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## The History of Steam Generation

Sebastian Teir

Helsinki University of Technology  
Department of Mechanical Engineering  
Energy Engineering and Environmental Protection

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## Early boilers

### Introduction

Furnaces were developed originally from a need to fire pottery (4000 B.C.) and to smelt copper (3000 B.C.). Closely associated with furnaces are boilers, that were first used for warming water and are of Roman and Greek origin. Early boilers were recovered from the ruins of Pompeii.

In 1698, Thomas Savery developed a steam-driven water pump. As the steam condensed, a vacuum was created causing the water to be drawn into the cylinder. The boiler continued to be refined and developed for use during the Industrial Revolution.

### Newcomen's boiler

The era of first boilers for industrial use stems from England in the 1700 - 1800. The first use of boilers was pumping water out from mines. These boilers had a very low efficiency, but since there was no lack of fuel supply the boilers replaced the horse driven pumps.

One of the first successful boilers was Thomas Newcomen's boiler (Figure 3). It was the first example of steam driven machine capable of extended period of operation. This type of boiler was called shell boiler. The steam was produced at atmospheric pressure. The boiler was made from copper, using rivets and bent metal sheets (Figure 4). In 1800, iron replaced copper in order to make the boiler last for increased pressures. Later the cylindrical design was replaced by the wagon-type design for increased capacities.

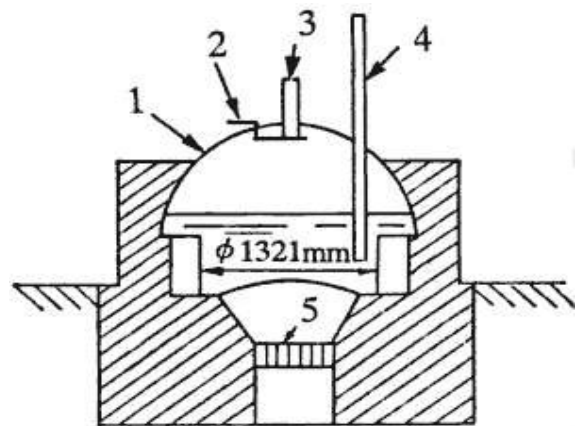


Figure 3: Newcomen's boiler, 1 - shell over the boiling water, 2 - steam valve, 3 - steam pipe, 4 - float for water level, 5 - grate doors

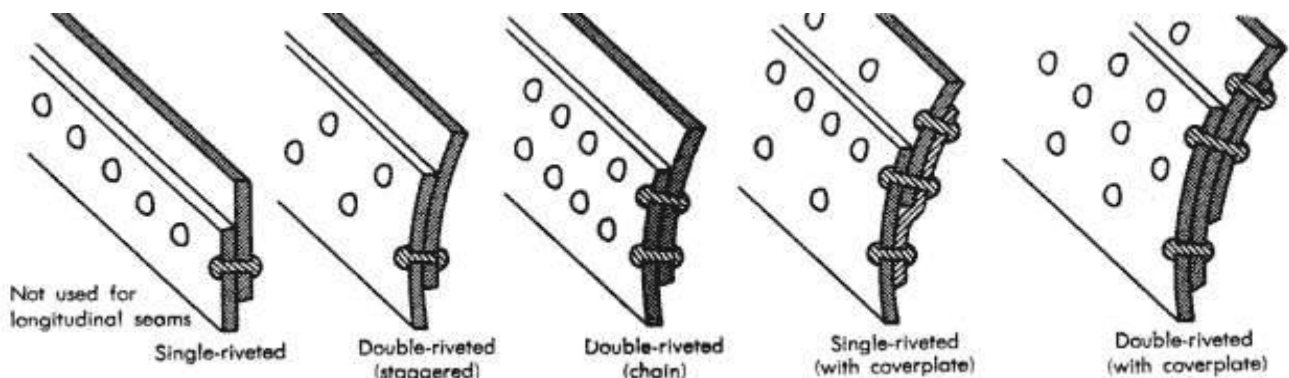


Figure 4: Different kinds of riveting techniques. Riveting was used as the main manufacturing method of boilers until the 1950's. Riveting is today used when manufacturing aircraft aluminium structures [Shields, 1961].

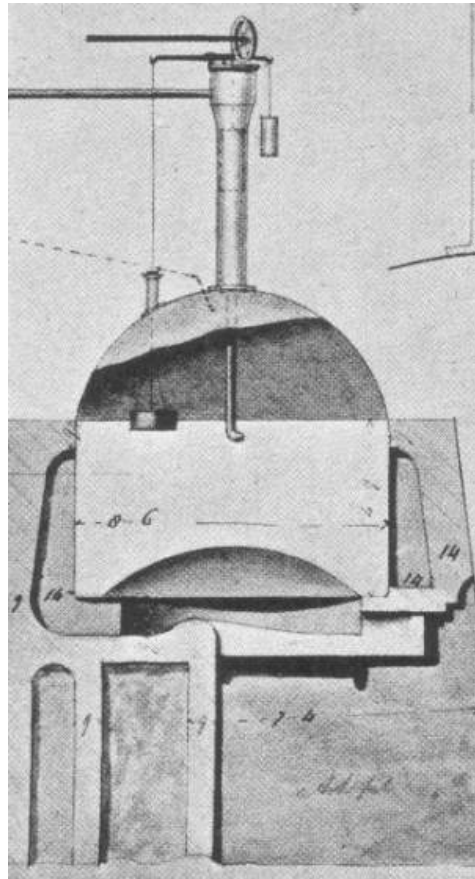
## Wagon boiler

When James Watt made some critical improvements to the Newcomen steam engine by separating the condenser from the cylinder and thus improving the efficiency substantially, the steam engine became in demand and provided a rapid growth of boilers.

