous straight-line cuts.

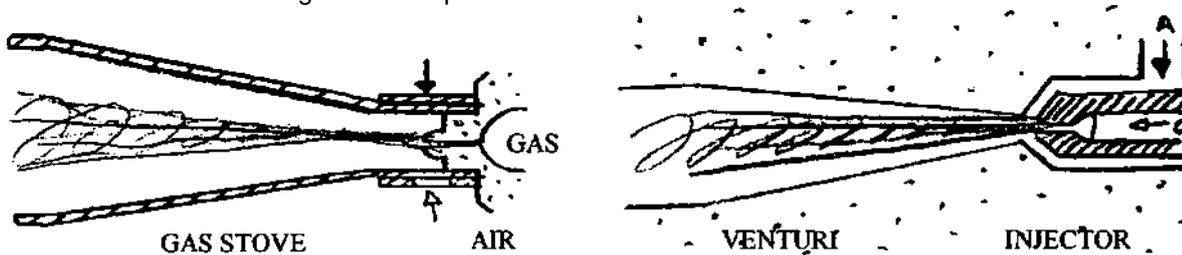
A special cutting nozzle with a central jet and a surrounding preheat flame was created to allow multi-directional cutting welding.

## Mixing Fuel gas and Oxygen

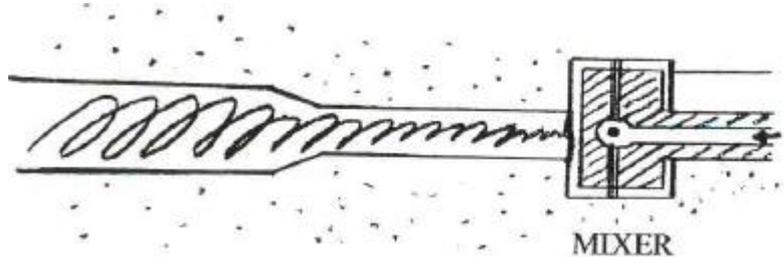
To safely use Oxygen and Fuel gas they must be thoroughly mixed to avoid local uneven combustion (explosion). This mixed gas can be ignited and burned safely under proper control.

Mixing of Fuel gas and Oxygen follows 2 basic methods:

1. **Dynamic pressure control:** Whereby a higher pressure jet of gas is used to aspirate a lower pressure gas into a tube - the Bunsen burner principle. Proper mixing is achieved by directing the jet into a narrow throat leading to an expanding venturi - as the central gas jet expands it mixes with the annulus of gas drawn in. The venturi style mixing was based upon experience with town gas in gas stoves and furnaces, first using gas pressure to entrain Air and later compressed Air to aspirate the lower pressure town gas. Acetylene generated at low pressure 0.05 -0.1 bar was first used with an Oxygen jet at 2-4 bar to entrain the Fuel gas into a tapered venturi.



2. **Volume control:** where the two gases at equal pressures are controlled by expanding through fixed orifices.



Drilled holes are easy to produce and multiple small holes improve mixing and help to reduce flashback. When Acetylene was dissolved in Acetone and compressed, it could be used at pressures of 0.1—1.0 bar. By using Oxygen at equal pressure in equal pressure mixers the passages through the equipment could be reduced and so the bulk of the hand piece and its weight reduced.

In modern equipment, the venturi principle still survives in Europe and Asia but in UK, USA and Australia, the equal pressure method is in the majority.

## Mixing gases and Flashback

Gases used for welding and cutting are chosen for their ability to release heat quickly in a controlled manner. In order to burn a fuel gas must be mixed with air or oxygen. To achieve a concentrated flame this mixing is done inside the blowpipe or the nozzle.

When the mixture is ignited, the flame will travel backwards against the flow of gas at a speed which is determined by the mixture. Generally, the lowest flame speeds are achieved with fuel rich mixtures and the highest speeds with oxygen rich mixtures.

Provided that the exit velocity of the gas mixture from the nozzle is equal to the flame speed, the flame will be stable at the nozzle tip. Problems arise, however, when the flame speed is greater than the gas velocity and the flame passes into the nozzle.

Once this happens, the flame reaches slow moving gases in larger gas passages and the rate of burning will further increase.

Generally, once a flame enters a nozzle, it will always reach the point where the gases mix. If the flow through the small orifices in the mixer is high enough, the flame may be extinguished.

However, the shock wave may have forced unburnt gases backwards and the flame may pass through the mixer and on to the next points of restriction which is the control valve.

Once past the valve the flame can pass into the whole supply system without restriction.

The flame stability is therefore of critical importance. The mixture must be stable and the gas velocity must be adequate and this is controlled by the inlet pressures.

This balance can be upset in a number of ways. Falling supply pressures, unpurged equipment and trapped hoses can all lead to a rise in the oxygen proportion and therefore increase the flame speed.

Excessive pressures can increase the gas velocity but if it results in turbulence the flame speed is also increased. Gases which are pre-heated by passing through hot nozzles will burn faster.

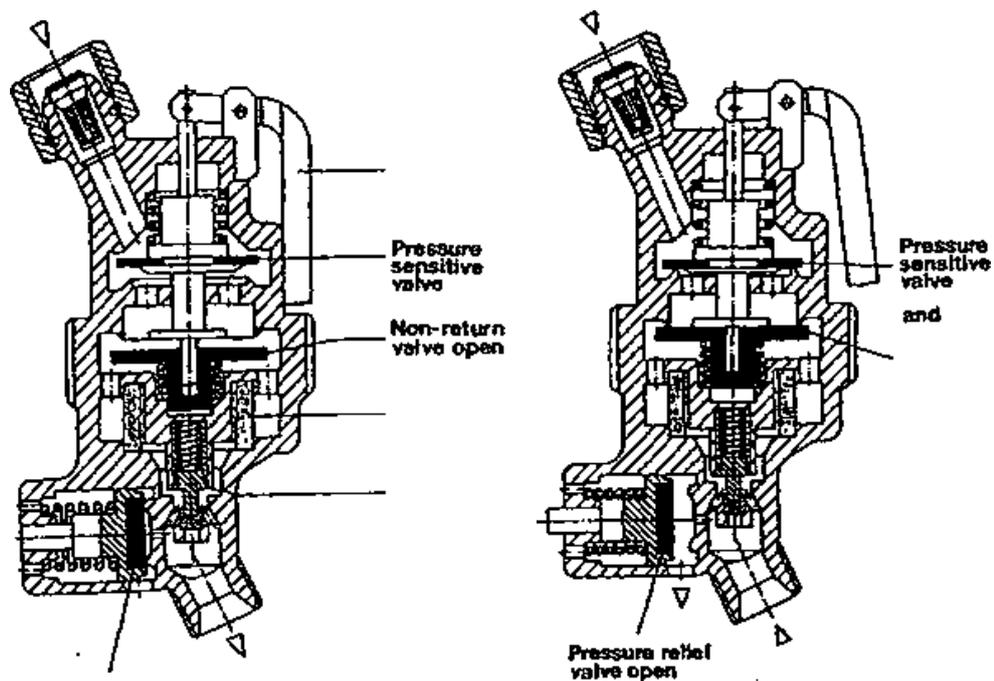
Only good working practice and correctly maintained equipment can avoid these problems but day-to-day control of every condition is difficult and accidents do happen with results that range from damaged equipment to loss of life.

