



**Ministry of State for Environmental Affairs
Egyptian Environmental Affairs Agency (EEAA)
Egyptian Pollution Abatement Project (EPAP)**

Self Monitoring Manual Energy Generating Plants



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1. Introduction

The Egyptian Pollution Abatement Project (EPAP) sponsored by FINIDA has assigned Egyptian consultants for the task of developing self-monitoring manuals for utilities common to various industrial sectors. Self-monitoring manuals for the following sectors have been developed:

- Food Industry with specific reference to the five sub-sectors of Dairy products, Vegetables and Fruit processing, Grain Milling, Carbonated Beverages and Confectionery.
- Pulp and Paper Industry
- Metallurgical Industry with specific reference to the two sub-sectors of Iron and Steel and Aluminum.
- Engineering Industry
- Textile Industry.

EPAP realized that there are other issues common to all sectors and that deserve in-depth investigation in separate cross-cutting manuals. Egyptian and Finnish consultants were assigned to the task of developing manuals that deal with the inspection and self-monitoring of:

- Energy Generating Plants
- Hazardous wastes
- Wastewater treatment plants

Energy generating plants represent an important component common to most industrial sectors. This manual presents the self-monitoring guidelines of energy generating plants including the fuel line (storage, supply and combustion) as well as the water line (intake, treatment, supply and steam distribution).

1.1 Objectives of the Manual

With respect to the Energy generating plants, there are two distinct manuals, one for inspection and the other for self-monitoring. The description of the industry, pollution data and relevant environmental laws are similar in both manuals. Each manual is cross-referenced to the General Guidelines previously developed to avoid undue repetitions.

This manual is intended for use as a supplement to the sector specific manuals. It provides vital information about the operation of the different types of energy generating plants. It also identifies the sources of pollution and describes means to minimize pollutant release. Self-monitoring activities are linked to the sources of pollution with respect to compliance monitoring. Monitoring of process operation parameters is also discussed.

1.2 Organization of the Self-Monitoring Manual

The first chapter represents an introduction to the whole project and chapters two to four deal with the energy generating plants and their environmental impacts. The description of energy generating plants is presented in chapter 2. Chapter 3 describes the potential sources of pollution and the various emissions, effluents and solid wastes generated from the different operations. Chapter 4 describes the environmental and health impacts of the various pollutants, whereas chapter 5 gives a summary of the articles in the Egyptian environmental laws relevant to steam generating plants. Chapter 6 gives examples of pollution abatement techniques and measures applicable to these plants. Chapter 7 illustrates the SM definitions and its link to the EMS, whereas chapter 8 describes the planning phase of SM and the types of collected data.

The SM activities are described in chapters 9 to 12. Chapter 9 is concerned with monitoring of inputs and outputs whereas chapters 10 and 11 are devoted to the operations control and compliance monitoring respectively. Chapter 12 describes how to use the SM outputs.

1.3 Using the Manual

The self-monitoring manual for Energy Generating Plants is not meant to be used alone. Energy Generating Plants are part of the industrial facility and their self-monitoring plan will usually be part of that of the facility.

Developing the SM plan for energy generating plants requires studying the technical aspects related to the operation of these units (combustion requirements), the softening of the boiler feed water, the steam distribution network and the fuel supply line. Chapter 2 and 3 of the manual present the most important technical information relative to energy generating plants.

Site specific information about plant location and final wastewater receiving media will be important to determine the applicable laws and regulations.

1.4 Background

Various types of boilers have been developed along the years, starting with the simple cylindrical shell-type boiler heated by a flame applied to the outer surfaces. In selecting a boiler, or in designing one, thermal, hydraulic, and structural factors, as well as fuel and its associated firing equipment must be reviewed for the application on hand.

Because of the variety of boiler systems and boiler types that exhibit different problems, it is appropriate to review briefly such terms as boilers; steam generators; critical-pressure boilers; low-pressure, high-pressure, steam, and hot-water-heating boilers, and hot-water-supply boilers, as well as some jurisdictional requirements.

The following definition of boilers is usually found in government laws and codes on boilers in reference to installation or re-inspection requirements as well as license for operating this type of equipment.

A boiler or steam generator is a closed pressure vessel in which a fluid (water in most cases) is heated. If the water is heated for the purpose of obtaining hot water then is boiler is defined as a hot-water boiler. If the water is heated to generate steam (wet, saturated, or superheated) under pressure then the boiler is referred to as steam generator. The energy is supplied to the water by the application of heat resulting from the combustion of fuel (solid, liquid, or gaseous) or by the use of electricity or nuclear energy. Heat is transferred to the water through the heating surfaces.

Annex A-1 presents the boiler related terminology.

The operation, maintenance, and inspection of boiler plants require the continuous service of well-trained technical people. The development in control technology and measuring devices has made it necessary for the operators to be familiar with modern boiler controls that are based on an integrated system involving the following parameters:

- Load flow for heat, process use, or electric power generation.
- Fuel flow and its efficient burning.
- Airflow to support proper and efficient combustion with minimal combustion generated pollution.
- Water and steam flow rate to follow the variation in load.
- Exhaust flow rate of products of combustion to achieve the maximum heat gain from fuel.

In addition to that, highly automated plants require the knowledge of how the system works to produce the desired results and what to do to make it perform according to design. However, manual operation may still be required under emergency conditions, which is why a knowledge of the different "loops" of a boiler system will assist the operator to restore conditions to normal much faster. If a boiler system is out of limits, then with the access of modern measuring devices, instruments, and computers, skilled personnel must trace through the system to see if the problem is in the measuring instruments or if a component of the system has had an electrical or mechanical breakdown. Annex (A-2) presents basic definitions for valves, controls and fittings, whereas rating terminology is presented in annex (A-3).

Stack height is an important parameter for the operation of the boilers. Its function is to supply draft for exhaust gases. Annex (B) shows how to calculate the minimum stack height necessary for optimum operation. Stack height is also regulated for environmental purposes, by law 4/1994.

2. Description of Energy Production/Thermal Power Plants

The most important energy generating plants in industrial facilities are steam generating plants. These plants involve two distinct lines, the fuel line and the water line, each completely independent of the other in terms of mass transfer. The only interaction between these two lines is through the transfer of the heat generated by fuel combustion to water. The heat transfer process is responsible for the generation of steam. Accordingly, there are different ways to differentiate between steam generating plants, depending on:

- Type of steam generating plant
- Utilization
- Type of fuel
- Type of water treatment technology

Other energy generating units used in industry are:

- Diesel generators
- Gas turbines

2.1 Categorization of Boilers According to Type of Steam Generating Plant (configuration)

Boiler types do not have a direct impact on pollutant emissions during normal operation. However, understanding how each type is operated gives an insight on the control of boilers operation to avoid malfunctioning through preventive maintenance.

The types of boilers available for industrial use are generally classified as:

- 1) Fire-tube or shell,
- 2) Water-tube, and
- 3) Composite (fire-tube and water-tube combination).

Water-tube boilers can be subdivided by method of construction into:

- Shop-assembled,
- Modular,
- Site-assembled.

2.1.1 Fire-Tube Boiler

In fire-tube boilers, products of combustion, or hot gases, flow through ducts (mostly tubes), which are wholly contained within a water vessel (shell). Combustion may also take place within a large tube (referred to as flame tube) also enclosed in that vessel. Refer to Fig (2.1). The fire-tube boiler is the most prevailing boiler used for heating purposes, as well as commercial and industrial applications. Boiler configurations are influenced by heat-transfer requirements, so that as much as possible of the heat released by a fuel may be extracted and transferred to the water.

Fire-tube boilers are classified into horizontal-return-tubular, economic or firebox-type, locomotive firebox-type, scotch-marine-type, vertical tubular, and vertical tubeless boilers. The scotch marine boiler design Fig (2.1) is the dominant fire-tube type for both heating and industrial process uses of up to about 20,000-kg/hr capacity. Above this capacity, water-tube boilers are generally used.

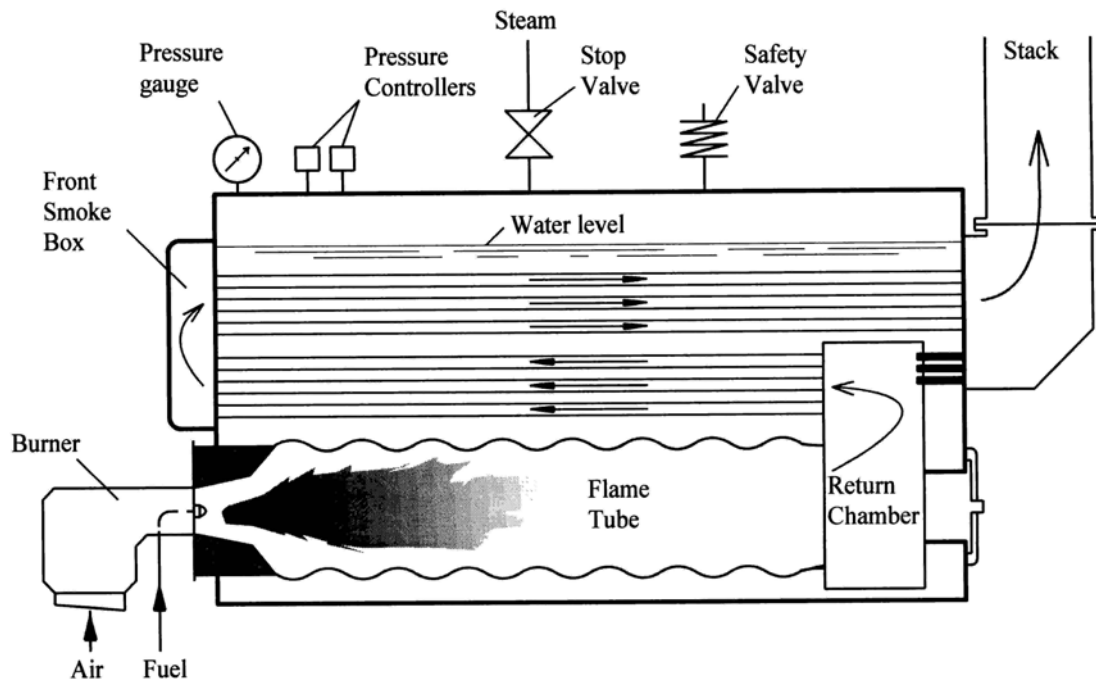


Fig (2.1) Three-P Fire-Tube Boiler

The largest number of fire-tube boilers in use today for commercial and small industrial plants is the scotch marine boiler. Therefore, when we mention the fire-tube boiler we are generally referring to this type. The fire-tube boiler was originally used for marine services, because the furnace forms an integral part of the boiler assembly, permitting very compact construction that requires a small space for the capacity produced.

The fire-tube boiler is sold as a package consisting of the pressure vessel, burner, controls, and other components assembled into a fully factory-fire-tested unit. Most manufacturers test their models as a unit before it is shipped to the site, basically delivering a product that is pre-engineered and ready for quick installation and connection to services such as electricity, water, and fuel. Some manufacturers provide starting service as part of the purchase price. A factory-trained specialist starts up the unit, readjusts controls, checks out the unit in operation, makes necessary adjustments, and trains an operator to troubleshoot on controls. In Egypt, this type used to be manufactured by El-Nasr Company for Boilers and Pressure Vessels, which after being privatized, is now under the name 'Babcock and Wilcox'.

The fire-tube boiler is built either as a wetback furnace or as a dry-back furnace. The dry-back fire-tube boiler consists of an outer cylinder shell, a furnace, front and rear tube sheets, and a crown sheet. The hot gases from the furnaces (flame tube) pass into a return chamber, which is lined with refractory bricks at the back. The gases are returned through the fire tubes (second pass) to the front of the boiler where they then reach the third pass to the stack. In the wetback design, the shell, tube, and furnace construction are similar to the dry-back type, but the return chamber is surrounded by water. Therefore, no refractory is needed.

The dry-back type is a quick steamer because of its large heating surface. It is also compact and easily set up and is fairly economical.

The types of boilers sold in Egypt are suitable for gas and oil firing.

The internal furnace of the fire-tube boiler is subject to compressive forces and must therefore be designed to resist them. Furnaces of relatively small diameter and short length may be self-supporting if the wall thickness is adequate. For larger furnaces, one of these four methods of support may be used:

- 1) Corrugating the furnace walls;
- 2) Dividing the furnace length into sections with a stiffening flange between sections;
- 3) Using welded stiffening rings; and
- 4) Installing stay bolts between the furnace and the outer shell.

The shell of the fire-tube boiler may be built up to about 3 m in diameter. Since the area of the segment of heads above the tubes is large, diagonal stays are usually precluded because of the great number that would be required. Instead, it is customary to use a smaller number of head-to-head through-stays of 2- to 3-in. diameter.

For boilers of large diameter, when the rate of heat input is greater than 12 MW, it is the practice to use more than one furnace, (usually two or more). Figure (2.1) is a cutaway view of a three-pass model. This unit maintains a continuously high gas velocity. As the hot gases travel through the three passes, as shown in Fig. (2.1) they transfer heat to the boiler water and thus cool and occupy less volume as the gases pass through the different tube passes. The number of tubes is reduced proportionately to maintain the high gas velocity and thus keep the heat transfer rate constant. The furnace of a fire-tube boiler may provide up to 65 percent of the boiler output even though it may have only about 7 to 8 percent of the total heating surface. In the furnace, most of the heat is transferred by radiation. The furnace should have sufficient volume to permit complete combustion of the fuel-air mixture before the flue gases reach the tube passes. Most designers try to limit the heat-release rate in the furnace to below 1.8 MW/m^3 of furnace volume; otherwise, the ratio of air to fuel becomes critical. Rates above 1.8 MW/m^3 of furnace volume can cause the fuel to continue to burn on entry to the second pass of tubes, which may result in the cracking of tube ends or the cracking of welds between the furnace and the rear tube sheets. Temperature of the flue gases at the return chamber is limited to 950°C in case of fuel-oil-firing and to 1150°C in case of gas-fuel-firing. Any scale or other deposits can aggravate this cracking with high furnace heat-release rates. Good feedwater treatment is thus essential for fire-tube boilers with high heat-release rates in the furnace.

There is also the problem of corrosion on the fireside when sulfur-burning fuels are used. Corrosion can occur when the plate or tube temperatures drop below the acid dew point, such as may occur from on-off firing; corrosion reaches a maximum rate when the temperatures fall to less than the water dew point. On-off firing usually requires purging of the furnace, and this can also produce thermal gradients in the boiler which might result in cracking from the effects of expansion and contraction.

Compact designs also tend to make surfaces less accessible for inspection and cleaning. Thus today's higher heat-transfer rates can easily cause overheating, especially if forced. This may result in loose tubes in tube sheets, cracks between ligaments on tube sheets, weld cracks in high-heat zones, bulged furnaces, and low water.

2.1.2 Water-Tube Boilers

The development of industry during the last two centuries, encouraged the widespread use of boilers for raising steam. Consequently, disastrous explosions sometimes occurred for various reasons. Boilers of that period consisted of heated pressure vessels of large diameter. These vessels were subject to internal pressure that created tensile stresses in the walls of the enclosure. The value of this stress, known as 'hoop stress' is given in the following equation:

$$S = \frac{P \times D}{2T}$$

Where:

S is the hoop stress,

P is the internal working pressure,

D is the vessel diameter, and

T is the thickness of the metal.

(All in self-consistent units).

Thus, for a given stress S, as D increases with increasing output of the boiler, T (thickness of the metal) must also increase. If the working pressure P increases, then either D must be decreased or T be increased to keep S within acceptable limits. If T is increased, then the mass of the boiler and the cost of its manufacture both increase. The attractive alternative is to decrease D. This approach formed the basis for the water-tube boiler in which the water is contained within tubes and the flue gases pass outside and across the tubes, Fig (2.2).

The boiler-heated surfaces consist of a group or 'bank' of tubes of about 75 mm bore, some of which are exposed to the fire, others to the flow of hot gases produced by the combustion process. Baffles are provided in the bank of tubes to create a number of gas paths and thus increase the effectiveness of the heated surface. In this manner, the heat is transferred to the water in the boiler through tubes of relatively thin section when compared with the thickness of a fire-tube boiler shell. Hence, the working pressure could be raised considerably

above that of a fire-tube boiler. Moreover, should a tube rupture occur, the consequences would be less serious than if the furnace or shell of a fire-tube boiler ruptured.

While this construction persisted for many years, it had pressure limitations, and eventually multi-drum boilers with bent tubes were developed. The lower drums into which boiler water impurities settled became known as 'mud drums'.

In the early boilers, the tubes were situated in an enclosure made of brickwork lined on the inside with firebrick. Eventually, the brick walls were partially covered on the fireside by water-tubes called water-walls, connected to the steam drum directly or by headers and pipes. These absorbed heat from the combustion process, thereby reducing the temperature of the gases flowing to the tube bank. Moreover, they provided some protection to the brick walls, and eventually, as the percentage of the wall area covered by tubes increased, gave scope for reducing the heat loss from the walls to the atmosphere.

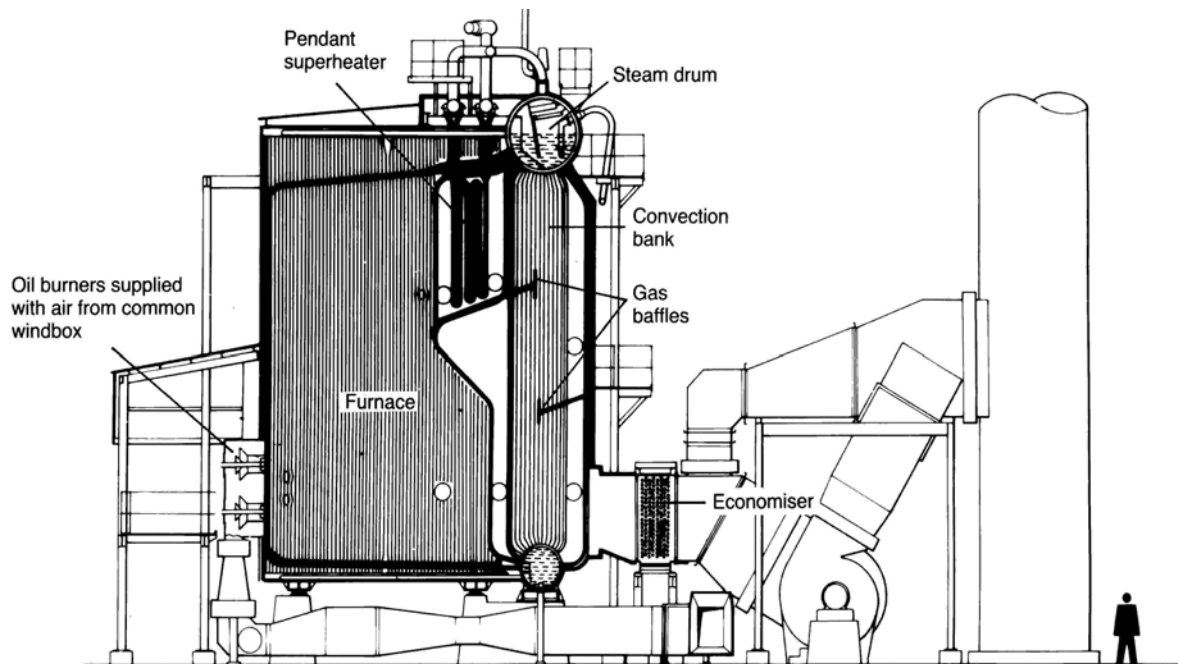


Fig (2.2) Two-Drum Oil- or Gas-Fired Water-Tube Boiler

Designs have progressed considerably over the years. At present, the walls have completely covered with a water-cooled surfaces. These walls are formed either by tubes touching each other, known as 'tangent tubes', or by tubes connected together by strips of steel welded axially known as "welded walls".

With increasing working pressures and the use of economizers and air-heaters, it has become more economical to reduce the number of boiler drums. The two-drum type of boiler's now the most popular design among industrial water-tube boilers operating at pressures up to 100 bar, although a number of single-drum types are available.

Table (2.1) summarizes the main characteristics for both fire-tube and water-tube boilers.

2.1.3 Composite Boilers

Recently, water-tube and fire-tube principles have been combined with the development of the composite boiler (Fig 2.3). With this design, the steam drum and convection bank of a conventional water-tube boiler are replaced by a shell containing a large number of small-bore tubes only that is, a fire-tube boiler with no furnaces. The water-walls of the furnace are connected by pipes to the fire-tube boiler, which also acts as the steam drum. The design combines the advantages of the low-cost fire-tube boiler: the large steam/water drum and consequent low steam disengagement velocity; the ability to arrange the water-tube furnace; flexible combustion space so as to incorporate the type of firing equipment most suitable for a particular fuel and application.

