Egyptian Environmental Affairs Agency (EEAA)

Egyptian Pollution Abatement Project (EPAP)

Inspection Manual For Energy Generating Plants

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1. Introduction

The Egyptian Pollution Abatement Project (EPAP) sponsored by FINNIDA has recently developed sector-specific inspection and monitoring guidelines. Five industrial sectors were selected:

- 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 production.
- Engineering Industry
- Textile Industry.

Inspection characteristics common to all industrial sectors are covered in the General Inspection Manual, GIM, which was developed at an earlier date. EPAP realized that there are other issues common to all sectors and that each deserves 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

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. Inspection activities are linked to the sources of pollution and an inspection checklist is included as a tool for site inspections.

1.2 Organization of the Inspection Manual

The first chapter represents an introduction to the whole project and chapters 2 to 4 deal with the steam generating plants and their environmental impacts. The description of steam 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 impact of pollutants on health and environment, while 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.

The inspection procedures are described in chapters 7 to 9, starting with a brief description of the pre-field visit activities in chapter 7. The inspection tasks for the actual field visit are defined in chapter 8. Chapter 9 is concerned with the post-field visit including inspection report writing, supporting the enforcement case, and following-up the compliance status of the facility.

1.3 Using the Manual

The inspection manual for Energy Generating Plants is not meant to be used alone. Energy Generating Plants are part of the industrial facility and their inspection will usually be part of the inspection of the facility unless a complaint, specific to the operation of those units, is filed or an accident occurs. Therefore, the sector specific manuals will be consulted in conjunction with the cross-cutting manuals and the General Inspection Manual, (GIM EPAP, 2002), that provides details on the inspection objectives and procedures.

Planning for the inspection of energy generating plants includes 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 steam generating plants.

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

The required personnel, tools and equipment depend on the size of the steam generating plants to be inspected. The inspection team leader, in coordination with the inspectorate management, are responsible for assessing the inspection needs.

1.4 Background

Various types of boilers have been developed over the years, the first being the simple cylindrical shell-type boiler, which is 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 at hand.

Because of the variety of boiler systems and boiler types, and the different problems they exhibit, 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.

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 the 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 a 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 heating surfaces.

Annex A-1 presents 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, highly automated plants require having 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)

Boilers 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 mal functioning through preventive maintenance.

2.1.1 Fire-Tube Boiler

In fire-tube boilers, products of combustion, or hot gases, flow through ducts (mostly tubes), which are completely 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. The fire-tube boiler, fig (2.1), 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.

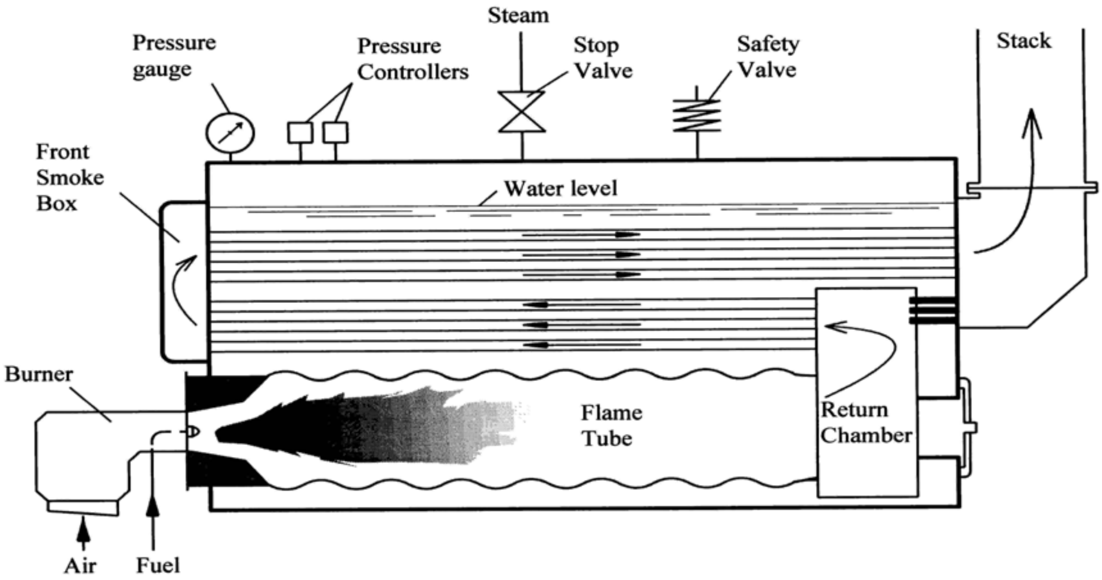


Fig (2.1) Three-P Fire-Tube Boiler

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.

2.1.2 Water-Tube Boilers

In water-tube boiler, 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 bundle of tubes, 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. Boiler water impurities settle at the bottom.

