2-1 Boiler [1]

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process. Water is a useful and cheap medium for transferring heat to a process. When water is boiled into steam its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder. This causes the boiler to be extremely dangerous equipment that must be treated with utmost care.
The process of heating a liquid until it reaches its gaseous state is called evaporation. Heat is transferred from one body to another by means of
1- Radiation, which is the transfer of heat from a hot body to a cold body without a conveying medium,
2- Convection, the transfer of heat by a conveying medium, such as air or water
3- Conduction, transfer of heat by actual physical contact, molecule to molecule.

2-2 Boiler Types [1]

Boiler systems are classified in a variety of ways. They can be classified according to the end use, such as foe heating, power generation or process requirements. Or they can be classified according to pressure, materials of construction, size tube contents (for example, waterside or fireside), firing, heat source or circulation. Boilers are also distinguished by their method of fabrication. Accordingly, a boiler can be pack aged or field erected. Sometimes boilers are classified by their heat source. The boilers can be classified according to flow of water and hot gases.

1- Water tube.
2- Fire tube.

2-2-1 Fire tube

Fire in tube boilers contains long steel tubes through which the hot gasses from a furnace pass and around which the water to be converted to steam circulates.
(Refer Figure no.2-1). Fire tube boilers, typically have a lower initial cost, are more fuel efficient and easier to operate, but they are limited generally to capacities of 25 tons/hr and pressures of 17.5 bar.

