Module 234-5

THE CONDENSER AND ITS AUXILIARY SYSTEMS

OBJECTIVES:

After completing this module you will be able to:

5.1 a) State the main reason why operating limits are placed on the condenser cooling water (CCW) outlet temperature and temperature rise across the condenser. ⇔ ***Page 4***

  b) Describe three general operating practices used to meet the above limits. ⇔ ***Page 4***

5.2 a) Describe three general operating practices used to minimize water hammer during CCW pump startups and normal shutdowns (not trips). ⇔ ***Page 5***

  b) For the vacuum breakers in the vacuum priming system: ⇔ ***Pages 5- 6***

    i) State the major operating event that triggers their operation;

    ii) State the purpose of their operation;

    iii) Describe how they operate to achieve this purpose.

5.3 Explain the effect of a change in condenser pressure on the turbine steam flow and generator output. Consider the reactor lagging and reactor leading modes of unit operation. ⇔ ***Pages 7-9***

5.4 a) Explain the adverse consequences/operating concerns caused by improper condenser vacuum:

    i) Reduced vacuum (4); ⇔ ***Pages 10-12***

    ii) Excessive vacuum (2). ⇔ ***Pages 14-16***

  b) List the following actions and explain how each of them alleviates the improper condenser vacuum:

    i) Five automatic actions carried out when condenser pressure is too high; ⇔ ***Pages 12-14***

    ii) Two actions that the operator may take upon high condenser pressure in an attempt to restore normal pressure while the original problem is being diagnosed and rectified; ⇔ ***Page 12***

NOTES & REFERENCES

Page 16 ⇔ iii) Two actions that the operator may take in response to excessive vacuum.

Page 11 ⇔ c) State the provision that is made to protect the condenser and LP turbine exhaust cover from overpressure.

Pages 18-20 ⇔ 5.5 a) List six major causes of low condenser vacuum and explain why each of them results in decreased vacuum.

Pages 20-21 ⇔ b) Assuming a constant load, determine the actual cause of poor condenser vacuum, given the following parameters:

- CCW inlet and outlet temperature;
- CCW flow rate;
- Condenser pressure and corresponding saturation temperature;
- Hotwell temperature,

for:

i) Normal operation, and

ii) Upset conditions.

Page 21 ⇔ 5.6 a) State the purpose of breaking condenser vacuum during turbine rundown.

Page 22 ⇔ b) Describe how condenser vacuum is broken.

Page 22 ⇔ c) State the reason why breaking condenser vacuum at high turbine speeds is not recommended during a normal turbine shutdown.

Pages 22- 23 ⇔ d) List three turbine generator operational upsets that require this action at high turbine speed.

Page 23 ⇔ e) i) Describe two methods of relieving condenser vacuum during a normal turbine shutdown.

ii) State the merits and disadvantages of each of these methods.

Pages 24-25 ⇔ 5.7 a) State three potential condenser problems caused by main steam being rejected into the condenser via the condenser steam discharge valves (CSDVs).

Pages 25-26 ⇔ b) i) List three operating parameters that can trip the CSDVs and two parameters that can restrict their opening.

ii) Explain why each of these parameters affects the CSDV operation.

NOTES & REFERENCES

5.8 a) Describe three major consequences/operating concerns caused by a chronic condenser tube leak. ⇔ ***Pages 27-28***

b) State two indications of this abnormality. ⇔ ***Pages 28-29***

c) i) State one important action that the operator should take to minimize the consequences of a chronic leak while it is being located and repaired. ⇔ ***Page 29***

ii) Explain why this action should be taken.

d) Describe: ⇔ ***Page 30***

i) One method of identifying the leaking condenser;

ii) Two methods of finding out which half of this condenser is leaking.

5.9 a) Describe the method that can be used to monitor the rate of air leakage into the condenser. ⇔ ***Page 31***

b) State two important actions that the operator should take to minimize the consequences of increased air in-leakage while it is being located and repaired. ⇔ ***Page 32***

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INSTRUCTIONAL TEXT

INTRODUCTION

The previous turbine courses describe the functions of the major condenser components and auxiliary systems. Based on this general knowledge, the following topics are covered in this module:

- Assorted operational limitations and problems in the condenser cooling water system;
- Operation with abnormal condenser vacuum;
- Breaking of condenser vacuum;
- Operating concerns and limits associated with the condenser steam discharge (dump) valves;
- CCW and air leaks.

For easy reference, simplified pullout diagrams of a typical condenser (Fig. 5.6) and CCW system (Fig. 5.7) are attached at the end of the module.

ASSORTED OPERATIONAL LIMITATIONS AND PROBLEMS IN THE CONDENSER COOLING WATER (CCW) SYSTEM

Operational limits

Obj. 5.1 a) ⇔

You will recall that the CCW system circulates large quantities of cooling water in order to condense the steam entering the condenser. Naturally, during this process the cooling water temperature increases. Because the **station effluent** is warmer than the intake water, it can **influence the local aquatic life**, promoting the growth of some species and endangering others. To minimize this thermal pollution of the environment, **some limits are imposed on the cooling water temperature rise (ΔT) and the effluent temperature (T_E).** Some of these limits are absolute (ie. should never be exceeded), while the others are time-dependant (ie. can be exceeded for a limited period of time). Note that in multiple unit stations, **these limits apply to the whole station**, and not the individual units.

Obj. 5.1 b) ⇔

Both ΔT and T_E increase with increasing thermal load on the condensers and/or decreasing CCW flow rate. In addition, T_E increases with rising CCW inlet temperature. From this, you can see that exceeding the ΔT and/or T_E limits is possible when the CCW flow rate is too small for the actual heat load on the condensers. In addition, the T_E limits can be exceeded when the available cooling water is too warm (eg. during a hot summer day). Consequently, one or more of the following **actions** must be taken **if any one of these limits is exceeded**:

1. **Placing another CCW pump** (if available) **in service.**
2. **Eliminating obstructions to the CCW flow.**

   For example, this can be achieved by:

   - Checking the pressure drop across the CCW intake screens (and cleaning them if necessary);
   - Checking the operation of the vacuum priming system to make sure that the CCW flow through the highest condenser tubes is not blocked due to excessive accumulation of gases in the condenser water boxes;
   - Mechanical cleaning of the fouled condenser tubes (if other actions failed). This would also enhance heat transfer through the tubes.
3. **Derating the station** if the above actions have failed to raise the CCW flow rate satisfactorily.

In some stations, in addition to the above methods, special tempering water pumps are available to dilute the station effluent with fresh intake water if necessary to meet the T_E limits.

Water and steam hammer prevention

⇔ *Obj. 5.2 a)*

The very large CCW flow rate results in enormous kinetic energy of the flowing water, and hence it promotes severe water hammer during CCW pump startups, shutdowns and trips. To minimize water hammer, the following general **operating practices** are **used during CCW pump startup and shutdown**:

1. **A sufficient time delay* before the next pump is started up or shut down.**

   This allows the energy of pressure waves in the system to dissipate before the system is subjected to another flow surge.

2. **Proper position and slow opening/closing of the CCW pump discharge valve during pump startup and shutdown.**

   More specifically:

   a) Each CCW pump is started against its discharge valve fully closed or slightly pre-opened (depending on the station), and then the valve opens gradually;

   b) During normal pump shutdown, first the discharge valve closes gradually, and when it is fully closed (or nearly fully closed, depending on the station), the pump motor is switched off.

   Both these techniques minimize flow and pressure surges in the CCW system.

3. **Opening the condenser outlet isolating valves before the first CCW pump is started up.**

   This prevents a water collision with these valves when the first water is delivered by the pump.

In most stations, the above practices are incorporated into the automatic controls of the CCW pumps and valves.

⇔ *Obj. 5.2 b)*

Note that the normal pump shutdown technique described in point 2b) above does not apply to **pump trips** during which the pump motor is switched off immediately **while the pump discharge valve is still fully open. If not counteracted**, this **could result in severe steam hammer** in the CCW system, particularly if all the CCW pumps tripped simultaneously.

Here is how severe steam hammer could develop under these circumstances. Upon a CCW pump trip, the water flow through the system decreases as the water column loses its forward momentum. Because the condensers are located a few meters above the CCW pumps, the water ascending into the condensers (ie. moving against the gravitational forces) slows down faster than the outlet water which descends into the discharge duct. As a result, **separation of the water column** can occur in the condenser outlet boxes.

* About 5 minutes.

Large vapour pockets would be created there, and the vapour pressure would be very low due to the low CCW temperature*. This **high vacuum** in itself **could overstress the water box covers and the CCW piping**. In addition, the high vacuum would pull the separated water columns towards each other. The resultant reverse flow would eventually lead to condensation of the vapour pockets and a **collision of the water columns. The high pressure surges produced could severely damage the CCW system.**

* Note that the saturation pressure corresponding to 10-20°C is in the order of 1-2 kPa(a).

In most stations, the above adverse consequences are **prevented by** operation of fast acting valves, commonly referred to as **vacuum breakers.** They are part of the vacuum priming system and are connected to the condenser outlet water boxes (see Fig. 5.7 on page 48). The vacuum breakers – normally closed – open automatically for several seconds upon a CCW pump trip. As atmospheric air is sucked into the discharge boxes, excessive vacuum is prevented. When the vacuum breakers close, an air cushion is formed inside the water boxes which prevents violent collisions of the separated water columns.

Note that the amount of the admitted air should not be so large as to cause a total loss of siphon in the CCW system. Otherwise, a trip of just one CCW pump would result in a turbine trip on high condenser pressure due to loss of the CCW flow. To prevent this undesirable outcome:

- The number of the vacuum breakers called upon to operate decreases with decreasing number of the CCW pumps that have tripped;
- The vacuum breakers open only for several seconds.

Both features limit the amount of the admitted air, allowing the CCW pump(s) that remains in service to maintain some flow, while the vacuum priming system gradually evacuates the admitted air.

SUMMARY OF THE KEY CONCEPTS

- Limits are imposed on the CCW temperature rise and the station effluent temperature in order to minimize their negative effect on the local aquatic life.
- If any one of these limits is exceeded, proper actions must be taken. These actions include placing another CCW pump in service, eliminating obstructions to CCW flow and, derating the station if the other actions have failed.
- To minimize water hammer in the CCW system, proper pump startup and shutdown operating practices are used. In addition, vacuum breakers are installed in the CCW system to protect it against severe steam hammer caused by a CCW pump trip.

