NOTES & REFERENCES

Module 234-2

THE BOILER

OBJECTIVES:

After completing this module you will be able to:

2.1 a) Describe three adverse consequences/operating concerns caused by: ⇔ ***Pages 4-5***

- i) Boiler level too high;
- ii) Boiler level too low.

b) Explain the effect of steady unit operation at different reactor power on: ⇔ ***Page 6***

- i) The average density of boiler water;
- ii) Boiler water inventory, assuming constant boiler level through the whole power range.

c) For both transient shrink and transient swell of boiler water: ⇔ ***Pages 7-9***

- i) State two major operational causes of each;
- ii) Describe how it happens;
- iii) Explain why it is only a transient phenomenon.

d) Describe how boiler level is controlled during: ⇔ ***Pages 10-11***

- i) Unit startup and low power operation;
- ii) High power operation.

e) Explain the major reason why: ⇔ ***Pages 11-14***

- i) Trim valves are used with a bank of boilers;
- ii) The boiler level is ramped up with increasing reactor power.

f) List three protective actions in response to each of the following upsets: ⇔ ***Pages 15-16***

- i) Boiler level too high;
- ii) Boiler level too low,

and explain how each action protects the equipment.

NOTES & REFERENCES

Pages 16-17 ⇔ g) List the causes of each of the following boiler level upsets:

- i) Too high a level (3);
- ii) Too low a level (2).

Page 18 ⇔ 2.2 a) Define carryover as it applies to boiler steam.

Page 18 ⇔ b) Describe four mechanisms of carryover.

Pages 18-19 ⇔ c) Describe four important factors that affect the amount of moisture carryover in boiler steam.

Pages 19-20 ⇔ d) Describe four adverse consequences/operating concerns caused by carryover in boiler steam.

Pages 20-21 ⇔ e) Describe three general operating practices used to minimize carryover.

2.3 For a boiler tube leak:

Pages 22-23 ⇔ a) Describe its four adverse consequences;

Pages 23-24 ⇔ b) i) List its three characteristic indications;

ii) Describe how these indications can identify the faulty boiler;

Page 24 ⇔ c) State the automatic protective action carried out in case of a leak large enough to cause acute boiler level control problems;

Pages 24-25 ⇔ d) i) List three parameters which should be carefully monitored to allow for continued operation in case of a small leak;

ii) Explain how these parameters are evaluated to decide if operation can be continued;

Page 25 ⇔ e) State one general operating practice used to prevent boiler tube leaks.

* * *

INSTRUCTIONAL TEXT

INTRODUCTION

According to the Ontario Boiler and Pressure Vessel Act, the correct name for the equipment used in our stations to produce turbine steam is *steam generators*. But in station documents, the term *boilers* – perhaps for its simplicity – is commonly used. Because of this, and for consistency, the latter term is used in these course notes.

In the previous turbine courses, the principle of operation and the major components of typical boilers used in CANDU stations are described. This module supplements this basic knowledge with a detailed discussion of the following important operational aspects:

- Boiler level control;
- Carryover of impurities in boiler steam;
- Boiler tube leak.

Three other boiler-related operational problems are covered in other modules as follows:

- Boiler pressure control (in module 234-3);
- Thermal shock due to excessively cool feedwater (in module 234-6);
- Emergency sources of feedwater (also in module 234-6).

A simplified pullout diagram showing a typical boiler with a built-in preheater is attached at the end of the module. The diagram can be unfolded and kept in sight for easy reference.

BOILER LEVEL CONTROL

Recall that in a CANDU unit, its boilers perform two very important functions:

- They provide reactor cooling by removing heat from the HT system;
- They produce high pressure, high temperature, dry* steam that is needed to drive the turbine generator.

* Normally, there is less than 0.2% of moisture in this steam.

Thus, the performance of the whole unit strongly depends on the performance of its boilers. And they can perform adequately only when proper boiler level is maintained.

Since this parameter is so essential to unit operation, a large part of this module is devoted to it. From the section below, you will learn about the following:

- What adverse consequences/operational concerns are caused by improper boiler level;
- What steady state and transient shrink and swell of boiler water are, and how they occur;
- How boiler level is controlled at various power levels*;
- What protective actions are performed when the normal control is ineffective, and;
- What typical operational causes of improper boiler level are.

* More information on boiler level control is given in the instrumentation and control courses.

NOTES & REFERENCES

Obj. 2.1 a) ⇔

Adverse consequences and operating concerns caused by improper boiler level

What exactly can happen if the level is wrong? Let us first consider **too high a boiler level**. It causes three adverse consequences/operating concerns:

1. **Increased carryover of impurities in boiler steam.**

   Carryover is a term used to refer to entrainment of water and various other impurities (eg. salts) in boiler steam. High boiler level results in **flooding of the cyclone separators** inside the boiler, reducing their effectiveness, and thereby increasing moisture carryover. With increased moisture carryover, the concentration of other impurities in the steam also increases because water droplets are like mini-samples of boiler water which is not chemically pure. If **operation** with increased carryover in boiler steam is **continued** for several days or longer, it **can have some detrimental effects*** on the turbine and the steam system.

* These effects are described later in this module.

2. **Increased hazard of water hammer in the steam system and water induction to the turbine***.

   If the level were allowed to rise even more, it could eventually result in **slugs of water** being thrown into the steam system and quickly driven by steam towards the turbine. **Severe damage** to this equipment could occur immediately, forcing a **prolonged outage for repairs**.

* More information on water hammer in the steam system and water induction to the turbine is given in module 234-3 and 234-13, respectively.

3. **Operational constraints and loss of production due to forced protective actions.**

   To prevent water induction, **the turbine is tripped** (automatically or manually if the automatic trip has failed) **upon a very high boiler level**. Though this protective action is absolutely necessary, it results in **loss of production** for which poor boiler level control may be responsible.

   In the stations where **condenser steam discharge valves** (CSDVs) are used for boiler pressure control, they **are tripped closed** to prevent water induction into the steam pipelines*. Note that the same very high level causes also a turbine trip. The resultant thermal mismatch in the boilers causes boiler pressure to rise. If the CSDVs were available, they could handle the pressure rise. But they are tripped. And the ASDVs (whose flow capacity is only 8-10% FP) are far too small to accommodate the thermal mismatch that results from a turbine trip from a high load. Therefore, boiler pressure is likely to rise enough to force boiler safety valves to open.

* How this action prevents water induction to the pipelines is described on page 16.

   You realize that tripping the CSDVs and relying on the safety valves – which are the last line of defence against overpressure – is certainly disadvantageous, as it increases the probability of an overpressure accident. Besides, opening of any boiler safety valve has its own adverse consequences such as increased makeup water consumption. And last but not least, the combined turbine and CSDV trip is likely to cause a poison outage.

Too low a boiler level can result in very serious adverse consequences/ operating concerns:

1. **Decreased post-accident heat sink (following a loss of feedwater accident) due to reduced boiler water inventory.**

   Assuming that the average density of boiler water and steam stays constant for a given reactor power, the boiler water inventory (in terms of its mass) decreases with dropping level. Of course, this reduced water inventory can absorb less heat from the reactor coolant. Should a **loss of boiler feedwater accident** occur, the reduced water inventory would be depleted sooner. Consequently, **the operator would have less time to secure long-term cooling for the reactor** fuel (either by restoring feedwater supply to the boiler or by placing in service an alternate heat sink for the reactor). This is why a low boiler level is potentially dangerous even if the boiler tubes are still fully covered.

2. **Jeopardized reactor cooling due to uncovering of the tubes.**

   Even a partial uncovering of boiler tubes would **immediately impair heat transfer from the reactor coolant** due to decreased effective tube surface area. This would raise the average coolant temperature, assuming constant reactor power. If no adequate protective actions were taken, excessive boiling of the reactor coolant could result, leading to **fuel failures due to overheating.**

3. **Loss of production due to various protective actions.**

   As outlined above, too low a boiler level can seriously jeopardize reactor safety. To prevent this, **the reactor is set back/stepped back** (depending on the station) **and finally tripped** when the dropping level reaches certain setpoints. These forced protective actions, although being the lesser evil, result in loss of production.

