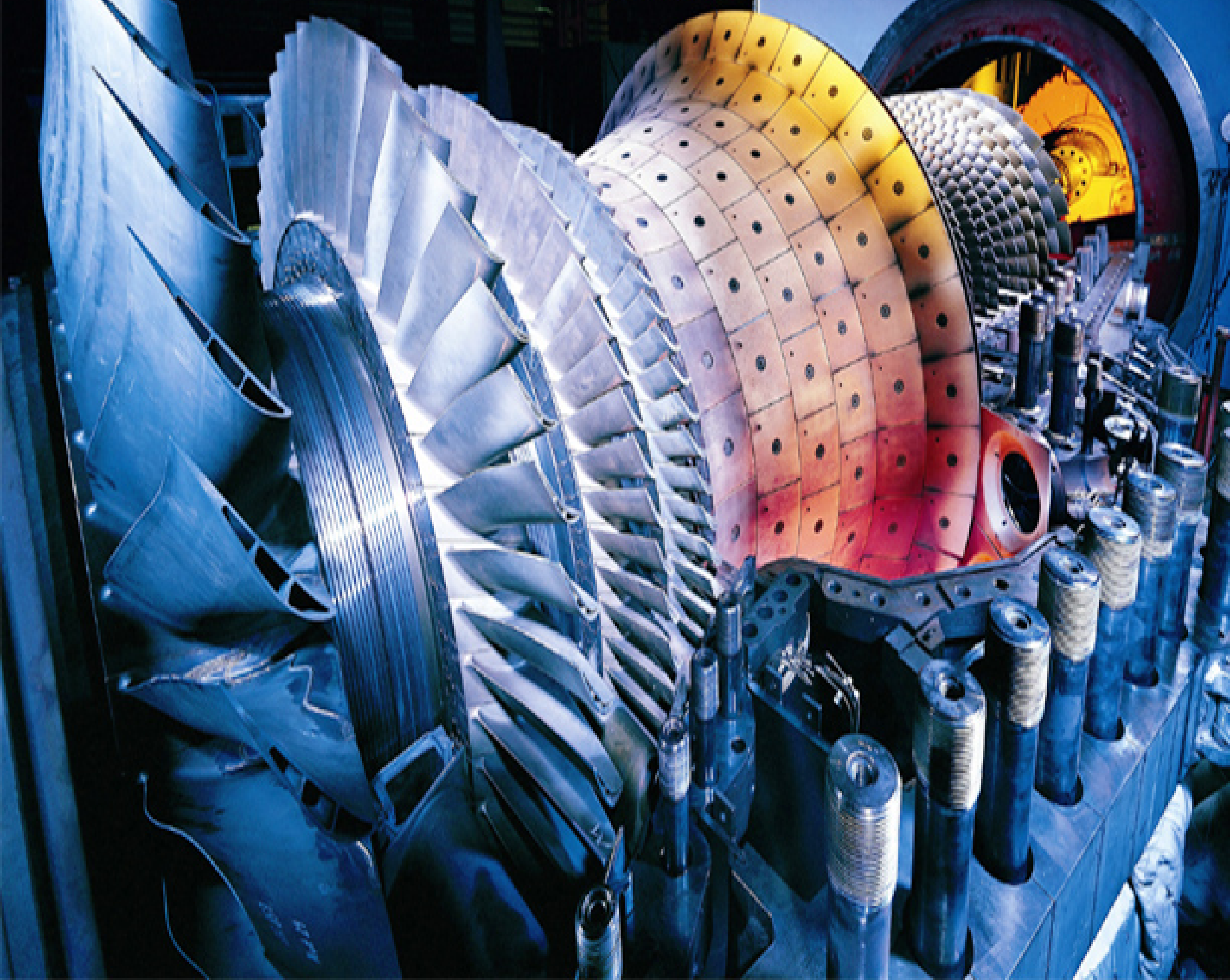
Gas Technologies

Josh Wiseman



First Edition, 2012

ISBN 978-81-323-4141-3

Published by:
White Word Publications
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

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Chapter 1

Amine Gas Treating

Amine gas treating, also known as **gas sweetening** and **acid gas removal**, refers to a group of processes that use aqueous solutions of various alkylamines (commonly referred to simply as amines) to remove hydrogen sulfide (H_2S) and carbon dioxide (CO_2) from gases. It is a common unit process used in refineries, and is also used in petrochemical plants, natural gas processing plants and other industries.

Processes within oil refineries or chemical processing plants that remove hydrogen sulfide and/or mercaptans are commonly referred to as ***sweetening*** processes because they result in products which no longer have the sour, foul odors of mercaptans and hydrogen sulfide.

There are many different amines used in gas treating:

- Monoethanolamine (MEA)
- Diethanolamine (DEA)
- Methyldiethanolamine (MDEA)
- Diisopropylamine (DIPA)
- Aminoethoxyethanol (diglycolamine) (DGA)

The most commonly used amines in industrial plants are the alkanolamines MEA, DEA, and MDEA.

Amines are also used in many oil refineries to remove sour gases from liquid hydrocarbons such as liquified petroleum gas (LPG).

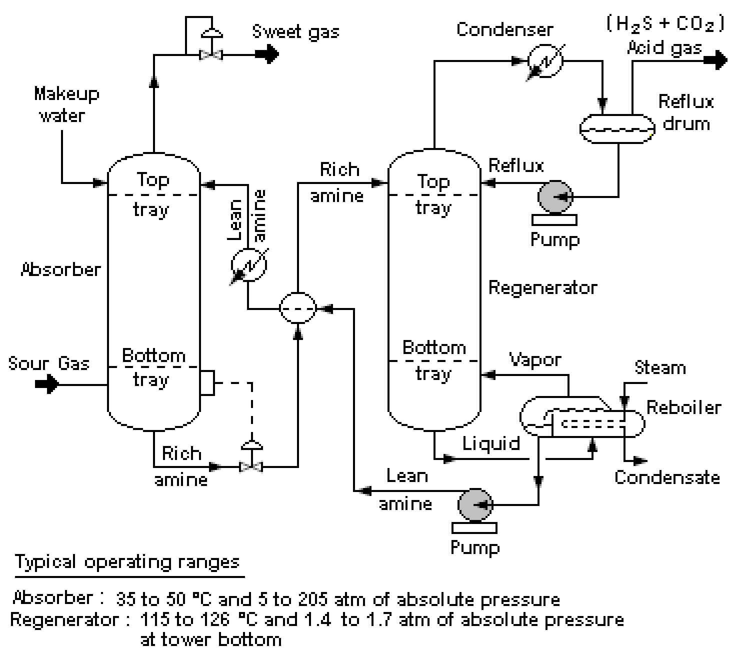
Description of a typical amine treater

Gases containing H_2S or both H_2S and CO_2 are commonly referred to as *sour gases* or *acid gases* in the hydrocarbon processing industries.

The chemistry involved in the amine treating of such gases varies somewhat with the particular amine being used. For one of the more common amines, methanolamine (MEA) denoted as *RNH2*, the chemistry may be simply expressed as:

$$RNH_2 + H_2S \iff RNH_3HS$$

A typical amine gas treating process (as shown in the flow diagram below) includes an **absorber** unit and a **regenerator** unit as well as accessory equipment. In the absorber, the downflowing amine solution absorbs H_2S and CO_2 from the upflowing sour gas to produce a sweetened gas stream (i.e., an H_2S-free gas) as a product and an amine solution rich in the absorbed acid gases. The resultant "rich" amine is then routed into the regenerator (a stripper with a reboiler) to produce regenerated or "lean" amine that is recycled for reuse in the absorber. The stripped overhead gas from the regenerator is concentrated H_2S and CO_2. In oil refineries, that stripped gas is mostly H_2S, much of which often comes from a sulfur-removing process called hydrodesulfurization. This H_2S-rich stripped gas stream is then usually routed into a Claus process to convert it into elemental sulfur. In fact, the vast majority of the 64,000,000 metric tons of sulfur produced worldwide in 2005 was byproduct sulfur from refineries and other hydrocarbon processing plants. Another sulfur-removing process is the WSA Process which recovers sulfur in any form as concentrated sulfuric acid. In some plants, more than one amine absorber unit may share a common regenerator unit.



Process flow diagram of a typical amine treating process used in industrial plants

The amine concentration in the absorbent aqueous solution is an important parameter in the design and operation of an amine gas treating process. Depending on which one of the following four amines the unit was designed to use and what gases it was designed to remove, these are some typical amine concentrations, expressed as weight percent of pure amine in the aqueous solution:

- Monoethanolamine: About 20 % for removing H_2S and CO_2, and about 32 % for removing only CO_2.
- Diethanolamine: About 20 to 25 % for removing H_2S and CO_2
- Methyldiethanolamine: About 30 to 55% % for removing H_2S and CO_2
- Diglycolamine: About 50 % for removing H_2S and CO_2

The choice of amine concentration in the circulating aqueous solution depends upon a number of factors and may be quite arbitrary. It is usually made simply on the basis of experience. The factors involved include whether the amine unit is treating raw natural gas or petroleum refinery by-product gases that contain relatively low concentrations of both H_2S and CO_2 or whether the unit is treating gases with a very high percentage of CO_2 such as the offgas from the steam reforming process used in ammonia production or the flue gases from power plants. Both H_2S and CO_2 are acid gases and hence corrosive to carbon steel. However, in an amine treating unit, CO_2 is the stronger acid of the two. H_2S forms a film of iron sulfide on the surface of the steel that acts to protect the steel. When treating gases with a very high percentage of CO_2, corrosion inhibitors are often used and that permits the use of higher concentrations of amine in the circulating solution. Another factor involved in choosing an amine concentration is the relative solubility of H_2S and CO_2 in the selected amine. For more information about selecting the amine concentration, the reader is referred to Kohl and Nielsen's book.

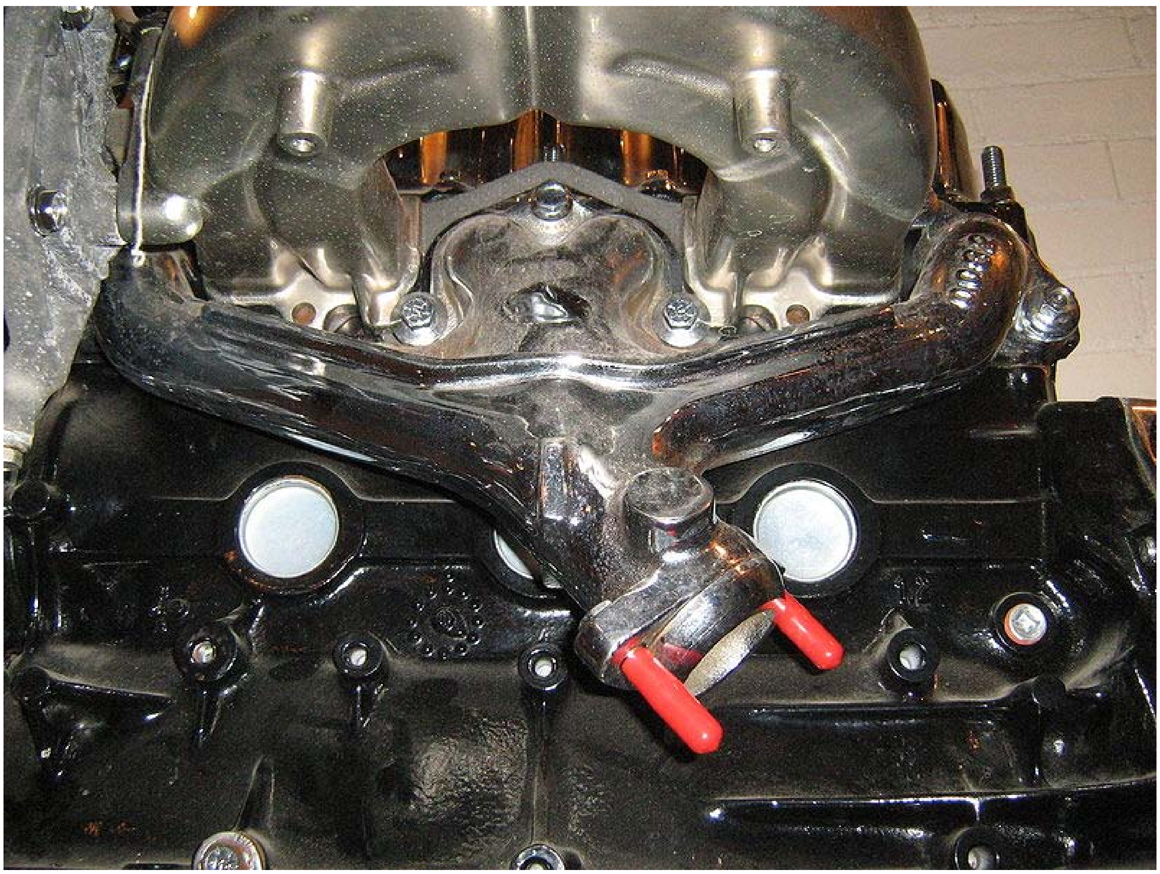
The choice of the type of amine will affect the required circulation rate of amine solution, the energy consumption for the regeneration and the ability to selectively remove either H_2S alone or CO_2 alone if desired.

The current emphasis on removing CO_2 from the flue gases emitted by fossil fuel power plants has led to much interest in using amines for that purpose.

In the specific case of the industrial synthesis of ammonia, for the steam reforming process of hydrocarbons to produce gaseous hydrogen, amine treating is one of the commonly used processes for removing excess carbon dioxide in the final purification of the gaseous hydrogen.

Chapter 2

Exhaust System



Exhaust manifold (chrome plated) on a car engine

Muffler and tail pipe on a car

An **exhaust system** is usually tubing used to guide reaction exhaust gases away from a controlled combustion inside an engine or stove. The entire system conveys burnt gases from the engine and includes one or more **exhaust pipes**. Depending on the overall system design, the exhaust gas may flow through one or more of:

- Cylinder head and exhaust manifold
- A turbocharger to increase engine power.
- A catalytic converter to reduce air pollution.
- A muffler (North America) / silencer (Europe), to reduce noise.

Design criteria

An exhaust pipe must be carefully designed to carry toxic and/or noxious gases away from the users of the machine. Indoor generators and furnaces can quickly fill an enclosed space with carbon monoxide or other poisonous exhaust gases if they are not properly vented to the outdoors. Also, the gases from most types of machine are very hot; the pipe must be heat-resistant, and it must not pass through or near anything which can burn or can be damaged by heat. A chimney serves as an exhaust pipe in a stationary structure. For the internal combustion engine it is important to have the Exhaust System "Tuned" (refer to tuned pipe) for optimal efficiency. Also this should meet the regulation norms maintained in each country.In Europeon countries, EURO 5, India BS-4 etc.,

Motorcycles

Ducati muffler

In most motorcycles all or most of the exhaust system is visible and may be chrome plated as a display feature. Aftermarket exhausts may be made from steel, aluminium, titanium, or carbon fiber.

Motorcycle exhausts come in many varieties depending on the type of engine and its intended use. A twin cylinder may flow its exhaust into separate exhaust sections, such as seen in the Kawasaki EX250 (also known as the Ninja 250 in the US, or the GPX 250). Or, they may flow into a single exhaust section known as a two-into-one (2-1). Larger engines that come with 4 cylinders, such as Japanese supersport or superbikes (such the Kawasaki ZX series, Honda's CBR series, Yamaha's YZF series, also known as R6 and R1, and Suzuki's GSX-R series) often come with a twin exhaust system. A "full system" may be bought as an aftermarket accessory, also called a 4-2-1 or 4-1, depending on its layout. In the past, these bikes would come standard with a single exhaust, as seen on the Kawasaki ZX-6R 2000 and 2001 models. However, EU noise and pollution regulations have generally stopped this practice, forcing companies to use other methods to increase performance of the motorcycle. This has often led to a decrease in fuel economy, because of increased weight of the exhaust system and manufacturers forcing more fuel into the engine to gain extra power.

Trucks

In many trucks / lorries all or most of the exhaust system is visible. Often in such trucks the silencer is surrounded by a perforated metal sheath to avoid people getting burnt touching the hot silencer. This sheath may be chrome plated as a display feature. Part of the pipe between the engine and the silencer is often flexible metal industrial ducting, as in the image in the section "Terminology"; this helps to avoid vibration from the engine being transferred into the exhaust system. Sometimes a large diesel exhaust pipe is vertical, to blow the hot noxious gas well away from people; in such cases the end of the exhaust pipe often has a hinged metal flap to stop debris and birds and rainwater from falling inside.

Two-stroke engines

In a two-stroke engine, such as that used on dirt bikes, a bulge in the exhaust pipe known as an expansion chamber uses the pressure of the exhaust to create a pump that squeezes more air and fuel into the cylinder during the intake stroke. This provides greater power and fuel efficiency.

Marine engines

With an onboard diesel engine below-decks on marine vessels:-

- Lagging the exhaust pipe stops it from overheating the engine room where people must work to service the engine.
- Feeding water into the exhaust pipe cools the exhaust gas and thus lessens the back-pressure at the engine's cylinders' exhaust ports and thus helps the cylinders to empty quicker.

Outboard motors

In outboard motors the exhaust system is usually a vertical passage through the engine structure and to reduce out-of-water noise blows out underwater, sometimes through the middle of the propeller.

Terminology

Manifold or header

Aftermarket exhaust manifold

In most production engines, the **manifold** is an assembly designed to collect the exhaust gas from two or more cylinders into one pipe. Manifolds are often made of cast iron in stock production cars, and may have material-saving design features such as to use the least metal, to occupy the least space necessary, or have the lowest production cost. These design restrictions often result in a design that is cost effective but that does not do the most efficient job of venting the gases from the engine. Inefficiencies generally occur due to the nature of the combustion engine and its cylinders. Since cylinders fire at different times, exhaust leaves them at different times, and pressure waves from gas emerging from one cylinder might not be completely vacated through the exhaust system when another comes. This creates a back pressure and restriction in the engine's exhaust system that can restrict the engine's true performance possibilities.

A **header** (sometimes called **extractor** in Australia) is a manifold specifically designed for performance. During design, engineers create a manifold without regard to weight or cost but instead for optimal flow of the exhaust gases. This design results in a header that is more efficient at **scavenging** the exhaust from the cylinders. Headers are generally circular steel tubing with bends and folds calculated to make the paths from each cylinder's exhaust port to the common outlet all equal length, and joined at narrow angles to encourage pressure waves to flow through the outlet, and not back towards other cylinders. In a set of **tuned headers** the pipe lengths are carefully calculated to enhance exhaust flow in a particular engine revolutions per minute range.

Headers are generally made by aftermarket automotive companies, but sometimes can be bought from the high-performance parts department at car dealerships. Generally, most car performance enthusiasts buy aftermarket headers made by companies solely focused on producing reliable, cost-effective well-designed headers specifically for their car. Headers can also be custom designed by a custom shop. Due to the advanced materials that some aftermarket headers are made of, this can be expensive. Luckily, an exhaust system can be custom built for any car, and generally is not specific to the car's motor or design except for needing to properly connect solidly to the engine. This is usually accomplished by correct sizing in the design stage, and selecting a proper gasket type and size for the engine.

Header-back

The **Header-back** (or **header back**) is the part of the exhaust system from the outlet of the header to the final vent to open air — everything from the header back. Header-back systems are generally produced as aftermarket performance systems for cars without turbochargers.

Turbo-back

The **Turbo-back** (or **turbo back**) is the part of the exhaust system from the outlet of a turbocharger to the final vent to open air. Turbo-back systems are generally produced as aftermarket performance systems for cars with turbochargers. Some turbo-back (and header-back) systems replace stock catalytic converters with others having less flow restriction.

With or without catalytic converter

Some systems (including in former time all systems) (sometimes nowadays called **catless** or **de-cat**) eliminate the catalytic converter. This is illegal in some places if the vehicle is driven on public roads.

Cat-back

Cat-back (also **cat back** and **catback**) refers to the portion of the exhaust system from the outlet of the catalytic converter to the final vent to open air. This generally includes the pipe from the converter to the muffler, the muffler, and the final length of pipe to open air.

Cat-back exhaust systems generally use larger diameter pipe than the stock system. Good systems will have mandrel-bent turns that allow the exhaust gas to exit with as little back pressure as possible. The mufflers included in these kits are often glasspacks, to reduce back pressure. If the system is engineered more for show than functionality, it may be tuned to enhance the lower sounds that are lacking from high-RPM low-displacement engines.

Tailpipe and exhaust

With trucks, sometimes the silencer is crossways under the front of the cab and its tailpipe blows sideways to the offside (right side if driving on the left, left side if driving on the right). The side of a passenger car on which the exhaust exits beneath the rear bumper usually indicates the market for which the vehicle was designed, i.e. Japanese (and some older British) vehicles have exhausts on the right so they are furthest from the curb in countries which drive on the left, while European vehicles have exhausts on the left.

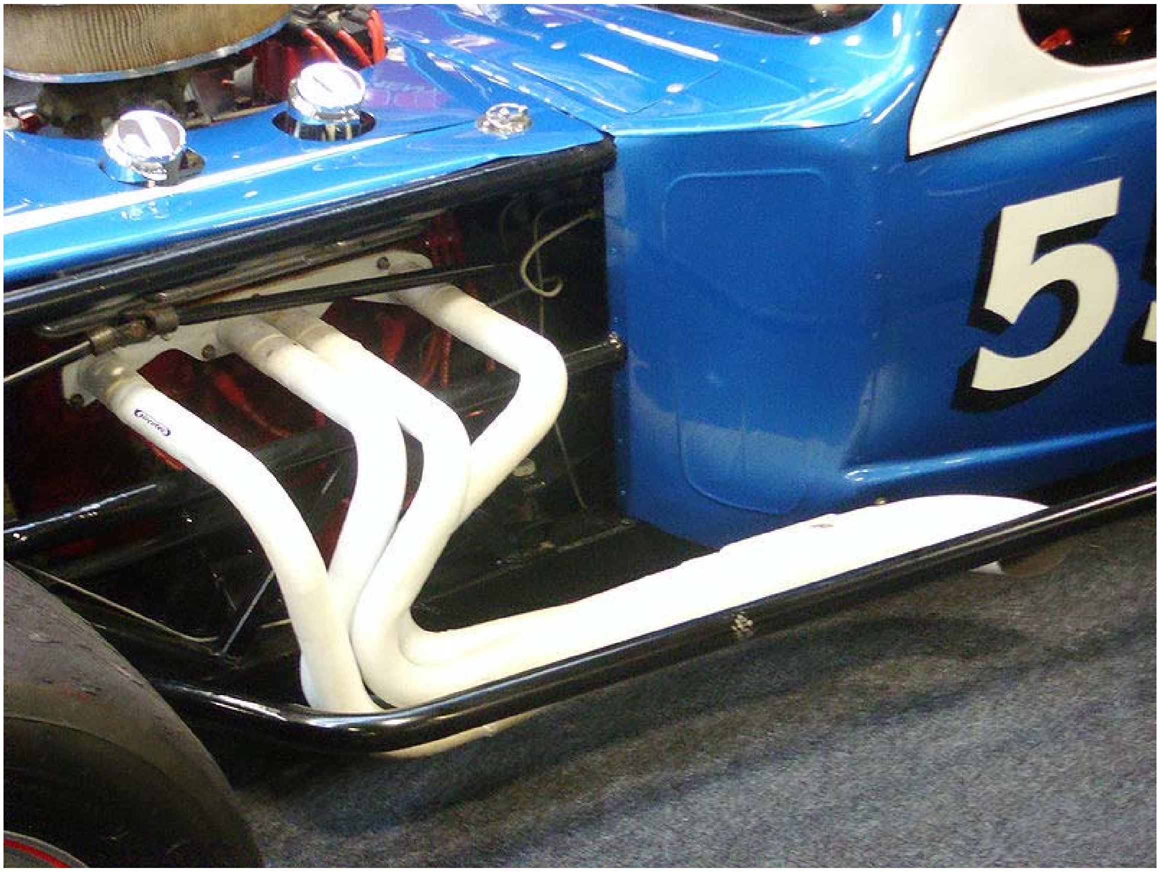
The end of the final length of exhaust pipe where it vents to open air, generally the only visible part of the exhaust system part on a vehicle, often ends with just a straight or angled cut, but may include a fancy tip. The tip is sometimes chromed. It is often of larger pipe than the rest of the exhaust system. This produces a final reduction in pressure, and sometimes used to enhance the appearance of the car.

In the late 1950s in the United States manufacturers had a fashion in car styling to form the rear bumper with a hole at each end through which the exhaust would pass. Two outlets symbolized V-8 power, and only the most expensive cars (Cadillac, Lincoln, Imperial, Packard) were fitted with this design. One justification for this was that luxury cars in those days had such a long rear overhang that the exhaust pipe scraped the ground when the car traversed ramps. The fashion disappeared after customers noted that the rear end of the car, being a low-pressure area, collected soot from the exhaust and its acidic content ate into the chrome-plated rear bumper.

When a bus, truck or tractor or excavator has a vertical exhaust pipe (called stacks or pipes behind the cab), sometimes the end is curved, or has a hinged cover flap which the gas flow blows out of the way, to try to prevent foreign objects (including droppings from a bird perching on the exhaust pipe when the vehicle is not being used) getting inside the exhaust pipe.

In some trucks, when the silencer is front-to-back under the chassis, the end of the tailpipe turns 90° and blows downwards. That protects anyone near a stationary truck from getting a direct blast of the exhaust gas, but often raises dust when the truck is driving on a dry dusty unmade surface such as on a building site.

Exhaust System Tuning



Aftermarket exhaust system including headers and a white plasma-sprayed ceramic coating

Many automotive companies offer aftermarket exhaust system upgrades as a subcategory of engine tuning. This is often fairly expensive as it usually includes replacing the entire exhaust manifold or other large components. These upgrades however can significantly improve engine performance and do this through means of two main principles:

- By reducing the exhaust back pressure, engine power is increased in four-stroke engines

- By reducing the amount of heat from the exhaust being lost into the underbonnet area. This reduces the underbonnet temperature and consequently lowers the intake manifold temperature, increasing power. This also has positive side effect of preventing heat-sensitive components from being damaged. Furthermore, keeping the heat in the exhaust gases speeds these up, therefore reducing back pressure as well.

