Development of Boiler Design

Learning Outcome
When you complete this module you will be able to:

Discuss historical developments of, and the general requirements for proper boiler design.

Learning Objectives
Here is what you will be able to do when you complete each objective:

1. Describe early boiler designs and explain developments that improved boiler operation.

2. List the general requirements for proper boiler design.
INTRODUCTION

The majority of larger industrial and commercial or institutional buildings are equipped with boilers to supply steam or hot water for processing or to the heating systems and/or the heating coils in air conditioning systems during the colder seasons in order to maintain the temperature at a level comfortable to the occupants. Therefore, the boiler plays a vital role in the operation of any steam or hot water system.

Even though the modern boiler is automated for easier operation, it requires regular supervision and maintenance to achieve uninterrupted, efficient, and safe operation.

The satisfactory operation of a boiler depends to a great extent on the knowledge the boiler operator has of the proper operational and maintenance procedures.

A steam boiler is basically a closed container, partially filled with water which is evaporated into steam under pressure by the application of heat. This heat is usually obtained from the burning of a fuel such as gas, oil or coal in a furnace, although in some cases electrical elements may be used to provide the heat.

A hot water boiler is also a closed container, but it is completely filled with water. By the application of heat, the temperature and pressure of the water is raised but no steam is generated. Although it is called a boiler, the water in it does not actually “boil”, since no steam is produced.

The Boilers Act defines a boiler as: a pressure vessel in which a gas or vapor can be generated under pressure, or in which a liquid can be put under pressure, by the direct application of a heat source.

BASIC DEVELOPMENT OF BOILERS

The development of the boiler from its first primitive, commercial forms to the more complicated and much more efficient types of the present day should be looked at. This will provide a better understanding of the principles of modern boiler design and it will enable the advantages and disadvantages of various types of heating boilers to be seen much more clearly later on.

The earliest steam boilers consisted essentially of a single closed container or shell, partially filled with water and enclosed in a brick setting which formed a furnace under the shell.
Advancement came with the addition of a chimney or stack to help improve combustion under the boiler.

It was found that a long shell or drum could contain higher pressures and increase the heating surface as indicated in Fig. 3.
The fuel was burned on a grating near the front of the boiler. The flames and hot gases played against the lower part of the shell as they travelled towards the rear of the boiler on the way to the smoke stack. The combustion heat was conducted through the wall of the lower half of the shell and heated up the water inside the shell. When the water reached its boiling temperature, steam was generated which collected in the upper part of the shell.

The part of a boiler through which the heat is transferred from the combustion products to the boiler water is called the “heating surface”. In this early boiler, the heating surfaces consisted only of the lower half of the shell.

Since the furnace was located outside the shell, this type of boiler was classified as an “externally fired boiler.”

However, this boiler design was still very inefficient because the heating surface was small and the time the hot gases were in contact with the heating surface was very short. Most of the heat generated by the combustion of the fuel went up the stack instead of being absorbed by the boiler water. Also a large amount of heat was lost through the brick walls of the furnace.

Over the years, various improvements were made to the design of the earlier boiler, and as a result, the efficiency improved considerably. Major improvements were made by the following changes.

The heating surface was enlarged by the installation of a large number of firetubes mounted between the heads of the boiler. The hot combustion gases were passed through these tubes and gave up their heat to the boiler water surrounding the tubes.
The length of the gas travel, and thus the time of contact between combustion gases and heating surface, was extended. This was accomplished by the introduction of the horizontal return tubular boiler (HRT). This boiler became very popular in North America. It was classified as a two-pass, horizontal, firetube boiler, externally fired. (A boiler pass is the travel of the combustion gases along the length of the boiler).

The boilers described previously all required extensive brickwork for the external furnaces which contributed to the heat losses, increased the cost of the boiler, and required extensive maintenance.

![Figure 4: Horizontal Return Tubular Boiler](image)

In order to reduce the extensive heat losses from the furnace walls of externally fired boilers, one designer enlarged the diameter of the return flue and put the firing grating inside this enlarged flue. The boiler was now internally fired; the furnace placed inside the shell and completely surrounded by water. However, brickwork was still used to guide the hot gases, after leaving the furnace, around the outside of the shell in order to remove as much heat as possible.

Elimination of external brickwork was now only one step away. By combining the features of this internally fired boiler and the HRT boiler in Fig. 4, a boiler was developed which was internally fired, had a large heating surface and a reasonably long gas travel, and required no external brickwork. This boiler became known as the Scotch Marine boiler since it was extensively used for marine services.

Fig. 5 shows a modified Scotch boiler. The hot gases flow from the fire to the reversing chamber at the rear of the boiler and then forward again through the firetubes. All parts are inside the shell and completely surrounded by water. This boiler is the forerunner of the modern packaged type firetube boiler now so popular in heating services and small to medium industrial service.
The modern, modified Scotch boiler may use three or four passes of the flue gas to maximize heat transfer from the combustion gases.

Another method of enclosing the combustion chamber in a water cooled setting was used in the locomotive boiler. Extensions from the shell, called water legs, surrounded the grate area to increase the heat capture from the burning fuel.
Boilers consisting of a shell containing straight tubes through which the hot gases travel from the fire to the stack are classified as “firetube” boilers. The water in the shell surrounds the tubes and the heat from the hot gases inside the tubes passes through the tube walls to the water.

Another boiler design features one or more small diameter shells, called boiler drums, with a large number of tubes connecting the drums. Water circulates from the drum through the tubes back to the drum. The heat from the fire and hot gases comes in contact with the outside of the tubes. This type is known as the “watertube” boiler. Watertube boilers are mainly used in industry and in large capacity, high pressure plants. Fig. 7 shows an early style of straight tube watertube boiler.

![Figure 7: Watertube Boiler](AL1_fig7.gif)

Boilers used for heating systems are of the firetube, watertube and tubular types as well as cast-iron sectional boilers.

Different types of boilers have evolved to take care of specific industrial requirements. High pressure, high temperature, high capacity boilers are used for producing electrical power. Thermo flooding boilers are used to inject large amounts of heat energy into geological formations. Some process boilers have been developed which use fluids other than water as the heat transfer medium.
GENERAL REQUIREMENTS FOR PROPER BOILER DESIGN

The chief aim in modern boiler design is the production of a boiler that will be safe and efficient in operation and economical in fuel consumption. To ensure this result, the following points must be observed:

1. It must have a large heating surface so that the maximum amount of heat can be absorbed.

2. All parts of the boiler heating surface exposed to fire or hot gases must be covered by water.

3. It must have a thorough circulation of water through all parts of the boiler in order to prevent overheating of any part of the heating surface.

4. The boiler must be properly insulated to minimize heat loss to the surroundings.

5. The steam space must be large and the steam able to rise freely from the surface of the water, so that any water contained in the steam may be separated before the steam is drawn off from the boiler.

6. All parts of the boiler must be readily accessible for inspection, cleaning, and repairs.

7. It must incorporate proper workmanship, simple construction, and low maintenance costs.

8. It must have strong enough construction according to code for pressures and temperatures encountered.

9. It must have proper allowance for expansion and contraction of the boiler and its parts.

10. It must be furnished with the approved fittings such as gages, safety valves, etc.

In general, the boiler should be designed to absorb the maximum amount of heat available from the furnace and, at the same time, provide the maximum of safety and reliability in operation. The design should also feature compactness in order to keep down building costs but should still provide adequate access to the parts for maintenance and inspection.