Flashbacks can be stopped effectively by fitting flashback arrestors. These devices will automatically stop any flashback at the point of installation. To be effective, a Flashback Arrestor will have a number of functions. These can be divided into 3 groups. The first is concerned with solving the initial problem, i.e. the flashback. This requires first a flame arrestor which will deal with any mixture of the gases in use and quench the flame front without fail.

Secondly a non-return valve must be fitted to stop the pressure wave following the flashback and preventing any damage to the upstream equipment.

The second group of functions concerns the secondary effect of flashback. The flashback can easily burst hoses. Even if the flame has been extinguished the escaping gas can be ignited and result in secondary fires. To prevent this an automatic cut off valve can be incorporated. This senses the pressure rise and immediately cuts off the gas supply. Tests have shown that these will operate even if complete hose failure occurs over 200 feet away from the point of installation.

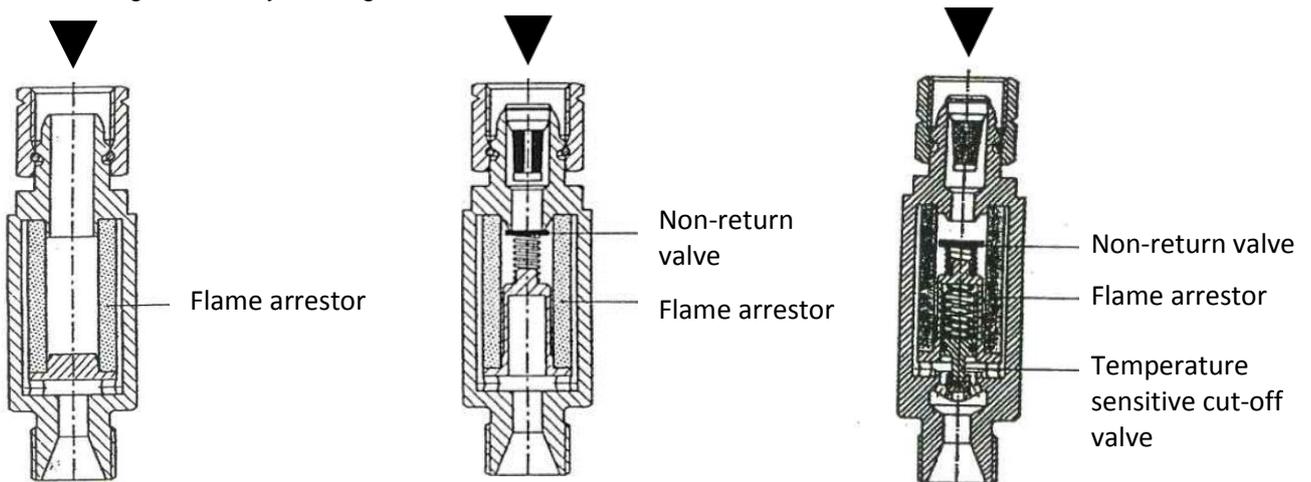
Another result of flashback can be overheating of the arrestor due to a slow flame return which settles on the arresting element. Although unusual with Acetylene or Propane it can occur with Hydrogen. This can also happen if repeating flashbacks occur and a pressure sensing valve is not fitted.



This can be overcome by the fitting of a temperature sensitive cut off valve which will close before dangerous temperatures are reached. However, it is important that such a valve performs no other function. Although some cost savings can be made by performing this function by forcing the non-return valve closed this must be considered a false economy.

Firstly, the valve has to close against the incoming gas pressure and it may not be effective, and secondly the non-return valve is the most worked function in the system and statistically is the first to fail. It makes no sense to rely on this in an emergency when alternatives exist.

Both types of cut off valve have applications. The temperature sensitive types may be used in most applications where the operator has ease of access to the main gas shut off or cylinder. The pressure sensitive type should always be used if there is any risk of the operators escape route or access to isolation valves being blocked by burning hoses.



The third group of functions concern the service life of an arrestor. Every flashback will produce some free carbon or other debris such as particles of burnt hoses. These will eventually block the arrestor causing gas starvation.

A relief valve which vents these at the time of flashback will increase the life by up to 5 times. Blowing through with compressed air is an alternative but only if it is oil free and easily available.

Flashback arrestors are made and tested to high standards. The effectiveness of the valves can be ruined by any dirt entering the device. The flame arrestor protects the outlet and the inlet should be protected by a dirt filter. If the filter has been removed or not visible, then it should not be used until all functions have been checked to ensure that no foreign matter has entered and caused damage.

Otherwise arrestors are virtually maintenance free needing only an annual check for valve function and flow capacity and in normal service will give many years of protection.

## Cocks and taps and valves

Valves to close off and to vary the release of fluids are derived from the chemical, town gas, steam and water industries.

The tapered cork or bung utilises the mechanical advantage of the wedge to seal bottles and barrels. A tapered plug of metal with a through hole, ground to fit a tapered hole in a body provides both shut-off and control of flow. Grease on the taper reduces friction and seals against leakage. These taper cocks are used for laboratory glassware, gas appliances and water tanks - all low pressure.