SUMMARY OF THE KEY CONCEPTS

- Excessively high boiler level increases carryover of various impurities in boiler steam and can create a hazard of water induction. To prevent water induction and water hammer, the turbine and the CSDVs must be tripped which causes loss of production and may lead to a poison outage.
- Too low a boiler level jeopardizes reactor cooling due to reduced boiler water inventory and possibly uncovered tubes. This forces protective actions which cause a loss of production.

NOTES & REFERENCES

SWELL AND SHRINK OF BOILER WATER

All these serious consequences of improper boiler level make its reliable and precise control essential. This task is, however, considerably complicated by the fact that usually there are many steam bubbles submerged in the boiler water. Their total volume depends strongly on the intensity of the boiling process. This, in turn, changes with reactor thermal power and undergoes transient fluctuations whenever the thermal equilibrium in the boiler is upset. These two effects are described below in more detail.

But first, let us clarify the aforementioned term *thermal equilibrium*. In essence, it means that the temperature distribution in a given piece of equipment remains constant. This also includes the temperature of all the fluids that flow through or stay in the equipment. Thus, a boiler is in a thermal equilibrium when its metal, steam, light water and heavy water temperatures stay constant. This requires all the heat and mass inputs to the boiler to stay in balance with its heat and mass outputs. Needless to say, a boiler in thermal equilibrium operates at a constant power and steam pressure.

Obj. 2.1 b) ⇔

Steady state swell and shrink

During **unit operation at a steady load**, a thermal equilibrium in the boiler is maintained. The intensity of the boiling process is constant and dependent on the reactor thermal power. At zero power, there is negligible boiling (minor boiling can occur due to the HT pump heat). Hence, in principle, there are no steam bubbles in the boiler water. When the reactor thermal power is increased, some steam bubbles appear in the water, and **the higher the reactor power, the larger the total volume of these bubbles**. Because the density of water is many times as large as that of steam*, the average density of the boiler water and the submerged steam bubbles decreases dramatically when more boiling occurs at increased reactor power. In other words, boiler water swells when reactor power is increased – a phenomenon referred to as a **steady state swell**. Conversely, when reactor power is reduced, a **steady state shrink** takes place because the boiler water shrinks as fewer steam bubbles are present within it.

To maintain a constant boiler water inventory throughout the whole power range, the boiler would have to accommodate a very large steady state swell or shrink. This could result in significant changes in boiler level. Conversely, **the mass inventory would be considerably reduced at full power if a constant boiler level were maintained throughout the whole power range**. This steady state swell is so large that in most CANDU stations, the boiler water inventory decreases with increasing reactor power despite ramping the boiler level up.

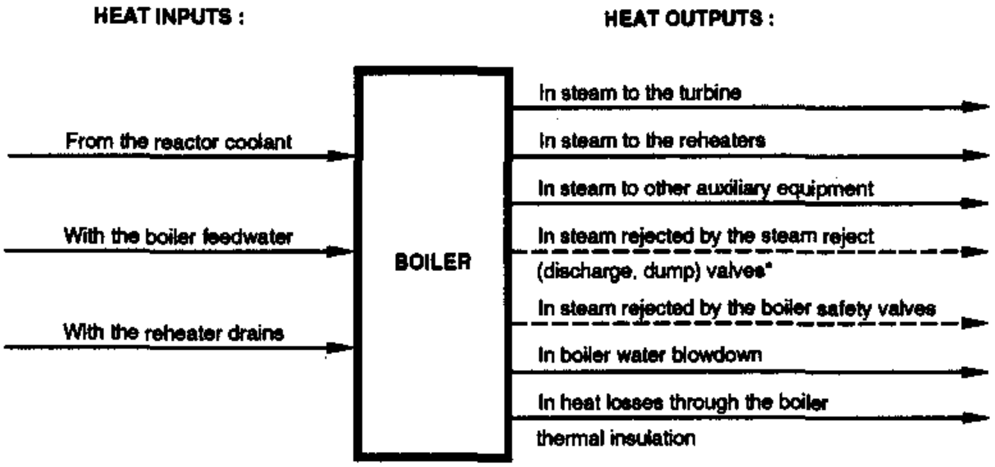
* Eg. at 4 MPa(a) pressure, the ratio of these densities is about 40:1 !!!

Transient swell and shrink

⇔ Obj. 2.1 c)

It gets more complicated when the thermal equilibrium in the boiler is upset. A temporary unbalance between the heat input and the heat output in a boiler can greatly affect the rate of boiling occurring before a new thermal equilibrium is finally established in the boiler. During this transition period the boiler water can experience a **transient swell** (defined as a temporary increase in the level over and above that which would exist at a given reactor thermal power during steady power operation) or a **transient shrink** (ie. a temporary drop of the level below that corresponding to steady operation at a given reactor power).

There are many reasons why the thermal equilibrium in a boiler can be disturbed resulting in a transient shrink or swell. Strictly speaking, it can be caused by an abrupt change to any one or more of its heat inputs or outputs as depicted in Fig. 2.1.



* Different names of these valves are used in different stations.

Fig. 2.1. Heat inputs and outputs in a CANDU boiler:
——— Usually present, – – – – – Usually absent.

Of course, not all of the heat inputs and outputs shown in Fig. 2.1 are equally important. Some of them, like the heat contained in boiler water blowdown, are very small in comparison with others. Therefore, they do not have a large effect on the thermal equilibrium in the boiler and hence, they cannot cause a large transient shrink or swell. Note that when the heat flow through the boiler is unbalanced, some heat is either deposited in the boiler water and steam or removed from them, causing boiler pressure and temperature to vary.

It turns out that among all possible causes of transient swell or shrink of boiler water, the largest two are abrupt changes in reactor power and rapid changes in boiler pressure. However, automatic control of boiler pressure minimizes its changes during power manoeuvres and upsets, whereas changes in reactor power (particularly due to a trip) are sometimes both large and fast. Therefore, changes in reactor power have the strongest effect on transient shrink/swell of boiler water.

Specifically, major causes of **transient swell** are:

- **A rapid loading of the reactor** (eg. while recovering from a reactor trip to prevent reactor poisoning);
- **A drop in boiler pressure** (eg. due to fast turbine loading in the reactor lagging mode of unit operation)*.

* This and other causes of a boiler pressure drop are covered in the next module.

Here is how it happens. A fast increase in reactor thermal power quickly increases production of steam bubbles in the water surrounding the tubes in the riser section. Similarly, a drop in boiler pressure causes some boiler water to flash to steam because the water temperature is above the saturation temperature corresponding to the reduced boiler pressure*. In either case, **the volume of the steam bubbles present within the boiler water rapidly increases.** As the bubbles in the riser section quickly expand in all directions, two **dynamic effects** occur:

* Recall that for liquid water, such a superheated condition is abnormal. This is why it spontaneously flashes to steam.

1. **The water in the riser section above the tube bundle is pushed upward.**

   This raises the water level in the riser section and increases the flow of water through the cyclone separators. As a result, more water enters the downcomer annulus.

2. **The water at the bottom of the riser section is pushed towards the downcomer annulus.**

   This reduces the flow of water exiting the downcomer annulus.

A combination of these two effects makes the level in the downcomer annulus to rise because more water enters it at the top than exits it at the bottom. The significance of this level rise becomes obvious when you realize that boiler level transmitters are connected to the downcomer annulus, and not the riser section.

When boiler pressure is dropping, the above two effects are accompanied by another one:

3. **Some water in the downcomer annulus flashes to steam, which further raises level in the steam drum.**

Transient swell is **a short-lasting phenomenon** which ceases when a new thermal equilibrium is established in the boiler. Note that in an equilibrium condition, no flashing occurs in the downcomer annulus (because boiler pressure is constant), and the flow of recirculated water entering the downcomer annulus matches the outflow (because the total volume of the vapour bubbles in the riser section is constant).