Back pressure is most commonly reduced by replacing exhaust manifolds with headers, which have smoother bends and normally wider pipe diameters.

Exhaust Heat Management is the term that describes reducing the amount of exhaust heat loss. One dominant solution to aftermarket upgraders is the use of a ceramic coating applied via thermal spraying. This not only reduces heat loss and lessens back pressure, but provides an effective way to protect the exhaust system from wear and tear, thermal degradation and corrosion.

Large truck's diesel exhaust pipe

Waste collection vehicle's diesel exhaust pipe

Dual exhaust pipes attached to a car's muffler

Exhaust system of diesel telescopic-arm vehicle

Chapter 3

Gas Detector

Portable gas detector

A **gas detector** is a device which detects the presence of various gases within an area, usually as part of a safety system. This type of equipment is used to detect a gas leak and interface with a control system so a process can be automatically shut down. A gas detector can also sound an alarm to operators in the area where the leak is occurring, giving them the opportunity to leave the area. This type of device is important because there are many gases that can be harmful to organic life, such as humans or animals.

Gas detectors can be used to detect combustible, flammable and toxic gases, and oxygen depletion. This type of device is used widely in industry and can found in a variety of locations such as on oil rigs, to monitor manufacture processes and emerging technologies such as photovoltaic. They may also be used in firefighting.

Gas detectors are usually battery operated. They transmit warnings via a series of audible and visible signals such as alarms and flashing lights, when dangerous levels of gas vapors are detected. As detectors measure a gas concentration, the sensor responds to a calibration gas, which serves as the reference point or scale. As a sensor's detection exceeds a preset alarm level, the alarm or signal will be activated. As units, gas detectors are produced as portable or stationary devices. Originally, detectors were produced to detect a single gas, but modern units may detect several toxic or combustible gases, or even a combination of both types.

Types

Gas detectors come in two main types: portable devices and fixed gas detectors. The first is used to monitor the atmosphere around personnel and is worn on clothing or on a belt/harness. They can also be classified according to the operation mechanism (semiconductors, oxidation, catalytic, infrared, etc.).

Oxygen concentration

Oxygen deficiency gas monitors are used for employee and workforce safety. Cryogenics such as liquid nitrogen (LN2), helium (He), and argon (Ar) are inert and can displace oxygen (O_2) in a confined space if a leak is present. A rapid decrease of oxygen can provide a very dangerous environment for employees. With this in mind, an oxygen gas monitor is important to have when cryogenics are present. Laboratories, MRI rooms, pharmaceutical, semiconductor, and cryogenic suppliers are typical customers.

Oxygen fraction in a breathing gas is measured by electro-galvanic fuel cell sensors. They may be used stand-alone, for example to determine the proportion of oxygen in a nitrox mixture used in scuba diving, or as part of feeback loop which maintains a constant partial pressure of oxygen in a rebreather.

Hydrocarbons and VOCs

Detection of hydrocarbons can be based on the mixing properties of gaseous hydrocarbons – or other volatile organic compounds – and the sensing material incorporated in the sensor. The selectivity and sensitivity depends on the molecular structure and concentration; however it is difficult to design a sensor capable of detecting only one single type of molecule.

Combustible

- Catalytic bead sensor

- Explosimeter
- Infrared point sensor
- Infrared open path detector

Other

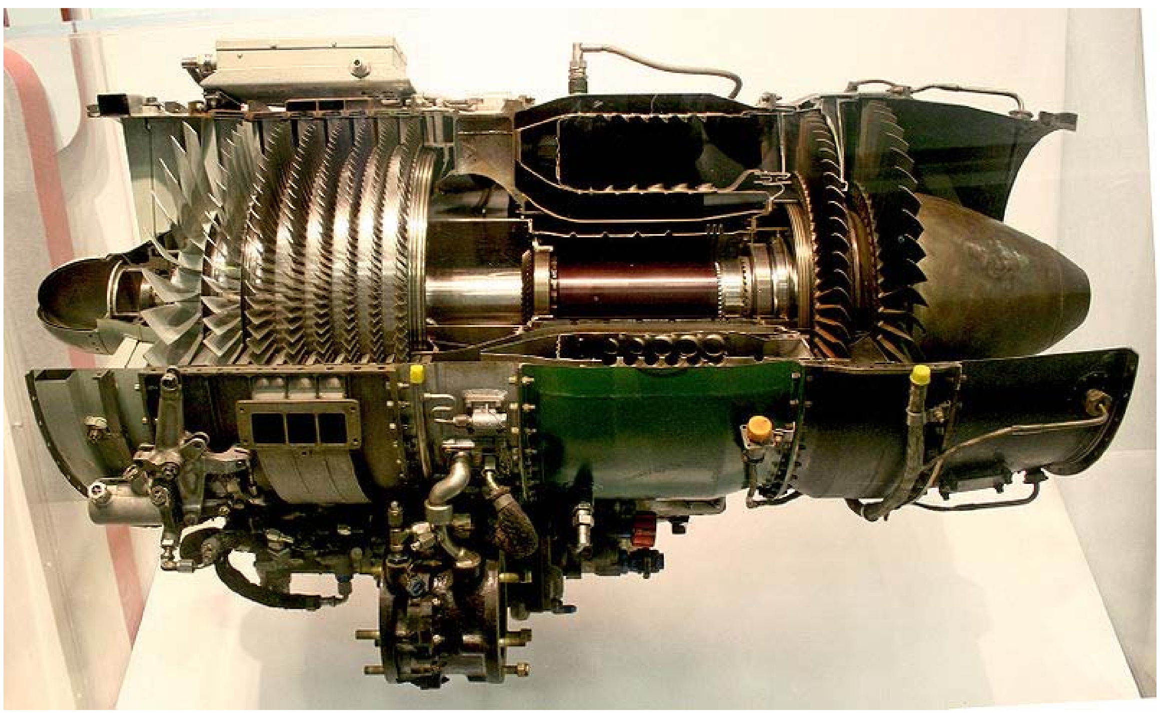
- Flame ionization detector
- Nondispersive infrared sensor
- Photoionization detector
- Zirconium oxide sensor cell
- Catalytic sensors
- Metal oxide semiconductor
- Gold film
- Detector tubes
- Sample collection and chemical analysis
- Piezoelectric microcantilever
- Holographic Sensor
- Thermal Conductivity Detector

Manufacturers

- 3M
- Honeywell Analytics
- Dräger
- Industrial Scientific Corporation
- Linde G-TECTA
- respoRAE

Chapter 4

Gas Turbine



A typical axial-flow gas turbine turbojet, the J85, sectioned for display. Flow is left to right, multistage compressor on left, combustion chambers center, two-stage turbine on right

A **gas turbine**, also called a **combustion turbine**, is a rotary engine that extracts energy from a flow of combustion gas. It has an upstream compressor coupled to a downstream turbine, and a combustion chamber in-between. Gas turbine may also refer to just the turbine component.

Energy is added to the gas stream in the combustor, where fuel is mixed with air and ignited. In the high pressure environment of the combustor, combustion of the fuel increases the temperature. The products of the combustion are forced into the turbine section. There, the high velocity and volume of the gas flow is directed through a nozzle over the turbine's blades, spinning the turbine which powers the compressor and, for some turbines, drives their mechanical output. The energy given up to the turbine comes from the reduction in the temperature and pressure of the exhaust gas.

Energy can be extracted in the form of shaft power, compressed air or thrust or any combination of these and used to power aircraft, trains, ships, generators, or even tanks.

History

- 150: Hero's Engine (*aeolipile*) — Apparently, Hero's steam engine was taken to be no more than a toy, and thus its full potential not realized for centuries.
- 1500: The "Chimney Jack" was drawn by Leonardo da Vinci: Hot air from a fire rises through a single-stage axial turbine rotor mounted in the exhaust duct of the fireplace and turning the roasting spit by gear/ chain connection.
- 1551: Taqi al-Din invented a rudimentary form of an impulse steam turbine, which he used to power a self-rotating spit.
- 1629: Jets of steam rotated an impulse turbine that then drove a working stamping mill by means of a bevel gear, developed by Giovanni Branca.
- 1678: Ferdinand Verbiest built a model carriage relying on a steam jet for power.
- 1791: A patent was given to John Barber, an Englishman, for the first true gas turbine. His invention had most of the elements present in the modern day gas turbines. The turbine was designed to power a horseless carriage.
- 1872: A gas turbine engine was designed by Dr. Franz Stolze, but the engine never ran under its own power.
- 1894: Sir Charles Parsons patented the idea of propelling a ship with a steam turbine, and built a demonstration vessel, the *Turbinia*, easily the fastest vessel afloat at the time. This principle of propulsion is still of some use.
- 1895: Three 4-ton 100 kW Parsons radial flow generators were installed in Cambridge Power Station, and used to power the first electric street lighting scheme in the city.
- 1899: Charles Gordon Curtis patented the first gas turbine engine in the USA ("Apparatus for generating mechanical power", Patent No. US635,919).
- 1900: Dr. Sanford Moss submitted a thesis on gas turbines. In 1903, Dr. Moss became an engineer for General Electric's Steam Turbine Department in Lynn, Massachusetts. While there, he applied some of his concepts in the developement of the turbosupercharger. His design used a small turbine wheel, driven by exhaust gases, to turn a supercharger.
- 1903: A Norwegian, Ægidius Elling, was able to build the first gas turbine that was able to produce more power than needed to run its own components, which was considered an achievement in a time when knowledge about aerodynamics was limited. Using rotary compressors and turbines it produced 11 hp (massive for those days). His work was later used by Sir Frank Whittle.

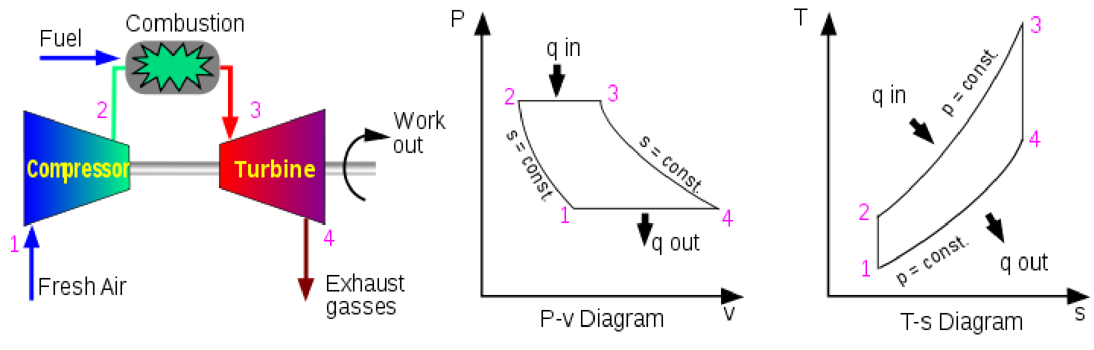
- 1906: The Armengaud-Lemale turbine engine in France with water-cooled combustion chamber.
- 1910: Holzwarth impulse turbine (pulse combustion) achieved 150 kilowatts.
- 1913: Nikola Tesla patents the Tesla turbine based on the boundary layer effect.
- 1918: One of the leading gas turbine manufacturers of today, General Electric, started their gas turbine division.
- 1920: The practical theory of gas flow through passages was developed into the more formal (and applicable to turbines) theory of gas flow past airfoils by Dr. A. A. Griffith.
- 1930: Sir Frank Whittle patented the design for a gas turbine for jet propulsion. His work on gas propulsion relied on the work from all those who had previously worked in the same field and he has himself stated that his invention would be hard to achieve without the works of Ægidius Elling. The first successful use of his engine was in April 1937.
- 1932: BBC Brown, Boveri & Cie of Switzerland starts selling axial compressor and turbine turbosets as part of the turbocharged steam generating Velox boiler. Following the gas turbine principle, the steam evaporation tubes are arranged within the gas turbine combustion chamber; the first Velox plant was erected in Mondeville, France.
- 1934: Raúl Pateras de Pescara patented the free-piston engine as a gas generator for gas turbines.
- 1936: Hans von Ohain and Max Hahn in Germany developed their own patented engine design at the same time that Sir Frank Whittle was developing his design in England.
- 1939: First 4 MW utility power generation gas turbine from BBC Brown, Boveri & Cie. for an emergency power station in Neuchâtel, Switzerland.

Theory of operation

Gasses passing through an ideal a gas turbine undergo three thermodynamic processes. These are isentropic compression, isobaric (constant pressure) combustion and isentropic expansion. Together these make up the Brayton cycle.

In a practical gas turbine, gasses are first accelerated in either a centrifugal or radial compressor. These gasses are then slowed using a diverging nozzle known as a diffuser, these process increase the pressure and temperature of the flow. In an ideal system this is isentropic. However, in practice energy is lost to heat, due to friction and turbulence. Gasses then pass from the diffuser to a combustion chamber, or similar device, where heat is added. In an ideal system this occurs at constant pressure (isobaric heat addition). As there is no change in pressure the specific volume of the gasses increases. In practical situations this process is usually accompanied by a slight loss in pressure, due to friction. Finally, this larger volume of gasses is expanded and accelerated by nozzle guide vanes before energy is extracted by a turbine. In an ideal system these are gasses expanded isentropicly and leave the turbine at their original pressure. In practice this process is not isentropic as energy is once again lost to friction and turbulence.

If the device has been designed to power to a shaft as with an industrial generator or a turboprop, the exit pressure will be as close to the entry pressure as possible. In practice it is necessary that some pressure remains at the outlet in order to fully expel the exhaust gasses. In the case of a jet engine only enough pressure and energy is extracted from the flow to drive the compressor and other components. The remaining high pressure gasses are accelerated to provide a jet that can, for example, be used to propel an aircraft.



Brayton cycle

As with all cyclic heat engines, higher combustion temperatures can allow for greater efficiencies. However, temperatures are limited by ability of the steel, nickel, ceramic, or other materials that make up the engine to withstand high temperatures and stresses. To combat this many turbines feature complex blade cooling systems.

As a general rule, the smaller the engine the higher the rotation rate of the shaft(s) needs to be to maintain tip speed. Blade tip speed determines the maximum pressure ratios that can be obtained by the turbine and the compressor. This in turn limits the maximum power and efficiency that can be obtained by the engine. In order for tip speed to remain constant, if the diameter of a rotor is reduced by half, the rotational speed must double. For example large Jet engines operate around 10,000 rpm, while micro turbines spin as fast as 500,000 rpm.

Mechanically, gas turbines can be considerably less complex than internal combustion piston engines. Simple turbines might have one moving part: the shaft/compressor/turbine/alternative-rotor assembly, not counting the fuel system. However, the required precision manufacturing for components and temperature resistant alloys necessary for high efficiency often make the construction of a simple turbine more complicated than piston engines.

More sophisticated turbines (such as those found in modern jet engines) may have multiple shafts (spools), hundreds of turbine blades, movable stator blades, and a vast system of complex piping, combustors and heat exchangers.

Thrust bearings and journal bearings are a critical part of design. Traditionally, they have been hydrodynamic oil bearings, or oil-cooled ball bearings. These bearings are being surpassed by foil bearings, which have been successfully used in micro turbines and auxiliary power units.

Types of gas turbines

Jet engines

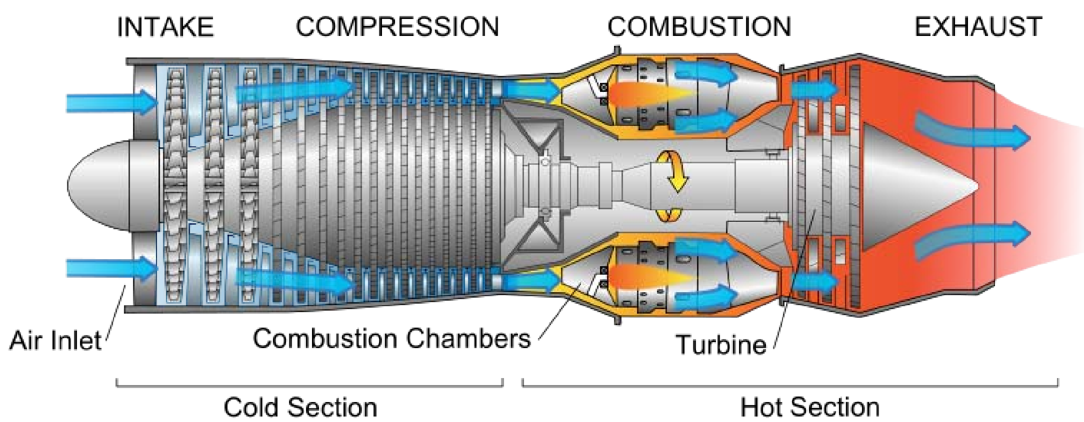


Diagram of a gas turbine jet engine

Airbreathing jet engines are gas turbines optimized to produce thrust from the exhaust gases, or from ducted fans connected to the gas turbines. Jet engines that produce thrust primarily from the direct impulse of exhaust gases are often called turbojets, whereas those that generate most of their thrust from the action of a ducted fan are often called turbofans or (rarely) fan-jets.

Gas turbines are also used in many liquid propellant rockets, the gas turbines are used to power a turbopump to permit the use of lightweight, low pressure tanks, which saves considerable dry mass.

Aeroderivative gas turbines

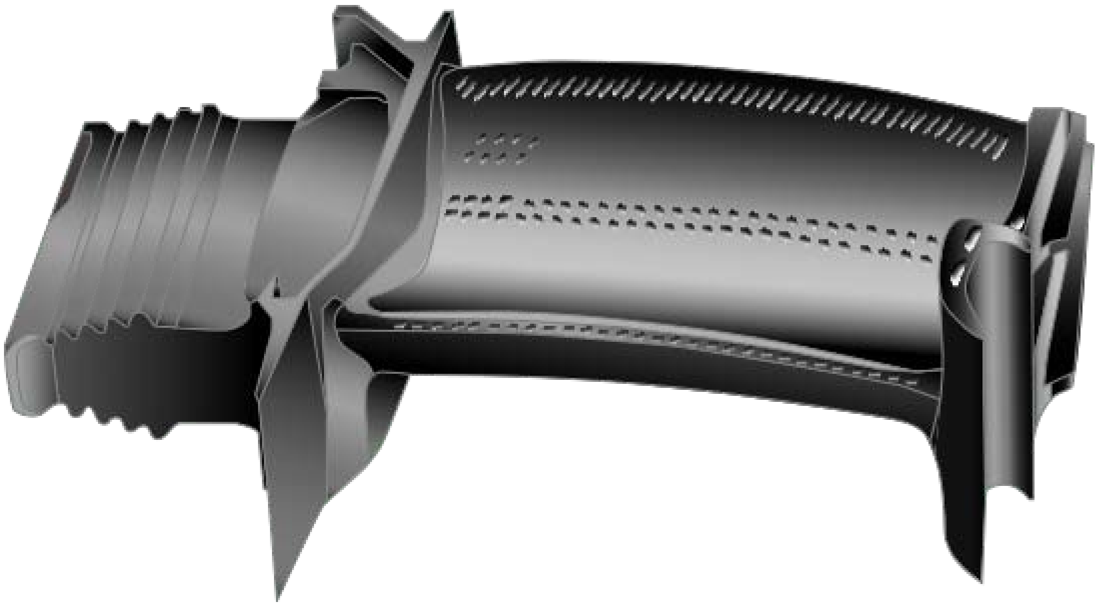


Diagram of a high-pressure turbine blade

Aeroderivatives are also used in electrical power generation due to their ability to startup, shut down, and handle load changes more quickly than industrial machines. They are also used in the marine industry to reduce weight. The General Electric LM2500, General Electric LM6000, Rolls-Royce RB211 and Rolls-Royce Avon are common models of this type of machine.

Amateur gas turbines

Increasing numbers of gas turbines are being used or even constructed by amateurs.

In its most straightforward form, these are commercial turbines acquired through military surplus or scrapyard sales, then operated for display as part of the hobby of engine collecting. In its most extreme form, amateurs have even rebuilt engines beyond professional repair and then used them to compete for the Land Speed Record.

The simplest form of self-constructed gas turbine employs an automotive turbocharger as the core component. A combustion chamber is fabricated and plumbed between the compressor and turbine sections.

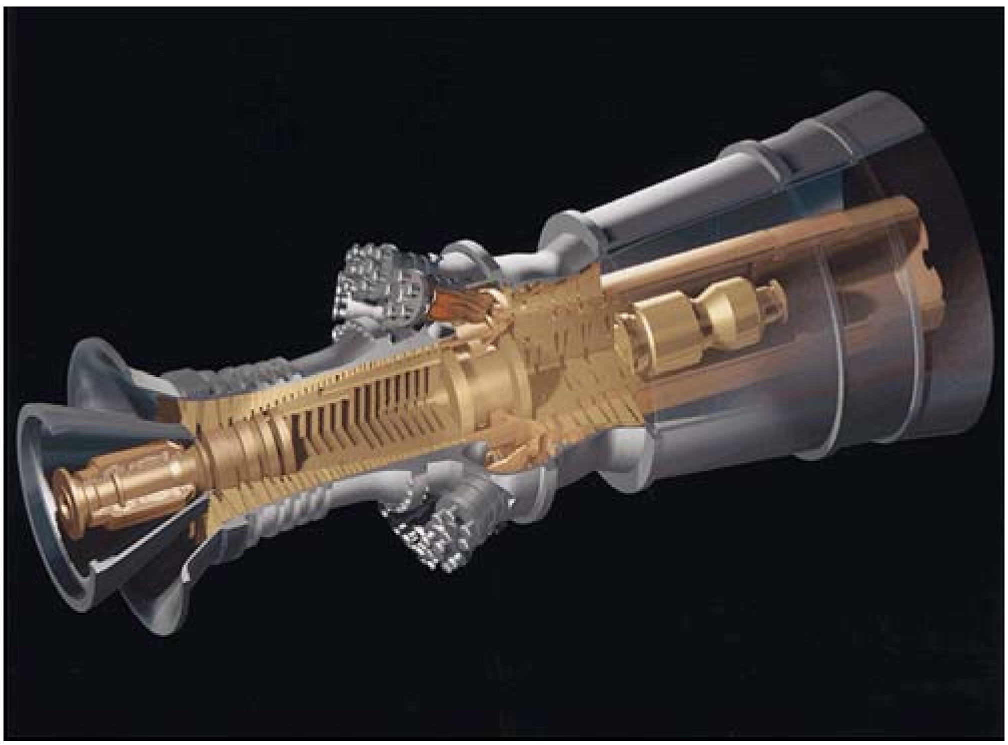
More sophisticated turbojets are also built, where their thrust and light weight are sufficient to power large model aircraft. The Schreckling design constructs the entire engine from raw materials, including the fabrication of a centrifugal compressor wheel from plywood, epoxy and wrapped carbon fibre strands.

Like many technology based hobbies, they tend to give rise to manufacturing businesses over time. Several small companies now manufacture small turbines and parts for the amateur. Most turbojet-powered model aircraft are now using these commercial and semi-commercial microturbines, rather than a Schreckling-like home-build.

Auxiliary power units

APUs are small gas turbines designed for auxiliary power of larger machines, such as those inside an aircraft. They supply compressed air for aircraft ventilation (with an appropriate compressor design), start-up power for larger jet engines, and electrical and hydraulic power.

Industrial gas turbines for power generation



GE H series power generation gas turbine: in combined cycle configuration, this 480-megawatt unit has a rated thermal efficiency of 60%.

Industrial gas turbines differ from aeroderivative in that the frames, bearings, and blading is of heavier construction. Industrial gas turbines range in size from truck-mounted mobile plants to enormous, complex systems. They can be particularly efficient—up to 60%—when waste heat from the gas turbine is recovered by a heat recovery steam generator to power a conventional steam turbine in a combined cycle configuration. They can also be run in a cogeneration configuration: the exhaust is used for space or water heating, or drives an absorption chiller for cooling or refrigeration. Such engines require a dedicated enclosure, both to protect the engine from the elements and the operators from the noise.

The construction process for gas turbines can take as little as several weeks to a few months, compared to years for base load power plants. Their other main advantage is the ability to be turned on and off within minutes, supplying power during peak demand. Since single cycle (gas turbine only) power plants are less efficient than combined cycle plants, they are usually used as peaking power plants, which operate anywhere from several hours per day to a few dozen hours per year, depending on the electricity demand and the generating capacity of the region. In areas with a shortage of base load and load following power plant capacity or low fuel costs, a gas turbine power plant may regularly operate during most hours of the day. A large single cycle gas turbine typically produces 100 to 400 megawatts of power and have 35–40% thermal efficiency.

Compressed air energy storage

One modern development seeks to improve efficiency in another way, by separating the compressor and the turbine with a compressed air store. In a conventional turbine, up to half the generated power is used driving the compressor. In a compressed air energy storage configuration, power, perhaps from a wind farm or bought on the open market at a time of low demand and low price, is used to drive the compressor, and the compressed air released to operate the turbine when required.

