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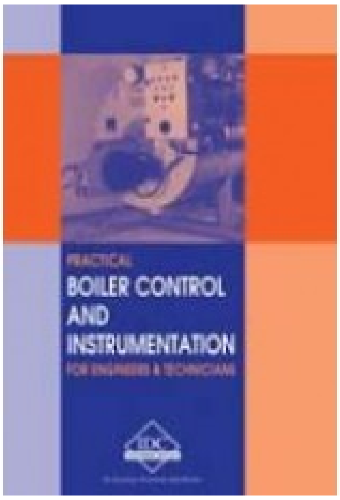
Phone: +61 8 9321 1702 - Email: books@idc-online.com

BI-E - Practical Boiler Control and Instrumentation for Engineers and Technicians



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Short Description

This manual introduces the basic practices of controls systems and safety controls for industrial steam generating boilers. It focuses on the control and safety requirements applicable to most types of boilers from small gas-fired units to large multi-fuel installations. This manual will provide training in how control and instrumentation is designed to manage the main variables such as drum water level, furnace draft, combustion fuel and air conditions.

Description

This manual introduces the basic practices of controls systems and safety controls for industrial steam generating boilers. It focuses on the control and safety requirements applicable to most types of boilers from small gas-fired units to large multi-fuel installations. This manual will provide training in how control and instrumentation is designed to manage the main variables such as drum water level, furnace draft, combustion fuel and air conditions.

Burner management systems are introduced with their principal features including flame safety systems. The essential safety requirements for boilers and burners are identified and the corresponding safety interlocks are explained as practical solutions in accordance with the latest safety standards.

Table of Contents
Download Chapter List

Table of Contents

First Chapter
Practical Boiler Control and Instrumentation for Engineers and Technicians - An introduction to Boiler Controls

1 Introduction to Boiler Controls

This chapter reviews the scope and objectives of boiler control systems as applied to industrial boilers ranging from small packaged units to large custom built types. It presents a simplified view of the combustion and steam generating processes of relevance to control engineers. The hazards of boiler operations are summarized as first stage in the training for knowledge of safety controls. Finally the main control functions are introduced for background to the succeeding chapter.

Learning Objectives:

- To achieve a first level understanding of boiler types and their processes
- To recognize the main operational and safety requirements of boilers
- To know the basic control functions and be able to present them in block diagram form to support the tasks of design, setting up, commissioning and maintenance.
- To be aware of the principal hazards of boilers and learn how trips and interlocks provide protection against hazardous event.

1.1 Objectives of boiler controls

The overall objectives of boiler controls are to ensure that the performance requirements of the boiler installation are met at all times in a safe and efficient manner. The requirements will of course vary according to the purpose of the boiler installation. These purposes may be to drive turbines for electrical power or for compressors in a chemical process or they may be for general heat energy supplies to a process.

The control objective is usually to manage the operating conditions of the boiler such that the steam or hot water supply is provided on specification in required quantities with a reasonable speed of response and without wastage of energy.

This objective requires a wide range of supporting activities, many of which fall under the scope of duties for the control and instrumentation engineers and technicians. These objectives and activities are mapped out in Figure 1.1

Figure 1.1

Key objectives and performance indicators for boiler control systems

Figure 1.1 shows three key objectives for boiler control systems activities with typical subjects in each area.

Safety: Boilers present a considerable level of risk to persons because they handle combustible fuels and generate hot gases as well storing vast amounts of energy in the steam system. Control and Instrument engineers carry a large share of the responsibility for making a boiler installation safe through the provision of safety interlocks, alarms and trips. The primary safety functions served by instrumentation are:

- Protection against high and low water levels
- High steam pressure protection
- Protection against super heater overheating
- Furnace draft protection, high and low.
- Furnace explosion protection including fuel/air mixture limit conditions, start up sequencing interlocks, and flame out trips

Availability: It is easy to see that the plant or business management looks for a highly available supply of steam at the correct pressure and temperature conditions. The control system contributes to this by ensuring that the boiler can be controlled at all times within its operating limits. We are looking fpr

- Reliable sensing instruments
- Reliable control equipment
- Robust control loop designs that remain stable and are easy to supervise
- Avoidance of safety trip conditions.

Performance: Its not enough to have stable and safe control of the boiler. The costs of steam production are a major item in any production process or as a utility in heating services. Stability of controls and ease of operation are essential for efficient operation of the boiler and are critical to the manning requirements. A fully automatic boiler station encourages very low manning levels and business will look for unmanned operation wherever this practicable and safe.