Note that as long as loading of the unit is slow enough, boiler pressure can be maintained at setpoint, and the boiler heat input increases slowly. Consequently, the volume of the steam bubbles submerged in the boiler water increases so slowly that the aforementioned dynamic effects are insignificant. As a result, transient swell is negligible and boiler level follows accurately changes in its setpoint.

Similarly, the **major causes of transient shrink** are:

1. **A rapid decrease in reactor power** (eg. on a reactor trip);
2. **A rapid increase in boiler pressure** (eg. on a turbine trip).

In both cases, **the volume of the steam bubbles in the boiler water decreases rapidly**, resulting in two dynamic effects (you may notice that they are opposite to the first two effects described on page 8):

1. **Reduced water flow into the cyclone separators** because of dropping level in the riser section. As a result, the water flow entering he downcomer annulus is decreased.
2. **Increased water flow leaving the downcomer annulus** and entering the riser section.

A combination of these two effects makes the level in the downcomer annulus to drop. Note that these effects occur only while the total volume of the steam bubbles in the riser section is decreasing. When a new thermal equilibrium is reached, that volume stabilizes as boiling is resumed at a new stable rate. Hence, the two effects cease to exist, and so does the transient shrink.

Note that transient shrink is negligible when unloading of the unit is slow enough. As boiler pressure can be maintained at setpoint and the boiler heat input decreases slowly, the volume of the steam bubbles submerged in the boiler water decreases slowly as well. This enables maintenance of boiler level at its setpoint.

SUMMARY OF THE KEY CONCEPTS

- Boiler level is greatly influenced by the intensity of the boiling process which affects the volume of the steam bubbles in the boiler water. Because the steam density is only a small fraction of the water density, the boiler level tends to rise with increased boiling.
- Steady operation at different reactor power levels results in a steady state shrink or swell of boiler water because the volume of the steam bubbles changes. The higher the reactor power, the larger the volume of the bubbles, and the smaller the average density of boiler water.

NOTES & REFERENCES

- Because of the steady power swell and shrink, the boiler would have to accommodate large changes in the boiler water volume in order to maintain a constant water inventory throughout the whole power range. Conversely, the inventory would decrease considerably if a constant level were maintained.
- Transient shrink and swell of boiler water are caused by fast changes in power such that the thermal equilibrium in the boiler gets upset. Both phenomena are short lasting and exist only until a new thermal equilibrium is established in the boiler.

Pages 27-29 ⇔

You can now work on **assignment questions 1-5**.

BOILER LEVEL CONTROL AT VARIOUS POWER LEVELS

Obj. 2.1 d) ⇔

Input signals for boiler level control

Boiler level control (BLC) is executed by adjusting the boiler feedwater flow. **At high and medium reactor power**, three parameters are typically used for BLC: **the actual boiler level, the steam flow and the feedwater flow**, as shown in Fig. 2.2.

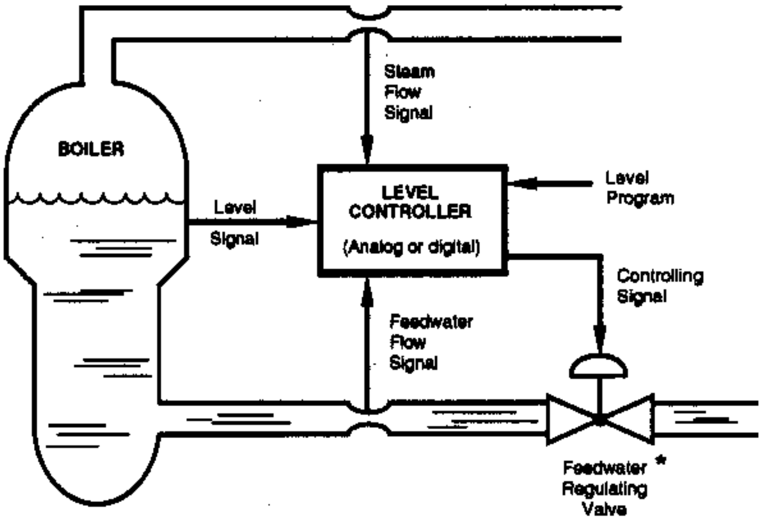


Fig. 2.2. Three-element boiler level control.

* In some stations, this valve is called *boiler level control valve.*

In the level controller, the actual level is compared with the required level producing a level error signal. This error signal attempts to increase the feedwater flow when the actual level drops below the required one. In addition, the steam and feedwater flows are measured and inputted to the controller. These are disturbances which will eventually affect the boiler level. For example, if the steam flow exceeds the feedwater flow, a drop in the boiler level can be expected. By measuring and acting upon the disturbances, level changes can be anticipated before they occur, and hence, large swings in boiler level can be prevented.

The three-element BLC system as symbolically shown in Fig. 2.2 is used in early CANDU stations. In the new CANDU stations, advanced computerized BLC systems are used. They incorporate also other signals (eg. the rate of reactor power change and the rate of boiler pressure change) in order to be able to respond better to transient shrinks and swells.

When the unit load is low, steam and feedwater flow measurements become pretty inaccurate. Recall from the instrumentation courses that flow is typically measured indirectly, ie. by measuring the pressure drop (Δp) across a nozzle, orifice or even a pipeline elbow. In this method of flow measurement, the Δp changes in proportion to the square of the flow rate. A serious drawback of this is that the Δp quickly drops with decreasing flow. For example, if the flow drops to 10% of its full power value, the measured Δp would be only $(0.1)^2 = 0.01 = 1\%$ of its full power value. Hence, at light loads, both the steam and feedwater flows would be measured pretty inaccurately. Therefore, **at light loads**, the flow signals are ignored and **the BLC operates in a single-element mode** that incorporates only the level signal. Because the responsiveness of a single-element BLC is poor, **BLC is more difficult and less accurate during unit startup and at light loads.**

To improve feedwater flow control within the whole power range, **two different sizes of feedwater regulating valves** are used. The larger valves control the flow at high and medium power, whereas the smaller ones operate during startup and at light loads.

Trim valves

⇔ *Obj. 2.1 e)*

In many CANDU stations, two or three boilers are grouped together in a bank that is served by common feedwater regulating valves. In this case, a trim valve is installed at the feedwater inlet to each boiler in the bank (see Fig. 2.3 on the next page).

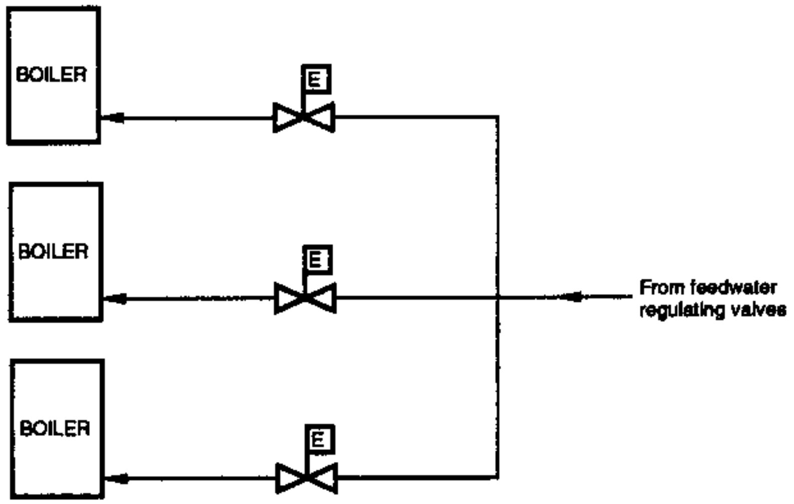


Fig. 2.3. Trim valves in a bank of boilers.

The main reason why this is necessary is that **the steaming rates in seemingly identical boilers are in fact slightly different** as explained in the next paragraph. To maintain the proper level, the boiler with the larger steaming rate needs slightly more feedwater than the remaining boiler(s) in the bank. The required fine adjustment of the feedwater flow to each boiler in the bank is done by the trim valves. Depending on the station, the valves are either controlled manually or automatically. The control is based on boiler levels in the bank. The other signals, that are used to control the feedwater regulating valves, are ignored.