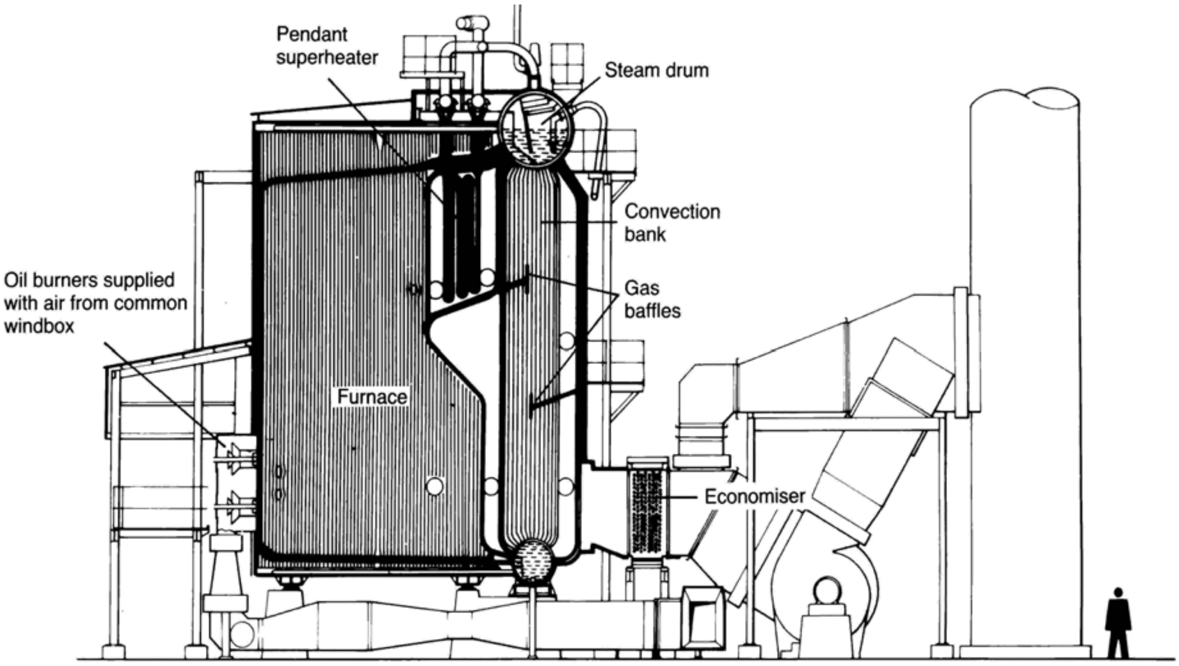


Fig (2.2) Two-Drum Oil- or Gas-Fired Water-Tube Boiler

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).

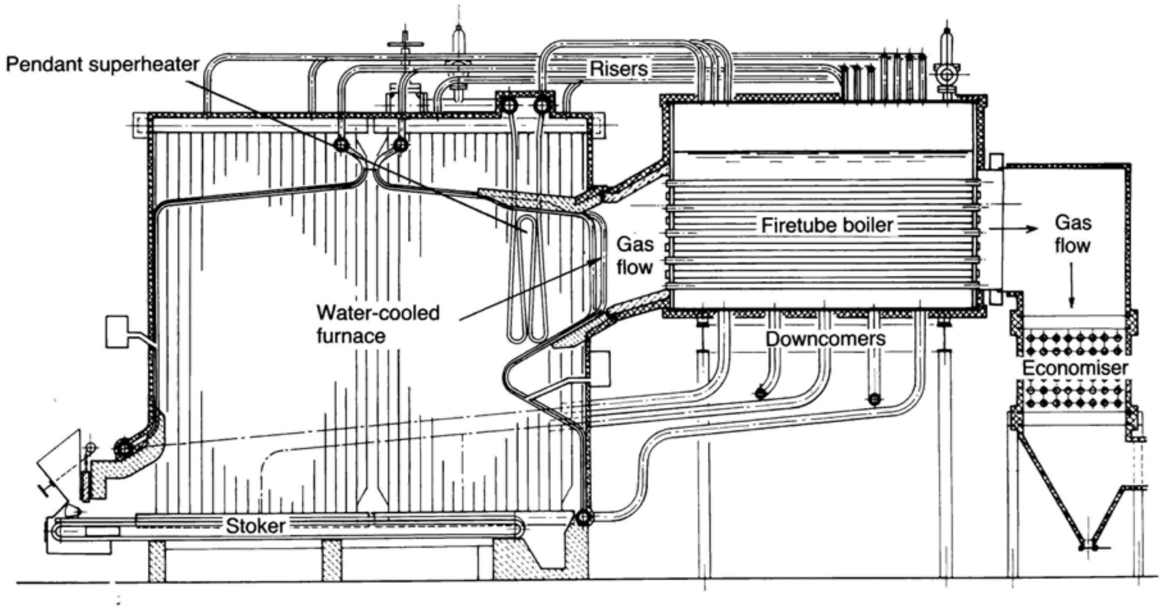


Fig. (2.3) Composite Boiler

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 emission 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 N_2, CO_2 and H_2S. The concentration of H_2S 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, however, 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_2O	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 $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$, 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 $CaCl_2$, $MgCl_2$, $CaSO_4$, $MgSO_4$, $Ca(NO_3)_2$ and $Mg(NO_3)_2$. 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:

$$SO_4^{2-}, Cl^-, NO_3^-, HCO_3^-, \text{ and } CO_3^{2-}.$$

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 (NaCI).

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 deareation. 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, there 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 uncompounded 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.

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.

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 is 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.

In industrial gas turbine units, used two-thirds of the mechanical power developed by the turbine is used for driving the compressor, and a small amount of turbine power for 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.

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 depends on the type of fuel.

Liquid fuels

Fuel is delivered to the plant by tankers (heavy trucks). The fuel is purchased either in tones (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 attached with the proper venting system.

Mazot storage tanks are equipped with the necessary fuel heating system to overcome the high viscosity of the fuel especially in wintertime and facilitate fuel handling.