Boiler plant managers will always strive to achieve the best possible operating efficiencies for their plant. Efficiencies will come from operating the boiler at its most efficient conditions through optimizing the fuel and energy inputs needed to meet the steam demand at any given load. Boiler controls provide the means to achieve these efficiencies through trimming for optimal conditions as well as through load following control strategies.

Unlike typical process control applications in the chemicals and oil industries boilers present an opportunity to very carefully match control actions to the individual characteristics of each boiler. There is considerable reward to had from good tuning and characterization of the

The C&I team has a major role to play all the above areas and hence we see the scope of the workshop should provide some training and support to the subjects seen in the diagram

1.2 Boiler processes

The job of a boiler is to generate steam in the correct condition through the combustion of various types of fuel. Hence we can represent the essential process as a block flow diagram with two major processes known as waterside systems and fireside systems.

Figure 1.2

Elementary model for the boiler process

Figure 1.2 shows that the waterside consists of feedwater into the boiler where it is heated and converted into steam. The generation of steam requires vast amounts of heat, which of course must be produced by the combustion of fuel and air in a furnace supported by a flue gas extraction system that will draw the hot gases over the heating surfaces of the water system before it takes the flue gases away. This is the fireside system. The really difficult part for the boiler designer is to arrange for:

- Efficient heat transfer between the fireside and the waterside.
- Safe containment of the water/steam circuits under high pressure.
- Safe and complete combustion of fuels

- Maximum utilization of the heat energy of the fuel for the generation of steam. (There is no value in heating the atmosphere or putting unburned fuel into the ash pit)

This task has challenged boiler designers over the past 200 years along with the need to find steam systems that can deliver steam at high pressures and at high superheat temperatures as needed for power generation through steam turbines.. This had led to the development of various boiler types arranged according to size and performance requirements and we shall look briefly at the main types in a moment. But from a control system point of view the basic features of the processes are generally common to most types of boiler. So in general we can work with block diagrams to describe the processes that we must understand well enough to be able to develop and operate the control systems.

As a first step we can expand the basic process diagram to reveal more of the essential processes as seen in Figure 1.3.

Figure 1.3

Expanded model for the boiler process

In figure 1.3 you can see some of the common components of a typical industrial boiler arranged by function although their physical positioning is of course much different.

Water/steam system: On the water side the feedwater is preheated by the flues gases leaving the steam generation (or evaporation stage). Feedwater then enters the boiler water system usually at the boiler drum where it is heated by the hot flue gases to generate the steam. When superheating is included the steam from the boiler drum passes through super heater tube assemblies mounted in the parts of the furnace where radiant heat and hot flue gases will transfer heat into them. A typical de-super heater spray point is shown where the temperature of the steam is controlled by cooling before the final super heater tubes.

The steam generation process requires that heat be transferred into the water for heating, evaporation (conversion to steam) and superheating. The diagram in figure 1.4 gives an approximate indication of the heat conversion distribution in a typical water tube boiler process. The amounts of heat required for each phase per kilogram of steam depends on the specific enthalpy of water or steam at the required conditions. Specific enthalpy is the measure of heat stored per unit of substance. In this case: kJ/kg or BTUs/lbm of water or steam. (1 Btu/lbm = 2.326 kJ/kg). At low steam pressures the heat required for evaporation forms the major part of the heat load taken from the furnace. As pressure rises the evaporative duty forms a smaller proportion of the heat load whilst the water and steam heating load increases. This means that boilers designed for specific operating pressure will exhibit a different heat distribution ratio between evaporation and superheating when operating at a different pressure.

Figure 1.4

Heat input requirements for steam generation at atmospheric pressure

Furnace/combustion system: On the fireside, the diagram identifies a forced draft fan to drive air into the furnace and provide fuel-mixing energy before the combustion stage. The furnace space provides time, temperature and turbulence to enable complete combustion to take place provided enough air has been supplied. The combustion product gases (flue gases) then flow over the heat transfer surfaces to give up much of their heat before reaching the Induced Draft (ID) Fan and being discharged to atmosphere. The last heat exchange stage is an air pre-heater which recycles some of the low-grade (i.e. low temperature) heat in the flue gases into the combustion air feed.