Pages 33-35 ⇔

You may now go to **assignment questions 1-3.**

NOTES & REFERENCES

OPERATION WITH ABNORMAL CONDENSER VACUUM

In this section, you will learn about the following:

- How the turbine steam flow and generator output change with condenser vacuum;
- What adverse consequences and operating concerns are caused by improper condenser vacuum;
- What major automatic and operator actions are taken in response to improper vacuum;
- How the actual cause(s) of poor vacuum is diagnosed.

Effect of a change in condenser vacuum on the turbine steam flow and generator output

⇔ *Obj. 5.3*

Recall that during normal operation, condenser pressure is about 4-6 kPa (a), ie. very close to perfect vacuum. Obviously, this pressure cannot be reduced much. On the other hand, its increase is also limited. If the pressure rises to a certain level (10-40 kPa(a), depending on the station), automatic vacuum unloading* causes the governor valves to reduce the turbine steam flow. A turbine trip would follow if condenser pressure increased to about 25-50 kPa(a), depending on the station.

What about the effect of condenser pressure on the turbine steam flow and generator output **when condenser pressure is below the level at which unloading begins**? It turns out that **the answer** to this question **depends on the unit operation mode** as follows:

1. **Reactor leading mode.**

   Recall that in this mode, reactor power is controlled independently (typically, it is maintained constant), whereas boiler pressure is controlled by adjusting the turbine steam flow. Let us now assume the most typical case of maintaining reactor power constant. At first glance, it appears that a change in condenser pressure should result in some change in the turbine steam flow, eg. an increase in the pressure should reduce the flow. In reality, the change is so small that for all practical purposes **the flow remains constant**. The reason: the maximum possible change in condenser pressure (only a few kPa under the above assumption that unit unloading is not triggered) is extremely small in comparison with the turbine inlet pressure which is typically in the order of 4,000-4,500 kPa(a).

   Unlike the turbine steam flow, **the generator output changes with condenser pressure** because the enthalpy drop in the turbine is affected. That is, when condenser pressure increases, the generator output

* More details about this and other automatic actions carried out upon high condenser pressure are given later in this module. You are not required to memorize the quoted values of condenser pressure – they are given here only for orientation purposes.

decreases because each kilogram of the turbine steam does less work. Conversely, when condenser pressure decreases, the generator output tends to increase. However, excessive condenser vacuum may finally reduce the generator output slightly as shown in Fig. 5.1.

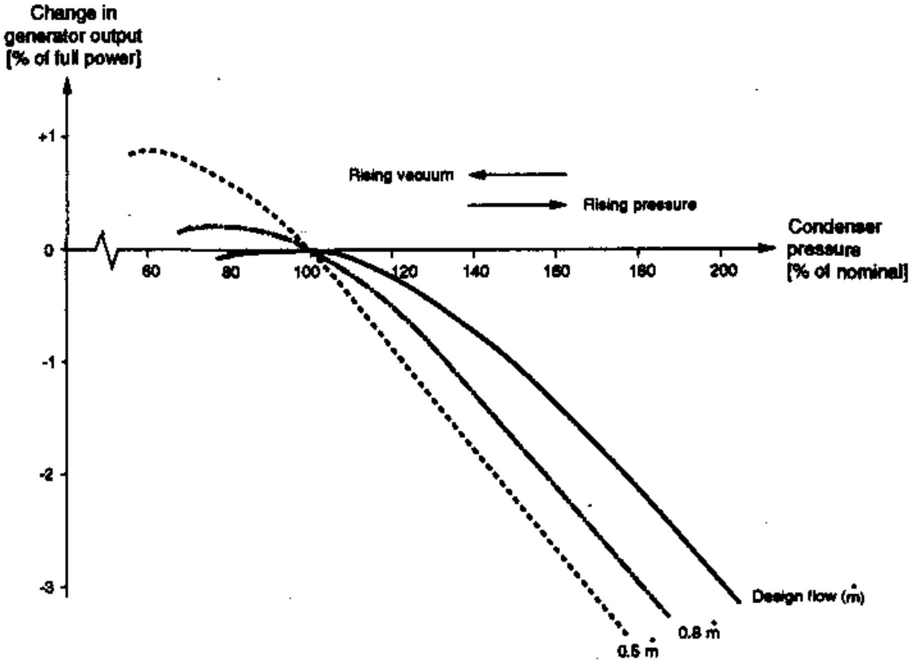

Fig. 5.1. Approximate effect of condenser pressure on generator output at different turbine inlet steam flow rates.

The effect is caused by increased losses in the turbine last stage. These losses increase because of:

a) Excessive amount of available heat which causes steam to flow too fast. As a result:

   i) The steam flow pattern in the last stage poorly matches the blade shape as discussed in module 234-1;

   ii) Friction losses increase*;

   iii) Unused kinetic energy of the turbine exhaust steam increases. At the turbine exhaust, steam kinetic energy (which comes from steam heat) is useless because it is too late for its conversion into turbine MW output. Therefore it is an energy loss, often referred to as *turbine exhaust* loss.

b) Increased steam wetness (as condenser pressure decreases, the turbine can extract more heat from the steam).

* Recall that friction losses increase with the second power of velocity.

At partial loads, these effects are weaker since the exhaust steam is dryer, and the last stage inlet pressure is reduced in comparison with normal full power operation. Therefore, at partial loads, the loss of generator output starts at higher condenser vacuum. The lower the load, the higher the vacuum at which this undesirable effect occurs.

2. **Reactor lagging mode.**

   Recall that in this mode, the overall unit control typically attempts to maintain the generator output by adjusting the turbine steam flow. The resultant changes in boiler pressure are compensated by appropriate adjustments to reactor power. Because changes in condenser pressure affect the amount of work performed by each kilogram of **turbine steam, its flow rate must be adjusted in order to maintain the generator output**. For instance, when condenser pressure rises above its nominal level, the turbine steam flow must be increased. Consequently, reactor power must also increase. Of course, **once a limit on the governor valve opening or reactor power is reached, any further increase in condenser pressure results in a corresponding drop in the generator output while the turbine steam flow stays constant at its maximum achievable level**.

SUMMARY OF THE KEY CONCEPTS

- Excessive condenser pressure can result in unit unloading which can be followed by a turbine trip if condenser pressure rises enough. These actions are carried out regardless of the unit operation mode prior to the loss of condenser pressure.
- When the unit operates in the reactor leading mode with reactor power maintained at a constant level, moderate changes in condenser pressure result in opposite changes in generator output, while the turbine steam flow remains constant. An excessive increase in condenser vacuum can finally result in a slight reduction in generator output because the performance of the turbine last stage deteriorates due to increased steam wetness and excessive available heat.
- In the reactor lagging mode, the full generator output can be maintained by adjusting the turbine steam flow, and consequently reactor power, as long as the limits on the governor valve opening and reactor power allow for it.

You can now do **assignment question 4**.

⇔ *Page 35*

Obj. 5.4 a) i) ⇔

Adverse consequences and operating concerns caused by low condenser vacuum

When condenser pressure increases, the following **changes in the LP turbine and condenser operating conditions** occur:

1. Decreased pressure ratio, and hence the available heat, in the turbine last stage.
2. Increased temperature of the turbine exhaust steam.

   For example, when condenser pressure changes from 4 to 10 kPa(a), the saturation temperature increases from 29°C to 46°C. Recall that at light loads and during motoring, the steam can be superheated, ie. at a temperature above the saturation level.
3. Increased density of the turbine exhaust steam.

   Note that steam density is nearly proportional to absolute pressure. For instance, when condenser pressure rises from 4 to 10 kPa(a), the steam density increases nearly 2.5 times.

These changes lead to the following adverse consequences and operating concerns:

1. **Reduced generator output (loss of production).**

   As explained above and illustrated in Fig. 5.1, low condenser vacuum (high condenser pressure) reduces generator output unless the turbine steam flow can be increased. Due to the limits on reactor power and the governor valve opening, this action can be successful only in case of a mild pressure increase (a few kPa, maximum).

   A more drastic loss of generator output occurs when condenser pressure rises enough to cause automatic **turbine unloading** or – even worse – a **turbine trip**. Both these actions, although absolutely necessary, may lead to a **poison outage**. Its risk is particularly increased in the stations equipped with CSDVs. The reasons behind it are explained later in this module (pages 13-14).
2. **Reduced thermal efficiency** of the unit, and hence **increased cost of the electric energy produced**.

   Note that the thermal efficiency is reduced even if the condenser pressure increase is so small that the full generator output can be maintained. In this case, the turbine steam flow must be increased which naturally requires extra reactor power. And if turbine unloading occurs, the unit efficiency is reduced even more due to increased throttling across the governor valves*.

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* Recall from the 225 course that throttling reduces the amount of heat available to the turbine.

NOTES & REFERENCES

3. **Increased chances of equipment damage** due to hot, dense steam present in the turbine last stage(s), exhaust hood and condenser.

   More specifically, damage can be caused by:

   a) **Overstressing of the long moving blades** in the turbine last stage due to their churning dense steam. The resultant stresses may be particularly large under the following operating conditions:

      - **High condenser pressure combined with light turbine load***;
      - **High condenser pressure coincidental with a turbine overspeed.**

   b) **Overheating of the LP turbine exhaust.** This can happen during the following operating conditions if the cooling provided by the LP turbine exhaust cooling system is inadequate:

      - **At light loads** (and particularly **during motoring**) when the small steam flow may not be able to provide adequate cooling to remove the heat generated due to churning dense hot steam by the fast moving blades in the last stage(s);
      - At any turbine load, if **low vacuum turbine trip failed** to occur. Of course, the lower the load, the larger the tendency for turbine overheating.

      While turbine overheating can contribute to overstressing of the moving blades in the last stage, other turbine components can be also damaged as described in module 234-4.

   c) **Overpressurizing of the condenser shell and LP turbine exhaust cover (hood).** This could happen, for instance, if all the CCW pumps tripped and a turbine trip on high condenser pressure failed to occur. **To protect this equipment from overpressure,** the exhaust cover of each LP turbine has a few rupture discs or lifting diaphragms (depending on the station) that should operate at a pressure of a few kPa(g).

   ⇔ Obj. 5.4 c)

   d) **Thermal overstressing of condenser components** due to their contact with excessively hot steam. For example, condenser tubes can buckle due to excessive expansion relative to the condenser shell.