The adoption of the continuous wedge or screw thread allowed taps to be made with either a pointed or flat end to be jammed onto a hole for closure and a degree of control over the opening. A compressible soft leather or rubber nose provided tight closure even with minor damage to the seating faces.

Alternatively, a hard nose on the valve stem can operate on a softer metal seat but the twisting of the surfaces on each other can result in leakage.

To limit the leakage along the thread, a seal was necessary. Heavy grease stops leakage at low pressure but for high pressure a stuffing box packed with a soft compressible material is used to seal around the shaft. (Not suitable for Oxygen)

Better control of the outlet fluid can be achieved by using a tapered point and a finer pitch thread to allow controllable throttling.

The taper plug cock provides unrestricted full bore through flow. Valves such as the garden taps involve acute changes in direction what cause turbulence and loss of capacity.

## Valves in gas torches

Gas blowpipes started with taper gas cocks because low pressure gas supply necessitated straight-through flow to minimise losses. They are compact and have the least components but matching the tapers requires specialised machines for modern mass production. They are difficult to seal at higher pressures.

When higher gas pressures were used for welding and cutting using Oxygen, threaded spindle taps or valves became necessary along with stuffing box sealing with gland packings around the spindles.

The twisting action of the valve spindle causes cold welding of the metals and tearing of the surfaces and results in leakage. Over the years there has been much effort put into devising ways to overcome this at low cost penalty:

We have spindles with hard points, loose points and soft points, each has its advantages and manufacturing difficulties.

In blowpipes, the control valves generally have metal-to-metal seating in order to ensure the seat cannot be burnt out in the event if gases burning inside. They also work in poorly lubricated conditions with very high torque and loads.

In order to overcome failure arising from tearing and galling of the valve and seating it is usual to have dissimilar materials for the nose and seating. Nose pieces which are loose will not twist upon the valve seat. Hard balls are used for spindle noses, as hard surfaces tend to crush and planish the seat rather than weld and tear the surface.

These refinements improve the life of the valve but introduce extra cost that needs to be balanced against reduction in customer complaints and improved safety in operation. Seals to prevent leakage of gas are today normally O-Rings. In these, the fluid pressure forces a sealing edge against the shaft and housing. The shaft can be turned under pressure without likelihood of leakage.

## Essential constructional aspects for safety

No leakage externally or internally at joints, seals, valves and seatings.

The mixing chamber construction must minimise the chances of and consequences of back-firing and flashback.

The essential requirement is the flame velocity exceeds the ignition velocity of the mixed gas as it issues from the tip - otherwise the explosive wave may travel back and result in back firing the gas.

Any failure of the above may result in personal or property damage. Proper maintenance of the equipment will avoid most problems.

## Materials compatibility

This is essentially similar to that already outlined for high pressure gas, with the provision that welding tips being under very low pressure may be pure copper for Acetylene.

Brass is the material usually used because of the relative ease of machining, brazing and finishing.

Brass has a smooth machines surface with low coefficient of friction, it does not rust and the copper alloy is below 70%, so it is compatible with Oxy and Acetylene.

Aluminium has been used to reduce weight but usually requires inserts for seats and sliding connections subject to repeated wear.

## Pressure reducing valves or Regulators

Oxygen is stored in cylinders compressed to 230 bar (300 bar cylinders are being introduced) and Acetylene at 20 bar.

Oxygen for welding is normally required at much lower pressures, 0.1-3 bar and cutting 1.5-8.0 bar. Acetylene is required at pressures from 0.5-1.0 bar

However, when O<sub>2</sub> is used as a laser assist gas, the pressures used can be much higher, depending on the material thickness. For cutting thin material, pressures over 20 barg are used, where the contribution of the combustion process is insignificant and the melt-shear removal process does all the work. For thick sheets however, the maximum applicable oxygen pressure drops rapidly.

The cylinder pressure must be reduced and regulated or governed so that it remains steady, independent of the pressure in the cylinder. This is achieved by a **pressure reducing valve** or **pressure Regulator** / governor.

This could be done by using a fine adjustment throttling valve with a pressure gauge, but if the flow from the torch is changed or blocked then the pressure would rise quickly to cylinder pressure and would burst hoses etc.

This could be manual regulation, provided a very watchful eye is maintained...

## Early pressure reducers and governors

Early Regulators were developed from experience with steam and town gas. Town gas was supplied from the gas works to a district through a governor to smooth out irregularities of pressure from the various gas holders.

The original governor devised by Clegg and Crossley in 1819, was the dry type with leather diaphragm and conical plug valve.

The district governors were of the wet type in which a bell floating in the water operated a conical plug to throttle the inlet gas so as to maintain the bell in balance by a steady outlet pressure maintaining equilibrium with the weight of the bell.

At the consumer's premises, Regulators were installed to maintain a steady gas pressure to appliance. In addition, domestic gas lights included a built-in dry Regulator to hold an even pressure so the light would not fluctuate.

Modern gas appliances have a gas governor which reduces the supply to a slightly lower operating pressure so that flames do not vary. They may use weights or springs to load the diaphragm.

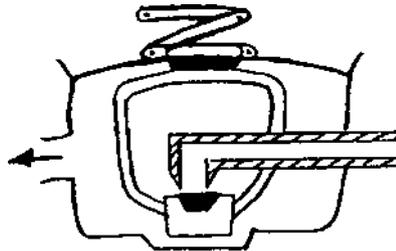
Governors usually operate with a small difference between the inlet and delivery pressures whereas Regulators operate with a wide difference between the inlet and delivery pressures and must stop the inlet gas flow when outlet flow stops.

Obtaining this gas tight shut-off to seal off cylinder pressure is where the finesse comes in when devising reliable Regulators.

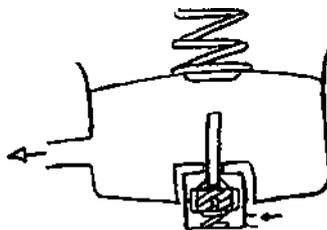
### Regulator types

Early designs had the throttling valve linked to the diaphragm by a stirrup or lever - any leakage at the valve seat caused the diaphragm to pull harder to close off the gas.

This construction in which the seat is closed against inlet pressure is called **direct action** and in addition **tied seat** if the seat is linked to the diaphragm.