Boiler processes are highly interactive: Whilst the process block diagram in Figure 1.4 is a highly simplified representation of the boiler process it does serve to remind us that for the purposes of building effective control systems it must be recognized that the process variables are highly interactive, i.e. if you change one variable in the process it will affect several others.

This means that most control loops in a boiler have a complex response to a corrective action and these factors must be allowed for when setting up measurements and control functions. The simplest way to show these interactions is to draw up an input/output model to show cause and effect. Figure 1.5 shows how some of the basic variables in a boiler are influenced by each other. Later on we can use this simple type of modeling to assist with the design of control functions. Bear in mind that this model only shows directions of influence and does not show the time responses involved, these are the process dynamics that we shall be learning about later.

Figure 1.5

Example of interaction of variables in the boiler process

Figure 1.5 shows typical interactions without the presence of any controller actions. Imagine that the boiler is operating in steady state conditions but all controls are frozen.

- If we demand more steam flow from the boiler the model shows, as you would expect, that the pressure would fall.
- The steam temperature will also fall because more steam is passing through the super heater for the same heat flux,
- and the water inventory in the boiler will fall as we use the water.
- but the water level will rise initially because the pressure has fallen and more team bubbles have occurred in the water. (imagine a Coke bottle suddenly opened.)

These directional and interactive responses can be exploited in boiler controls to achieve the stabilities and smooth responses we are looking for. In particular whenever we can predict how changing one variable will affect the others we can start to use feedfoward techniques to provide compensation without waiting for feedback effects to do the job for us.

1.3 Process dynamics in boilers

Process dynamics describe the ways in which process variables change over a time period in response to disturbances. We are all familiar with the sorts of time delays and slow or quick responses that we can experience with heating systems. Two examples:

- Waiting for the geyser to warm up when you want to take a shower and the tank is cold. This is an example of a simple but slow lag in temperature response to the heater input.
- When the shower water is too hot the adjustment of the cold tap can sometimes be very fast and it creates a cold shock! This could be because the time lag in mixing is very short. But sometimes there is no response at all for several seconds. This is due to the “transport delay” or “process dead time” before the change in settings appears at the sensing points!

First order time lags and transport deals are typical dynamic effects in boilers. For example: There is always going to be a time delay between the demand for more steam and the delivery of more steam resulting from the time delays in getting the firing rate up to a higher level. However the stored energy in the boiler allows the increased steam delivery to be drawn off immediately but only for a short while before the pressure falls significantly. So with a well-designed control system the dynamic lags of the steam system can be used to assist in overcoming the dynamic lags of the firing system.

We shall look into the basics of dynamic lags and dead times in the next module from a control system point of view. Then we shall look at the particular dynamics of the main processes and their control systems as we work through the main control functions in the modules of the workshop.

It should already be possible to see how some basic corrective control actions can be applied to the process diagram in Figure 1.4. We shall look at these in a moment but first it is a good idea to get to know something about the various types of boilers and then see how the basic process appears in each type.

1.4 Overview of Boiler types

It is essential for control engineers to develop a good understanding of the processes that they are working on. In the case of boilers it is important to understand something of the principles of boiler designs and the characteristics of their processes.

Boilers have been developed in a wide range of shapes and sizes according to need and only the best known types can be outlined here. From a control viewpoint we need to see only the major differences between types. Here we see two basic types:

- Firetube and shell boilers for small to medium steam and hot water supply duties
- Water tube boilers for industrial and power generation services

1.4.1 Development of the fire tube boiler

Early boilers were built on the kettle principle of having a large domed tank of water with headspace for steam and heating from beneath. But as demand for steam increased with the growth of industry and the railways engineers tried ways to improve the capacity and efficiency of steam generators. In the 1850s fire tube boilers became established on the principles shown in Figure 1.6. Heat transfer in this type of boiler was improved by the use of fire tubes to carry the furnace gases through the water jacket in single, double or triple passes thereby increasing the time period and surface area for the gases to transfer heat to the water side.

Figure 1.6

Early type of firetube boiler

A cylindrical water jacket encloses the fire tube assembly and steam separates from the water in the heat space above the tubes. The problem with this type of construction is that the large cylinder stores a large amount of energy and requires a strong pressure vessel. In the 19th century these boilers were very dangerous because the materials and fabrication techniques were not adequate for the high stresses involved and presumably relief valves were not so effective. The following insert serves to remind us of the history of boiler accidents that formed a background to today's engineering practices.