There are a few reasons why individual boilers have slightly different steaming rates. For one thing, the thermal conductivity of their tubes is not identical, eg. due to local differences in scale deposits. The major cause, however, is that the **reactor thermal power is not distributed uniformly between all the boilers**. This is mainly because the flow pattern inside reactor outlet headers (that collect coolant from many fuel channels and distribute it to a few boilers as shown in Fig. 2.4) is such that the coolant exiting a fuel channel is not distributed evenly between the boilers. For example, the coolant flow from feeder F1 in this diagram mostly enters boiler B1, whereas the remotest boiler B3 gets the smallest share.

This would be of little consequence if each fuel channel were producing the same power. But because the neutron flux in the reactor is not uniform, some fuel channels produce more heat than the others, and therefore some boilers get a larger share of the reactor thermal power. Note that many events, such as on-power refuelling, can cause some local changes in the neutron flux even if the reactor thermal power stays constant. The trim valves must then adjust feedwater supply to individual boilers to prevent level excursions in the boiler bank.

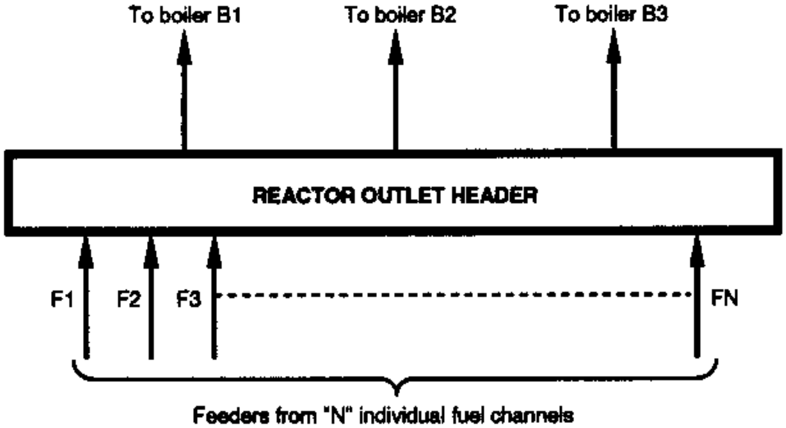


Fig. 2.4. Arrangement of the reactor coolant piping at the inlet to a bank of boilers.

Boiler level ramp

The **main reason** why boiler level is ramped up with increasing reactor power is to accommodate the transient swell and shrink of boiler water with the smallest size of the steam drum. This is shown in Fig. 2.5, where two boilers are compared: one with a constant level setpoint control, the other with a ramped level setpoint. Note that both boilers hold the same water in-

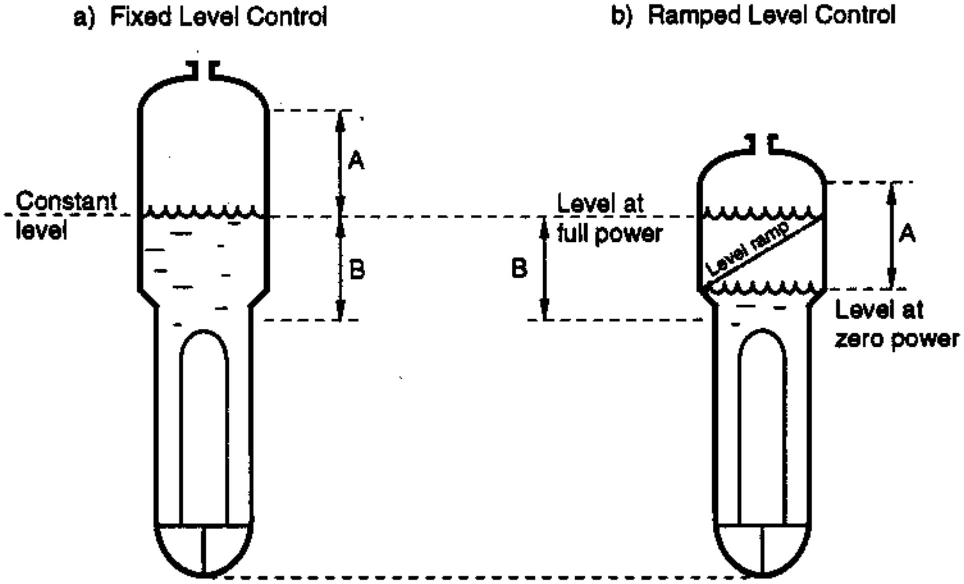


Fig. 2.5. Effect of the type of boiler level control on the minimum size of the steam drum required to accommodate transient shrink and swell:

A = Margin of protection against swell,
B = Margin of protection against shrink.

ventory at full power. Thus, they provide the same post-accident heat sink for the reactor in the event of a loss of feedwater accident. They can also accommodate the same swell and shrink of the boiler water. But the boiler with a ramped level setpoint achieves it with a much smaller steam drum.

Why is it desirable to reduce the steam drum size? First, it decreases the cost and weight of the boiler. Second, it improves its operational characteristics. The smaller the steam drum is, the easier it is to maintain its temperature uniform, thereby minimizing thermal stresses. Heating and cooling of the boiler during unit startup and shutdown is also easier due to its reduced thermal capacity.

Note in Fig. 2.5 b) that at zero power, the level is kept low and there is little room to accommodate any transient shrink. Likewise, at full power, the level is kept high, not leaving much room for a transient swell. This practice is safe because the tendency of boiler water to undergo a transient shrink or swell varies with reactor power. At low power, the potential for transient shrink is small, while a large transient swell can occur. The opposite is true when the unit operates at high power. This is explained below.

Let us first discuss the transient shrink. Recall that its two major causes are a fast reduction in reactor power or a fast increase in boiler pressure. The larger and faster these changes, the larger the resultant transient shrink. Naturally, the fastest reduction in reactor power is due to a reactor trip. Similarly, among typical unit upsets, the fastest increase in boiler pressure is caused by a turbine trip, which abruptly stops steam flow from the boiler. Tripping the turbine or the reactor from a low power level (say, 10% of full power) causes a much smaller transient shrink of boiler water than that experienced if the power level were high. As you can see, **the lower the power level, the smaller the potential transient shrink** of boiler water that can occur.

As for transient swell, recall that its two major causes are a fast increase in reactor power or a fast decrease in boiler pressure. The larger and faster these changes, the larger the resultant transient swell. When the unit operates at high power (say, 90% FP), reactor power cannot be increased much. Thus, the resultant transient swell cannot be large. Ignoring abnormal conditions (such as a steam pipeline break or spurious opening of a steam reject valve), the fastest decrease in boiler pressure is caused by fast turbine loading in the reactor lagging mode of operation. At light loads, the magnitude of this loading, and thus the resultant transient swell, can be much larger than in the case of high power operation. Thus, **the higher the power level, the smaller the potential transient swell.**

SUMMARY OF THE KEY CONCEPTS

- At high and medium power levels, at least three parameters: boiler level, steam and feedwater flow rates, provide input for BLC. At light loads, the flow signals are not used because they become inaccurate.
- Two different sizes of feedwater regulating (boiler level control) valves are used in order to improve feedwater flow control over the whole power range.
- Trim valves are used in banks of boilers to compensate for some differencies in the steaming rates of individual boilers.
- The main advantage of ramping up boiler level with increasing reactor power is a considerable reduction in the minimum steam drum size required to accommodate transient shrink and swell of boiler water while maintaining its adequate inventory.

Protective actions

⇔ ***Obj. 2.1 f)***

Typical automatic protective actions upon an improper boiler level are depicted in Fig. 2.6. Be aware that the information presented in this diagram is very general and somewhat simplified to avoid confusion due to many station specific differences. For instance, in some stations, the setpoints for some of the protective actions depicted in Fig. 2.6 are ramped up with reactor power, somewhat similar to the level setpoint.