   ⇔ Obj. 5.4 a) i)

   Continued

4. **Reduced availability of the CSDVs.**

   For the reasons described in the next section, high condenser pressure results in a partial or total unavailability of the CSDVs. This greatly **complicates boiler pressure control** when these valves are required to operate. The major concern is that loss of these valves increases con-

* Recall from module 234-1 that under these operating conditions, the flow pattern in the last stage can deteriorate so much that the long moving blades can be subjected to large flow-induced vibration. More information about blade vibration is given in the final module.

NOTES & REFERENCES

siderably the risk of a **poison outage** if a large turbine unloading or a turbine trip occurs. This is explained in more detail on the next page.

Actions in response to high condenser pressure

Obj. 5.4 b) i) ⇔

Five major automatic actions in response to high condenser pressure (poor condenser vacuum) are depicted in Fig. 5.2.

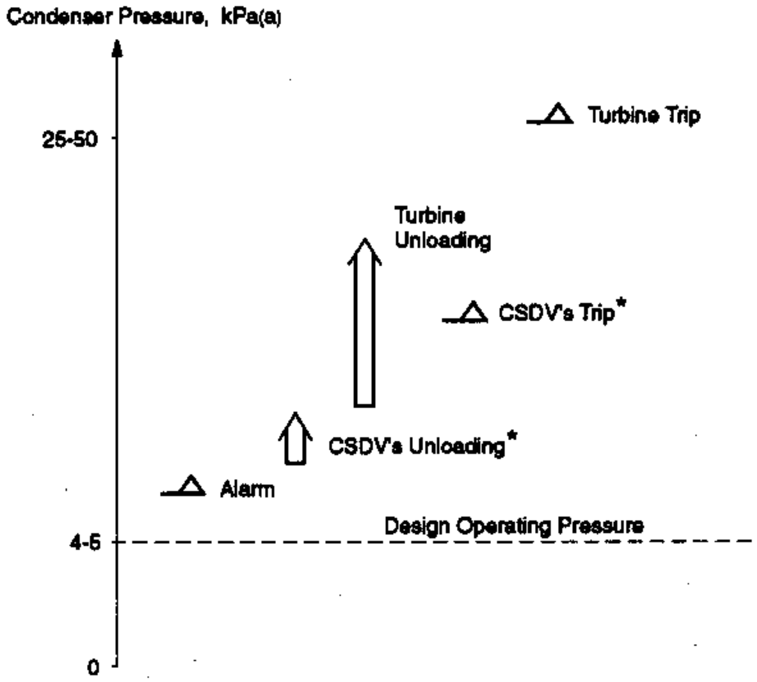

Fig. 5.2. Major automatic responses to high condenser pressure:

* = Applies only to the stations equipped with CSDVs.

When an **alarm** is given, the cause of poor vacuum should be diagnosed and rectified (more information about this is provided later in this module). Meanwhile, the **operator can take the following actions** in an attempt to restore normal condenser pressure:

Obj. 5.4 b) ii) ⇔

- Place more vacuum pumps* in the condenser air extraction system in service (in some stations, this action is automatic);
- Place another CCW pump in service (if available).

* Recall that this general term includes not only mechanical vacuum pumps but also steam jet air ejectors.

Obj. 5.4 b) i) ⇔ *Continued*

If condenser pressure rises above the alarm point, other automatic actions occur as depicted in Fig. 5.2. In the stations equipped with CSDVs, the maximum allowable opening of these valves is gradually reduced when condenser pressure is excessive. This action is referred to as **CSDV unload-**

ing. Note that during those unit operating states when the CSDVs remain closed (eg. operation at a steady load), their unloading has no effect on the valve position, and hence on unit operation. But if the unloading occurs when the valves are open, it can reduce the steam flow discharged by these valves into the condenser. As a result, the unloading may prevent a further increase in condenser pressure, and hence other, more drastic actions.

At a higher condenser pressure, **CSDV** unloading is backed up by their **trip** in the "closed" position. This action ensures this source of steam to the condenser is eliminated even if CSDV unloading failed to close all these valves. Stopping the CSDV steam flow to the condenser may reduce its thermal load enough to stabilize the condenser pressure. Thus, further turbine unloading and trip can be avoided as shown in Fig. 5.2. More information about CSDV unloading and trip is provided later in this module.

When condenser pressure reaches a certain level*, **turbine unloading** is carried out. By reducing the turbine steam flow, and thus the condenser thermal load, this action attempts to prevent a further increase in condenser pressure which would ultimately force a **turbine trip** to prevent equipment damage. In most stations, the turbine is unloaded first, and BPC causes reactor power to decrease. In a few CANDU units, the unloading process is reversed, ie. poor condenser vacuum reduces reactor power first, and this is followed by the appropriate reduction in turbine load to maintain boiler pressure.

* About 10-40 kPa(a), depending on the station.

In either case, condenser pressure determines how much turbine power is reduced. The maximum **unloading ends at about 10-30% FP**, depending on the station. This prevents potential operational problems (eg. overheating of the LP turbine exhaust) caused by prolonged operation at high condenser pressure combined with a small steam flow. It also allows the generator to maintain the unit service load supply, thereby minimizing chances of a loss of class IV power.

If the above actions fail, **the turbine is tripped** automatically when condenser pressure has risen to a certain level*. This drastic action is taken to prevent damage as described on page 11.

* About 25-50 kPa(a), depending on the station.

Note that the drastic reduction in reactor power that accompanies a large turbine unloading or trip carries the risk of a forced **poison outage** which we strive to avoid. Unfortunately, in the stations equipped with CSDVs, this task is difficult because poor condenser vacuum makes these valves unavailable, and the small ASDVs can accommodate only up to 10% of the full power steam flow. Therefore, when high condenser pressure forces a large turbine unloading or – even worse – a turbine trip, reactor power cannot be maintained high enough to prevent reactor poisoning. Instead, reactor power must be reduced to a level at which the ASDVs can control boiler pressure.

In the stations with large atmospheric SRVs, reactor power does not have to be reduced so drastically. However, the makeup water inventory limits the duration of poison prevent operation as already described in module 234-3. If satisfactory condenser vacuum cannot be restored within this time limit, the reactor must be shut down, resulting in a poison outage.

SUMMARY OF THE KEY CONCEPTS

- Reduced condenser vacuum decreases the unit thermal efficiency, and may result in reduced generator output if the turbine steam flow cannot be increased enough. Automatic turbine unloading, and even a trip, can also occur, resulting in a loss of production.
- Reduced condenser vacuum increases chances for equipment damage. Long moving blades in the last stage can become overstressed, and the LP turbine exhaust overheated. Excessive thermal stresses can also occur in the condenser. In addition, the condenser shell and the LP turbine exhaust cover can become overpressurized.
- In the stations equipped with CSDVs, high condenser pressure makes these valves unavailable. This complicates boiler pressure control and may lead to a poison outage.
- Rising condenser pressure should result in the following major automatic responses: alarm, CSDV unloading, CSDV trip, turbine unloading, and finally – a turbine trip.
- For overpressure protection, rupture discs or lifting diaphragms are installed in each LP turbine exhaust cover.
- Upon a high condenser pressure alarm, the operator can place more vacuum pumps and CCW pumps (if available) in service. Meanwhile, the cause of poor vacuum should be investigated and rectified.

Obj. 5.4 a) ii) ⇔

Adverse consequences and operating concerns caused by excessive condenser vacuum

When condenser pressure decreases, the following **changes in the LP turbine and condenser operating conditions** occur:

1. Moisture content of the LP turbine exhaust steam increases because more heat is extracted from the steam when it expands to higher vacuum.
2. The pressure ratio, and hence the available heat, in the turbine last stage increase.
3. Steam velocity within the last stage, exhaust hood and condenser inlet increases because the steam volumetric flow rate increases (recall that when pressure drops, specific volume increases).

4. The volume of noncondensible gases (mainly air) in the condenser increases as they expand with decreasing pressure.

The latter two effects are very sensitive to condenser vacuum. For example, a reduction in condenser pressure from 5 kPa(a) to 4 kPa(a), ie. only by 1 kPa, increases specific volume by about 20%.

Through these changes, excessive condenser vacuum results in the following **adverse consequences/operating concerns**:

1. **Accelerated equipment wear** because of:

   a) **Faster erosion** of the turbine last stage, turbine exhaust hood and condenser tubes due to increased moisture content and velocity of the exhaust steam;

   b) **Increased fatigue** of components such as moving blades, lacing wires and condenser tubes, as a result of increased flow-induced vibration caused by faster moving steam;

   c) **Accelerated corrosion** of the condenser and condensate system due to increased concentration of dissolved gases – oxygen, carbon dioxide and ammonia being the main culprits.

   As mentioned above, gases in the condenser expand significantly when pressure is even slightly lowered. Consequently, their density decreases. This is why the mass flow of gases removed from the condenser by the vacuum pumps in the condenser air extraction system is reduced. Therefore, the concentration of gases in the condenser atmosphere rises, leading to increased dissolved gases in the condensate.

   Note that normal condenser pressure (4-5 kPa(a)) is so close to perfect vacuum that it cannot be significantly reduced. Therefore, equipment deterioration due to the above concerns is not so fast as to cause rapid equipment failure (weeks, months). Nevertheless, prolonged operation at excessive vacuum **increases maintenance costs and may eventually result in failure.**

2. **A slight reduction in the unit thermal efficiency**.

   Recall that excessive condenser vacuum increases losses in the turbine last stage due to excessive steam velocity and increased wetness. This reduces the generator output as shown in Fig. 5.1 on page 8. As a result, the unit thermal efficiency decreases as well.

It turns out that turbine load affects the above consequences. At partial loads, as opposed to full power operation, a moderate increase in condenser vacuum above its design value is beneficial. Why? Because it increases slightly the unit thermal efficiency, while the exhaust steam wetness and velocity are not large enough to cause any operating concern. And higher than

NOTES & REFERENCES

* Recall from module 234-1 that at light loads and normal condenser pressure, the flow pattern in the last stage(s) deteriorates because the pressure ratio, and hence the available heat, are too small due to greatly reduced inlet pressure. With rising vacuum at the turbine exhaust, this small pressure ratio increases. As a result, the flow pattern improves.

normal condenser vacuum improves the flow pattern in the last stage(s)*, thereby minimizing LP turbine exhaust heating and blade vibration.

