4.1 Introduction

Boiler is a container into which water is fed, and by the application of heat, it is evaporated into steam. In early designs, the boiler was a simple shell with a feed pipe and steam outlet, mounted on a brick setting. Fuel was burnt on a grate within the setting and the heat so released was directed over the lower shell surface before most of it went out.

Soon the designers realized that heating a single shell is inefficient and it was necessary to bring more of water into close contact with heat. One way, is to direct flue gases through tubes in the boiler shell. Such a "fire-tube design" not only increases the heating surface but also distributes area of steam formation more uniformly.

Second way is water-tube design. It consists of one or more relatively small drums with number of tubes in which water-steam mixture circulates. Heat flows from flue gases outside tubes to the mixture. Thus sub-division of pressure parts make possible construction of large capacity and high pressure boilers.

Fire-tube boilers and simple water-tube boilers are described in detail in chapter-8 of volume-1. Fire-tube boilers are limited to a maximum design working pressure of 25 bar and steam generating capacity of 25 tonnes per hour. Conventional water-tubes boilers work upto steam pressures of about 70 bar and 250°C superheat with a steam generating capacity of 40 tonnes per hour.

Shell or fire-tube boilers are cheaper than water-tube boilers but they are suitable for low pressures and low output. There is no such limit to water-tube boilers. Water-tube boiler can be erected at site from easily transportable parts. They are flexible from constructional point of view. They are capable of quick steam generation and their constructional design can be varied to suit a wide range of situations. Furnace of a water-tube boiler is not limited to cylindrical form. Therefore, water-tube boilers are generally preferred for high pressure high duty performance.

The present-day demand for higher power outputs from the thermal power plants requires high pressure high duty boilers. A high pressure boiler is much more than an assembly of certain components like burners, superheaters, air heaters, etc. The functions of these components are inter-related. The quality of coal and the operating conditions have a great influence on the types of components to be selected and more than that, they influence the philosophy underlying the general design. For increasing the steam pressure and the rate of steam generation of a boiler, forced circulation of water and/or steam and radiant heat transfer from the furnace to the water were considered essential.

4.2 Water-Tube Boilers

Introduction of water-tube boilers dates back to the eighteenth century. The last twenty five years have been a period of significant change in their design and construction.
Horizontal water-tube boilers with vertical or slightly inclined sectional headers having a longitudinal or transverse drum (fig. 4-1), were quite popular during first quarter of the twentieth century. Now-a-days they are not built, as they can not cope up with high pressure and high duties demanded from modern boilers.

Bent tube boilers (fig. 4-2) are more flexible in construction. Where head room is limited, they can be made wide and low or narrow, and high where floor space is limited. Thus, their overall dimensions can be adjusted according the space available.

As the demand for large capacity and high pressure boilers grew, the demand for more active furnace cooling methods increased. Water cooled furnace walls were developed because of increasing rate of heat transfer in furnace proper. Water from drum is supplied to lower header as shown in fig. 4-2. Steam is actively generated in walls, to rise to upper drum where it separates from boiler water.

In a simple water-tube circuit, steam bubbles are formed on the heated side. The resulting steam-water mixture weighs less than cooler water on the unheated side and thus free convective currents (circulation) are established. In drum, steam bubbles rise to water surface and steam is generated in this manner. Free circulative currents are affected by two factors:

- Difference in density between water and steam-water mixture, and
- Frictional forces opposing circulation.

At a higher pressure, the effect of first factor reduces and thus forced circulation is inevitable. Also the forced circulation increases the rate of heat transfer thus permitting higher rate of steam generation and reduction in overall size of the boiler. Thus, large capacity boilers are possible. Even recently, designers have gone one step further to increase the boiler capacity by adopting once-through boiler. It consists of a single tube (no drum) into which goes feed water and out of which comes saturated or superheated steam. In actual units (boilers), the theoretical single circuit becomes a number of parallel circuits. At pressures below critical, a “once through unit” may have a separator to deliver saturated steam to the superheater and to return collected moisture to the feed pump suction.

The “once through” cycle is, of course, ideally suited for pressures above critical point where water turns to steam without actually boiling. At critical pressure, the density of
water and steam is same and hence natural convective flow does not take place at critical pressure. Thus, the use of natural circulation is limited to sub-critical boilers up to about 140 bar boiler pressure and use of forced circulation becomes essential for higher pressures. High water velocities rather than high gas velocities are suitable, as a smaller quantity of fluid is dealt with and increase in pressure can be more easily attained than gas. Hence, the tubes of smaller diameter may be used for a boiler of a given output.