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 keep 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 to stop pumping the fuel into the daily tank when the level has reached the highest position and start pumping when the level drops below 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	Storage Tank	Fugitive air emission	Leaks and spills	
	Boiler House	VOCs and noise	Leaks and spills	
	Stack	Exhaust gases		
Water Cycle				
Feed water	Pumping Station	Noise		
	Clarification			Sludge
Back wash water	Softening		Back wash	
	Boiler		Blowdown	
	Steam Distribution		Heat and Humidity	

Fig (3.1) (contd) 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		

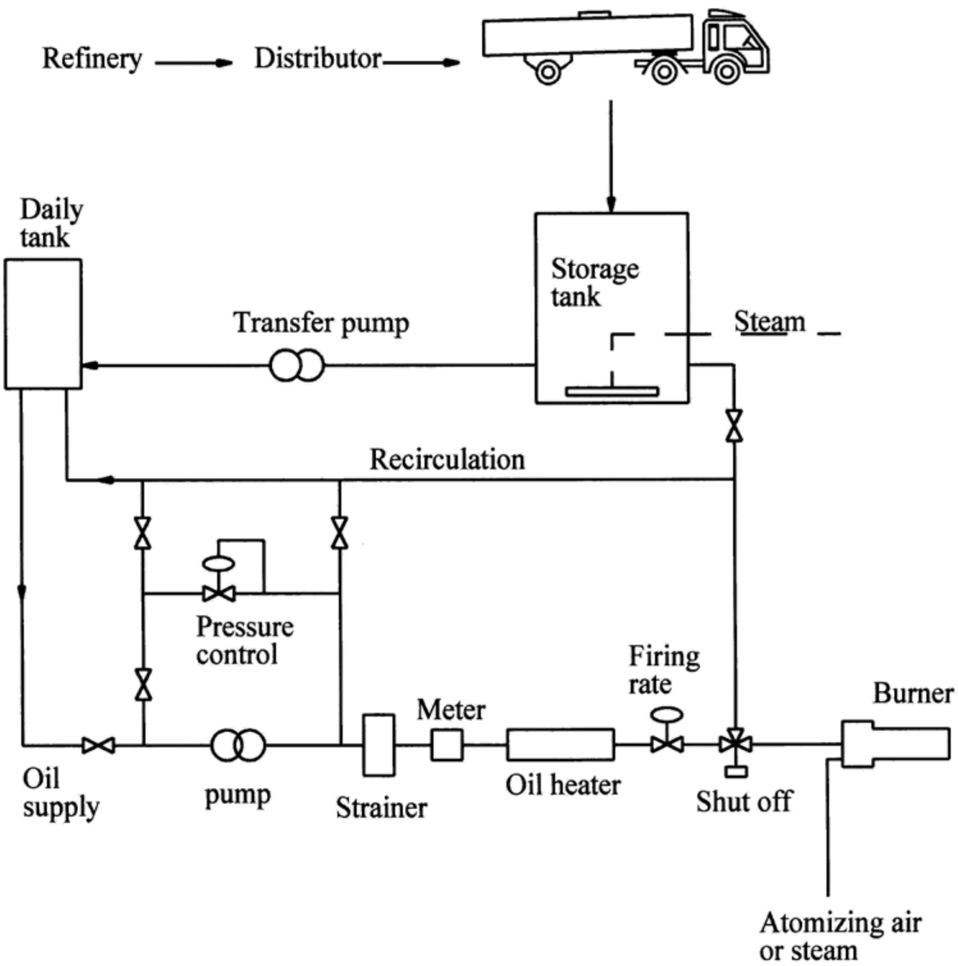


Fig. (3.2) Storage and handling of fuel oil

Natural gas

Natural gas is distributed via 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 admitted to the industrial plant. The primary reducing station belongs to the plant and is located in a safe location inside the enclosure of the plant. The reducing station is equipped with the necessary safety and measuring components such as:

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

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

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

b) Fuel combustion

Combustion is an exothermic (heat releasing) process. The heat released is about 32,800 kJ/kg of carbon burned, and about 142,000 kJ/kg of hydrogen burned. The objective of good combustion is to release all of this heat while minimizing losses 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 ignite all of the combustible constituents in the fuel.

The three above-mentioned points (referred to as three T's) are the physical aspects of the combustion process.
In addition to these 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 mentioned. The chemistry of combustion is presented in Annex (D-1), and heat release rates are given in Annex (D-3).

c) Stack emissions

As seen from the chemistry of combustion of hydrocarbon fuels (Annex D-1), the flue gases contain mainly CO_2, H_2O, N_2, and SO_2. Due to the inevitable use of excess air, excess O_2 also appears in the products. In practice traces of nitrogen oxides such as NO_2, NO, and N_2O are also emitted from the combustion process. Some minor traces of organic gases such as aldehydes might also released with products due the existence of organic matter especially with heavy fuels. The main pollutants from the stack are;

- Sulphur dioxide (SO_2)
- Nitrogen oxides (NO_x)
- Carbon dioxide (CO_2)
- 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, SO_2, NOx, and particulate matter (carbon particles) are measured for the purpose of environmental compliance; other species such as O_2, CO_2, 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 O_2 or CO_2, depending on the chemical compound filling the tester. The O_2 tester is filled with pyrogallol $C_6H_3(OH)_3$, and CO_2 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 (± 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 O_2 is ± 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 CO_2, 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.