The only problem that gets worse with reduced turbine load is the concentration of gases in the condenser. This is because **at low turbine loads**, additional portions of the equipment (feedheaters, extraction steam piping, etc.) normally operating above atmospheric pressure must operate under vacuum, thereby increasing air in-leakage. This, combined with more difficult air removal from the condenser (as explained earlier) may result in **high oxygen content in the condensate**. All vacuum pumps in the condenser air extraction system may have to be used (despite high condenser vacuum) to minimize this effect.

From the above, you can see that **high condenser vacuum is beneficial only to the level at which the unit thermal efficiency reaches its maximum**. Any further increase in vacuum is disadvantageous because the efficiency decreases while the equipment is subjected to accelerated wear.

Obj. 5.4 b) iii) ⇔

Actions in response to excessive condenser vacuum

Excessive vacuum results in no automatic actions. But if other operating concerns allow, the **operator** can take the following **actions**:

1. **Shut down a CCW pump**.

   An example of the unit operating state when this action can be beneficial is full power operation in wintertime with all three CCW pumps running. Not only can this bring excessive condenser vacuum closer to its normal range, but it also decreases the unit service load by about 1-1.5 MW, depending on the station. This contributes slightly to improved thermal efficiency. Of course, this action should not be taken if it could result in exceeding the operational limit on the CCW temperature rise.

2. **Shut down a vacuum pump**.

   This action should not be taken if the dissolved oxygen content in the condensate is high, for example, during low power operation.

SUMMARY OF THE KEY CONCEPTS

- Excessive condenser vacuum accelerates equipment wear through faster erosion, corrosion, and increased flow-induced vibration. A slight reduction in the unit thermal efficiency can also occur.
- At low turbine loads, the optimum condenser vacuum is higher than at full load.
- At high condenser vacuum, the concentration of gases in the condenser atmosphere increases because their removal is more difficult. Low tur-

bine load aggravates this problem because increased air in-leakage is promoted as more feedheaters, extraction steam pipes, etc. operate under vacuum. All available vacuum pumps may have to be used to prevent excessive dissolved oxygen content in the condensate.

- No automatic actions occur in response to higher than normal condenser vacuum. If other considerations allow for it, the operator may shut down a CCW pump or a vacuum pump to bring condenser vacuum to its proper range.

You may now complete **assignment questions 5-8.**

⇔ Pages 35-38

Diagnosis of the actual cause(s) of poor condenser vacuum

Let us first review the **basic theory** of condenser operation. To condense steam, a certain amount of heat ($\dot{Q}$) must be transferred across the condenser tubes to the CCW. During this process condenser pressure adjusts itself such that the condensing steam is hot enough to maintain the mean temperature drop across the tubes (ΔT_m) sufficiently high to transfer the heat through the tube surface area (A). Mathematically, this is expressed by the familiar equation:

$$\dot{Q} = U\ A\ \Delta T_m$$

where U = the overall heat transfer coefficient. The smaller it is, the more difficult the heat transfer is.

From the above equation, you can see that ΔT_m increases when one or more of the following changes occurs:

- $\dot{Q}$ increases. This is affected mainly by the flow and wetness of the turbine exhaust steam which vary with the turbine load. Other factors, such as operation of the CSDVs or dumping hot drains into the condenser, contribute to this thermal load, too.
- U decreases. This can be caused by tube fouling or accumulation of gases in the condenser atmosphere, to name the most important factors.
- A decreases. This can be caused by plugging of the leaking tubes or by flooding of some tubes due to abnormally high hotwell level.

An increase in ΔT_m promotes an increase in steam temperature, causing a corresponding increase in the saturation pressure at which the steam condenses. However, steam temperature (and hence, pressure) can rise even when ΔT_m is constant. This happens when the mean CCW temperature increases which can be caused by increased CCW inlet temperature and/or reduced flow. In the latter case, each kilogram of CCW picks up more heat which increases the mean temperature of the CCW.

The **presence of gases** in the condenser atmosphere promotes increased condenser pressure because:

1. Their partial pressure (p_g) contributes to condenser pressure (p_c), ie.

$$p_c = p_{steam} + p_g$$

2. Heat transfer is impaired due to the insulating effect of the gases.

The latter is commonly referred to as ***tube blanketing***, reflecting the fact that gases act as an insulating blanket wrapped around the tubes. Tube blanketing is particularly bad near the air extraction headers where p_g can reach its maximum (note that the concentration of gases in steam increases as the steam/gas mixture passes many condenser tubes on the way to the headers, causing most of the steam to condense). As the local heat transfer through the blanketed tubes is impaired, the mean steam temperature (and hence, its pressure) in the whole condenser must rise to get more heat transferred in the other parts of the tube bundle.

The fact that the partial pressure of steam is below condenser pressure results also in **apparent** subcooling of condensate in the hotwell. Note that the temperature of the condensing steam is governed by its actual partial pressure as opposed to the total condenser pressure. The condensate, strictly speaking, is saturated when the actual steam pressure is taken into account, but it appears subcooled when compared with the saturation temperature corresponding to condenser pressure.

Obj. 5.5 a) ⇔

Based on the above, and assuming a constant turbine inlet steam flow, the following **major causes of poor condenser vacuum** can be discussed:

1. **Reduced CCW flow rate.**

   This can be caused by a CCW pump trip or obstruction to the CCW flow such as clogged screens in the CCW system or fouled condenser tubes. Malfunction of the vacuum priming system resulting in accumulation of gases in the condenser water boxes can also reduce the CCW flow by impairing the syphon action.

   When the CCW flow is reduced, its **temperature rise in the condenser increases** because each kilogram of water picks up more heat. As the outlet CCW temperature increases, so does the mean temperature. The warmer CCW forces steam to condense at higher temperature, and hence pressure. Consequently, the condensate is warmer, though it remains saturated. ΔT_m remains approximately unchanged unless the reduced CCW flow is caused by severe tube fouling (discussed in point 3 below).

2. **Increased CCW inlet temperature.**

   This is typically due to seasonal changes. But in some cases, a strong wind can cause the warm station effluent to approach the CCW intake, thereby raising the inlet temperature.

   Again, the outlet and mean CCW temperature increase. But because the CCW flow has not changed, the CCW temperature rise in the condenser remains essentially unchanged. How the other parameters change is described in point 1 above.

3. **Tube fouling.**

   The inner surface is affected most because it is in contact with raw CCW. This results in corrosion product and scale formation, organic fouling and silt deposition. Note that severe tube fouling may account for up to 50% of the total resistance to heat flow!!! In addition, increased frictional resistance developed by the fouled tube surface reduces the CCW flow rate. This is particularly true in the case of large organic and inorganic debris (eg. sticks, leaves, fish or mussel shells) being trapped inside the tubes or water boxes.

   As the heat transfer is impaired, **ΔT_m increases**, driving the steam temperature (hence, pressure) up. This can be combined with a reduction in the CCW flow which would contribute to increased condenser pressure as described above. The condensate, of course, remains saturated.

4. **Tube flooding.**

   An abnormally high condensate level in the hotwell, submerging lower condenser tubes, is the cause. It is probably the least frequent cause of poor condenser vacuum.

   Tube flooding reduces the number of tubes (hence, their surface area) exposed to the condensing steam. As a result, **ΔT_m increases**, causing the steam temperature and pressure to rise. **The condensate**, however, **is subcooled**, and its temperature approaches the CCW temperature range.

5. **Accumulation of gases in the condensate atmosphere.**

   This can be caused by increased air in-leakage and/or malfunction of the condenser air extraction system. As mentioned in the review of condenser theory above, accumulation of gases in the condenser shell impairs heat transfer resulting in **increased** ΔT_m across the tubes which drives the mean steam temperature and pressure up. The partial pressure of accumulated gases contributes also to condenser pressure and results in **apparent subcooling of the condensate**. Compared with tube flooding, the condensate is warmer than normal.

NOTES & REFERENCES

In addition, **the dissolved oxygen content in the condensate is increased.** Usually, this parameter can indicate increased accumulation of gases in the condenser atmosphere before any deterioration in the condenser thermal performance can be detected.

6. **Abnormally large thermal load on the condenser** (ie. over and above the normal condenser thermal load for a given unit output).

   Examples of causes of abnormally large condenser thermal load are:

   - **A large steam leak** into the condenser, eg. through a passing CSDV or RV;
   - **Hot** feedheater, moisture separator or reheater **drains** dumped into the condenser.

   When more steam and possibly hot drains enter the condenser, it must transfer more heat to the CCW. As a result, ΔT_m across the tubes, CCW temperature rise and CCW outlet temperature are increased. The condensate remains saturated, and the dissolved oxygen content and condenser hotwell level stay normal.

Recall that regardless of its cause, poor condenser vacuum reduces the unit thermal efficiency. For a given unit output, this loss of efficiency increases the condenser thermal load above its normal value. However, for a moderate increase in condenser pressure (say, a few kPa), the effect of the increased load on the CCW outlet temperature is too small to be easily measurable.

Obj. 5.5 b) ⇔

The above causes of poor condenser vacuum are summarized in Fig. 5.3. From this table, you can see that **each cause of low condenser vacuum has its own "signature"**, ie. its effect on the listed parameters differs from that of any other cause of low vacuum. This enables diagnosis of the actual cause. In practice, some alarms and annunciations may be received, pinpointing the source of trouble. For instance, an annunciation "*High travelling screen* Δp" makes it clear that the CCW flow may be reduced, while a high hotwell level alarm makes tube flooding the primary suspect.

SUMMARY OF THE KEY CONCEPTS

- Low condenser vacuum can be caused by reduced CCW flow, increased CCW inlet temperature, tube fouling, tube flooding, accumulation of gases in the condenser atmosphere, or abnormally large condenser thermal load.
- Each of these cases has its own "signature" which – combined with possible alarms/annunciations – makes diagnosis of the actual cause of low vacuum possible.