If the flow takes place through one continuous tube, large pressure drop takes place due to friction. This can be reduced by arranging the flow to pass through parallel systems of tubing.

The best examples of high pressure boilers are:

- La Mont boiler,
- Benson boiler,
- Loeffler boiler,
- Schmidt-Hartmann boiler, and
- Velox boiler.

La Mont boiler is a first forced circulation boiler introduced by La Mont in 1925. This boiler is of the water-tube type and is used in Europe and America. Water circulation and schematic location of different components of the boiler are shown in fig. 4-3.

This boiler incorporates water circulation in tubes surrounded by gases. Water is supplied through an economiser to a separating and storage drum which contains a feed regulator that controls the speed of the feed pump. Most of the sensible heat is supplied to the feed water passing through the economiser. From the drum a centrifugal pump circulates about 8 to 10 times the quantity of water evaporated. This large quantity of water circulated prevents the tubes from being overheated. The circulating pump passes water first to radiant evaporator or water wall (of which the sides for the combustion chamber are composed). Then steam and water
pass to convective evaporator and again to the drum. From the drum the released steam then passes to the superheater.

This boiler is capable of generating 40 to 50 tonnes of superheated steam per hour at about 500°C and 120 to 130 bar pressure.

This boiler has the advantage of flexibility of design, compactness and small size of drum. It generally resembles a natural circulation boiler. Formation and attachment of bubbles on the inner surfaces of the heating tubes of LaMont boiler reduces the heat flow and steam generation as it offers high thermal resistance than water film. Mark Benson argued that if the boiler pressure was raised to the critical value (220.9 bar), the steam and water would have the same density, and therefore danger of bubble formation can be eliminated.

Fig-4-4 shows the layout sketch of a Benson boiler. Benson boilers are drumless or "once through" type. Feed water is pumped through the economiser, radiant and convective evaporators, and superheater. The boiler pressure is critical pressure and hence water turns to steam directly without actually boiling.

If distilled water is not used, heavy deposits of salt occur in the transformation zone from water into steam. To avoid this difficulty, the evaporator is flushed out after every 4,000 working hours to remove salt. Because of the reduced value of entropy at the critical pressure, the steam rapidly becomes wet when it is expanded in a turbine, thereby causing erosion of the blading. To obviate erosion and to provide a more moderate working pressure, the steam is throttled to a pressure of about 150 bar.

From the figure, it appears that the boiler consists of a single tube of great length, but actually it consists of many parallel circuits which yield a thermal efficiency of about 90%. Benson boilers of 150 tonnes of steam per hour generating capacity at 50 MPa (500 bar) pressure and 650°C temperature have been constructed and are in use. The main advantages of the Benson boiler are:

- Absence of drums reduces the total weight of boiler and hence low cost of transport,
- The boiler can be erected easily and quickly,
- Operation is economical, and
- Quick starting and can reach full capacity operation within 10 minutes from start.

Loeffler Boiler uses circulation of steam instead of water. Thus, the difficulty experienced in La Mont boiler, a deposition of salt and sediment in boiler tubes, is avoided. This boiler has advantages of forced circulation and indirect heating. In this boiler, steam is used as heat carrying and heat absorbing medium.

A line diagram of Loeffler boiler is shown in fig. 4-5. This boiler has economiser and superheater units in the path of gases from furnace to chimney. The
evaporator drum is outside the boiler. A portion of main superheated steam (about 35%) is tapped off for external use, whilst the remainder passes on to the evaporator drum, where, by giving up its superheat to water coming from economiser, steam is generated equal to the steam tapped off. The steam circulating pump draws the saturated steam from the evaporator drum and is passed through the radiant and convective superheaters.

The nozzles distributing the superheated steam throughout the water in the drum are of special design to avoid priming and noise. This boiler can carry higher salt concentrations than any other type and is more compact than indirectly heated natural circulation boilers. These qualities make this boiler fit for land or sea transport power generation. Loeffle boilers of generating capacity 90 tonnes per hour and pressure 125 bar are in use.