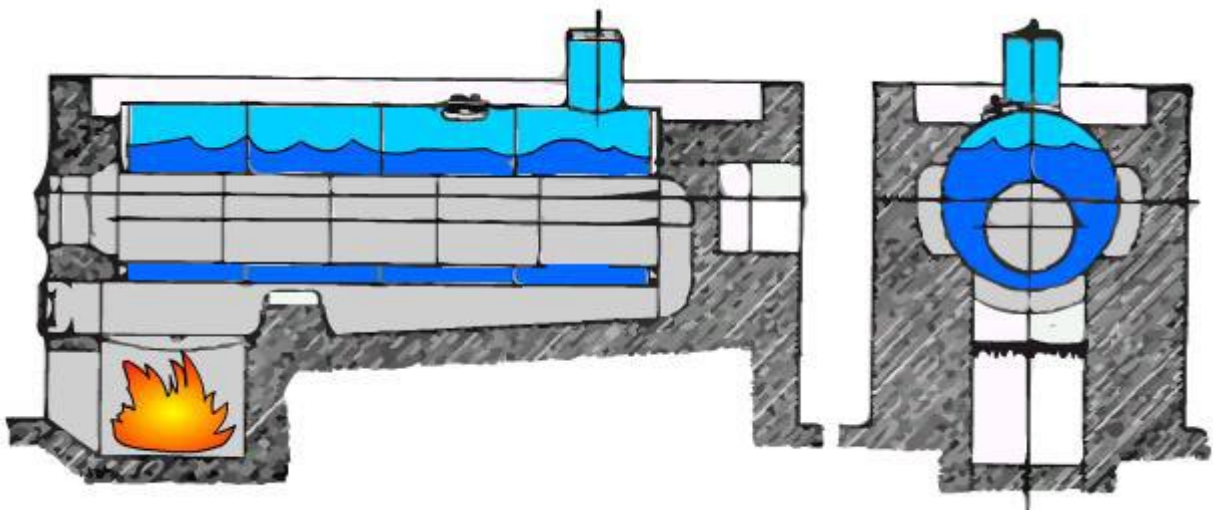
The earliest steam boilers were usually spheres or sections of spheres, heated entirely from the outside (Figure 5). Watt introduced the use of the wagon boiler (shaped like the top of a covered wagon), which is still being used with low pressures.

## Cylindrical boiler

Watt and Newcomen steam engines all operated at pressures only slightly above atmospheric pressure. In 1800 the American inventor Oliver Evans built a high-pressure steam engine utilizing a horizontal cylindrical boiler. Evans's boiler consisted of two cylindrical shells, one inside the other with water occupying the region between them. The fire grate was housed inside the inner cylinder, so flue gas flowed through the smaller cylinder and thus heated the water, permitting a rapid increase in steam pressure.



*Figure 5: Wagon boiler*



*Figure 6: Cylindrical boiler [Forsman-Saraoja, 1928].*

As can be seen from the picture (Figure 6), the flue gas passes also around the cylindrical boiler. One of the advantages of the cylindrical boiler is that it has a larger heat transfer surface per unit of working fluid. Therefore cylindrical boiler can be built cheaper than the earlier boilers. The pressure (and thus the temperature) can also be increased with the cylindrical design. Simultaneously but

independently, the British engineer Richard Trevithick developed a similar boiler, which was used in the world's first practical steam locomotive that he invented in 1801. The cylindrical boiler was later expanded to contain several passes and eventually formed the fire tube boiler.

# The development of modern boiler technology

## Introduction

The steam boiler became ever more important towards the end of the last century. The industry and transportation methods had become heavily dependant of steam power. Inventive engineers were set to work to develop increasingly new boiler types. There was room for improvement as efficiency and safety of many boilers frequently left a lot to be desired. Again and again there were boiler explosions with catastrophic consequences. Hundreds of workers died. In the USA in 1880, for instance, 170 notified boiler explosions are recorded involving 259 dead and 555 injured.

The principles of the boiler technologies introduced in this chapter are still in use today.