Pages 38-42 ⇔

You may now go to **assignment questions 9-12.**

Cause of low condenser vacuum	CCW				Condenser pressure	Saturation temperature corresponding to condenser pressure (T_S)	Condensate temperature	Dissolved oxygen content	Hotwell level
	T_{in}	T_{out}	ΔT	Flow					
Reduced CCW flow	N	↑	↑	↓	↑	↑	$=T_S$	N	N
Increased CCW inlet temperature	↑	↑	≈N	N	↑	↑	$=T_S$	N	N
Tube fouling	N	≈N	≈N	N or ↓	↑	↑	$=T_S$	N	N
Tube flooding	N	≈N	≈N	N	↑	↑	$<T_S$ and $<$ N	N	↑
Accumulation of gases in the condenser atmosphere	N	≈N	≈N	N	↑	↑	$<T_S$ and $>$ N	↑	N
Abnormally large condenser thermal load	N	↑	↑	N	↑	↑	$=T_S$	N	N

Fig. 5.3. Causes of low condenser vacuum and their effect on assorted operating parameters:

N = Normal value at a given power level;
≈N = Slightly larger than normal but the increase may be too small to be measurable;
↑↓ = Above or below normal, respectively.

CONDENSER VACUUM BREAKING

In this section, you will learn about:

- The purpose of condenser vacuum breaking and how it is done;
- Turbine generator operating conditions during which condenser vacuum is broken;
- The reason why this action should not be performed at high turbine speeds unless absolutely necessary;
- Two alternate methods of relieving condenser vacuum while shutting down the turbine.

⇔ *Obj. 5.6 a)*

The **purpose** of condenser vacuum breaking is to shorten the turbine generator rundown. This is achieved by letting atmospheric air into the condenser. As the pressure of the condenser atmosphere increases sharply, so does its density. Compared with the normal condenser vacuum, the dense atmosphere resists the turbine blade motion much more strongly, causing the rotor to decelerate more quickly. The retarding forces are particularly large in the last stage where the velocity of the moving blades is maximum. With dropping turbine speed, the blade velocity decreases, reducing the retarding forces. Therefore, the deceleration rate decreases as well.

Savings in the turbine rundown time depend on how much the condenser vacuum is reduced (full versus partial vacuum break) and the turbine speed at which this action occurs. The most extreme case of full vacuum break at the rated turbine speed is illustrated in Fig. 5.4 on the next page. Remember that this is only a general case, and the turbine rundown time in your station may differ somewhat.

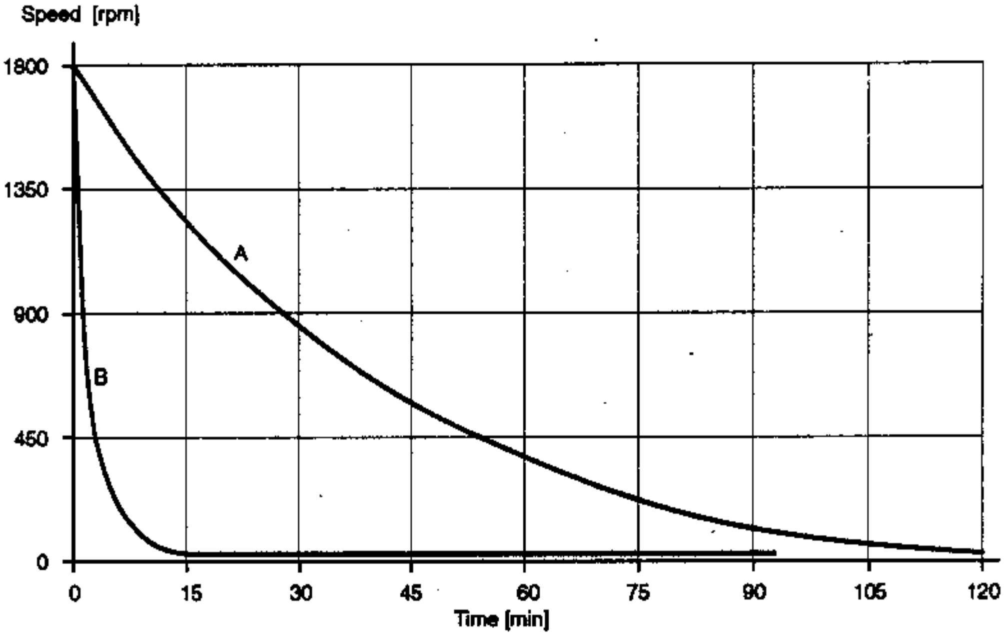

Fig. 5.4. Effect of condenser vacuum breaking on turbine rundown:

A = Rundown at full condenser vacuum;
B = Rundown with vacuum breakers fully opened at 1800 rpm.

Obj. 5.6 b) ⇔

Breaking of condenser vacuum is **performed by** special valves (called, not surprisingly, ***vacuum breakers***) which connect the condenser shell to atmosphere. In most stations, the breakers – which are normally closed and water sealed to prevent air in-leakage – can be opened remotely from the control room when a need arises for condenser vacuum breaking.

Obj. 5.6 c) ⇔

A full vacuum break at a high turbine speed (say, above 1200 rpm) **is not recommended during a normal turbine shutdown.** The reason is that **heavy mechanical and thermal stresses are produced in the long moving blades in the turbine last stages** when they are forced to churn the dense steam/air atmosphere. The large stresses reduce the blade life, and eventually – if imposed many times – may finally result in their premature failure.

Obj. 5.6 d) ⇔

To prevent it, this drastic action **is carried out only** when it is absolutely necessary, ie. **following a turbine trip caused by**:

- **Very high vibration;**
- **Loss of lube oil pressure;**
- **Loss of generator hydrogen seal oil pressure.**

In all these cases, a rapid reduction in turbine speed and fast passing through the critical speed ranges (where vibrations increase due to resonance) are essential to prevent/minimize damage to the turbine generator.

Therefore **condenser vacuum should be broken right after the trip**, ie. at nearly full turbine speed. Under these emergency conditions, the aforementioned adverse consequence of this action on the turbine blading is the lesser evil.

⇔ *Obj. 5.6 e)*

During **normal turbine shutdown and trips other than those listed above** condenser vacuum is relieved in two different ways, depending on the station:

1. **The vacuum breakers are opened once the turbine is on turning gear.**

   The main drawback of this method is a long rundown time. Nonetheless, this is the **preferred method** of relieving condenser vacuum for the three reasons outlined below.

   First, introduction of large quantities of air into the condenser is delayed. Thus, during turbine rundown, when feedwater is still being supplied to the boiler, a large increase in the dissolved oxygen content in the condensate – with its all attendant adverse consequences – can be prevented.

   Second, the CSDVs remain available* during turbine rundown. This is advantageous during those shutdowns when reactor cooling is maintained via the boilers, and during HT system cooldown via the boilers. If these valves were unavailable, the ASDVs would have to be used. Since they discharge steam to atmosphere, the demand on makeup water (hence, the operating costs) would increase. Besides, the ASDVs are far too small to maintain the desired rate of cooldown to a temperature low enough* for the shutdown cooling system to take over the further cooldown.

   Third, because condenser vacuum is not broken until turbine rundown is complete, recovery from a turbine trip is easier.

2. **The vacuum breakers are opened during turbine rundown** provided that turbine speed is sufficiently low*. This prevents excessive stresses on the turbine blading while still reducing the rundown time.

   In some units, the vacuum breaker instrumentation allows for breaking condenser vacuum in two stages. First, at a high turbine speed, condenser pressure is increased a little bit*. Then, once turbine speed has decreased enough, the vacuum is broken completely. This method allows for faster deceleration (and hence, faster passing through the critical speed ranges) without overstressing the turbine blading.

   Because breaking condenser vacuum during turbine rundown does not offer the advantages outlined in point 1 above, this is not the preferred method of relieving condenser vacuum.

* Recall that poor condenser vacuum trips these valves in the closed position.

* About 150°C.

* The limit is about 900-1200 rpm, depending on the station.

* To about 20 kPa(a).

SUMMARY OF THE KEY CONCEPTS

- Condenser vacuum breaking performed during turbine rundown reduces the rundown duration.
- Condenser vacuum is broken by opening special valves called vacuum breakers. They admit atmospheric air into the condenser shell.
- Full vacuum breaking at a high turbine speed should be carried out only after a turbine trip on high vibration, loss of lube oil pressure or loss of generator hydrogen seal oil pressure when fast deceleration is necessary to prevent/minimize damage. Heavy stresses on the last stage blading are the major disadvantage of this drastic action.
- The preferred method of relieving condenser vacuum during normal turbine shutdown and trips other than those stated above is that the vacuum breakers stay closed until the turbine is put on turning gear. The advantages include delayed introduction of large quantities of air into the condenser atmosphere, keeping the CSDVs available during turbine rundown, and easier recovery from a turbine trip. In the other method, condenser vacuum gets broken during turbine rundown after the turbine has slowed down below a certain speed.

Pages 42-43 ⇔

You may now do **assignment questions 13-15.**

OPERATING CONCERNS AND LIMITATIONS ASSOCIATED WITH THE CONDENSER STEAM DISCHARGE VALVES

Obj. 5.7 a) ⇔

Operating concerns

Recall that the condenser steam discharge valves (CSDVs) are used in many stations to control boiler pressure by discharging to the main condenser the surplus steam that the turbine and other systems cannot use. This arrangement results in a large pressure drop across the CSDVs, and consequently, a very high velocity of **hot steam jets** entering the condenser. The following **potential problems** can occur **in the condenser**:

1. Steam jets can damage condenser internals due to impingement and flow-induced vibration.
2. Excessive temperature gradients in the condenser can result in overstressing of some components.
3. The turbine/condenser rubber expansion joint (used in many stations) can crack if dried out and overheated, leading to loss of condenser vacuum.

These problems are addressed by a proper condenser design and placing some constraints on the operation of the CSDVs. Some of these design features are shown in Fig. 5.6 at the module end. For example, the arrangement of the steam discharge headers and nozzles inside the condenser is such that the steam jets are prevented from impinging directly on the condenser tubes and support plates. Another design feature, which is closely associated with the operational constraints on the CSDVs, is the cooling water sprays installed in the condenser neck. Their purpose is to keep the turbine/condenser rubber expansion joint wet and cool. The sprays are supplied with cool condensate from the discharge of the condensate extraction pumps. Note that the sprays are not used during normal operation when the turbine exhaust steam is wet and cool.

⇔ Obj. 5.7 b)

Operational limits imposed on the CSDVs

The following parameters affect **CSDV unloading**:

1. **Reduced condenser vacuum.**

   Recall that the purpose of CSDV unloading on low condenser vacuum is to limit condenser thermal load in an attempt to prevent a further increase in condenser pressure. Thus, a loss of production due to automatic turbine unloading or trip can be avoided.

2. **Turbine load.**

   The higher the turbine load, the larger the restriction on the CSDV opening. This prevents condenser overloading which could result in low vacuum with all its adverse consequences. Fig. 5.5 illustrates the typical limit on the CSDV opening as a function of turbine load.