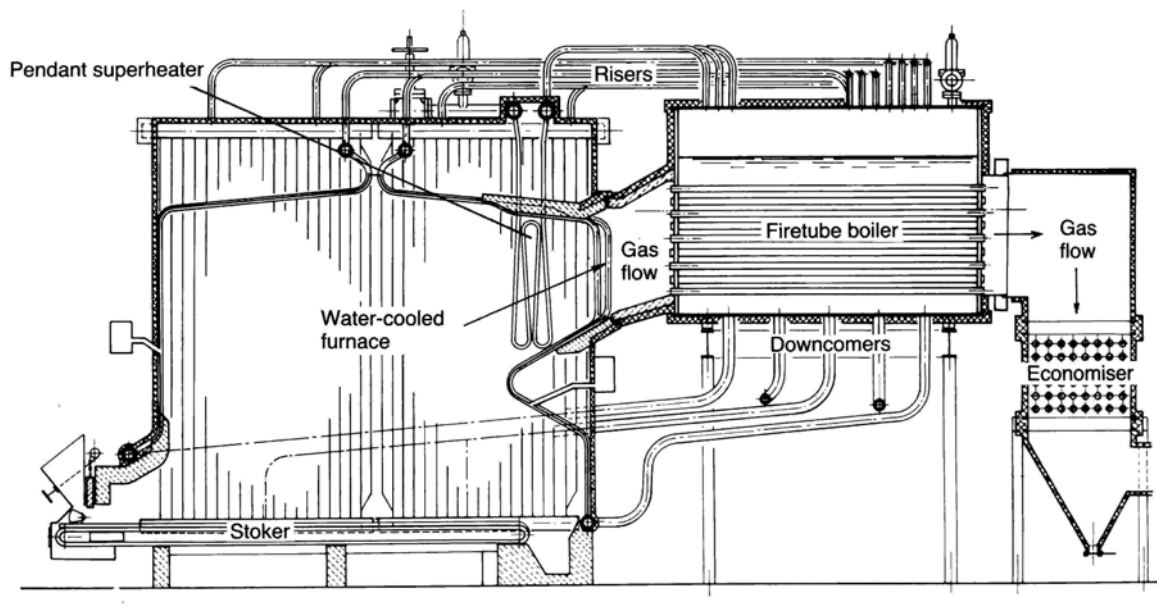


Fig (2.3) Composite Boiler

Table (2.1) Characteristics of Fire-Tube and Water-Tube Boilers

| | Fire-tube | Water-tube |
|-----------------|--|--|
| Pressure | Limited to 20 – 30 bar (20 bar in the larger sizes). | Virtually unlimited |
| Unit output | Limited to about 20 MW. | Virtually unlimited. |
| Fuel acceptance | All commercial fuels. | Virtually unlimited due to the large furnace, which can be designed for a particular fuel. |
| Cost | Low compared to water-tube. | High compared to fire-tube. |

| | | |
|--------------------|---|---|
| Erection | Packaged ready for work after connecting to services at site. | Can be shop-assembled or site erected. |
| Efficiency | 80 – 85 % (Gross calorific value) according to fuel. Can be increased by adding economizer. | 85 – 90 % (Gross calorific value) according to fuel. Economizer or air preheater normally included as standard. Both may be used together to maximize efficiency. |
| Feed water purpose | For heating purposes. | For power plus heating purposes. |

2.2 Categorization According to Utilization

Boiler systems can be grouped into the following:

- 1) Electric power generation
- 2) High-pressure-steam for industry
- 3) Low-pressure-steam for industry
- 4) Steam-heating systems
- 5) Hot-water systems, both low-pressure and high-pressure
- 6) Systems using a different working fluid than the water-steam cycle, such as dowtherm.

2.2.1 Steam Systems for Electric Power Generation

The utility boilers that are used for electric power generation are of the water-tube type. These work at remarkably high sub-critical pressures, and in some power stations at super-critical pressures. The steam generator supplies the steam turbine(s) with live superheated steam. In modern utility plants, the utility boilers include auxiliaries such as heaters, superheaters, reheaters, and preheaters which increase the thermal efficiency of the plant.

2.2.2 High-Pressure Process Systems

High-pressure process systems may use fire-tube or water-tube boilers, depending on the pressure or capacity needed. The steam is used for mechanical drive turbine power to drive compressors, pumps, and similar equipment. It is also used to provide high pressure or temperature for manufacturing needs.

2.2.3 Low Pressure Steam Systems/ Hot Water Systems

Boilers or water heaters working below 1 bar gauge are classified as low-pressure systems.

2.2.4 Steam-Heating Boiler Systems

Steam-heating boilers are usually low-pressure units of steel construction, although high-pressure steel boilers may also be used for large residential buildings or for large, industrial facilities. Usually if this is done, pressure-reducing valves in the steam lines lower the pressure to the radiators, convectors, or steam coils. The term steam heating also generally implies that all condensate is returned to the boiler in a closed-loop system.

Low-pressure heating boilers are usually operated automatically by on-off or modulating burner controls. Quite often the mistake made is thinking that low-

pressure boilers thus automated are perfectly reliable because they operate as a robot.

On the contrary, serious explosions can occur from faulty operation or controls that malfunction. For example, if a limit control fails or is blocked so that it cannot operate when needed, over firing can result. Over firing may be caused by:

- Failure of a limit control to stop the burner because of a relay or mechanical defect.
- Mechanical failure of a fuel valve, or dirt blocking a valve preventing closure.
- Lack of temperature monitoring when burner is on manual operation.
- Oversized burner in relation to boiler system (or mild steam demand in conjunction with non-operational pump).
- Wiring short circuit, causing controls to be bypassed.
- Fusing of contacts on a stop-go switch into the go position.
- Solenoid or air-operated valves isolating the boiler from the load because of mechanical or electrical defect of the controls on the solenoid or on the air stop-go device.

Steam-heating systems use either gravity or mechanical condensate-return systems. The differences between each type of systems are defined as follows: when all the heating elements (such as radiators, convectors, and steam coils) are located above the boiler and no pumps are used, the mechanism is known as a gravity return, since the condensate returns to the boiler by gravity. If traps or pumps are installed to aid the return of condensate, the system is known as mechanical return system. In addition to traps, this system usually includes a condensate tank, a condensate pump, or a vacuum tank or vacuum pump.

2.2.5 Hot-Water Systems

There are three general classes of hot-water systems:

- 1) Hot-water supply systems for washing and similar uses;
- 2) Space-heating systems of the low-pressure type, often referred to as building heating systems; and
- 3) High-temperature high pressure water systems operating at temperatures of over 120 °C and pressures of over 10 bar.

Both the hot-water-heating system and the high-temperature hot-water systems require some form of expansion tank in order to permit the water to expand as heat is supplied, without a corresponding increase in pressure. A common problem of hot-water-heating systems is that expansion tanks lose their air cushion, so that the water system can no longer expand without raising the pressure of the system. If this problem is neglected, pressure can build up to the point where the relief valve may open and dump water in the property. Thus periodic draining of the expansion tank is necessary to re-establish the air cushion.

2.2.6 Systems Using a Different Working Fluid

Boilers are not limited to the use of water as their working fluid. Their function extends to other fluids, such as dowtherm oils, especially when the oil acts as a

heat-carrying agent between boiler and heating or drying applications, such as in the textile industry. Dowtherm oil is an organic chemical with a high boiling point. It is composed of diphenyl and diphenyl-oxide.

2.3 Type of Fuel Used

The combustion process is a special form of oxidation in which oxygen from the air combines with fuel elements. The environmental impact of combustion varies significantly depending on the fuel used. There are three main commercial fuels that are fired in boilers, namely:

- Heavy fuel oil, commercially known as 'Mazout'
- Light fuel oil, commercially known as 'Solar'
- Natural gas (NG)

Other types of fuels are used in insignificant amounts:

- Kerosene
- Liquefied petroleum gas (LPG)
- Bagasse and agricultural wastes
- Black liquor

Air emissions are directly related to the type of fuel. Table (2.2) presents the emission rate of pollutants per kg of fuel for the main types of fuel. Agricultural wastes generate more ashes and particulate matter than allowed by environmental regulations.

2.3.1 Fuel Oil (Mazout)

Mazout is a brownish-black petroleum fraction consisting largely of distillation residues from asphaltic-type crude oils, with a relative density of about 0.95. The fuel is highly viscous at atmospheric condition. Preheating is therefore necessary before combustion. For proper atomization, a maximum viscosity of about 24 cStoke at the burner tip is commonly adopted. For storage precautions, the minimum flash point is commonly 66 °C, and a minimum temperature must be set for storage and handling of the fuel.

Sulfur content may reach about 3.0 - 3.5 per cent by mass, and is considered to restrict corrosion problems. The maximum water-content is specified as 0.25 per cent. The mineral matter retained in petroleum residues appears as ash during combustion, and may contain hazardous materials. Hence, a maximum ash-content of about 0.25 per cent is also specified. Mazout is generally used for heating in furnaces and kilns and for steam-raising (boilers). Mazout shows advantages over other petroleum-based fuels for furnace applications due to its high luminosity.

2.3.2 Gas Oil (Solar)

Solar is a darkish-yellow petroleum fraction comprising distillate and small residual components, with a relative density of about 0.87. Solar fuel is used in the heavier, larger diesel engines employed in marine and stationary electricity-generating installations, which operate at relatively low rotational speeds and are less critical of fuel quality. The fuel is also used in burners for industrial heating, hot-water and steam production (boilers), and for drying. It

has a maximum viscosity of 12.5 cStoke at about 80 °C, and its minimum temperature for satisfactory handling is about 10 °C. The flash-point of the gas oil (solar) has recently been reduced to 60 °C. The sulfur content in Egyptian solar is 1-1.2 wt%.

2.3.3 Natural Gas

Natural gas (NG) consists mainly of methane, some proportions of ethane to heptane components, together with traces of N₂, CO₂ and H₂S. The concentration of H₂S in natural gas is 0.2 % by volume. Although pentane and heavier hydrocarbons boil above ambient temperature, they vaporize in small proportions below ambient temperature.

2.3.4 Liquefied Petroleum Gases

Commercial butane and propane are essentially by-products of petroleum processing. The mixture of the two gases in varied ratio form what is called petroleum gas. Both gases have high heating values and are easily liquefied at low pressure forming liquefied petroleum gas (LPG), sometimes referred to as refinery gas. LPG is widely used as bottled fuels. On vaporization, the vapor-liquid volume ratio can reach a value of 250/1.

2.3.5 Bagasse and Other Agricultural Wastes

Bagasse is a low-density waste, which must be disposed off. It has always been used as a fuel in sugar cane factories. It has a fibrous structure, with a maximum dimension of about 50-mm and moisture content of 45-55%, as supplied to the boilers. A wide variety of combustion equipment has been used to fire this waste, some of the most common being pile burning in refractory furnaces, firing on inclined or stepped grates and suspension firing over static, dumping or travelling grates.

Static 'pinhole' grates, consisting of perforated grate bars resting on boiler tubes, and dumping grates, where the grate surface is tilted in sections to remove ash from the furnace, can be used for the whole range of outputs currently required. Either mechanical or pneumatic distributors disperse the fuel across the furnace.

Boilers used for firing bagasse have low gas velocities to avoid tube erosion which occurs due to carryover of particulates, such as sand. They also have ample hoppers into which suspended matter from the gases can fall to avoid blockage of the gas passages.

Suspension fired boilers tend to have tall, moderately rated furnaces to reduce particulate carryover to a minimum. Nevertheless, some form of dust collection equipment is necessary to avoid high induced-draught fan wear, and chimney emission nuisance. Until recently, thermal efficiency has been of no great concern, the main aim of the plant being to achieve a good balance between fuel availability and the energy or fuel required. Any surplus bagasse, being of low density, is expensive to transport for other uses and requires large areas for storage. Moreover, long-term storage is not recommended due to the fact that it will decompose and attract vermin.

The use of bagasse in paper and paper pulp industries has recently been initiated. Therefore, other available commercial fuels, such as mazout, will soon replace bagasse as fuel in the cane sugar industry in Egypt. In addition, bagasse drying is being introduced, where the heat in the flue gases leaving the boiler is used to drive off some of the moisture in the fuel. This has the effect of lowering the temperature of gas discharged to the chimney; giving a higher thermal efficiency than would otherwise be achieved. Combustion is also improved.

While most solid liquid-fuel fired boilers are fed with fuel from a bunker or tank, bagasse-fired boilers are unique in that the fuel is continuously transported from the mills where it is produced, directly to the boilers, with no intermediate storage. This is done because of the difficulties, associated with reclaiming fibrous fuels from storage, as previously mentioned. A breakdown in the milling plant that causes a stoppage in the flow of fuel will, therefore, result in a loss of boiler output. This is particularly significant with suspension firing unless a very efficient system of reclaiming from the fuel store is available, or unless facilities for firing a readily available fuel, such as oil or gas, are fitted.

Other agricultural wastes are not used commercially.

2.3.6 Black Liquor

In pulp mills, where the cellulose fibers in wood are extracted for paper-making, a liquid waste or liquor is produced and used as a source of heat and power. This liquor has a solids content of 10-20%, a typical analysis of which is given on Table (2.3). It also contains chemicals used in the pulping process, such as sodium sulfate or sodium sulfite. This effluent is called black liquor, or sulfite liquor, depending on the chemical process being used. It is concentrated to about 68% solids, using the products of combustion from the boiler to evaporate the water in direct-contact heat exchangers. It is then fired in boilers in order to dispose of the combustible solids, the heat, and the process chemicals for reuse. The boilers used for this purpose are called chemical recovery units. They are essential units in all pulping processes in Egypt.

Present-day power and steam requirements in pulp mills necessitate the use of high-pressure boilers of either the two-drum type, with a single-pass convection bank, or of the single-drum type. Because of the high particulate loading and its low fusion temperature, the furnace design is tall, to reduce the gas temperature to the convection surfaces. However, it is still necessary for the convection bank, superheater and economizer, to have very wide tube spacing to prevent bridging and blockage in the gas passages. The wide spacing also simplifies slag and dust removal. Numerous soot blowers are included for on-load cleaning.

Table (2.3) displays the composition and heating value of Egyptian commercial fuels.

Table (2.2) Emission Rate of Pollutants for Different Fuels

| Commercial Fuel | Amount of Pollutant (kg/kg fuel) |
|-----------------|----------------------------------|
|-----------------|----------------------------------|

| | CO ₂ | CO | SO ₂ | NO _x |
|-------------|-----------------|----------|-----------------|-----------------|
| Mazout | 3.1694 | 0.0004 | 0.04 | 0.00564 |
| Solar | 3.08137 | 0.00036 | 0.0152 | 0.001487 |
| Natural Gas | 2.01 | 0.000042 | 0 | 0.00125 |

Table (2.3) Heating Value and Composition of Egyptian Fuels

| Fuel | Analysis, weight % | | | | | | | Heating value kJ/kg | |
|--------------|--------------------|------|------|----------------|----------------|------|------------------|------------------------|--------|
| | C | H | S | N ₂ | O ₂ | Ash | H ₂ O | Gross | Net |
| Natural gas | 75 | 25 | — | — | — | — | — | 55 300 | 49 830 |
| LPG | 82.4 | 17.6 | — | — | — | — | — | 46 860 | 43 285 |
| Kerosene | 86.0 | 13.7 | 0.07 | — | — | — | — | 45 900 | 43 030 |
| Solar | 86.3 | 12.5 | 1.0 | 0.05 | 0.05 | 0.1 | — | 44 570 | 41 900 |
| Mazout | 86.0 | 10.5 | 3.0 | 0.05 | 0.05 | 0.2 | 0.2 | 43 250 | 41 080 |
| Bagasse | 24.7 | 2.7 | 0.1 | 0.4 | 20.6 | 1.5 | 50.0 | 9 473 | 7 796 |
| Black liquor | 42.6 | 3.6 | 3.6 | 0.2 | 31.7 | 18.3 | — | 15 352 | 14 621 |

2.4 Type of Water Treatment Technology

Water quality is an important element in the efficient operation of boilers and steam systems. All water supplies contain some impurities in the form of dissolved gases and solids in solution or suspension. Treatment consists essentially of either removing objectionable constituents (or at least reducing their concentration to a level at which they are relatively harmless), or adding substances which suppress their undesirable effects. Water treatment of some sort is thus necessary for all boiler makeup water to:

- Treat scale formation in boilers and ancillary equipment, which may cause the boiler metal to overheat and fail disastrously.
- Minimize foaming and avoid contamination of steam by carry-over of boiler water.
- Minimize corrosion in the boiler due to dissolved oxygen in the feedwater, and in the steam mains and networks due to carbon dioxide in the steam.

Recommended water quality is given in Annex (C).

There are two basic methods of water treatment, namely, external and internal.

2.4.1 External Water Treatment

External treatment is the reduction or removal of impurities from water outside the boiler. In general, external treatment is used when the amount of one or more of the feedwater impurities is too high to be handled by the boiler system. The most common external treatment methods include ion exchange, deaeration, and demineralization.

Before discussing water treatment processes, it is worth pointing out that routine checks of key water quality parameters should be made and the results logged. The most important parameters to monitor are shown in Table (2.4).

Table (2.4) The Most Important Item to Check

| | Makeup Water | Condensate | Boiler Feed | Boiler Water | Blow-down |
|------------------------|--------------|------------|-------------|--------------|-----------|
| Total dissolved solids | X | X | X | X | X |
| Alkalinity | X | X | X | X | |
| Chlorides | X | X | X | X | X |
| Hardness | X | X | X | X | |
| pH | X | X | X | | |

The quality of water can easily be checked using water test kits; conductivity meters can be used to check total dissolved solids.

Scale and Sludge Formation

Water always contains bicarbonates, chlorides, sulfates, and nitrates of calcium, magnesium and sodium in varying proportions, as well as silica, and occasional traces of iron, manganese and aluminum.

Calcium (Ca) and magnesium (Mg) salts cause hardness in water; most of the scales and deposits formed from natural waters in the boiler plant and in cooling systems are largely compounds of calcium and magnesium.

Calcium and magnesium salts may be divided into two groups:

- 1) The bicarbonates $\text{Ca}(\text{HCO}_3)_2$ and $\text{Mg}(\text{HCO}_3)_2$, which cause alkaline hardness, also known as temporary hardness or carbonate hardness. These are easily decomposed by heat. Carbon dioxide is released and can cause acidic steam condensation and corrosion problems.
- 2) The sulfates, chlorides and nitrates CaCl_2 , MgCl_2 , CaSO_4 , MgSO_4 , $\text{Ca}(\text{NO}_3)_2$ and $\text{Mg}(\text{NO}_3)_2$. These are not decomposed by boiling and cause non-alkaline hardness (also called non-carbonate or permanent hardness). The nitrates are normally present in very small quantities.

The most objectionable effect of using raw water in a boiler is, therefore, the deposition of hard adherent scales on the heating surfaces. These have a low thermal conductivity estimated between 1.15 and 3.45 W/m °C, so that the metal temperature will rise to the point at which it softens, bulges and splits under pressure, with dangerous results.

The parts of the heating surface most sensitive to this effect are water tubes exposed to radiant heat, or furnace tubes of shell boilers, where rates of heat transfer and water evaporation are high. In tubes receiving heat by convection and conduction, greater thickness of scale can be tolerated before failure takes place. The direct loss of heat or waste of fuel caused by scale has been

estimated at about 2 percent or even less in watertube boilers, but may be up to 5 or 6 percent in fire tube boilers where heating surfaces are small.

In addition to the deposition of scales and sludge, dissolved gases can pose problems. Carbon dioxide and oxygen that are dissolved in water, together with the carbon dioxide liberated when water containing bicarbonates is heated, can cause corrosion in economizers and boilers. Since dissolved gases pass out with steam, they reappear in condensate, which is therefore corrosive. Finally, salts and suspended solids in boiler water can, under certain conditions, be carried out of the boiler in the steam and deposited in steam mains and steam using equipment.

External water treatment processes include:

a. *Ion-Exchange Processes*

Ion exchange encompasses a number of variations on a process known as water softening, that is, reducing the hardness of water. Salts dissolved in water, separate into their constituent ions, and these have some degree of mobility. Ions carrying a positive charge are termed *cations*, and include metallic and hydrogen ions. *Anions* carry a negative charge. Those chiefly of interest in water treatment are:



The interaction between ions in solution is the principle behind a considerable number of chemical reactions, including precipitation. Moreover, some solid materials will exchange ions with those dissolved in water passing through them. This ion exchange phenomenon was first noticed in relation to certain minerals known as zeolites, which are essentially sodium aluminum silicates. When hard water is allowed to percolate through a bed of suitably graded zeolite, nearly all the calcium and magnesium ions are replaced by sodium, and the water is thus softened. Eventually, all the sodium in the zeolite is used up, and the bed consists essentially of calcium and magnesium zeolite. However, can be reconverted into the sodium zeolite by treatment with a strong solution of brine (NaCl).