## Fairbarn's fire tube boiler

The first major improvement over Evans and Trevithick's boilers was the fire-tube Lancashire Boiler, patented in 1845 by the British engineer Sir William Fairbairn, in which hot combustion gases were passed through tubes inserted into the water container, increasing the surface area through which heat could be transferred. The saturated steam was led out from the top. The main use was to run steam engines for motive power: It was used to power steamboats, railroad engines and run industrial machinery via belt drives. Fire-tube boilers (Figure 7) were limited in capacity and pressure and were also, sometimes, dangerously explosive. [A more detailed explanation of the Lancashire Boiler can be found here.](#)

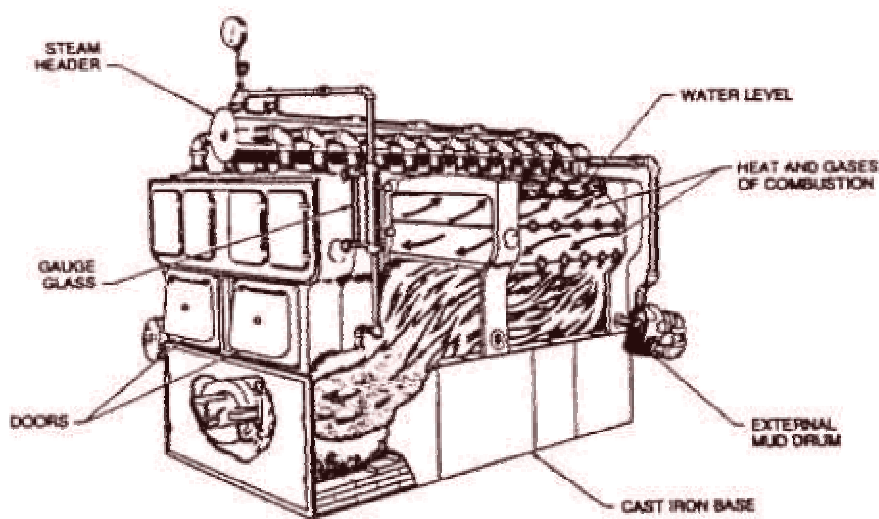


Figure 7: Cast iron fire tube boiler.

## Wilcox' water tube boiler

The water tube boiler (Figure 8 and Figure 9) was patented in 1867 by the American [inventors George Herman Babcock and Stephen Wilcox](#). The boiler had larger heating surfaces, allowed better water circulation, and, most noteworthy, reduced the risk of explosion drastically. In the water-tube boiler, water flowed through tubes heated externally by combustion gases through radiation and convection and steam was collected above in a drum. The large number of tubes and use of cross gas flow increases the heat transfer rate. Boilers of this type could be built with larger

heat transfer surface per unit of working fluid than the previous design. Due to the higher rate of heat transfer cooler flue gases could be used. Tubes could be made inexpensively and with higher quality than plate. [7]

The water-tube boiler became the standard for all large boilers as they allowed for higher pressures than earlier boilers as well. Their first use was to run the largest steam machines but it quickly became the boiler type of choice for a steam turbine. Wilcox and Babcock founded in 1867 the first boiler-making company in Providence. This company exists still today and one of its former subsidiaries delivers boilers in Europe under the name [Babcock Borsig](#). [8]

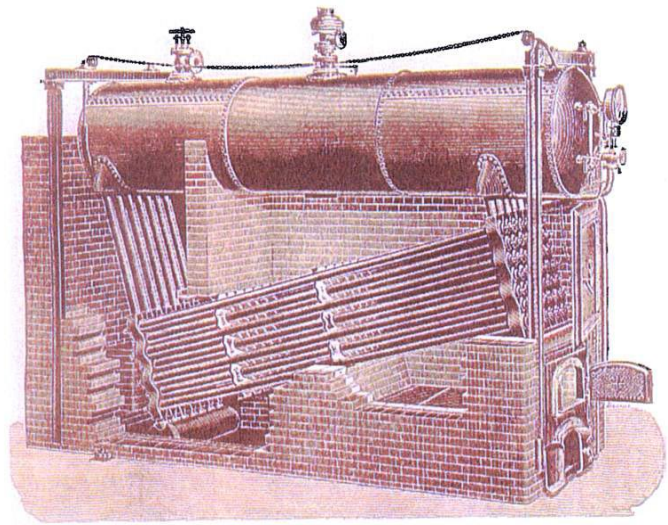


Figure 8: Wilcox' water tube boiler [\[Babcock\]](#).