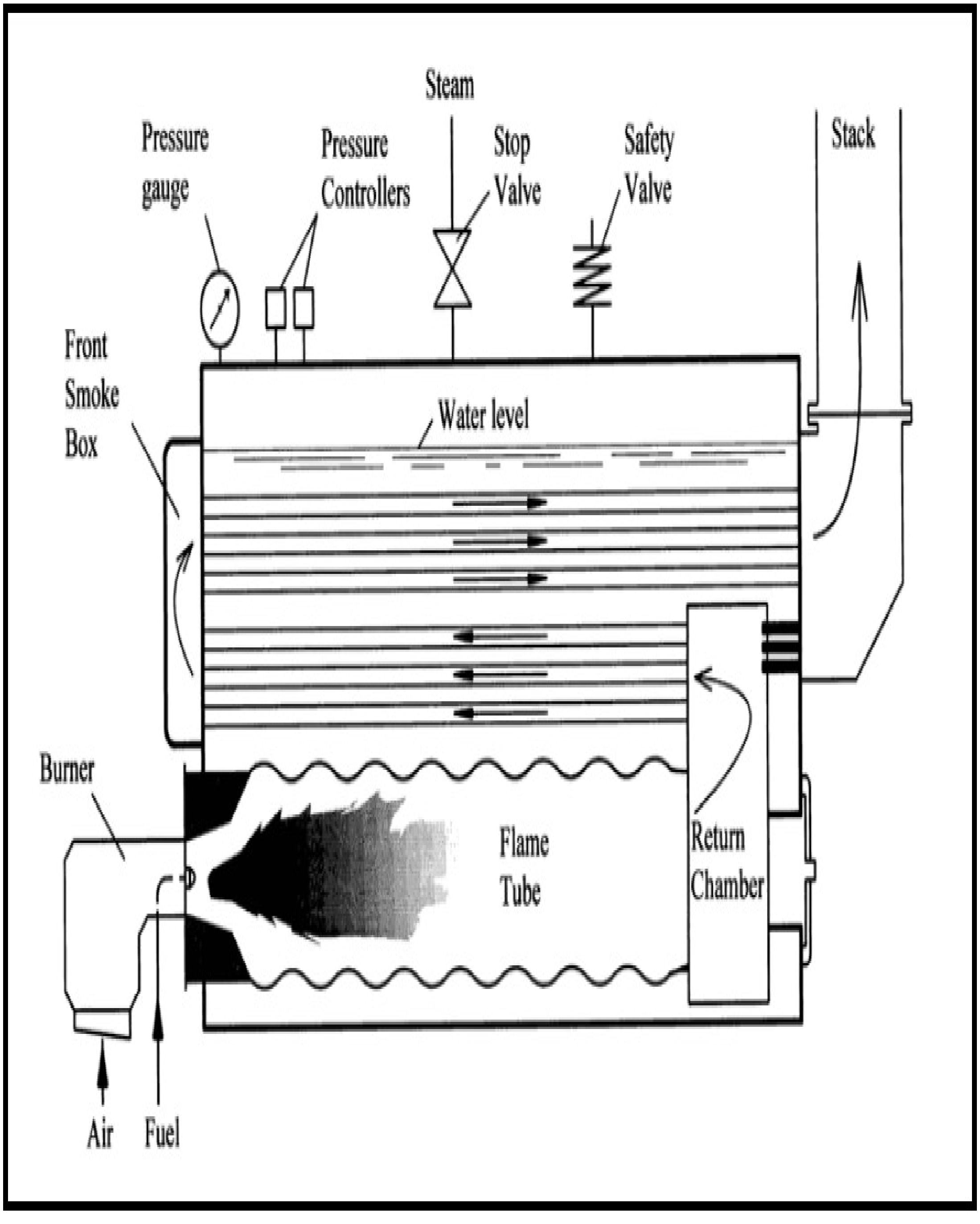

Fig no. 2-1 fire tube boiler

2-2-2 Water tube

Water in tube boilers in which the conditions are reversed with the water passing through the tubes and the hot gasses passing outside the tubes (see figure no. 2-2). These boilers can be of single- or multiple-drum type. These boilers can be built to any steam capacities and pressures, and have higher efficiencies than fire tube boilers.[1]