Synthetic zeolites are more efficient for water softening than the natural minerals, but these man made materials have been surpassed by other substances. Resins made by the condensation of phenols and formaldehyde have good exchange properties. Other types of resins with similar properties have more recently been developed, such as the polystyrene and carboxylic resins.

These processes work best with clean water. Suspended solids in the raw water should be removed by filtration using coagulants if necessary. Otherwise they will clog the pores of the exchange material and reduce its exchange capacity. There

are also working losses due to abrasion and carryover of fine material, so that some fresh material must be added after a year or two, as make-up. These losses vary according to working conditions, and the plant suppliers should be consulted for estimates of losses in any given case

b. Deaeration

Deaerators are used to remove the oxygen in water by the use of heat. Oxygen gas dissolves in water and does not react chemically with it. As the water temperature increases, it becomes less and less soluble. Thus, it is easily removed by bringing the water to the boiling temperature corresponding to the operating pressure. Pressure and vacuum designs are used for deaeration. In pressure deaerators, steam is injected through the water to remove oxygen and simultaneously provides heat to the feed water. Consequently, this method is preferred for boiler feed water. Vacuum units are mainly used when heating is not required.

Steam deaerators break up water into a spray or film and then sweep the steam across to force out dissolved gases such as oxygen or carbon dioxide. The oxygen content can be reduced below 0.005 cubic centimeters per liter (cm^3/l), almost the limit of sample testing by chemical means. As carbon dioxide is removed, pH increases. This increase gives an indication to the deaeration efficiency.

c. Demineralization

Demineralization involves passing water through both cation- and anion-exchange materials. The cation-exchange process is operated on the hydrogen cycle. That is, hydrogen is substituted for all the cations. The anion exchanger operates on the hydroxide cycle, which replaces hydroxide for all the anions. The final effluent from this process consists essentially of hydrogen ions and hydroxide ions, or water.

The demineralization process may take any of several forms. In the mixed-bed process, the anion- and cation-exchange materials are intimately mixed in one unit. Multibed arrangements may consist of various combinations of cation exchange beds, weak and strong based anion exchange beds, and degasifiers.

2.4.2 Internal Water Treatment Processes

Internal treatment is the conditioning of impurities within the boiler system itself. The conditioning may take place either in the feed lines or inside the boiler. Internal treatment may be used alone or in combination with external treatment. Internal treatment is designed to take proper account of feedwater hardness, to control corrosion, to scavenge oxygen, and to prevent boiler water

carry-over. Through internal treatment, the alkaline hardness in the raw water is decomposed and precipitates as the water is heated.

Permanent hardness is precipitated in the boiler by the addition of alkali in the form of sodium carbonate, caustic soda, or sodium phosphates. Due to their high price, their use is limited to cases where intake water has poor quality. However, for boilers working at pressures above approximately 14 bar or low-hardness feedwater, they are essential.

2.4.3 Conditioning of Boiler Feed Water

Conditioning of boiler feed water involves the use of some additives, whose number and types have increased appreciably over the last twenty years. Brief notes on selected items are given below. A program devised for a particular boiler plant would be unlikely to include all items shown:

- 1) Sodium Carbonate: Used to promote zero hardness in low-pressure boilers operating below about 14 bar and so prevent scale; also to raise the alkalinity of feed so as to minimize corrosion. Some external treatment processes provide adequate sodium carbonate in the treated make-up water.
- 2) Caustic Soda: Can be used in place of sodium carbonate in low-pressure boilers as above. If external treatment is performed providing sufficient softening, caustic soda is not required.
- 3) Phosphates: All forms are used for scale prevention at boiler pressures above about 14 bar. Glassy phosphates can also reduce the precipitation of calcium carbonate in hot feed lines. Both glassy and acidic phosphate may be used to eliminate excess caustic soda (if used in external treatment) from the boiler water.
- 4) Chelating Agents: Used as an alternative to phosphates to prevent scaling in boilers.
- 5) Anti-foams: Used to prevent foam formation in boilers. Proprietary boiler-chemical mixtures often contain an antifoam agent. Anti-foams can also be obtained separately for individual application in severe cases.
- 6) Neutralizing Amines: Used to neutralize carbon dioxide in steam condensate and feed lines, and so diminish corrosion. Not economic in systems with high make-up of untreated water. Unsuitable where steam comes into direct contact with foods, beverages, or pharmaceutical products.
- 7) Sodium Sulfite: Used to eliminate dissolved oxygen and consequently decrease corrosion. Compounded sodium sulfite is known to react 20 to 500 times as fast as the un-compounded material, and this offers more protection to short feed systems. When boilers are not in operation or used as stand-by, they are filled with water to which sodium sulfite is added.
- 8) Hydrazine: Also used to eliminate dissolved oxygen and so diminish corrosion. Has the advantage of not increasing dissolved solids. Reacts slowly at temperatures below about 245 °C. Not used when steam is applied in processing food or beverages.
- 9) Sodium Sulfite: Used to prevent caustic cracking in riveted boilers.
- 10) Sodium Nitrate: Also used to prevent caustic cracking.

- 11) **Sludge Mobilizers:** Natural and synthetic organic materials are used to reduce adherence of sludge to boiler metal. Some of these materials have temperature limitations; the advice of the vendors should be followed closely in their use.

2.4.4 Blowdown

Blowdown is an integral part of the proper functioning of a boiler water treatment program, and usually requires continuous monitoring for positive control. Through the blowdown, most of the dirt, mud, sludge, and other undesirable materials are removed from the boiler drum. This section describes blowdown systems and their control. When considering blowdown methods, it is important to estimate the quantity of required blowdown. A simple relation gives blowdown as a percentage of evaporation in the boiler:

$$\% \text{ Blowdown} = \frac{B_f}{B_f - B_b} \times 100\%$$

Where:

B_f = Total dissolved solids in feedwater (ppm or mg/l)

B_b = Maximum allowable TDS in boiler water (ppm or mg/l)

For example, typical figures for a package boiler might be:

B_b = 3000 ppm and B_f = 100 ppm. Thus,

$$\% \text{ Blowdown} = \frac{100}{3000 - 100} \times 100\% = 3.45\% \text{ of the steam production.}$$

Intermittent and Continuous Blowdown

The blowdown may be intermittent, and taken from the bottom of the boiler to remove any sludge that has settled. This is generally a manual operation carried out once per drift in a series of short, sharp blasts; the amount of blowdown is estimated by monitoring the reduction of sludge level in the gauge glass, or simply from the duration of the blow. This has been the traditional method used with shell boilers.

Blowdown may also be continuous as a bleed from a source near the nominal water level. Since the concentration of solids will be the highest at the surface of the water (where boiling is occurring), surface blowdown is an efficient way to reduce the solids concentration. A bleed valve opening is adjusted according to periodic TDS measurements, and the flow is continuous. In more recent years, this has become "step-continuous". This means the valve is opened or closed cyclically from a time signal, or from a signal derived from some property of the boiler water, such as electrical conductivity. Automatic TDS control systems, based on this signal, are commercially available.

In modern practice both intermittent and continuous blowdown methods are used, the former mainly to remove the suspended solids which have settled, the latter to control TDS. It is important to carry out the intermittent blowdown sequence at periods of light load. It is also important that it should not be neglected; otherwise, sludge may build up to such an extent that heat transfer is impeded and the boiler fails, perhaps disastrously.

2.5 Diesel Generators

Diesel engines are used for stationary power generation in a wide variety of services: central stations, oil fields, pipelines, sewage disposal, and commercial, institutional, and military bases. Diesel engines are also used to supply auxiliary power in industrial plants or as emergency stand-by sources of energy in the event of main power-supply failure. Sometimes diesel engines are operated simultaneously with steam units to supply the peak-load electricity of the plant.

Ancillary equipment for Diesel engine plants are:

- *Air-intake systems.* Intake filters, ducts, and silencers
- *Exhaust gas systems.* Ducts, mufflers
- *Fuel systems.* Storage tanks, pumps, strainers, oil filters, meters, oil heaters, piping
- *Engine cooling systems.* Pumps, heat exchangers, cooling towers, spray ponds, water treatment, piping
- *Lube-oil systems.* Pumps, tanks, relief valves, filters, coolers, purifiers, piping
- *Engine starting systems.* Battery, electric motor, mechanical air compressor and engine, wiring, control panel
- *Electrical systems.* Generators, switchgear, exciters, busses, transformers, auxiliary power and light

2.5.1 Air-Intake Systems

They are used to lead air into the engine cylinders through ducts, or pipes and filters. Filters remove air-borne solids that may act as an abrasive in the engine cylinders. Filter types include: (1) dry, (2) oil-bath, (3) viscous-impingement, and (4) electrostatic precipitator filters. The intake system must cause a minimum pressure loss to avoid the reduction of engine capacity and the increase in specific fuel consumption.

Filters must be cleaned periodically to prevent pressure loss from clogging. Silencers must be used on some systems to reduce high-velocity air noises.

2.5.2 Exhaust Gas Systems

The system leads the engine exhaust gas outside the building, and discharge it to the atmosphere. Must be designed for low-pressure loss to avoid cutting engine capacity and reducing efficiency.

All exhaust systems need mufflers to attenuate gas-flow noises, which are highly objectionable. The exhaust stack usually stands on the muffler top.

Where some of the exhaust energy may be useful, it may be recovered in gas-to-air heat exchangers or gas-to-water exchangers or in waste-heat boilers for steam generation. These devices also act as mufflers.

2.5.3 Fuel Systems

Bulk storage tanks and engine daily tanks hold the engine fuel oil. The former receive the oil delivered to the plant, and stand outdoors for safety. Pumps draw oil from the storage tank to supply the smaller daily tanks in the plant at

daily or shorter intervals. Large storage capacity allows purchasing fuel when prices are low.

A large enough dike to form a moat, must be installed underneath aboveground storage tanks to hold the tank contents. Tanks must have manholes, for internal access and repair; fill lines, to receive oil; vent lines; to discharge vapors; sounding connections, to measure content; overflow return lines for controlling oil flow, and a suction line to withdraw oil. Coils heated by hot water, electric or steam elements, reduce oil viscosity to lower pumping power needs.

Delivered oil sometimes holds water, dirt, metallic fragments, and other foreign matter that must be removed by filtering. Much of this will settle out in the storage tank, especially with the lighter fuel oils and at higher temperatures. Filters may remove a light degree of contamination, but heavier fouling requires manual cleaning.

Dip-stick measurements and/or side glass give quick spot checks of tank contents, but meters give continuous indications. Volumetric meter readings must be corrected for oil temperature to determine the weight of oil burned.

2.5.4 Engine Cooling System

The thermal energy supplied to the engines leaves the engine as follows:

- shaft power delivered to the load;
- energy in the high-temperature exhaust gases; and
- heat transferred to the jacket of cooling water.

Removing the latter heat prevents damaging the cylinder liners, heads, and walls and the piston and its rings. Small engines may be air-cooled, but larger stationary engines use water circulating in the cylinder jacket.

The temperature of the cooling water must be controlled: if too low, the lube oil will not spread properly and the cylinder and piston will wear out; if too high, the lube oil burns. Small-diameter cylinders have leaving temperatures up to about 80 °C; large-diameter cylinders use lower leaving temperatures. Constant cooling-water flow rate and inlet temperature makes jacket-temperature rise when the load varies.

When large bodies of water are nearby (or city water is available), they may be used for once-through jacket cooling. Most plants, however, use a spray pond, cooling tower, or evaporative cooler.

When cooling towers are used, the make-up water is usually treated. Treatment depends on the type of contaminants. Zeolite softeners, lime or lime-soda-ash treatment may be used.

2.5.5 Lubricating-Oil System

The lubricating oil, or lube oil, performs several duties:

- It lubricates moving parts,
- Removes heat from cylinders and bearings;
- Helps piston rings to seal gases in the cylinder; and
- Carries away solid matter generated from rubbing moving parts.

Lube oils must be chosen with care, and purified at intervals.

Modern lube oils have additives to act as oxidation inhibitors, foam-reducing agents, pour-point depressants, and other agents. Dopes and additives may be used in oils to refresh them.

Using several brands with possible different additives may cause trouble. Oil in service becomes contaminated with dust, atmospheric moisture, dirt, carbon, and metallic chips. Heat causes chemical changes in the oil. Oil must be used as long as possible to keep costs down; purifying extends its life. Temperatures above 105 °C shorten lube-oil life.

2.5.6 Engine Starting System

Starting systems include:

- Air starting for medium and large-capacity, stationary and mobile units;
- Auxiliary-engine starting for medium-capacity mobile units; and
- Electric motor starting for small, high-speed gasoline and diesel engines.

Air starting uses valve arrangements to admit pressurized air, about 14 bar, to some cylinders, making them act as reciprocating air motors or engines to turn over the engine shaft. Admitting fuel oil to the remaining engine cylinders makes the engine start under its own power. A gas-engine-driven compressor usually supplies air to the compressed-air starting tanks.

2.5.7 Waste-Heat Recovery

Thermal energy in exhaust gas and jacket-cooling water may supply heat for a variety of purposes, such as for heating fuel oil, space heating, hot water, or generating process steam.

Recovery arrangements include:

- Circulating air around the exhaust system;
- Using hot water from the engine jackets; and
- Using waste-heat boilers in mufflers to provide steam or hot water.

These arrangements represent different forms of cogeneration.

2.6 Gas Turbines

Industrial gas turbine systems are composed of a gas turbine, coupled to a rotary air compressor. The gas turbine drives the compressor as well as any load (such as a generator, fan, or pump) connected to the coupling. In the case of power generation, the load is an electric generator unit. Atmospheric air enters the compressor from the intake side. Moving blades mounted on the rotor, force the air between the stationary blades to raise its pressure and temperature. The pressurized air leaves the compressor to enter the combustor. Part of the air enters the combustion space to mix and burn with the fuel. The remaining air enters the combustor liner through openings farther downstream to mix with and cool the combustion products. The 1600°C combustion gases are cooled by the excess air to a level that will not destroy the turbine first-row buckets (exceeding their allowable stresses). Inlet gas temperature ranges from 650 to 850 °C. As the hot pressurized gas expands through the turbine stages, it develops the motive force for turning the turbine rotor. The gases leave the turbine at a temperature in the range of 450 to 550 °C.

The industrial gas turbine unit is delivered to the site as a completely assembled unit; the intake duct of the compressor, the fuel supply line, and the turbine exhaust duct, all need only to be connected, and the unit is ready to run.

2.6.1 Controls and Auxiliaries

Gas-turbine engines need ancillary equipment, namely, starting motor or engine, motor-driven auxiliary lube pump, starting step-up gear, fuel-control system, oil coolers and filters, inlet and exhaust silencers, and control panels.

The starting motor, or engine, drives the gas turbine and compressor through a clutch and step-up gear. During start-up, stored, compressed air expands the clutch member until it grips a clutch drum on the step-up gear. The starting motor then accelerates the gas turbine and compressor to about 600 rpm for the unit. Holding this speed for 5 min ensures purging the entire air-gas flow system of any unburned fuel. After accelerating the speed to about 4,000 rpm, fuel enters the combustor baskets, and an electric spark in alternate baskets, ignites the fuel. Cross tubing between baskets assures fuel ignition in all. The starting motor continues accelerating the turbine to about 5,800 rpm, at which point it shuts down and the clutch automatically disconnects. Continuous fuel feed to the turbine brings it up to the rated speed.

The starting step-up gear also acts as the reduction-gear drive for the lubricating-oil pump governor impeller and over-speed trip. This engine-driven lubricating oil pump supplies high-pressure oil to the hydraulic control system and low-pressure lubricating oil for the gas turbine, gears, and driven apparatus. A separate motor-driven pump usually acts as stand-by if the main pump should fail.

For generator drive, the fuel feed is made responsive to the speed governor. A drop in speed (increasing load) opens the fuel valves to restore speed to normal. A rise in speed (dropping load) closes the fuel valves to lower the rate of fuel feed and restore speed.

Thermal switches at the turbine exhaust act on the fuel controls to limit exhaust gas temperature to a preset maximum. Lubricating failure also shuts down the unit automatically.

In industrial gas turbine units, it is common for about two-thirds of the mechanical power developed by the turbine is responsible for driving the compressor. A small amount of turbine power is also used in driving other auxiliaries such as the fuel pump. Therefore, the efficiency of a gas turbine unit is low in comparison with steam and diesel engine plants. The factors that affect efficiency are many, the most important being maximum temperature. The higher the maximum temperature, the greater the thermal efficiency. However, it is worth mentioning that the metallurgical barrier stands against further increase in maximum efficiency. New advances have been introduced in the last three decades, the most important of which are cooling turbine disks and blades by bled air from the compressor and improving blade alloy characteristics.

2.6.2 Regenerative Gas Turbine

Regeneration in gas industrial turbine units improves thermal efficiency by allowing the compressed air to recover some of the energy of the turbine exhaust gas. This preheating reduces the amount of fuel that must be burned to bring the gas up to rated turbine-inlet temperature. Shell-and-tube regenerators (heat exchangers) are usually used in regenerative gas turbine systems.

2.6.3 Gas-Turbine Fuels

Present industrial-gas-turbine units burn natural gas, blast-furnace gas, distillate oils, and even heavy oils (residual oil). With gaseous fuel firing, gas pressure must be raised to about 10 bar to ensure proper injection into the combustors. With a pressure ratio of 6:1, combustor pressure runs about 6 bar. Gas pressure must be higher than this to establish good combustion condition.

With liquid fuels, it is important to use storage and daily tanks, transfer pumps, connecting piping, and injection pumps to burn oil. Storage tanks usually hold at least a 2 weeks' supply of fuel. Industrial gas turbines can burn either gas or oil in the same unit (dual fuel burning). Fuels may be transferred under load, both burning while changing over. Such units must have parallel systems for each fuel, but the nozzles in the combustor can burn either, or both together. Mechanical atomizing nozzles may be used for the oils, but air-atomizing nozzles are recommended for units making long runs.

Oil fuels usually contain sodium, vanadium, and calcium as part of the ash constituent. Sodium corrodes hot metals and builds up hard deposits that choke gas passages in the blading. Vanadium corrodes hot-metal blading at a high rate. To burn oil fuels successfully, they must meet the following specifications:

- The sodium content in ash must be no greater than 30% cent of the vanadium content. The maximum sodium content should not exceed 10 ppm, and 5 ppm is preferable. With less than 5 ppm sodium, the ratio of sodium to vanadium is not critical.
- The magnesium content in the ash must be at least three times the vanadium. This is not critical when vanadium is less than 2 ppm.
- Calcium should be 10 ppm or lower. Up to 20 ppm can be tolerated at the expense of higher turbine-nozzle plugging.
- Lead should not exceed 5 ppm; it cancels out the inhibiting action of magnesium on vanadium.

In general, the appropriate additives, recommended by the suppliers, usually treats gas turbine-oil fuels.

2.6.4 Advantages of Using Gas Turbine Units in Power Generation

With regards to the levels of efficiency in power generation, industrial gas turbine units are less efficient compared with steam and diesel plants. However, there are some advantages to the use of gas turbine units:

1. Gas turbine units are ready to operate immediately as opposed to steam power plants, which need significant time to reach the required rates.

2. When power generation is needed in remote areas where water is not available, gas turbine units are suitable since they do not need cooling. Oil fields are example of this case.
3. In water desalination plants, the heat energy associated with exhaust gases emitted from gas turbine units can be efficiently used.
4. Gas turbine units are perfect when used in conjunction with steam power plants to form what is known as combined power stations. In this technology, hot exhaust gases from gas turbine units are employed in waste heat recovery boilers to produce steam. Power is produced from both gas turbine units and steam turbines driven by the generated steam.
5. In some steam power plants, steam units are used in base load and gas turbine units are used during peak demand.
6. In industry, gas turbine units are seldom used as standby units, and diesel units are preferred for their higher efficiency.

3. Potential Pollution Sources of Energy Production and Emission Measurement

Pollution sources from the different energy production plants are identified in this section.

3.1 Steam Generating Plants

Pollution sources in steam generating plants can occur in the fuel cycle or the water cycle.