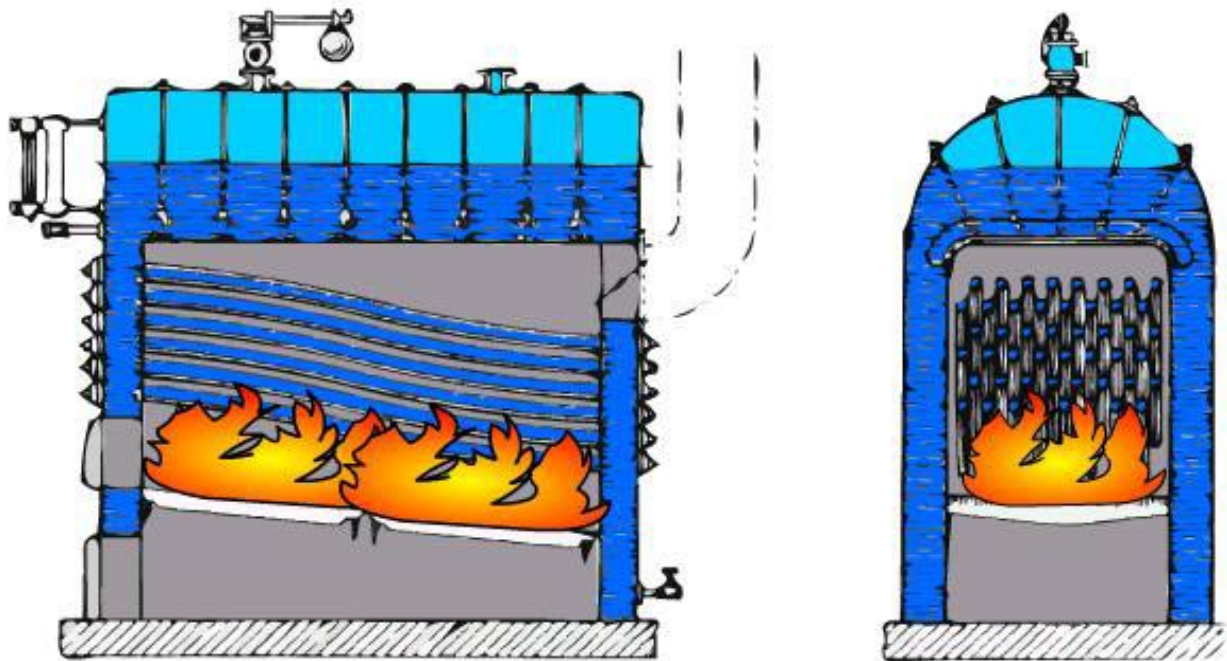


Figure 9: A drawing of a Wilcox' water tube boiler. Bent tubes in a tight bundle receive heat from flue gas mainly convectively. The tubes are in a tilted position in order to achieve a natural circulation of water/steam. The furnace is usually made of bricks. [For more details, follow this link](#) [Croft, 1922].



## Steam drum boiler

The next step was the emergence of the drum boiler, which introduced a steam drum for separating steam from water (Figure 10). This coincided with the spreading of a new tube manufacturing technology, forming. This allowed cheap and reliable joint between the drum and a tube. Except from being easier to manufacture, the drum boiler was also beneficial by providing better control of the water quality by having a mud drum. Some early designs incorporated a number of steam drums, as in the picture. A boiler with two drums became quickly a standard. The limitation of a tube shell is its thickness required to withstand pressure. If larger units were required multiple boilers needed to be operated. In late 1800 some ten water tube boilers could be connected to a single steam engine or a turbine. With the new design much larger boilers could be built.

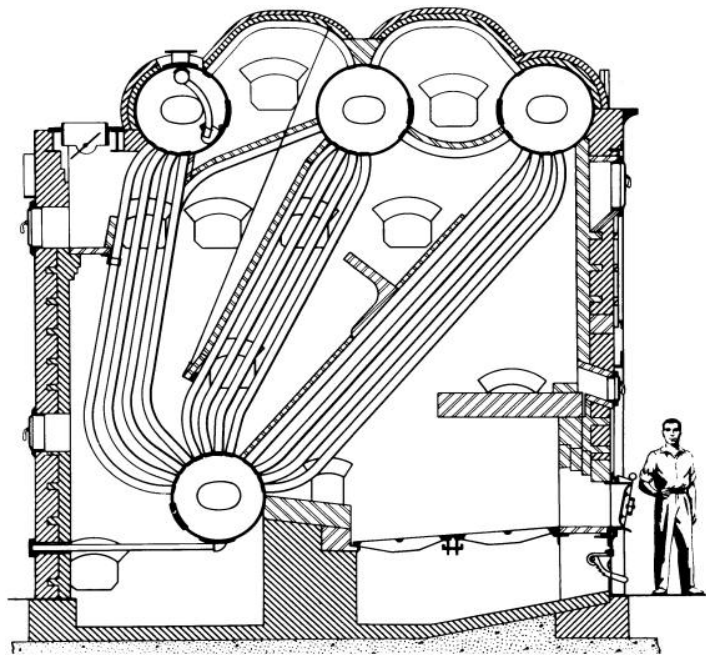


Figure 10: Multi drum boiler of Stirling type. [Steam, 1992]

## Tube walled furnace

The demand for even bigger boiler unit sizes to drive steam turbines required larger furnace volume, which eventually led to the development of the tube walled furnace (Figure 11). The tube walled furnace finally integrated the earlier separated combustion and heat transfer into the same space by building heat transferring tubes into the furnace. This meant high savings and started rapid unit size increase. About 1955 the first fully welded furnace (membrane wall) was developed.

In a modern tube walled furnace the inside of the furnace wall is completely covered of heat transferring water tubes, welded together side by side. Since the water tubes are in the furnace the heat is being transferred mainly by radiation from the combustion process. A utility boiler is a boiler that is part of an industrial process.

Welding forms today the basis of all modern steam boiler manufacture. The first applications of welding to boiler manufacturing were in the 1930's ().