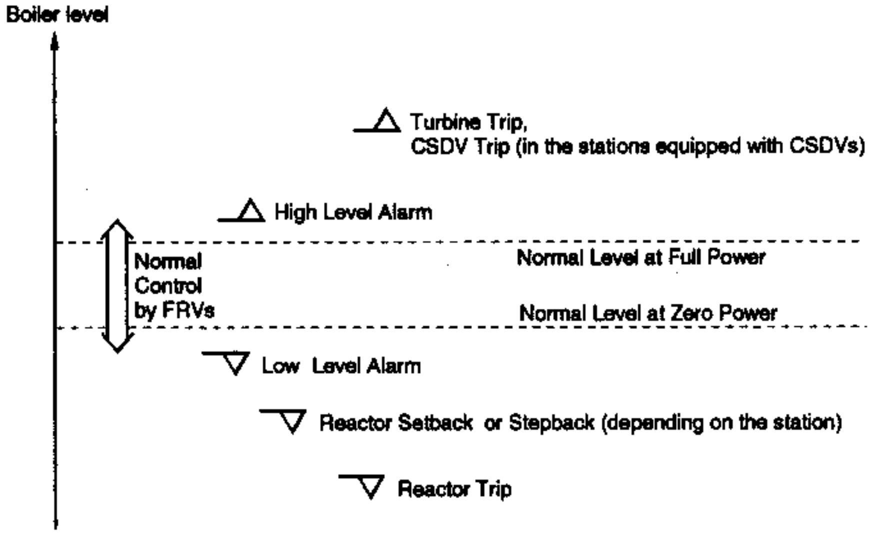


Fig. 2.6. Automatic responses to boiler level:

FRVs = Feedwater regulating (boiler level control) valves;

CSDVs = Condenser steam discharge (dump) valves*.

* Different names of these valves are used in different stations.

NOTES & REFERENCES

First, **an alarm is given to advise the operator about the wrong level.** This gives him/her a chance to investigate the problem and rectify its cause if possible. For example, if the high level alarm is caused by loading the unit too fast, a reduction of the rate of loading may solve the problem.

If the level gets worse, **more drastic actions** are taken, as depicted in Fig. 2.6. Specifically, **in case of too high a boiler level**:

1. The **turbine should be tripped** to prevent serious damage due to water induction;
2. In the stations equipped with **condenser steam discharge**/dump **valves** (CSDVs), they **should trip in the closed position**. Not only does this prevent water hammer in the steam pipelines going to the valves, but it also prevents a further increase in the level due to a transient swell caused by a boiler pressure drop should these valves open.

Too low a boiler level should trigger (in addition to the aforementioned alarm) the two following actions, listed in the order of dropping level:

1. At a certain low level when the boiler tubes are still fully covered, the **reactor power should be set back or stepped back** (depending on the station). By reducing the heat input to the boiler, its steaming rate – and hence, feedwater demand – would be decreased. The available feedwater supply may then be sufficient to prevent a further drop in the level.
2. The **reactor should be tripped** to conserve as much boiler water inventory as possible, and thus defer the moment that the boilers would be lost as a heat sink for the reactor. The extra time gained would help the operator secure some long-term cooling for the reactor before the short-term cooling provided by the boiler water inventory is depleted. Also, tripping the reactor reduces its heat production to a decay heat level where alternate heat sinks (whose heat removal capacity is limited to about 3% of the reactor full power) are adequate.

One more comment – and this is **a universal rule applicable to all operational upsets**: if any of these automatic protective actions has failed to occur, the operator should carry it out manually as soon as he/she realizes what is going on.

Obj. 2.1 g) ⇔

Causes of improper boiler level

There are many possible **causes of improper boiler level**. The most typical of them are listed below:

1. **Too high** a level can occur due to:
   a) **Faulty BLC** which can include, for example, a faulty or miscalibrated level controller or a feedwater regulating valve stuck in open position;

   b) **An excessive transient swell** caused by:
      i) Excessive loading rates;
      ii) Spurious opening of some steam reject (discharge, dump) valves or boiler safety valves;
      iii) A large steam pipeline rupture;
   c) **A massive boiler tube failure** (more about this later).

2. **Too low** a boiler level can be caused by:
   a) **Faulty BLC**;
   b) **Loss of feedwater** due to:
      i) A boiler feedwater pump(s) trip;
      ii) A valving error or valve malfunction such that feedwater flow to the boiler has been cut off or grossly reduced;
      iii) A large leak (eg. a pipeline rupture) in the feedwater system.

Some of these causes affect the levels in only one bank of the boilers, others in all of them. These changes in boiler levels, combined with other accompanying indications (eg. valve positions) allow diagnosis of the actual cause and hopefully, its rectification.

SUMMARY OF THE KEY CONCEPTS

- Too high a boiler level should automatically cause an alarm, a turbine trip and, a CSDV trip (the latter is not applicable to some stations).
- Automatic protective actions upon too low a boiler level include an alarm, reactor setback/stepback (depending on the stations) and finally, a reactor trip.
- Too high a boiler level can be caused by faulty BLC, an excessive transient swell or a massive boiler tube failure.
- Too low a boiler level can occur due to faulty BLC or a loss of feedwater accident.

You can now work on **assignment questions 6-11.**

⇔ ***Pages 29-31***

CARRYOVER

Carryover is an important aspect of boiler operation. In the following section, you will learn what carryover is, how it occurs, and what operating factors affect its severity. You will also learn what potential operational problems carryover can cause and what the operator can do to minimize it.

Types of carryover

Obj. 2.2 a) ⇔

Carryover is defined as the entrainment of various impurities in boiler steam. They can be solid, liquid (mainly water droplets) or gaseous. There are four major mechanisms of carryover as outlined below.

Obj. 2.2 b) ⇔

Volatile carryover is the entrainment of volatile impurities that vapourize in the hot boiler environment and diffuse in boiler steam. Among them silica* is the worst culprit. Fortunately, in CANDU stations, volatile carryover of silica is much less troublesome than in conventional thermal generating stations where boiler pressure and temperature are much higher. This statement is true as long as the silica content in boiler water is kept within specs.

* In power plants, *silica* refers to silicon-containing compounds found in water. These can be hydrated silica (SiO_2*nH_2O) and silicates, especially of calcium and magnesium. Silica can be dissolved or suspended.

Foaming promotes carryover due to the formation of bubbles on the surface of the boiler water. As these bubbles burst, moisture is entrained in the steam. Intensive foaming can also impair the performance of the cyclone separators and steam scrubbers, as the whole steam drum space may be filled up with foam. Oil and other organics can be a cause of very intensive foaming, for they turn into soap in the high pH, high temperature boiler environment.

Priming is a violent spasmodic process (similar to what can be seen in a coffee percolator) which can throw slugs of water into the outlet steam. It can be caused by a sudden surge of steam due to rapid loading or a drop in boiler pressure.

Mist or spray carryover is caused by the formation of very fine water droplets when steam bubbles leave the surface of the boiler water. Due to their very small size, some of these droplets manage to pass through the boiler separators and scrubbers. While foaming and priming can be prevented by proper operating practices, mist carryover exists even during normal operation, resulting in the moisture content of the steam leaving the boiler in the order of 0.2%.

It must be stressed that **moisture carryover results in the entrainment of other impurities in the boiler steam.** This is because water droplets carried over in the steam are like mini-samples of the boiler water. This water is not chemically pure but contains various dissolved and suspended impurities.

Obj. 2.2 c) ⇔

Factors affecting the amount of carryover

1. **Boiler level.**

   If the level is too high, the cyclone separators become flooded which decreases their effectiveness.

NOTES & REFERENCES

2. **Impurities in the boiler water.**

   As mentioned above, **oil and other organics** can result in increased moisture carryover due to foaming on the boiler water surface.

   Inorganic impurities promote spray carryover, eg. due to a reduction in the surface tension of the boiler water. It is agreed that, part for part, suspended solids have a larger effect on carryover than dissolved impurities.

3. **Steam release rate**, ie. the steam flow rate per unit surface area of the boiler water.

   If the steam release rate is excessive, the cyclone separators and steam scrubbers become overloaded, allowing more moisture to pass through. This problem can happen when the steam flow from one or more boilers is excessive. For example, a rapid loading can increase moisture carryover not only through a transient swell flooding the separators, but also through a temporary overloading of the separators as the steam rushes out of the boilers.