3.1.1 The Fuel Cycle

Fig (3.1) shows a block flow diagram for the fuel cycle from supply to combustion and exhaust, and the potential pollution sources for the different steps involved.

a) Fuel Transportation, Handling and Storage

Pollution sources related to transportation, handling and storage of fuel, depend on the type of fuel.

Liquid Fuels

Fuel is delivered to the plant by tankers (heavy trucks). The fuel is purchased either in tons (heavy fuel, Mazout) or in thousands of liters (light fuel oil, Solar). The liquid fuel is stored either in underground or aboveground tanks. These tanks are referred to as 'main tanks'. Underground tanks are built either of concrete, and lined to be perfectly impermeable, or of steel. Aboveground tanks are usually built of steel. Either type is provided with the proper venting system.

Mazot storage tanks are equipped with the necessary fuel heating system to facilitate fuel handling and overcome the high viscosity of the fuel, especially in winter. A pumping system is used to deliver the fuel to the burner through a piping system. When pumping mazout from the main tank to the daily tank in the plant, the fuel line must be provided with a heating source to maintain the fluidity of the fuel. The heating source is mostly steam. Supplementary electric heaters are also appended to the fuel pipe to supply heat when steam is not generated.

In the boiler house, the fuel is stored in an overhead daily tank, which has enough capacity for one working day operation at least. The daily tank should also be equipped with a side glass, or other means, to indicate the level of the fuel inside the tank, and in the case of mazout, there should be a fuel preheating element. There is always a feedback signal (through a float system) between the daily tank and the main tank. This signal is designed to stop the pumping of the fuel into the daily tank when the level has reached the highest position, and start pumping when the level drops below a specified height. Figure (3.2) displays the storage and handling of fuel oil in the plant.

Fig (3.1) Potential Pollution Sources from Energy Generating Plants

| Input | Processes | Air | Water | Solid |
|---------------------------------------|---|--|--|--------|
| Steam Boilers | | | | |
| Fuel Cycle | | | | |
| Fuel | <pre> graph TD Fuel --> ST[Storage Tank] ST --> BH[Boiler House] BH --> S[Stack] </pre> | Fugitive air emission VOCs and noise Exhaust gases | Leaks and spills Leaks and spills | |
| Water Cycle | | | | |
| Feed water Back wash water | <pre> graph TD FW[Feed water] --> PS[Pumping Station] PS --> C[Clarification] C --> S[Softening] BWW[Back wash water] --> S S --> B[Boiler] B --> SD[Steam Distribution] </pre> | Noise Noise Noise Noise | Back wash Blowdown Heat and Humidity | Sludge |

Fig (3.1) (cont) Potential Pollution Sources from Energy Generating Plants

| Input | Processes | Air | Water | Solid |
|----------------------------|----------------|-----------------------|-----------------------------------|-------|
| Diesel Engines | | | | |
| Fuel Cycle | | | | |
| Fuel | Storage Tank | Fugitive air emission | Leaks and spills | |
| Lube oil | Diesel Engine | VOCs and noise | Leaks & spills and Spent lube oil | |
| | Stack | Exhaust gases | | |
| Water Cycle | | | | |
| Treated water | Cooling Towers | | Blowdown | |
| Gas Turbine Engines | | | | |
| Fuel | Storage Tank | Fugitive air emission | Leaks and spills | |
| Lube oil | Gas Turbines | VOCs and noise | Leaks & spills and Spent lube oil | |
| | Stack | Exhaust gases | | |

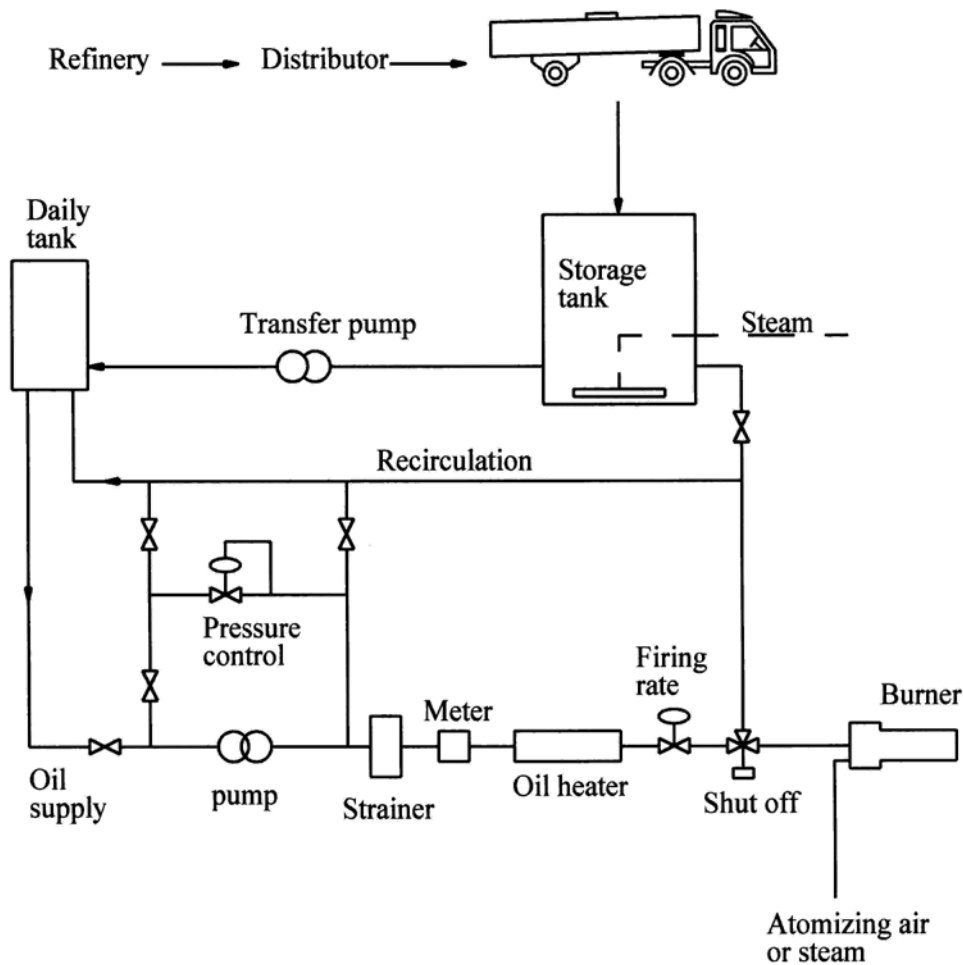


Fig (3.2) Storage and Handling of Fuel Oil

Natural Gas

Natural gas is distributed via the public gas network. The gas is delivered to the community at about 10 bar. This pressure is reduced to 2 bar in a primary reducing station before being admitted to the industrial plant. The primary reducing station belongs to the plant and is situated in a safe location inside the enclosure of the plant. The reducing station is equipped with necessary safety and measuring components, such as:

- Gas detecting devices.
- Gas meter, measuring the consumption in cubic meters.
- Pressure gauges.
- Gas flow regulator with a high-pressure and low-pressure cut-off valve.

The fuel gas is fed into the equipment via the local network at 2-bar pressure. In the gas firing system (burner), gas pressure is reduced to between 300 and 500 mbar, according to the operating conditions of the burner.

The fuel gas burner itself contains a built-in gas train. The gas train constitutes the same safety and measuring components.

b) Fuel Combustion

Combustion is an exothermic (heat releasing) process. The heat released represents approximately 32,800 kJ/kg of carbon burned, and approximately 142,000 kJ/kg of hydrogen burned. The objective of good combustion is to release all of this heat while minimizing loss from the combustion imperfections and superfluous air. For the combustible elements in fuel to burn with air, the burner (combustion system) must be designed to insure the following:

- Turbulence level that is sufficient to ensure that all of the fuel components mix sufficiently with the air;
- Time sufficient for the combustion to complete; and
- Temperature high enough to sustain the ignition of all of the combustible constituents in the fuel.

These three points, referred to as three T's, are the physical aspects of the combustion process.

In addition to the three T's, the air-fuel ratio is of primary interest in the evaluation of combustion efficiency. To explain the term 'Air-Fuel Ratio', the chemistry of combustion must be discussed. The chemistry of combustion is presented in Annex (D-1), and heat release rates are given in Annex (D-3).

In addition, table (2.2), previously given in sec (2), presents the emission rate of pollutants per kg of fuel for the main types of fuel.

c) Stack Emissions

As seen from the chemistry of combustion of hydrocarbon fuels (Annex D-1), the flue gases contain mainly CO₂, H₂O, N₂, and SO₂. Due to the inevitable use of excess air, excess O₂ also appears in the products. In practice traces of nitrogen oxides such as NO₂, NO, and N₂O are also emitted from the combustion process. Some minor traces of organic gases such as aldehydes might also be released with products due to the existence of organic matter especially with heavy fuels. The main pollutants from the stack are;

- Sulphur dioxide (SO₂)
- Nitrogen oxides (NO_x)
- Carbon dioxide (CO₂)
- Particulate matter
- Heavy metals
- Other toxic substances adherent to particulate matter

Measurement of different species of combustion products varies according to the objective of measurement. While pollutants such as CO, SO₂, NO_x, and particulate matter (carbon particles) are measured for the purpose of environmental compliance; other species such as O₂, CO₂, and CO are measured for the purpose of boiler evaluation and tune up

procedure. The calculation of excess oxygen is presented in Annex (D-2).

The following measurement equipment is used for boiler evaluation and for measuring gaseous emissions from the stack:

Bacharach combustion tester

Bacharach Combustion Tester (Fyrite indicators) is used to measure the concentration of either O₂ or CO₂, depending on the chemical compound filling the tester. The O₂ tester is filled with pyrogallol C₆H₃(OH)₃, and CO₂ tester is filled with caustic soda solution (NaOH). The testers have proven to be reliable, need practically no maintenance, and are relatively inexpensive. In addition, their operation is so simple that any one can learn to operate them in a short time. On the other hand, their accuracy is not adequate ($\pm 0.5\%$), in addition they can serve in continuous measurement of the two gases.

Electronic electro-chemical gas analyzer

Electronic gas analyzers contain electro-chemical cells that can measure different gases (a particular cell for a particular gas). The theory of an electro-chemical cell is that the potential generated across its poles, upon exposing to the gas, is proportional to the concentration of that gas. The generated potential is interpreted as digital display on the screen (LCD display). Such electronic instrument may cost several thousands of Egyptian pounds and requires frequent checking, calibration, and maintenance. On the other hand, they are reliable, portable, and accurate (the accuracy of measuring O₂ is $\pm 0.1\%$). They are also suitable for continuous monitoring. Electronic gas analyzers can measure up to 7 gases instantaneously and simultaneously. They are designed to display some calculated figures such as estimated CO₂, excess air per cent, and combustion efficiency. Electronic gas analyzers are equipped to measure the temperature of the exhaust gases.

Zirconia Probe

Other instruments for oxygen measurement are based on zirconium oxide (zirconia), which conducts oxygen ions at temperatures above 650 °C. The sensor is maintained at a high temperature, ideally about 800°C, and consists of a heated cell with two electrodes. One electrode is surrounded by a reference gas (usually air) and the other electrode has the sample gas passed over it. Any difference in oxygen content at the electrodes is translated into a potential difference, and hence an electronic signal.

Because a zirconia cell must have a heater and controls to ensure operation at a fixed high temperature, instruments based on zirconia tend to be bulky and heavy. Portable analyzers are available, but the zirconia system is normally restricted to fixed gas analyzers mounted in the stack of medium to large boilers and furnaces, and more recently, package boilers. The life of a zirconia probe in a typical boiler stack should be five years or more.

Infrared Gas Analyzers

Another highly specific measuring technique that can be used in very many applications (CO₂ measurement is one of them) exploits the effect that all hetroatomic gases (gases consisting of different types of atoms) absorb infrared radiation in distinctive bands specific to each gas. An infrared radiator heated in a defined manner serves as the radiation source. The radiation emitted is modulated in phase by a motor driven aperture disk (chopper). On the measurement side, the modulated radiation reaches the detector compartment via the sample cell; on the reference side, the radiation is routed to an identical detector compartment via a reference cell filled with N₂. All parts are sealed with windows transparent to infrared radiation.

The detector compartments, which are separated from one another by a diaphragm capacitor, are each filled with a gas, the concentration of which must be determined. In this way, they can only absorb IR radiation in the bands specific to the component being measured. If sample gas flows through the sample cell, part of the IR radiation is already absorbed there, by the component being measured. The detector compartment is thus heated less than the compartment in the reference branch, which is exposed to the full-intensity radiation. A temperature difference, which depends on the concentration of the component being measured and fluctuates at the frequency of modulation, is produced between the detector compartments. The resulting flexing of the capacitor's diaphragm produces a modulated change in capacitance, and thus a change in an alternating voltage across a resistor.

3.1.2 The Water Cycle

The water cycle starts from a water supply with related pumping system, and goes through the clarification and softening system to steam generation and distribution. Fig (3.1) presents a block flow diagram for the cycle with potential pollution sources.

3.2 Diesel Generators

Water-cooled diesel engines will have a fuel cycle and a water cycle to be inspected.

3.2.1 The Fuel Cycle

The fuel cycle is similar to that of boilers. It starts with fuel storage, fuel supply line to the combustor, then fuel combustion to exhaust gases. Diesel fuel has less sulfur content than fuel oil. The flue gases discharged from the stack should be analyzed for CO, NO_x, SO_x, VOCs and particulate matter. Noise should also be monitored.

Lube oil used for lubrication, is considered hazardous. Its handling is regulated by Law 4/1994, as well as the disposal of spent lube oil. Fig (3.1) presents a block flow diagram for the fuel cycle with potential pollution sources.

3.2.2 The Water Cycle

Some diesel engines are water cooled either by once-through water, or by water recycled through a cooling tower. The spent cooling water in once-through cooling could be contaminated with oil, and its temperature should be checked. In cooling towers, the waste effluent is the blowdown which is high in TDS. The make-up water to the cooling towers is usually treated for hardness. Waste effluents from water treatment plants have been identified in relation to steam boilers.

3.3 Gas Turbines

Gas turbines do not require cooling and their fuel line is similar to that of steam boilers, presenting the same pollution problems. Noise should be checked periodically.

4. Impact of Emissions and Effluents of Different Stages on Health and Environment

4.1 Impacts of Gaseous Emissions

Gaseous emissions are generated from various sources. There are: fuel combustion (Fig 3.1), steam leaks from the steam distribution network and fugitive emissions from storage tanks and fuel distribution network.

4.1.1 Exhaust Gas Emissions

The gaseous components emitted to air differ significantly according to the fuel used, the boiler capacity and the gas cleaning system. The most important pollutants and their related impact on health and environment are given below:

Particulate Matter

Recent epidemiological evidence suggests that much of the damage to health caused by exposure to particulates is associated with particulate matters smaller than $2.5\mu\text{m}$ ($\text{PM}_{2.5}$) and $10\mu\text{m}$ (PM_{10}). Dust particles are bigger and are therefore not absorbed by the lungs as easily as smaller particles. When particles are absorbed, they cause a wide spectrum of illnesses (e.g. asthma, and bronchitis). Emissions of particulates include ash, soot, and carbon compounds, which are often the result of incomplete combustion. Acid condensate, sulfates and nitrates, as well as lead, cadmium, and other metals, can all be detected.

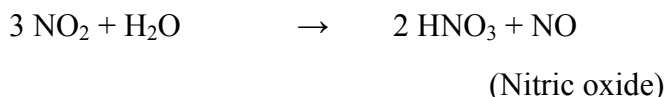
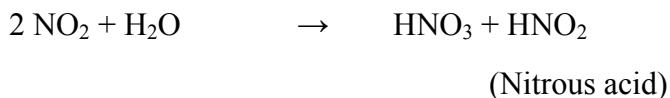
Sulfur Oxides

Air pollution by sulfur oxides is a major environmental problem. High concentrations are harmful to plant and animal life, as well as many building materials. Another problem of great concern is wet or dry acid deposition. Dissolution of sulfur oxides in atmospheric water droplets forms sulfuric acid, which causes acidification. Acid deposition is corrosive to metals, limestone, and other surfaces.

Nitrogen Oxides

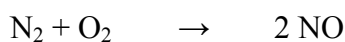
Oxides of nitrogen (NO_x) include six known gaseous compounds: nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), nitrogen sesquioxide (N_2O_3), nitrogen tetroxide (N_2O_4), and nitrogen pentoxide (N_2O_5). The two oxides of nitrogen of primary concern in air pollution are nitric oxide (NO) and nitrogen dioxide (NO_2), the only two oxides of nitrogen that are emitted in significant quantities in the atmosphere.

Being heavier than air, nitrogen dioxide (NO₂) is readily soluble in water, forming nitric acid and either nitrous acid or nitric oxide, as indicated in the following equations:



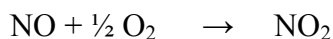
Both nitric and nitrous acid will dissolve in the rain or combine with ammonia (NH₃) in the atmosphere to form ammonium nitrate (NH₄NO₃). In this instance, the NO₂ will produce a plant nutrient. A good absorber of energy in the ultraviolet range, NO₂ consequently plays a major role in the production of secondary air contaminants such as ozone (O₃).

Nitric oxide (NO) is emitted to the atmosphere in much larger quantities than NO₂. It is formed in high-temperature combustion processes when atmospheric oxygen and nitrogen combine according to the following reaction:



Effects of nitrogen oxides on human health

Nitric oxide (NO) is a relatively inert gas and only moderately toxic. Although NO, like CO, can combine with hemoglobin to reduce the oxygen-carrying capacity of the blood, NO concentrations are generally less than 1.22 mg/m³ (1 ppm) in the ambient air, and are thus not considered health hazards. However, NO is readily oxidized to NO₂, which does have biological significance.



NO₂ irritates the alveoli of the lungs.

Carbon Dioxide

Combustion of fossil fuels to produce electricity and heat contribute to the green house effect caused by the formation of carbon dioxide. The greenhouse phenomenon occurs when heat radiation from earth is absorbed by the gases, causing a surface temperature increase.

Dioxins, Furans

In waste combustion, small amounts of dioxins, furans, HCl, HF, PAH, etc. may be emitted from the stack to the environment. These compounds are toxic

to human health. Low concentrations of dioxins and furans affect human health.

4.1.2 Steam Leaks from Steam Networks

Water Vapor (Humidity) Humidity can effect the respiratory system, especially among asthma suffer; therefore its level in the workplace has been regulated by law 4/1994.

4.1.3 Fugitive Air Emissions from Fuel Line

Fugitive emissions from fuel storage tanks, pipe leaks, and spills are caused by escaping hydrocarbons. Such emissions are considered to be hazardous to the health and carcinogenic. In areas where natural gas pipelines exist, activities that harm pipelines may cause the risk of fire. It is necessary that the pressurized equipment be in good condition.

4.2 Impact of Effluent

Different waste effluents are generated from energy generating plants.

4.2.1 Blowdown and Backwash

Boiler blowdown is characterized by high TDS. It can be contaminated by chemicals used as deaerators to suppress corrosion. Some of these chemicals are hazardous (hydrazine).

Cooling towers blowdown is also characterized by high TDS and can be contaminated by hazardous materials used as anti-fouling agents, and corrosion inhibitors such as biocides.

Softeners backwash is characterized by high TDS, and can be contaminated by chemicals used for softening (sodium chloride, acids..).

The main pollutants and their effect are:

| | |
|-------------------------------------|---|
| Total Dissolved Solids (TDS) | Solids accelerate corrosion in water systems and pipes. Depresses crop yields when used for irrigation, and at higher levels adversely affect fish and other aquatic life. Depresses may also affect the quality of drinking water. |
| Nitrogen, Phosphorus | At high levels, these stimulate growth of algae and seaweed, increasing eutrophication and oxygen depletion. |
| Oil and Grease | These are detrimental to water quality and aquatic life. |

4.2.2 Spent Lube Oil

Spent lube oil is a hazardous material that should be disposed of according to the articles of Law 4/1994.

4.3 Impact of Solid Waste

Solid waste generated by energy generating plants includes

- Clarifier sludge
- Chemicals containers
- Particulate matter separated from flue gases by ESP (electrostatic precipitators and bag filters).

Clarifier sludge is not considered hazardous since it consists mainly of magnesium hydroxide and calcium carbonate, in addition to traces of other inorganic compounds.

Chemicals containers are considered hazardous and should be handled and disposed of according to the requirements of law 4/1994.

4.4 Impact of Noise

Noise is generated near blowers, compressors and due to pressure of exhaust gases in stacks. Constant noise causes an increase in blood pressure, and may affect the nervous system. Moreover, it can reduce a person's attention and concentration, and cause hearing loss as a result of long periods of exposure.