Other designs utilise the cylinder pressure to help close the seat against the nozzle. These are identified by the stem of the valve passing through the nozzle and a spring is usually used to close the seat against the nozzle. Some have the stem coupled to the diaphragm so the diaphragm can pull the seat closed. This construction is called **inverse action**.



With the tied seat design any leakage at the seating causes the diaphragm to pull the seat closed until leakage stops or the link breaks.

The rise in pressure between initial and final closure is called **creep**.

With the inverse action type, the seat spring and inlet pressure urge the seat closed against defects and particles, but beyond this loading the gas leaks. In order to prevent runaway pressure inside the Regulator, a pressure relief valve is fitted which will vent excess pressure.

The inverse action allowed the reliable use of rubber valve seats operating on a broad nosed nozzle. Rubber

unlike harder materials, will absorb some quantity of particles before leakage occurs.

The lever and stirrup designs are rugged and reliable, but modern designs favour inverse action because it simplifies machining and assembly for mass production and so reduces costs. Specialised fluoroplastics such as PTFE (Teflon) and PTFE (kel-f) are now used for seats because they have high resistance to ignition and good seating characteristics.

**Pressure Regulator - How it works**

A Regulator comprises:

An inlet connection (capable of withstanding cylinder pressure) with the throttling valve orifice or nozzle and cylinder pressure gauge.

The throttling valve seating with stem or linkage.

The low pressure chamber with diaphragm or piston and low pressure gauge and outlet connection.

The bonnet houses the spring and loading screw, also a breather hole.

A pressure reducing Regulator is a balanced valve in which a throttling valve is connected to a diaphragm. Gas pressure on the diaphragm against a load applied by either weights, spring or gas pressure.

The throttling valve reduces the cylinder pressure & allows gas to flow until the pressure force upon the diaphragm balances the load applied by the weight, spring or pressure.

When gas is drawn from the Regulator the pressure within falls, the diaphragm moves to open the throttling valve and gas flows in until equilibrium is again automatically re-established. When the gas flow is reduced or stops the pressure rises and lifts the diaphragm and the valve closes.

The action is similar to that of the float and valve in a toilet cistern.

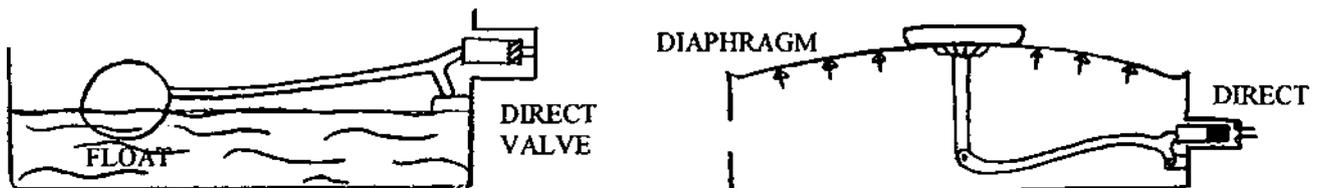
The load applied to the diaphragm sets the outlet pressure of the Regulator. To change pressure means changing weights, spring loading or pressure. Weights are satisfactory only if the Regulator is in a fixed position and the diaphragm is level whereas springs compressed by a screw will exert high forces in any position, similarly gas pressure gas loading allows any configuration.

**Cylinder pressure and outlet pressure**

The outlet pressure of a Regulator is influenced by changes in pressure in the cylinder and also by the flow of gas from the Regulator. These changes affect the diaphragm loading and thus the pressure to maintain equilibrium - so steady pressure is not achieved.

In the direct action design the pressure reaction force from the nozzle on the seat disc adds to the load applied to the diaphragm, so as the cylinder empties, the force on the seat reduces and as well the load on the diaphragm and thus the outlet balancing pressure diminishes in proportion. This is called a falling pressure characteristic.

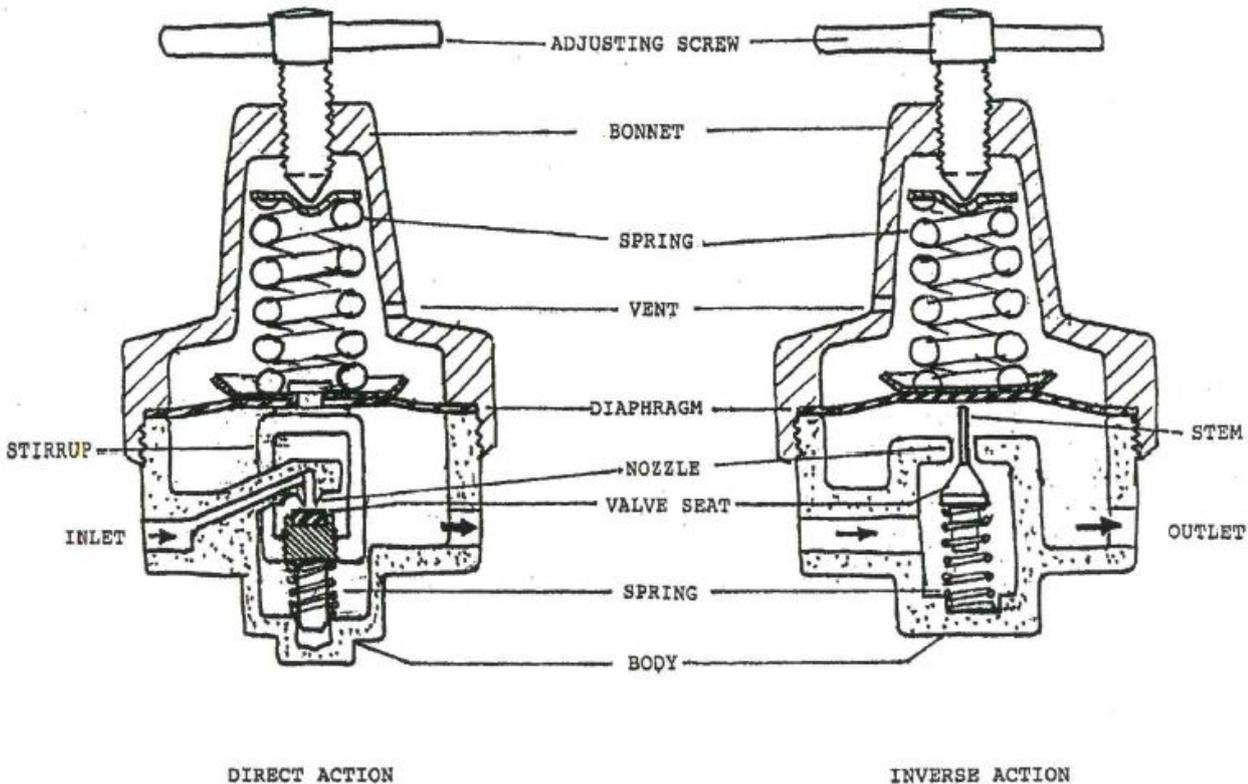
In the inverse action type the pressure piston force on the seat disc opposes the load applied to the diaphragm, so as the cylinder empties the force on the seat reduces but the nett result is the load on the diaphragm increases and so the outlet pressure rises in proportion. This is called a rising characteristic.