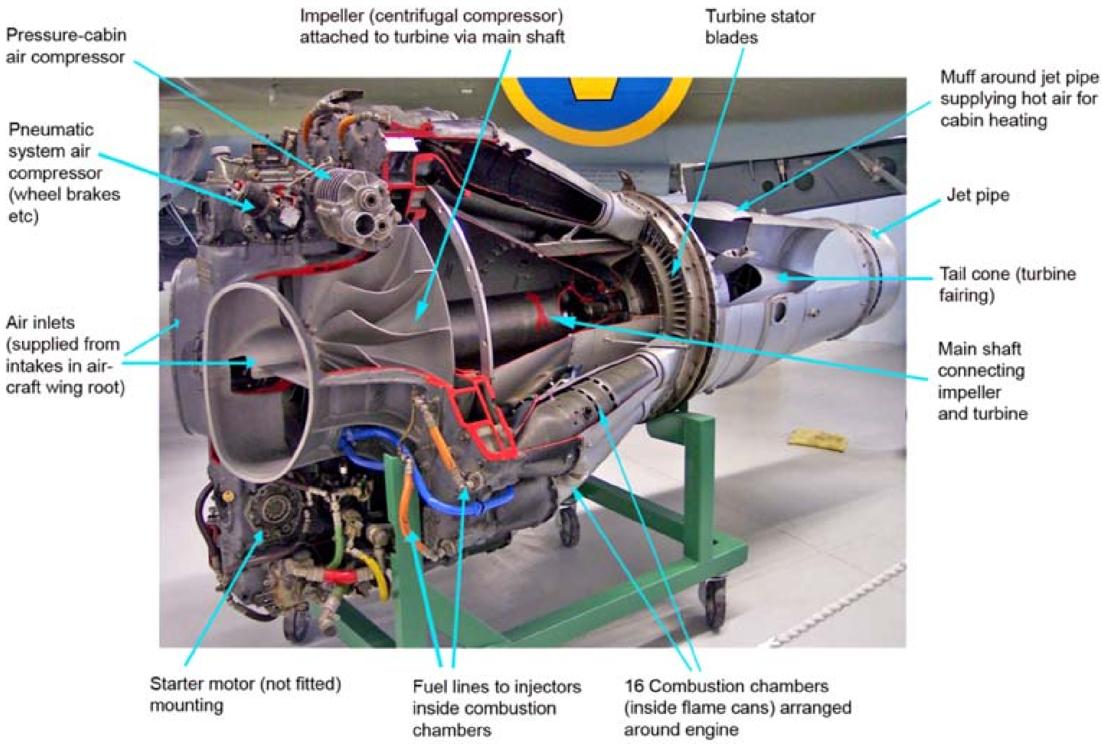
Turboshaft engines

Turboshaft engines are often used to drive compression trains (for example in gas pumping stations or natural gas liquefaction plants) and are used to power almost all modern helicopters. The first shaft bears the compressor and the high speed turbine (often referred to as "Gas Generator" or "Ng"), while the second shaft bears the low speed turbine (or "Power Turbine" or "Nf" - the 'f' stands for 'free wheeling turbine' on helicopters specifically due to the fact that the gas generator turbine spins separately from the power turbine). This arrangement is used to increase speed and power output flexibility.

Radial gas turbines

In 1963, Jan Mowill initiated the development at Kongsberg Våpenfabrikk in Norway. Various successors have made good progress in the refinement of this mechanism. Owing to a configuration that keeps heat away from certain bearings the durability of the machine is improved while the radial turbine is well matched in speed requirement.

Scale jet engines



Scale jet engines are scaled down versions of this early full scale engine

Also known as miniature gas turbines or micro-jets.

With this in mind the pioneer of modern Micro-Jets, Kurt Schreckling, produced one of the world's first Micro-Turbines, the FD3/67. This engine can produce up to 22 newtons of thrust, and can be built by most mechanically minded people with basic engineering tools, such as a metal lathe.

Microturbines

Also known as:

- Turbo alternators
- MicroTurbine
- Turbogenerator

Microturbines are becoming widespread for distributed power and combined heat and power applications. They are one of the most promising technologies for powering hybrid electric vehicles. They range from hand held units producing less than a kilowatt, to commercial sized systems that produce tens or hundreds of kilowatts. Basic principles of microturbine are based on micro combustion.

Part of their success is due to advances in electronics, which allows unattended operation and interfacing with the commercial power grid. Electronic power switching technology eliminates the need for the generator to be synchronized with the power grid. This allows the generator to be integrated with the turbine shaft, and to double as the starter motor.

Microturbine systems have many advantages over reciprocating engine generators, such as higher power-to-weight ratio, low emissions and few, or just one, moving part. Advantages are that microturbines may be designed with foil bearings and air-cooling operating without lubricating oil, coolants or other hazardous materials. Microturbines also have a further advantage of having the majority of the waste heat contained in the relatively high temperature exhaust making it simpler to capture, whereas the waste heat of reciprocating engines is split between its exhaust and cooling system. However, reciprocating engine generators are quicker to respond to changes in output power requirement and are usually slightly more efficient, although the efficiency of microturbines is increasing. Microturbines also lose more efficiency at low power levels than reciprocating engines. When used in extended range electric vehicles the static efficiency drawback is irrelevant, since the gas turbine can be run at or near maximum power, driving an alternator to produce electricity either for the wheel motors, or for the batteries, as appropriate to speed and battery state. The batteries act as a "buffer" (energy storage) in delivering the required amount of power to the wheel motors, rendering throttle response of the GT completely irrelevant. There is, moreover, no need for a significant or variable-speed gearbox; turning an alternator at comparatively high speeds, allows for a smaller and lighter alternator than would otherwise be the case. The superior power-to-weight ratio of the gas turbine and its fixed speed gearbox, allows for a much lighter prime mover than such hybrids as the Toyota Prius (which utilised a 1.8 litre petrol engine) or the Chevrolet Volt (which utilises a 1.4 litre petrol engine). This in turn allows a heavier weight of batteries to be carried. The weight can be made up of more batteries, which allows for a longer electric-only range. Alternatively, the vehicle can use heavier types of batteries such as lead acid batteries (which are cheaper to buy) or safer types of batteries such as Lithium-Iron-Phosphate. When gas turbines are used in extended-range electric vehicles, like those planned by Land-Rover/Range-Rover in conjunction with Bladon, or by Jaguar also in partnership with Bladon, the very poor throttling response (their high moment of rotational inertia) does not matter, because the gas turbine, which may be spinning at 100,000 rpm, is not directly, mechanically connected to the wheels. It was this poor throttling response that so bedevilled the 1960 Rover gas turbine-powered prototype motor car, which did not have the advantage of an intermediate electric drive train.

Gas turbines accept most commercial fuels, such as gasoline, natural gas, propane, diesel, and kerosene as well as renewable fuels such as E85, biodiesel and biogas. However, when running on kerosene or diesel, they will typically be unable to start without the assistance of a more volatile product, such as propane gas.

Microturbine designs usually consist of a single stage radial compressor, a single stage radial turbine and a recuperator. Recuperators are difficult to design and manufacture because they operate under high pressure and temperature differentials. Exhaust heat can be used for water heating, space heating, drying processes or absorption chillers, which create cold for air conditioning from heat energy instead of electric energy.

Typical microturbine efficiencies are 25 to 35%. When in a combined heat and power cogeneration system, efficiencies of greater than 80% are commonly achieved.

MIT started its millimeter size turbine engine project in the middle of the 1990s when Professor of Aeronautics and Astronautics Alan H. Epstein considered the possibility of creating a personal turbine which will be able to meet all the demands of a modern person's electrical needs, just like a large turbine can meet the electricity demands of a small city. Problems have occurred with heat dissipation and high-speed bearing in these new microturbines. Moreover, their expected efficiency is very low 5-6%. According to Professor Epstein current commercial Li-ion rechargeable batteries deliver about 120-150 Wh/kg. MIT's millimeter size turbine will deliver 500-700 Wh/kg in the near term, rising to 1200-1500 Wh/kg in the longer term.

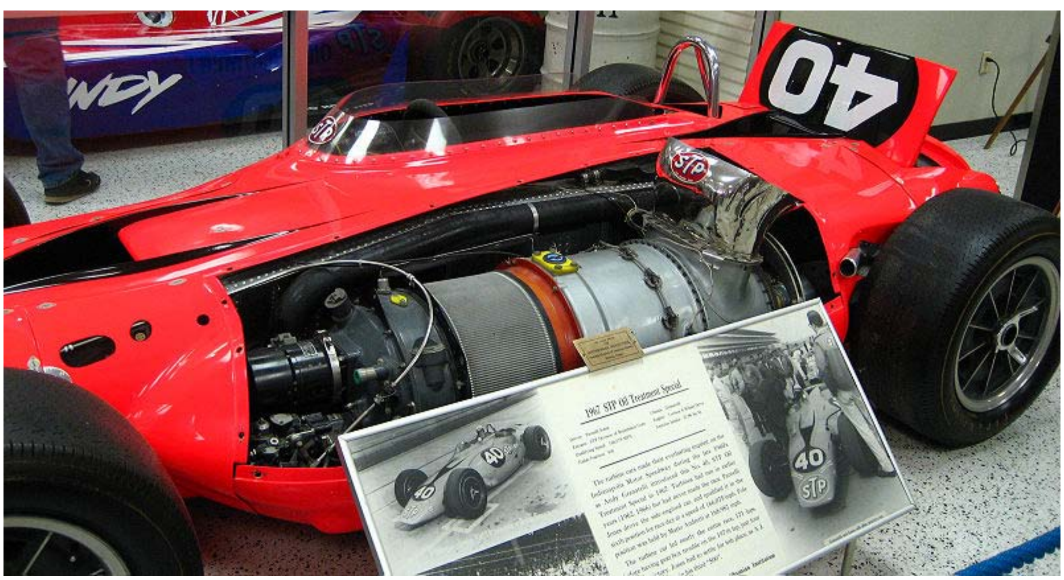
External combustion

Most gas turbines are internal combustion engines but it is also possible to manufacture an external combustion gas turbine which is, effectively, a turbine version of a hot air engine. Those systems are usually indicated as EFGT (Externally Fired Gas Turbine) or IFGT (Indirectly Fired Gas Turbine).

External combustion has been used for the purpose of using pulverized coal or finely ground biomass (such as sawdust) as a fuel. In the indirect system, a heat exchanger is used and only clean air with no combustion products travels through the power turbine. The thermal efficiency is lower in the indirect type of external combustion, however the turbine blades are not subjected to combustion products and much lower quality (and therefore cheaper) fuels are able to be used. Indirectly fired systems are now commercially available. BTOLA, an Australian based company is now marketing 250 kW - 2MW units.

Gas turbines in surface vehicles

The 1950 Rover JET1



The 1967 *STP Oil Treatment Special* on display at the Indianapolis Motor Speedway Hall of Fame Museum, with the Pratt & Whitney gas turbine shown.

A 1968 Howmet TX, the only turbine-powered race car to have won a race.

Gas turbines are often used on ships, locomotives, helicopters, tanks, and to a lesser extent, on cars, buses, and motorcycles.

A key advantage of jets and turboprops for aeroplane propulsion - their superior performance at high altitude compared to piston engines, particularly naturally aspirated ones - is irrelevant in automobile applications. Their power-to-weight advantage, though less critical than for aircraft, is still important.

Gas turbines offer a high-powered engine in a very small and light package. However, they are not as responsive and efficient as small piston engines over the wide range of RPMs and powers needed in vehicle applications. In series hybrid vehicles, as the driving electric motors are mechanically detached from the electricity generating engine, the responsiveness, poor performance at low speed and low efficiency at low output problems are much less important. The turbine can be run at optimum speed for its power output, and batteries and ultracapacitors can supply power as needed, with the engine cycled on and off to run it only at high efficiency. The emergence of the continuously variable transmission may also alleviate the responsiveness problem.

Turbines have historically been more expensive to produce than piston engines, though this is partly because piston engines have been mass-produced in huge quantities for decades, while small gas turbine engines are rarities; however, turbines are mass-produced in the closely related form of the turbocharger.

Passenger road vehicles (cars, bikes, and buses)

A number of experiments have been conducted with gas turbine powered automobiles, the largest by Chrysler. More recently, there has been some interest in the use of turbine engines for hybrid electric cars. For instance, a consortium led by micro gas turbine company Bladon Jets has secured investment from the Technology Strategy Board to develop an Ultra Lightweight Range Extender (ULRE) for next generation electric vehicles. The objective of the consortium, which includes luxury car maker Jaguar Land Rover and leading electrical machine company SR Drives, is to produce the world's first commercially viable - and environmentally friendly - gas turbine generator designed specifically for automotive applications.

The common turbocharger for gas or diesel engines is also a turbine derivative.

Concept cars

The first serious mention investigation of using a gas turbine in cars, was in 1946 when two engineers, Robert Kafka and Robert Engerstein of Carney Associates a New York engineering firm, came up with the concept where a unique compact turbine engine design would provide power for a rear wheel drive car. After an article appeared in *Popular Science*, there was no further work, beyond the paper stage.

In 1950, designer F.R. Bell and Chief Engineer Maurice Wilks from British car manufacturers Rover unveiled the first car powered with a gas turbine engine. The two-seater JET1 had the engine positioned behind the seats, air intake grilles on either side of the car, and exhaust outlets on the top of the tail. During tests, the car reached top speeds of 140 km/h (87 mph), at a turbine speed of 50,000 rpm. The car ran on petrol, paraffin or diesel oil, but fuel consumption problems proved insurmountable for a production car. It is on display at the London Science Museum.

American car manufacturer Chrysler demonstrated several prototype gas turbine-powered cars from the early 1950s through the early 1980s. Chrysler built fifty Chrysler Turbine Cars in 1963 and conducted the only consumer trial of gas turbine-powered cars. Their turbines employed unique rotating recuperator that significantly increased efficiency. Chrysler put many cars into the hands of consumers, making this effort a small-scale near-production run.

The original General Motors Firebird was a series of concept cars developed for the 1953, 1956 and 1959 Motorama auto shows, powered by gas turbines.

Toyota demonstrated several gas turbine powered concept cars such as the Century gas turbine hybrid in 1975, the Sports 800 Gas Turbine Hybrid in 1979 and the GTV in 1985. No production vehicles were made. The GT24 engine was exhibited in 1977 without a vehicle.

The fictional Batmobile is often said to be powered by a gas turbine or a jet engine. The 1960s television show vehicle was said to be powered by a turbine engine, with a parachute braking system. For the 1989 *Batman* film, the production department built a working turbine vehicle for the Batmobile prop. Its fuel capacity, however, was reportedly only enough for 15 seconds of use at a time.

In the early 1990s Volvo introduced the Volvo Environmental Concept Car(ECC) which was a gas turbine powered hybrid car.

In 1993 General Motors introduced the first commercial gas turbine powered hybrid vehicle—as a limited production run of the EV-1 series hybrid. A Williams International 40 kW turbine drove an alternator which powered the battery-electric powertrain. The turbine design included a recuperator. Later on in 2006 GM went into the EcoJet concept car project with Jay Leno.

At the 2010 Paris Motor Show Jaguar demonstrated its Jaguar C-X75 concept car. This electrically powered supercar has a top speed of 204 mph (328 km/h) and can go from 0 to 62 mph (0 to 100 km/h) in 3.4 seconds. It uses Lithium-ion batteries to power 4 electric motors which combine to produce some 780 bhp. It will do around 100 miles on a single charge of the batteries but in addition it uses a pair of Bladon Micro Gas Turbines to re-charge the batteries extending the range to some 560 miles.

Racing cars

Rover and the BRM Formula One team joined forces to produce the Rover-BRM, a gas turbine powered coupe, which entered the 1963 24 Hours of Le Mans, driven by Graham Hill and Richie Ginther. It averaged 107.8 mph (173 km/h) and had a top speed of 142 mph (229 km/h). American Ray Heppenstall joined Howmet Corporation and McKee Engineering together to develop their own gas turbine sports car in 1968, the Howmet TX, which ran several American and European events, including two wins, and also participated in the 1968 24 Hours of Le Mans. The cars used Continental gas turbines, which eventually set six FIA land speed records for turbine-powered cars.

For open wheel racing, 1967's revolutionary *STP Oil Treatment Special* four-wheel drive turbine-powered special fielded by racing and entrepreneurial legend Andy Granatelli and driven by Parnelli Jones nearly won the Indianapolis 500; the STP Pratt & Whitney powered turbine car was almost a lap ahead of the second place car when a gearbox bearing failed just three laps from the finish line. The next year the STP turbine car won the Indianapolis 500 pole position even though new rules restricted the air intake dramatically. In 1971 Lotus principal Colin Chapman introduced the Lotus 56B F1 car, powered by a Pratt & Whitney gas turbine. Chapman had a reputation of building radical championship-winning cars, but had to abandon the project because there were too many problems with turbo lag.

Buses

The arrival of the Capstone Microturbine has led to several hybrid bus designs, starting with HEV-1 by AVS of Chattanooga, Tennessee in 1999, and closely followed by Ebus and ISE Research in California, and DesignLine Corporation in New Zealand (and later the United States). AVS turbine hybrids were plagued with reliability and quality control problems, resulting in liquidation of AVS in 2003. The most successful design by Designline is now operated in 5 cities in 6 countries, with over 30 buses in operation worldwide, and order for several hundred being delivered to Baltimore , and NYC.

Brescia Italy is using serial hybrid buses powered by microturbines on routes through the historical sections of the city.

Motorcycles

The MTT Turbine SUPERBIKE appeared in 2000 (hence the designation of Y2K Superbike by MTT) and is the first production motorcycle powered by a turbine engine - specifically, a Rolls-Royce Allison model 250 turboshaft engine, producing about 283 kW (380 bhp). Speed-tested to 365 km/h or 227 mph (according to some stories, the testing team ran out of road during the test), it holds the Guinness World Records for most powerful production motorcycle and most expensive production motorcycle, with a price tag of US$185,000.

Trains

Several locomotive classes have been powered by gas turbines, the most recent incarnation being Bombardier's JetTrain.

Tanks

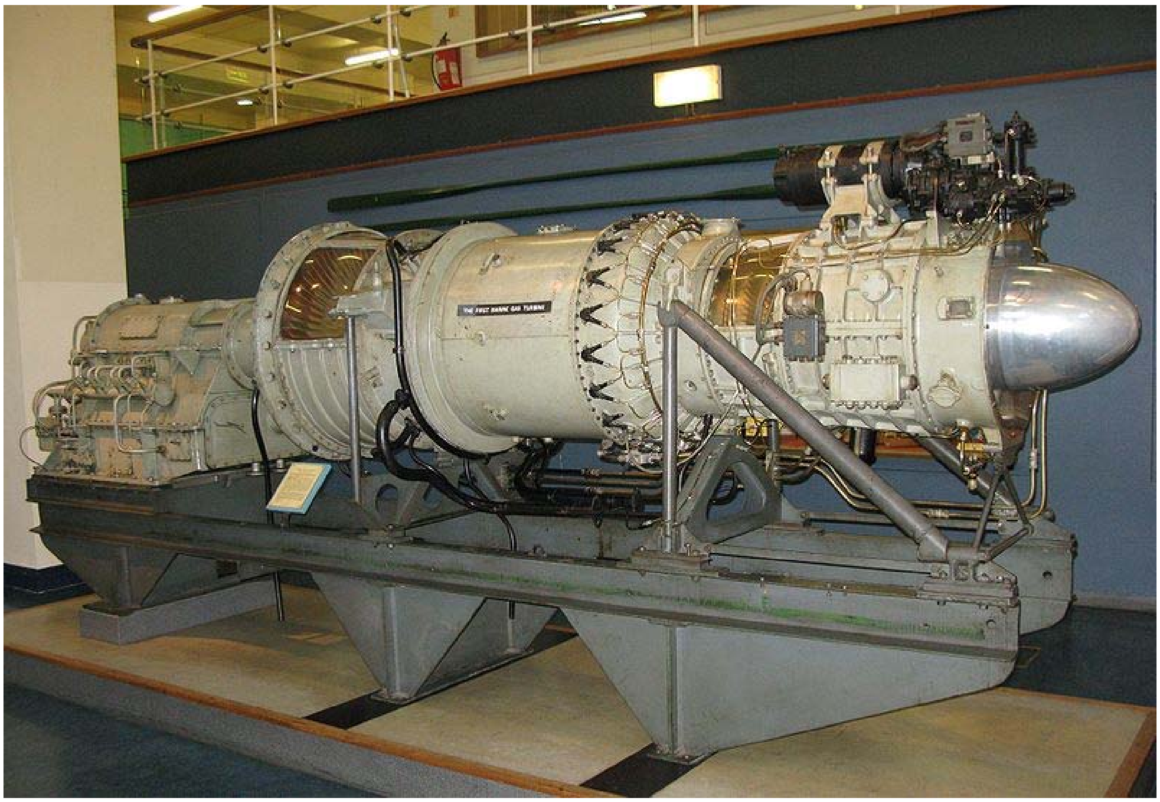
Marines from 1st Tank Battalion load a Honeywell AGT1500 multi-fuel turbine back into the tank at Camp Coyote, Kuwait, February 2003.

The German Army's development division, the Heereswaffenamt (Army Ordnance Board), studied a number of gas turbine engines for use in tanks starting in mid-1944. The first gas turbine engines used for armoured fighting vehicle GT 101 was installed in Panther tank. The second use of a gas turbine in an armoured fighting vehicle was in 1954 when a unit, PU2979, specifically developed for tanks by C. A. Parsons & Co., was installed and trialled in a British Conqueror tank. The Stridsvagn 103 was developed in the 1950s and was the first mass produced main battle tank to use a turbine engine. Since then, gas turbine engines have been used as APUs in some tanks and as main powerplants in Soviet/Russian T-80s and U.S. M1 Abrams tanks, among others. They are lighter and smaller than diesels at the same sustained power output but the models installed to date are less fuel efficient than the equivalent diesel, especially at idle, requiring more fuel to achieve the same combat range. Successive models of M1 have addressed this problem with battery packs or secondary generators to power the tank's systems while stationary, saving fuel by reducing the need to idle the main turbine. T-80s can mount three large external fuel drums to extend their range. Russia has stopped production of the T-80 in favour of the diesel-powered T-90 (based on the T-72), while Ukraine has developed the diesel-powered T-80UD and T-84 with nearly the power of the gas-turbine tank.

A turbine is theoretically more reliable and easier to maintain than a piston engine, since it has a simpler construction with fewer moving parts but in practice turbine parts experience a higher wear rate due to their higher working speeds. The turbine blades are highly sensitive to dust and fine sand, so that in desert operations air filters have to be fitted and changed several times daily. An improperly fitted filter, or a bullet or shell fragment that punctures the filter can damage the engine. Piston engines also need well-maintained filters, but they are more resilient if the filter does fail.

Like most modern diesel engines used in tanks, gas turbines are usually multi-fuel engines.

Naval



The Gas turbine from MGB 2009

Gas turbines are used in many naval vessels, where they are valued for their high power-to-weight ratio and their ships' resulting acceleration and ability to get underway quickly.

The first gas-turbine-powered naval vessel was the Royal Navy's Motor Gun Boat *MGB 2009* (formerly *MGB 509*) converted in 1947. Metropolitan-Vickers developed the "Beryl" engine equipping an existing F2/3 jet engine with a power turbine. As the test was successful, the Fast Patrol Boats *Bold Pioneer* and *Bold Pathfinder* built in 1953 were the first ships created specifically for gas turbine propulsion.

The first large scale, gas-turbine powered ships, were the Royal Navy's Type 81 (Tribal class) frigates, the first of which (HMS *Ashanti*) was commissioned in 1961.

The Germany Navy launched the first Köln class frigate in 1961 with 2 GTs from BBC in the worlds first combined diesel and gas propulsion system.

The Swedish Navy produced 6 Spica class torpedoboats between 1966 and 1967 powered by 3 Bristol Siddeley Proteus 1282, each delivering 4300 hp. They were later joined by 12 upgraded Norrköping class ships, still with the same engines. With their aft torpedo tubes replaced by antishipping missiles they served as missile boats until the last was retired in 2005.

The Finnish Navy issued two Turunmaa class corvettes, Turunmaa and Karjala, in 1968. They were equipped with one 22,000 shp Rolls-Royce Olympus TMB3 gas turbine and three Wärtsilä marine diesels for slower speeds. They were the fastest vessels in the Finnish Navy; they regularly achieved 35 knot speeds, with 37.3 knots on sea trials. The Turunmaas were paid off in 2002. *Karjala* is today a museum ship in Turku, and *Turunmaa* serves as a floating machine shop and training ship for Satakunta Polytechnical College.

The next series of major naval vessels were the four Canadian Iroquois class helicopter carrying destroyers first commissioned in 1972. They used 2 ft-4 main propulsion engines, 2 ft-12 cruise engines and 3 Solar Saturn 750 kW generators.

The first U.S. gas-turbine powered ships were the U.S. Coast Guard's *Hamilton*-class High Endurance Cutters the first of which (USCGC *Hamilton*) commissioned in 1967. Since then, they have powered the U.S. Navy's *Perry*-class frigates, *Spruance*-class and *Arleigh Burke*-class destroyers, and *Ticonderoga*-class guided missile cruisers. USS *Makin Island*, a modified *Wasp*-class amphibious assault ship, is to be the Navy's first amphibious assault ship powered by gas turbines. The marine gas turbine operates in a more corrosive atmosphere due to presence of sea salt in air and fuel and use of cheaper fuels.

Maritime

There have been a number of experiments in which gas turbines were used to power seagoing commercial vessels. The earliest of these experiments may have been the oil tanker "Auris" (Anglo Saxon Petroleum) - circa 1949.

The United States Maritime Commission were looking for options to update WWII Liberty ships and heavy duty gas turbines were one of those selected. In 1956 the "John Sergeant" was lengthened and installed with a General Electric 6600 SHP HD gas turbine, reduction gearing and a variable pitch propeller. It operated for 9700 hours using residual fuel for 7000 hours. The success of this trial opened the way for more development by GE on the use of HD gas turbines for marine use with heavy fuels. The "John Sergeant" was scrapped in 1972 at Portsmouth PA.

Boeing launched its first passenger-carrying waterjet-propelled hydrofoil Boeing 929, in April 1974. Those ships were powered by twin Allison gas turbines of the KF-501 series.

Between 1970 and 1982, Seatrain Container Lines operated a scheduled container service across the North Atlantic with four 26,000 tonne dwt. container ships. Those ships were powered by twin Pratt & Whitney gas turbines of the FT 4 series. The four ships in the class were named "Euroliner", "Eurofreighter", "Asialiner" and "Asiafreighter". They operated a transatlantic container service between ports on the eastern seaboard of the United States and ports in north west Europe. Following the dramatic OPEC(Organization of the Petroleum Exporting Countries) price increases of the mid-nineteen seventies, operations were constrained by rising fuel costs. Some modification of the engine systems on those ships was undertaken to permit the burning of a lower grade of fuel (i.e., marine diesel). The modifications were partially successful. It was proved that particular fuel could be used in a marine gas turbine but, savings made were less than anticipated due to increased maintenance requirements. After 1982 the ships were sold, then re-engined with more economical diesel engines. Because the new engines were much larger, there was a consequential loss of some cargo space.