5. Egyptian Laws and Regulations Concerning the Emissions and Effluents from Energy Generating Plants

Steam generating plants are regulated and inspected by three different entities other than EEAA. These entities are concerned with the safe operation of the boilers. Inspection determines whether repairs are required. These entities are:

- Industrial Control Agency (Ministry of Industry). This agency checks that all provisions of the boiler and pressure-vessel law are observed, and that all rules and regulations of the jurisdiction, regarding safety devices and operating conditions, especially working pressure are observed. The facility must comply with the inspectors' recommendations. .
- Insurance companies, if commissioned under the law of the jurisdiction where the unit is located, can also make the required periodic inspection. As commissioned inspectors, they require compliance with all the provisions of the law and its rules and regulations. In addition, they may recommend changes that will prolong the life of the boiler or pressure vessel.
- Owner/user inspectors are employed by a company to inspect unfired pressure vessels on their provisions only.

However, this manual is concerned with compliance with environmental laws.

5.1 Relevant Regulations Concerning Gaseous Emissions

Boilers are among fuel-burning systems. Therefore, in order to have minimal effects on the environment, the executive regulations of the Egyptian Environmental law 4/1994 has shown, through article No. (42), the maximum permissible limits of pollutants released upon burning different types of fuels.

The statutes relevant to fuel combustion are:

- The use of solar oil, other heavy oil products, as well crude oil shall be prohibited in dwelling zones.
- The sulfur percentage in fuel used in urban zones and near dwelling zones shall not exceed 1.5%.
- The design of the burner and fire-house shall allow for complete mixing of fuel with the required amount of air, and for uniform temperature distribution to ensure complete combustion and minimize gas emissions caused by incomplete combustion..
- Gases containing sulfur dioxide shall be emitted through sufficiently tall chimneys to allow them to become lighter before reaching the ground. Otherwise, gases shall be emitted or using fuel that contains high proportions of sulfur in power generating stations, as well as in

industry and other regions lying outside inhabited urban areas. Atmospheric factors and adequate distances shall be observed, to prevent these gases from reaching dwelling, agricultural regions, and the water courses.

- Chimneys from which a total emission of wastes reaches 7000 – 15000 kg/hr, shall have heights ranging between 18 – 36 meters.
- Chimneys from which a total emission of gaseous wastes reaches more than 15000 kg/hour, shall have heights exceeding at least two and a half times the height of surrounding buildings, including the building served by the chimney.

Modifications to this article have been recently released and enforced (by Ministerial Decree no. 495/ 2002). These modifications concern the permissible limits of CO, SO₂, and particulate, in addition to the already applicable limit of NO_x. The maximum permissible limits are displayed in table (5.1).

Table (5.1) The Maximum Limits of Emissions from Boilers

| Pollutant | Maximum permissible limits for gas pollutants in boiler stack | |
|-----------------|--|--------|
| | Unit | Limits |
| Carbon monoxide | mg/m ³ | 250 |
| Sulfur dioxide | mg/m ³ | 3400 |
| Nitrogen oxides | mg/m ³ | 300 |
| Particulates | mg/m ³ | 50 |

5.2 Relevant Regulations Concerning Effluents

Effluents from steam generating plants consist of

- Backwash of softeners which are high in TDS and can be contaminated with chemicals used in the process.
- Blowdown of boilers which are high in TDS and can be contaminated with anticorrosion additives. The wastewater can also be contaminated with lube oil and may contain suspended solids.

Table (5.2) gives the permissible limits of pollutants in the effluent wastewater discharged to different bodies.

Table (5.2) Permissible Limits of Pollutants in the Effluent Wastewater

| Parameter (mg/l unless otherwise noted) | Law 4/94: Discharge Coastal Environment | Law 93/62 Discharge to Sewer System (as Decree 44/2000) | Law 48/82: Discharge into : | | | |
|--|--|--|--|-----------------------|-----------|------------|
| | | | Underground Reservoir & Nile Branches/Canals | Nile (Main Stream) | Drains | |
| | | | | | Municipal | Industrial |
| pH | 6-9 | 6-9.5 | 6-9 | 6-9 | 6-9 | 6-9 |
| Temperature (deg.) | 10C>avg. temp of receiving body | <43 | 35 | 35 | 35 | 35 |
| Total Suspended Solids | 60 | <800 | 30 | 30 | 50 | 50 |
| Total Dissolved Solids | 2000 | — | 800 | 1200 | 2000 | 2000 |
| Oil & Grease | 15 | 100 | 5 | 5 | 10 | 10 |

5.3 Relevant Regulations Concerning Solid Wastes

A number of laws address solid waste management. Solid waste generated from steam generating plants consists of sludge from clarifying units and empty containers of chemicals. These containers could be hazardous depending on the type of chemical.

- Law 38/1967 which addresses public cleanliness, regulates the collection and disposal of solid wastes from houses, public places, and commercial and industrial establishments.
- Ministry of Housing, Utilities and Urban Communities (MHUUC) decree No. 134 of 1968, which provides guidelines from domestic and industrial sources, including specifications for collection, transportation, composting, incineration and land disposal.
- Law 31/1976, which amended law 38/1967
- Law 43/1979, the Law of Local administration, which stipulates that city councils are responsible for “physical and social infrastructure”, effectively delegating responsibility for infrastructure functions.
- Law 4/1994 regulates incineration of solid waste.

5.4 Relevant Regulations Concerning Workplace Emissions

Fugitive emissions of hydrocarbons and exhaust gases may occur in the work place, resulting in the violation of work environment safety regulations. Below are laws limiting such violations:

- In the boiler house: gas emissions, regulated by article 43 of Law 4/1994, article 45 of the executive regulations, and annex 8. Permissible limits for workplace emissions are given in table (5.3).

- Wherever heating takes place: temperature and humidity are regulated by article 44 of Law 4/1994, article 46 of the executive regulations and annex (9).
- The noise is regulated by article 42 of law 4/ 1994, article 44 of the executive regulations and table (1) annex (7). The maximum limit are given in tables (5.4 and 5.5).

Table (5.3) Permissible Limits as Time Average and for Short Periods

| Material | Threshold | | | |
|-----------------|--------------|-------------------|-----------------------------------|-------------------|
| | Time average | | Exposure limits for short periods | |
| | ppm | mg/m ³ | ppm | mg/m ³ |
| Carbon dioxide | 5000 | 9000 | 15000 | 27000 |
| Carbon monoxide | 50 | 55 | 400 | 440 |
| Sulfur dioxide | 2 | 5 | 5 | 10 |

Table (5.4) Maximum Permissible Noise Levels (law 4/1994)

| No | Type of place and activity | Maximum permissible noise decibel (A) |
|----|---|---------------------------------------|
| 1 | Work place with up to 8 hour and aiming to limit noise hazards on sense of hearing | 90 dB |
| 2 | Work place where acoustic signals and good audibility are required | 80 dB |
| 3 | Work rooms for the follow up, measurement and adjustment of high performance operations | 65 dB |
| 4 | Work rooms for computers, typewriters or similar equipment | 70 d.B |
| 5 | Work rooms for activities requiring routine mental concentration | 60 dB |

Table (5.5) Noise Intensity Level Related to the Exposure Period

| Noise intensity level decibel (A) | 95 | 100 | 105 | 110 | 115 |
|-----------------------------------|----|-----|-----|-----|-----|
| Period of exposure (hour) | 4 | 2 | 1 | ½ | ¼ |

6. Methods and Techniques (M&T) for Pollution Abatement

6.1 M&T of Air Pollution Abatement

Emissions can be decreased through the following:

6.1.1 Boiler Tune-Up

Effective fuel combustion means greater plant output and considerable cost savings. Variations in fuel quality and equipment performance mean constant adjustment to the combustion process to maintain peak performance. CO monitoring is essential for combustion efficiency. An increase in excess air results in heat loss via the stack, while a decrease results in incomplete combustion. CO levels in the flue gas give an accurate indication when incomplete combustion begins. Therefore, CO measurement along with O₂ measurement offer information to the plant operator on optimal air feed requirements.

Incorrect fuel-air ratio can result in flame out conditions and excess loss of ignition source. These conditions pose a major threat of plant explosion. Proper monitoring gives an early indication of incomplete combustion so that potential problems can be recognized.

6.1.2 Using Low NO_x Burners

The low-NO_x and staged burners are new advances in the burner-design. With this type of burner, mixing between fuel and air is improved. The formation of prompt, thermal, and fuel nitrogen oxides are, therefore, less concentrated in the flue gases.

6.1.3 Fuel Substitution

If available, natural gas can substitute the liquid fuels used in firing. Natural gas uses less excess air and, therefore, improves boiler efficiency. Moreover, the probability of CO being produced is significant less. Nox formation is also found to be less when using natural gas as substitute fuel. On the other hand, natural gas firing with excess air in the range of 10% or fuel gases with an O₂ concentration of 2-3% prevents almost any formation of soot and particulates in the stack.

6.1.4 Reduction of SO_x Emissions

The range of options and removal efficiencies for SO_x controls is wide. Pre-ESP sorbent injections can remove 30-70% of sulfur oxides. Post-ESP sorbent injections can remove 70-90% of sulfur oxides at almost double the cost. Wet scrubbing can also be performed but this will cause a switch from one form of pollution to another, unless an integrated pollution management approach is adopted.

6.1.5 Reduction of Particulate Emissions

The options for removing particulates from exhaust gases are cyclones, baghouses (fabric filters) and Electrostatic precipitators (ESP) on stack outlet

or bag filters. Cyclones may be adequate as precleaning devices: they have a removal efficiency of less than 90% for all PM and considerably lower for PM₁₀. Baghouses can achieve removal efficiencies of 99.9% for PMs of all sizes. ESPs are available in a broad range of sizes and can achieve removal efficiencies of 99.9% or better for PM of all sizes.

6.2 M&T of Water Pollution Abatement

6.2.1 Substitution of Hazardous Materials

In the process of water treatment, the use of hydrazine to condition the feed water, is presently being replaced by pro-environmental substitutes. However, in addition to hydrazine there are other hazardous materials also used to deoxidize water. These include amines and sodium sulfite. Traces of these substances will contaminate the produced steam and could pollute the product whenever live steam is used in the production process.

6.3 Cleaner Production

Cleaner production can be achieved using a number of measures:

6.3.1 Operation and Maintenance Procedures for Heating and Small Boilers

Operation personnel must be familiar with certain fundamentals procedures that have been commonly posted, especially in manually operated systems. Moreover, the need to train power plant boiler operators has been augmented by the use of diagnostic equipment. This development has been motivated by retrofitting and stricter environmental regulations. The following are regulations for heating and small steam boilers:

- Water level maintenance and checking should be done at least once per shift.
- Low water should be checked and appropriate action taken by the operator to minimize damage.
- Low water cutoff testing to make sure boiler is functional should be performed once per shift. This includes blowing down the float chamber or the housing, in which the sensor is located, to avoid obstruction with internal deposits.
- Gauge cocks must be kept clean and dry. They should be tested once per shift in order to make sure that all connections to the water glass and water column are clear, and to determine, the true level in the gauge glass.
- Safety valves should be tested at least once per week by raising the valve off the seat slowly. If the valve does not lift, it is an indication that rust or boiler compound is binding the valve and corrections or repairs are needed. The boiler should be secured and not operated with a defective safety valve.
- Burners should be kept clean and free of leaks with the flame adjusted so that it does not impinge sidewalls, shells, or tubes. Flame safeguards should be checked every shift in order to make sure that they are functional and thus prevent a furnace explosion.

- Boiler internals must be kept free of scale, mud, or oily deposits in order to prevent overheating bagged and buckled sheets, and the occurrence of a serious rupture or explosion.
- The outside of the boiler should be kept clean and dry. Soot or unburned products should not be allowed to accumulate, as these will cause controls and actuators to bind and malfunction. They will also cause different parts of the boiler to corrode.
- Leaks are a sign of distress in the boiler system and should be repaired immediately because of the possible danger involved; moreover they will accelerate corrosion and grooving of system components and result in forced shutdowns.
- When taking a boiler out of service, do not accelerate the process by blowing off the boiler under pressure in order to prevent the heat of the boiler from baking mud and scale on the internal surfaces. Let the boiler cool slowly, then drain and thoroughly wash out the top and bottom parts of the internal surfaces.
- Dampers should be kept in good condition to avoid unconsumed fuel from accumulating in the combustion chamber or furnace, and cause a fireside explosion. All connections and belongings should be kept in good working order so as to maintain efficient operation and also to prevent forced shutdowns.
- Boilers left idle for any length of time should have their manholes and handholes removed followed by thorough washing of the interior surfaces to remove scale and other contaminants. The boiler should be kept dry.
- Purging should be done on any firing or restart in order to clear the furnace passages of any unconsumed fuel, and thus prevent a fireside explosion. Modern burners have been designed to purge gases before new ignition and firing.
- Preparing a boiler for inspections per legal statute requires all critical internal surfaces to be made available for inspection. This entails the removal of manholes and handholes, cooling boiler slowly, and cleaning it internally and externally, including firesides of boiler components. All valves should be tight in order to prevent any steam or water from backing into the idle boiler.

6.3.2 Operation and Maintenance Procedures for Fire-Tube Boilers

Because the shell is exposed to fire, the boiler requires careful internal inspection for scale, bulging and blisters. During an inspection, some of the areas to check carefully on a boiler are the following:

Internal inspection, on the section above the tubes,

- Check for corrosion and pitting.
- Look for grooving on the knuckles of heads, shells, welds, rivets, and tubes. Check the seams for cracks, broken rivet heads, porosity, and any thinning near the water line of the shell plate.
- Check all stays for soundness and proper tension.
- Examine the internal feed pipe for soundness and support, check that it is not partially plugged.

- Check the openings to the water column connections, safety valve, and pressure gauge for scale obstruction.
- Check shell and tube surfaces for scale buildup.
- Follow the same procedure internally below the tubes.
- Check the opening to the blowdown connections, and make sure that the bottom of the shell is pitched toward blowdown and that it has no blisters or bulges.

External inspection

- Examine tube ends and rivets or welds for cracks and weakening of the tube to the tube-sheet connection.
- Check for fire cracks around the circumferential seam, and for leakage at the caulked edge.
- Examine the setting and supports for soundness.

6.3.3 Instrumentation and Control for Steam Heating Boiler Systems

Minimum protective instrumentation and control devices required on steam-heating boiler systems are outlined in different 'boiler codes and standards'. Among the most prominent are the following:

- Each steam-heating boiler must have a steam pressure gauge with a scale in the dial graduated from 1 kg/cm² to the allowable testing pressure. Connections to the boiler must be not less than ¼-in. standard pipe size; however, if steel or wrought iron pipe is used, it should be not less than ½ in.
- Each steam-heating boiler must have a water gauge glass attached to the boiler by valve fittings not less than ½ in. and with a drain on the gauge glass not less than ¼ in. The lowest visible part of the gauge glass must be at least 1 in. above the lowest permissible water level as stipulated by the boiler manufacturer.
- Two pressure controls are required on automatically fired steam-heating boilers:
 - An operating-pressure cutout control that cuts off the fuel supply when the desired operating pressure is reached.
 - An upper-limit control, set no greater than 0.5 bar, which backs the operating-pressure limit control so that the fuel is shut off when the operating-pressure control does not function.
- An automatically fired steam-heating boiler must have a low-water fuel cutoff, located so that the device will cut off the fuel supply when the water level drops to the lowest visible part of the water gauge glass.
- Each steam-heating boiler must have at least one safety valve of the spring-loaded pop type, adjusted and sealed to discharge at a pressure not greater than the maximum allowable pressure of the boiler. No safety valve can be smaller than ½ in. or greater than 4½ in. The capacity of the safety valves must exceed the output rating in kilograms per hour of the boiler. In no case, however, should the capacity of the valve be less, so that with the fuel-burning equipment firing at maximum capacity, the pressure cannot rise 0.2 bar above the stamped maximum allowable pressure of the boiler.

- All electric control circuitry on automatically fired steam-heating boilers must be positively grounded. The wiring system must include a grounded neutral as well as equipment grounding.
- Automatically fired steam-heating boilers must be equipped with flame safeguard safety controls.
- Stop valves on the steam supply line are not required for a single-boiler installation that is used for low-pressure heating, if there are no other restrictions in the steam and condensate line and all condensate is returned to the boiler. However, if a stop valve (or trap) is placed in the condensate-return line, a valve is required on the steam supply line. A stop valve is required on the steam supply line where more than one heating boiler is used on the same steam supply system and also on the condensate-return line to each boiler.

6.3.4 Instrumentation and Control for Hot-Water Systems.

The ASME Heating Boiler Code requires some minimum protective devices on hot-water-heating boiler systems. Among these are the following:

- A pressure gauge is required on the hot-water boiler with a scale on the dial graduated to not less than 1½ times nor more than 3 times the pressure at which the relief valve is set.
- A thermometer gauge is needed on the hot-water boiler. Graduation of the thermometer must be clear, and the thermometer must be located so that the water temperature in the boiler is measured at or near the outlet of the heated hot water. Reading should be taken along with boiler pressure.
- Two temperature controls are required in automatically fired hot-water boilers:
 - (a) An operating limit control, that cuts off the fuel supply when the water temperature reaches the desired operating limit.
 - (b) An upper-limit-control that backs up the operating-limit control and cuts off the fuel supply. This upper-limit control is set at a temperature above the desired operating temperature, but must be set so that the water temperature cannot exceed 120 °C at the boiler outlet.
- A low-water fuel cutoff is required on automatically fired hot-water boilers. It must be installed so that it cuts off the fuel when the water level drops below the safe, permissible water level established by the boiler manufacturer.
- All electric control circuitry on automatically fired hot-water boilers, as well as on steam-heating boilers, must be positively grounded. The wiring system must include a grounded neutral as well as equipment grounding.
- A hot-water-heating boiler must be equipped with spring-loaded Code-approved relief valves set at or below the maximum stamped allowable pressure of the boiler. The minimum size of the valve is ¾ in., and the maximum permitted size is 4½ in. Capacity must be greater than the stamped output of the boiler, but in no case should the pressure rise more than 10 % above the maximum allowable pressure if the fuel-burning equipment operates at maximum capacity.

- Automatically fired hot-water-heating boilers and steam-heating boilers must also be equipped with flame safeguard safety controls that cut off the fuel when an improper flame (or combustion) exists by the burner. These usually include pilot and main-flame proving, as well as pre-firing and post-firing purging cycles.

To avoid the dangers of complete reliance on automatic controls to safely cycle a boiler, it is a must to periodically **check** the controls for:

- Conditions of electric contacts,
- Electric connections,
- Water-column connections,
- Waterside plugging of pressure switches,
- Low-water fuel cutoffs,
- Soot accumulation in tubes,
- Operation of solenoid valves in fuel-cutoff lines,
- Firing-equipment timing and operation of flame-failure devices, and
- Operation of safety valves.

7. Self Monitoring, Definition and link to EMS

The monitoring of industrial processes, their releases and their impact on the environment are key elements of regulatory control. The self-monitoring system is a system that primarily relates to measurements of process conditions (process operation and controls), process inputs, releases and environmental pollution levels as well as reporting of the results to the competent authorities. Monitoring can be carried out by the industrial establishment or carried out on behalf and paid for by the industrial establishment. The information obtained from a sampling and monitoring system must be recorded and the results reported to the appropriate internal and external decision-makers.

This definition refers to integrated self-monitoring which includes:

- Process monitoring
- Environmental self-monitoring

Regarding the regulatory basis, self-monitoring is not explicitly mandated by Egyptian environmental regulations. However, industrial process operators are required to keep a record of their inputs, outputs and releases in the environmental register as stated by Law 4/1994, which implicitly requires operator self-monitoring.

The Egyptian Environmental Affairs Agency (EEAA) is mandated to check the validity of the data in the Environmental Register. The responsibilities of the operator and the competent authority are not affected by who carries out the monitoring. It is the responsibility of the operator to comply with laws and regulations, and to ensure that all necessary measures have been taken to protect the environment. The inspectors (competent authorities) are responsible for assessing and ensuring the operator's compliance.

A description of the Environmental Management Systems and its relation to self-monitoring plans is covered in the sectors specific manuals for self-monitoring.

7.1 Objectives and Motivation for SM for Energy Generating Plants

a) Process Operation and Production Self-Monitoring

In most industrial production facilities monitoring of process operations already exists. Some process operation controls should be monitored for improved environmental benefits. The main objectives of process self-monitoring is:

- Quality control.
- Planned maintenance and repair as opposed to emergency maintenance and shutdown.
- Minimization of losses.
- Optimization of process operation.