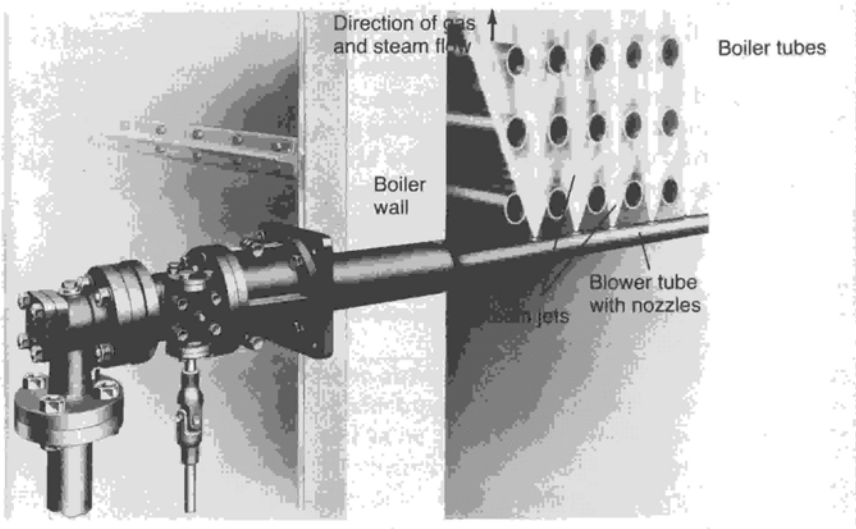
Infrared gas analyzers

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 N_2. 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 is to be determined; thus 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, winch 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.

d) Soot blowing

To ensure that the performance and thermal efficiency of a boiler are maintained it is essential that the heated surfaces are maintained 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 reduce and the gas temperatures will rise. On most solid-fuel fired boilers and, dependent upon the 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. Fig (3.3) displays multi-nozzle rotary



sootblower.

The use of sootblowers applies mainly to water-tube boilers, where regular on-load cleaning is essential. In most cases firetube 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

Fig. (3.3) Multi-nozzle rotary sootblower

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.

3.1.2. The Water Cycle

The water cycle starts from 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 water 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 case of 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. Environmental and Health Impacts of the Emissions and Effluents of Different Stages

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:

a) 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 2.5µm ($PM_{2.5}$) and 10µm (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.

b) 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.

c) 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 (NO_2) is readily soluble in water, forming nitric acid and either nitrous acid or nitric oxide, as indicated in the following equations:

$2\ NO_2 + H_2O \longrightarrow HNO_3 + HNO_2$

(Nitrous acid)

$3\ NO_2 + H_2O \longrightarrow 2\ HNO_3 + NO$

(Nitric oxide)

Both nitric and nitrous acid will dissolve in the rain or combine with ammonia (NH_3) in the atmosphere to form ammonium nitrate (NH_4NO_3). In this instance, the NO_2 will produce a plant nutrient. A good absorber of energy in the ultraviolet range, NO_2 consequently plays a major role in the production of secondary air contaminants such as ozone (O_3).
Nitric oxide (NO) is emitted to the atmosphere in much larger quantities than NO_2. It is formed in high-temperature combustion processes when atmospheric oxygen and nitrogen combine according to the following reaction:

$N_2 + O_2 \longrightarrow 2\ NO$

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/m^3 (1 ppm) in the ambient air, and are thus not considered health hazards. However, NO is readily oxidized to NO_2, which does have biological significance.

$NO + ½\ O_2 \longrightarrow NO_2$

NO_2 irritates the alveoli of the lungs.

d) 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.

e) 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 deaeratorsto 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:

a) 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.
b) Nitrogen, Phosphorus	At high levels, these stimulate growth of algae and seaweed, increasing eutrophication and oxygen depletion.
c) 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 Wastes

Solid wastes generated by energy generating plants includes

- Clarifier sludge
- Chemicals containers
- Particulate matter separated from flue gases by ESP (elctrostatic 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 NOx. 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/1 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/m³**	**ppm**	**mg/m³**
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) of 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 O_2 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-NOx 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 propability 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 O_2 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 SOx 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 PM_{10}. 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. Inspection Pre-Field Visit Activities

As presented in the (GIM EPAP, 2002), tasks necessary for preparation for field inspection, are:

- Gathering information about the specific facility to be inspected.
- Preparing the inspection plan.
- Preparing the checklists.

7.1 Gathering and Reviewing Information

The inspection team should review the general information presented in chapters 3 and 4 then check, if possible, the type of boilers present at the facility and their capacity, fuel type and consumption rate. It is also important at this stage to determine the following:

- The type of receiving body for the industrial wastewater, and review relevant Egyptian laws.
- The scope of inspection (complaint or part of facility inspection) and related activities based on the type and objectives of inspection required by the inspectorate management.
- The potential pollution hazards and, accordingly, define measurement and analyses needs.
- The characteristics of steam generating plants and their implications on the inspection process.

7.2 Preparation of the Inspection Plan

The plan should take into account the following:

- At the beginning of the field visit, the inspection team should check the environmental register for completeness using the checklist provided in Annex (g) of the General Inspection Manual (GIM EPAP, 2002).
- The results of the analyses included in the environmental register should be checked at the end of the field visit (if suspicion arises about them) and copies of these results should be obtained.

7.3 Preparation of the Required Checklists

The checklist for the energy generating plants is presented in Annex 1 of this manual. The development of the checklists goes through the following steps:

- Draw the block flow diagrams for the steam generating plants with their pollution sources as presented in table.
- Identify the areas of possible non-compliance and the parameters that need checking. For example, noise

should be checked near the compressors and temperature and humidity where steam leaks occur.