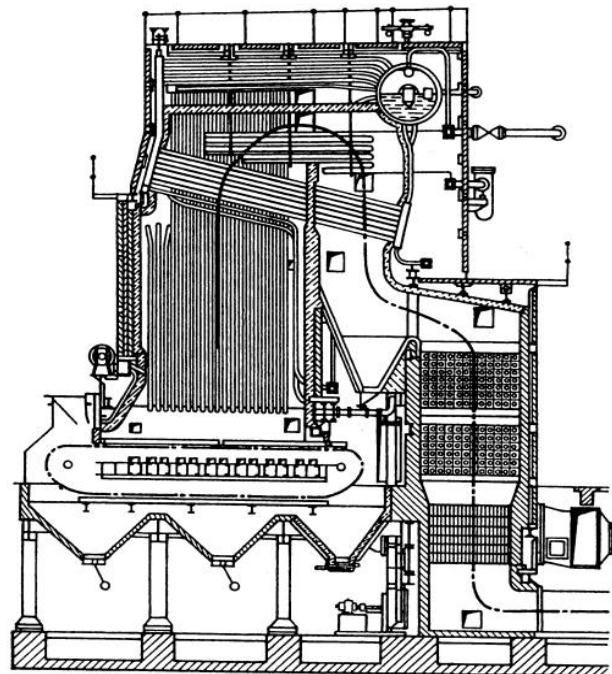


Figure 11: Early boiler with tube walled furnace [Effenberg, 2000].

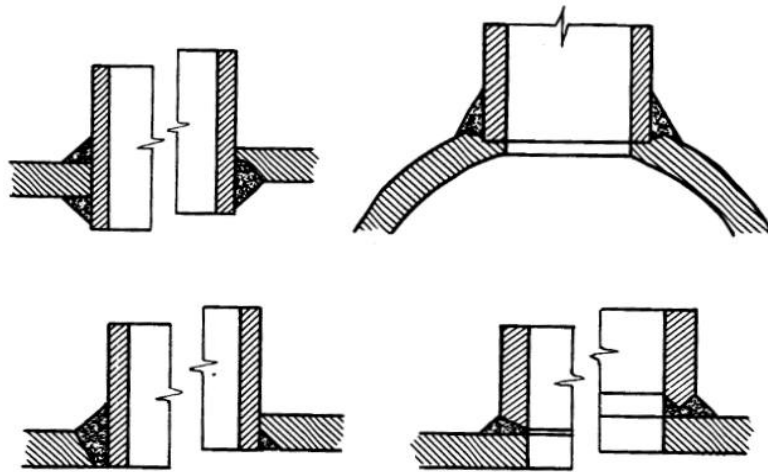


Figure 12: Different methods of welding boiler tubes.

### Once-through boiler

In order to be able to increase the current unit size and efficiency of boilers, the restriction of natural circulation boilers needed to be overcome. The idea of a once through boiler, where no steam drum would be used and thus no circulation of non-vaporized water would take place, was not new. Patents for once through boiler concepts date from as early as 1824.

The first significant commercial application of a once through boiler was not made until 1923, when the Czechoslovakian inventor Mark Benson provided a small 1,3 kg/s once through boiler for English Electric Co. The unit was designed to operate at critical steam pressure, but due to frequent tube failures, the pressure had to be dropped.

The once through boiler uses smaller diameter and thinner walled tubes than the natural circulation boiler. In addition, the once through boiler eliminates the need for thick steel plate for the steam drum. Due to limited material availability in Europe, the once through philosophy was followed during the 1930's and 1940's, while the United States continued to rely on natural circulation boiler design. [9]