4. **Mechanical condition of the cyclone separators and steam scrubbers.**

   Improper design or any damage or deterioration can reduce their effectiveness and hence increase moisture carryover.

Adverse consequences and operating concerns caused by carryover

⇔ *Obj. 2.2 d)*

Carryover of water and other impurities in boiler steam can have some detrimental effects on the turbine and the steam system. In the extreme case, enough water can be carried over into the main steam piping to cause water hammer there and possibly water induction to the turbine, leading to severe damage to this equipment. The description below does not cover these acute upsets. Instead, it addresses the typical chronic carryover where **water in boiler steam exists in the form of fine mist** rather than large slugs. Such **chronic carryover** can cause the following adverse consequences/operating concerns:

1. **Erosion** of steam pipelines, valves and turbine components. It increases maintenance costs and, in extreme case, may result in equipment failure. Also, steam valves may leak when closed due to some erosion damage to their seats and discs. Finally, badly eroded turbine blades decrease the turbine efficiency, and hence increase the fuel consumption.

2. Accelerated **corrosion** in the main steam system and the turbine. As mentioned in the preceding module, corrosion and erosion often assist each other, accelerating wear of the equipment. Again, maintenance

costs are increased, and component failures (eg. due to stress corrosion cracking) are more likely.

3. Formation of **deposits** in the steam valves and the turbine. The deposits can hinder the operation of the steam valves to such an extent that the turbine can get severely damaged during an emergency condition such as a turbine trip*. Deposits – in which the concentration of corrosive impurities is very high as compared with the steam – also accelerate various corrosion mechanisms, eg. stress corrosion cracking of blade roots. Finally, deposits on the blade surface reduce the turbine efficiency, thereby increasing the fuel costs.

* More information on turbine trip is provided in the next module.

4. **Reduced turbine efficiency** due to increased wetness of the HP turbine steam. This compounds to the loss of efficiency due to erosion and deposits in the turbine as mentioned above. As a result, operating costs are increased.

Note that although chronic carryover, as opposed to water induction, cannot cause immediate damage, some damage can eventually happen if operation with an excessive carryover is continued long enough.

Obj. 2.2 e) ⇔

Operating practices used to minimize carryover

Carryover cannot be eliminated entirely. However, **prudent operating practices can limit the wetness of the boiler outlet steam** to about 0.2% and often less than that. Also, the concentration of chemical impurities in the turbine steam can be kept well below the limits specified by the turbine manufacturers. If these conditions are met, the adverse consequences described above are very limited and – as shown by operating experience in CANDU stations – do not cause any serious operational problem. This can be achieved by the use of the following general operating practices:

1. **Proper boiler level control**, including measures such as: accurate calibration of the level controllers, proper maintenance of the feedwater regulating valves and the trim valves, as well as a prompt operator response to level alarms.

2. **Maintaining the boiler water chemistry within specification**. This includes proper blowdown of boiler water, good chemical treatment and degassing of the boiler feedwater, prompt isolation of impure makeup water supply and prompt corrective actions in response to a condenser leak.

3. **Not exceeding the allowable steam release rate**. In most CANDU stations, this is equivalent to not exceeding the maximum allowable loading rate. Recall that loading the unit too fast can result not only in an excessive transient swell, but also in a larger-than-normal steam release rate when the steam rushes out of the boiler. As loading

does not last long in comparison with steady power operation (particularly so in the case of base load units), excessive loading rates cannot contribute much to the long-term consequences of chronic carryover. Instead, they can promote water induction and result in a turbine trip on a very high boiler level.

In some units, however, it is possible to overload some boilers even during a steady power operation. In these stations, the HT system is designed such that individual boilers can be isolated from the coolant flow and yet operation can be continued. This can lead to excessive steaming rates in the boilers remaining in service if the unit output is not reduced appropriately. Compared with excessive loading rates, this operation can last much longer, thereby aggravating the adverse consequences of chronically increased carryover.

SUMMARY OF THE KEY CONCEPTS

- Carryover is defined as entrainment of various impurities (solid, liquid or gaseous) in the boiler steam.
- There are four mechanisms of carryover: volatile carryover, priming, foaming and mist (spray) carryover.
- The amount of moisture carryover is affected by the boiler level, impurities in the boiler water, steam release rate and, condition of the separators and scrubbers.
- Carryover accelerates erosion and corrosion in the main steam system and the turbine. Chemicals in the steam can form deposits in the steam valves and the turbine. Finally, the average moisture content of the HP turbine steam is increased which, along with erosion and deposits in the whole turbine, reduces the turbine efficiency.
- Carryover cannot be eliminated entirely but certain operating practices, such as proper boiler level control, maintaining high purity of the boiler water and not overloading the boilers with excessive steaming rates, can greatly minimize it.

You can now work on **assignment questions 12-18.**

⇔ Pages 31-33

BOILER TUBE LEAK

Boiler tubes are a part of the HT system pressure envelope that houses the reactor coolant. Hence, any tube leak is potentially dangerous because the integrity of the pressure envelope is jeopardized. As the pressure difference across the boiler tubes is as high as 5-6 MPa, a full guillotine cut of just one tube can result in a large leak*. Fortunately, typical tube leaks are much smaller – in the order of a few kg/h.

* In the order of 7-9 kg/s, depending on the station.

This section covers the following aspects of a boiler tube leak:

- Adverse consequences;
- Indications;
- Identification of the faulty boiler;
- Effects on unit operation;
- Prevention.

Obj. 2.3 a)⇔

Adverse consequences of a boiler tube leak

The adverse consequences of a boiler tube leak depend strongly on its size. In the extreme case of **massive failure of several tubes**, the leak rate **would** be large enough to **cause**:

1. **Acute problems with the boiler level control.**

   More specifically, **the level in the faulty boiler would rapidly rise, tripping the turbine within a few seconds** after the tubes have failed. In the stations where banks of boilers are used, the other boilers in the bank would experience falling levels. This would happen due to the common feedwater regulating valve closing in response to the very high level in the faulty boiler*. The falling levels would trigger some automatic protective actions as described earlier in the module.

2. **Dropping HT pressure.**

   A massive failure of boiler tubes can exceed the capacity of the HT pressurizing system, causing the coolant pressure to drop. This would mean **a loss of coolant accident** (LOCA) with its potential adverse consequences as outlined in the 233 and 225 courses. A long shutdown would be required for boiler repairs and possibly upgrading of the reactor coolant if any light water has been injected into the coolant during the LOCA.

* Recall from the I&C courses that in a bank of boilers, the highest level is selected to control the common feedwater regulating valve.

Although a **small boiler tube leak** would not cause the above acute problems, it would still have the following serious adverse consequences:

1. **Radioactive releases to the steam and feedwater cycle systems and the environment.**

   Recall that the reactor coolant contains tritium, other activation products and possibly some fission products. A boiler tube leak causes these radioactive substances to mix with the boiler water and steam, and thus spread throughout the whole steam and feedwater cycle. This opens a few paths for unmonitored radioactive releases to the environment such as:

   a) Via the boiler blowdown, deaerator vents, and the condenser air extraction system;

b) Via those steam valves (eg. boiler safety valves) which are normally closed, but can open during some operational transients or upsets, discharging boiler steam to atmosphere.

2. **Increased operating costs due to the cost of replenishing the leaking reactor coolant.**

   Heavy water used for reactor cooling is very expensive. Its cost is in the order of several hundred dollars per kilogram. Therefore, the cost of the coolant lost due to a boiler tube leak may be too high* to make continued operation financially sound.

Either consequence can force a unit outage, resulting in a loss of production.

* For example, assuming a coolant price of $500/kg, a leak rate of 10 kg/h would cost about $5,000/h (or about $120,000 a day).