- Identify what to observe, ask and/or estimate what can convey information about pollutants.

8. Performing the Field Inspection

8.1 Starting the Field Visit

The General Inspection Manual, (GIM EPAP, 2002) describes the procedures involved for entering an industrial facility, whether the inspection of the steam generating plant is part of the facility inspection or whether it is triggered by complaint or accident. The inspector's attitude and behavior are very important from the start, and will dictate the factory's personnel response to the inspection tasks.

8.2 Proceeding with the Field Visit

Information gathered during the facility tour is dependent on interviews of facility personnel and visual observation. Annex (H) in the General Inspection Manual, (GIM EPAP, 2002) presents some useful interviewing techniques.

8.2.1 Inspecting Steam Generating Plants

The Fuel Line
- Check the height of the chimney in relation to surrounding buildings. - Check the type of fuel, if it is mazot, check the type of surrounding area. - Check for fuel storage regulations and spill prevention measures. - Notice the presence of any fugitive emissions in the surface storage tanks, or leaks in underground reservoirs. - Check for the combustion efficiency and (fuel/ air) ratio. - Check the maintenance schedule for the boiler, and the date of the last maintenance procedure. - Notice the presence of any unsafe features (e.g. corrosion). - Check the environmental register for noise and heat stress measurements around the boiler. - Check the insulation of boiler and steam lines. - Notice the color of the exhaust gases from the stack. - Perform flue gas analysis if mazot is used as fuel, or if suspicious about results of analysis presented by facility management in the opening meeting.
The Water Line
- If chemicals and coagulants, such as lime, alum and ferric sulfate, are used, inorganic sludge will be generated. Check the amount and method of disposal.

	- Check the noise measurements at the pumping station of the water intake. - In case of ion exchange units and reverse osmosis, the effluent wastewater will be high in dissolved solids. - Check the use of sulfuric acid and caustic soda for ion exchange regeneration; take note of the safety measures for their storage, handling and use. - Check the use of chemicals for internal water treatment. - If hazardous chemicals (e. g. hydrazine, amines, sodium sulfite ...etc) are used for internal water treatment, then check the safety of their storage, handling and use. - When hazardous materials are used for internal water treatment, check if there are any direct heating with the steam (in case of food processing and similar industries). - Blowdown from the boiler is high in TDS. - Check if there is any steam condensate recycling.

8.2.2 Inspecting Diesel Generators

The Fuel Line	
	- Check the height of the chimney in relation to surrounding buildings. - Check for fuel storage regulations and spill prevention measures. - Notice the presence of any fugitive emissions in the surface storage tanks - Check for the presence of dike around the storage tank to hold the tank content - Check for combustion efficiency and (fuel/ air) ratio. - Check the maintenance schedule for the diesel engine, and the date of the last maintenance procedure. - Notice the presence of any unsafe manifestation (e.g. corrosion). - Notice the color of the exhaust gases from the stack. - Perform flue gas analysis, or if suspicious about results of analysis presented by facility management in the opening meeting. - Check the noise measurements of the air intake system.
The Water Line	
	- Check amount of cooling water - Check characteristics of spent cooling water in once through cooling (temp, O&G)

	- If cooling water is recycled in cooling towers, check the addition of chemicals and the amount of blowdown

8.2.3 Inspecting Gas Turbines

The Fuel line	
	- Check the height of the chimney in relation to surrounding buildings. - Check the type of fuel. If it is mazot, check the type of surrounding area. - Check for fuel storage regulations and spill prevention measures. - Note the presence of any fugitive emissions in surface storage tanks, or leaks in underground reservoirs. - Check for combustion efficiency and (fuel/ air) ratio. - Check the maintenance schedule for the gas turbine plant, and the date of the last maintenance procedure. - Note the presence of any unsafe features (e.g. corrosion due to the presence of sodium or vanadium in the fuel oil). - Check the environmental register for noise surrounding the gas turbine plant. - Note the color of the exhaust gases from the stack. - Perform flue gas analysis if mazot is used as fuel, or if suspicious about results of analysis presented by facility management in the opening meeting.

8.3 Concluding the Field Visit

When violations are detected, a legal report is prepared stating information pertaining to sampling location and time. Violations of work environment regulations should also state location and time of measurements. Other visual violations, such as solid waste accumulation, hazardous material, waste handling and storage, and material spills, should be photographed and documented. It is preferable that facility management signs the field-inspection report, but this is not a necessary procedure. A closing meeting with the facility management can be held to discuss findings and observations.

Note to inspector:

The less certain the team leader is about a specific violation, the more reason not to discuss it at the closing meeting.

9. Conclusion of the Field Inspection

The activities performed during the site inspection are essential for the following: preparation of the inspection report; assessing the seriousness of the violations; pursuing a criminal or civil suit against the facility; presenting the legal case and making it stand in court without being contested; and further follow-up of the compliance status of the facility.

9.1 Preparing the Inspection Report

An example of an inspection report is included in Annex (K) of the General Inspection Manual, (GIM EPAP, 2002). The inspection report presents the findings, conclusions, recommendations and supporting information in an organized manner. It provides the inspectorate management with the basis for proposing enforcement measures and follow-up activities.

9.2 Supporting the Enforcement Case

Many issues may be raised and disputed in typical enforcement actions. Enforcement officials should always be prepared to:

- Prove that a violation has occurred. The inspector must provide information that can be used as evidence in a court of law.
- Establish that the procedures were fairly followed.
- Demonstrate the effect of the violating parameter on health environment.