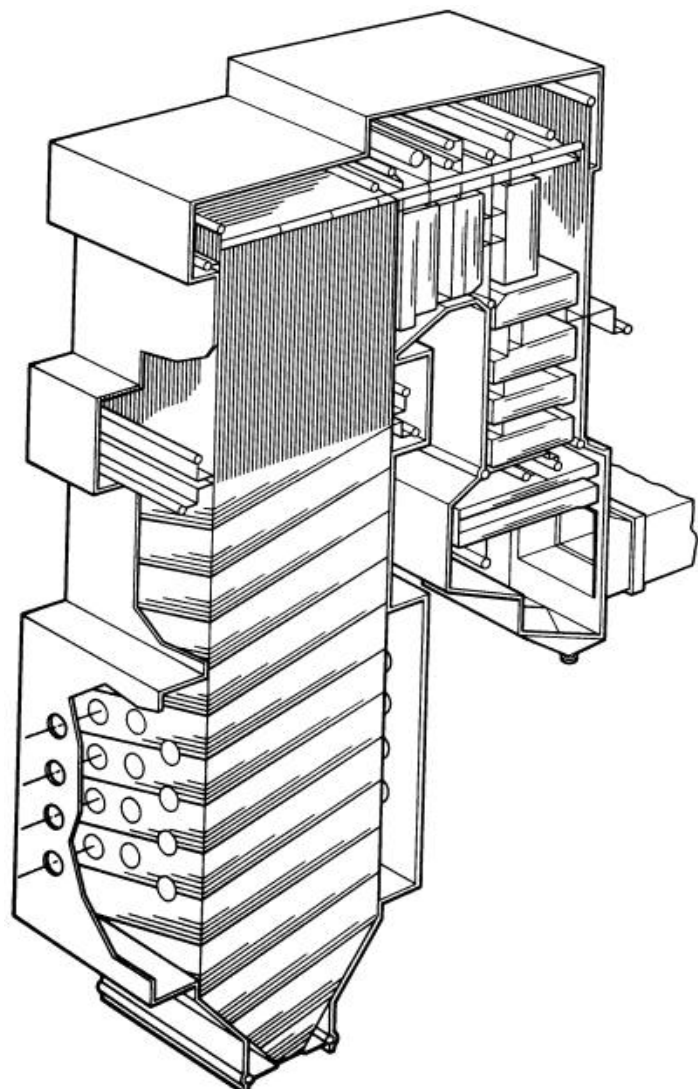
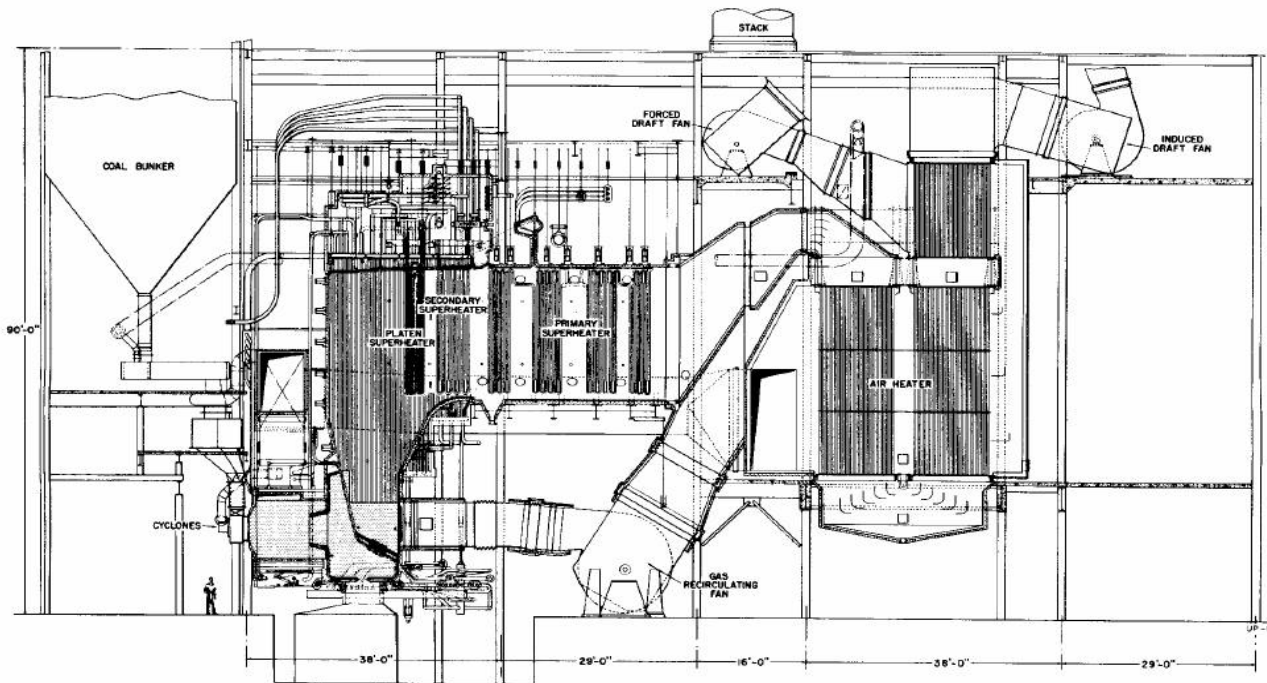


Figure 13: Benson type once through boiler with tilted tube wall [Stultz and Kitto, 1992].

## Supercritical boiler

The era following the Second World War brought on rapid economic development in the United States and the desire for more efficient power plant operation increased. Improvements in both boiler tube metallurgy and water chemistry technologies in combination with once through boiler-technology made a power plant, operating at supercritical water pressure, possible.



*Figure 14: The world's first supercritical power plant, built by Babcock&Wilcox and General Electric, started operating at 125 MW in 1957 with a main steam condition of 31 MPa and 621°C [Babcock].*

# Graphs and timelines of development in boiler technology

## Development of unit size

To conclude the chapter on the history of boiler technology up to date, we start with presenting a timeline on how the unit sizes of boilers have changed throughout history (