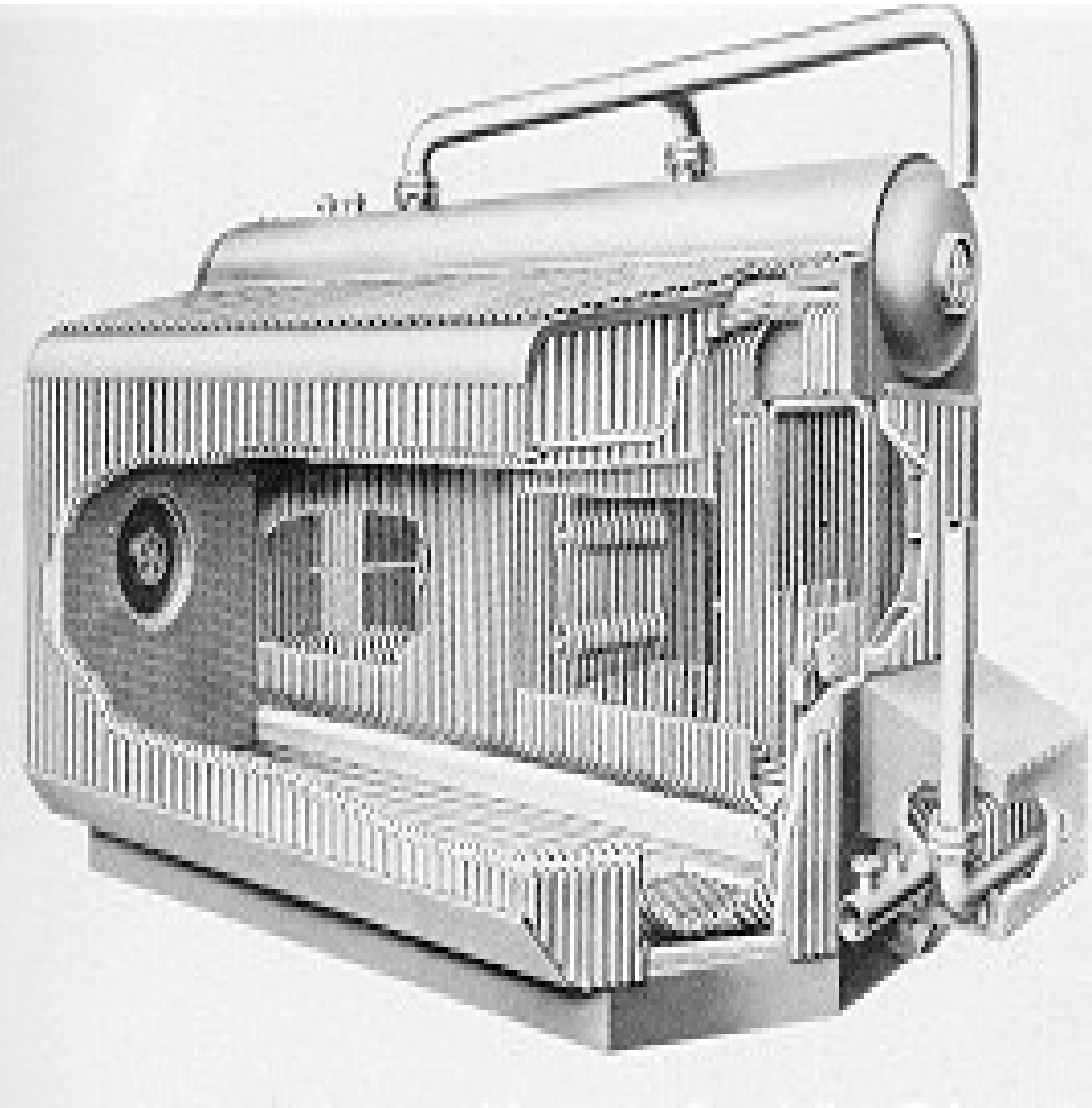

Figure 1.11 Type FM integral-furnace package boiler. (Babcock & Wilcox, a McDermott company)

Fig no. 2-2 water tube boiler

2-3 Boiler Efficiency [4]

There are two methods of assessing the boilers efficiency

1. Input – output or direct method, and
2. Heat loss or indirect method.

2-3-1 Direct Method for Calculating Boiler Efficiency

Direct method compares the energy gain of the working fluid (water and steam) to the energy content of the fuel. This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. The efficiency is than estimated using equation below:

= x 100

2-3-2 Indirect Method or Heat Loss Method for Calculating Boiler Efficiency [4]

Here the efficiency is estimated by summing the losses and comparing with the heat input. The major heat losses from boiler are due to:

1. High temperature flue gas leaving the stack
2. Moisture in fuel and combustion air
3. Combustion of hydrogen (leaves boiler stack as water vapor)
4. Heat in un-burnt combustibles in refuse
5. Radiation from the boiler surfaces
6. Unaccounted for un-measured losses

Sum up the losses and calculate the efficiency using equation:

Efficiency () = 100 – Σ Losses %

2-4 Heat losses [1]

2-4-1 Flue Gas Temperature

Flue gas temperature is the temperature of the combustion gases as they exit the boiler. The flue gas temperature must be a proven value for the efficiency calculation to be reflective of the true fuel usage of the boiler. A potential way to manipulate an efficiency value is to utilize a lower-than-actual flue gas temperature in the calculation. When reviewing an efficiency guarantee or calculation, check the flue gas temperature. Is it realistic? Is it near or less than the saturation temperature of the fluid in the boiler? Can the vendor of the equipment refer you to an existing jobsite where these levels of flue gas temperatures exist? Jobsite conditions will vary and have an effect on flue gas temperature. However, if the efficiency value is accurate, the flue gas temperatures should be repeatable in similar applications. One of the parameters affecting flue gas temperature is the boiler fluid temperature; thus, care should be taken to ensure that efficiency comparisons between boilers are made at the same bulk water temperature or steam pressure.

The use of flue gas economizers should be considered in certain types of applications, particularly those in which high pressure steam is used. Economizers are available in both condensing and non-condensing types. Typically an economizer preheats boiler feedwater using the heat available in the flue gases, thus saving energy, and, inasmuch as the flue gas temperature is now the economizer exit temperature rather than the boiler flue exit temperature, the overall boiler efficiency is enhanced.

2-4-2 Stack Losses

Stack temperature is a measure of the heat carried away by dry flue gases and the moisture loss. It is a good indicator of boiler efficiency. The stack temperature is the temperature of the combustion gases (dry and water vapor) leaving the boiler and reflects the energy that did not transfer from the fuel to the steam or hot water. The lower the stack temperature is, the more effective the heat exchanger design and the higher the fuel-to-steam or fuel-to-water efficiency.

2-4-3 Heating Medium Temperatures

Similarly, the efficiency of a boiler typically is higher when the heating medium is cooler. This effect is most pronounced in condensing hot water boilers, which do not even condense when feed water temperatures exceed the dew point temperature of the flue gases. Be sure that when comparing boilers, you compare efficiency ratings at similar system operating temperatures. A boiler’s efficiency can increase by several percentage points when testing at extremely and unusually cool feed water temperatures and high flow rates.

2-4-4 Radiation and Convection Losses

All boilers have radiation and convection losses. Radiation and convection losses represent the heat losses radiating from the boiler vessel. Boilers are insulated to minimize these losses. Radiation and convection losses, expressed in Btu/hr, are essentially constant throughout the firing range of a particular boiler, but vary between different boiler types, sizes, and operating pressures. Radiation and convection losses also are a function of air velocity across the boiler. A typical boiler room does not have high wind velocities. However, boilers operating outside will have higher radiation and convection losses. Sometimes efficiency is represented without any radiation and convection losses. This is not a true reflection of fuel usage of the boiler.