> ***Note to inspectorate management:***
>
> - *Although the inspector is not required to suggest pollution abatement measures, the inspectorate management should be able to demonstrate that a remedy for the violation is available.*
> - *Enforcement should not cause financial collapse of the facility and inspectorate management should demonstrate the ability of the violator to pay.*

9.3 Following-Up Compliance Status of Violating Facility

After performing the comprehensive inspection and detecting the violations, the inspectorate management should:

- Decide on the sanctions and send the legal report to the judicial authority.
- Plan routine follow-up inspections. This type of inspection focuses on the violating source and its related pollution abatement measure. Self-monitoring results are reviewed during the visit.
- Follow-up the enforcement case (legal department).

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Annexes

Annex A

Basic Definitions

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 m^3) 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℉ (120℃). 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℉ (11 bar or 120℃).

- ***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 ℃ 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 ℃ 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/cm^2 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 ▯ . 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

Annex B

Calculating Minimum Stack Height

All early boilers met the total draft requirement with the natural draft supplied by the stack effect. However, for industrial and larger units equipped with superheaters, economizers and especially air heaters, it is neither practical, nor economical, to draft the entire unit from stack induced draft only. These units require fans in addition to the stack in three typical types of draft, namely:

1. The entire unit is under pressure that is supplied by a forced draft fan or,
2. Using both induced and forced-draft fans are used for balanced draft operation,
3. A combination of induced-draft fan and stack is used (this is not a commonly used operation condition).
4. The required height and diameter of stacks for natural draft units depend on the following technical factors:
    - Draft loss through the boiler from the point of balanced draft to the stack entrance;
    - Temperature of the gases entering to the stack and the temperature of the surrounding air;
    - Required gas flow from the stack; and
    - 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 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 ½) 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. A boiler with this typical capacity usually has an efficiency of 0.85 based on gross heating value; the expected amount of fuel burned is approximately 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, $\dot{m}_{gases} = \dot{m}_{fuel}\left(1 + \frac{A}{F}\right) = 13650 \text{ kg/hr}$
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 equation, 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 ½ times the height of surrounding buildings, including the building served by the chimney.

Annex C
Recommended Water Quality

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**

		Notes
Total hardness, mg/l expressed as $CaCO_3$	2 – 40	(2)
Oxygen		(3)
Total solids, alkalinity, silica		(4)
pH	7.5 – 9.5	

- **Boiler Water**

Total hardness, mg/l expressed as $CaCO_3$	Not detected
Tri-sodium phosphate, mg/l as Na_3PO_4	50 – 100
Caustic alkalinity, mg/l as $CaCO_3$	350 – 200
Total alkalinity, mg/l 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_2SO_3 or	30 – 70
Hydrazine as N_2H_4	0.1 – 1.0
Suspended solids, mg/l max.	50 – 300
Dissolved solids, mg/l 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/l expressed as $CaCO_3$	10	0.5	ND
Oxygen	0.05	0.01	0.001
Iron + copper + nickel, mg/l 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/l expressed as $CaCO_3$			
Tri-sodium phosphate, mg/l as Na_3PO_4	50 – 100	20 – 50	0 – 3
Caustic alkalinity, mg/l as $CaCO_3$	300	60	5
Total alkalinity, mg/l as $CaCO_3$	700	300	40
Silica, mg/l as SiO_2, max.	Less than 0.4 of caustic alkalinity	20	2
Sodium sulfite, mg/l as Na_2SO_3 or	30 – 50	15 – 30	None
Hydrazine [(1)] as N_2H_4	0.1 – 1.0	0.05 – 0.3	—
Suspended solids [(2)], mg/l max.	200	minimize	Minimize
Dissolved solids, mg/l max.	3000	1200	100

Chloride, mg/lit Cl^- max.	—	—	5

- **Notes**

  (1) Hydrazine decomposes in 120 bar boilers. Residue cannot be measured; therefore 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/l.

Annex D

Chemistry of Combustion

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 CH_4 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
$CH_4 + 2 O_2 \rightarrow CO_2 + 2 H_2O$
Multiplying through by 0.9385
$0.9385 CH_4 + 1.877 O_2 \rightarrow 0.9385 CO_2 + 1.877 H_2O$

• Ethane 2.23 %
$C_2H_6 + 3.5 O_2 \rightarrow 2 C O_2 + 3 H_2O$
Multiply through by 0.029
$0.0323 C_2H_6 + 0.11305 O_2 \rightarrow 0.0646 CO_2 + 0.0969 H_2O$

• Propane 1.22 %
$C_3H_8 + 5 O_2 \rightarrow 3 CO_2 + 4 H_2O$
Multiply through by 0.004
$0.0122 C_3H_8 + 0.061 O_2 \rightarrow 0.0366 CO_2 + 0.0488 H_2O$

• Butane 0.5 %
$C_4H_{10} + 6.5 O_2 \rightarrow 4 CO_2 + 5 H_2O$
Multiply through by 0.002
$0.005 C_4H_{10} + 0.0325 O_2 \rightarrow 0.02 CO_2 + 0.025 H_2O$

• Pentane 0.3 %
$C_5H_{12} + 8 O_2 \rightarrow 5 CO_2 + 6 H_2O$
Multiply through by 0.001
$0.003 C_5H_{12} + 0.024 O_2 \rightarrow 0.015 CO_2 + 0.018 H_2O$

• Hydrogen sulfide 0.2 %
$H_2S + 1.5 O_2 \rightarrow SO_2 + H_2O$
Multiply through by 0.002
$0.002 H_2S + 0.003 O_2 \rightarrow 0.002 SO_2 + 0.002 H_2O$

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 kmoles of O2 are required to burn 1 kmole of the considered gas fuel.