Like Loeffler boiler, Schmidt-Hartmann Boiler is also high pressure indirectly heated boiler. The arrangement of the boiler components is shown in fig. 4-6. This boiler is very similar to an electric transformer. Two pressures are used to effect an interchange of energy. In the primary circuit, steam at pressure 100 bar is produced from distilled water. This steam is passed through submerged heating coil, located in the evaporator drum. The high pressure steam of primary circuit possesses sufficient thermal heat to produce steam at pressure 60 bar with a heat transfer rate of 2,900 watts/m²°C. This main steam is passed through a superheater placed in the uptake and then to the application point. The condensate of high pressure primary circuit steam is circulated through the

In the primary circuit, natural circulation is used which is sufficient to produce the desired rate of heat transfer in conjunction with high gas velocities. In this way, circulating velocities of 0.5 to 0.8 metre per second for thermo-siphon head of about 2.5 to 10 metres are possible.

As a safeguard against leakage or the safety valve lifting, a combined pressure gauge and thermometer are fitted to the primary circuit. An arrangement is provided for making distilled water of the primary circuit. Main advantages of the Schmidt-Hartmann boiler are:

... Due to distilled water in the primary circuit, there is rare chance of overheating or burning of the high heated components as there is no danger of salt deposition.

... There is no chance of interruption to the circulation either by rust or other material, due to use of distilled water in the primary circuit.

... Feed water is external to the heating coil and hence it is easy to brush off salt deposits, just by removing the heating coil from the evaporator drum.

... Due to high thermal and water capacity, wide fluctuations of load are allowed without undue priming or abnormal increase in the primary pressure.
... The absence of water risers in the drum, and the moderate temperature difference across the heating coil, allows evaporation to proceed without priming.

When the velocity of gas exceeds the velocity of sound, the heat is transferred from the gas at a much greater rate than the rate achieved with subsonic flow. This fact is used in the Velox Boiler to achieve the large amount of heat transfer from the given surface area.

In the velox boiler, air is compressed to 2.5 bar pressure by an air compressor run by a gas turbine, before supplying to the combustion chamber as shown in fig. 4-7. The object of this compression is to secure a supersonic velocity of the gases passing through the combustion chamber and gas tubes. As a result of this high rate of heat release (32 to 40 million kJ per m$^3$ of combustion chamber volume) is achieved and hence this boiler is a very compact one. The steam generating capacity of this boiler is limited to about 100 tonnes per hour because large power (brake power of about 4,400 kW) is required to run the air compressor at this output.

Fuel and air are injected downwards into a vertical combustion chamber which consists of annulus gas tubes and annulus water tubes (fire tube principle). On reaching the bottom of the combustion chamber, the products of combustion are deflected upwards into the evaporator tubes which consist of an outer annulus through which 10 to 20 times the water evaporated is circulated at a high velocity (this prevents the overheating of the metal walls). This way heat is transferred from gases to the water at a very high rate. The mixture of water and steam thus formed then passes into a separator from which the separated steam passes to the superheater and finally to the application point. The water removed from steam in the separator is again passed through the water tubes along with preheated feed water coming from economiser. The gases coming out from
the evaporator tubes are first passed over the superheater tubes and are then led to the gas turbine. The power output of the gas turbine is supplied to drive the compressor, and the exhaust gases coming out from the gas turbine are passed through the economiser before going to the atmosphere.

Advantages of Velox boiler over similar boiler are:

... Very high rate of heat transfer,
... Compact steam generating unit of great flexibility,
... Capable of quick starting, even though the separating drum has a storage capacity of about one-eighth of the maximum hourly output,
... Low excess air is required as compressed air is used and the problem of draught is simplified,
... The control is entirely automatic, and
... A thermal efficiency of about 90 to 95% is maintained over a wide range of load.

4.3 Materials of Construction

Modern boilers consist of steel tubes of various dimensions, shape and thickness. The material used is of great importance as it has to withstand high temperatures and pressures. Low-carbon steel, is used in most water-tube boilers operating between 270°C and 400°C. Medium-carbon steel, with 0.35% maximum of carbon, permits higher stresses than low-carbon steel at temperature upto 500°C.

For superheater tubes, alloy steels are required as they have to resist temperatures above 500°C. These may contain chromium, chromium-molybdenum and chromium-nickel. They may be of ferric structure or, for the highest temperature at which modern boilers operate, of an austenitic structure.