2-4-5 Excess Air

Excess air is the extra air supplied to the burner beyond the air required for complete combustion. Excess air is supplied to the burner because a boiler firing without sufficient air or “fuel rich” is operating in a potentially dangerous condition. Therefore, excess air is supplied to the burner to provide a safety factor above the actual air required for combustion.

Excess air uses energy from combustion, however, thus taking away potential energy for transfer to water in the boiler. In this way, excess air reduces boiler efficiency. A good quality burner design will allow firing at minimum excess air levels of 15% (3% as O2) or less while maintaining acceptable carbon monoxide levels (generally accepted at less than 100 ppm). Excess air is measured by sampling the O2 in the flue gas. If 15% excess air exists, the oxygen analyzer would measure the O2 in the excess air and show a measurement of approximately 3%.

Seasonal changes in temperature and barometric pressure can cause the excess air in a boiler to fluctuate 5%-10%. Furthermore, firing at low excess air levels can result in high CO and boiler sooting.

When reviewing an efficiency guarantee or calculation, check the excess air levels. If 15% excess air is being used to calculate the efficiency, the burner should be of a very high quality design with repeatable damper and linkage features. Without these features, your boiler will not be operating at the low excess air values being used for the calculation, at least not for long. If less than 15% excess air is being used for the calculation, you are probably basing your fuel usage on a higher efficiency than will be achieved in your day to day operation. You should ask the vendor to recalculate the efficiency at realistic excess air values.

2-4-6 Ambient Air Temperature

Ambient air temperature can have a dramatic effect on boiler efficiency. A 20 °c variation in ambient temperature can affect efficiency by 1% or more. Most boiler rooms are relatively warm. Therefore, most efficiency calculations are based on 27°c ambient temperatures. When reviewing an efficiency guarantee or calculation, check the ambient air conditions utilized. If a higher than 27°c value was utilized, it is not consistent with standard engineering practice and will result in a higher efficiency. If the boiler is equipped with combustion air heating, this should be noted in the calculations. If the boiler is going to be outside, the actual efficiency will be lower due to lower ambient air temperatures regardless of the boiler design. To determine your actual fuel usage, ask for the efficiency to be calculated at the actual ambient air conditions.

2-4-7 Turndown

Turndown is the ability of the boiler to achieve a wide range (from low to high) of output. The higher the turndown the wider the range of output capabilities. Boilers with higher turndown ratios are capable of supplying steam or hot water at lower rates without shutting down and re-starting. Generally speaking, higher turndowns can offer efficiency improvements when load demand varies. The burner should be able to maintain a reasonable excess air level at the low fire position. Efficiency calculations should be made at low, fifty percent and high-fire boiler rates.

2-4-8 Fuel Specification

The fuel specification can also have a dramatic effect on efficiency. In the case of gaseous fuels, the higher the hydrogen content, the more water vapor is formed during combustion. The water vapor uses energy as it changes phases in the combustion process. Higher water vapor losses when firing the fuel result in lower efficiency. This is one reason why fuel oil fires at higher efficiency levels than natural gas. To get an accurate efficiency calculation, a fuel specification that represents the jobsite fuel to be fired must be used. When reviewing an efficiency guarantee or calculation, check the fuel specification. Is it representative of the fuel you will use in the boiler? The representation of efficiency using fuel with low hydrogen content will not provide an accurate evaluation of your actual fuel usage.

2-5 Other Efficiency Considerations

Some boiler designs can supply steam or hot water with very little start-up or warm-up time. When load demands fluctuate or are intermittent, consideration for optimum use of fuel and steam should recognize this factor. The ability to quickly start a boiler and produce steam vs. operating in a standby mode will improve the operational efficiency of your boiler installation.

In order to get a complete picture of boiler energy use, such items as fan, air compressor and other electrical requirements, and the system related requirements of water treatment make-up and blowdown rates should all be evaluated. On oil burning equipment, the use of steam atomization also has an energy impact.

2-6 Insulation [7]

Thermal insulation is defined as a material or assembly of materials used to provide resistance to heat flow. The temperature ranges within which the term "thermal insulation" will apply is from -73.3ºC to 815.6ºC.