The firetube boiler design has evolved into the small shell type of boilers seen today in steam supply service for large buildings and small industrial plants . Figure 1.7 shows an example.

Figure 1.7

Example of the firetube boiler

This is how the American Boiler Manufacturers Association describes such packaged fire tube boilers

"Today's Packaged Firetube Boilers are available in a wide variety of designs. The basic combustion gas flow pattern for all designs has the actual combustion occurring in the furnace with hot gases passing through the full-length banks of firetubes. These boilers are available in single pass, 2 pass, 3 pass and 4 pass patterns. All patterns are available in both Wet-Back and Dry-Back designs.

In the past few years, improvements in construction have resulted in more *compact and less costly packages. Larger access doors supported by hinges or davits have made interior surfaces more accessible for cleaning and inspection. Radiation heat losses have been reduced to a minimum by improved shell design and insulation.*

Fuel burning and combustion control equipment have been continuously improved. A majority of the packaged firetube boilers use forced draft fans. An increasing number of the units are equipped with modulating or other control systems to match the firing rate to load demand as nearly as possible.

Flame safeguard control systems are generally of the programming type and are frequently microprocessor based. Such systems may include LED displays for self-diagnosis of system problems. Flame detectors have been improved and are matched to the unit and fuels.

As the various unit components complement one another, the PFT assemblies are quite compact and can be shipped complete with several auxiliary components. The only size restrictions are common carrier shipping clearance and weight restrictions.

APPLICATION

Packaged firetube boilers are available in sizes from 10 to 3,000 boiler horsepower (335 to 100,425 MBH). They can be ordered and are suitable for either low pressure steam (15 psig) or hot water (not exceeding 160 psig or 250°F) applications (ASME Section IV) or for high pressures steam to 450 psig (ASME Section I) for process applications.

They are particularly useful for steam heating applications with sluggish condensate return systems because their relatively large water content will partially compensate for the time delay during which condensate is returned to the boiler.

PFT units are fuel flexible. Standard units are available with fuel burning equipment to fire natural or LP gas, and all grades of fuel oil, #2 through #6. Units to fire both fuel gas and fuel oil with either manual or automatic fuel changeover can also be ordered.”

The important aspect of the packaged firetube or shell boiler from the C&I perspective is that these units require control and instrumentation that is simple, reliable and economic and yet good enough for the boiler to be operated unmanned for long periods. The controls must provide all essential safety functions as well pressure, start up and combustion control functions and yet . We are going to include this type of equipment in this workshop as we proceed through the workshop as it represents a substantial part of the boiler controls activity and many C&I products are available for this market

1.4.2 Development of the water tube boiler

The limitations of the firetube boiler in term of pressure and performance were overcome by reversing the arrangement to contain the water system in tubes and pass the hot gases over the outside of them. The water tube boiler has become the standard for most medium to large industrial boilers and power utility boilers ever since its invention in the 1856 and its developments leading to the integral furnace designs in the 1930s.

Figure 1.8 illustrates the basic principle showing a water circulation system with riser tubes that are heated by hot furnace gases and radiated heat producing a 2-phase steam and water mixture that rises rapidly to the steam drum at the highest point. Separation of the steam from the water takes place in the drum whilst the cooler water descends in the downcomer tubes to repeat the process. Many boilers have a lower drum or mud drum where the water is distributed to the riser tubes and where any solids present can separate and be collected.

Steam from the drum is then in saturated form and has a high moisture content. Most boilers are required to deliver superheated steam that has been heated well above the saturation point and is therefore able to deliver greater energy to the various users. In particular the conversion to motive power uses steam turbines, which require high temperature steam at closely controlled temperature and pressure conditions to perform efficiently. The water tube boiler provides superheated steam by passing it through superheater tubes located in the hottest part of the flue gas path where they can extract the greatest amount of heat whilst providing an essential cooling function before the gases pass from the furnace.

Figure 1.8

Fundamentals of the water tube boiler circulation and superheat system.

1.4.3 The integral furnace boiler

The characteristic feature of most water tube boilers is that the furnace enclosure is constructed from water wall tubes forming a membrane of tubes that create a cooled enclosure whilst absorbing the heat and transferring it to the steam generating process. As furnace size is increased so the available heat for heating and boiling the water increases. However the need for superheater surfaces begins to exceed the need for boiling surface as the pressure and temperature specifications of boilers are increased. The larger designs therefore feature very large superheater tube assemblies followed by the heat recovery sections of the economizer and air heater.