- Control operating conditions.
- Minimization of cost through conservation of energy and water.
- Maximization of profit through product development.

b) Environmental Self-Monitoring

It includes two aspects: emission and impact monitoring. Impact monitoring deals with the impact of the pollutant on the receiving media. Compliance with the limits set by the environmental regulations ensures the quality of that media. Impact monitoring is not preventive but assesses the situation after the harm has been done. On the other hand, the objectives for emission monitoring are to minimize emissions at the source through pollution abatement and prevention measures. Egyptian environmental regulations consider only the pollutants concentration and not their loads. Inspectors assess compliance through direct measurement and analysis. The objectives of emission monitoring go beyond compliance, to improved environmental performance. Monitoring emissions can be achieved through a number of methods, one of the most important being operation controls (process operation monitoring).

Self-monitoring covers the monitoring of emissions to air, water and soil as well as the reporting of pollutant releases and transfers. An inventory for hazardous materials and wastes is also mandatory with procedures for handling and storage as regulated by law 4/1994. It is clear from the above definition of EMS that self-monitoring is an integral part in any EMS that sets compliance with environmental laws as an objective.

7.2 Distinction Between Self-Monitoring and Inspection

Self-monitoring does not constitute self-regulation. SM provides additional information on which the competent authorities can judge whether an operator is complying with relevant legislation and conditions of permits. It does not change the duty of the competent authority to assess compliance by means of inspection and by performing its own monitoring or choose to rely on the operator's monitoring data or a combination of both. The competent authority continues to be responsible for enforcement.

Additional information about checking self-monitoring results by inspectors is provided in the sector specific manuals for self-monitoring. The benefits of SM to both inspectors and operators is also described in the same mentioned manual.

8. Planning of Self-Monitoring and Data Collection

The main elements of the self-monitoring plan can be summarized in the following:

- Objectives and results required of the self-monitoring system
- Organization and share of responsibilities and tasks
- Planning activities and design of an implementation schedule
- Definition of the parameters and relevant monitored indicators to reach the objectives
- Design of an appropriate measurement and sampling program
- Data processing and reporting procedures
- System for follow-up of decisions, actions and monitoring development
- Quality assurance and control, checking and approving by the competent authority

More details can be found in the sectors specific manuals for self-monitoring.

8.1 Specific Objectives of Monitoring Process

These objectives cover both operation control and compliance self-monitoring.

8.1.1. Operation Control

The following parameters should be monitored to ensure efficient and safe operation of the steam generating plants:

- Water level in boilers
- Cleanliness of gauge cocks
- Safety valve operation: rust can cause safety valves to be stuck
- Scale deposition on boiler internals.
- Occurrence of leaks
- Steam pressure
- Air to fuel ration
- Oxygen concentration in flue gases.
- Soot formation

8.1.2. Compliance Self-Monitoring

Law 4/1994 and other relevant environmental regulations have set the limits for emissions to air and water as well as the regulations for solid waste management and quality of workplace conditions as presented in chapter 5.

Wastewater quality is inspected by competent authorities at the final discharge point. Therefore, inspectors are not required to check the waste water generated by steam generating plants in industrial facilities.

With respect to stack emissions, environmental laws have regulated these emissions and therefore compliance monitoring on flue gas analysis should be performed. Stacks should be provided with probes to allow regular sampling and analysis. Monitored parameters are SO_x, NO_x, carbon monoxide, particulate matter, ash.

8.2 Identifying Key Items

The identification of the key monitoring parameters requires good familiarization for the energy generating process and its relevant operations. However, these parameters can be classified into the following:

- Monitored parameters for water cycle
- Monitored parameters for fuel cycle
- Monitored parameters for boiler operating conditions

8.3 Dependence of Monitoring on Plant Type and Size (e.g. boilers of 1 MW, 5 MW and 50 MW)

Steam generation plants of sizes of 1 MW and 5 MW normally use fire-tube boilers. Therefore, their monitoring is simple and consider water level and steam pressure.

On the other hand, steam generation plants of size of 50 MW employ water-tube boilers for the purpose of power generation using steam turbines. Their monitoring is sophisticated and considers water level, steam pressure and temperature, burner control, feed-water quality, emission levels in the stack, synchronizing flow rate with load variation, etc.

9. Monitoring of Inputs and Outputs

Monitoring of inputs and outputs is necessary for the safe operation of the boiler and for the quality of the produced steam which influences the steam utilization in other operations (e.g. heating, generating energy, ...etc).

The inputs of the energy generating plants include water, fuel, chemicals, greasing oils and electricity. While the outputs include hot water or steam (superheated or saturated).

9.1 Effect of Boiler Feed Water Quality and Flow Rate

Total dissolved solids is the most important monitoring parameter with regard to feed water quality. High TDS is responsible for scale depositions within the boiler causing a decrease in heat transfer coefficient and consequently in the efficiency of steam generation. High oxygen level in the feed water causes corrosion and in general the oxygen level is an indication of the performance of the deaerator. Feed water flow rate is related to steam flow rate and blowdown rate and directly affects the water level in the boiler.

Table (9.1) shows the monitoring aspects for boiler feed water

Table (9.1) Monitoring Aspects for the Inputs

| Inputs | Monitoring Parameters | Monitoring Method | Frequency | Indications |
|---------------|---|-------------------------------------|------------------------|--|
| Process water | - Flow rate - Quality (TDS and oxygen level) | - Flowmeter - Conductivity meter | Once a day | Blowdown and carry over |
| Cooling Water | - Flow rate - Temperature | - Pump capacity - Thermocouple | Log book Continuous | Cooling Efficiency |
| Chemicals | - Type - Quantity/ day | Inventory | One a week | WW quality |
| Fuel | - Type - Consumption rate | Inventory | Once a week | Air pollution and amount of steam produced |
| Lube oils | - Type - Consumption rate | Inventory | Once a week | Engine condition |

9.2 Effect of Quality and Quantity of Cooling Water for Diesel Generators

There are two important parameters for monitoring cooling water: the flowrate and the temperature. They both affect the cooling rate of diesel generators, which in turn affects their performance. Table (9.1) shows the monitoring aspects for cooling water

9.3 Effect of Monitoring Chemicals and Lube Oils

Chemicals are used for different purposes in energy generating plants:

- As additives to boiler feed water to prevent corrosion.
- As backwash solution for softeners
- As coagulants in water treatment facilities

Monitoring these chemicals helps rationalize their use, find substitutes for some of the hazardous corrosion-inhibitors and minimize their concentration in the generated wastewater.

Lube oils are classified as hazardous and proper management practices should be observed in their handling. Waste oil should be sold to recycling plants for reuse. Table (9.1) shows the monitoring aspects for chemicals and lube oil.

9.4 Effect of Monitoring Fuel

Different fuels have different heating values, as indicated in table (2.3). The heat required to convert water into steam is supplied by fuel combustion. Therefore, the theoretical amount of fuel required to provide this heat can be calculated by heat balance.

An increase in fuel combustion per kg of steam produced is an indication of combustion efficiency.

9.5 Effect of Monitoring Outputs

Table (9.2) presents the monitoring aspects for the outputs of energy generating plants.

Table (9.2) Monitoring Aspects for the Outputs

| Outputs | Parameters | Method | Frequency | Indication |
|------------------------------------|--------------------------------|-------------------------------------|------------|------------|
| Steam | - Pressure and/ or temperature | Pressure gauge and/ or thermocouple | Continuous | |
| Hot water | - Temperature | Thermocouple | Continuous | |
| Gas turbines and Diesel generators | - Electricity | Voltmeter or Ammeter | Continuous | |

10. Operation Control

10.1 Operation Control for Water Treatment Unit

Table (10.1) shows the aspects to be monitored for water treatment unit

Table (10.1) Operation Control for Water Treatment Unit

| Treatment Method | Monitored Parameters | | Monitoring Method | Frequency | Indication |
|------------------|--|---|-------------------|-----------|------------|
| | Feed water | Outlet water | | | |
| Clarification | <ul style="list-style-type: none"> - Flow rate - BOD and COD - O & G - SS - TDS - Hardness | <ul style="list-style-type: none"> - S.S - TDS - Chlorides - Hardness - pH | Chemical analysis | | |
| Filtration | | <ul style="list-style-type: none"> - S.S | Chemical analysis | | |
| Ion-exchange | <ul style="list-style-type: none"> - Flow rate - TDS - Chlorides - pH | <ul style="list-style-type: none"> - TDS - Chlorides - Hardness - PH | Chemical analysis | | |
| Demineralization | | <ul style="list-style-type: none"> - S.S - TDS - Chlorides - Hardness - pH | Chemical analysis | | |

10.2 Operation Control for Boilers

Controls are those items which carry out the function of regulating the various quantities indicated by the instruments and which can be arranged, with interlocks, to shut the plant down if any values pass outside the allowable operating range. Control systems can vary in sophistication from local manual operation of the various valves and dampers to a fully computerized system with little manual intervention once the system is programmed and verified. It is worth reflecting on the statement, "Before you can control you must measure". This applies to manual as well as to automatic control.

Manual control, however, is tedious, it is prevailing in small capacity boilers. It requires continuous watch on all the instruments to ensure that safe conditions exist. It is also necessary to include alarms to alert the operator to the fact that corrective action is required.

To control a boiler, the following quantities require to be regulated as applicable to a particular system:

1. The heat input to the boiler to match the required heat output;
2. The fuel/air ratio to maintain optimum combustion conditions (combustion control);
3. In the case of steam boilers the water flow to match the steam flow from the boiler;
4. Combustion chamber pressure in the case of balanced-draught boilers to maintain a small negative pressure on the gas side;
5. Where high degrees of superheat are generated, the steam temperature may be controlled to protect the superheater, steam pipework, and the device using the steam against overheating; and
6. Combustion safety (burner management).

The scope and complexity of automatic controls and instrumentation can vary enormously from the simple on/off schemes as applied to small fire-tube boilers to the more complex modulating schemes with extensive visual-display and computer data storage facilities used on some of the larger boilers.

10.2.1 Boiler Pressure Measurement, Indication and Relief

Local Pressure Indication

This, along with the corresponding temperature measurement and control is perhaps the most basic function required. First, the display (which must be easily seen and read by the operator) is necessary to ensure the safety of the plant, a pressure rising above a clear mark indicating the working pressure on the dial signals that the heat input must be reduced immediately. A falling pressure means that the demand for heat is exceeding the heat input and therefore that the firing rate must be increased. The indicating instrument is the well-known Bourdon gauge, which consists of a flat tube bent to a curve. This tends to straighten out as the internal pressure increases and is arranged to drive a pointer over a circular scale.

Safety Valves

Boilers are designed to withstand certain pressures only, and on no account must be subjected to greater pressures. In most cases the measuring and control devices described suffice to avoid an overpressure condition but it is mandatory, on both steam and hot water boilers, to fit safety valves, which lift and relieve the pressure.

10.2.2 Combustion Control

This incorporates both the control of the boiler heat input and that of fuel to air ratio. Combustion control systems must ensure that at all times adequate quantities of air are available to meet the fuel requirements, so as to burn the fuel efficiently without smoke and with minimum harmful emissions discharge from the stack.

The main source of signal for the operation of a combustion control system is the steam pressure at the boiler outlet, in the case of steam generators, and the water outlet temperature, in the case of hot-water boilers. Combustion controls therefore also control the boiler pressure as a stage in controlling the heat input.

Combustion Control Schemes

There are three basic control schemes used for regulating multiple variables such as fuel and airflow in a combustion control system. These are:

- Series, in which a variation of the master control signal, steam pressure, causes a change to take place in the combustion airflow, which, in turn, causes a change in fuel flow,
- Parallel control, in which a variation of the master control signal adjusts the fuel and air flows simultaneously and represents a typical positional control system, and
- Series/parallel control, in which a variation of the master control signal adjusts the fuel flow and, as steam flow is approximately proportional to air flow, variations of steam flow resulting from a change of load are measured and used to adjust the air flow.

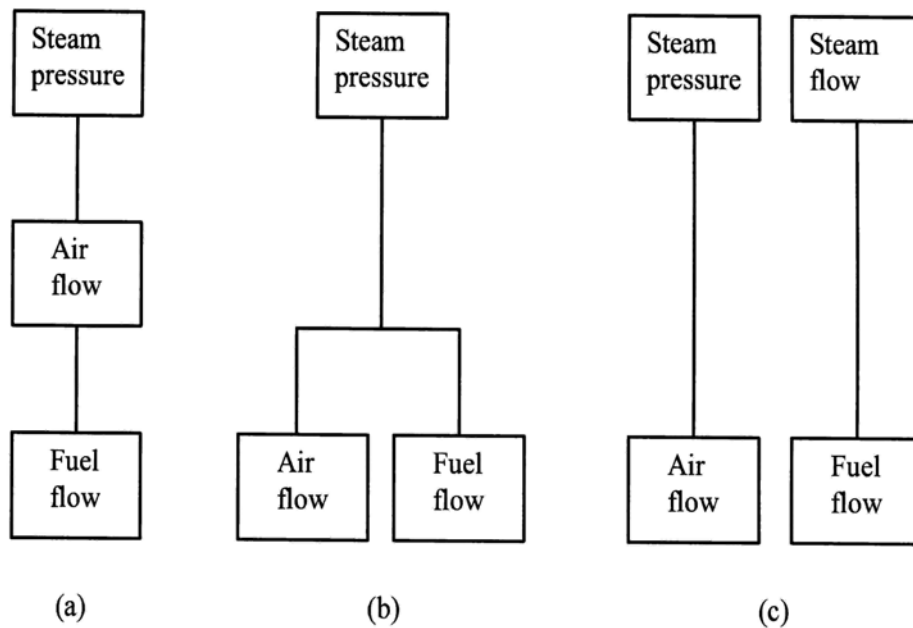


Fig (10.1) Basic Control Schemes

(a) Series control, (b) Series/parallel control, (c) Parallel control

Types of Combustion Control System

There are three basic types of automatic combustion control. These are: on/off, positioning and metering.

a) On/off Control Systems

On a steam boiler, using an on/off system, the fuel and air are shut off as the steam pressure rises to a preset value. The steam pressure then falls gradually as the demand continues, until it reaches a preset low value at which the fuel and air are turned on again.

With hot-water boilers, high and low water temperatures are used as the initiating signals. A typical example of the on/off control is the system used with a gas-fired domestic heating system. This method of control results in a fluctuating steam pressure. Its use tends to be restricted to very small units generating hot water or saturated steam. It cannot be used when generating superheated steam because, during the off periods, there are no gases flowing over the superheater from which the steam can receive its superheat. A variation of the on/off system is “high/low/off”, where there are three control settings instead of two.

b) Positioning Control Systems

With positioning systems, the fuel and combustion air controllers (the fuel valve in the case of oil or gas firing, and dampers or fan speed in the case of combustion air) are interconnected mechanically in such a way that for a given fuel valve position the air damper will always be in the same position. Such systems are called “open-loop” and assume that the flow through the valve or damper will always be the same for a given valve or damper position. The interconnecting linkage usually incorporates some form of cam, the shape of which is determined during commissioning by manual adjustment of the fuel and air controllers to give optimum conditions over the load range of the boiler.

On a typical positioning system applied to fire-tube boilers the pressure control signal is generated by separate sensors, two of which are generally used. The first is to signal an overpressure condition to the fuel-feed regulator, which in turn is linked to the combustion air supply. Should an overpressure condition occur, the firing appliance is shut down, generally accompanied by visual and audible alarms, and needing manual reset. This control is mandatory for automatic boilers. The second sends an electrical signal, which is proportional to the change of pressure from the set point to a

servomotor connected to the fuel regulator and to the air-regulating dampers (or to the fan-motor speed controls). These are thus adjusted to restore the pressure to the set value.

c) *Metering/Modulating Control Systems*

With metering systems, the fuel and air are regulated by the master signal from the steam pressure, a fall in pressure indicating that an increase in fuel and air inputs is required. The fuel and airflows are measured, the two signals are compared in a ratio controller (feedback) and one of them is adjusted by operating the flow controller until the correct ratio or set point is achieved. The combustion conditions are therefore maintained at the optimum irrespective of any changes that may occur to the system resistance or characteristics of the controller. Such systems are called “closed-loop”. The ratio controller is arranged so that the set point can easily be adjusted manually while the boiler is in operation should there be any change in the fuel characteristics and hence in the heat input to the boiler for a given fuel flow signal. Metering systems require a flow-measuring device in the fuel and air systems.

10.2.3 Soot Blowing

To ensure that the performance and thermal efficiency of a boiler are maintained, it is essential that the heated surfaces are kept clean. On the gas-swept surfaces, this necessitates removal of material deposited on the tubes from the flue gases. If this is not done, the rate of heat transfer from the gases will be reduced and the gas temperatures will rise. On most solid-fuel fired boilers and (depending upon fuel properties), on some gas- and oil-fired and waste-heat boilers, sootblowers are installed to enable the boiler surfaces to be cleaned while the boiler is operating.

A sootblower is a device that directs a jet of steam or compressed air to blow across tube surfaces in contact with the flue gases. This technique is used to remove material deposited on the tubes. Sootblowers can be of the multi-nozzle or multi-jet rotary type, or of the retractable type.

A multi-nozzle sootblower (Fig 10.2) consists of a steel tube of 50-64 mm diameter which is inserted through the wall of the boiler, which has been equipped with nozzles, which project a blowing medium (steam). The nozzles are positioned to coincide with the spaces between the tubes to enable the steam to blow down the gas passages between the tubes. The blower can be rotated through any angle up to about 280°, to cover the greatest amount of heated surfaces. Where it is required to blow around a full 360°, two rows of diametrically opposite nozzles are used and the blower is rotated through 180°. The effective radius of cleaning from the centerline of tube is about 2 meters. Multi-nozzle blowers which remain in the gas stream can only be used in gas

temperatures up to about 1000 °C due to the lack of suitable materials of construction for higher gas temperatures. Their use is, therefore, mainly restricted to the evaporative convection, economizer, and air heated surfaces.

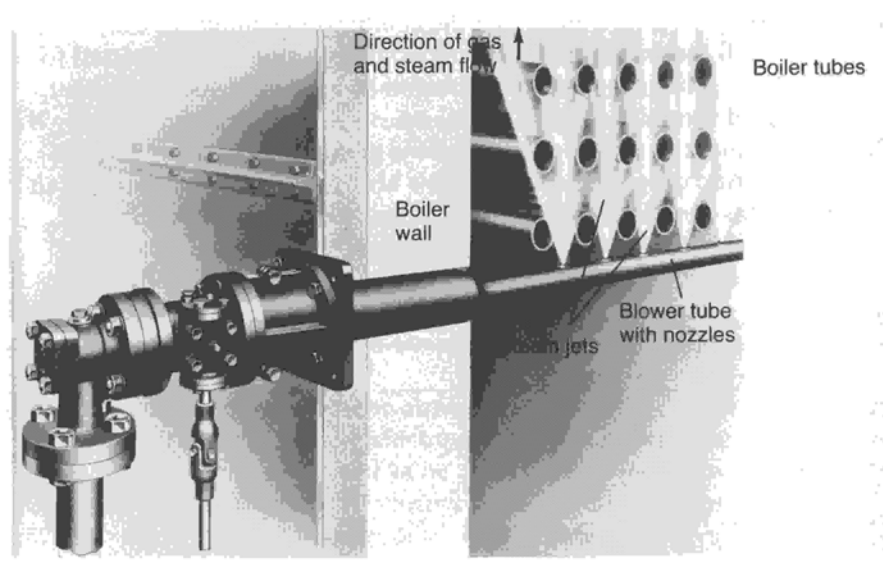


Fig (10.2) Multi-Nozzle Rotary Sootblower

Where gas temperatures exceed those for which fixed blowers are suitable, the retractable type has to be used. These can be either short or long. With the short type, see fig (10.3), the nozzle projects just beyond the boiler wall and can be used to blow either the combustion chamber wall tubes, or the convection heating surfaces on narrow boilers. With retractable blowers, the tube is withdrawn from the gas stream when not in use, and there are nozzles only at the end of the tube. When soot-blowing is being carried out with a long retractable blower, it is rotated and moved in such a way to traverse the gas stream and cover the full width of the boiler. Consequently, the steam jet will follow a helical path.

The full cycle includes blowing while the tube traverses back across the boiler and withdrawn. The steam issues from the nozzles immediately as they enter the gas stream to ensure that the tube is always adequately cooled. Long retractable blowers have opposing nozzles at the end to ensure that the reaction of the steam jets is balanced, so as to reduce deflection of the tube. The tube is available in lengths up to about 15 m as required by the width of the boiler. Blowers can be fitted in both sides if required, to reduce the length of the tube. For wide boilers, allowance has to be made in the layout of the heated surfaces for the deflection of the tube due to its own weight.