When the delivery flow is increased, the seat opens in response which lowers the diaphragm and thus the spring is allowed to lengthen which lowers the load on the diaphragm and in turn the balancing pressure. This results in a drooping pressure characteristic.

This droop does not occur if the loading is by weight or gas pressure loading.

A steadier pressure results by using 2 Regulators in series - Two stage pressure reduction.



Two stage regulators are essentially a fixed outlet pressure regulator which reduces the cylinder pressure down to a set amount usually 17-20 bar. A second regulator which has an adjustable outlet then reduces that pressure to the level required. The rising characteristic of the first stage regulator is reversed in the second stage. Since this effect is so minor for all intents and purposes the outlet pressure is constant until the cylinder pressure falls below the pressure set on the first stage.

The pressure rise or fall can be reduced by using a small nozzle and a large diaphragm - this reduces the proportion of change caused by the pressure load of the seat.

### Dome-loaded Pressure Regulators

Dome-loaded pressure regulators are operated with gas pressure. Unlike spring-loaded pressure controllers, the opening force of the valve required for pressure reduction is generated by the pressure of a so-called pilot gas and not by a spring.

The pilot gas can be a separate gas, or the gas to be regulated is itself used as the pilot gas („own-medium controlled“). In that case, the gas to be regulated is supplied to the dome where it reaches the valve seat. The pilot gas is controlled via a built-in pilot gas regulator and led into the pressure chamber. Here, it acts on a diaphragm whose stroke movement is transferred to the valve seat via a diaphragm plate. So the valve gets opened or closed via the pressure of the pilot gas and the relevant stroke movement of the diaphragm, dependent upon the chosen operating pressure, and the flow required. The excess pilot gas is routed to the outlet pressure side via an integrated non-return valve. It is thus a closed system, with zero emissions, and it allows the outlet pressure to be adjusted whilst in service.

As an alternative to a pilot gas regulator, an electrically controlled proportional valve can be used, and the

control of this device can be incorporated into a wider control system.

Generally, dome-loaded pressure regulators provide more stable outlet pressure, even when the flowrates and or inlet pressures are varying.

With some types, outlet pressure control is so accurate that two-stage pressure regulation is no longer necessary.

### Safety of Regulators

Pressure gauges are an important feature of most Regulators as they register the pressure in the cylinder and change in the delivery chamber.

The inlet gauge indicates by change in pressure the amount of gas remaining in the cylinder - it is the “petrol gauge” (except liquefied gases).

The outlet gauge indicates changes or pressure in the delivery chamber arising from high flows and any deterioration of the seating - “creep”. This indication is a vital safety function.

The pressure rating, construction and materials used in a Regulator are all influenced by the gas to be used. To prevent coupling of a Regulator to an incompatible source, the inlet and outlet connections are unique to prevent dangerous mistakes.

Oxygen, Nitrous Oxide as oxidising gases have right hand threads and non-interchangeable fittings.

Fuel gases - Acetylene, Hydrogen, LP-gas, Ethylene, Methane have left hand threads and different connections.

Inert gases - Nitrogen, Argon, CO<sub>2</sub> have right hand threads and various fittings.

In addition, the introduction of much higher cylinder filling pressure has created an extra hazard as the coupling of current equipment is not safe, so more unique connections have been introduced to avoid coupling that could overload pressure gauges and promote seat ignition in older designs – NEVOC (New European Valve Outlet Connections).

Safety with Oxygen and oxidising gases means **no oil, grease or other contaminant** can be tolerated because sudden adiabatic compression could ignite such materials and result in a dangerous **Regulator burnout** with release of molten metal particles and high pressure gas plus the likelihood of throwing other components.

Fuel gases must not be contaminated with Oxygen otherwise uncontrolled combustion may result. Any leakage of Fuel gas could result in fire.

Copper (exceeding 70%) must not be used in Acetylene and Ethylene Regulators.

### Safety of Oxygen Regulators

Ignition of the seating of Oxygen Regulators has been a long-standing industry problem and differing means have been tried to prevent this occurring.

Early Oxy Regulators using a copper rod in the inlet close to the nozzle with the objective of absorbing heat generated in adiabatic compression. This could lower the temperature rise to below the ignition point of the seating material or any contaminants present.

Of course, opening the cylinder valve so that the Oxygen pressure rises slowly will largely prevent straining the pressure gauge.

The use of a porous sintered metal filter is accredited as a heat absorber as well as restricting the entry of foreign particles.

For many years, no hydrocarbon lubricants and sealants were permitted in the gas stream of Oxygen Regulators and valves but in recent time chloro-fluorinated lubricants have been used. Any application must use minimum quantities to avoid focusing contaminants.

All materials in Regulators are carefully chosen to ensure long service and high resistance to ignition and chemical breakdown.

Deliberate promoted ignition tests are a feature of design proving of Oxygen Regulators and valves in which conditions are exaggerated to reveal any weak points in the design.

Once a particular Regulator has a reliable history one needs to be guarded in allowing even minor changes in configuration and materials. The cause of some ignition and contamination may arise from the use or misuse in industrial use.

### **The welding system**

Now we have reviewed the elements required to carry out welding and cutting:

- Cylinders of Oxygen and dissolved Acetylene.
- Regulators to reduce cylinder pressure to working pressure.
- A blowpipe or torch with valves to adjust the balance of gases and flame size.
- A blowpipe or torch with mixer to prepare a consistent combustible mixture.
- Tips or nozzles to set the size of the flame(s).