Figure 1.9

Section through a typical PF fired industrial boiler

Figure 1.9 illustrates a typical bi-drum industrial boiler with its integral furnace arrangement. Small versions of this as packaged industrial boilers can be supplied as a complete assembly from a manufacturer’s works. Larger units of course have to be built up on site and these are typically the large power generating units we see in power plants.

1.4.4 Water tube boiler types

There are some major types of boilers in water tube range that we need to recognize in this introduction. These include:

Fossil fueled power utility boilers for electricity generation.

Sub-critical and supercritical very high pressure versions are widely used. These dominate the field for very large high performance installations for obvious reasons of power generation efficiency. The control systems for power boilers are large and complex but the fundamental control principles remain the same as for the simpler boilers.

Nuclear powered boilers for electricity generation.

Approximately 30% of the world’s electricity is generated by nuclear-fueled power plants. Boilers for these plants receive their heat energy from the nuclear fission processes and hence the furnace controls are replaced by reactor controls. We are not going to venture into this field in this workshop but the feedwater and steam conditioning principles are still applicable. The techniques of control and instrumentation are also basically the same for the water/steam systems.

Industrial steam generating boilers.

Industrial boilers follow the same principles as power boilers but are typically adapted to available fuels related to the plants or areas they serve. Their sizes are usually smaller than the power boilers and the steam specifications are not so high. However in many cases the industrial boiler has to supply steam for large turbine units either for electrical power or for compressor duties in chemical processes. Therefore superheat control and load following response are critically important.

1.4.5 Furnace and firing system types

The fuel types determine furnace types and firing systems for the power and industrial boilers. Principle types are summarized here so that we can be aware of the variations we may encounter as control engineers.

- Pulverized coal firing
- Gas fired furnaces
- Oil fired furnace and multi-fuel combinations.
- Stoker fired boilers for granular coal or other solid fuels including refuse combustion systems.
- Atmospheric fluidized bed combustion (AFBC) boilers for coal or waste materials
- Pressurized fluidized bed combustion (PFBC) boilers
- Chemical recovery furnace/ boilers. These are seen in petrochemicals and in the pulp and paper industries. In particular there is a large population of “black liquor recovery boilers” as part of the Kraft process for pulp and paper production seen in most large pulp and paper facilities.

Pulverized coal firing furnaces generally burn pulverized coal in multiple burner units although single burner units are used in small boilers. Pulveriser systems grind coal into fine granular form that is conveyed by pipes to the burners located in furnace sidewalls. Burner management systems (BMS) provide control of the individual operations of each burner as well as providing supervisory control of the burner sequencing operations to control flame distribution and loading across the furnace. We shall look at these concepts in chapter 5.

Oil and gas fired furnaces require distributed burner modules arranged in the same way as coal burners. Most coal-fired units also include oil or gas fired burners for light up or alternative fuel sources so the requirements for oil and gas firing control and safety system must be well understood by the control and instrument team for almost any boiler.

Atmospheric fluidized bed combustion (AFBC) boilers have become widely established over the past 20 years for industrial steam generation where there are opportunities to extract energy from difficult fuel sources. (AFBCs are named “atmospheric” to distinguish them from “pressurized FBCs” which have pressurized combustion chambers and are designed for special high performance purposes.) In the so called bubbling bed type of AFBC the bottom of the furnace contains a layer of sand and ash materials that is fluidized by means of arrays of air nozzles in distributor plates that cover the entire base of the furnace. When the fluidized bed has been heated to above the fuel ignition temperature it becomes a very efficient medium for the burning of coal or waste materials. Figure 1.10 gives an indication of the typical design arrangements.

AFBC boilers are particularly attractive for their ability to reduce sulphur emissions from coal burning by mixing limestone with the fuel. The fluidized allows sufficient contact time for the calcium in the limestone to capture the sulphur released from the coal during combustion.

Figure 1.10

Example of a fluidized bed boiler with gravimetric feeder for coal or waste material

From the control system viewpoint AFBC had the added requirement that temperature control can be applied to the fluidized bed to achieve the desired combustion conditions. Combustion takes place at relatively low temperatures and this is also advantageous for avoiding NOx generation.

Stoker fired boilers and fluidized bed boilers have the particular characteristic of retaining a moderate amount of fuel inventory within the furnace. The fuel inventory has the effect of creating larger time lags in the combustion responses and hence these types require slightly different combustion and load control strategies from the burner-fired boilers.