The corresponding stoichiometric volume of air is

$$2.11055 \times \frac{100}{21} = 10.05 \qquad \text{kmoles of air}$$

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

The volumetric air-fuel ratio is =

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

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

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:

$C + O_2 = CO_2$

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

12 kg of C + 32 kg of O_2 = 44 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 kg of C + 2.293 kg of O_2 = 3.153 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 H_2 / kg of fuel,

$H_2 + ½O_2 = H_2O$

2 kg of H_2 + 16 kg of O_2 = 18 kg of H_2O

Multiplying through by (0.105/2)

0.105 kg of H_2 + 0.84 kg of O_2 = 0.945 kg of H_2O

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

$S + O_2 = SO_2$

32 kg of S + 32 kg of O_2 = 64 kg of SO_2

Multiplying through by (0.03/32)

0.03 kg of S + 0.03 kg of O2 = 0.06 kg of SO2
The mass of stoichiometric oxygen required for burning 1 kg of fuel is, therefore,
(2.293 + 0.84 + 0.03) – 0.0005 = 3.1625 kg O2/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,

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

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:

$$\left.\frac{A}{F}\right)_{actual} = 17.181 \times 1.1 = 18.8995 \qquad \text{kg air / kg fuel}$$

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:

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

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 O_2 and/or CO_2 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:

$$\%\ \text{Excess air} = \left[\frac{O_2}{21 - O_2}\right] \times 100$$

$$\%\ \text{Excess air} = \left[\frac{CO_{2,max}}{CO_2} - 1\right] \times 100$$

$CO_{2,max}$ is the theoretical $CO_2\,\%$ 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:

$$CO_2 = CO_{2,max}\left[1 - \frac{O_2}{21}\right]$$

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.

Annex E

Checklist for Energy Generating Plants

Information about the inspection process

Date and time of inspection	--
Facility name and address	-- -- --
Contact person at the facility	Name --- Title --- Phone ---

Inspection team	**Name**	**Title/affiliation**	**Phone number**
Team leader	--------------------------------------	-----------------------------	-----------------------
Inspector	--------------------------------------	-----------------------------	-----------------------
Inspector	--------------------------------------	-----------------------------	-----------------------
Inspector	--------------------------------------	-----------------------------	-----------------------
Lab specialist	--------------------------------------	-----------------------------	-----------------------

General Information about the facility

1.	Year of start of operation	---
2.	Final receiving body for industrial wastewater	---
3.	Law relevant to receiving body	---
4.	Number of final discharge points	---
5.	In case of more than one discharge point, note which disposal point is used for discharging effluents from steam generating plant.	--- ---

Information about operation

1	Inputs	Rate t/d	2	Product	Rate t/d
	Fuel	-------------		Generated Steam	-------------
	Alum	-------------			
	Lime	-------------			
	Ferric Sulfate	-------------			
	Hydrazine	-------------			
	Amine	-------------			
	Sodium Carbonate	-------------			
	Caustic Soda	-------------			
	Phosphate	-------------			
	Anti-foams	-------------			
	Sodium Sulfite	-------------			
	Sulfuric Acid	-------------			
3	Manpower:	-------------	4.	No. of shifts/day	-------------
5.	Amount of wastewater generated	-------------	6.	Type of feed water used	-------------
7.	Electricity source	Public Network	☐	Generated in facility	☐

Annex E

Energy Generating Plants

1- Steam Boilers

Checklist for Fuel Line (Boilers)

1. General	
1.1 Number of boilers and capacities.	-- -- -- -- --
1.2 Type of fuel used for boilers	☐ Mazot ☐ Solar ☐ Natural gas ☐ Kerosene ☐ Other
1.3 Nature of surrounding area	☐ Residential ☐ Agricultural ☐ Industrial
1.4 Type and capacity of fuel storage tank	☐ Over ground ☐ Underground
1.5 Are there any leaks	☐ Yes ☐ No
1.6 Emergency measures in case of leaks or spills	☐ Exist ☐ Do not exsist
1.7 Periodical maintenance records	☐ Available ☐ Not available
2. Status of the Air Pollution	
2.1 Numbers and heights of stacks	-- -- --
Note: The height of stack must be 2.5 times the height of the adjacent buildings	
2.2 Available monitoring data	☐ SO_2 ☐ CO ☐ CO_2 ☐ Particulates ☐ NO_x ☐ None
2.3 Do you smell VOCs generated as fugitive emissions from the fuel storage tanks, fuel pipes or fittings	☐ Yes ☐ No
2.4 Are there any records for monitoring fuel/ air ratio? If no, perform analysis	☐ Yes ☐ No
2.5 Do you notice black smoke coming out with the exhaust gases from the boilers stacks	☐ Yes ☐ No

3. Status of the Work Environment	
3.1 Availability of noise and heat stress measuerements	☐ Available ☐ Not available
3.2 Availability of safety measures in case of using hazardous materials for internal treatment	---
3.3 Check VOCs in the boiler house	---
4. Status of Hazardous Materials	
4.1 Do you notice anything that can provoke a fire, such as a pump underneath the fuel tank? (the start-up of the engine can produce spark)	☐ Yes ☐ No Comment --- ---

Checklist for Water Cycle (Boilers)