The first passenger ferry to use a gas turbine was the GTS *Finnjet*, built in 1977 and powered with two Pratt & Whitney FT 4C-1 DLF turbines, generating 55 MW and propelling the ship to a speed of 31 knots. However, the Finnjet also illustrated the shortcomings of gas turbine propulsion in commercial craft, as high fuel prices made operating her unprofitable. After just four years of service additional diesel engines were installed on the ship to allow less costly operations during off-season. Another example of commercial usage of gas turbines in a passenger ship are Stena Line's HSS class fastcraft ferries. HSS 1500-class *Stena Explorer*, *Stena Voyager* and *Stena Discovery* vessels use COGAG setups of twin GE LM2500 plus GE LM1600 power for a total of 68 MW. The slightly smaller HSS 900-class *Stena Charisma*, uses twin ABB–STAL GT35 turbines rated at 34,000 kW gross. The *Stena Discovery* was withdrawn from service in 2007, another victim of too high fuel costs.

In July 2000, the Millennium became the first cruise ship to be propelled by gas turbines, in a Combined Gas and Steam Turbine configuration. The RMS Queen Mary 2 uses a Combined Diesel and Gas Turbine configuration.

Advances in technology

Gas turbine technology has steadily advanced since its inception and continues to evolve; research is active in producing ever smaller gas turbines. Computer design, specifically CFD and finite element analysis along with material advances, has allowed higher compression ratios and temperatures, more efficient combustion and better cooling of engine parts. On the emissions side, the challenge in technology is increasing turbine inlet temperature while reducing peak flame temperature to achieve lower NOx emissions to cope with the latest regulations. Additionally, compliant foil bearings were commercially introduced to gas turbines in the 1990s. They can withstand over a hundred thousand start/stop cycles and eliminated the need for an oil system.

On another front, microelectronics and power switching technology have enabled commercially viable micro turbines for distributed and vehicle power.

Advantages and disadvantages of gas turbine engines

Reference for this section:

Advantages of gas turbine engines

- Very high power-to-weight ratio, compared to reciprocating engines;
- Smaller than most reciprocating engines of the same power rating.
- Moves in one direction only, with far less vibration than a reciprocating engine.
- Fewer moving parts than reciprocating engines.
- Low operating pressures.
- High operation speeds.
- Low lubricating oil cost and consumption.
- Can run on a wide variety of fuels.

Disadvantages of gas turbine engines

- Cost
- Less efficient than reciprocating engines at idle
- Longer startup than reciprocating engines
- Less responsive to changes in power demand compared to reciprocating engines

Chapter 5

Piping and Pneumatics

Piping

Large-scale piping system in an HVAC mechanical room

Within industry, **piping** is a system of pipes used to convey fluids (liquids and gases) from one location to another. The engineering discipline of piping design studies the efficient transport of fluid.

Industrial process piping (and accompanying in-line components) can be manufactured from wood, fiberglass, glass, steel, aluminum, plastic, copper, and concrete. The in-line components, known as fittings, valves, and other devices, typically sense and control the pressure, flow rate and temperature of the transmitted fluid, and usually are included in the field of Piping Design (or Piping Engineering). Piping systems are documented in piping and instrumentation diagrams (P&IDs). If necessary, pipes can be cleaned by the tube cleaning process.

"Piping" sometimes refers to Piping Design or the performance of the actual layout of the physical piping within a process plant or commercial building. In earlier days, this was sometimes called Drafting, Technical drawing, Engineering Drawing, and Design but is commonly performed by Designers who have learned to used automated computer aided drawing/computer aided design (CAD) software.

Plumbing is a piping system that most people are familiar with, as it constitutes the form of fluid transportation that is used to provide potable water and fuels to their homes and business. Plumbing pipes also remove waste in the form of sewage, and allow venting of sewage gases to the outdoors. Fire sprinkler systems also use piping, and may transport potable or nonpotable water, or other fire-suppression fluids.

Piping also has many other industrial applications, which are crucial for moving raw and semi-processed fluids for refining into more useful products. Some of the more exotic materials of construction are Inconel, Titanium, chrome-moly and various other steel alloys.

Piping Branches

Generally, Industrial piping has three major branches as follows:

- Piping Material field
- Piping Design field
- Stress analysis field

Pipe stress analysis

Process piping and power piping are typically checked by pipe stress engineers to verify that the routing, nozzle loads, hangers, and supports are properly placed and selected such that allowable pipe stress is not exceeded under different situation such as sustain, operating, hydro test etc as per the ASME or any other legislative code and local government standards. It is necessary to evaluate the mechanical behavior of the piping under regular loads (internal pressure and thermal stresses) as well under occasional and intermittent loading cases such as earthquake, high wind or special vibration, water hammer. This evaluation is usually performed with the assistance of a specialized (finite element) pipe stress analysis computer program such as Caesar II, ROHR2, CAEPIPE and AUTOPIPE.

Wooden piping history

Early wooden pipes were constructed out of logs that had a large hole bored lengthwise through the center. Later wooden pipes were constructed with staves and hoops similar to wooden barrel construction. Stave pipes have the advantage that they are easily transport as a compact pile of parts on a wagon and then assembled as a hollow structure at the job site. Wooden pipes were especially popular in mountain regions where transport of heavy iron or concrete pipes would have been difficult.

Wooden pipes were easier to maintain than metal, because the wood did not expand or contract with temperature changes as much as metal and so consequently expansion joints and bends were not required. The thickness of wood afforded some insulating properties to the pipes which helped prevent freezing as compared to metal pipes. Wood used for water pipes also does not rot very easily. Electrolysis that bugbear many iron pipe systems, doesn't affect wood pipes at all, since wood is a much better electrical insulator.

In the Western United States where redwood was used for pipe construction, it was found that redwood had "peculiar properties" that protected it from weathering, acids, insects, and fungus growths. Redwood pipes stayed smooth and clean indefinitely while iron pipe by comparison would rapidly begin to scale and corrode and could eventually plug itself up with the corrosion.

Pneumatics

Preserved Porter Locomotive Company No. 3290 of 1923.

Pneumatics is a branch of technology, which deals with the study and application of use of pressurized gas to affect mechanical motion.

Pneumatic systems are extensively used in industry, where factories are commonly plumbed with compressed air or other compressed inert gases. This is because a centrally-located and electrically-powered compressor that powers cylinders and other pneumatic devices through solenoid valves is often able to provide motive power in a cheaper, safer, more flexible, and more reliable way than a large number of electric motors and actuators.

Pneumatics also has applications in dentistry, construction, mining, and other areas.

Examples of pneumatic systems and components

- Air brakes on buses and trucks
- Air brakes, on trains
- Air compressors
- Air engines for pneumatically powered vehicles
- Barostat systems used in Neurogastroenterology and for researching electricity
- Cable jetting, a way to install cables in ducts
- Compressed-air engine and compressed-air vehicles

- Gas-operated reloading
- Holman Projector, a pneumatic anti-aircraft weapon
- Lego pneumatics can be used to build pneumatic models

- Pipe organs:
    - Electro-pneumatic action
    - Tubular-pneumatic action

- Pneumatic actuator
- Pneumatic air guns
- Pneumatic cylinder
- Pneumatic Launchers, a type of spud gun
- Pneumatic mail systems
- Pneumatic motor
- Pneumatic tire

- Pneumatic tools:
    - Jackhammer used by road workers
    - Pneumatic nailgun

- Pressure regulator
- Pressure sensor
- Pressure switch

- Vacuum pump

Gases used in pneumatic systems

Pneumatic systems in fixed installations such as factories use compressed air because a sustainable supply can be made by compressing atmospheric air. The air usually has moisture removed and a small quantity of oil added at the compressor, to avoid corrosion of mechanical components and to lubricate them.

Factory-plumbed, pneumatic-power users need not worry about poisonous leakages as the gas is commonly just air. Smaller or stand-alone systems can use other compressed gases which are an asphyxiation hazard, such as nitrogen - often referred to as OFN (oxygen-free nitrogen), when supplied in cylinders.

Any compressed gas other than air is an asphyxiation hazard - including nitrogen, which makes up 77% of air. Compressed oxygen (approx. 23% of air) would not asphyxiate, but it would be an extreme fire hazard, so is never used in pneumatically powered devices.

Portable pneumatic tools and small vehicles such as Robot Wars machines and other hobbyist applications are often powered by compressed carbon dioxide because containers designed to hold it such as soda stream canisters and fire extinguishers are readily available, and the phase change between liquid and gas makes it possible to obtain a larger volume of compressed gas from a lighter container than compressed air would allow. Carbon dioxide is an asphyxiant and can also be a freezing hazard when vented inappropriately.

Comparison to hydraulics

Both pneumatics and hydraulics are applications of fluid power. Pneumatics uses an easily compressible gas such as air or a suitable pure gas, while hydraulics uses relatively incompressible liquid media such as oil. Most industrial pneumatic applications use pressures of about 80 to 100 pounds per square inch (550 to 690 kPa). Hydraulics applications commonly use from 1,000 to 5,000 psi (6.9 to 34 MPa), but specialized applications may exceed 10,000 psi (69 MPa).

Advantages of pneumatics

- **Simplicity of Design And Control**
  - Machines are easily designed using standard cylinders & other components. Control is as easy as it is simple ON - OFF type control.
- **Reliability**
  - Pneumatic systems tend to have long operating lives and require very little maintenance.
  - Because gas is compressible, the equipment is less likely to be damaged by shock. The gas in pneumatics absorbs excessive force, whereas the fluid of hydraulics directly transfers force.
- **Storage**
  - Compressed Gas can be stored, allowing the use of machines when electrical power is lost.
- **Safety**
  - Very low chance of fire (compared to hydraulic oil).
  - Machines can be designed to be overload safe.

Advantages of hydraulics

- Liquid (as a gas is also a 'fluid') does not absorb any of the supplied energy.
- Capable of moving much higher loads and providing much higher forces due to the incompressibility.
- The hydraulic working fluid is basically incompressible, leading to a minimum of spring action. When hydraulic fluid flow is stopped, the slightest motion of the load releases the pressure on the load; there is no need to "bleed off" pressurized air to release the pressure on the load.

Pneumatic logic

Pneumatic logic systems (sometimes called **air logic control**) are often used to control industrial processes, consisting of primary logic units such as:

- And Units
- Or Units
- 'Relay or Booster' Units
- Latching Units
- 'Timer' Units
- Sorteberg relay
- fluidics amplifiers with no moving parts other than the air itself

Pneumatic logic is a reliable and functional control method for industrial processes. In recent years, these systems have largely been replaced by electrical control systems, due to the smaller size and lower cost of electrical components. Pneumatic devices are still used in processes where compressed air is the only energy source available or upgrade cost, safety, and other considerations outweigh the advantage of modern digital control.

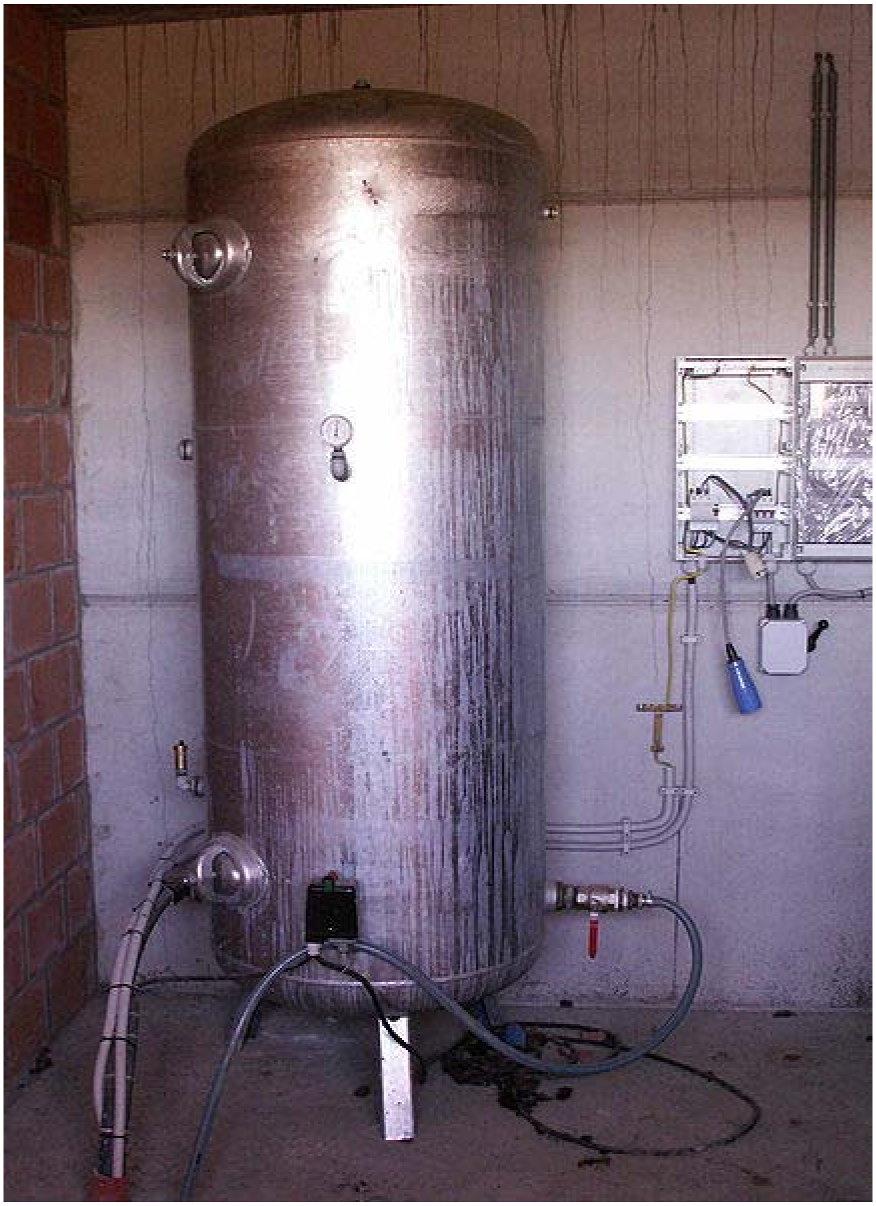
Chapter 6

Pressure Vessel

A **pressure vessel** is a closed container designed to hold gases or liquids at a pressure substantially different from the ambient pressure.

The pressure differential is dangerous and many fatal accidents have occurred in the history of their development and operation. Consequently, their design, manufacture, and operation are regulated by engineering authorities backed up by laws. For these reasons, the definition of a pressure vessel varies from country to country, but involves parameters such as maximum safe operating pressure and temperature.

Uses



A pressure tank connected to a water well and domestic hot water system

A few pressure tanks, here used to hold propane

Pressure vessels are used in a variety of applications in both industry and the private sector. They appear in these sectors as industrial compressed air receivers and domestic hot water storage tanks. Other examples of pressure vessels are diving cylinder, recompression chamber, distillation towers, autoclaves, and many other vessels in mining or oil refineries and petrochemical plants, nuclear reactor vessel, habitat of a space ship, habitat of a submarine, pneumatic reservoir, hydraulic reservoir under pressure, rail vehicle airbrake reservoir, road vehicle airbrake reservoir and storage vessels for liquified gases such as ammonia, chlorine, propane, butane, and LPG.

Shape of a pressure vessel

Pressure vessels may theoretically be almost any shape, but shapes made of sections of spheres, cylinders, and cones are usually employed. A common design is a cylinder with end caps called heads. Head shapes are frequently either hemispherical or dished (torispherical). More complicated shapes have historically been much harder to analyze for safe operation and are usually far tougher to construct.

Theoretically, a sphere would be the best shape of a pressure vessel. Unhappily, a spherical shape is tough to manufacture, therefore more expensive, so most pressure vessels are cylindrical with 2:1 semi-elliptical heads or end caps on each end. Smaller pressure vessels are assembled from a pipe and two covers. A disadvantage of these vessels is that greater breadths are more expensive, so that for example the most economic shape of a 1,000 litres (35 cu ft), 250 bars (3,600 psi) pressure vessel might be a breadth of 914.4 millimetres (36 in) and a width of 1,701.8 millimetres (67 in) including the 2:1 semi-elliptical domed end caps.

Construction materials

Steel Pressure Vessel

Theoretically almost any material with good tensile properties that is chemically stable in the chosen application could be employed. However, pressure vessel design codes and application standards (ASME BPVC Section II, EN 13445-2 etc.) contain long lists of approved materials with associated limitations in temperature range.

Many pressure vessels are made of steel. To manufacture a cylindrical or spherical pressure vessel, rolled and possibly forged parts would have to be welded together. Some mechanical properties of steel, achieved by rolling or forging, could be adversely affected by welding, unless special precautions are taken. In addition to adequate mechanical strength, current standards dictate the use of steel with a high impact resistance, especially for vessels used in low temperatures. In applications where carbon steel would suffer corrosion, special corrosion resistant material should also be used.

Some pressure vessels are made of composite materials, such as filament wound composite using carbon fibre held in place with a polymer. Due to the very high tensile strength of carbon fibre these vessels can be very light, but are much more difficult to manufacture. The composite material may be wound around a metal liner, forming a composite overwrapped pressure vessel.

Other very common materials include polymers such as PET in carbonated beverage containers and copper in plumbing.

Pressure vessels may be lined with various metals, ceramics, or polymers to prevent leaking and protect the structure of the vessel from the contained medium. This liner may also carry a significant portion of the pressure load.

Scaling

No matter what shape it takes, the minimum mass of a pressure vessel scales with the pressure and volume it contains and is inversely proportional to the strength to weight ratio of the construction material (minimum mass decreases as strength increases).

Scaling of stress in walls of vessel

Pressure vessels are held together against the gas pressure due to tensile forces within the walls of the container. The normal (tensile) stress in the walls of the container is proportional to the pressure and radius of the vessel and inversely proportional to the thickness of the walls. Therefore pressure vessels are designed to have a thickness proportional to the radius of tank and the pressure of the tank and inversely proportional to the maximum allowed normal stress of the particular material used in the walls of the container.

Because (for a given pressure) the thickness of the walls scales with the radius of the tank, the mass of a tank (which scales as the length times radius times thickness of the wall for a cylindrical tank) scales with the volume of the gas held (which scales as length times radius squared). The exact formula varies with the tank shape but depends on the density, ρ, and maximum allowable stress σ of the material in addition to the pressure P and volume V of the vessel.

Spherical vessel

For a sphere, the mass of a pressure vessel is

$$M = \frac{3}{2} PV \frac{\rho}{\sigma},$$

where

M is mass,
P is the pressure difference from ambient (the gauge pressure),
V is volume,
ρ is the density of the pressure vessel material,
σ is the maximum working stress that material can tolerate.

Other shapes besides a sphere have constants larger than 3/2 (infinite cylinders take 2), although some tanks, such as non-spherical wound composite tanks can approach this.

Cylindrical vessel with hemispherical ends

This is sometimes called a "bullet" for its shape.

For a cylinder with hemispherical ends,

$$M = 2\pi R^2 (R + W) P \frac{\rho}{\sigma},$$

where

- R is the radius
- W is the middle cylinder width only, and the overall width is W + 2R

2:1 Cylindrical vessel with semi-elliptical ends

In a vessel with an aspect ratio of middle cylinder width to radius of 2:1,

$$M = 6\pi R^3 P \frac{\rho}{\sigma}.$$

Gas storage

In looking at the first equation, the factor PV, in SI units, is in units of (pressurization) energy. For a stored gas, PV is proportional to the mass of gas at a given temperature, thus

$$M = \frac{3}{2} nRT \frac{\rho}{\sigma}.$$

The other factors are constant for a given vessel shape and material. So we can see that there is no theoretical "efficiency of scale", in terms of the ratio of pressure vessel mass to pressurization energy, or of pressure vessel mass to stored gas mass. For storing gases, "tankage efficiency" is independent of pressure, at least for the same temperature.

So, for example, a typical design for a minimum mass tank to hold helium (as a pressurant gas) on a rocket would use a spherical chamber for a minimum shape constant, carbon fiber for best possible ρ / σ, and very cold helium for best possible M / pV.

Stress in thin-walled pressure vessels

Stress in a shallow-walled pressure vessel in the shape of a sphere is

$$\sigma_\theta = \frac{pr}{2d},$$

where σ_θ is hoop stress, or stress in the circumferential direction, p is internal gauge pressure, r is the inner radius of the sphere, and d is depth. A vessel can be considered "shallow-walled" if the diameter is at least 10 times (sometimes cited as 20 times) greater than the wall depth.

Stress in a shallow-walled pressure vessel in the shape of a cylinder is

$$\sigma_\theta = \frac{pr}{d},$$
$$\sigma_{\text{long}} = \frac{pr}{2d},$$

where σ_θ is hoop stress, or stress in the circumferential direction, σ_{long} is stress in the longitudinal direction, p is internal gauge pressure, r is the inner radius of the cylinder, and d is wall depth.

Almost all pressure vessel design standards contain variations of these two formulas with additional empirical terms to account for wall thickness, quality control of welds and in-service corrosion allowances.

Winding angle of carbon fibre vessels

Wound infinite cylindrical shapes optimally take a winding angle of 54.7 degrees, as this gives the necessary twice the strength in the circumferential direction to the longitudinal.

Design and operation standards

Pressure vessels are designed to operate safely at a specific pressure and temperature, technically referred to as the "Design Pressure" and "Design Temperature". A vessel that is inadequately designed to handle a high pressure constitutes a very significant safety hazard. Because of that, the design and certification of pressure vessels is governed by design codes such as the ASME Boiler and Pressure Vessel Code in North America, the Pressure Equipment Directive of the EU (PED), Japanese Industrial Standard (JIS), CSA B51 in Canada, AS1210 in Australia and other international standards like Lloyd's, Germanischer Lloyd, Det Norske Veritas, Société Générale de Surveillance (SGS S.A.), Stoomwezen etc.

Note that where the pressure-volume product is part of a safety standard, any incompressible liquid in the vessel can be excluded as it does not contribute to the potential energy stored in the vessel, so only the volume of the compressible part such as gas is used.

List of standards

- EN 13445: The current European Standard, harmonized with the Pressure Equipment Directive (97/23/EC). Extensively used in Europe.
- ASME Code Section VIII, in addition supported by Sections II (materials), V (NDT/NDE) and IX (welding). Published by the American Society of Mechanical Engineers.
    - ASME Code Section VIII Division 1: US standard, design by formula. Almost exclusively used in North America, widely used worldwide.
    - ASME Code Section VIII Division 2: Alternative Rules, design by analysis.
    - ASME Code Section VIII Division 3: Alternative Rules for Construction of High Pressure Vessel
- BS 5500: Former British Standard, replaced in the UK by EN 13445 but retained under the name PD 5500 for the design and construction of export equipment.
- AD Merkblätter: German standard, harmonized with the Pressure Equipment Directive.
- EN 286 (Parts 1 to 4): European standard for simple pressure vessels (air tanks), harmonized with Council Directive 87/404/EEC.
- BS 4994: Specification for design and construction of vessels and tanks in reinforced plastics.
- ASME PVHO: US standard for Pressure Vessels for Human Occupancy
- CODAP
- AS 1210
- API 510
- ISO 11439
- IS 2825-1969 (RE1977)_code_unfired_Pressure_vessels
- FRP tanks and vessels
- AIAA S-080-1998: AIAA Standard for Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components
- AIAA S-081A-2006: AIAA Standard for Space Systems - Composite Overwrapped Pressure Vessels (COPVs)
- B51-09 Canadian Boiler, pressure vessel, and pressure piping code
- Stoomwezen: Former pressure vessels code in the Netherlands

Leak Before Burst

Leak before burst describes a pressure vessel designed such that a crack in the vessel will grow through the wall, allowing the contained fluid to escape and reducing the pressure, prior to growing so large as to cause fracture at the operating pressure.

Many pressure vessel standards, including the ASME Boiler and Pressure Vessel Code and the AIAA metallic pressure vessel standard, either require pressure vessel designs to be leak before burst, or require pressure vessels to meet more stringent requirements for fatigue and fracture if they are not shown to be leak before burst.

Alternatives to pressure vessels

Depending on the application and local circumstances, alternatives to pressure vessels exist. Examples can be seen in domestic water collection systems, where the following may be used:

- Gravity controlled systems which typically consist of an unpressurized water tank at an elevation higher than the point of use. Pressure at the point of use is the result of the hydrostatic pressure caused by the elevation difference. Gravity systems produce 0.43 pounds per square inch (3.0 kPa) per foot of water head (elevation difference). A municipal water supply or pumped water is typically around 90 pounds per square inch (620 kPa).
- Inline pump controllers or pressure-sensitive pumps.

History of pressure vessels

A 10,000 psi (69 MPa) pressure vessel from 1919, wrapped with high tensile steel banding and steel rods to secure the end caps.

Large pressure vessels were invented during the industrial revolution, particularly in Great Britain, to be used as boilers for making steam to drive steam engines.

Design and testing standards and a system of certification came about as the result of fatal boiler explosions.

In an early effort to design a tank capable of withstanding pressures up to 10,000 psi (69 MPa), a 6-inch (150 mm) diameter tank was developed in 1919 that was spirally-wound with two layers of high tensile strength steel wire to prevent sidewall rupture, and the end caps longitudinally reinforced with lengthwise high-tensile rods.

Chapter 7

Valve

These water valves are operated by handles.

A **valve** is a device that regulates the flow of a fluid (gases, liquids, fluidized solids, or slurries) by opening, closing, or partially obstructing various passageways. Valves are technically pipe fittings, but are usually discussed as a separate category. In an open valve, fluid flows in a direction from higher pressure to lower pressure.

Valves are also found in the human body. For example, there are several heart valves which control the flow of blood in the chambers of the heart and maintain the correct pumping action.