1.5 Hazards of boiler operations

Before we progress any further its good time to consider the basic hazards presented by boilers in service. As noted earlier a large part of the C&I

responsibility in a boiler installation is to take care of the safety instrumentation requirements arising from the hazards of boiler. The overall name for any control system that has been engineered for the purpose of safety is “Functional safety system”, i.e. a system that provides safety through the functions that it performs. The name for any instrument and control system providing functional safety is “Safety instrumented system” or SIS. We shall be studying this subject in module 2 and applying it throughout the workshop.

In line with well established and legal requirements for occupational health and safety all owners of boilers are obliged to carry out a formal risk assessment procedure to determine the hazards and risks of their particular installation. In the case of boilers this task is made much easier by the existence of industry specific safety codes such as the NFPA 85 “Boiler and Combustion Systems Hazards Code”. In this workshop we shall be referring frequently to the current 2004 edition.

In designing or supporting any SIS application the first stage of any project is to identify the hazards of the process and carry out an assessment of the risk levels. Whilst we can simply follow the instructions of codes such as NFPA 85 it is better from a training viewpoint and as general practice to get to understand the hazards of a process and the prevention measures by starting from first principles. In this chapter we can begin by identifying the principal hazards of boiler operations.

Because of the long history of boilers in service in so many industries we have the advantage of a great deal of past experience being accumulated into a list of well known hazards of boilers and their furnaces. The following table lists the main hazards commonly known for boilers. This does not mean that no other hazards may exist.

This list represents only the best-known hazards that are likely to be found in most types of boilers. The causes and consequences are described without taking into account the safety devices and trip systems that are normally in place to provide protection or “risk reduction” to prevent these events or mitigate the consequences.

Table 1

Water/steam system hazards

Hazard	Typical causes	Possible consequences
High steam pressure	Over-firing.	Rupture of pressure parts leading to

exceeding design limits	Rapid loss of load	violent release of steam. Injuries
High steam temperature	Failure of de-superheater control.	Thermal damage to pressure tubes, possible rupture.
Low water level (drum level)	Failure of level sensing/ control. Loss or restriction of feedwater supply. Major leak in boiler.	Flash drying of circulation tubes, overheating and cracking at drum. Violent release of steam.
High water level	Failure of level sensing/ control. Sudden loss of load.	Problems with steam separation, choking of circulation. Carry over of water to superheater, thermal shock damage. Turbine damage in power applications
High TDS in feedwater	Failure of treatment plant. Failure to carry out blowdown	Deposition and scaling, corrosion in tubes. Damage to boiler parts
Thermally induced stressing of the pressure parts	Rapid temperature changes of the high pressure parts. Too fast warm ups of a cold boiler.	Material failures, rupture and loss of containment. Shortened life of superheater sections. Possible injuries due to steam release.
Condesning of flue gases containg SO2	High sulphur fuels and low flue gas temperatures causing condensation.	Acid corrosion of air heater

Table 2

Combustion and furnace system hazards

Hazard	Typical causes	Possible consequences
High furnace pressure	Loss of ID fan service. Failure of draft control	Loss of containment of furnace gases. Flames and gas escapes with fire and toxic effects on persons. Damage to seals and structures. Blowbacks from burners
Low furnace pressure (High	Loss of FD fan service. Failure of draft control or	Damage to seals and structures.

suction)	damper setting errors	Excess air to burners, possible loss of flame. Excess draft carries over dust and ash to flue gas systems
Flammable and toxic gases build up in flues.	Insufficient combustion air or excess fuel/ air ratio.	Explosion in flues gas areas. Possible toxic exposure. Injuries
Explosive gas mixture in the furnace or flues	Failed ignition during light up Loss of flame during firing.	Furnace explosion. Injuries and damage. Potential destruction of boiler.
	Fuel leakages during shutdown.	Fires in flues gas system
	Failure to air purge furnace after shutdown or before relighting.	
Soot build up in flues	Poor combustion, low furnace temperatures. High furnace temperatures creating softened or plasticized ash.	Soot fires in furnace areas.

Table 3

Environmental hazards

Hazard	**Typical causes**	**Possible consequences**
Nitrous oxide emissions (Nox)	High flame temperatures at burners	Atmospheric pollution leading to acid rain and corrosion. Non-compliance with regulations, penalties, closure.
Sulphur dioxide emissions	High sulphur content in fuels. Failure of sulphur removal systems	Atmospheric pollution leading to acid rain and corrosion.
Dust releases gases build up in flues.	High gas flows , faulty dust control equipment	Smoke emissions and dust pollution

We may be able to add to this list by discussion during the workshop. During the next chapters of the workshop we shall develop the understanding of safety control systems and then look at specific details of each of main safety control functions.