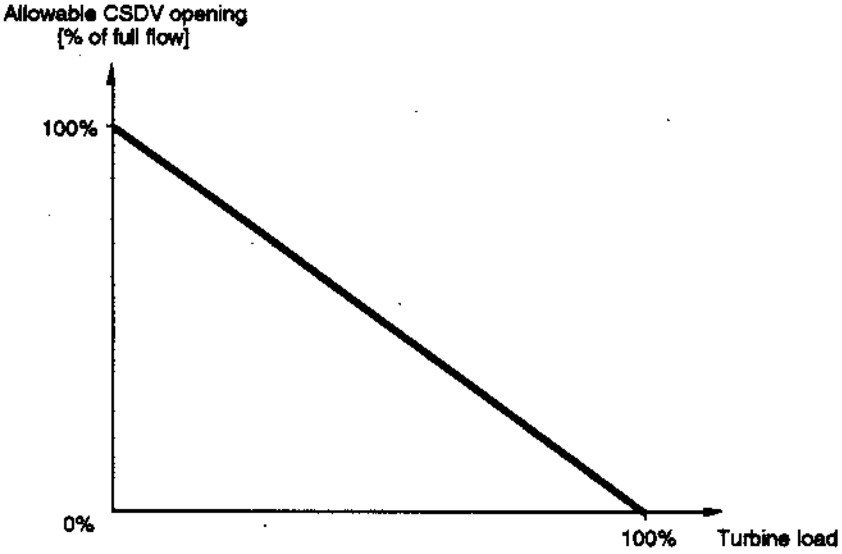

Fig. 5.5. Effect of turbine load on the allowable opening of the CSDV's.

NOTES & REFERENCES

In turn, a **CSDV trip** in the closed position is caused by the following parameters:

1. **Low condenser vacuum.**

   Recall that this action backs up the CSDV unloading that ideally should be completed before condenser vacuum deteriorates to this level. Should the unloading fail to occur, tripping the CSDVs ensures this source of steam to the condenser is eliminated. Not only does this attempt to avoid a turbine trip, but it also protects the equipment from damage due to loss of condenser vacuum as outlined on page 11.

2. **Unavailability of the condenser cooling sprays.**

   As mentioned before, these sprays are necessary to protect the turbine/condenser rubber expansion joint whose failure could ultimately lead to loss of condenser vacuum. The unavailability of the sprays is indicated by loss of cooling water pressure.

3. **Very high boiler level.**

   Recall from module 234-2 that the purpose of this action is to prevent introduction of large quantities of boiler water into the steam pipelines which could result in severe water hammer. Note that if the CSDVs were allowed to open, the already high boiler level would rise even more due to a transient swell caused by the boiler pressure drop from the CSDV action. The rising level would greatly increase the risk of water hammer in the steam pipelines. As for possible water induction to the turbine, recall that this is prevented by tripping the turbine at the same time the CSDVs are tripped.

SUMMARY OF THE KEY CONCEPTS

- Hot jets of steam discharged by the CSDVs into the condenser can damage its internals due to impingement, flow-induced vibration or excessive thermal stresses. In the stations where a rubber expansion joint is used between the turbine and the condenser, it can crack if dried out and overheated, ultimately leading to loss of condenser vacuum.
- The permissible opening of the CSDVs is limited by condenser vacuum and turbine load.
- A CSDV trip is triggered by high condenser pressure, loss of the condenser cooling sprays or very high boiler level.

Page 43 ⇔

You may now go to **assignment questions 16-18.**

CONDENSER LEAKS

Air and CCW leaks into the condenser are a common operational problem. In this section, the following aspects of these leaks are discussed:

- Adverse consequences/operating concerns caused by a CCW leak;
- Indications of such a leak;
- Method used to monitor the rate of air in-leakage;
- Operator actions used to minimize the consequences of CCW/ air leaks;
- Methods used to locate such leaks.

CCW LEAKS INTO THE CONDENSER

When the condenser is under vacuum, the CCW pressure is greater than the steam pressure. Thus, any leakage which occurs causes the CCW to enter the steam space where it finally mixes with the condensate. Because tube failures are usually responsible for the majority of the leakage, the term *condenser tube leak* is commonly used to refer to this problem. However, significant leakage can occur also in other places such as tube-to-tubesheet joints.

Adverse consequences and operating concerns

⇔ Obj. 5.8 a)

Leakage of raw CCW into the condensate contaminates the latter with suspended and dissolved minerals and organics. Note that the leaking CCW is degassed in the condenser and therefore it does not result in increased concentration of dissolved gases in the condensate.

While the leakage rate is often very small, the concentration of the impurities can be high. As a result, **the purity of boiler feedwater and steam is compromised.** This applies particularly to the water inside the boiler where the boiling process causes most of the impurities to accumulate in the same way as happens in a kettle. Hence, through upsetting the proper chemistry of boiler feedwater and steam, a condenser tube leak causes the following **adverse consequences/operating concerns**:

1. **Accelerated corrosion.**

   Increased concentration of ionic impurities in boiler feedwater and steam promotes various types of electrochemical corrosion in the whole boiler steam and feedwater cycle. Certain ions, like chlorides, can be particularly harmful as they promote stress corrosion cracking and corrosion fatigue of some materials. Given enough time, corrosion can result in costly and potentially dangerous damage, eg. boiler tube or turbine blade failures.

   Like other deposits, corrosion products promote further problems as described on the next page.

2. **Accelerated formation of deposits in the boilers and feedheaters.**

   When a condenser tube leak occurs, the concentration of dissolved and suspended minerals and organics in boiler feedwater increases. These impurities – combined with corrosion products as mentioned above – tend to deposit on the hottest surfaces and in low flow areas in the boilers and – to much smaller extent – feedheaters. Tubes and their support plates, as well as boiler tubesheets are the primary sites of these deposits.

   Such deposits can cause serious problems as follows. First, heat transfer is impaired which may force unit derating to prevent overheating of the HT coolant and reactor fuel. Second, corrosion underneath the deposits is promoted. Third, large deposits on the boiler tube support plates may result in large fluctuations of boiler level because the upward movement of steam bubbles is restricted to a point where pressure builds up periodically under the fouled plates finally resulting in a violent passage of the accumulated steam. This problem has recently been experienced in some CANDU units, forcing their derating.

3. **Possible foaming (hence, boiler level control problems) and increased carryover in boiler steam*.**

* These problems have already been described in module 234-2.

Note that the above consequences affect the whole boiler feedwater and steam cycle, though the leak occurs locally in the condenser. How severe the consequences can be depends, among other factors, on the size of the leak, its duration, and the impurities present in the leaking CCW.

Due to the very large number of condenser tubes, complete elimination of CCW leakage is practically impossible. Minor leakage that normally occurs is compensated for by proper boiler blowdown such that satisfactory purity of boiler water can be maintained. However, **excessive CCW leakage upsets the boiler water chemistry to a point that prolonged operation with no corrective action can finally result in severe consequences.** The operational experience of many power plants shows that prompt response to excessive condenser leakage is absolutely necessary to prevent costly maintenance, eg. boiler retubing.

The above consequences cover the case of a prolonged leak with no operator action. In practice, the operator should take certain actions (described on the next page) to minimize these consequences. Though they are the lesser evil, these actions have some adverse consequences, too. For example, a large leak can force a unit shutdown, resulting in loss of production.

Obj. 5.8 b) ⇔

Indications of a condenser tube leak

A condenser tube leak is detectable because it changes some chemical parameters of the condensate and boiler water. The most typical indications of this abnormality are:

NOTES & REFERENCES

1. **Increased sodium ion (Na^+) content** in the boiler water and, if the leak is large enough, at the discharge of the condensate extraction pumps (CEPs).
2. **Increased conductivity** in the same locations.

Usually, sodium ion analyzers are much more sensitive to a CCW leak than are conductivity meters. While some leaks may be large enough to be detected at the CEP discharge, a typical condenser tube leak is usually detected first in boiler water where impurities, including sodium ions, accumulate when the water boils away.

Note that the above indications can be caused by other problems such as addition of dirty makeup water. Hence, some other checks must be made to eliminate the other causes, thereby confirming a CCW leak.

Mitigating actions

⇔ Obj. 5.8 c)

Once an excessive condenser tube leak has been detected, some actions must be taken to minimize its possible adverse consequences. In the **extreme case, the leak may be large enough to force a unit shutdown** – this happens when the concentration of some critical impurities (such as sodium and chloride) has reached its shutdown limit as specified in the appropriate operating manual.

In the more typical case of a **small leak**, operation can be continued while **the following actions** are taken:

1. The leak should be located and repaired as soon as possible (more about this below).
2. Meanwhile, boiler blowdown should be increased enough to maintain the concentration of impurities in samples of boiler water within acceptable limits.

Note that increased boiler blowdown has its own disadvantages:

- Increased consumption of makeup water;
- Reduced thermal efficiency due to loss of heat in the hot boiler blowdown water;
- Increased consumption of morpholine or its equivalent, depending on the station. This is necessary to compensate for increased flow of neutral makeup water whose pH is too low for the condensate and boiler feed systems.

As a result, the operating costs are increased – particularly when operation with high blowdown is continued for a long time (weeks, months). In addition, the effectiveness of blowdown in removal of suspended solids is very limited. Therefore, **prompt leak repair is important**.

NOTES & REFERENCES

Obj. 5.8 d) ⇔

Leak location

With about 25-30 thousand tubes (and twice as many tube joints) in a typical condenser, finding the leak location is quite a task. To simplify this, the following steps are usually taken:

1. **Locating the leaking condenser.**

   This relies on checking the sodium content in the hotwell (or its discharge) of each of the three condensers. Of course, the condenser with the highest sodium content is suspected to be leaking. In some stations, permanent in-line sodium analyzers are installed, whereas in others a portable analyzer can be used. Problems associated with taking reliable samples under high vacuum are the reason why this step is not performed in some stations.

2. **Locating the leaking half of this condenser.**

   Typically, this is accomplished by **isolating and draining the CCW from one condenser half at a time while the sodium content at the CEP discharge (and possibly conductivity) are monitored**. If these parameters have decreased, the leak is located in the isolated condenser half – if not, in the other one. Of course, if the first step has not been performed, this procedure may have to be repeated up to six times as there are three condensers altogether.