Valves are used in a variety of contexts, including industrial, military, commercial, residential, and transport.

The industries in which the majority of valves are used are oil and gas, power generation, mining, water reticulation, sewerage and chemical manufacturing.

Plumbing valves, such as taps for hot and cold tap water are the most noticeable types of valves. Other valves encountered on a daily basis include gas control valves on cookers, small valves fitted to washing machines and dishwashers, and safety devices fitted to hot water systems.

Valves may be operated manually, either by a handle, lever or pedal. Valves may also be automatic, driven by changes in pressure, temperature, or flow. These changes may act upon a diaphragm or a piston which in turn activates the valve, examples of this type of valve found commonly are safety valves fitted to hot water systems or boilers.

More complex control systems using valves requiring automatic control based on an external input (i.e., regulating flow through a pipe to a changing set point) require an actuator. An actuator will stroke the valve depending on its input and set-up, allowing the valve to be positioned accurately, and allowing control over a variety of requirements.

Valves are also found in the Otto cycle (internal combustion) engines driven by a camshaft, tappets or push rods where they play a major role in engine cycle control.

Applications

Valves vary widely in form and application. Sizes typically range from 0.1 mm 60 cm (2 ft). Special valves can have a diameter exceeding 5 meters.

Valve cost ranges from simple inexpensive disposable valves to specialized valves cost thousands of US dollars per inch of diameter.

Disposable valves may be found inside common household items including mini-pump dispensers and aerosol cans.

Types

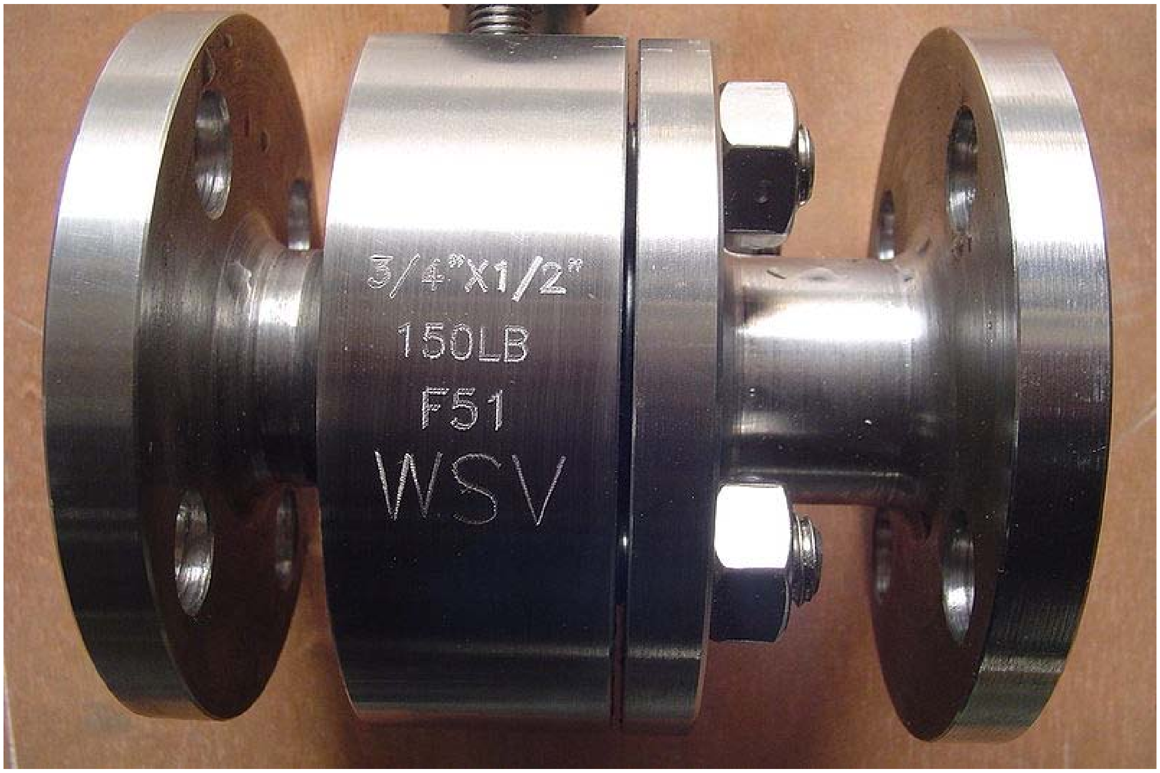
The inside of an extremely large butterfly valve

Valves are quite diverse and may be classified into a number of basic types. Valves may also be classified by how they are actuated:

- Hydraulic
- Pneumatic
- Manual
- Solenoid
- Motor

Basic types

Valves can be categorized into the following basic types:



Duplex ball valve

- Ball valve, for on/off control without pressure drop, and ideal for quick shut-off since a 90º turn offers complete shut-off angle, compared to multiple turns required on most manual valves.
- Butterfly valve, for flow regulation in large pipe diameters.
- Ceramic Disc valve, used mainly in high duty cycle applications or on abrasive fluids. Ceramic disc can also provide Class IV seat leakage
- Check valve or non-return valve, allows the fluid to pass in one direction only.

Hastelloy check valve

- Choke valve, a valve that raises or lowers a solid cylinder which is placed around or inside another cylinder which has holes or slots. Used for high pressure drops found in oil and gas wellheads.
- Diaphragm valve, some are sanitary predominantly used in the pharmaceutical and food-industry.
- Gate valve, mainly for on/off control, with low pressure drop.

Stainless steel gate valve

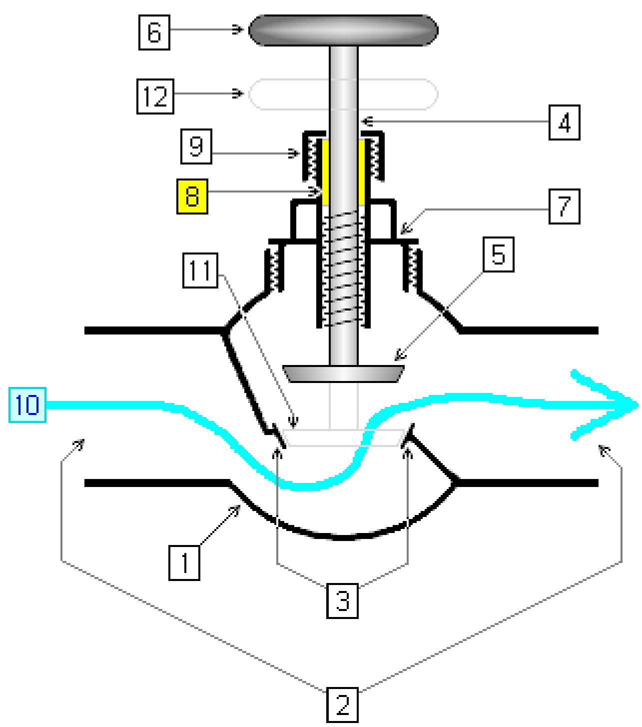
- Globe valve, good for regulating flow.
- Knife valve, for slurries or powders on/off control.
- Needle valve for accurate flow control.
- Pinch valve, for slurry flow regulation.
- Piston valve, for regulating fluids that carry solids in suspension.
- Plug valve, slim valve for on/off control but with some pressure drop.
- Poppet valve
- Spool valve, for hydraulic control
- Thermal expansion valve, used in refrigeration and air conditioning systems.

Specific types

- Aspin valve: a cone-shaped metal part fitted to the cylinder head of an engine
- Ball cock: often used as a water level controller (cistern)
- Bibcock: provides a connection to a flexible hosepipe
- Blast valve: prevents rapid overpressures in a fallout shelter or a bunker
- Cock: colloquial term for a small valve or a stopcock
- Demand valve: on a diving regulator
- Double beat valve
- Double check valve
- Duckbill valve
- Flipper valve
- Flow control valve: an application which maintains a variable flow rate through the valve
- Heimlich valve: a specific one-way valve used on the end of chest drain tubes to treat a pneumothorax
- Foot valve: a check valve on the foot of a suction line to prevent backflow
- Four-way valve: was used to control the flow of steam to the cylinder of early double-acting steam engines
- Freeze seal/Freeze plug: in which freezing and melting the fluid creates and removes a plug of frozen material acting as the valve
- Gas pressure regulator regulates the flow and pressure of a gas
- Heart valve: regulates blood flow through the heart in many organisms
- Leaf valve: one-way valve consisting of a diagonal obstruction with an opening covered by a hinged flap
- Pilot valve: regulate flow or pressure to other valves
- Poppet valve and sleeve valve: commonly used in piston engines to regulate the fuel mixture intake and exhaust
- Pressure regulator or pressure reducing valve (PRV): reduces pressure to a preset level downstream of the valve
- Pressure sustaining valve, or back-pressure regulator: maintains pressure at a preset level upstream of the valve
- Presta and Schrader valves are used to hold the air in bicycle tires
- Reed valve: consists of two or more flexible materials pressed together along much of their length, but with the influx area open to allow one-way flow, much like a heart valve
- Regulator: used in SCUBA diving equipment and in gas cooking equipment to reduce the high pressure gas supply to a lower working pressure
- Rocker valve
- Rotary valves and piston valves: parts of brass instruments used to change their pitch
- Rupture disc: a one time use replaceable valve for rapid pressure relief, used to protect piping systems from excessive pressure or vacuum; more reliable than a safety valve
- Saddle valve: where allowed, is used to tap a pipe for a low-flow need

- Safety valve or relief valve: operates automatically at a set differential pressure to correct a potentially dangerous situation, typically over-pressure
- Schrader valve: used to hold the air inside automobile tires
- Solenoid valve: an electrically controlled hydraulic or pneumatic valve
- Stopcock: restricts or isolates flow through a pipe
- Swirl valve: A specially designed Joule-Thompson pressure reduction/expansion valve imparting a centrifugal force upon the discharge stream for improving gas-liquid phase separation
- Tap (British English), faucet (American English): the common name for a valve used in homes to regulate water flow
- Thermal expansion valve, used in air conditioning and refrigeration systems.
- Thermostatic Mixing Valve
- Thermostatic Radiator Valve
- Trap primer: sometimes include other types of valves, or are valves themselves
- Vacuum breaker valve: prevents the back-siphonage of contaminated water into pressurized drinkable water supplies

Components



Cross-sectional diagram of an open globe **valve**.
1. **body**
2. **ports**
3. **seat**
4. **stem**
5. **disc** when valve is open

6. **handle** or **handwheel** when valve is open
7. **bonnet**
8. **packing**
9. **gland nut**
10. **fluid flow** when valve is open
11. position of disc if valve were shut
12. position of handle or handwheel if valve were shut

The main parts of a valve are the **body** and the **bonnet**. These two parts form the casing that holds the fluid going through the valve.

Body

The valve's **body** is the outer casing of most or all of the valve that contains the internal parts or *trim*. The bonnet is the part of the encasing through which the stem (see below) passes and that forms a guide and seal for the stem. The bonnet typically screws into or is bolted to the valve body.

Valve bodies are usually metallic or plastic. Brass, bronze, gunmetal, cast iron, steel, alloy steels and stainless steels are very common. Seawater applications, like desalination plants, often use duplex valves, as well as super duplex valves, due to their corrosion resistant properties, particularly against warm seawater. Alloy 20 valves are typically used in sulphuric acid plants, whilst monel valves are used in hydrofluoric acid (HF Acid) plants. Hastelloy valves are often used in high temperature applications, such as nuclear plants, whilst inconel valves are often used in hydrogen applications. Plastic bodies are used for relatively low pressures and temperatures. PVC, PP, PVDF and glass-reinforced nylon are common plastics used for valve bodies.

Bonnet

A **bonnet** acts as a cover on the valve body. It is commonly semi-permanently screwed into the valve body or bolted onto it. During manufacture of the valve, the internal parts are put into the body and then the bonnet is attached to hold everything together inside. To access internal parts of a valve, a user would take off the bonnet, usually for maintenance. Many valves do not have bonnets; for example, plug valves usually do not have bonnets. Many ball valves do not have bonnets since the valve body is put together in a different style, such as being screwed together at the middle of the valve body.

Ports

Ports are passages that allow fluid to pass through the valve. Ports are obstructed by the **valve member** or **disc** to control flow. Valves most commonly have 2 ports, but may have as many as 20. The valve is almost always connected at its ports to pipes or other components. Connection methods include threadings, compression fittings, glue, cement, flanges, or welding.

Handle or actuator

A **handle** is used to manually control a valve from outside the valve body. Automatically controlled valves often do not have handles, but some may have a handle (or something similar) anyway to manually override automatic control, such as a stop-check valve. An **actuator** is a mechanism or device to automatically or remotely control a valve from outside the body. Some valves have neither handle nor actuator because they automatically control themselves from inside; for example, check valves and relief valves may have neither.

Disc

Valve disc

A **disc** or **valve member** is a movable obstruction inside the stationary body that adjustably restricts flow through the valve. Although traditionally disc-shaped, discs come in various shapes. Depending on the type of valve, a disc can move linearly inside a valve, or rotate on the stem (as in a butterfly valve), or rotate on a hinge or trunnion (as in a check valve). A *ball* is a round valve member with one or more paths between ports passing through it. By rotating the ball, flow can be directed between different ports. Ball valves use spherical rotors with a cylindrical hole drilled as a fluid passage. Plug valves use cylindrical or conically tapered rotors called **plugs**. Other round shapes for rotors are possible as well in **rotor valves**, as long as the rotor can be turned inside the valve body.

However not all round or spherical discs are rotors; for example, a ball check valve uses the ball to block reverse flow, but is not a rotor because operating the valve does not involve rotation of the ball.

Seat

The **seat** is the interior surface of the body which contacts the disc to form a leak-tight seal. In discs that move linearly or swing on a hinge or trunnion, the disc comes into contact with the seat only when the valve is shut. In disks that rotate, the seat is always in contact with the disk, but the area of contact changes as the disc is turned. The seat always remains stationary relative to the body.

Seats are classified by whether they are cut directly into the body, or if they are made of a different material:

- **Hard seats** are integral to the valve body. Nearly all hard seated metal valves have a small amount of leakage.
- **Soft seats** are fitted to the valve body and made of softer materials such as PTFE or various elastomers such as NBR, EPDM, or FKM depending on the maximum operating temperature.

The shut off butterfly valve for a Francis turbine at Gordon Power Station, Tasmania

Ball valve

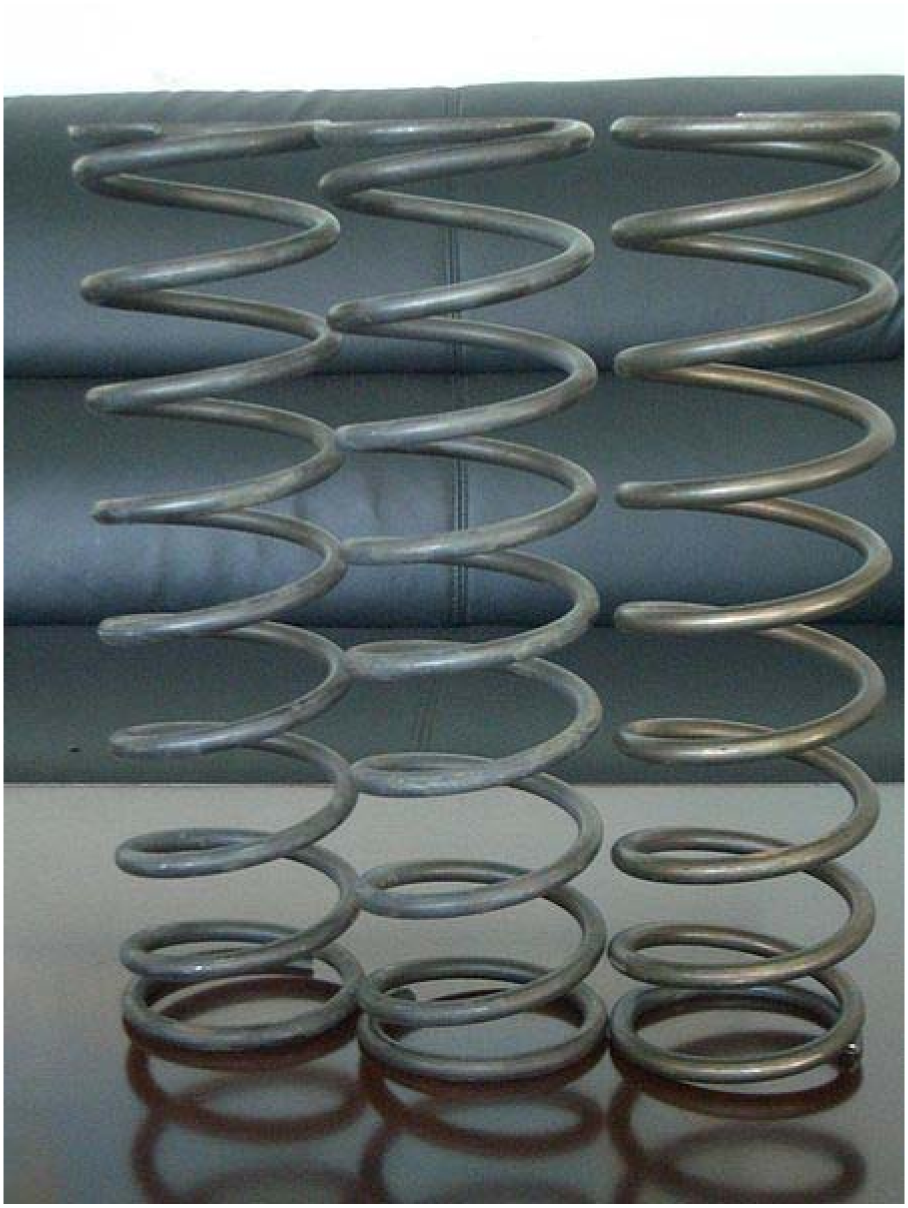
A closed soft seated valve is much less liable to leak when shut while hard seated valves are more durable. Gate, globe, and check valves are usually hard seated while butterfly, ball, plug, and diaphragm valves are usually soft seated.

Stem

The **stem** transmits motion from the handle or controlling device to the disc. The stem typically passes through the bonnet when present. In some cases, the stem and the disc can be combined in one piece, or the stem and the handle are combined in one piece.

The motion transmitted by the stem may be a linear force, a rotational torque, or some combination of these(Angle valve using torque reactor pin and Hub Assembly). The valve and stem can be threaded such that the stem can be screwed into or out of the valve by turning it in one direction or the other, thus moving the disc back or forth inside the body. Packing is often used between the stem and the bonnet to maintain a seal. Some valves have no external control and do not need a stem as in most check valves.

Valves whose disc is between the seat and the stem and where the stem moves in a direction into the valve to shut it are **normally-seated** or **front seated**. Valves whose seat is between the disc and the stem and where the stem moves in a direction out of the valve to shut it are **reverse-seated** or **back seated**. These terms don't apply to valves with no stem or valves using rotors.



Inconel X750 Spring

Gaskets

The seals or packings used to prevent the escape of a gas or fluids from valves.

Valve balls

A valve ball is also used for severe duty, high-pressure, high-tolerance applications. They are typically made of stainless steel, titanium, Stellite, Hastelloy, brass, or nickel. They can also be made of different types of plastic, such as ABS, PVC, PP or PVDF.

Spring

Many valves have a spring for spring-loading, to normally shift the disc into some position by default but allow control to reposition the disc. Relief valves commonly use a spring to keep the valve shut, but allow excessive pressure to force the valve open against the spring-loading. Coil springs are normally used. Typical spring materials include zinc plated steel, stainless steel, and for high temperature applications Inconel X750.

Trim

The internal elements of a valve are collectively referred to as a valve's **trim**. According to API Standards 600, "Steel Gate Valve-Flanged and Butt-welding Ends, Bolted Bonnets", the trim consists of stem, seating surface in the body, gate seating surface, bushing or a deposited weld for the backseat and stem hole guide, and small internal parts that normally contact the service fluid, excluding the pin that is used to make a stem-to-gate connection (this pin shall be made of an austenitic stainless steel material).

Valve operating positions

A seacock for cooling seawater, on a marine diesel engine.

Valve **positions** are operating conditions determined by the position of the disc or rotor in the valve. Some valves are made to be operated in a gradual change between two or more positions. Return valves and non-return valves allow fluid to move in 2 or 1 directions respectively.

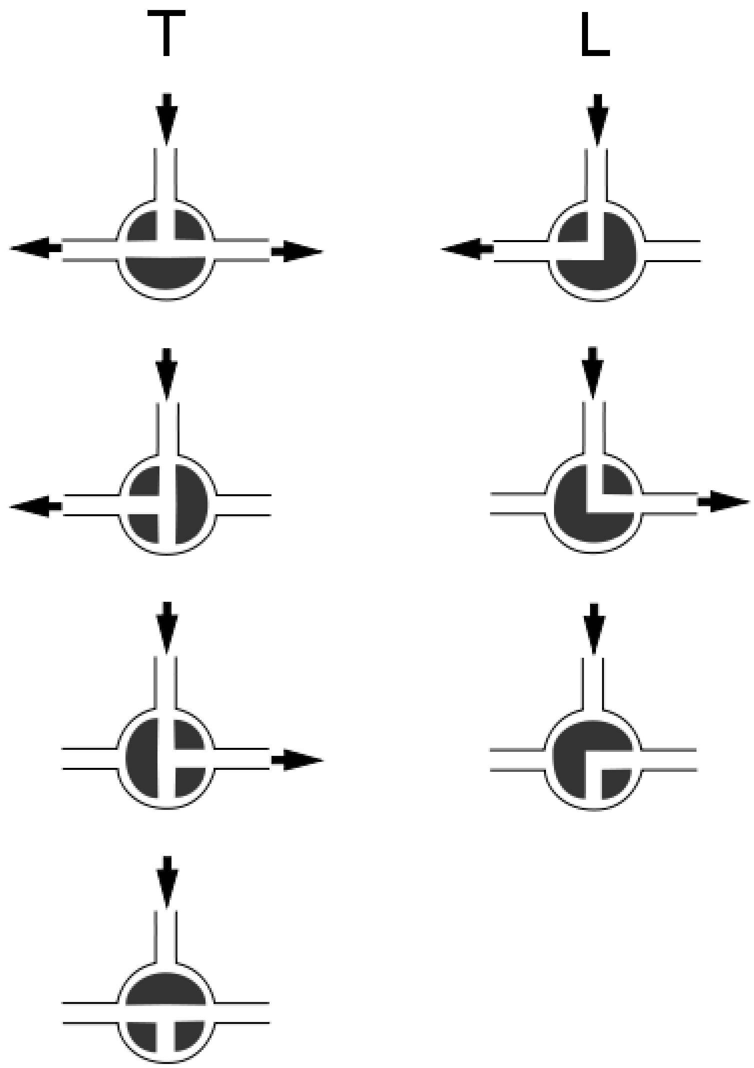
Two-port valves

Operating positions for 2-port valves can be either shut (closed) so that no flow at all goes through, fully open for maximum flow, or sometimes partially open to any degree in between. Many valves are not designed to precisely control intermediate degree of flow; such valves are considered to be either open or shut. Some valves are specially designed to regulate varying amounts of flow. Such valves have been called by various names such as *regulating*, *throttling*, *metering*, or *needle valves*. For example, needle valves have elongated conically-tapered discs and matching seats for fine flow control. For some valves, there may be a mechanism to indicate by how much the valve is open, but in many cases other indications of flow rate are used, such as separate flow meters.

In plants with remote-controlled process operation, such as oil refineries and petrochemical plants, some 2-way valves can be designated as normally closed (NC) or normally open (NO) during regular operation. Examples of normally closed valves are *sampling valves*, which are only opened while a sample is taken. Examples of normally open valves are *isolation valves*, which are usually only shut when there is a problem with a unit or a section of a fluid system such as a leak in order to isolate the problem from the rest of the system.

Although many 2-way valves are made in which the flow can go in either direction between the two ports, when a valve is placed into a certain application, flow is often expected to go from one certain port on the **upstream** side of the valve, to the other port on the **downstream** side. Pressure regulators are variations of valves in which flow is controlled to produce a certain downstream pressure, if possible. They are often used to control flow of gas from a gas cylinder. A back-pressure regulator is a variation of a valve in which flow is controlled to maintain a certain upstream pressure, if possible.

Three-port valves



Schematic 3 way ball valve: L-shaped ball right, T-shaped left

Valves with three ports serve many different functions. A few of the possibilities are listed here.

Three-way ball valves come with a T- or L- shaped fluid passageways inside the rotor. The T valve might be used to permit connection of one inlet to either or both outlets or connection of the two outlets. The L valve could be used to permit disconnection of both or connection of either but not both of two inlets to one outlet.

Shuttle valves automatically connect the higher pressure inlet to the outlet while (in some configurations) preventing flow from one inlet to the other.

Single handle mixer valves produce a variable mixture of hot and cold water at a variable flow rate under control of a single handle.

Thermostatic mixing valves mix hot and cold water to produce a constant temperature in the presence of variable pressures and temperatures on the two input ports.

Four-port valves

A 4-port valve is a valve whose body has four ports equally spaced round the body and the disc has two passages to connect adjacent ports. It is operated with two positions.

It can be used to isolate and to simultaneously bypass a sampling cylinder installed on a pressurized water line. It is useful to take a fluid sample without affecting the pressure of a hydraulic system and to avoid degassing (no leak, no gas loss or air entry, no external contamination)....

Control

A sailor aboard a ship operates the wheel controlling a fuel valve.

Many valves are controlled manually with a handle attached to the stem. If the handle is turned ninety degrees between operating positions, the valve is called a **quarter-turn valve**. Butterfly, ball valves, and plug valves are often quarter-turn valves. If the handle is circular with the stem as the axis of rotation in the center of the circle, then the handle is called a **handwheel**. Valves can also be controlled by actuators attached to the stem.