1.6 Boiler control functions

Whatever type of boiler you are working with there is a great deal of commonality in the essential and basic control systems that are required to provide stable and safe operations. It is therefore practical to study the main control functions in general terms and become familiar with those techniques that are widely used. Then it should be possible to develop the adaptations that may be needed for a particular type of boiler by recognizing the dynamic response characteristics that it presents.

To be able to control the boiler processes we need to measure or at least estimate the relevant process variables and then adjust those parameters that are accessible to us to keep everything in the working range. So the essential control tasks begin with identifying each control function. We can show the main functions easily with a set of simple, if rudimentary control function diagrams. In later chapters we shall develop these functions into more interesting details.

1.6.1 Feedwater and drum level control

The water level in the boiler shell or in the drum must be kept as stable as possible by fully automatic control. The process variable is the water level and the manipulated variable is the feedwater flow rate. Figure 1.11 shows the basic block diagram notation for this function in its simplest form.

Figure 1.11

Basic control function for drum level

The level measurement transmitter LT is compared to the set point and the controller adjust feedwater flow either by pump speed or by a control valve or a combination of both. This control function is not as simple as it appears at first but it is essential for good performance from the boiler. In chapter 3 we will develop the details of measurement and control of drum levels and the associated alarm and safety functions.

1.6.2 Furnace air and draft control

Most furnaces for boilers are designed to be operated at slightly below atmospheric pressure to ensure furnace gases do not escape to the atmosphere. The control function is therefore to adjust the draft extraction rate of the ID fan system to ensure the negative pressure conditions are maintained at the furnace within a narrow band whilst correcting for disturbances caused mainly by air flow changes required by the combustion systems.

Figure 1.12

Basic control function for furnace draft

This control function must also be adjusted for disturbances in the complete flue gas train to ensure pressure profiles are maintained. Measurement of draft pressure is also potentially troublesome. We will look at the details of this function and its safety requirements in chapter 4.

1.6.3 Combustion and firing control

The duty of the combustion control system is to ensure safe and correct firing conditions are maintained under all load conditions. Combustion controls are closely linked to the boiler master load control system but should be considered as a separate system that is commanded by the load controls. Where firing is provided by oil, gas or pulverized coal burner systems these will have individual burner management systems for each burner. These can also be regarded as subsystems slaved to the overall combustion control scheme.

We shall be looking at combustion control schemes in chapter 6 so for the first introduction to the subject we can restrict the present description to the overall schematic shown in Figure 1.13.

Figure 1.13

Basic combustion control function.

Figure 1.13 shows that combustion control must respond to a firing rate demand either set by an operator or from the master pressure and load control of the boiler. The combustion control function has the following basic tasks:

- It first develops the total airflow demand and the total fuel flow demand for the furnace from a master load control signal by applying a ratio control calculation. The demand signals are calculated to ensure a desired ratio of air to fuel such that there is always sufficient excess air to ensure complete combustion of the fuel.
- It then applies the demands to the air flow and fuel rate master controls.
- The fuel and air flow demands are subjected to various constraints or limiters derived from measurements of the current process variables of air, fuel flow and flue gas conditions, principally oxygen. These functions must ensure that there is always an excess of air over the combustion needs of the fuel being fed to the furnace.
- Constraints are also required during large load changes as the dynamic response of fuel feeds and air feeds are different and the possibility of insufficient air must be avoided during load changing.

This control function has to be adapted to the particular arrangement of burners for each boiler and hence there are numerous variations on the basic scheme described here and we shall look more closely at some examples in chapter 5.

1.6.4 Steam pressure and load control

Pressure control in a single boiler is achieved by adjusting the firing rate so that the steam generation rate matches the steam flow rate at the desired pressure. The down stream users will largely determine the steam flow extracted from the boiler so that the boiler will operate in load following mode if it is adjusted to maintain the pressure at the drum or alternatively at the load entry point such as the steam header or turbine throttle. The general arrangement is shown in Figure 1.14.