Steamless tubes or electric-resistance welded tubes are used in water-tube boilers. Electric-resistance welded tubes are becoming increasingly popular for most applications, except for high pressures where wall thickness makes the use of steamless tubes more practical.

4.4 Advantages of High pressure Boilers

The principal advantages of high pressure boilers are as under:

... Greater freedom for disposing of the heating surfaces and hence greater evaporation for a given size.
... Reduction in the number of drums required.
... Smaller bore tubes, and therefore lighter tubes.
... Lighter for a given output.
... Rapid changes of load can be met without the use of complicated, or delicate control devices.
... Using external supply of power, a very rapid start from cold is possible. Hence the boiler is suitable for carrying peak loads, or for stand-by purposes in hydraulic stations.
... Tendency of scale formation is eliminated due to high velocity of water through the tubes.
... Due to uniform heating of all parts, the danger of overheating is reduced and thermal stress problem is simplified.

Against above advantages, the high cost of the pumping equipment, the power required to run the pumps, and safety of the boiler are some of the limitations to be kept in mind.
4.5 Arrangement of Heating Surfaces

Commonly used furnace layout for pulverised fuel boilers is shown in fig. 4-8. Three zones are seen in the elevation of a boiler in this figure. In zone I, the heat transfer is by radiation and it includes the space marked R + C which can receive heat by convection as well as radiation if suitable heat transfer surface is introduced into the path. In zone II and III, the main mode of heat transfer is convection. Gas temperatures are high in zone II. Clear cut demarcation cannot be made even though zone III is essentially treated as a low temperature zone. In order to achieve the complete combustion of fuel, opportunity must be given to the combustible constituents of the fuel to interact with oxygen. This opportunity, however, decreases rapidly as the reaction proceeds towards completion. In order to ensure complete combustion of fuel, it becomes essential to supply excess air. The supply of excess air and turbulence assume a greater significance in the final stages of combustion. The presence of excess air reduces the boiler efficiency. With increased surface contact between fuel and air and with created turbulence, the demand of excess air is very limited in a pulverised fuel fired furnace relative to stoker fired furnace.

A very high flame temperature is produced by hot turbulent air coupled with low excess air. At this temperature, ash is always in a molten stage. Metal temperature of all heat transfer surfaces are less than the ash fusion temperature. In order to reduce the possibility of this molten ash solidifying on tube surfaces, the use of convective heat transfer should be avoided as long as the gas temperature are higher than ash fusion temperature. Till then the heat transfer must be by radiation only. Zone I has radiant heat transfer surfaces. The furnace exit gas temperature has a profound bearing on the safe operation of the unit. This should be as high as possible so as to give a good temperature potential for the heat transfer surfaces to be located in convective zone, but at the same time, it should be lower than ash fusion temperature to avoid slag deposition. Roughly about 50 per cent of the heat liberated during combustion is absorbed in the radiant zone. This value increases with a fall in ash fusion temperature, rise in air temperature or fall in excess air. If a low ash-fusion-temperature coal is fired in a furnace designed for high ash-fusion-temperature coal, operational and maintenance problems are created. During radiation heat transfer, the tube metal temperature should be as low as feasible in order to have a smaller furnace. Relative to superheaters, evaporators offer lower metal temperature and hence the evaporator is the most appropriate component to be located in the radiant zone.

Slagging should not be ignored in zone II, where the gas temperatures are fairly high and convection is the mode of heat transfer. Sometimes panels and platens are located before this zone II so as to bring down the gas temperature to a safer level. These panels and platens can be evaporator or superheater. Panels are heat transfer surfaces at a considerably greater distance from each other. Panels permit large radiant heat absorption. Platens are heat transfer surfaces which are closer to each other. In platens, heat transfer takes place by convection and radiation.

Because of higher metal temperatures, superheater elements are more expensive than evaporator surfaces and hence it is desirable to put limit to superheater surfaces. Thus, this high temperature convection zone (zone II) is the most appropriate zone for superheaters.
In zone III, the gas temperatures are relatively low. Location of superheaters in this zone makes them expensive due to lower temperature potentials. So the heat recovery units like economiser and air heater are most appropriate for this temperature convection zone.