They can be electromechanical actuators such as an electric motor or solenoid, pneumatic actuators which are controlled by air pressure, or hydraulic actuators which are controlled by the pressure of a liquid such as oil or water. Actuators can be used for the purposes of automatic control such as in washing machine cycles, remote control such as the use of a centralised control room, or because manual control is too difficult such as when the valve is very large. Pneumatic actuators and hydraulic actuators need pressurised air or liquid lines to supply the actuator: an inlet line and an outlet line. Pilot valves are valves which are used to control other valves. Pilot valves in the actuator lines control the supply of air or liquid going to the actuators.

The fill valve in a toilet water tank is a liquid level-actuated valve. When a high water level is reached, a mechanism shuts the valve which fills the tank.

In some valve designs, the pressure of the flow fluid itself or pressure difference of the flow fluid between the ports automatically controls flow through the valve.

Other considerations

Valves are typically rated for maximum temperature and pressure by the manufacturer. The wetted materials in a valve are usually identified also. Some valves rated at very high pressures are available. When a designer, engineer, or user decides to use a valve for an application, he/she should ensure the rated maximum temperature and pressure are never exceeded and that the wetted materials are compatible with the fluid the valve interior is exposed to. In Europe, valve design and pressure ratings are subject to statutory regulation under the Pressure Equipment Directive 97/23/EC (PED)

Some fluid system designs, especially in chemical or power plants, are schematically represented in piping and instrumentation diagrams. In such diagrams, different types of valves are represented by certain symbols.

Valves in good condition should be leak-free. However, valves may eventually wear out from use and develop a leak, either between the inside and outside of the valve or, when the valve is shut to stop flow, between the disc and the seat. A particle trapped between the seat and disc could also cause such leakage.

Globe valve

A valve controlled by a wheel

Large butterfly valve

Cast iron butterfly valve

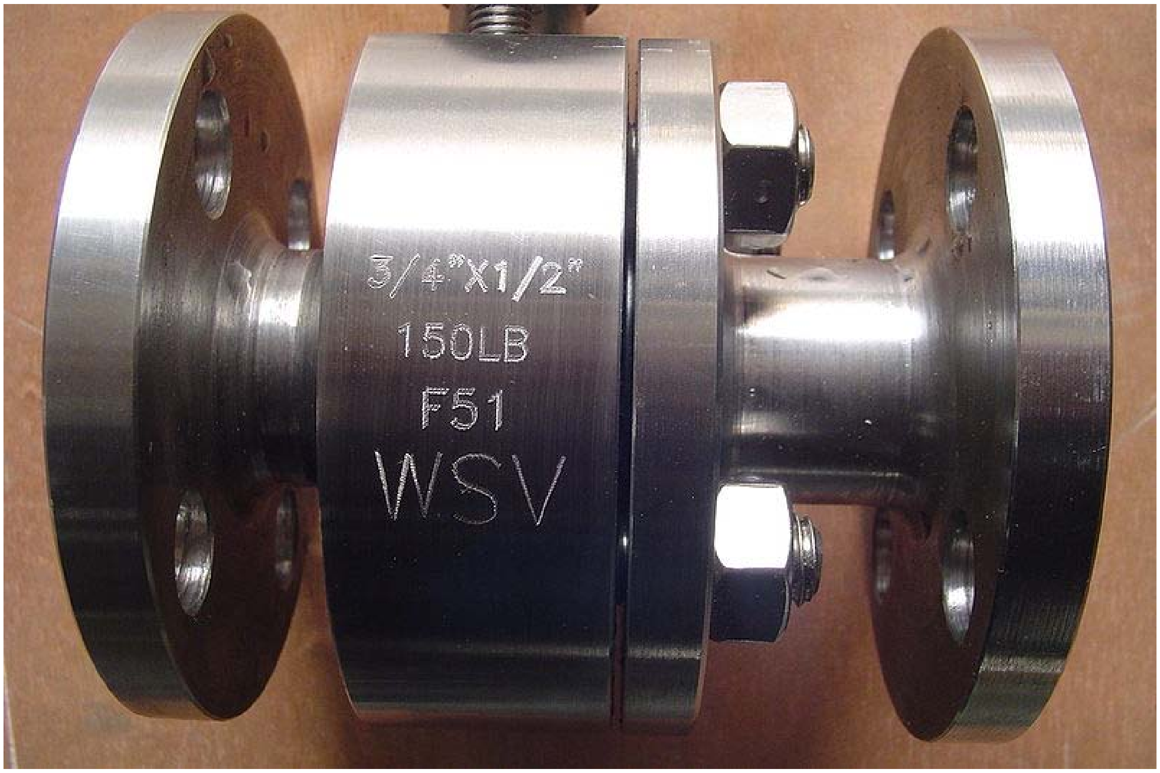
Cast iron butterfly valve

Hastelloy ball valve

Stainless steel gate valve

Stainless steel gate valve

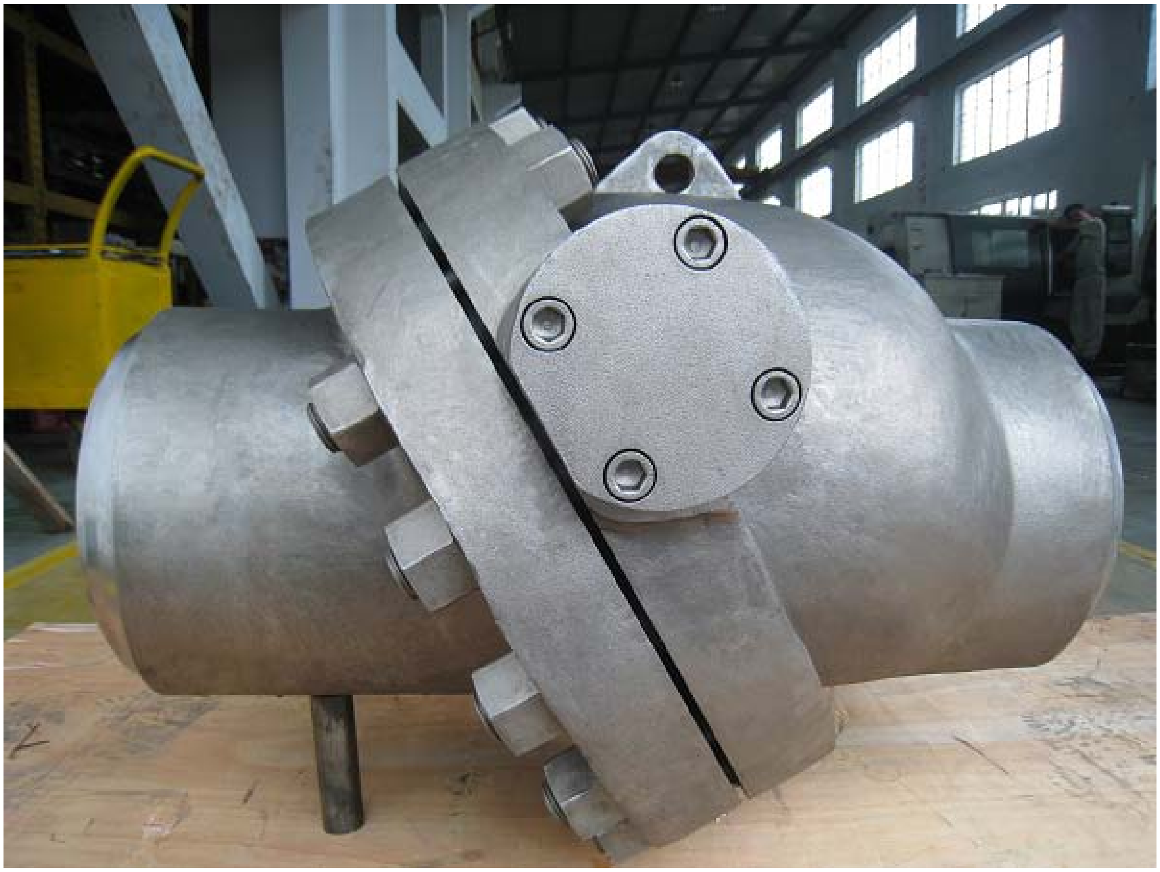
Hastelloy check valves



Duplex ball valve

Inconel gate valve

Stainless steel wafer check valve



Inconel check valve

Stainless steel ball valve

Cryogenic 254 SMO gate valve

Inside view of a tilting disc inconel check valve

Duplex ball valves

Cryogenic super duplex gate valve frozen up during operation

Super duplex ball valves

Flanged nozzle inconel check valve or axial check valve

Inside hastelloy check valve, wafer configuration

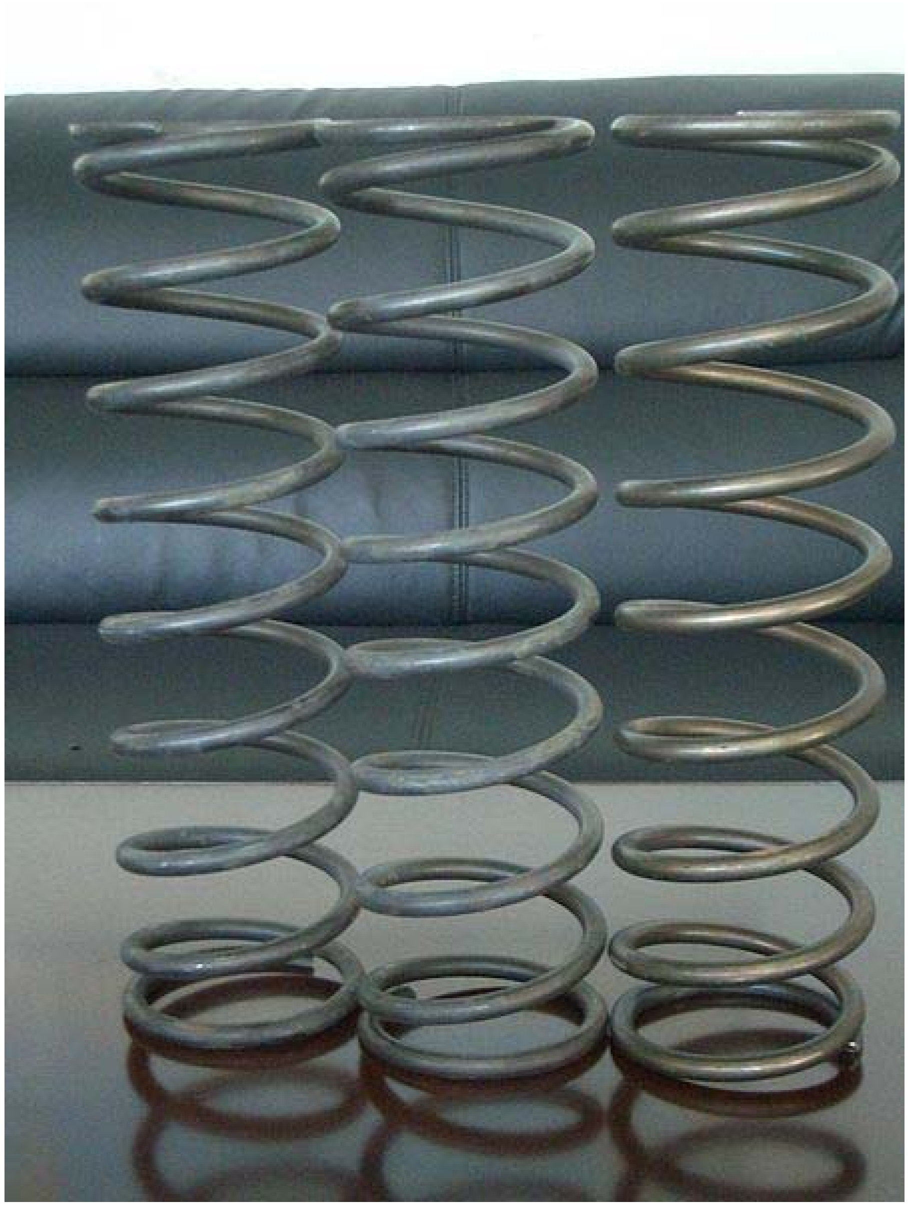
Large carbon steel swing check valve

Disc for an alloy check valve also known as axial check valve

Balls for alloy ball valves

Wafer check valve

Nuts and bolts for incoloy valves



Inconel check valve springs

Ball for a titanium ball valve

Chapter 8

Gas Cylinder

Industrial compressed gas cylinders used for oxy-fuel welding and cutting of steel.

A **gas cylinder** or tank is a pressure vessel used to store gases at above atmospheric pressure. High pressure gas cylinders are also called bottled gases.

Nomenclature differences

In the United States, 'bottled gas' typically refers to liquefied petroleum gas. 'Bottled gas' is sometimes used in medical supply, especially for portable oxygen tanks. Packaged industrial gases are frequently called 'cylinder gas', though 'bottled gas' is sometimes used.

The United Kingdom and other parts of Europe more commonly refer to 'bottled gas' when discussing any usage whether industrial, medical or liquefied petroleum. However, in contrast, what the United States calls liquefied petroleum gas is known generically in the United Kingdom as 'LPG'; and it may be ordered using by one of several Trade names, or specifically as butane or propane depending on the required heat output.

Regulations and testing

The transportation of high pressure cylinders is regulated by many governments throughout the world. Various levels of testing are generally required by the governing authority for the country in which it is to be transported. In the United States, this authority is the United States Department of Transportation (DOT). For Canada, this authority is Transport Canada (TC). Cylinders may have additional requirements placed on design and or performance from independent testing agencies such as Underwriter's Laboratory (UL). Each manufacturer of high pressure cylinders is required to have independent quality agent that will inspect the product for quality and safety.

There are a variety of tests that may be performed on various cylinders. Some of the most common types of tests are hydrostatic test, burst test, tensile strength, Charpy impact test and pressure cycling.

During the manufacturing process, vital information is usually stamped or permanently marked on the cylinder. This information usually includes the type of cylinder, the working or service pressure, the serial number, date of manufacture, the manufacture's registered code and sometimes the test pressure. Other information may also be stamped depending on the regulation requirements.

High pressure cylinders that are used multiple times—as most are—can be hydrostatically or ultrasonically tested and visually examined every few years. In the U.S., hydrostatic/ultrasonic testing is required either every five years or every ten years, depending on cylinder and its service. Helium Gas tanks have the highest pressures possible when full, around 1000 atmospheres.

Valve connections

A gas regulator attached to a nitrogen cylinder. From right - main valve, tank pressure gauge, low-pressure valve, outlet pressure gauge, 3-way outlet terminated by needle valves.

When gases are supplied in gas cylinders, the cylinders have a stop angle valve at the end on top. Often, gas cylinders are somewhat long and narrow and may stand upright on a flattened bottom at one end with the valve at the top. During storage, transportation, and handling when the gas is not in use, a cap may be screwed over the protruding valve to protect it from damage or breaking off in case the cylinder were to fall over. Instead of a cap, cylinders commonly have a protective collar or neck ring around the service valve assembly.

When the gas in the cylinder is ready to be used, the cap is taken off and a pressure-regulating assembly is attached to the stop valve. This attachment typically has a pressure regulator with upstream (inlet) and downstream (outlet) pressure gauges and a further downstream needle valve and outlet connection. For gases that remain gaseous under ambient storage conditions, the upstream pressure gauge can be used to estimate how much gas is left in the cylinder according to pressure. For gases that are liquid under storage (e.g. propane), the outlet pressure is dependent on the vapor pressure of the gas, and does not fall until the cylinder is nearly exhausted. The regulator could be adjusted to control the flow of gas out of the cylinder according to pressure shown by the downstream gauge. The outlet connection is attached to whatever needs the gas supply, such as a balloon for example.

The valves on industrial, medical and diving cylinders are usually of different size and type, as are the valves for different products, making it more difficult to mistakenly misuse a gas.

In the US, valve connections are sometimes referred to as 'CGA connections,' since the Compressed Gas Association (CGA) publishes guidelines on what connections to use for what products (e.g., In the USA, an argon cylinder will have a CGA 580 connection on the valve).

- Note: if the nut on a CGA connection has a notch in it, it uses a left-handed thread.

High purity gases will sometimes use CGA-DISS ('Diameter Index Safety System') connections.

In the EU, DIN connections are more common than in the US.

Color coding

Gas cylinders are often color coded, but the codes are not standard across different jurisdictions, and sometimes are not regulated. Cylinder color can not safely be used for positive product identification; cylinders have labels which identify the gas they contain and the label alone should be used for positive identification.

Safety and standards

Good Handling: **Gas cylinders** chained to a wall for safety at Duke University. Note the protective caps covering the valves at top of each cylinder.

Bad Handling: A **gas cylinder** in an Indian Auto rickshaw with the valve sticking out without protective cap.

Because the contents are under pressure and are sometimes hazardous, there are special safety regulations for handling bottled gases. These include chaining bottles to prevent falling and breaking, proper ventilation to prevent injury or death in case of leaks and signage to indicate the potential hazards. Installing and replacing gas cylinders should be done by trained personnel.

In a fire, the pressure in a gas cylinder rises in direct proportion to its temperature. If the internal pressure exceeds the mechanical limitations of the cylinder and there are no means to safely vent the pressurized gas to the atmosphere, the vessel will fail mechanically. If the vessel contents are ignitable, this event may result in a "fireball". If the cylinder's contents are liquid but become a gas at ambient conditions, this is commonly referred to as a Boiling Liquid Expanding Vapour Explosion (BLEVE).

Medical gas cylinders in the UK and other countries have a seal of Wood's metal between the valve block and the cylinder body. This seal melts at a comparatively low temperature

(70°C) and allows the contents of the cylinder to escape in a controlled fashion, lessening the risk of explosion.

More common pressure relief devices are of a simple burst disc type. In these, a small burst disc is installed in the back of the valve. A burst disc is a small metal gasket engineered to rupture at a pre-determined pressure. Some of these burst disc are backed with a low-melting-point metal, so that the valve must be exposed to excessive heat before the burst disc can rupture.

The Compressed Gas Association sells a number of booklets and pamphlets on safe handling and use of bottled gases.

If the valve of a compressed air cylinder is broken or sheared off, the released pressure may cause the cylinder to act like a rocket, shooting away quickly.

Standards

- ISO 11439: Gas cylinders—High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles
- ISO 15500-5: Road vehicles -- Compressed natural gas (CNG) fuel system components -- Part 5: Manual cylinder valve

Management

Carelessness with pressurized gas cylinders can have devastating consequences including serious injuries or death, property and environmental damage.

Cylinders should be properly labeled and securely stored. Substances that may react with each other (e.g., oxidizers and flammable materials) should not be stored in close proximity.

Sizes

In scuba diving, the USA measures cylinder volume by the amount of free air that can be compressed into the cylinder; Europe measures the cylinder volume as the internal volume of the cylinder: e.g. USA 19 cubic feet = European 3 liter at 180 bar.

The below are example cylinder sizes and do not constitute an industry standard.

Cyl. Size	Size* Diameter X Height (inches) Includes 5.5 inches for valve and cap.	Nominal* Tare Weight (lbs.) Includes 4.5 lbs. for valve and cap.	Water Capacity (lbs.)	Internal Volume @ 70°F (21°C), 1 ATM (liters/cubic feet)	US DOT Specs

T	9.25 X 60	135	110	49.9 / 1.76	3AA2400
K	9 X 51	115	96	43.8 / 1.55	3AA2015
B	8.5 X 31	60	37.9	17.2 / 0.61	3AA2015
C	6 X 24	27	15.2	6.88 / 0.24	3AA2015
D	4 X 18	12	4.9	2.24 / 0.08	3AA2015
AL	8 X 53	52	64.8	29.5 / 1.04	3AL2015
BL	7.25 X 39	33	34.6	15.7 / 0.55	3AL2216
CL	6.9 X 21	19	13	5.9 / 0.21	3AL2216
XL	14.5 X 50	75	238	108 / 3.83	4BA240
SSB	8 X 37	95	41.6	18.9 / 0.67	3A1800
10S	4 X 31	21	8.3	3.8 / 0.13	3A1800
LB	2 X 15	4	1	0.44 / 0.016	3E1800
XF	12 X 46	180		60.9 / 2.15	8AL
XG	15 X 56	149	278	126.3 / 4.46	4AA480
XM	10 X 49	90	120	54.3 / 1.92	3A480
XP	10 X 55	55	124	55.7 / 1.98	4BA300
QT	3 X 14 includes 4.5 inches for valve	2.5 includes 1.5 lbs for valve	2.0	0.900 / 0.0318	4B-240ET
LP5	12.25 X 18.25	18.5	47.7	21.68 / 0.76	4BW240
Medical E	4 x 26 excludes valve and cap	14 excludes valve and cap		4.5 / 0.16	3AA2015

Chapter 9

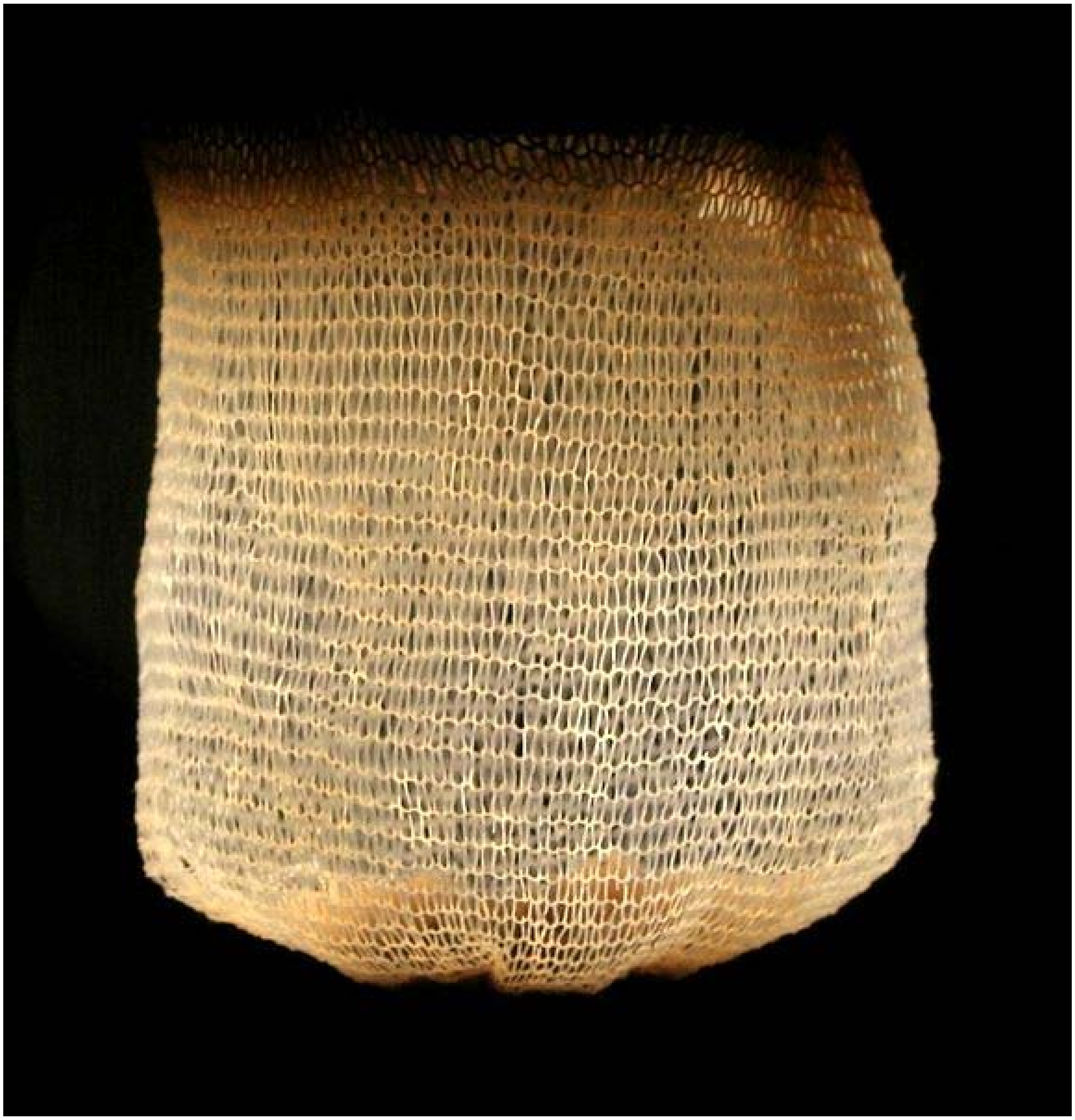
Gas Mantle and Gas Stove

Gas mantle

An **incandescent gas mantle**, **gas mantle**, or **Welsbach mantle** is a device for generating bright white light when heated by a flame. The name refers to its original heat source, existing gas lights, which filled the streets of Europe and North America in the late 19th century, mantle referring to the way it was hung above the flame. Today they are still used for portable camping lanterns and pressure lamps.

Mantles in their unused flat-packed form

Mechanism



A Coleman white gas lantern mantle burning at full brightness

The mantle is made from oxides that, when heated, glow brightly in the visible spectrum while emitting little infrared radiation. The rare earth oxides (cerium) and actinide (thorium) in the mantle have a low emissivity in the infrared (in comparison with an ideal black body), but have high emissivity in the visible spectrum. This is because of candoluminescence. Hence, when heated by a kerosene or liquified petroleum gas flame, the mantle emits radiation that is weighted less heavily in the infrared and more heavily in the visible spectrum, leading to an enhanced output of useful light.

Modern mantles are made by saturating a ramie-based artificial silk or rayon fabric with rare earths. When the mantle, which resembles a small net bag, is placed in the flame for the first time, the fabric burns away, leaving a residue of metal oxide, which glows brightly.

The mantle shrinks and becomes very fragile after this first use.

The mantle also aids the combustion process, keeping the flame small at higher flow rates than in a simple lamp. This concentration of combustion near the mantle, in turn, improves the transfer of heat from the flame to the mantle.

History

For centuries, artificial light had been generated using open flames. Limelight had been invented in the 1820s, but the temperature required was too high to be practical for small lights. In the late 19th century several inventors tried to develop an effective alternative based on heating a material to a lower temperature but using spectral lines to simulate white light.

Many early attempts used platinum-iridium gauze soaked in metal nitrates, but were not successful because of high cost materials and poor reliability.