Figure 1.14

Basic control functions for steam pressure and load

In the diagram note that steam flow is the direct indicator of load on the boiler and hence many control schemes will use a feedfoward signal added to the output of the pressure control stage to derive the nominal load demand. This will improve the dynamic response of the boiler to load changes since it does not have any time lag compared with the pressure response. We shall see more of this in chapter 5.

1.6.5 Steam temperature control

Steam temperature is critically important to many applications for example:

- Steam turbines operate most efficiently at specifically designed temperatures and are also liable to be damaged by rapid temperature changes arising in the steam supply.
- Chemical process plants require steam at fixed superheat temperatures for stable and correct operation of their heat exchanger stages.

Steam temperature of saturated steam is determined by the pressure so for saturated steam supplies only the pressure control is needed. For all other applications superheated steam must have its temperature controlled. This becomes more difficult as the boiler firing rate is reduced when the distribution of heat transfer between evaporation duty and superheating duty swings usually in favour of evaporation. Therefore superheat control strategies have to be devised by the boiler designers so that the fireside duty can be adjusted along with the water spray de-superheater system.

Figure 1.15 outlines a basic control function where the de-superheater spray rate is controlled to deliver the required steam temperature. More complex strategies will be considered in chapter 7.

Figure 1.15

Basic control function for steam temperature

1.6.6 Boiler start up sequencing control

So far we have looked at the main continuous control functions needed for most boilers. The other major control function is the provision of logical interlocks and sequencing controls to assist in the startup and warm up phases of boiler operations as well the supervision of furnace operating conditions and shutdown. Due the fact that virtually all of these operations involve potentially hazardous conditions most of the controls for such tasks come under the safety category and are implemented in burner management systems (BMS) or similar equipment. Other titles for these systems include:

- Combustion safeguard system
- Furnace safeguard supervisory system (FSSS)
- Emergency shutdown system (ESD)
- Safety instrumented system (SIS)

These titles apply to equipment that monitors the burner supply systems and the furnace to prove conditions are safe for ignition, provides flame monitoring and responds to flame failure events. Furnace supervisory systems go further and provide interlocks to ensure that each burner that is to be introduced into the firing regime can be started only when the furnace conditions and levels of existing firing are suitable for more burners to be used.

All the safety requirements for boilers of most types can be found in the NFPA 85 code of practice and these requirements define the essential trip and interlock functions that are to be implemented through the BMS.

Safety trip and alarm functions that fall outside of the furnace or combustion safeguard functions can be implemented separately from the BMS but in most cases these trip actions require shutdown actions to be implemented through the BMS. Hence in large boiler systems is common to see that the BMS serves as the logic solver component for all the safety instrumented systems. We shall see in the next chapter how the new standards for functional safety are presenting a challenging problem to the traditional designs of BMS.

1.7 Safety control functions

We have noted that the safety control requirements can be found in the NFPA 85 code. Similar safety requirements will be found in European standards, in particular BS EN 12592. These standards call for certain essential safety related alarms and trips to be provided through instrument equipment that is separated from and independent of the basic process control system (BPCS). Each trip is called a safety function and has specific purpose related to the hazards of boilers.

For training purposes if we work from first principles it should be possible to identify the necessary safety functions from the list of hazards that we have seen in this chapter. So here we suggest that the workshop participants should do this as a practical exercise. The details of this task are set out under “Practical exercise no1” at the back of this manual.

The answer sheet we have provided can ultimately be used as summary of the boiler safety functions we require.

1.8 Practical Exercise No 1:

Given the hazards listed in tables 1 and 2 and main control functions as above this practical asks participants to suggest safety control functions in terms of simple block diagrams and notes for protection against each of the above hazards.

1.9 Summary

In this introductory chapter we have seen that although there is wide range of boiler type and sizes the essential control requirements for basic stability and safety of operations follow the same principles regardless of type or size.

The simple diagrams we have used should help to build a first level of understanding of the thermal processes at work in the boiler. We have seen that boiler processes are highly interactive and that this leads to extensive use of feedback control, ratio functions and compensation signals in most boiler control schemes. The dynamic responses of the process conditions in boilers play a large part in our ability to stabilize the control functions and affect the boiler's ability to respond to load changes. We have seen some preliminary examples of how these problems are treated in practice.

We have also identified the best-known hazards of boiler operations as a foundation for more training in the techniques of safety instrumented systems and the requirements of safety codes for boiler controls. We have been introduced to burner management systems and their role in the supervision and safety-related control of boiler start up and shutdown operations.