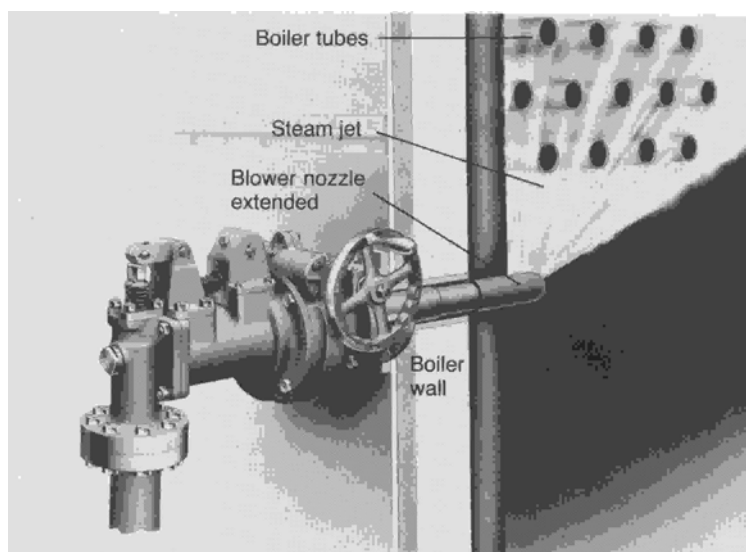


Fig (10.3) Short Retractable Sootblower

Soot blowers use steam at a rate of 2 – 4 t/hr, which on small industrial boilers can be a significant percentage of the boiler output for the duration of the blowing sequence. This can be several minutes, depending on the width of the boiler and the number of blowers fitted. Because of this rate of steam consumption, blowers are only used one at a time to reduce the effect on the boiler steam production. For this reason also, soot-blowing should preferably only be carried out during periods of low load. The steam usage has to be taken into account when designing the feed water system.

Multi-nozzle and short retractable blowers can be manually operated by hand wheels, but the effectiveness of blowing is then dependent on how the operator manipulates the blower. However, electronically operated blowers are increasingly used.

Long retractable blowers are always electronically operated to ensure that the sequence is completed and the blower safely withdrawn from the gas stream. While the sootblowers can be operated locally or remotely, automatic sequence operation is now more usual, with programmable controls enabling the sequence of operation of the various blowers to be varied to suit the cleaning requirements of the boiler.

The use of sootblowers applies mainly to water-tube boilers, where regular on-load cleaning is essential. In most cases fire-tube boilers are not required to operate for such long continuous periods and sootblowers are not often fitted. The boilers are shut down at weekends, the smoke-box door opened, and the tubes swept by brushes which may be mechanized and equipped with a vacuum extraction device to remove the loosened material. An effective method is to use a “percussion lance” This discharges rapid pulses of compressed air down each tube to which the lance is presented. Both brushes and lances are hand-held and are not attached to the boiler.

A more recent method of soot-blowing, still to achieve its full potential, is to use intense sound. This is the 'sonic' soot-blower which, as with the percussion lance, discharges rapid pulses of compressed air into the cavities in the boiler which it is designed to clean. The frequency of the pulses can be tuned to resonate with the natural frequency of the cavity, so increasing the amplitude of the pulse. In many cases deposits are of a porous structure, gases existing in the pores. A positive compression wave is followed by a negative wave, which causes the gases included in the deposit to expand, thus disintegrating the mass. Sonic soot-blowers are now increasingly used on both fire-tube and water-tube boilers, and in some cases are proving very effective.

10.2.4 Water Level Indication

This applies essentially to steam boilers where there is a visible water level. A simple gauge glass or, at high pressures, a double-plate glass variation on the steam/water drum or boiler shell is used as the indicator (shown in fig 10.4). Two must be provided and arrangements made so that a breakage will not be a hazard to the operator. The instrument should also be easily read from the operating level and be adequately illuminated. This time-tested device is used on the vast majority of boilers and is arranged to give a visible range of water level of ± 125 mm from normal water level.

There have, in recent years, been developed more sophisticated devices, which involve the use of electrodes, which are sensitive to water level. These may be of either the capacitance or the conductivity type. As well as providing a very clear visual display, the fact that they use electricity enables them to generate signals from which controls and alarms can be operated.

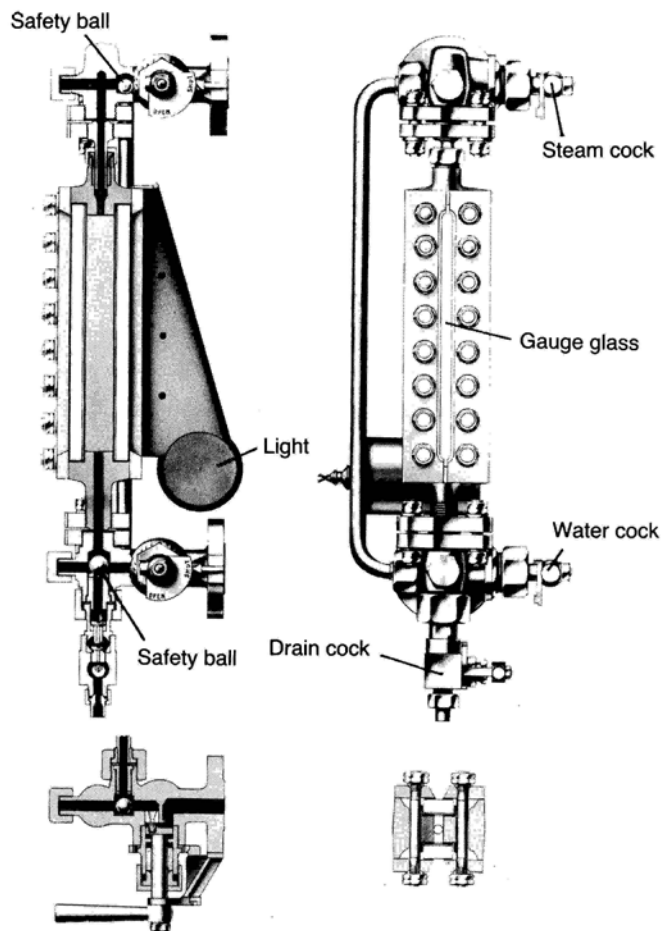


Fig (10.4) Double-Plate Glass Water Level Indicator

10.2.5 Boiler Water Quality

It is important that the quality of water within the boiler be kept within the limits recommended. Sampling and testing the water on a regular basis generally carry this out. The conductivity of the water is, broadly, a measurement of the total dissolved solids content of the boiler water, which is an important property. This should be limited as indicated by the boiler vendor. The recommended limit for TDS is 3500 ppm. For water-tube boilers, the recommended TDS is according to boiler pressure (up to a maximum of 3000 ppm).

The conductivity instrument can be arranged to trim the discharge from the continuous blowdown system and the display should guide the operator to adjust his manual blowdown regime as necessary.

Measurement of pH gives an indication of alkalinity. Normally, this should be about 9: higher figures indicating high alkalinity with the likelihood of priming; low figures warning that the water in the boiler could be corrosive.

Given that blowdown is essential for the maintenance of the boiler and the quality of the steam it supplies, two things require attention:

- 1) The quantity of blowdown should not exceed the minimum amount necessary. Anything in excess is a waste of energy. Proper control is most important.
- 2) When control of blowdown has been achieved, the recovery of heat from the blowdown should be examined to see whether it is economical. On average, about 50 percent may be recoverable.

Control of Blowdown

In a simple, manually controlled system, the blowdown valve must be set by hand to give the required amount of blowdown. The aim is to maintain the total dissolved solids in the boiler water (usually expressed in ppm, parts per million) just below the prescribed maximum limit. It is therefore essential to sample and analyze the water and adjust the blowdown until the desired conditions are achieved.

The following provides a simple checklist for estimating the quantity of blowdown from a boiler if it is not already known:

- For existing plants, the present blowdown method may consist of blowing down say one inch from the gauge glass at regular intervals. This may be converted to a volume by estimating the water surface area of the boiler (width times length), and multiplying this by the frequency, so that an equivalent continuous blowdown flow rate can be calculated. Remember that this will be related to the present average steam generation rate.
- Alternatively, the existing blowdown method may consist of opening the bottom blowdown valve for a given time at certain intervals. For the standard full-bore valve, the flow rate is controlled by the length and bore of the blowdown line, and the boiler pressure. A pressure drop calculation may be used for estimating the flow rate when the valve is open. From the figure obtained, an equivalent continuous blowdown flow rate can be calculated. Again, results will be related to the average generation rate.

To check boiler water quality, it is necessary to take samples at regular intervals. It is most important that the sample is properly cooled and not drawn directly off the boiler at the blowdown line, or flash loss will completely upset a true analysis. A sample cooler is essential.

Provided the average blowdown requirement exceeds 40 kg/h, blowing down a boiler continuously to control the TDS becomes the ideal procedure. With constant make-up water flow and steam-generating conditions, the continuous blowdown rate can be determined and controlled precisely. With varying conditions, a compromise has to be made either:

- The average continuous blowdown rate is accepted, resulting in the actual TDS level fluctuating up and down about a norm or
- The blowdown rate maintains the base level of TDS, and the peaks are controlled intermittently.

Reliable maintenance-free continuous blowdown can only be achieved using good quality valves. Given the need for fine control, large pressure reduction, and the presence of suspended solids, the valve must:

- Control accurately, and be easily and precisely set for the given flow

rate.

- Withstand arduous duty.
- Be easily moved to a purge position for cleaning deposits, and easily reset to the control position.

10.2.6 Combustion Safety (Burner Management)

A burner management system incorporates interlocks to ensure that the correct sequence of events is carried out during start-up, operation and shutdown of the boiler. There are a number of codes of practice and guidelines for safety interlocks and pre-and post-ignition purging for the various systems. A simple system is where the operator manually positions the various dampers and valves in the correct sequence during the start-up procedure. Interlocks are included to prevent one stage being carried out if the previous stage is incomplete. For most modern boilers with gas or oil burners, a fully automated system can be incorporated in which the start-up procedure is initiated by the press of one button.

One of the major features of a burner management system is the use of scanners that detect the presence of ignition and of the main flame of individual burners with oil, gas and pulverized fuel firing. These ensure that, in the event of a flame failure, the burner or burners concerned are shutdown. On a single burner installation this means a boiler shutdown until the fault has been rectified.

Table (10.2) summarizes the important items which should be monitored for safety operation control for the boilers.

Table (10.2) Operation Control for Boiler

| Equipment | Monitored Item | Monitoring Method | Frequency | Indication |
|------------------|--------------------------------|-------------------|-----------|------------|
| Boiler no. (...) | - Insulation | Visual | | |
| | - Pressure | Pressure Gauge | | |
| | - Fuel consumption/ day | Inventory | | |
| | - Fuel/ air ratio | Flow meter | | |
| | - Excess air | Stack analysis | | |
| | - Actual combustion efficiency | Calculations | | |
| | - Leakage in pipelines | Visual | | |
| | - Blowdown rate | Flow meter | | |

10.3 Operation Control for Diesel Engines and Gas Turbines

When large diesel engines and gas turbine units are connected to electric-generators for the purposes of power generation their speed must be maintained while supplying a varying load. This is achieved by attaching governors to the engines.

An engine governor is, commonly, a speed-sensitive device that automatically controls or limits the speed of the engine by adjusting the amount of fuel fed to the engine. The usual kind of governor adjusts the rate of fuel supply in such a way as to keep the engine running at a steady speed regardless of the amount of load. Engine governor can be of mechanical type, which is less accurate in speed controlling, or hydraulic type, which is more sensitive to load variation and therefore is more suitable for engines of power generation.

Table (10.3) summarizes the major items for monitoring operation control for the diesel engines.

Table (10.3) Operation Control for Diesel Engines

| Equipment | Monitored Item | Monitoring Method | Frequency | Indication |
|-------------------------|----------------------|-------------------|-----------|------------|
| Diesel Engine no. (...) | - Air flow rate | | | |
| | - Cooling water rate | Flow meter | | |

11. Compliance Monitoring

Section (5) presents the various laws and regulations that apply to emissions, effluents and wastes from the steam generating plants. Tables (11.1, 11.2, 11.3 and 11.4) give the compliance monitoring activities for the different aspects of pollution as per environmental laws.

Table (11.1) Compliance Monitoring for Air Pollution

| Major Pollution Sources | Monitored Parameters | Monitoring Method | Frequency | Operating | |
|-------------------------|--|-------------------------|-------------|-----------|-------------|
| | | | | Normal | Exceptional |
| Stacks | SO _x , CO, CO ₂ , particulates, heavy metals | Stack measurements | Once a week | | |
| Storage tanks | VOCs | Ambient air measurement | Once a week | | |

Table (11.2) Compliance Monitoring for Wastewater

| Major Pollution Sources | Monitored Parameters | Monitoring Method | Frequency | Operating | |
|-------------------------|----------------------|-------------------|--------------|-----------|-------------|
| | | | | Normal | Exceptional |
| Boiler | | | | | |
| - Blowdown | - Rate | Flow meter | Continuous | | |
| | - TDS | Chemical analysis | Once a month | | |
| Water treatment unit | | | | | |
| - Backwash water | - Rate | Flow meter | Once a month | | |
| | - TDS | Chemical analysis | Once a month | | |
| Cooling tower | | | | | |
| - Blowdown | - Rate | Flow meter | Once a month | | |
| | - TDS, oils | Chemical analysis | Once a month | | |

Table (11.3) Compliance Monitoring for Work Place

| Major Pollution Sources | Monitored Parameters | Monitoring Method | Frequency | Operating | |
|-------------------------|----------------------|-------------------|-----------|-----------|-------------|
| | | | | Normal | Exceptional |
| Boiler | - Noise | Noise meter | | | |
| | - Temperature | Thermocouple | | | |
| Diesel engine | - Noise | Noise meter | | | |

| | | | | | |
|-------------|---------|-------------|--|--|--|
| Gas turbine | - Noise | Noise meter | | | |
|-------------|---------|-------------|--|--|--|

Table (11.4) Compliance Monitoring for Solid Wastes

| Pollution Source | Type of Waste | Quantity | Operating | | Disposal Method |
|----------------------------|---------------|----------|-----------|-------------|-----------------|
| | | | Normal | Exceptional | |
| Clarifier | Sludge | | | | Dumping site |
| Softener | Sludge | | | | Dumping site |
| Chemicals empty containers | Plastic | | | | Sold |

12. Using SM Outputs

The implementation of the self-monitoring plan will basically result in three outputs:

- Data and information about the facility
- Preparing the environmental register as required by law.
- Reports describing results of the self-monitoring and problems faced during implementation
- Feed back and decision making

12.1 Techniques for Summarizing and Illustrating Data

It is best practice to record process and environmental information in a detailed archive or database. It can then be related easily to the monitoring results and used to evaluate, compare and manage aspects of process performance such as:

- the rate of release of pollutants compared to production
- the rate of generation of waste compared to production
- the rate of consumption of energy and/or materials compared to production
- the impacts on environmental receptors compared to production or to their sensitivity
- the overall resource efficiency of the process, i.e. production compared to inputs or raw materials and energy, and outputs of pollutants and waste

There are many techniques used in the interpretation of results (e.g. statistical analysis of the measurement results, reduction of operating conditions to normal conditions when monitoring gaseous emissions).

12.2 Environmental Register

Only monitoring data related to compliance will be included in the environmental register. Description of the measuring and/or analytical techniques used should be reported as well as the location of sampling and measuring. The competent authorities could request the inspection of the measuring devices to check their operability and the maintenance record for these devices. The procedures for taking samples could also be checked by the inspector. The inspectors check whether the facility has provided information that is relevant and of sufficient quality. To assess compliance, a simple numerical or statistical comparison between the measurements, their uncertainty and the limit value is performed.

According to Law 4/1994, compliance self-monitoring data should be recorded and kept for a minimum of 10 years.

12.3 Reporting

Description of the reporting scheme, its content, recipient and purpose should be included in the self-monitoring plan. A monitoring report is a uniform presentation of data over a fixed period. An annual monitoring report that provides information of the past calendar year is always required. Shorter period reports are required for significant polluters. The conditions of the process and equipment as well as location of monitoring points should be specified. Reporting can be:

- Internal to inform management and raise the environmental awareness of the facility personnel. It should include problems met during the implementation of the SM plan to be used in decision making.
- External for the competent authority and it is done through the environmental register.

12.4 Internal Auditing and Conclusions on Results

The data obtained must be compared regularly with the objectives written down in the monitoring program to check that they are being met.

12.5 Feedback and Decision Making

Feedback on the assessment of compliance based on the monitoring results should include all parties involved with the monitoring activities. The participants should make the necessary improvements and corrections to the next monitoring program.

In those parts of the monitoring program where compliance is met, possible reduction in frequency of monitoring can be considered and instead move resources to parts that need more accurate monitoring, e.g. borderline or non-compliance situations.

Feedback should include all parts of the monitoring program, process, product control, maintenance, environmental management and occupational safety. Detailed requirements should be set for the improvements needed and a date fixed for their implementation.

12.6 Using Outputs in Public Relations

The monitoring data is refined and distributed to the end users such as national and international reporting, research and statistical purposes, citizens, and the media.

The citizens have the right to present complaints about the health or environmental impacts caused by the operation these complaints are directed to the permitting and supervising authority.

Monitoring data is needed e.g. in national research and statistics, for planning and evaluation purposes, by national group organizations and the media.

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Annex A

Basic Definitions

A- 1 Definitions — Boiler Terminology

- ***Tiny (miniature) Boilers***

According to Section I of the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME), tiny boilers are those with a 16-inch (40-cm) inside diameter of shell, and 5-cubic-feet (0.14 m³) gross volume exclusive of casing and insulation.

- ***High-pressure Steam Boiler***

Generates steam or vapor at a pressure of more than 1 bar gauge. Below this pressure it is classified as a low-pressure steam boiler.

Small high-pressure boilers are classified as *miniature boilers*.

- ***Hot-water-Supply Boiler***

A boiler completely filled with water. Furnishes hot water to be used externally to itself (not returned) at a pressure not exceeding 160 psig (11 bar), or a water temperature not exceeding 250°F (120 °C). This type of boiler is also considered low-pressure. If the pressure or temperature is exceeded, it must be designed as high-pressure boilers.

- ***Low-Pressure Boiler***

A steam boiler that operates below 15-psig (1 bar gauge) pressure, or a hot-water boiler that operates below 160 psig or 250°F (11 bar or 120 °C).

- ***Packaged Boiler***

Is a completely factory-assembled boiler, water-tube, fire-tube, or cast-iron, and it includes boiler firing apparatus, controls, and boiler safety appurtenances. A shop-assembled boiler is less costly than a field-erected unit of equal steaming capacity. While a shop-assembled boiler is not an off-the-shelf item, it can generally be put together and delivered in a lot less time than a field-erected boiler; installation and start-up times are substantially shorter. Shop-assembled work can usually be better supervised and done at lower cost.

- **Power Boiler**

A steam or vapor boiler operating above 15 psig (1 bar gauge), and exceeding the miniature boiler size.

- **Supercritical Boiler**

Operates above the critical pressure of 221.2 bar and 374.15 °C saturation temperature. Steam and water have a critical pressure at 221.2 bar. At this pressure, steam and water are at the same density, which means that the steam is compressed as tightly as the water. When this mixture is heated above the corresponding saturation temperature of 374.15 °C for this pressure, superheated steam is produced to perform high-pressure work. This dry steam is especially well suited for driving turbine generators.

They are subdivided into two classes:

- **Fire-tube boilers**

the products of combustion pass through the inside of tubes with the water surrounding the tubes. Fire-tube boilers are described later in detail.

- **Water-tube boilers**

the water passes through the tubes, and the products of combustion pass around the tubes.

- **Waste-Heat Boiler**

Uses by-product heat such as from a blast furnace in a steel mill or exhaust from a gas turbine, or by-products from a manufacturing process. The waste heat is passed over heat-exchanger surfaces to produce steam or hot water for conventional use.

A- 2 Definitions — Valves, Controls, and Fittings

The following definitions on valves, controls, and fittings will help operators to understanding their purpose.