The first effective mantle was the *Clamond basket* in 1881, named after its inventor. It was exhibited in the Crystal Palace exhibition of 1883. This device was made from a mixture of magnesium hydrate, magnesium acetate and water which was squeezed through holes in a plate to form threads, which were then moulded into a basket shape and ignited. The acetate burnt, the combustion products forming a matrix to support the magnesium oxide formed as the hydrate decomposed. The fragile structure was supported by a platinum wire cage and heated by a coal gas flame.

The modern gas mantle was one of the many inventions of Carl Auer von Welsbach, a chemist who studied rare earth elements in the 1880s and who had been Robert Bunsen's student. Ignaz Kreidl worked with him on his early experiments to create the Welsbach mantle. His first process used a mixture of 60% magnesium oxide, 20% lanthanum oxide and 20% yttrium oxide, which he called *Actinophor*, and patented in 1885.

The original mantles gave off a green-tinted light and were not very successful, and his first company, which established a factory in Atzgersdorf in 1887, failed in 1889. In 1890 he discovered that thorium was superior to magnesium, and in 1891 perfected a new mixture of 99% thorium dioxide and 1% cerium dioxide that gave off a much whiter light and produced a stronger mantle. After introducing it commercially in 1892 it quickly spread throughout Europe. The gas mantle remained an important part of street lighting until the widespread introduction of electric lighting in the early 1900s.

To produce a mantle, cotton is woven into a net bag and impregnated with the soluble nitrates of these metals and then heated; the cotton burns away and the nitrates are converted to nitrites, which fuse together to form the solid mesh. As the heating continues, the nitrites decompose into the final solid, (but fragile) very high melting point oxides.

Early mantles were sold in the unheated cotton mesh condition, since the oxide structure was too fragile to transport easily, and the purchaser carried out the conversion when it was first used. The cotton quickly rotted because of the corrosive nature of the acidic metal nitrates (although was later reduced by soaking the mantle in ammonia solution to neutralise the excess acid).

Later mantles were made from guncotton (nitrocellulose) or collodion rather than ordinary cotton, since extremely fine threads of it could be produced; it was converted back to cellulose before heating (since these materials are highly flammable or explosive) by dipping in ammonium sulfide.

It was discovered that the finished mantle could be strengthened sufficiently by dipping in a solution of collodion, which would coat it with a thin layer of the material to be burnt off when the mantle was first used, although modern mantles are now usually sold in their original fabric condition.

Early mantles often had a binding thread of asbestos for tying onto the lamp fitting, but because of its carcinogenic properties it has been replaced with wire or ceramic fiber thread in modern mantles.

Safety of thorium

Since thorium is radioactive and produces a radioactive gas, radon-220, as one of its decay products, there are concerns about the safety of thorium mantles. Some nuclear safety agencies make recommendations about their use . A study in 1981 estimated that the dose from using a thorium mantle every weekend for a year would be 0.3-0.6 millirems, tiny in comparison to the normal annual dose of a few hundred millirems, although a person ingesting an entire mantle would receive a comparable dose of 200 mrem (2 mSv; ,). However, the radioactivity is a major concern for those people involved with the manufacture of mantles and with contamination of soil around some former factory sites . All of these issues have meant that alternatives, usually yttrium or sometimes zirconium, are used in some countries although they are either more expensive or less efficient.

One potential cause for concern is that particles from thorium gas mantles "fall out" over time and get into the air, where they may be ingested in food or drink. These particles can also be inhaled and remain in the lungs or liver. Also of concern is the release of thorium bearing dust if the mantle shatters due to mechanical impact.

Gas stove

Many stoves use natural gas to provide heat.

In cooking, a **gas stove** is a cooker which uses natural gas, propane, butane, liquefied petroleum gas or other flammable gas as a fuel source.

History

The first gas stoves were developed as early as the 1820s, but these remained isolated experiments. James Sharp patented a gas stove in Northampton, England in 1826 and opened a gas stove factory in 1836. At the World Fair in London in 1851, a gas stove was shown, but only in the 1880s did this technology start to become a commercial success. The main factor for this delay was the slow growth of the gas pipe network.

The first gas stoves were rather unwieldy, but soon the oven was integrated into the base and the size reduced to fit in better with the rest of the kitchen furniture. In the 1910s, producers started to enamel their gas stoves for easier cleaning. A high-end gas stove called the AGA cooker was invented in 1922 by Swedish Nobel prize winner Gustaf Dalén.

Ignition

Gas stoves today use two basic types of ignition sources, standing pilot and electric. A stove with a standing pilot has a small, continuously burning gas flame (called a pilot flame) under the cooktop. The flame is between the front and back burners. When the stove is turned on, this flame lights the gas flowing out of the burners. The advantage of the standing pilot system is that it is simple and completely independent of any outside power source. A minor drawback is that the flames continuously consume fuel even when the stove is not in use. Early gas ovens did not have a pilot. One had to light these manually with a match [Stove Lighting]. If one accidentally left the gas on, gas would fill the oven and eventually the room. A small spark, such as an arc from a light switch being turned on, could ignite the gas, triggering a violent explosion. To prevent these types of accidents, oven manufacturers developed and installed a safety valve in the oven. The safety valve uses a pilot flame to ignite the main burner when the oven is turned on. The pilot flame heats a thermocouple that sends a signal to the valve to stay open. If a draft blows out the pilot flame or it goes out due to loss of gas pressure, the thermocouple cools and signals the valve to close, shutting off the gas to the oven.

A modern ignited gas stove

Electric ignition stoves use electric sparks to ignite the surface burners. This is the "clicking sound" audible just before the burner actually lights. The sparks are initiated by turning the gas burner knob to a position typically labeled "LITE." Once the burner lights, the knob is turned further to modulate the flame size. Auto reignition is an elegant refinement: the user need not know or understand the wait-then-turn sequence. They simply turn the burner knob to the desired flame size and the sparking is turned off automatically when the flame lights. Auto reignition also provides a safety feature: the flame will be automatically reignited if the flame goes out while the gas is still on--for example by a gust of wind. If the power fails, surface burners must be manually match-lit. Electric ignition for ovens uses a "hot surface" or "glow bar" ignitor. Basically it is a heating element that heats up to gas's ignition temperature. A sensor detects when the glow bar is hot enough and opens the gas valve.

Chapter 10

Gas Meter

A residential gas meter of the usual *diaphragm* style

A **gas meter** is used to measure the volume of fuel gases such as natural gas and propane. Gas meters are used at residential, commercial, and industrial buildings that consume fuel gas supplied by a gas utility. Gases are more difficult to measure than liquids, as measured volumes are highly affected by temperature and pressure. Gas meters measure a defined volume, regardless of the pressurized quantity or quality of the gas flowing through the meter. Temperature, pressure and heating value compensation must be made to measure actual amount and value of gas moving through a meter.

Several different designs of gas meters are in common use, depending on the volumetric flow rate of gas to be measured, the range of flows anticipated, the type of gas being measured and other factors.

Types of gas meters

Diaphragm/bellows meters

These are the most common type of gas meter, seen in almost all residential and small commercial installations. Within the meter there are two or more chambers formed by movable diaphragms. With the gas flow directed by internal valves, the chambers alternately fill and expel gas, producing a near continuous flow through the meter. As the diaphragms expand and contract, levers connected to cranks convert the linear motion of the diaphragms into rotary motion of a crank shaft which serves as the primary flow element. This shaft can drive an odometer-like counter mechanism or it can produce electrical pulses for a flow computer.

Diaphragm gas meters are positive displacement meters.

Rotary meters

Rotary meters are highly machined precision instruments capable of handling higher volumes and pressures than diaphragm meters. Within the meter, two figure "8" shaped lobes, the rotors (also known as impellers or pistons), spin in precise alignment. With each turn, they move a specific quantity of gas through the meter. The operating principle is similar to that of a Roots blower. The rotational movement of the crank shaft serves as a primary flow element and may produce electrical pulses for a flow computer or may drive an odometer-like counter.

Turbine meters

Turbine gas meters infer gas volume by determining the speed of the gas moving through the meter. Because the volume of gas is inferred by the flow, it is important that flow conditions are good. A small internal turbine measures the speed of the gas, which is transmitted mechanically to a mechanical or electronic counter. These meters do not impede the flow of gas, but are limited at measuring lower flow rates.

Orifice meters

An orifice gas meter consists of a straight length of pipe inside which a precisely known orifice affects the flow. Orifice meters are a type of differential meter, all of which infer the rate of gas flow by measuring the pressure difference across a deliberately designed and installed flow disturbance. The gas static pressure, density, viscosity, and temperature must be measured or known in addition to the differential pressure. Orifice meters are less accurate than other measurement methods and they do not handle a large range of flow rates. They are however accepted and understood in industrial applications since they are easy to field-service and have no moving parts.

Ultrasonic flow meters

Ultrasonic flow meters are more complex than meters that are purely mechanical, as they require significant signal processing and computation capabilities. Ultrasonic meters measure the speed of gas movement by measuring the speed at which sound travels in the gaseous medium within the pipe. American Gas Association Report No. 9 covers the proper usage and installation of these meters, and it specifies a standardised speed-of-sound calculation which predicts the speed of sound in a gas with a known pressure, temperature and gas composition.

The most elaborate types of ultrasonic flow meters average speed of sound over multiple paths in the pipe. The length of each path is precisely measured in the factory. Each path consists of an ultrasonic transducer at one end and a sensor at the other. The meter creates a 'ping' with the transducer and measures the time elapsed before the sensor receives the sonic pulse. Some of these paths point upstream so that the sum of the times of flight of the sonic pulses can be divided by the sum of the flight lengths to provide an average speed of sound in the upstream direction. This speed differs by the speed of sound in the gas by the velocity at which the gas is moving in the pipe. The other paths may be identical or similar, except that the sound pulses travel downstream. The meter then compares the difference between the upstream and downstream speeds to calculate the velocity of gas flow.

Ultrasonic meters are high-cost and work best with no liquids present at all in the measured gas, so they are primarily used in high-flow, high-pressure applications such as utility pipeline meter stations, where the gas is always dry and lean, and where small proportional inaccuracies are intolerable due to the large amount of money at stake. The turndown ratio of an ultrasonic meter is probably the largest of any natural gas meter type, and the accuracy and rangeability of a high-quality ultrasonic meter is actually greater than that of the turbine meters against which they are proven.

Inexpensive varieties of ultrasonic meters are available as clamp-on flow meters, which can be used to measure flow in any diameter of pipe without intrusive modification. Such devices are based on two types of technology: (1) time of flight or transit time; and (2) cross correlation. Both technologies involve transducers that are simply clamped on to the pipe and programmed with the pipe size and schedule and can be used to calculate flow. Such meters can be used to measure almost any dry gas including natural gas, nitrogen, compressed air and also steam. Clamp-on meters are available for measuring liquid flow as well.

Coriolis meters

A coriolis meter is usually one or more pipes with longitudinally or axially displaced section(s) that are excited to vibrate at resonant frequency. Coriolis meters are used with liquids and gases. When the fluid within the displaced section is at rest, both the upstream and downstream portion of the displaced section will vibrate in phase with each other. The frequency of this vibration is determined by the overall density of the pipe (including its contents). This allows the meter to measure the flowing density of the gas in real time. Once the fluid begins to flow, however, the coriolis effect comes into play. This effect implies a relationship between the phase difference in the vibration of the upstream and downstream sections and the mass flow rate of the fluid contained by the pipe.

Again, owing to the amount of inference, analog control and calculation intrinsic to a coriolis meter, the meter is not complete with just its physical components. There are actuation, sensing, electronic and computational elements that must be present for the meter to function.

Coriolis meters can handle a wide range of flow rates and have the unique ability to output mass flow - this gives the highest accuracy of flow measurement currently available for mass flowr measurement.Since they measure flowing density, coriolis meters can also infer gas flow rate at flowing conditions.

American Gas Association Report No. 11 provides guidelines for obtaining good results when measuring natural gas with a coriolis meter.

Heating value

The volume of gas flow provide by a gas meter is just that, a reading of volume. Gas volume does not take into account the quality of the gas, the amount of heat available when burned. Utility customers are billed according to the heat available in the gas. The quality of the gas is measured and adjust for in each billing cycle. This is known by several names as the calorific value, heating value, or therm value.

The calorific value of natural gas can be obtained using a process gas chromatograph, which measures the amount of each constituent of the gas, namely:

- methane
- ethane
- carbon dioxide
- water

Additionally, to convert from volume to thermal energy, the pressure and temperature of the gas must be taken into consideration. Pressure is generally not a problem; the meter is simply installed immediately downstream of a pressure regulator and is calibrated to read accurately at that pressure. Pressure compensation then occurs in the utility's billing system. Varying temperature cannot be handled as easily, but some meters are designed with built-in temperature compensation to keep them reasonably accurate over their designed temperature range. Others are corrected for temperature electronically.

The indicator on the above meter

Indicating devices

Any type of gas meter can be obtained with a wide variety of indicators. The most common are indicators that use multiple clock hands (pointer style) or digital readouts similar to an odometer, but remote readouts of various types are also becoming popular.

Remote Readouts

Remote reading is becoming popular for gas meters. It is often done through an electronic pulse output mounted on the meter. There are different styles available but most common is a contact closure switch.

Flow measurement calculations

Turbine, rotary and diaphragm meters can be compensated using a calculation specified in American Gas Association Report No. 7. This standardised calculation compensates the quantity of volume as measured to quantity of volume at a set of base conditions. The AGA 7 calculation itself is a simple ratio and is, in essence, a density correction approach to translating the volume or rate of gas at flowing conditions to a volume or rate at base conditions.

Orifice meters are a very commonly used type of meter, and because of their widespread use, the characteristics of gas flow through an orifice meter have been closely studied. American Gas Association Report No. 3 deals with a broad range of issues relating to orifice metering of natural gas, and it specifies an algorithm for calculating natural gas flow rates based on the differential pressure, static pressure and temperature of a gas with a known composition.

These calculations depend in part on the ideal gas law and also require a gas compressibility calculation in order to account for the fact that real gases are not ideal. A very commonly used gas compressibility calculation is American Gas Association Report No. 8, detail characterization.

Chapter 11

Gasification

Gasification is a process that converts carbonaceous materials, such as coal, petroleum, biofuel, or biomass, into carbon monoxide and hydrogen by reacting the raw material at high temperatures with a controlled amount of oxygen and/or steam. The resulting gas mixture is called *syngas* (from *synthesis gas*) and is itself a fuel. Gasification is a method for extracting energy from many different types of organic materials.

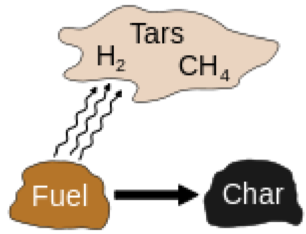
The advantage of gasification is that using the syngas is potentially more efficient than direct combustion of the original fuel because it can be combusted at higher temperatures or even in fuel cells, so that the thermodynamic upper limit to the efficiency defined by Carnot's rule is higher or not applicable. Syngas may be burned directly in internal combustion engines, used to produce methanol and hydrogen, or converted via the Fischer-Tropsch process into synthetic fuel. Gasification can also begin with materials that are not otherwise useful fuels, such as biomass or organic waste. In addition, the high-temperature combustion refines out corrosive ash elements such as chloride and potassium, allowing clean gas production from otherwise problematic fuels.

Gasification of fossil fuels is currently widely used on industrial scales to generate electricity. However, almost any type of organic material can be used as the raw material for gasification, such as wood, biomass, or even plastic waste.

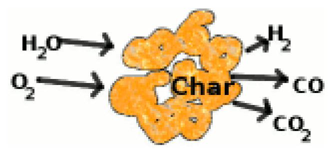
Gasification relies on chemical processes at elevated temperatures >700°C, which distinguishes it from biological processes such as anaerobic digestion that produce biogas.

Chemistry

In a gasifier, the carbonaceous material undergoes several different processes:



Pyrolysis of carbonaceous fuels



Gasification of char

1. The *pyrolysis* (or devolatilization) process occurs as the carbonaceous particle heats up. Volatiles are released and char is produced, resulting in up to 70% weight loss for coal. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char, which will then undergo gasification reactions.
2. The *combustion* process occurs as the volatile products and some of the char reacts with oxygen to primariliy form carbon dioxide and small amounts of carbon monoxide, which provides heat for the subsequent gasification reactions. Letting **C** represent a carbon-containing organic compound, the basic reaction here is $C + O_2 \rightarrow CO_2$
3. The *gasification* process occurs as the char reacts with carbon dioxide and steam to produce carbon monoxide and hydrogen, via the reaction $$C + H_2O \rightarrow H_2 + CO$$
4. In addition, the reversible gas phase water gas shift reaction reaches equilibrium very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen. $$CO + H_2O \leftrightarrow CO_2 + H_2$$

In essence, a limited amount of oxygen or air is introduced into the reactor to allow some of the organic material to be "burned" to produce carbon monoxide and energy, which drives a second reaction that converts further organic material to hydrogen and additional carbon dioxide. Further reactions occur when the formed carbon monoxide and residual water from the organic material react to form methane and excess carbon dioxide. This third reaction occurs more abundantly in reactors that increase the residence time of the reactive gases and organic materials, as well as heat and pressure. Catalysts are used in more sophisticated reactors to improve reaction rates, thus moving the system closer to the reaction equilibrium for a fixed residence time.

History

Adler Diplomat 3 with gas generator (1941)

The process of producing energy using the gasification method has been in use for more than 180 years. During that time coal and peat were used to power these plants. Initially developed to produce town gas for lighting & cooking in 1800s, this was replaced by electricity and natural gas, it was also used in blast furnaces but the bigger role was played in the production of synthetic chemicals where it has been in use since the 1920s.

During both world wars especially the Second World War the need of gasification produced fuel reemerged due to the shortage of petroleum. Wood gas generators, called Gasogene or Gazogène, were used to power motor vehicles in Europe. By 1945 there were trucks, buses and agricultural machines that were powered by gasification. It is estimated that there were close to 9,000,000 vehicles running on producer gas all over the world.

Gasification processes

Four types of gasifier are currently available for commercial use: counter-current fixed bed, co-current fixed bed, fluidized bed and entrained flow.

The **counter-current fixed bed ("up draft") gasifier** consists of a fixed bed of carbonaceous fuel (e.g. coal or biomass) through which the "gasification agent" (steam, oxygen and/or air) flows in counter-current configuration. The ash is either removed dry or as a slag. The slagging gasifiers have a lower ratio of steam to carbon, achieving temperatures higher than the ash fusion temperature. The nature of the gasifier means that the fuel must have high mechanical strength and must ideally be non-caking so that it will form a permeable bed, although recent developments have reduced these restrictions to some extent. The throughput for this type of gasifier is relatively low. Thermal efficiency is high as the gas exit temperatures are relatively low. However, this means that tar and methane production is significant at typical operation temperatures, so product gas must be extensively cleaned before use. The tar can be recycled to the reactor.

The **co-current fixed bed ("down draft") gasifier** is similar to the counter-current type, but the gasification agent gas flows in co-current configuration with the fuel (downwards, hence the name "down draft gasifier"). Heat needs to be added to the upper part of the bed, either by combusting small amounts of the fuel or from external heat sources. The produced gas leaves the gasifier at a high temperature, and most of this heat is often transferred to the gasification agent added in the top of the bed, resulting in an energy efficiency on level with the counter-current type. Since all tars must pass through a hot bed of char in this configuration, tar levels are much lower than the counter-current type.

In the **fluidized bed reactor**, the fuel is fluidized in oxygen and steam or air. The ash is removed dry or as heavy agglomerates that defluidize. The temperatures are relatively low in dry ash gasifiers, so the fuel must be highly reactive; low-grade coals are particularly suitable. The agglomerating gasifiers have slightly higher temperatures, and are suitable for higher rank coals. Fuel throughput is higher than for the fixed bed, but not as high as for the entrained flow gasifier. The conversion efficiency can be rather low due to elutriation of carbonaceous material. Recycle or subsequent combustion of solids can be used to increase conversion. Fluidized bed gasifiers are most useful for fuels that form highly corrosive ash that would damage the walls of slagging gasifiers. Biomass fuels generally contain high levels of corrosive ash.

In the **entrained flow gasifier** a dry pulverized solid, an atomized liquid fuel or a fuel slurry is gasified with oxygen (much less frequent: air) in co-current flow. The gasification reactions take place in a dense cloud of very fine particles. Most coals are suitable for this type of gasifier because of the high operating temperatures and because the coal particles are well separated from one another. The high temperatures and pressures also mean that a higher throughput can be achieved, however thermal efficiency is somewhat lower as the gas must be cooled before it can be cleaned with existing technology. The high temperatures also mean that tar and methane are not present in the product gas; however the oxygen requirement is higher than for the other types of gasifiers. All entrained flow gasifiers remove the major part of the ash as a slag as the operating temperature is well above the ash fusion temperature. A smaller fraction of the ash is produced either as a very fine dry fly ash or as a black colored fly ash slurry. Some fuels, in particular certain types of biomasses, can form slag that is corrosive for ceramic inner walls that serve to protect the gasifier outer wall. However some entrained bed type of gasifiers do not possess a ceramic inner wall but have an inner water or steam cooled wall covered with partially solidified slag. These types of gasifiers do not suffer from corrosive slags. Some fuels have ashes with very high ash fusion temperatures. In this case mostly limestone is mixed with the fuel prior to gasification. Addition of a little limestone will usually suffice for the lowering the fusion temperatures. The fuel particles must be much smaller than for other types of gasifiers. This means the fuel must be pulverized, which requires somewhat more energy than for the other types of gasifiers. By far the most energy consumption related to entrained bed gasification is not the milling of the fuel but the production of oxygen used for the gasification.

Current applications

In small business and building applications, where the wood source is sustainable, 250-1000 kWe and new zero carbon biomass gasification plants have been installed in Europe that produce tar free syngas from wood and burn it in reciprocating engines connected to a generator with heat recovery. This type of plant is often referred to as a wood biomass CHP unit but is a plant with seven different processes: biomass processing, fuel delivery, gasification, gas cleaning, waste disposal, electricity generation and heat recovery.

Industrial-scale gasification is currently mostly used to produce electricity from fossil fuels such as coal, where the syngas is burned in a gas turbine.

Gasification is also used industrially in the production of electricity, ammonia and liquid fuels (oil) using Integrated Gasification Combined Cycles (IGCC), with the possibility of producing methane and hydrogen for fuel cells. IGCC is also a more efficient method of CO_2 capture as compared to conventional technologies. IGCC demonstration plants have been operating since the early 1970s and some of the plants constructed in the 1990s are now entering commercial service.

Gasification technologies have been developed in recent years that use plastic-rich waste as a feed.

Syngas can be used for heat production and for generation of mechanical and electrical power. Like other gaseous fuels, producer gas gives greater control over power levels when compared to solid fuels, leading to more efficient and cleaner operation.

Gasifiers offer a flexible option for thermal applications, as they can be retrofitted into existing gas fueled devices such as ovens, furnaces, boilers, etc., where syngas may replace fossil fuels. Heating values of syngas are generally around 4-10 MJ/m^3.

Diesel engines can be operated on dual fuel mode using producer gas. Diesel substitution of over 80% at high loads and 70-80% under normal load variations can easily be achieved. Spark ignition engines and SOFC fuel cells can operate on 100% gasification gas. Mechanical energy from the engines may be used for e.g. driving water pumps for irrigation or for coupling with an alternator for electrical power generation.

In 2009 21stCenturyMotorworks was reported on mass media to have developed gasification technology in a prototype pickup truck that could use any biomass materials for fuel. The vehicle was displayed at multiple events including the 2009 Boston Greenfest.

While small scale gasifiers have existed for well over 100 years, there have been few sources to obtain a ready to use machine. Small scale devices are typically DIY projects. However, currently in the United States, several companies offer gasifiers to operate small engines.

Potential for renewable energy

Gasification plant Güssing, Austria (2006)

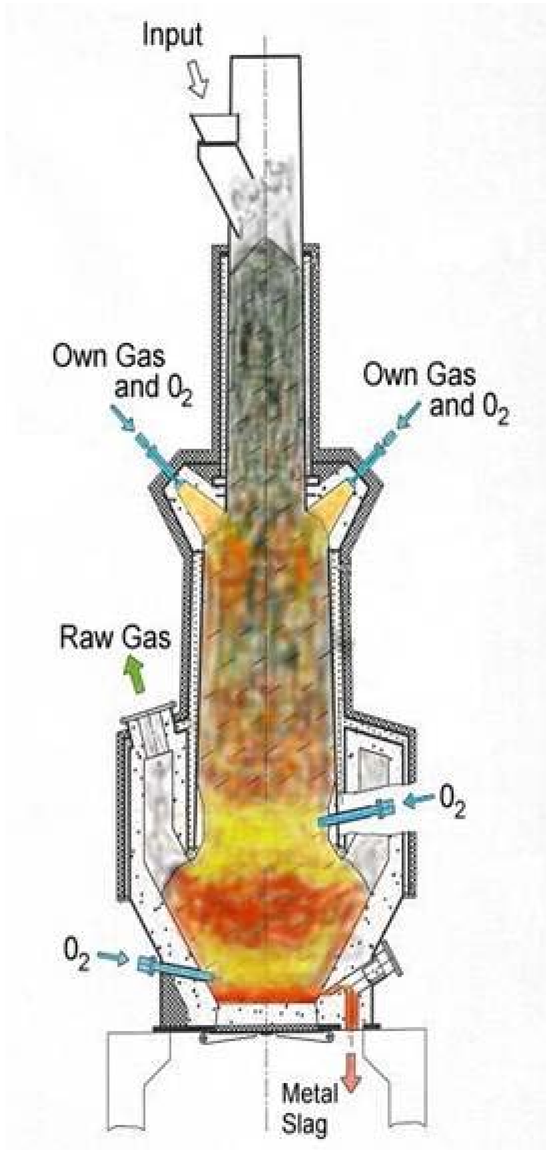
In principle, gasification can proceed from just about any organic material, including biomass and plastic waste. The resulting syngas can be combusted. Alternatively, if the syngas is clean enough, it may be used for power production in gas engines, gas turbines or even fuel cells, or converted efficiently to dimethyl ether (DME) by methanol dehydration, methane via the Sabatier reaction, or diesel-like synthetic fuel via the Fischer-Tropsch process. In many gasification processes most of the inorganic components of the input material, such as metals and minerals, are retained in the ash. In some gasification processes (slagging gasification) this ash has the form of a glassy solid with low leaching properties, but the net power production in slagging gasification is low (sometimes negative) and costs are higher.