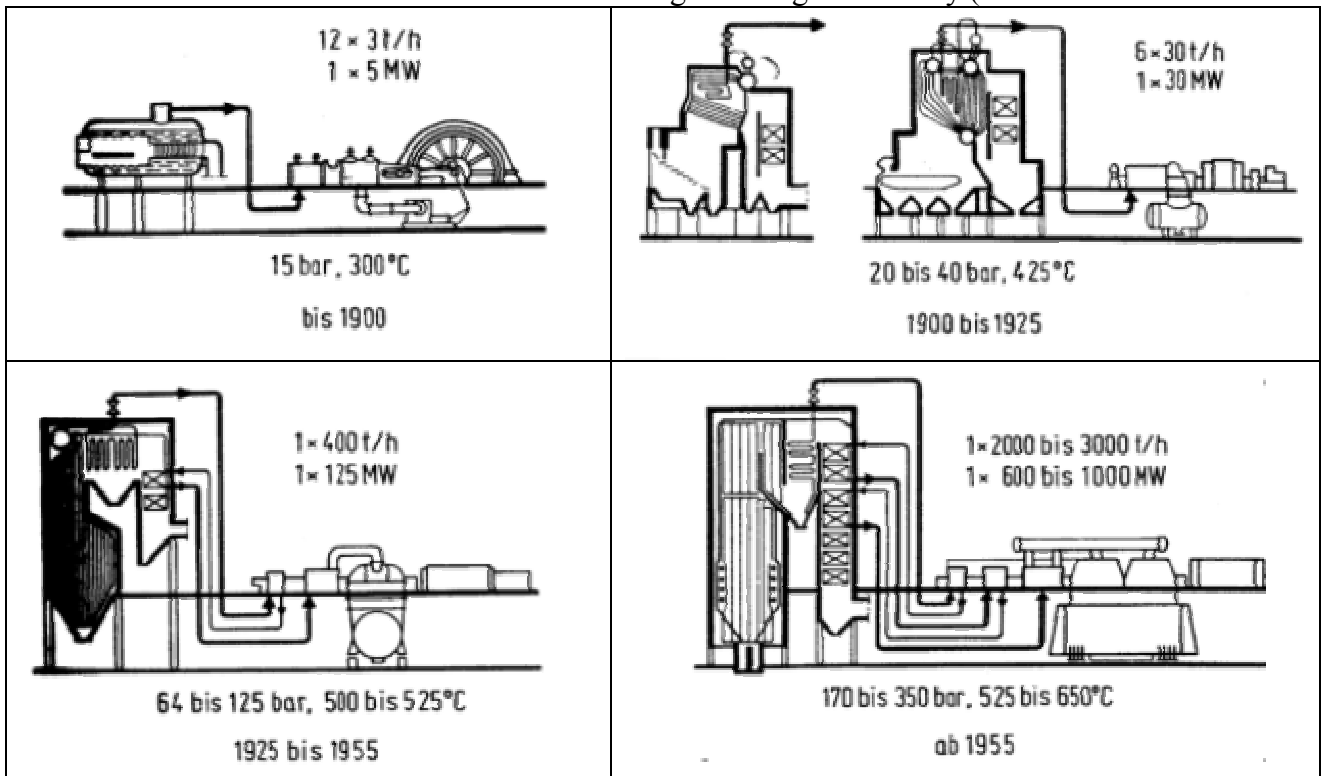
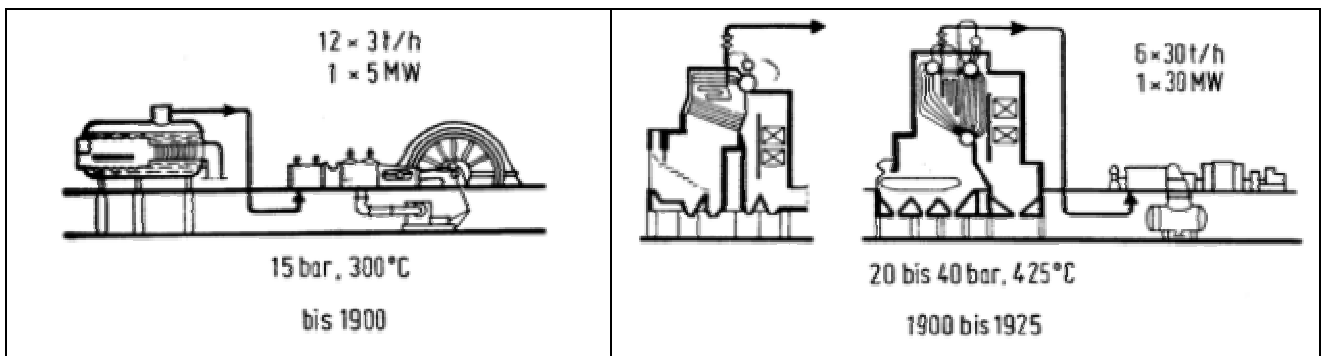


Figure 15).