What's missing? Hoses or tubing to join the Regulators to the blowpipe valves - they must be flexible over the range of temperatures experienced.

### **Hoses or tubing join the system**

The first Air-coal gas and Oxy-coal gas lead burning (lead welding) Blowpipes used flexible tubing with a pliable liner of the "new" rubber reinforced with a number of layers of woven canvas. Rubber lining was gas tight to Acetylene and Oxygen with good flexibility in cold and hot conditions, and the canvas layers wrapped around the liner provided reinforcement to contain pressure and as well gave protection from abrasion.

The hand wrapped layer construction of hoses provided a strong hose with good resistance to collapse and kinking. It is still the preferred hose sold to site workers.

Another construction was devised, in which the hose was built up by machine plaiting braids of cotton (later Terylene and Polyester) around a rubber liner and covered by an outside cover of vulcanised rubber either plain or ribbed. This produced a stronger, lighter and more flexible and uniform hose. A variety of colours and markings are easy to incorporate and being mechanised cost less.

To help the user identify the gas lines, a convention developed of using different colours for the Oxygen and Fuel hoses. Red for Fuel gas and Blue for Oxygen. Orange for LPG.

The liner, braid and cover must be made of materials chemically compatible with the gas and any contaminants likely to pass through the hose. In addition the materials have a high resistance to ignition as well as burning in the event of internal flashback or external hot particles lodging on the cover.

Acetylene hose must not degrade by Acetone vapour and LPG hose must be compatible with solvents like Heptane and Pentane.

### **The difficult job of the hose fittings**

The joint between the hose and the torch and Regulator started as push on over shaped bulbous nipple - later with multiple ridges to improve retention.

These were satisfactory for low pressure gas but there was always the risk of an end force pulling them off. With higher pressure the expansion of the hose made this more likely.

Early clamps to retain the tubing were wrapped bands or wire. The hose clip with side clamping bolt has a wide range of adjustment - still widely used in Europe. These clamps retain well but project into the operators hands. When re-used may lose integrity. Various smooth outline types have been devised from reuseable to

non-reuseable.

Today it is common to use a low cost barbed nipple with an outer sleeve that squeezes the rubber into the grooves of the nipple. This may be a squeezable ring (O-Clip) or a plain deformable sleeve.

The design of the simple hose connection must provide high resistance to leakage under a wide range of conditions -

- Pulling off the hose under tension.
- Damage to the liner during fitting.
- Abrasion across rough floors causing wear and fracture of the re-enforcement.
- Chemical attack of the liner by the gas under prolonged exposure.
- Crushing loads that may fracture the reinforcement and liner.

This simple connection must at low cost safely perform these highly demanding roles. In addition, it must fit hoses with a wide manufacturing tolerance and still provide a reliable leak free joint.

### **Non-interchangeable hose fittings**

In the early days, the colour of the hoses and markings on the torch were the means to identify the correct connections.

The screwed nut and nipple unions were introduced by using different threads, wither 2 sizes or right and left hand threads - right for Oxy, left for Fuel.

The metal-to-metal union is usually a ball-in-cone but the forms and angles vary, as well as the threads used.

In Europe, the Fuel gas thread is usually R3/8 (3/8 BSP) left hand, except France, which uses M16. The Oxy thread is usually R3/8 (3/8 BSP) but some makers use R1/4 (1/4 BSP). In the USA 9/16-18 is the standard with LH for Fuel and RH for Oxygen, although the American railroad companies adopted 5/8-18 in an attempt to reduce theft. This has now fallen into disfavour.

### **Hoses and pressure drop**

The bore of the hose used to be adequate to supply the volume of gas for the process being used. In particular, heating requires high flows of both Oxygen and Fuel gas whereas cutting requires high flows of Oxygen.

Larger bore hoses are less flexible therefore the smaller sizes 5-6mm are used but the larger 8-10 mm are required for cutting and heating.

Even modest flows will be restricted if long lengths of hose are used. This drop in capacity results from pressure drop caused by friction between the gas and the walls of the liner.

### **Routine safety checks**

To ensure gas equipment is in safe operating condition simple checks should be carried out every time the equipment is set up and used.

Leakage of gas is the prime indication of an unsafe condition. Leakage may be in either the High or Low pressure proportions of the system.

The presence of leaks is shown by either a pressure rise or loss from a sealed system as a result of either internal or external leaks. Leaks can be located by using a detection fluid such as water or soap solution to show bubbles of escaping gas.

Before lighting, both the Oxygen and Fuel gas hoses must be purged to ensure neat gas displaces any Fuel-Oxy mixture or Air-Fuel mixture from the hoses.

## How simple the checks can be

1. At cylinder valve connection to Regulator  
Before assembly inspect bullnose and O-ring for any contamination by Oil etc  
With Regulator screw released open cylinder valve slowly - let HP gauge rise - if obvious leak revealed by hissing, turn off, retighten and repeat.  
Turn off cylinder valve, watch pressure gauge - if it drops there is a leak, retighten connection and retest. If it persists, use soapy water to find leak.
2. Hose coupled to Regulator and Blowpipe. Valves closed. Bleed pressure into Reg and hoses to pressurise LP gauge and hose.  
Turn off cylinder valve, if LP gauge drops there is a leak. Retighten hose and valve. If it persists, use soapy water to find source of leak. Repeat for other hose.
3. Before lighting up - Purge hose(s) of Air-Fuel mixtures.  
Open blowpipe valve, purge Oxy for several seconds, close valve. Repeat for Fuel gas hose.
4. Lighting up  
Set Oxy to correct pressure setting, set Fuel gas to correct pressure.  
Open Fuel gas valve and ignite at tip, open valve until smoke eliminated, then bring back flame to tip.  
Open Oxy valve and adjust Oxy until inner cone is distinct without feather.
5. Flame alight  
If cracking occurs the tip or nozzle is loose - retighten.
6. Closing down  
Close Acet first - this extinguishes the flame and eliminates the soot.  
Close Oxy valve.  
Close cylinder valves, open valve(s) on torch and release gases.  
Wait until both HP and LP gauges of both gases return to zero. Close both torch valves.  
Release adjusting screws of both Regulators.