   This method usually requires some unit unloading in order to maintain satisfactory condenser vacuum during the test. From this description you can see that the operator's involvement in this test from the control room can be quite extensive because the test requires numerous isolation and deisolation activities, and usually some unit derating. Speaking of isolation, it is important that the condenser half under test be isolated not only from the CCW system and the vacuum priming system, but also from the condenser air extraction system. Otherwise, large quantities of steam could enter the air extraction header in the condenser half, overloading the vacuum pumps. As a result, air (and other gases) would accumulate in the condenser atmosphere with all the attendant adverse consequences.

   A new method – which does not require any tube bundle isolation – relies on **injection of a tracer gas** (eg. helium) into the inlet CCW piping of the condenser half being tested. At the same time, the exhaust of the vacuum pumps in the condenser air extraction system is monitored for the presence of the tracer gas. A positive indication points to the leaking bundle.

3. **Locating the leaking tube(s).**

   Once the leaking condenser half has been found, it is isolated, drained, and a work permit is issued to allow for work inside the water boxes (confined space). From that point on, the operator's involvement in leak detection is minimal until the leak repairs are over and the condenser is ready for return to service.

The techniques that are used to find the leaking tube(s) or tube joint(s) are described below. This information is only for orientation purposes (to help you understand some of the activities that one day may be taking place on your shift), and is not required for the checkout.

The most common techniques that are described here are performed with the condenser under vacuum. The unit can stay on power, though some unloading may be necessary to compensate for the loss of the condenser half under investigation.

The **plastic film** (sandwich wrap, cellophane film) **technique** is fairly common. A clear plastic sheet is applied over both tube ends of a section of the tube bundle. For a better seal, the tube sheet surface is wetted with water or thin oil. The leaking tube(s) pull the film inside which can be visually detected. A **variation of this technique** eliminates the sealing problems by using **rubber plugs** which have a center hole, across which a flexible diaphragm is stretched. The plugs are inserted in both ends of the condenser tubes. Any tube with a leak pulls a dimple on its two plugs. Note that these two methods are ineffective for tube joint leaks.

A **tracer gas technique** similar to the one described earlier, is used in some stations. The tracer gas is applied locally to a group of tubes (for rough location of the leak) or individual tubes (for fine location). This method is very sensitive (leaks as small as 0.3 cm^3/min are reported detectable) and effective for tubes and their joints alike.

The **ultrasonic technique** uses a hand-held sensor to detect ultrasound generated by the air rushing into a leak. Operational experience of many utilities shows that this is a very fast and accurate method, particularly when leaks close to the tube sheets are concerned. However, smaller leaks – located some way down the tube – may be difficult to detect. Adequate training of the test personnel is also required.

By the way, the last two techniques are also commonly used to locate air leaks.

AIR LEAKS INTO THE CONDENSER

⇔ *Obj. 5.9 a)*

Earlier in the module, the adverse consequences and symptoms of increased accumulation of gases in the condenser atmosphere have been described. More often than not, the problem is caused by increased air in-leakage rather than poor performance of the vacuum pump(s) in service. The actual cause can be found by **checking the rate of air in-leakage by means of a flow meter** (normally valved out) **at the vacuum pump discharge**.

Once increased air in-leakage has been confirmed by the flow indication, **work should be initiated to locate and repair the leak.** This can be a complicated task due to a very large number of possible leak sites. For example, it can happen through a turbine gland seal, poorly sealed LP turbine exhaust cover lifting diaphragms or subatmospheric extraction steam piping joints, just to name a few possible locations.

Obj. 5.9 b) ⇔

While the leak is being located and repaired, two **actions** should be taken by the operator **to minimize the adverse consequences of the leak**:

1. Placing additional vacuum pumps in service.
2. Advising the chem lab personnel about the leak. They should then check, and adjust if necessary, the hydrazine injection rate.

SUMMARY OF THE KEY CONCEPTS

- A chronic condenser tube leak accelerates corrosion and deposit formation in the feedwater and steam cycle – particularly in the boiler. Boiler level control problems (due to foaming) and increased moisture carryover are also possible.
- Typical indications of a leak are increased sodium content (and, perhaps, conductivity) of boiler water and – if the leak is large enough – at the condenser and CEP discharge.
- When an excessive leak is detected, work should be quickly initiated to locate and repair the leak. Meanwhile, boiler blowdown should be increased enough to keep the concentration of boiler water impurities within acceptable limits.
- Air leakage into the condenser can be monitored by means of a flow meter at the discharge of the vacuum pumps in the condenser air extraction system.
- When an air leak is being located and repaired, the operator should place more vacuum pumps in service, and have the hydrazine injection rate checked, and adjusted if necessary, by the chem lab.

Pages 44-45 ⇔

You may now complete **assignment questions 19-25.**

ASSIGNMENT

1. a) The reason why operating limits are placed on the CCW temperature rise and the station effluent temperature is ______________

____

b) If any one of these limits is exceeded, one or more of the following actions must be taken:

i) ____

____

ii) ____

____

iii) ____

____

c) Obstructions to the CCW flow can be eliminated by:

i) ____

____

ii) ____

____

iii) ____

____

2. a) The following general operating practices are used during CCW pump startup and shutdown in order to minimize water hammer:

i) ____

____

This minimizes water hammer by ______________

____

____

ii) ____

____

This minimizes water hammer by ______________

____

____

iii) ______________________________

____

This minimizes water hammer by ______________

____

____

b) i) During CCW pump startup, the pump discharge valve operates as follows:

____

____

____

ii) During CCW pump shutdown, the pump discharge valve operates as follows:

____

____

____

3. a) The vacuum breakers that are connected to the condenser water boxes operate upon ______________________________

if ______________________________

b) If the vacuum breakers failed to operate, ______________

______________ could develop in the CCW system as follows:

____

____

____

____

____

____

____

____

____

____

____

NOTES & REFERENCES

c) If not counteracted, the steam hammer could cause the following damage:

i) ____

____

____

ii) ____

____

____

d) For adequate protection of the CCW system against steam hammer, the vacuum breakers operate as follows: ______________

____

Their operation achieves its purpose by ________________

____

____

4. A small decrease in condenser vacuum (1-2 kPa) affects the turbine team flow and generator output as follows:

a) For the reactor leading mode of unit operation: ____________

____

____

____

____

b) For the reactor lagging mode of unit operation: ____________

____

____

____

____

____

____

____

NOTES & REFERENCES

5. a) Poor condenser vacuum results in the following adverse consequences/operating concerns:

i) ______________________

ii) ______________________

iii) ______________________

iv) ______________________

b) High condenser pressure can reduce generator output for the following reasons:

i) ______________________

ii) ______________________

iii) ______________________

c) When condenser vacuum decreases, the temperature of the turbine exhaust steam (decreases / increases) and its density (decreases / increases). This increases chances of equipment damage due to:

i) ______________________

____

ii) ______________________

____

iii) ______________________

____

iv) ______________________

____

d) The LP turbine exhaust cover and condenser shell are protected from overpressure by ______________________

6. a) The following actions – listed in the order of rising pressure – are carried out when condenser pressure is too high:

i) Action: ______________________

Purpose: ______________________

____

ii) Action: ______________________

Purpose: ______________________

____

iii) Action: ______________________

Purpose: ______________________

____

iv) Action: ______________________

Purpose: ______________________

____

v) Action: ______________________

Purpose: ______________________

____

b) When a high condenser pressure alarm is received, the operator can take the following actions in an attempt to restore normal vacuum when the cause of poor vacuum is being investigated:

i) ______________________

ii) ______________________

c) The maximum turbine unloading on low condenser vacuum reduces turbine power to about 10-30% FP, depending on the station. The reason for this limit is:

____

____

____

7. a) Excessive condenser vacuum can result in the following adverse consequences/operating concerns:

i) ______________________

ii) ______________________

b) Operation at excessive condenser vacuum accelerates equipment wear by:

i) ______________________

____

____

ii) ______________________

____

____

iii) ______________________________

____

____

c) Even a short-lasting operation at excessive condenser vacuum is likely to result in equipment failure. (False / true)

d) High dissolved oxygen content in the condensate can be expected when condenser vacuum is excessive because ____________

____

____

e) Excessive condenser vacuum may reduce the unit thermal efficiency due to increased losses in the turbine last stage. These losses increase because:

i) ______________________________

____

ii) ______________________________

____

8\. a) Excessive condenser vacuum (does / does not) result in automatic actions.

b) The operator can take the following actions in response to excessive vacuum:

i) ______________________________ upon condition that ______________________________

____

ii) ______________________________ upon condition that ______________________________

____

9\. In this question, assume a constant condenser thermal load and only one cause of low condenser vacuum at a time. For the first blank in each sentence, select the correct statement from the following: decreases, does not affect, increases.

a) Reduced CCW flow rate:

i) ____________________ the CCW temperature rise

because ______________________________

____

ii) ____________________ the CCW mean temperature

because ______________________________

____

iii) Results in subcooled condensate. (False / true)

iv) Results in increased dissolved oxygen content in the condensate. (False / true)

b) Increased CCW inlet temperature:

i) ____________________ the CCW temperature rise

because ______________________________

____

ii) ____________________ the CCW mean temperature

because ______________________________

____

iii) Results in subcooled condensate. (False / true)

iv) Results in increased dissolved oxygen content in the condensate. (False / true)

c) Tube flooding:

i) ____________________ the CCW temperature rise

because ______________________________

____

ii) ____________________ the CCW mean temperature

because ______________________________

____

iii) Results in subcooled condensate. (False / true)

iv) Results in increased dissolved oxygen content in the condensate. (False / true)

10. Tube fouling:

    a) Improves heat transfer by making the CCW flow more turbulent. (False / true)

    b) Impairs heat transfer due to the insulating effect of deposits on the tube inner surface. (False / true).

    c) May result in a substantial reduction in the CCW flow rate. (False / true)

    d) Results in a considerable increase in the dissolved oxygen content in the condensate. (False / true)

11. Accumulation of gases in the condenser atmosphere:

    a) Results in increased condenser pressure because:

    i) ______________________________________

    ____

    ____

    ii) ______________________________________

    ____

    ____

    b) Results in (apparent / real) subcooling of the condensate because

    ____

    ____

    ____

    ____

    c) Results in the condensate temperature being slightly (decreased / increased) as compared with normal operation at the same load.

    d) Results in increased dissolved oxygen content in the condensate

    because ______________________________________

    ____

12. Given the following data for normal operation and various upset conditions, and assuming a constant condenser thermal load, determine the actual cause(s) of poor condenser performance. Show your reasoning.