With increase in operating pressure, the superheat temperature increases. Usually beyond 100 bar pressure, reheat becomes necessary. The proportion of the heat generated in the furnace and absorbed in the various components like economiser, evaporator, superheater and reheater are listed in table 4-1.

Table 4-1

<table>
<thead>
<tr>
<th>Pressure bar</th>
<th>Temperature °C</th>
<th>Approximate % of energy distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Economiser and Preheater</td>
</tr>
<tr>
<td>63</td>
<td>480</td>
<td>12</td>
</tr>
<tr>
<td>90</td>
<td>510</td>
<td>9.9</td>
</tr>
<tr>
<td>130</td>
<td>540</td>
<td>27</td>
</tr>
<tr>
<td>170</td>
<td>565</td>
<td>3.6</td>
</tr>
</tbody>
</table>

From table-4-1, it is seen that the major parameters which influence the orientation of heat transfer surfaces are pressure and temperature. In support of this fact, features of four representative boilers working in power plants in India are discussed below. The particulars of the operating of the four high pressure boilers are given in table 4.2.

Table 4-2

<table>
<thead>
<tr>
<th>Power plant</th>
<th>Pressure bar</th>
<th>Temperature °C</th>
<th>Rate of steam generation tonnes/hr.</th>
<th>Output MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bokaro (two boilers)</td>
<td>62.5</td>
<td>485</td>
<td>136</td>
<td>25 + 25 = 50</td>
</tr>
<tr>
<td>Ramagundam</td>
<td>90</td>
<td>515</td>
<td>280</td>
<td>66</td>
</tr>
<tr>
<td>Chandrapura</td>
<td>135</td>
<td>540</td>
<td>435</td>
<td>140</td>
</tr>
<tr>
<td>Trombay</td>
<td>178.5</td>
<td>570</td>
<td>480</td>
<td>150</td>
</tr>
</tbody>
</table>

4.5.1 Bokaro Plant: The operating conditions are comparable with the data given at no.1 of the table 4-1. The arrangement of components is shown in fig. 4.9. The superheater requires about 24 per cent energy where as the evaporator needs 64 per cent. Therefore, the entire furnace is water cooled ($E_1$) and remaining part of the evaporator ($E_2$) is kept in the latter portion of zone II as tubes between two drums. For these operating conditions two drum construction is conventional. However, it is possible to have water cooled platens and panels instead of two drum arrangement but this arrangement if used excessively, can lead to lower gas temperature at zone II, which may be undesirable for superheater. The superheater in this boiler is a convective heat transfer type. Baffles are provided to increase the gas velocities.

4.5.2 Ramagundam Plant: The arrangement of components of this boiler is shown in fig. 4-10. Relative to the Bokaro plant, the evaporator duty is only slightly lower. Entire furnace walls ($E_1$) and convective tubes
between two drums \((E_2)\) form the evaporator surface. The low temperature section of the superheater \((S_1)\) is introduced as widely spaced platens and the finishing stage of the superheater \((S_2)\) is away from the flame. There are no baffles in the gas flow path.

4.5.3 Chandrapura Plant: The arrangement of components of this boiler is shown in Fig. 4-11. This boiler has significantly higher operating conditions, and reheat of the steam is adopted. As the evaporator duty is considerably reduced, it is not necessary to locate the evaporator in zone II as was needed for Bokaro and Ramagundam boiler plants. The furnace walls are totally covered with evaporator \((E_1)\) and a small portion of the evaporator is placed as radiant platens \((E_2)\) near the upper front wall. All the space of zone II is occupied by the superheater and reheater which need nearly 42 percent of the energy. A part of the superheater \((S_1)\) is platen. The reheater \((RH)\) and a part of superheater \((S_2)\) is pendant. The bulk of the superheater is located as three horizontal banks \((S)\) in the rear pass. It is interesting to note that the space occupied by the two drum arrangement of Bokaro and Ramagundam boiler plants is now utilised by the superheater.

4.5.4 Trombay Plant: This boiler has higher pressure and temperature as compared to boilers discussed above. The arrangement of components of this boiler is shown in Fig. 4-12.