Indications of a boiler tube leak and identification of the faulty boiler

⇔ Obj. 2.3 b)

How can a boiler tube leak be recognized and how can the faulty boiler be identified? To answer these questions let us focus attention on the fact that although there is a leak in the HT system, it is specifically located inside a boiler rather than somewhere else in the reactor vault or the boiler room. This generates a specific combination of **indications**, some associated with the HT system, others with the boilers. The following list gives the most indicative of those:

1. **Increased radioactivity of boiler steam and water.**

   Usually, a small boiler tube leak is indicated by an **increased concentration of tritium** in samples of boiler water and steam that are routinely analyzed by the chem lab. **If the leak is large enough**, an alarm on a **high D_2O-in-H_2O concentration** can be received if this parameter is measured automatically by an on-line analyzer. The presence of either indication strongly suggests a boiler tube leak.

2. **Dropping D_2O storage tank level combined with symptoms that suggest no D_2O leak in locations other than the boiler.**

   Listed below are a few examples of such symptoms:

   a) Absence of new beetle alarms;

   b) Normal pressure, temperature and humidity in the boiler room, the reactor vault and the annulus gas system;

   c) No change in the HT D_2O collection rate.

   Note that various minor losses of the HT D_2O occur even during normal operation, requiring periodic additions of D_2O to the tank to restore its level. Therefore, **only a massive boiler tube failure** – and not a small chronic leak – can cause a noticable drop in this level that can be attributed to a boilure tube leak, and not another cause.

3. **Possible boiler level problems and dropping HT pressure in the event of a very large leak.**

   It is very unlikely that large tube leaks would develop simultaneously in different boilers. Therefore, usually only one bank of boilers would be affected, while the others would be showing normal levels. In this bank of boilers, the leaking one would experience a rising level and the other boilers falling levels as explained earlier in the module. In the stations where each boiler has its own set of feedwater regulating valves, the leaking boiler would show a high level, whereas the other boiler levels would be normal. These characteristic level indications allow **identification of the leaking boiler** which simplifies repairs.

In the case of a small chronic tube leak, **identification of the faulty boiler** is much more difficult. The **classic method** relies on comparing the **tritium content** of water and steam samples taken from individual boilers. However, during normal unit operation, the analysis results are often inconclusive due to contamination of the other boilers with tritium from the leaking boiler via a recirculation of boiler steam and feedwater. More conclusive results can be achieved during unit shutdown (with the HT system pressurized) when this recirculation – and hence, the cross-contamination – can be stopped.

A **new method** of identifying the boiler with a small chronic leak has been recently used with a great success. The method relies on **monitoring the boiler outlet steam for** the characteristic gamma radiation produced by decaying **nitrogen 16** - an activation product created in the HT system. Because N-16 has a very short half-life, its recirculation into the nonleaking boilers is minimized, making this a more effective method.

Effects of a boiler tube leak on unit operation

Obj. 2.3 c) ⇔

As mentioned earlier, a **massive boiler tube failure** quickly causes a very high level in the faulty boiler. To protect the steam system and the turbine from water induction, **the turbine is automatically tripped.**

Obj. 2.3 d) ⇔

If the leak is small enough to cause no acute problem, operation may or may not be continued. The decision is based on **monitoring** of the following typical parameters:

1. **The leak rate.**

   Recall that the rate at which the D_2O storage tank level is dropping is useful only in determining the size of a large acute leak. The common method that is used to estimate the rate of a small leak is based on the rate at which the tritium content in boiler feedwater is rising.

   Monitoring of the leak rate allows us to determine if it is stable or increasing. In the latter case, the rate at which the leak is increasing can affect scheduling the nearest outage.

In addition, the following parameters are usually monitored to make sure that the emission limits will not be exceeded:

2. **Tritium concentration in boiler water and steam;**
3. **I-131 concentration in boiler water***.

* Samples of boiler steam are normally not analyzed for the presence of I-131 because it is nonvolatile in the alkaline boiler water environment.

To decide if operation can be continued, **the monitored parameters are checked against the limits** that are specified in the appropriate operating manuals. Based on the results of these checks, the earliest shutdown can be scheduled. In the extreme case, the unit must be shut down immediately (even though there are no acute problems with controlling boiler level and HT pressure) in order to avoid excessive radioactive releases and/or loss of expensive D_2O.

Prevention of boiler tube leaks

⇔ ***Obj. 2.3 e)***

Boiler tube failures have plagued many nuclear stations in the world. In extreme cases, plugging of the failed tubes resulted in derating some units to a point that the entire retubing of their boilers had to be carried out. The high costs of repairs and lost production led to comprehensive follow-up analyses of the root causes of the tube failures. These analyses, performed by many utilities, boiler manufacturers and research institutes, indicated improper chemistry of the reactor coolant and boiler water as one of the most typical causes of tube failures. Many failures turned out to have been caused by **various corrosion mechanisms** (tube denting and stress corrosion cracking being most common) promoted by improper chemistry of the two fluids. Hence, it follows that in many cases, boiler tube **failures can be prevented by proper chemical control of the HT D_2O and boiler water**. To be effective, this must be done during **all operating conditions, including shutdowns.**

SUMMARY OF THE KEY CONCEPTS

- Any boiler tube leak results in some radioactive releases to the environment and loss of expensive D_2O.
- A large leak can also cause acute boiler level problems and a LOCA with all their potential adverse consequences.
- Normally, a small boiler tube leak is detected through increased boiler steam and water radioactivity. A larger leak can be inferred from dropping D_2O storage tank level and symptoms that suggest no D_2O leak in locations other than the boilers. In the case of a very large leak, acute boiler level problems and dropping HT pressure would also be present.
- If the leak is large enough, the faulty boiler can be identified by its high level combined with normal or low level in the remaining boilers.

NOTES & REFERENCES

- The classic method of identifying the boiler with a small chronic leak relies on comparing the tritium content in samples of steam and water from individual boilers. A new, more conclusive method relies on monitoring the boiler outlet steam for the presence of N-16.
- In the event of a massive tube failure, a turbine trip on a very high boiler level can occur very quickly (a few seconds after the tube failure).
- In the case of a small leak, operation may or may not be continued, depending on the leak size (including the rate at which it is increasing), the tritium concentration in boiler water and steam, and the I-131 concentration in boiler water.
- Many boiler tube failures can be prevented by maintaining proper chemical control of the HT D_2O and the boiler water during all operating conditions, including shutdowns.

Pages 33-35 ⇔

You can now work on **assignment questions 19-25.**

ASSIGNMENT

1. Too high a boiler level can cause the following adverse consequences and operating concerns:

a) Consequence/concern: ______________________________

____

The reason why the high level causes it: ________________

____

____

b) Consequence/concern: ______________________________

____

The reason why the high level causes it: ________________

____

____

c) Consequence/concern: ______________________________

____

The reason why the high level causes it: ________________

____

____

2. a) Even when boiler tubes are still fully covered, a low boiler level is potentially dangerous because ______________________

____

____

____

____

b) Uncovering of boiler tubes creates an acute problem with reactor cooling because ______________________________

____

____

____

____

3. a) During steady operation at different reactor power levels, the average density of boiler water (decreases / increases / stays constant) with rising reactor power because ________________

____

____

b) If a constant boiler level were maintained throughout the whole power range, the boiler water inventory would (decrease / increase / stay constant) with rising power level.

c) If a constant boiler water inventory were maintained throughout the whole power range, the boiler level would (decrease / increase / stay constant) with rising power level.