	Normal	Upset conditions				
Parameter	Operation	#1	#2	#3	#4	#5
CCW inlet temp. [°C]	15	15	15	15	15	18
CCW outlet temp. [°C]	25	30	25	25	25	32
Cond.pressure [kPa(a)]	4.5	5.2	4.8	6.3	5.2	7.4
Saturation temp. [°C]	31	33.5	32	37	33.5	40
Condensate temp. [°C]	31	33.5	19	31.5	33.5	38

During normal operation: $\Delta T_{CCW} =$

$\Delta T_m \cong$

Upset condition #1:

Upset condition #2:

Upset condition #3:

Upset condition #4:

Upset condition #5:

13. a) The purpose of breaking condenser vacuum is ______________

____

b) Condenser vacuum is broken by shutting down:

i) The turbine gland steam sealing system. (False / true)

ii) The condenser air extraction system. (False / true)

14. a) Full breaking of condenser vacuum at high turbine speed – say, above 1200 rpm – is not recommended during a normal turbine shutdown because:

____

____

b) This action is, however, necessary in the event of:

i) ____

ii) ____

iii) ____

15. During normal turbine shutdown and most of turbine trips, condenser vacuum can be relieved by either method:

a) Preferred method: ______________________________

____

Disadvantage: ______________________________

b) Other method: ______________________________

____

Disadvantages: ______________________________

____

____

16. Discharging main steam into the condenser via the CSDVs causes the following operational concerns:

    a)

    b)

    c)

17. CSDV unloading increases with:

    a) Condenser pressure in order to

    b) Turbine load in order to

18. The purpose of tripping the CSDVs in the (closed / opened / partially opened) position by the following parameters is as follows:

    a) Low condenser vacuum

    b) Unavailability of the condenser cooling sprays

    c) Very high boiler level

19. A chronic condenser tube leak has the following adverse consequences and operating concerns:

    a) ______________________________

    ____

    b) ______________________________

    ____

    c) ______________________________

    ____

20. Accelerated formation of deposits in the boilers and, to much smaller extent, feedheaters promotes the following adverse consequences:

    a) ______________________________

    ____

    ____

    b) ______________________________

    ____

    ____

    c) ______________________________

    ____

    ____

21. Typical indications of a condenser tube leak are:

    a) ______________________________

    ____

    b) ______________________________

    ____

22. a) In order to minimize the consequences of a condenser tube leak while it is being located and repaired, the operator should perform the following action:

    ____

    b) Despite this action, prompt leak repair is very important because:

    i) ______________________________

    ____

ii) ______________________________________

____

iii) ______________________________________

____

23. The leaking condenser can be identified by __________________

____

24. The leaking condenser half can be identified by the following techniques:

a) ______________________________________

____

____

b) ______________________________________

____

____

25. a) The rate of air leakage into the condenser can be monitored by means of ______________________________

____

b) When an air leak is being located and repaired, the operator should take the following actions to minimize the adverse consequences of the leak:

i) ______________________________________

____

ii) ______________________________________

____

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

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Revision date: May, 1994

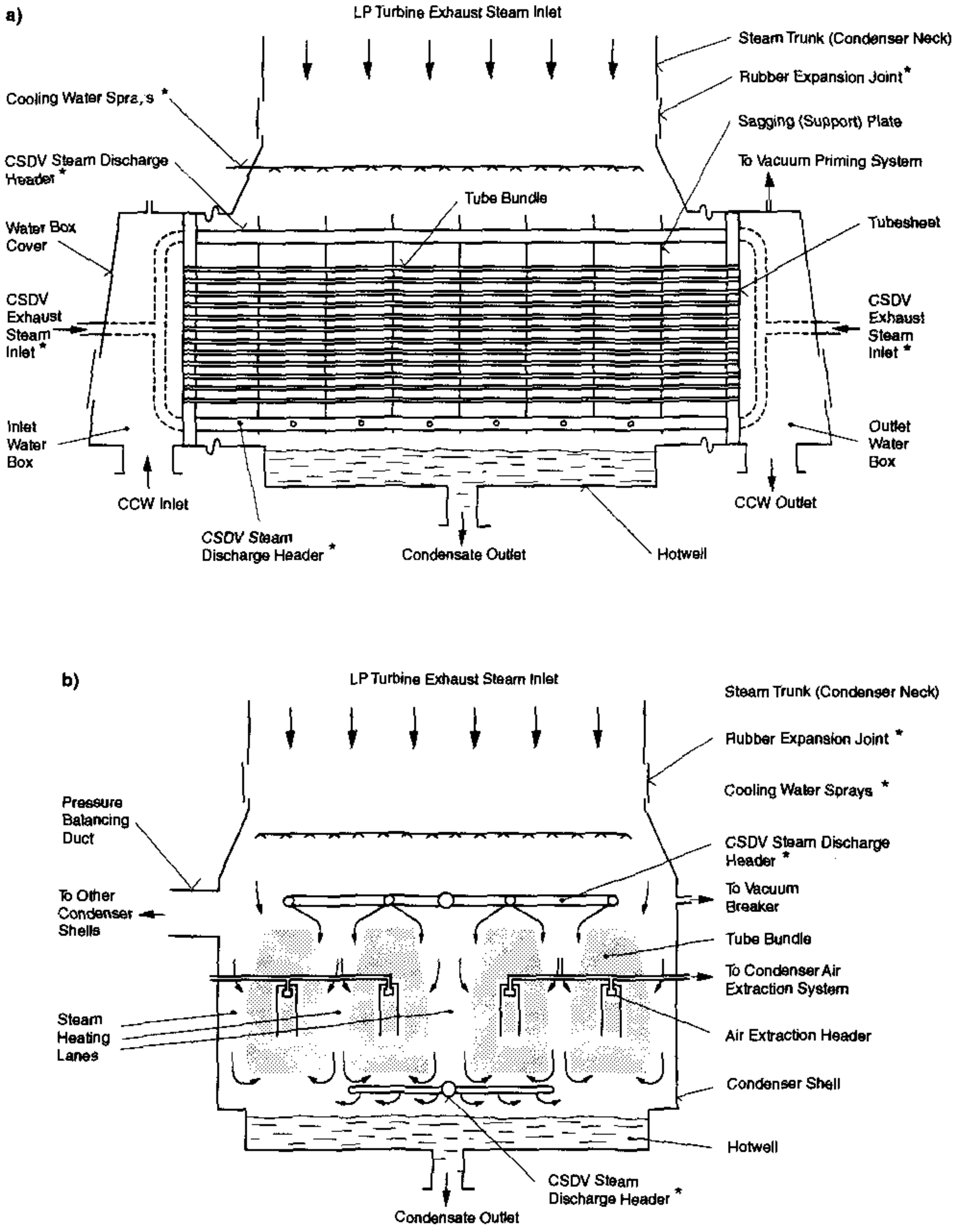

Fig. 5.6. Typical condenser capable of operating with CSDVs:
a) Longitudinal section, b) Cross section;
* Not in all stations.

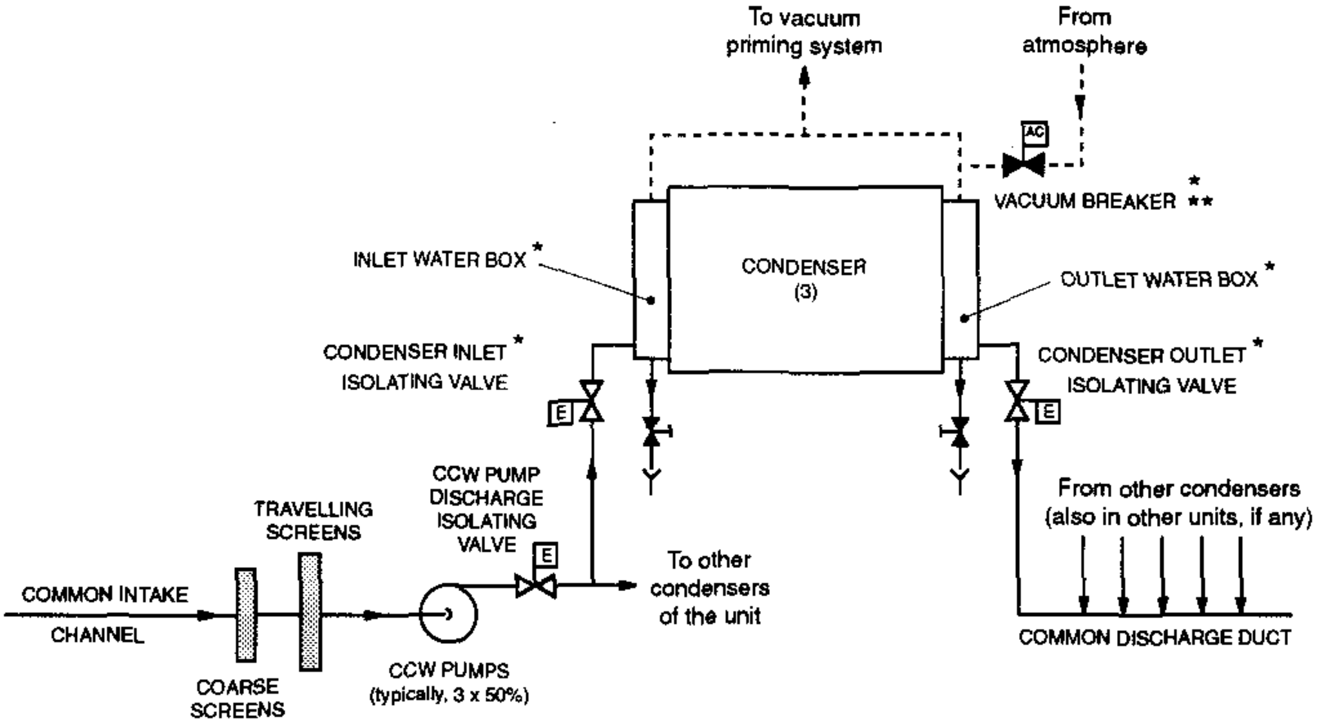

Fig. 5.7. Simplified condenser cooling water (CCW) system:

——— CCW ------- Air (mainly)

* Two per each condenser;

** Part of the vacuum priming system.