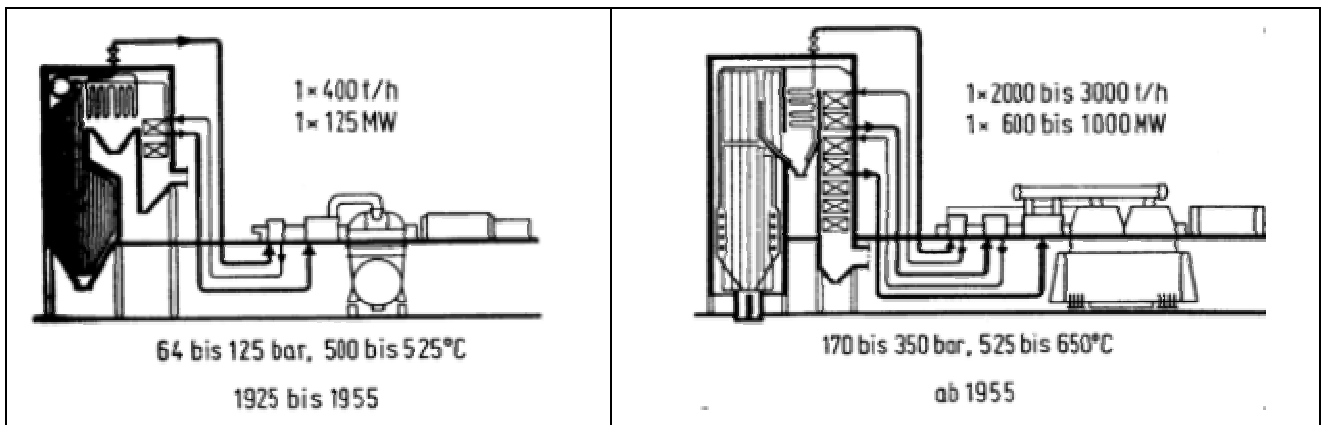


Figure 15: Development of unit size.

### Development of main steam temperature

The development of the main steam temperature in steam boilers increased until the 70's. The limiting factor for raising steam temperature is the tube materials. Although there are power plants running at main steam temperatures over 600°C, there are yet no good, economical materials that can take temperatures above 550°C available (Figure 16).

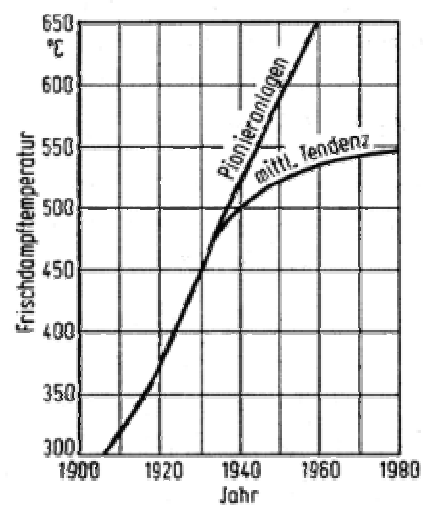


Figure 16: Graph presenting the development of the main steam temperature of boilers.

### Development of main steam pressure

The development of the main steam pressure increased also steadily until the 70's. The peak that can be spotted about 1930 comes from the early trials of once through boilers, cause the first once through boilers were run at critical steam pressures but later lowered since the tube material available couldn't take the high pressures. The pressure was stabilized in the 70's in order to correspond with steam temperature about 540-550°C.

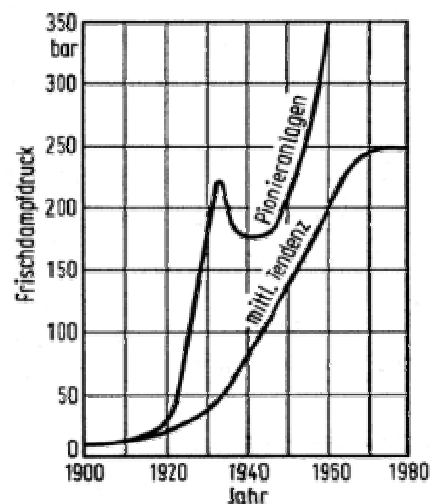


Figure 17: Graph presenting the development of the main steam pressure of boilers.

## Steam boilers and safety

The safety--or lack of safety--of steam was an important part of its history. The boilers, which contained the steam, were prone to explode. This occurred for a variety of reasons: undetected corrosion or furring of the heated surfaces, clumsy repairs, or failure to keep the water up to the required level, so causing firebox plates to overheat. As early as 1803 a safety device, a lead plug, was invented. The plug was designed to melt if the firebox crown became overheated and release steam before worse damage was done. However, this device was not adopted widely.

After an 1854 explosion in England that killed ten people, the Boiler Insurance and Steam Power Company was started. Not until 1882, though, was safety legislation introduced in Britain. In the United States there was no government regulation at all.

Following the action of safety legislation in England, the number of lives lost in England from boiler accidents fell from 35 in 1883 to 24 in 1900 and to 14 in 1905. During a comparable time period in the United States, 383 people were killed in boiler accidents. The problem of safety with steam engines was eventually reduced by the introduction of new forms of power, including the steam turbine. However, boiler accidents remain a fact of life even today, and continue to cause fatalities. [4]

## Internet links

Links to topics covered on this page:

- [Dreams of Steam: The History of Steam Power](#)
- [The Growth of the Steam Engine](#)
- [Inventors: Babcock & Wilcox](#)
- [Boiler - Water Tube Type](#)
- [Babcock & Wilcox: Supercritical \(Once Through\) Boiler Technology](#)

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