2-7 Thermal insulation installation

Thermal insulation is installed on the building structure, roof, walls and attic spaces; domestic hot water plumbing lines, chilled water supply and return lines and air distribution ducts to improve energy efficiency and to protect the building constructional elements against thermal impact and moisture related damage. Thermal insulation in winter minimizes heat loss and in summers reduces solar heat transmission.

For industrial facilities thermal insulation is installed on process equipment, piping, steam and condensate distribution systems, boilers, smoke stacks, bag houses, furnaces, kilns and storage tanks for process control, energy efficiency and safety.

2-8 Insulation Purpose

Principal uses of insulation are for personnel protection, process temperature control, prevention of condensation, and conservation of energy.

2-8-1 Personal & Fire Safety

Insulation reduces the surface temperature to a safer level. Studies indicate that the skin contact for more than 5 seconds with hot surfaces at temperatures above 58°C could result in second or third degree burns. To date, there are no mandates or statutes that govern any upper temperature limit for personnel protection. However, many industries have accepted or adopted 52°C as a common practice.

Insulation for personnel protection is generally applied only in those areas accessible to persons during normal plant operation and maintenance, and applied to a high of 2m above or 0.9m from platforms or work areas.

2-8-2 Process Control

Providing a stable temperature flow throughout a process system is in many cases more important than any other design criterion. Some processes may only allow for a minimal temperature fluctuation, for example, liquefied gases must be kept below their boiling points.

This is usually accomplished with a combination of pressure and insulation. If the temperature of the liquid gas is allowed to exceed the process control design parameters, the consequence is either a costly loss of gas through vaporization or a potentially hazardous buildup of pressure.

2-8-3 Hot Water & Steam Distribution Systems

Hot water or steam supply at rated temperatures and pressures could be a stringent process requirement for many industrial processes. Certain processes require uniform temperature in narrow tolerances to achieve proper chemical reaction. Too much or not enough heat can completely nullify the chemical reaction or can result in liquid crystallization and the batch loss.

For example, in the transport of liquid sulfur, if the temperature drops below its freezing point, the liquid becomes solid. The time and energy required to transform the sulfur back into a liquid and flowing state is more expensive than the cost of replacing the transport system altogether.

2-8-4 Condensation Control

In cooling and chilled water distribution lines, the insulation is often the target of condensation when water vapor is driven from the outside air toward the cooler piping systems.

In building air-conditioning applications, the moisture condensation can cause the discoloration or staining of ceiling panels, corrosion of cold piping, ducts, chillers etc. and pose health risk due to mold and fungus growth.

To prevent condensation, it is important to provide sufficient insulation to keep surfaces above the dewpoint temperature of air. Specifying sufficient insulation thickness with an effective vapor retarder system is the most effective means of providing a system for controlling condensation on the membrane surface and within the insulation system on cold piping, ducts, chillers and roof drains.

Sufficient insulation thickness is needed to keep the surface temperature of the membrane above the highest possible design dewpoint temperature of the ambient air so condensation does not form on the surface. The effective vapor retarder system is needed to restrict moisture migration into the system through the facing, joints, seams, penetrations, hangers, and supports.

2-8-5 Energy Savings

Insulation conserves energy by reducing or minimizing the heat loss or gain. Remember, insulation is merely a heat flow reducer, not a barrier to heat flow.

Substantial quantities of heat energy are wasted daily in industrial plants nationwide because of under insulated, under maintained or un-insulated heated and cooled surfaces. The reduction of heat loss by insulation is a practical means of achieving substantial economies of energy.

Associated benefits of insulation include greenhouse gas reduction. Energy efficiency leads to reduction of CO2, NOx and other hazardous gas emissions to the outdoor environment.

2-8-6 Sound Attenuation

Insulation materials can be used in the design of an assembly having a high sound transmission loss. Special or standard insulation materials can be used to encase or enclose a noise generating source, forming a sound barrier between the source and the surrounding area.

2-9 Classification of Insulation based on Application [7]

Choices of the materials available within each temperature range are based on design conditions (other than thermal) of the installation.

2-9-1 Low temperature range (15°C to -75°C)

The major design problems on low temperature installations are moisture penetration and operating efficiency. For below ambient applications, insulation should have low moisture absorption.

Vapour retarders are extensively used, but in practice it is difficult to achieve the perfect retarder in extreme applications. The pressure of the vapour flow from the warm outside surface to the cooler inside surface is such that, even with waterproof insulation, vapour may diffuse through the material, enter through unsealed joints or cracks, and condense, then freeze and cause damage.