4. a) Transient swell is defined as ________________________

____

____

b) The two major operational causes of transient swell are:

i) ____

ii) ____

c) The following dynamic effects make transient swell happen:

i) ____

____

____

ii) ____

____

____

iii) ____

____

____

d) Transient swell is a short-lasting phenomenon because _______

____

____

5\. a) Transient shrink is defined as ______

b) The two major operational causes of transient shrink are:

i) ______

ii) ______

c) The following dynamic effects make transient shrink to happen:

i) ______

ii) ______

d) Transient shrink is a short-lasting phenomenon because ______

6\. a) During unit startup and at low power, boiler level is controlled by the same valves as during high power operation. (False / true)

b) At high power, boiler level control is based on the following signals:

i) ______

ii) ______

iii) ______

In new stations, advanced computerized BLC uses also other signals such as ______

c) At low power, the ______ signals are not used for BLC because ______

7. a) The major reason why the steaming rates of apparently identical boilers are different is that ______________________________

____

____

____

   b) This is compensated for by ______________________________

____

8. a) The maximum potential for a boiler water swell exists when the unit operates at (full power / zero power).

   b) The maximum potential for a boiler water shrink exists when the unit operates at (full power / zero power).

   c) The major advantage of ramping boiler level up with increasing reactor power is ______________________________

____

____

9. a) The reason why the turbine is tripped upon a very (high / low) boiler level is to ______________________________

   b) The reason why the reactor is set or stepped back upon a (high / low) boiler level is ______________________________

____

____

   c) Two reasons why the reactor is tripped upon a very (high / low) boiler level are:

      i) ____

      ____

      ____

      ii) ____

      ____

      ____

10. a) Excessively high boiler level can be caused by:

    i) ______________________________

    ii) ______________________________

    iii) ______________________________

    b) An excessive swell of boiler water can be caused by:

    i) ______________________________

    ii) ______________________________

    iii) ______________________________

11. a) Too low a boiler level can be caused by:

    i) ______________________________

    ii) ______________________________

    b) A loss of feedwater accident can occur due to:

    i) ______________________________

    ii) ______________________________

    iii) ______________________________

12. a) Carryover is defined as ______________________________

    ____

    b) Moisture carryover contributes to the entrainment of other impurities in boiler steam because ______________________________

    ____

    c) Moisture carryover and water induction (are / are not) synonymous terms.

13. The major mechanisms of carryover are as follows:

    a) Name: ______________________________

    Description: ______________________________

    ____

    ____

    b) Name: ______________________________

    Description: ______________________________

    ____

    ____

c) Name: ______________________________

Description: ______________________________

____

____

d) Name: ______________________________

Description: ______________________________

____

____

14. The amount of moisture carryover in boiler steam is affected by the following factors:

a) ______________________________

because ______________________________

____

b) ______________________________

because ______________________________

____

c) ______________________________

because ______________________________

____

d) ______________________________

because ______________________________

____

15. Foaming of boiler water is promoted by ______________

16. Chronic carryover may cause equipment damage due to:

a) ______________________________

b) ______________________________

c) ______________________________

17. Carryover reduces the turbine efficiency by:

a) ______________________________

b) ______________________________

c) ______________________________

18. To minimize carryover, the following general operating practices are used:

    a) ____

    ____

    ____

    b) ____

    ____

    ____

    c) ____

    ____

    ____

19. a) A small chronic boiler tube leak has the following adverse consequences:

    i) ____

    ____

    ii) ____

    ____

    b) A large boiler tube leak can also have the following adverse consequences:

    i) ____

    ii) ____

    c) Some typical paths for unmonitored radioactive releases to the environment due to a boiler tube leak are:

    i) ____

    ii) ____

20. a) A small leak of a boiler tube is indicated by ______________

    ________________________________ and possibly by

    ____

    b) A large acute leak can also be indicated by:

    i) ____

    ii) ____

c) The following indications suggest that a D_2O leak is located in a boiler rather than somewhere else in the HT system:

i) ____

____

ii) ____

____

iii) ____

____

21\. a) When the boiler tube leak is so large as to cause acute operational problems, the faulty boiler can be identified by ____________

____

____

b) In case of a leak small enough to allow for continued operation, the faulty boiler can be identified by either method:

i) ____

____

____

ii) ____

____

____

22\. A very large leak results in the following automatic protective action:

____

23\. In the case of a small chronic leak,:

a) operation can be continued on condition of frequent monitoring and evaluation of:

i) ____

ii) ____

iii) ____

b) the leak rate and the rate at which it is increasing can be estimated by ________________________________

____

NOTES & REFERENCES

24. A boiler tube leak can force a maintenance outage for the following reasons:

    a) ____

    b) ____

25. To prevent boiler tube leaks, __________________________

    __________________ must be maintained during all operating

    conditions, including ______________________________

Before you move on to the next module, **review the objectives** and make sure that you can meet their requirements.

Prepared by: J. Jung, ENTD
Revised by: J. Jung, ENTD
Revision date: May, 1994

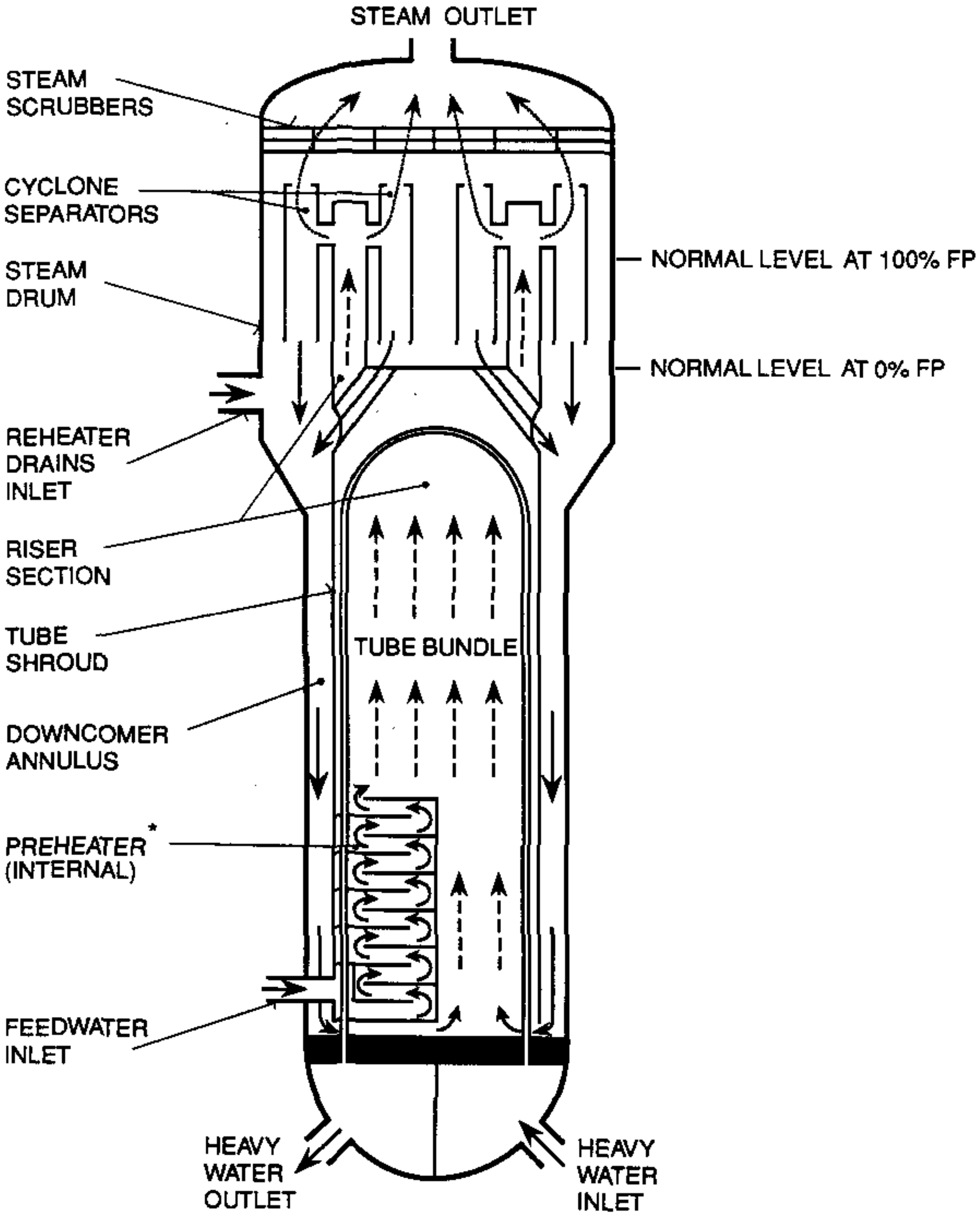


Fig. 2.7. Simplified boiler (steam generator) with a built-in preheater:

——→ Flow paths of water;
- - - - - → Flow paths of water with steam bubbles;
———→ Flow paths of steam.

Note: Some stations have external preheaters.