## The mechanism of combustion

**Combustion** is rapid high-temperature oxidation.

The mechanism is a rapid chain reaction. The essential ingredients of all combustion are Hydrogen and Carbon.

**Flame front** is an area of very rapid chemical reaction. It is the boundary between the burned and unburned gas - it continually moves toward the unburned gas.

Propagation of a flame is a thermal process, during which the flame must transfer heat to cause it to ignite.

**Ignition temperature** is the minimum temperature at which combustion of a gas mixture becomes self-propagating.

When ignition temp is reached accumulation of heat exceeds dissipation, temperature rises above ignition point and combustion is sustained.

**Limits of flammability** - a mixture of combustible gas cannot be ignited nor can it burn if there is too little or too much combustible gas present.

### Explosive Limits

|             |                     |                  |
|-------------|---------------------|------------------|
| Acetylene   | 2.5 - 80.0 % in Air | 3.0 – 93% in Oxy |
| Propane     | 2.3 – 9.5%          | 2.4 – 57%        |
| Natural Gas | 5.3 – 14.0%         | 5.0 – 59%        |

**Combustion Ratio** - the Oxy-Fuel gas ratio theoretically required for complete combustions called the Stoichiometric mixture. This does not represent the Oxy-Fuel ratio actually delivered by an operating torch because complete combustion obtains some of the Oxy from Air.

Oxy-Acet is 1:1 from the torch but 1:2½ overall – with 1½ from the Air.

## Flame speed

**Velocity of propagation** - In a burner the velocity of the gas-Oxy mixture must exceed that at which the flame will travel in the mixture, otherwise burning back occurs and combustion will take place in the burner and not at the outlet. When gas flow exceeds velocity of propagation the flame stands off from the tip outlet. The burning velocity of Acetylene-Oxy is 10 m/sec, Natural gas & Propane 5.5 m/sec whereas Hydrogen is about 12 m/sec.

**A stable flame** occurs when the velocity of the gas mixture and the burning rate are in balance. For each gas mixture there is a range of flow over which the flame is stable. When a disturbance occurs that lowers the gas flow or overheats the mixture, it may burn too soon or burn back.

**Flashback** is the recession of flame into the mixer chamber, where the mixed gas explodes. If as a result of this explosion, the mixture continues to burn in the mixer a sustained flashback results and this can burn out through the wall of the mixer chamber.

Flashback can be limited if not overcome by using narrow passages in the mixer to allow the conduction of the heat generated in Flashback and quenching of the burning.

The aim is to build blowpipes and mixers to reduce uncontrollable combustion and explosive flashback to a minute amount - whilst permitting reasonable variation from ideal manufacture and operation before dangerous conditions are reached.

## Flow through pipes and orifices

Gas differs from liquids because gas is compressible.

This means that accelerating the flow of liquid in a pipe will be smooth, but in a gas, acceleration will cause compression of the gas ahead. This results in rebound so the compression travels like a wave through the pipe.

Flow through a pipe occurs like a series of thin tubular layers (laminar flow). Those in contact with the walls are slowed by friction. The velocity of the centre layers is not affected but due to the slowing at the outer layers a velocity gradient is created across the pipe.

If gas flows through an orifice, eddies form which slow the flow and the outside of the jet is compressed and a neck results - called a vena contracta. Beyond the orifice the jet expands again.

These eddies occur whenever there is a change of direction or obstruction such as a bend or valve. If the pipe surface has projecting roughness thus higher friction and more pressure loss results - such as burrs or uneven finish.

If the nozzle is shaped to eliminate eddies there will be less pressure loss and distortion of the flow.

This nozzle shape is called a convergent-divergent nozzle (or diffuser).

As the pressure difference between the supply and exit is increased, a critical exit pressure can be reached at which sonic (speed of sound) velocity of flow is reached at the throat. At this condition increasing the pressure difference will not increase flow and the nozzle is said to be choked.

This shape is easy to produce for large throats as used in rockets and turbines, but for the very small holes used in gas equipment even approximation are difficult to produce.

## Tips and Nozzles

In the practical dimensions of welding tips and cutting nozzles any tiny defects or obstruction in the approach and exit of the flame orifice will distort the flame. Since this is an optical distortion even small faults are readily seen by even unskilled users.

The tip and nozzle passages must have a high finish without burrs, scratches, roughness and misaligned holes, within the bore or at the exit. This requires materials and processes that can form passages to a high

finish free from tool gouges and adhering burns.

Since high conductivity of the tip is advantageous to dissipate the heat, the most desirable material is copper. Copper is difficult to machine because the chips tear and clog rather than break off cleanly. For this reason brass and bronze are a practical alternative, with sufficient conduction plus excellent machinability. Drilling and turning can be performed with low wear on tools and easy size control along with good finishing.

Copper is best formed by using its malleability - such as drawing, swaging and other methods of cold working.

### **Welding tips**

The earliest tips were designed as a replaceable extension fitted to the end of a suitable barrel. Different orifice sizes are used to provide different flows of combustible gas according to the amount of heating required.

Most makers adopted the style of a screw-on tip with the seat protected inside the tip, but the external mating seating on the barrel is unprotected when the tip is removed.

A few makers adopted the screw-in tip in which the end of the barrel is larger with the seating inside. This means the tip (the replaceable item) can be made from smaller material.

The orifice in the tip varies from a simple parallel hole through stepped holes to a converging taper. The exit should be a square sharp edge to provide clean breakaway for a symmetrical flame. Any dents, burrs, scratches or mismatched diameters within the exit will be revealed by optical distortion of the flame.

The major problem is usually the metal burr left according to the direction of feed of the last operation. Every operation, no matter how small the depth of cut, produces a burr. De-burring operations often remove a major burr and leave another burr. Counter-sinking is an example.

The direction as well as the size of a burr determines the distortion revealed in the flame.

Some projections can be removed by using a suitable cleaning tool that breaks them off.

Careful use of tapered reamers and polished "knobby" rods can remove fine burrs. Polishing the end face with fine abrasive can leave a burr free square edged exit.

### **Production of tips and nozzles**

Drilling in brass with sharp drills can produce circular holes with minute burrs especially if an undersize drill precedes the finishing drill. An approximation to the "ideal" orifice can be achieved by a series of stepped diameters or a continuous converging taper. However, unless the tools are in good condition burrs and chattered surface may result.