- ***Safety Valve***
Prevents boiler pressure from rising above the setting of the valve by relieving excessive steam pressure and guarding against hazards of over pressure.
- ***Steam Supply Stop Valve***
The valve installed at the steam outlet of the boiler to shut off the flow of steam.
- ***Steam Pressure Gauge***
Indicates the steam gauge pressure in the boiler in kg/cm² or psig (pounds per square inch gauge).
- ***Steam Gauge Siphon***
The device installed between the steam gauge and the boiler to provide a water seal, so that live steam will not enter the gauge to cause a false reading or damage to the gauge.
- ***Inspectors' Test Gauge Connection and Cock***
Provides the necessary connection to check the accuracy of the steam pressure gauge on the boiler.
- ***Water Column***
The hollow casting or forging connected at the top to the boiler's steam space and at the bottom to the water space. The water gauge glass and water test cocks are installed on the column.
- ***Water Glass and Gauge Fixtures***
Designed to show the water level in the boiler.
- ***Water Test Gauges or Try Cocks***
Testing the water level in the boiler, should the water glass, for any reason, be out of service temporarily.

- ***Drain Valve***

Located under the water column and low-water cutoff switch. Provide a mean for daily flushing under the water column and water level controls, to keep the chamber and lines clean. This allows the water to register accurately in the glass. Also provides a means of testing the low-water cutoff.

A-3 Boiler-output rating terminology

Boiler output can be expressed in horsepower, pounds of steam per hour, ton of steam per hour, Btu per hour, and in MW.

- ***Boiler Horsepower (boiler hp)***

Often used in the USA; as the evaporation of water into dry saturated steam of 34.5 lb/hr at a temperature of 212 $^{\circ}\text{F}$. Thus 1 boiler hp by this method is equivalent to an output of 33,475 Btu/hr, and in the past commonly taken as 10 square feet (ft^2) of boiler heating surface. But 10 ft^2 of boiler heating surface in a modern boiler will generate anywhere from 50 to 500 lb/hr of steam. Today the capacity of larger boilers is stated as so many pounds per hour of steam, or Btu per hour, or megawatts of power produced.

- ***Boiler Turndown Ratios***

Used as a guide to note the range of outputs over which a boiler can be operated automatically while still maintaining peak and near-peak efficiency. On packaged fire-tube boilers, a 5:1 turndown is common, or a load from 20 to 100% rated is the guaranteed turndown efficiency.

Annex B

Calculating Minimum Stack Height

All early boilers operated with natural draft supplied by the stack effect to meet the total draft requirement. However, for industrial and larger units equipped with superheaters, economizers and especially air heaters, it is not practical, or economical, to draft the entire unit only from stack induced draft. These units require fans in addition to the stack, in three typical types of draft, namely:

- 1) Either the entire unit is under pressure that is supplied by a forced draft fan or,
- 2) Using both induced and forced-draft fans for balanced draft operation,
- 3) Combination of induced-draft fan and stack (this is not commonly operation condition).

The required height and diameter of stacks for natural draft units depend upon the following technical factors:

- 1) Draft loss through the boiler from the point of balanced draft to the stack entrance,
- 2) Temperature of the gases entering to the stack and the temperature of the surrounding air,
- 3) Required gas flow from the stack, and
- 4) Barometric pressure.

The relation between draft loss and stack height is determined from the relation:

$$(\Delta p) = H \cdot \frac{p_o g}{R_{air}} \cdot \left(\frac{1}{T_o} - \frac{1}{T_{gas}} \right) \approx 35 H \left(\frac{1}{T_o} - \frac{1}{T_{gas}} \right)$$

Where:

Δp is the draft loss, (cm H₂O),

H is the stack height, (m),

p_o is the atmospheric pressure, (100 kPa),

T_o is the atmospheric temperature (K),

T_{gas} is the gas average temperature in the stack (K),

R_{air} is the air constant, (0.287 kJ/kg-K),

g is the gravitational acceleration, (9.81 m/s²).

In addition to the aforementioned technical factors, there are some environmental factors that are enforced to the calculation of minimum stack height.

In the article No. 42, the executive statutes of the law 4/1994 on Environment states that:

1. The height of chimneys that emit a total of 7000 - 15000 kg/hour of gaseous waste shall be 18-36 meters.
2. The height of chimneys that emit a total amount of waste exceeding 15000 kg/hour shall be at least more than two and half times ($2 \frac{1}{2}$) the height of surrounding buildings, including the building served by the chimney.

An example of how to estimate the amount of gaseous waste from a chimney of a boiler is as follows:

1. Consider a fire-tube boiler of capacity of 8000-kg/hr steam,
2. Such type of boiler with this typical capacity usually has an efficiency of 0.85 based on gross heating value; the expected amount of fuel burned is about 650 kg/hr,
3. The air-fuel ratio for good combustion is normally in the range of 18 – 20.
4. For an air-fuel ratio of 20, the amount of leaving gases is, therefore,

$$\dot{m}_{\text{gases}} = \dot{m}_{\text{fuel}} \left(1 + \frac{A}{F} \right) = 13650 \text{ kg / hr}$$

5. Accordingly, the stack height, based on environmental consideration, should be of height of 18 – 33 meters.
6. The stack height should be checked for the expected total draft loss in the boiler according to the above-mentioned expression, which relate the technical draft-loss to the stack height.
7. In case of different larger boiler of a capacity of, for instance, 10-ton/hr and through the same procedure, the stack height shall be of $2 \frac{1}{2}$ the height of surrounding buildings, including the building served by the chimney.

Annex C

Recommended Water Quality

Water quality recommendations are normally provided by boiler manufacturers and in national standards. Some typical recommendations are given in the following tables. These confirm that the higher-pressure boilers require much more complete water treatment and higher quality water. As a general guide, the maximum TDS level of water in a typical industrial package boiler is around 3000 to 3500 ppm.

C-1 Recommended Water Characteristics for Shell (Fire-tube) Boilers (Basis: BS 2486:1978)

| | | |
|---|-------------------------------------|-----|
| • Feed Water | | |
| Total hardness, mg/lit expressed as CaCO ₃ | 2 – 40 | (2) |
| Oxygen | | (3) |
| Total solids, alkalinity, silica | | (4) |
| PH | 7.5 – 9.5 | |
| • Boiler Water | | |
| Total hardness, mg/lit expressed as CaCO ₃ | Not detected | |
| Tri-sodium phosphate, mg/lit as Na ₃ PO ₄ | 50 – 100 | |
| Caustic alkalinity, mg/lit as CaCO ₃ | 350 – 200 | |
| Total alkalinity, mg/lit as CaCO ₃ | 1200 – 700 | |
| Silica, mg/lit as SiO ₂ , max. | Less than 0.4 of caustic alkalinity | |
| Sodium sulfite, mg/lit as Na ₂ SO ₃ or | 30 – 70 | |
| Hydrazine as N ₂ H ₄ | 0.1 – 1.0 | |
| Suspended solids, mg/lit max. | 50 – 300 | |
| Dissolved solids, mg/lit max. | 3500 – 2000 | |
| • Notes | | |
| (1) For pressures up to 25 bar. | | |
| (2) High output boilers will need hardness near to the lower end of this range. | | |
| (3) No fixed limit but recommendation is to deaerate to the maximum before addition of O ₂ scavengers such as sodium sulfite or hydrazine. | | |
| (4) To be consistent with boiler water specifications and the blowdown rate recommended by manufacturers. | | |

C-2 Recommended Water Characteristics for Water-tube Boilers (Basis: BS 2486:1978)

| | | | |
|--|-------------------------------------|------------|-----------|
| • Boiler Outlet Pressure (bar) | 20 | 60 | 120 |
| • Feed water at economizer inlet | | | |
| Total hardness, mg/lit expressed as CaCO ₃ | 10 | 0.5 | ND |
| Oxygen | 0.05 | 0.01 | 0.001 |
| Iron + copper + nickel, mg/lit max. | | 0.02 | 0.02 |
| Total solids, alkalinity, silica | Consistent with blowdown rate | | |
| pH | 8.5 – 9.5 | 8.5 – 9.5 | 8.5 – 9.5 |
| Oil | ND | ND | ND |
| • Boiler Water | | | |
| Total hardness, mg/lit expressed as CaCO ₃ | | | |
| Tri-sodium phosphate, mg/lit as Na ₃ PO ₄ | 50 – 100 | 20 – 50 | 0 – 3 |
| Caustic alkalinity, mg/lit as CaCO ₃ | 300 | 60 | 5 |
| Total alkalinity, mg/lit as CaCO ₃ | 700 | 300 | 40 |
| Silica, mg/lit as SiO ₂ , max. | Less than 0.4 of caustic alkalinity | 20 | 2 |
| Sodium sulfite, mg/lit as Na ₂ SO ₃ or | 30 – 50 | 15 – 30 | None |
| Hydrazine (1) as N ₂ H ₄ | 0.1 – 1.0 | 0.05 – 0.3 | — |
| Suspended solids (2), mg/lit max. | 200 | minimize | Minimize |
| Dissolved solids, mg/lit max. | 3000 | 1200 | 100 |
| Chloride, mg/lit Cl ⁻ max. | — | — | 5 |
| • Notes | | | |
| (1) Hydrazine decomposes in 120 bar boilers; cannot measure residue so rate to be based on O ₂ content of feed water. | | | |
| (2) In boilers operating at above 40 bar, minimize suspended solids at < 200 mg/lit. | | | |

Annex D

D-1 Chemistry of Combustion

These are based on elementary chemical equations for the reactions with oxygen of each combustible constituent of the fuel.

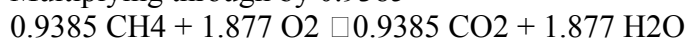
1. Gaseous Fuels

By far the most common gas used in boilers is natural gas. This consists mainly of methane. The composition of NG varies from one source to another, but still CH₄ is the main gas in its constituents. NG is virtually sulfur free, but a small amount of hydrogen sulfide has been included to illustrate the combustion calculations since sulfur could be a significant constituent in other fuel gases. The chemical reactions of the combustible gases with oxygen are as follows on a volume basis:

- Methane 93.85 % by volume



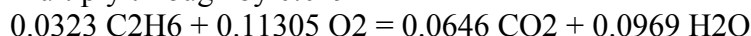
Multiplying through by 0.9385



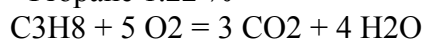
- Ethane 2.23 %



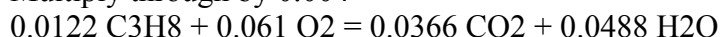
Multiply through by 0.029



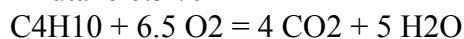
- Propane 1.22 %



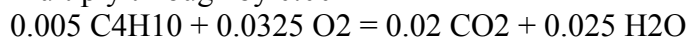
Multiply through by 0.004



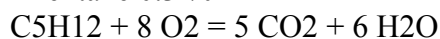
- Butane 0.5 %



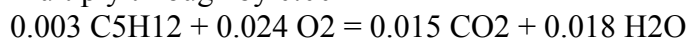
Multiply through by 0.002



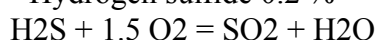
- Pentane 0.3 %



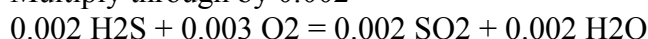
Multiply through by 0.001



- Hydrogen sulfide 0.2 %



Multiply through by 0.002



It should be appreciated that volumes cannot be summed across an equation; this is illustrated in combustion equations where the volumes on opposite sides are unequal. However, there is always a conservation of mass or number of atoms in right and left sides.

The next step is to obtain the total stoichiometric quantity of oxygen required for combustion. The stoichiometric term is referred to the minimum theoretical amount. If the fuel itself constitutes some oxygen, it should be first subtracted from the required stoichiometric oxygen.

In practice the combustion air will contain a small amount of moisture (humidity) which, if it is known, can be calculated and added to the products of combustion along with the excess air.

Summarizing the above combustion equations, 2.11055 kmols of O₂ are required to burn 1 kmole of the considered gas fuel.

The corresponding stoichiometric volume of air is

$$2.11055 \times \frac{100}{21} = 10.05 \quad \text{kmols of air}$$

$$\frac{\text{Volume of air}}{\text{Volume of fuel}} = \frac{10.05}{1} = 10.05$$

The volumetric air-fuel ratio is =

The stoichiometric air-fuel ratio (mass basis) is, therefore,

$$\left(\frac{A}{F} \right)_{\text{mass}} = \frac{\text{mass of air}}{\text{mass of fuel}} = \frac{10.05 \times 28.97}{1 \times 16.946} = 17.181 \quad \text{kg air / kg fuel}$$

2. Liquid Fuels

The analysis of solid and liquid fuels are based on masses of the combustible substances present as chemical elements, unlike those of gases which are based on volumetric proportions of constituents gases.

Residual liquid fuels, such as heavy fuel oil (Mazout), contains mineral matter and moisture, but to a much lesser degree than most solid fuel. Table (D-1) gives typical analyses for such fuels.

Table (D-1) Ultimate Analyses of Mazout Fuel (Percent by mass)

| Constituent | Weight % |
|-------------|----------|
| Carbon | 86.0 % |
| Hydrogen | 10.5 % |
| Sulfur | 3.0 % |
| Oxygen | 0.05 % |
| Nitrogen | 0.05 % |
| Moisture | 0.2 % |
| Ash | 0.2 % |
| Total | 100.0 % |

To calculate the air required for combustion and the analysis of the products of combustion, the procedure is rather similar to that for gaseous fuels. The combustible substances present are carbon, hydrogen, and sulfur. It will also be seen that oxygen presents in the fuel should be deducted from the total oxygen required for stoichiometric combustion. The equations of combustion will now be considered.

Because the fuel analysis is given on a mass basis the combustion calculations will be carried out on a mass basis. The basic equation for combustion of carbon is:



The molar mass (molecular weight) of carbon is 12 and that of oxygen is 32, the mass balance therefore becomes:

$$12 \text{ kg of C} + 32 \text{ kg of O}_2 = 44 \text{ kg of CO}_2$$

There is 86% carbon in the fuel analysis, i.e., 0.86 kg of carbon per kg of fuel. Therefore for the fuel in equation, the molar masses are multiplied through by (0.86/12), giving:

$$0.86 \text{ kg of C} + 2.293 \text{ kg of O}_2 = 3.153 \text{ kg of CO}_2$$

The other combustible constituents are treated in the same manner.

Hydrogen content in fuel is 10.5%, that is 0.105 kg H₂ / kg of fuel,

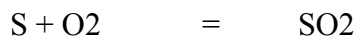


$$2 \text{ kg of H}_2 + 16 \text{ kg of O}_2 = 18 \text{ kg of H}_2\text{O}$$

Multiplying through by (0.105/2)

$$0.105 \text{ kg of H}_2 + 0.84 \text{ kg of O}_2 = 0.945 \text{ kg of H}_2\text{O}$$

Sulfur content in fuel is 3%, that is 0.03 kg/kg of fuel,



$$32 \text{ kg of S} + 32 \text{ kg of O}_2 = 64 \text{ kg of SO}_2$$

Multiplying through by (0.03/32)

$$0.03 \text{ kg of S} + 0.03 \text{ kg of O}_2 = 0.06 \text{ kg of SO}_2$$

The mass of stoichiometric oxygen required for burning 1 kg of fuel is, therefore,

$$(2.293 + 0.84 + 0.03) - 0.0005 = 3.1625 \text{ kg O}_2/\text{kg fuel}$$

Note that allowance is made for the oxygen already contained in the fuel.

Atmospheric air contains 23.3% O₂, therefore,

The mass of stoichiometric air required to burn 1 kg of that mazout fuel is

$$3.1625 \times \frac{100}{23.3} = 13.57 \quad \text{kg}$$

The stoichiometric air-fuel ratio (mass basis) is, therefore,

$$\left(\frac{A}{F}\right)_{\text{mass}} = \frac{\text{mass of air}}{\text{mass of fuel}} = \frac{13.57}{1} = 13.57 \text{ kg air / kg fuel}$$

Excess Air

In practice, since combustion conditions are never ideal, more than the theoretical amount of air must be supplied to achieve complete combustion. The actual quantity of combustion air required for a particular boiler, furnace or kiln depends on many factors. These include fuel type and composition, furnace design, firing rate, and the design and adjustment of the burners. The additional supply of combustion air above the theoretical requirement is called excess air. Excess air is usually expressed as a percentage of the stoichiometric (theoretical) requirement. Thus, use of double the amount of air theoretically required would result in an excess air rate of 100%, and so forth. 10% excess air being appropriate for natural gas fuel firing in fire tube boilers, less in large water tube boilers. In this case the actual air-fuel ratio will be:

$$\left(\frac{A}{F}\right)_{\text{actual}} = 13.57 \times 1.1 = 14.927 \quad \text{kg air / kg fuel}$$

30% excess air being appropriate for heavy oil fuel firing in fire tube boilers, less in large water tube boilers. In this case the actual air-fuel ratio will be:

$$\left(\frac{A}{F}\right)_{\text{actual}} = 13.57 \times 1.3 = 17.64 \quad \text{kg air / kg fuel}$$

Some typical excess air requirements are shown in Table (D-2). Note that these are typical figures, which represent “good combustion practice”.

Table (D-2) Excess Air Requirements According to Type of Fuel

| Fuel | Type of furnace or burner | % excess air |
|-------------|----------------------------------|---------------------|
| Mazout | Large boilers (power plant) | 15 – 20 |
| | Typical industrial boilers | 20 – 30 |
| Solar | Heating equipment | 10 – 15 |
| | Industrial boilers | 10 – 15 |
| Natural gas | Register burners | 5 – 10 |
| | Dual-fuel burners | 7 – 12 |
| Bagasse | All types | 25 – 30 |

D-2 Gas Analysis to Determine Excess Air

Gas analysis (measurement of O₂ and/or CO₂) is used to determine the combustion excess air. Knowing O₂ or CO₂, excess air can be directly estimated as follows:

1. Using graphs that are shown in Fig. (D-1). These graphs are direct plotting of calculated O₂ and/or CO₂ when fuel is burned with different excess air levels, assuming CO of 100 ppm. This range of CO in the combustion products is good indication that the combustion is complete.
2. Using the following relations:

$$\% \text{ Excess air} = \left[\frac{\text{O}_2}{21 - \text{O}_2} \right] \times 100$$

$$\% \text{ Excess air} = \left[\frac{\text{CO}_{2,\text{max}}}{\text{CO}_2} - 1 \right] \times 100$$

CO_{2,max} is the theoretical CO₂ % in dry flue gases assuming stoichiometric combustion (zero excess air).

In most electronic gas analyzers O₂ is measured and CO₂ is calculated through the relation:

$$\text{CO}_2 = \text{CO}_{2,\text{max}} \left[1 - \frac{\text{O}_2}{21} \right]$$

Fig (D-1)

D-3 Heat Release Rates

Two heat release rates are used:

1. Volumetric Rate

It is the heat release rate ratio of

$$\frac{\text{Maximum fuel input at boiler rating} \times \text{Higher heating value of fuel}}{\text{m}^3 \text{ of furnace volume}}$$

Recommended guidelines

With oil and gas firing, an appropriate figure for volumetric heat release in the flame tube of fire-tube boiler is up to 1.8 MW/m³ (BS2790 : 1986). This figure is used in the UK and is based on the net furnace volumes only, excluding the volume of the return chamber, and the volume occupied by burner refractory or firing appliances.

In the USA, a slightly different criterion is also used in fire-tube boilers, namely 1.55 MW/m³, but in this case the geometric projection of the furnace dimensions into the return chamber is allowed, which makes the figure about the same as in the UK based upon the actual furnace dimensions.

2. Effective Projected Radiant Surface

It is the ratio of $\frac{\text{Fuel release rate}}{\text{m}^2 \text{ of furnace radiant surface}}$

Recommended guidelines

Heat transfer in the furnace takes place mainly by radiation, where the heat flux (heat flow per unit area) is most intense in the boiler. The peak rate occurs at approximately one furnace diameter downstream from the burner front for oil or gas firing. It can reach a value of 320 kW/m² or even higher, so that high metal temperatures can prevail in this region. The peak heat flux depends on the cross-sectional area of the furnace, which is a function of the diameter, so that to avoid excess values, the permissible heat input to a furnace is related to the diameter. For oil and gas fuel firing the maximum heat input allowed per furnace is 12 MW, based on the net calorific value of the fuel. For inputs greater than these, two or more furnaces must be used. The mean heat flux in the furnace is generally a little over half the peak value, but is considerably more than that which occurs on other parts of the boiler except for the rear tube plate where local convection becomes important at the tube inlets.

The calculation for this guideline is made by taking the fuel heat release rate and dividing it by the furnace area normal to the flame axis. Flame impingement on boiler heating surfaces must be avoided for all firing rates.

Fire-tube boilers because of their compact design, automatic operation, and resultant reduced maintenance have a lower life expectancy in general than do water-tube boilers. Overfiring, rapid starting and cooling and poor water treatment programs affect life estimates.