In this boiler evaporator duty is decreased and superheater and reheater duty is increased. All the superheater and reheater elements cannot be located in zone II, and on other side the evaporator does not need all the energy available in zone I. Therefore, some of the superheater elements must be located in zone I. The evaporator is located in the furnace wall \((E)\). In the upper front wall some of the radiant
surface \((R)\) is actually reheater. Widely spaced panels \((S_1)\) and platens \((S_2)\) are superheater elements. The reheaters are located between the superheater elements. The unit has controlled circulation with pump \((P)\). The rear pass or zone III consists of horizontal banks \((S)\) of superheater elements. The important point to be noted is that superheater elements have entered zone I in a big way.

**Tutorial - 4**

1. What do you understand by high pressure high duty boilers?
2. Explain general features of water-tube boilers.
3. What are the trends observed in the design, construction and operation of modern steam generators?
4. Describe giving illustrations, the development which has taken place in water-tube boilers to attain higher operating pressure and higher steaming capacity.
5. Explain arrangement of components and working of La Mont boiler.
6. Sketch a layout and explain arrangement of components and working of Benson boiler.
7. Explain the construction and working of Loeffler boiler.
8. Sketch a layout, and explain arrangement of components and working of Schmidt Hartmann boiler.
9. What are the main advantages of Schmidt-Hartmann boiler?
10. Sketch a layout, and explain arrangement of components and working of Velox boiler.
11. What are the main advantages of Velox boiler?
12. Discuss the materials of construction of modern high pressure boilers.
13. What are the advantages of high pressure boilers?
14. Sketch a layout for a pulverised fuel boiler, showing important zones and explain efficient use of heat transfer surfaces.
15. Discuss most suitable arrangement of superheaters and reheaters in modern high pressure boilers.
16. Sketch a layout for pulvredised fuel boiler and divide it into three zones according to intensity of temperature. In this layout, show radiation heat transfer and convection heat transfer surfaces and hence discuss suitable location of evaporators, superheaters, economisers, and reheaters.
17. Give particulars and general arrangement of components of the boilers at the following power plants:
   (i) Bokaro, (ii) Ramagundum, (iii) Chandrapura, and (iv) Trombay.
18. Delete the phrase which is not applicable to complete the following statements:
   (i) Water-tube/fire-tube principle is preferred for high pressure boilers.
   (ii) In all modern high pressure boilers, the water circulation is maintained with the help of a pump/natural circulation due to density difference.
   (iii) At critical pressure, the density of water and steam is different/same.
   (iv) In Loeffler/La Mont boiler, heat of steam is used for evaporation of water.
   (v) La Mont/Benson boiler is drumless.
   (vi) Natural water circulation by convection in water tube boilers, increases/decreases with increase in pressure.
   (vii) When the velocity of gas exceeds the velocity of sound, the heat transferred from the gas is at much greater/smaller rate than the rate achieved with subsonic flow.
   (viii) Gas turbine and air compressor unit is provided in La Mont/Velox boiler.
   (ix) High temperature zone in a boiler is suitable for superheater/economiser.

19. Fill in the blanks in the following statements:
   (i) and are indirectly heated boilers.
   (ii) boiler is drumless and once through type.
   (iii) Maximum energy loss in a boiler occurs due to .
   (iv) A supercritical boiler is one that operates above the pressure and temperature of bar and °C.
   (v) In boiler, two pressures are used to effect interchange of energy.

[Delete: (i) fire-tube, (ii) natural circulation due to density difference, (iii) different, (iv) La Mont, (v) La Mont, (vi) increases, (vii) smaller, (viii) La Mont, (ix) economiser.]

20. Indicate the correct answer by selecting correct phrase in each of the following statements:
(i) Benson boiler has
   (a) no drum, (b) one drum, (c) two drums, (d) three drums.

(ii) In a boiler, whose walls are lined with water tubes, transference of heat to tubes is mainly by
    (a) convection, (b) conduction, (c) radiation, (d) combination of above modes.

(iii) Indirect heating and evaporation of water, is the underlying thermodynamic principle of
      (a) La Mont boiler, (b) Benson boiler, (c) Loeffler boiler, (d) Velox boiler.

(iv) Velocity of gases exceeds the velocity of sound in
     (a) La Mont boiler, (b) Benson boiler, (c) Loeffler boiler, (d) Velox boiler.

(v) Due to high velocity of water through tubes, the tendency of scale formation is
    (a) increased, (b) eliminated, (c) not affected.

[(i) a (ii) c, (iii) c, (iv) d, (v) b]