Since the cost of refrigeration is higher than the cost of heating, more insulation is often justified in low temperature applications. Extra thicknesses of insulation, even beyond what would be economically dictated for cold line applications, are sometimes employed to keep the warm surface temperature above the dewpoint, thus preventing condensation from forming.

The insulations generally used in this temperature range are: Cellular Glass, Elastomeric Foamed Plastic, Glass Fiber, Mineral Fiber, Phenolic (foamed), Polyethylene, Polyisocyanurate, Polyurethane and Polystyrene

2-9-2 Intermediate temperature ranges (15°C TO 315°C)

This temperature range includes conditions encountered in most industrial processes and the hot water and steam systems necessary in commercial installations. Selection of material in this range is based more on its thermal values than with low temperature applications. However, other factors such as mechanical and chemical properties, availability of forms, installation time, and costs are also significant.

The materials generally used in the intermediate range are: Calcium Silicate, Cellular Glass, Elastomeric Foamed Plastic, Expanded Silica, or Perlite, Glass Fiber, Mineral Fiber, Phenolic, Polystyreneand Polyurethane

2-9-3 High temperature ranges (315°C TO 815°C)

As the refractory range of insulation is approached, fewer materials and application methods are available. High temperature materials are often a combination of other materials or similar materials manufactured using special binders. Jacketing is generally field applied. Industrial power and process piping and equipment, boilers, breechings, exhausts and incinerators fall within this application range.
The materials generally used are:
Calcium Silicate, Cellular Glass, Cements, Ceramic Fibers, Glass Fibers, Mineral Fiber and Perlite

2-10 Optimum Thickness of Insulation [2]

It should be realized that insulation does not eliminate heat transfer; it merely reduces it. The thicker the insulation, the lower the rate of heat transfers but also the higher the cost of insulation. Therefore, there should be an optimum thickness of insulation that corresponds to a minimum combined cost of insulation and heat lost. The determination of the optimum thickness of insulation is illustrated in Figure 2-3 below. Notice that the cost of insulation increases roughly linearly with thickness while the cost of heat loss decreases exponentially. The total cost, which is the sum of the insulation cost and the lost heat cost, decreases first, reaches a minimum, and then increases. The thickness corresponding to the minimum total cost is the optimum thickness of insulation, and this is the recommended thickness of insulation to be installed.

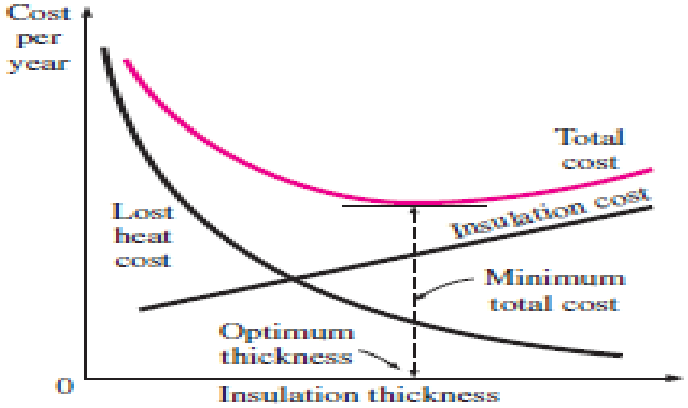

Fig no. 2-3 thermal insulation thickness calculation

If you are mathematically inclined, you can determine the optimum thickness by obtaining an expression for the total cost, which is the sum of the expressions for the lost heat cost and insulation cost as a function of thickness; differentiating the total cost expression with respect to the thickness; and setting it equal to zero. The thickness value satisfying the resulting equation is the optimum thickness. The cost values can be determined from an annualized lifetime analysis or simply from the requirement that the insulation pay for itself within two or three years. Note that the optimum thickness of insulation depends on the fuel cost, and the higher the fuel cost, the larger the optimum thickness of insulation. Considering that insulation will be in service for many years and the fuel prices are likely to escalate, a reasonable increase in fuel prices must be assumed in calculations.

Otherwise, what is optimum insulation today will be inadequate insulation in the years to come, and we may have to face the possibility of costly retrofitting projects. This is what happened in the 1970s and 1980s to insulations installed in the 1960s.