1. General	
1.1 Source of water used for boiler	--
1.2 Method of water treatment	☐ Clarification ☐ Lime process ☐ Filtration ☐ Reverse osmosis ☐ Ion exchange
1.3 Chemicals used for backwash:	☐ Sulfuric Acid ☐ Sodium Chloride ☐ Caustic Soda ☐ Others, specify
1.4 Chemicals used for internal treatment, m^3/d	☐ Hydrazine ☐ Amine ☐ Phosphate ☐ Sodium Sulfite ☐ Sodium Sulfate ☐ Sodium Carbonate ☐ Anti Foams
1.5 Availability of steam condensate recycling	☐ Available ☐ Not available
2. Statuse of Effluent	
2.1 Rate of softeners backwash, m^3/d	--
2.2 Rate of the boiler blowdown, m^3/d	--
2.3 Type of receiving body for the softeners backwash wastewater	--
2.4 Type of receiving body for the boiler blowdown	--
3. Status of Solid Wastes	
3.1 Rate of sludge generated from backwash	--
3.2 Method of disposal of backwash sludge	--
3.3 Amount of sludge generated from water treatment	--
3.4 Method of disposal of water treatment sludge	--
4. Status of Hazardous Materials	
4.1 Check the storage of hazardous materials used in water treatment. Does it comply law 4/ 1994?	☐ Yes ☐ No
4.2 Disposal method of the empty containers for the hazardous materials	--

Energy Generating Plants
2- Diesel Engines

Checklist for Fuel Line (Diesel Engine)

1. General	
1.1 What is the amount of diesel fuel used per day/month?	………………………………………………
1.2 Type and capacity of fuel storage tank	☐ Over ground ☐ Underground
1.3 Are there any leaks	☐ Yes ☐ No
1.4 Emergency measures in case of leaks or spills	☐ Exist ☐ Do not exsist
1.5 Periodical maintenance records	☐ Available ☐ Not available
1.6 What happens to the spent lube oil?	---
2. Status of the Air Pollution	
2.1 Numbers and heights of stacks	--- --- ---
Note: The height of stack must be 2.5 times the height of the adjacent buildings	
2.2 Available monitoring data	☐ SO_2 ☐ CO ☐ CO_2 ☐ Particulates ☐ NO_x ☐ None
2.3 Do you smell VOCs generated as fugitive emissions from the fuel storage tanks, fuel pipes or fittings	☐ Yes ☐ No
2.4 Are there any records for monitoring fuel/ air ratio? If no, perform analysis	☐ Yes ☐ No
2.5 Do you notice black smoke coming out with the exhaust gases from the boilers stacks	☐ Yes ☐ No
3. Status of the Work Environment	
3.1 Availability of noise and heat stress measuerements	☐ Available ☐ Not available
3.2 Check for VOCs near the storage tank	---
4. Status of Hazardous Materials	
4.1 Do you notice anything that can provoke a fire, such as pump underneath the fuel tank? (the start-up of the engine can produce spark)	☐ Yes ☐ No Comment ---

Checklist for Water Cycle (Diesel Engine)

1. General	
1.1 Source of water used	---
1.2 Method of water treatment	☐ Clarification ☐ Lime process ☐ Filtration ☐ Reverse osmosis ☐ Ion exchange
1.3 What is the chemicals used for treating water?	………………………………………………………..
2. Statuse of Effluent	
2.1 Rate of the cooling water blowdown, m^3/d	---
2.2 Type of receiving body for the softeners backwash wastewater	---
3. Status of Solid Wastes	
3.1 Rate of sludge generated from backwash	---
3.2 Method of disposal of backwash sludge	---
3.3 Amount of sludge generated from water treatment	---
3.4 Method of disposal of water treatment sludge	---

Energy Generating Plants
3- Gas Turbine Engines

Checklist for Fuel Line (Gas Turbine Engins)

1. General		
1.1 Type of fuel used for boilers	☐ Mazot ☐ Natural gas ☐ Other	☐ Solar ☐ Kerosene
1.2 Nature of surrounding area	☐ Residential ☐ Industrial	☐ Agricultural
1.3 Type and capacity of fuel storage tank	☐ Over ground	☐ Underground
1.4 Are there any leaks	☐ Yes	☐ No
1.5 Emergency measures in case of leaks or spills	☐ Exist	☐ Do not exsist
1.6 Periodical maintenance records	☐ Available	☐ Not available
1.7 What happens to the spent lube oil?	…………………………………	
2. Status of the Air Pollution		
2.1 Numbers and heights of stacks	-- -- --	
Note: The height of stack must be 2.5 times the height of the adjacent buildings		
2.2 Available monitoring data	☐ SO_2 ☐ CO_2 ☐ NO_x	☐ CO ☐ Particulates ☐ None
2.3 Do you smell VOCs generated as fugitive emissions from the fuel storage tanks, fuel pipes or fittings	☐ Yes	☐ No
2.4 Are there any records for monitoring fuel/ air ratio? If no, perform analysis	☐ Yes	☐ No
2.5 Do you notice black smoke coming out with the exhaust gases from the boilers stacks	☐ Yes	☐ No
3. Status of the Work Environment		
3.1 Availability of noise and heat stress measuerements	☐ Available	☐ Not available

3.2 Check VOCs near the storage tank	--
4. Status of Hazardous Materials	
4.1 Do you notice anything that can provoke a fire, such as a pump underneath the fuel tank? (the start-up of the engine can produce spark)	☐ Yes ☐ No Comment -- --