Copper, which has better conductivity and life, is difficult to drill without poor finish and breakage of small drills. Copper can be readily worked by hammering onto a polished mandrel called swaging. The orifice can be a smooth taper without burrs produced at a rapid rate.

A swaged copper tip offers a slim outline with a streamline flow and long life plus little obstruction to the view of the flame.

However, threads on copper cut by die heads are usually tom and rough but rolled threads are of high finish. Most manufacturers now supply swaged copper welding tips in their welding sets. Swaged tips generally produce a long parallel inner cone with a smooth pointed inner cone, whereas drilled tips have a shorter bulbous inner cone. The blunt inner cone is often regarded as more suitable than the long inner cone for pipe welding and hard surfacing because the blunt point is easier to position to achieve maximum heating. A swaged tip with an enlarged divergent-convergent diffuser chamber provides a "soft quiet" flame preferred for work where the harshness of the ordinary flame is not desirable.

## Cutting nozzles

The single hole welding tip is the simplest way to control the gas flow and to obtain the desired geometry for a flame of good appearance.

For higher flows, single large holes are often not suitable because the heat is too concentrated so melting occurs. Multiple small holes are preferred when heating and not fusion is the objective.

Multiple holes have the advantage they reduce burning back because it is more difficult to simultaneously obstruct all the holes.

Multiple holes require care to produce equally sized passages and sharp exits to avoid local unbalanced deformations that will be visible in the flames.

In cutting nozzles, the favoured design is a “ring” of preheating flames surrounding a central cutting jet. Designs vary from a full annulus of flame to individual flames from multiple holes and multiple slots. The overall problem is to produce a flame of symmetrical appearance using the orifice area necessary for the required flow.

An annular gap requires a very narrow gap, which is hard to control.

Multiple holes are easy to drill with equal diameters and good finish.

Multiple slots have larger area and perimeter than holes to give lower flame velocity essential for gases like LP-gas and Natural gas.

Early cutting nozzles favoured the two part construction with an annulus flame because reliable drills were not available for drilling small diameter deep holes. Maintaining the inner central and so an even gap is difficult because the tolerances of manufacture of the inner and outer are a high proportion of the gap width.

The large volume of mixed gas within the nozzle is not as flashback resistant as the smaller volume within drilled holes. This type still survives in Europe.

Most Oxy-Acet nozzles are of the solid type with a ring of drilled preheat, surrounding a central cutting orifice. Many are still made from brass wherein complete nozzles can be produced by drilling a series of stepped holes with larger back holes feeding the smaller flame exits.

Others are manufactured in copper. Small drilled holes are almost impossible to produce on an ongoing production basis, but larger diameter (3-5 mm) are possible.

These larger holes are reduced to smaller sizes by swaging the copper down to fine wires fitted inside the holes. Swaging stretches the copper and produces long tapered passages of a high polish. The wires are withdrawn and the nozzle face has to be faced to produce a square end and the finished by abrasive laps to wear away the burrs at the exits.

High quality passages result but with the cost of extra machining operations.

## Pre-mix and nozzle mix

A major variation in the design of nozzles results from whether the preheating gas is mixed before the nozzle or within the nozzle.

Early annular nozzles with uneven gap and large inner volume of mixed gas plus injector mixing were often prone to flashback if the nozzle touched against the metal during cutting.

Drilled hole nozzles used with equal pressure mixers are more resistant to flashback. The smaller passages in the nozzle and mixer help to absorb heat and so reduce flashback.

To reduce the possibility of the operator being burnt:

If a flashback occurs the point of mixing was moved forward from within the handle to near the head and nozzle. Mixing near or in the head surrounded by a mass of metal offers high cooling in the event of burning back.

Other makers chose to mix within the nozzle so none of the mixing was done in the torch. Together with copper nozzles some makers claim their torches are resistant to flashback.

The passages required within the nozzle to provide mixing are more complex as re-entrant passages are required as well as multiple fine drilled Fuel gas mixing holes. These require specialised production machinery.

Swaging allows re-entrant passages to be formed but swaging causes the passage to twist in helix, so precise location of the fuel gas hole has particular difficulties.

### Cutting nozzle seatings

The most major variation in nozzles is the seating within the torch head.

**Pre-mix** requires the co and mixed gases to be separated - 2 seats are required.

**Nozzle-mix** requires CO, HO and F to be separated so 3 seats are necessary.

Intimate metal-to-metal seats ensure good conductivity between nozzle and head.

Early designs favoured flat seatings like welding tips. The difficulty of maintaining seats leak tight was usually achieved by an adjustable seat with gland type seal.

Later taper seatings were adopted utilising the wedging action to seal. This requires very close tolerancing of the angles to obtain a leak tight seal. A variety of angles have been used - 40-45 degrees.

Most nozzle-mix nozzles are of the taper wedge design using very high accuracy of matching tapers plus malleability of the copper to obtain a seal at 3 seats.

Other manufacturers have tried to use soft seals to overcome the need to hold close tolerances necessary for metal-to-metal sealing. These materials must be able to withstand high temperatures without breaking down, at this stage, very few use non-metallic seats.

Interchangeability of nozzles with previous models in the market usually limit changes unless interchangeability can be retained with existing torch heads.

### Other Fuel gases

Acetylene remains supreme as Fuel gas for portable welding and cutting outfits. For production cutting other low cost alternative Fuel gases have won wide use Liquefied Petroleum gases - Propane and Propylene Natural gas - Methane and Ethane.

MAPP (Methylacetylene - Propadiene) is a substitute for Acetylene.

When Town gas (Coal gas) was available, it was used for cutting thin material because it produced less top edge melting than Acetylene. A "shandy" mix of Coal gas and Acetylene was used in a special Glasgow torch for critical cutting.

The Alternative Fuel gases have lower limits of flammability and flame speed so special nozzles have been developed to cause the flames to "hang on". A recess at the front and multiple slots instead of holes are used to retain the preheat flames on the nozzle.

As a result, 2-piece construction is necessary for manufacture. The inner is usually brass for easy machining of the slots, whereas the outer shell is of copper to help conduct heat to the torch head.

Such designs are unsuitable for Acetylene because of the high amount of mixed gas inside and the less streamlined slots slow the gas flows. Some makers have tried an inner with a small number of slots which is press fitted in an outer.