The discussion above on optimum thickness is valid when the type and manufacturer of insulation are already selected, and the only thing to be determined is the most economical thickness. But often there are several suitable insulations for

a job, and the selection process can be rather confusing since each insulation can have a different thermal conductivity, different installation cost, and different service life. In such cases, a selection can be made by preparing an annualized cost versus thickness chart like
Figure 2–4 for each insulation, and determining the one having the lowest minimum cost. The insulation with the lowest annual cost is obviously the most economical insulation, and the insulation thickness corresponding to the minimum total cost is the optimum thickness. When the optimum thickness falls between two commercially available thicknesses, it is a good practice to be conservative and choose the thicker insulation. The extra thickness will provide a little safety cushion for any possible decline in performance over time and will help the environment by reducing the production of greenhouse gases such as CO2.

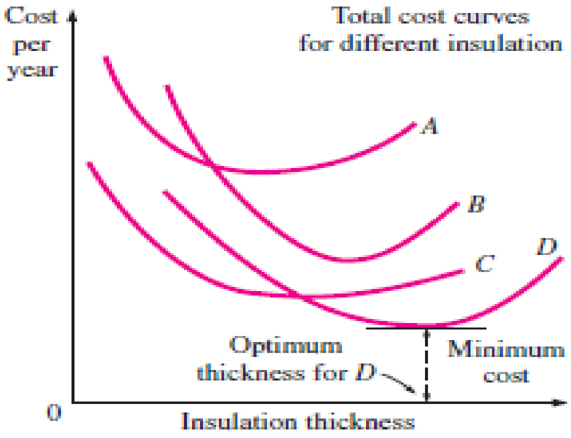

Fig no. 2-4 optimum thickness

2-11 Boiler insulation [7]

The insulation of boiler plant is normally carried out by the manufacturer of the boilers generally at the shop or in certain cases is applied onsite after erection of the plant. The field insulation shall be fundamentally at two places. One purpose will be to insulate the hot working medium, which will normally be water or steam form losing heat to surrounding air. The other will be to insulate the areas where only the hot gases would have their containing surfaces exposed to the surrounding air- an example of this is combustion chambers or flues.

In the first application the insulation will be provided in the form of mineral fiber slabs fixed to the outside surface of the boiler shell. It shall suitably protect the outer sheath. On older boiler plant this insulation may get damage with time and use. If this is the case it should not automatically be replaced with the same thickness of insulation. The new thickness should be calculated based on the prevailing fuel prices.