Regardless of the final fuel form, gasification itself and subsequent processing neither directly emits nor traps greenhouse gasses such as carbon dioxide. Power consumption in the gasification and syngas conversion processes may be significant though, and may indirectly cause CO_2 emissions; in slagging and plasma gasification, the electricity consumption may even exceed any power production from the syngas. Combustion of syngas or derived fuels emits exactly the same amount of carbon dioxide as would have been emitted from direct combustion of the initial fuel. Biomass gasification and combustion could play a significant role in a renewable energy economy, because biomass production removes the same amount of CO_2 from the atmosphere as is emitted from gasification and combustion. While other biofuel technologies such as biogas and biodiesel are carbon neutral, gasification in principle may run on a wider variety of input materials and can be used to produce a wider variety of output fuels.

There is at present very little industrial scale biomass gasification being done. Examples of demonstration projects include

- Those of the Renewable Energy Network Austria, including a plant using dual fluidized bed gasification that has supplied the town of Güssing with 2 MW of electricity and 4 MW of heat, generated from wood chips, since 2003.
- Chemrec's pilot plant in Piteå that has produced 3 MW of clean syngas since 2006, generated from entrained flow gasification of black liquor.

Waste disposal



HTCW reactor, one of several proposed waste gasification processes. According to the sales and sales management consultants *KBI Group* a pilot plant in Arnstadt implementing this process has completed initial tests.

Waste gasification has several principal advantages over incineration:

- The necessary extensive flue gas cleaning may be performed on the syngas instead of the much larger volume of flue gas after combustion.
- Electric power may be generated in engines and gas turbines, which are much cheaper and more efficient than the steam cycle used in incineration. Even fuel cells may potentially be used, but these have rather severe requirements regarding the purity of the gas.

- Chemical processing of the syngas may produce other synthetic fuels instead of electricity.
- Some gasification processes treat ash containing heavy metals at very high temperatures so that it is released in a glassy and chemically stable form.

A major challenge for waste gasification technologies is to reach an acceptable (positive) gross electric efficiency. The high efficiency of converting syngas to electric power is counteracted by significant power consumption in the waste preprocessing, the consumption of large amounts of pure oxygen (which is often used as gasification agent), and gas cleaning. Another challenge becoming apparent when implementing the processes in real life is to obtain long service intervals in the plants, so that it is not necessary to close down the plant every few months for cleaning the reactor.

Several waste gasification processes have been proposed, but few have yet been built and tested, and only a handful have been implemented as plants processing real waste, and most of the time in combination with fossil fuels.

Since 2008 in Svenljunga, Sweden, a biomass gasification unit generates up to 14 MWth, supplying industries and citizens with process steam and district heating, respectively. The gasifier uses biomass fuels such as CCA or creosote impregnated waste wood and other kinds of recycled wood. In 2011 a similar gasifier, using the same kinds of fuels, is being installed at Munkfors Energy's CHP plant. The CHP plant will generate 2 MWe (electricity) and 8 MWth (district heating).

In 2011 in Green Bay Wisconsin, a deal was made with the Oneida Nation and the city of Green Bay to build a gasification power plant which will supply electricity to over 4,000 homes.

One plant (in Chiba, Japan using the Thermoselect process) has been processing industrial waste since year 2000, but has not yet documented positive net energy production from the process.

Ze-gen is operating a waste gasification demonstration facility in New Bedford, Massachusetts. The facility was designed to demonstrate gasification of specific non-MSW waste streams using *liquid metal gasification*.

Chapter 12

Nitrogen Generator

Nitrogen generators and stations are stationary or mobile air-to-nitrogen production complexes. In advanced economies, membrane nitrogen plants have almost ousted alternative processes of nitrogen generation in all cases where nitrogen is not required in commercial volumes.

Adsorption nitrogen generator

Adsorption Technology

Adsorption concept

Adsorption nitrogen generator

The adsorption gas separation process in nitrogen generators is based on the phenomenon of fixing various gas mixture components by a solid substance called an adsorbent. This phenomenon is brought about by the gas and adsorbent molecules' interaction.

Swing adsorption technology

The technology of air-to-nitrogen production with the use of adsorption processes in nitrogen generators is well studied and widely applied at industrial facilities for the recovery of high-purity nitrogen.

The operating principle of a nitrogen generator utilizing the adsorption technology is based on the dependence of the adsorption rates featured by various gas mixture components upon pressure and temperature factors. Among nitrogen adsorption plants of various types, Pressure swing adsorption (PSA) plants have found the broadest application world-wide.

The system's design is based on the regulation of gas adsorption and adsorbent regeneration by means of changing pressures in two adsorber–adsorbent-containing vessels. This process requires constant temperature, close to ambient. With this process, nitrogen is produced by the plant at the above-atmospheric pressure, while the adsorbent regeneration is accomplished at below-atmospheric pressure.

The swing adsorption process in each of the two adsorbers consists of two stages running for a few minutes. At the adsorption stage the adsorbent serves to adsorb predominantly one of the gas mixture components with the recovery of product nitrogen. At the regeneration stage the adsorbed component is released from the adsorbent and is vented in the atmosphere. The process is then multiply repeated.

Advantages of nitrogen generators

High nitrogen purity

Adsorption nitrogen generator plants allow production of high-purity nitrogen from air, which membrane systems are unable to provide – up to 99.9995% nitrogen. This nitrogen purity may also be ensured by cryogen systems, but they are considerably more complex and justified only by large consumption volumes. The Nitrogen generators use CMS (Carbon Molecular Sieve) technology to produce a continuous supply of ultra high purity nitrogen and are available with internal compressors or without.

Low operating costs

- By substitution of out-of-date air separation plants nitrogen production savings largely exceed 50%.
- The net cost of nitrogen produced by nitrogen generators is 20 to 30 times less than the cost of bottled or liquefied nitrogen.

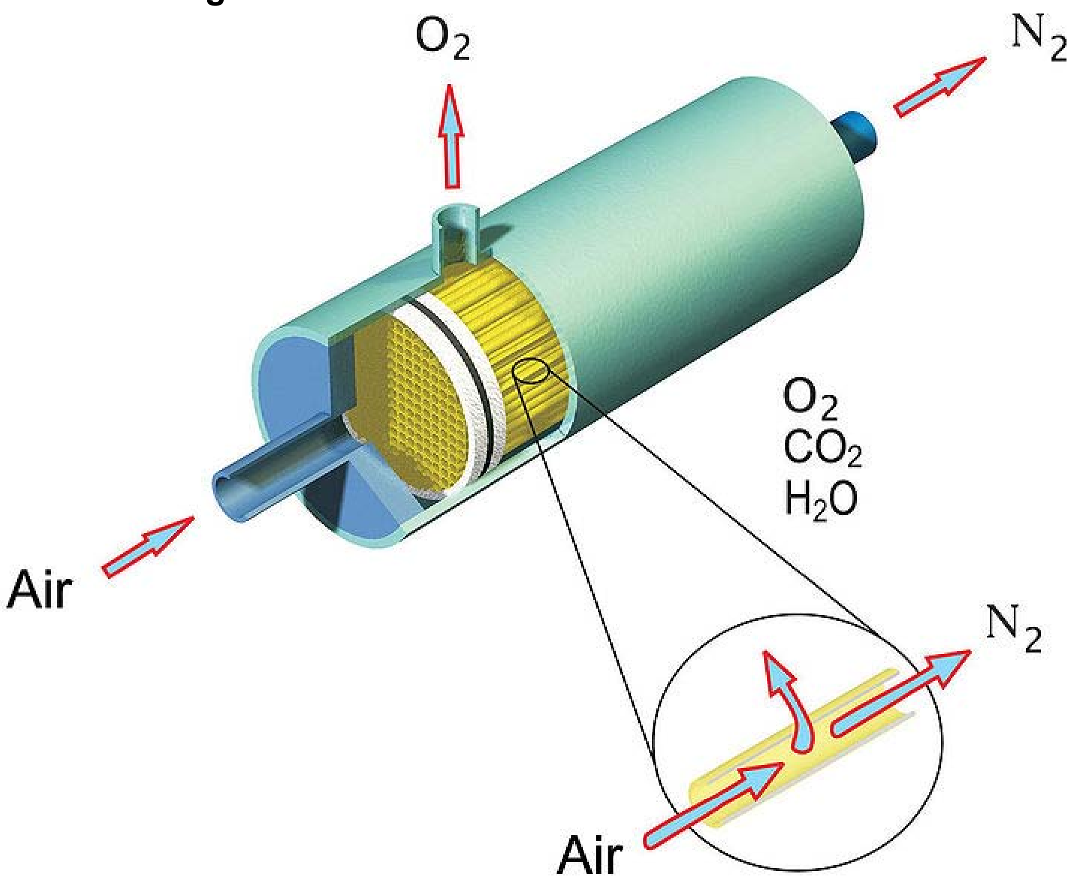
Membrane Technology

Membrane nitrogen generator

Gas separation concept

The operation of membrane systems is based on the principle of differential velocity with which various gas mixture components permeate membrane substance. The driving force in the gas separation process is the difference in partial pressures on different membrane sides.

Membrane cartridge



Flux distribution inside the fiber

Structurally, a hollow-fiber membrane represents a cylindrical cartridge functioning as a spool with specifically reeled polymer fibers. Gas flow is supplied under pressure into a bundle of membrane fibers. Due to the difference in partial pressures on the external and internal membrane surface gas flow separation is accomplished.

Advantages

Economic benefits

- By substitution of out-of-date cryogenic or adsorption systems nitrogen production savings generally exceed 50%.
- The net cost of nitrogen produced by nitrogen complexes is 20 to 30 times less than the cost of cylinder or liquefied nitrogen.

Module design

With respect to the simplicity of the system, a nitrogen generator can be split into modules. This is in direct contrast to classical systems where the equipment is designed for a certain stage of the separation process. Using a modular system, the generation facility may be built from a selection of preexisting equipment and where necessary, the output capacity of a plant may be increased at the minimum cost. This option appears all the more useful where a project envisages a subsequent increase in enterprise capacity, or where demand may simply require on site production of nitrogen by employing equipment that is already present.

Dependability

Gas separation units have no moving component parts, thus ensuring the exceptional reliability of Company plants. Membranes are highly resistant to vibration and shocks, chemically inert to greases, moisture-insensitive, and capable of operating over a wide temperature range of –40°C to +60°C. With appropriate maintenance, membrane unit useful life ranges between 130,000 and 180,000 hours (15 to 20 years of continuous operation).

Disadvantages

- limited capacity
- relativity low purity (higher purity applications are available at lower flow rates ≤ 10L/min)

Applications of nitrogen generators

- Petroleum industry

In the petroleum industry, nitrogen is an indispensable component in a number of processes. Most commonly, nitrogen is used to create an inert environment for preventing explosions and for fire safety and to support transportation and transfer of hydrocarbons. Additionally, nitrogen is used for pipeline testing and purging, cleaning technological vessels and cleaning liquefied gas carriers and hydrocarbon storage facilities.

- Metallurgy

The metal industry generally utilizes nitrogen as a means of protecting ferrous and non-ferrous metals during annealing. Also, nitrogen is helpful in such standard industry processes as neutral tempering, cementing, hard brazing, stress relieving, cyanide hardening, metal-powder sintering and extrusion die cooling.

- Chemical and petrochemical industries

The primary and very important application of nitrogen in chemical and petrochemical industries is the provision of inert environment aimed at ensuring general industrial safety during cleaning and protection of process vessels. Besides, nitrogen is used for pipelines pressure testing, chemical agents transportation, and regeneration of used catalysts in technological processes.

- Paint-and-varnish industry

Paint and varnish production uses nitrogen for the creation of an inert environment in process vessels to ensure safety, as well as for oxygen displacement during packing in order to prevent polymerization of drying oils.

- Pharmaceutical industry

In pharmaceutical industry, nitrogen finds application in pharmaceuticals packaging, and ensuring against explosion and fire safety in activities where fine dispersed substances are used.

- Electronics

In electronics, nitrogen serves as an antioxidant in the manufacture of semi-conductors and electric circuits, heat treatment of finished products, as well as in blowing and cleaning.

- Glass industry

In the glass production, nitrogen proves efficient as a cooling agent for bow oven electrodes, oxidation inhibitor during process procedures, as well as air cooler.

Chapter 13

Liquefaction of Gases, Liquid Ring Pump and Vortex Tube

Liquefaction of gases

Liquefaction of gases includes a number of phases used to convert a gas into a liquid state. The processes are used for scientific, industrial and commercial purposes. Many gases can be put into a liquid state at normal atmospheric pressure by simple cooling; a few, such as carbon dioxide, require pressurization as well. Liquefaction is used for analyzing the fundamental properties of gas molecules (intermolecular forces), for storage of gases, for example: LPG, and in refrigeration and air conditioning. There the gas is liquefied in the *condenser*, where the heat of vaporization is released, and evaporated in the *evaporator,* where the heat of vaporization is absorbed. Ammonia was the first such refrigerant, but it has been replaced by compounds derived from petroleum and halogens.

Liquid oxygen is provided to hospitals for conversion to gas for patients suffering from breathing problems, and liquid nitrogen is used in the medical field for cryosurgery, and by inseminators to freeze semen. Liquefied chlorine is transported for eventual solution in water, after which it is used for water purification, sanitation of industrial waste, sewage and swimming pools, bleaching of pulp and textiles and manufacture of carbon tetrachloride, glycol and numerous other organic compounds as well as phosgene gas.

Liquefaction of helium (^{4}He) with the Hampson-Linde cycle led to a Nobel Prize for Heike Kamerlingh Onnes in 1913. At ambient pressure the boiling point of liquefied helium is 4.22 K (-268.93°C). Below 2.17 K liquid ^{4}He becomes a superfluid (Nobel Prize 1978, Pyotr Kapitsa) and shows characteristic properties such as heat conduction through second sound, zero viscosity and the fountain effect among others.

The liquefaction of gases is a complicated process that uses various compressions and expansions to achieve high pressures and very low temperatures; using for example turboexpanders.

The liquefaction of air is used to obtain nitrogen, oxygen, and argon and other atmospheric noble gases by separating the air components by fractional distillation in an cryogenic air separation unit.

History

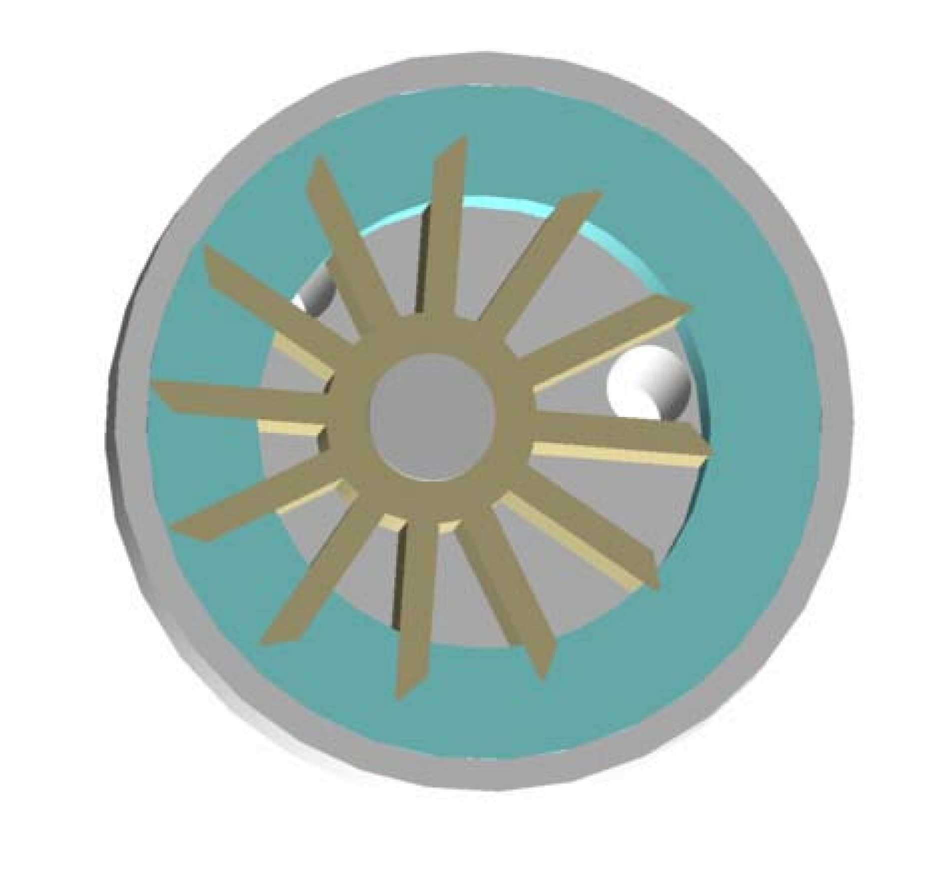
Linde's Process

Air is liquefied by the Linde process, in which air is alternately compressed, cooled, and expanded, the expansion resulting each time in a considerable reduction in temperature. With the lower temperature the molecules move more slowly and occupy less space, so the air changes phase to become liquid.

Claude's Process

Air can also be liquefied by Claude's process in which the gas is allowed to expand adiabatically twice in two chambers so that the liquefaction occurs quickly. This liquefaction takes place by the Joule-Thomson effect.

Liquid ring pump



Liquid ring pump

A **liquid ring pump** is a rotating positive displacement pump. They are typically used as a vacuum pump but can also be used as a gas compressor. The function of a liquid ring pump is similar to a rotary vane pump the difference being that the vanes are an integral part of the rotor and churn a rotating ring of liquid to form the compression chamber seal. They are an inherently low friction design, with the rotor being the only moving part. Sliding friction is limited to the shaft seals. Liquid ring pumps are typically powered by an induction motor.

Description of operation

The liquid ring pump compresses gas by rotating a vaned impeller within an eccentric to a cylindrical casing. Liquid (usually water) is fed into the pump and, by centrifugal acceleration, forms a moving cylindrical ring against the inside of the casing. This liquid ring creates a series of seals in the space between the impeller vanes, which form compression chambers. The eccentricity between the impeller's axis of rotation and the casing geometric axis results in a cyclic variation of the volume enclosed by the vanes and the ring.

Gas, often air, is drawn into the pump via an inlet port in the end of the casing. The gas is trapped in the compression chambers formed by the impeller vanes and the liquid ring. The reduction in volume caused by the impeller rotation compresses the gas, which reports to the discharge port in the end of the casing.

History

US Patent 1,091,529, for liquid ring vacuum pumps and compressors, was granted to Lewis H. Nash in 1914 . They were manufactured by the Nash Engineering Company in Norwalk, CT. Around the same time, in Austria, Patent 69274 was granted to Siemens-Schuckertwerke for a similar liquid ring vacuum pump.

Recirculation of ring-liquid

Some ring-liquid is also entrained with the discharge stream. This liquid is separated from the gas stream by other equipment external to the pump. In some systems, the discharged ring-liquid is cooled via heat exchanger or cooling tower, then returned to the pump casing. In some recirculating systems, contaminants from the gas become trapped in the ring-liquid, depending on system configuration. These contaminants become concentrated as the liquid continues to recirculate, eventually causes damage and reduced life to the pump. In this case, filtration systems are required to ensure contamination is kept to acceptable levels.

In non-recirculating systems, the discharged hot liquid (usually water) is treated as a waste stream. In this case, fresh, cool water is used to make up the loss. Environmental considerations are making such "once-through" systems increasingly rare.

Types and Applications

Liquid ring systems can be single or multi-stage. Typically a multi-stage pump will have up to two compression stages on a common shaft. In vacuum service, the attainable pressure reduction is limited by the vapour pressure of the ring-liquid. As the vacuum generated approaches the vapour pressure of the ring-liquid, the increasing volume of vapor released from the ring-liquid diminishes the remaining vacuum capacity. The efficiency of the system declines as a result.

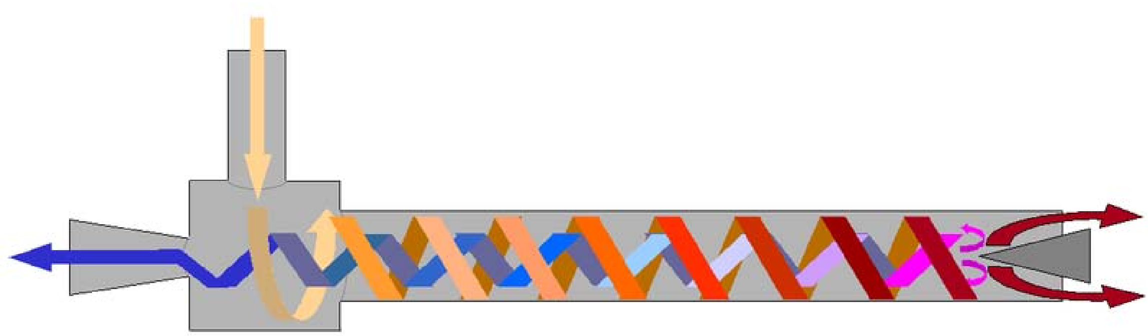
Single stage vacuum pumps typically produce vacuum to 35 torr (mm Hg) or 0.047 bar, and two-stage pumps can produce vacuum to 25 torr (mmHgA), assuming air is being pumped and the ring-liquid is water at 15°C (60F) or less. Dry air and 15°C sealant water temperature is the standard performance basis which most manufacturers use for their performance curves.

These simple, but highly reliable pumps have a variety of industrial applications. One typical industrial application is the vacuum forming of molded paper pulp products (egg cartons and other packaging). Other applications include soil remediation, where contaminated ground water is drawn from wells by vacuum. In petroleum refining, vacuum distillation also makes use of liquid ring vacuum pumps to provide the process vacuum. Liquid ring compressors are often used in vapor recovery systems.

Liquid Ring Vacuum Pumps can use any liquid compatible with the process, provided it has the appropriate vapor pressure properties, as the sealant liquid. Although the most common sealant is water, almost any liquid can be used. The second most common is oil. Since oil has a very low vapor pressure, oil-sealed liquid ring vacuum pumps are typically air-cooled.

The ability to use any liquid allows the liquid ring vacuum pump to be ideally suited for solvent(vapor) recovery. If a process, such as distillation, or a vacuum dryer is generating toluene vapors, for example, then it is possible to use toluene as the sealant, provided the cooling water is cold enough to keep the vapor pressure of the sealant liquid low enough to pull the desired vacuum.

Vortex tube



Separation of a compressed gas into a hot stream and a cold stream

The **vortex tube**, also known as the **Ranque-Hilsch vortex tube**, is a mechanical device that separates a compressed gas into hot and cold streams. It has no moving parts.

Pressurized gas is injected tangentially into a *swirl chamber* and accelerates to a high rate of rotation. Due to the conical nozzle at the end of the tube, only the outer shell of the compressed gas is allowed to escape at that end. The remainder of the gas is forced to return in an inner vortex of reduced diameter within the outer vortex.

There are different explanations for the effect and there is debate on which explanation is best or correct.

What is usually agreed upon is that the air in the tube experiences mostly "solid body rotation", which simply means the rotation rate (angular velocity) of the inner gas is the same as that of the outer gas. This is different from what most consider standard vortex behaviour — where inner fluid spins at a higher rate than outer fluid. The (mostly) solid body rotation is probably due to the long time which each parcel of air remains in the vortex — allowing friction between the inner parcels and outer parcels to have a notable effect.

It is also usually agreed upon that there is a slight effect of hot air wanting to "rise" toward the center, but this effect is negligible — especially if turbulence is kept to a minimum.

One simple explanation is that the outer air is under higher pressure than the inner air (because of centrifugal force). Therefore the temperature of the outer air is higher than that of the inner air.

Another explanation is that as both vortices rotate at the same angular velocity and direction, the inner vortex has lost angular momentum. The decrease of angular momentum is transferred as kinetic energy to the outer vortex, resulting in separated flows of hot and cold gas.

This is somewhat analogous to a Peltier effect device, which uses electrical pressure (voltage) to move heat to one side of a dissimilar metal junction, causing the other side to grow cold.

When used to refrigerate, heat-sinking the whole vortex tube is helpful.

History

The vortex tube was invented in 1933 by French physicist Georges J. Ranque. German physicist Rudolf Hilsch improved the design and published a widely read paper in 1947 on the device, which he called a *Wirbelrohr* (literally, whirl pipe). The vortex tube was used to separate gas mixtures, oxygen and nitrogen, carbon dioxide and helium, carbon dioxide and air in 1967 by Linderstrom-Lang. Vortex tubes also seem to work with liquids to some extent. In 1988 R.T.Balmer applied liquid water as the working medium. It was found that when the inlet pressure is high, for instance 20-50 bar, the heat energy separation process exists in incompressible (liquids) vortex flow as well.

Efficiency

Vortex tubes have lower efficiency than traditional air conditioning equipment. They are commonly used for inexpensive spot cooling, when compressed air is available. Commercial models are designed for industrial applications to produce a temperature drop of about 45 °C (80 °F). With no moving parts, no electricity, and no Freon, a vortex tube can produce refrigeration up to 6000 BTU using only filtered compressed air at 100

PSI. A control valve in the hot air exhaust adjusts temperatures, flows and refrigeration over a wide range.

Proposed applications

- Dave Williams, of dissigno, has proposed using vortex tubes to make ice in third-world countries. Although the technique is inefficient, Williams expressed hope that vortex tubes could yield helpful results in areas where using electricity to create ice is not an option.

- There are industrial applications that result in unused pressurized gases. Using vortex tube energy separation may be a method to recover waste pressure energy from high and low pressure sources.