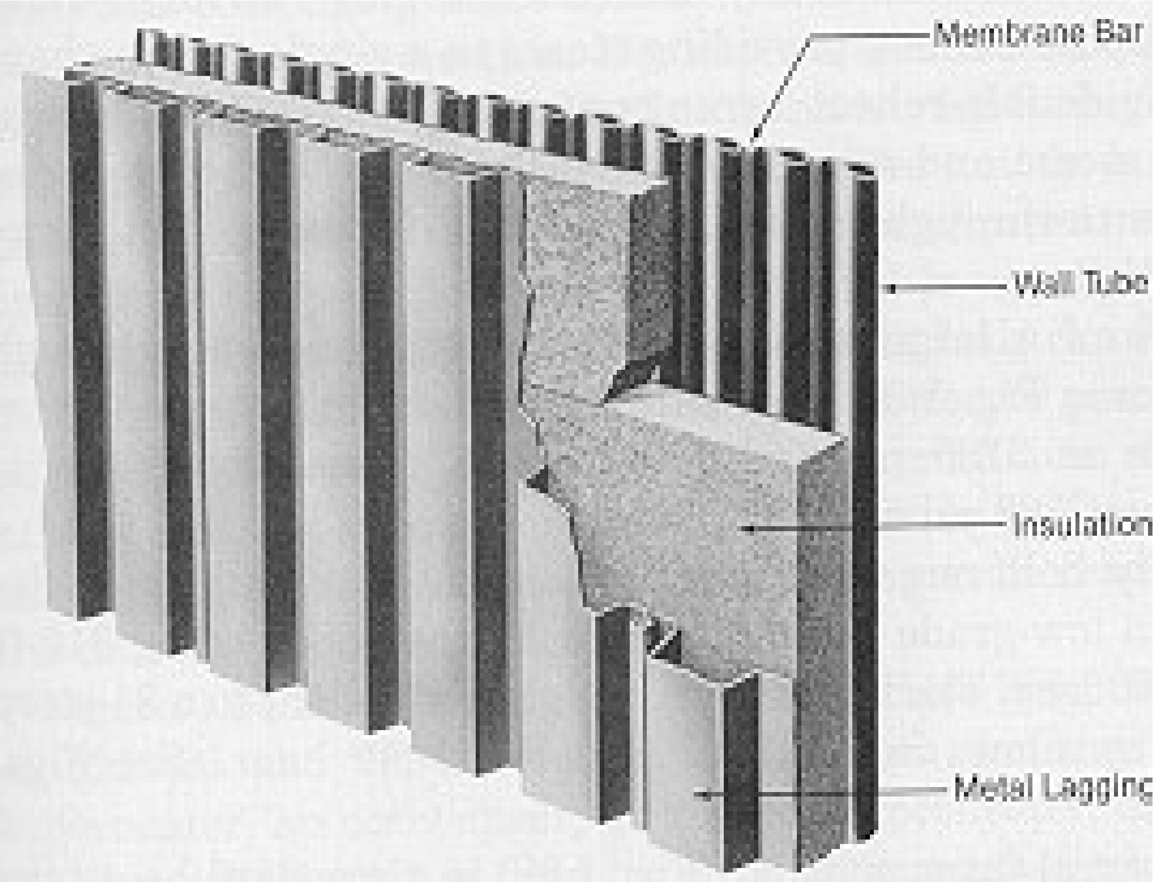

Fig no. 2-5 boiler wall insulation

2-11-1Insulation of gas flues (Stack/chimney)

The insulation of stack/chimney may be carried out for two reasons. One is the safety aspect from the point of view high external surface temperatures and the other is from the need to keep internal surface temperatures above the dewpoint of the gases being conveyed for corrosion control purposes.

From the point of boiler plant or furnace energy efficiency, the exit flue gas temperatures shall be as low as possible so that every bit of energy is extracted from the fuel. But there is limit to this. The SOx and NOx constituents of flue gas tend to form acid due to condensation of flue gas below ~120°C which can result in corrosion of chimney. The flue stack shall therefore need to be insulated in such a way that the flue wall temperature is above the dew point of gasses. Problems can arise particularly on light loads when flue gas velocities and temperatures are both naturally low.

The vertical sides and bottom of the flue may be insulated with low density mineral fibers, supported on studs and reinforcing mesh, but the areas which may be subject to wear or loading should be of minerals such as calcium silicate or dense mineral fibers.

Care should also be taken at any access points such as temperature probes or sampling points.

Any expansion joints should also be adequately insulated to prevent corrosion.

2-11-2 Furnaces

Furnaces particularly depending on heat treatment or melting applications operate at very high temperatures. The high temperature insulation application range is (315ºC through 815ºC). 1260° C is the maximum temperature for which insulation is applied. Above that refractory is used. The insulation of furnaces or kilns is a more complicated subject than normal items of plant where insulation can be applied over the hot surfaces. There are two broad categories of furnaces viz. continuous furnaces and intermittent batch type furnaces.

Whichever category of furnace is used, the heat losses result from the loss through the furnace walls due to conduction, radiation and convection.

The loss due to the thermal mass of the furnace storing unnecessary heat there is however a difference between continuously operated and intermittently operated furnaces.

In furnaces operated continuously at full working temperature, the heat loss through the walls is far greater than the heat required to heat up the mass of the furnace. In furnaces heated and cooled intermittently, the loss thorough heat stored in the mass of the furnace (and dissipated each time the furnace is cooled) may be much greater.

The problem is thus different in different configuration of furnace. In continuous or long time cycle furnaces the insulating problem is to prevent heat loss through the walls and roof. In intermittent or short time cycle furnaces, it is to reduce the heat storage loss whilst still not neglecting the external surface loss.

Heat losses can also be reduced to a certain extent by increasing the thickness of the refractory brick but this is not very effective as this method adds significant cost to the furnace structure. It is much better to use insulation.

The insulation of furnaces should not be adopted without careful consideration of the consequences and the changes in refractory temperatures that may result. .

2-11-2-1 Effect of insulation on refractory temperatures

If the outer wall of a furnace is insulted, heat losses shall reduce or more heat is retained within the system. This means that in practice, the average temperature of the refractory walls increases even when the fuel consumption is reduced to maintain the same internal furnace temperature.

This can result in the refractory or insulation becoming overheated so that:

The refractory may melt and the furnace collapse and the insulation may be spoiled or made ineffective

Whilst a refractory built into a wall or roof can be operated with its face above the safe temperature as long as the bulk of the brick is at a temperature low enough to stand up to conditions, evening up the temperature over the thickness of the brick by applying insulation to the outside may set up very dangerous conditions.