Heat and Thermodynamics - Course PI 25

PRESSURE CONTROL

Objectives

1. Describe the effects resulting from:

    (a) too high primary heat transport pressure
    (b) too low primary heat transport pressure

2. Given a simplified system diagram, explain how the heat transport system pressure is controlled using:

    (a) the feed and bleed system
    (b) the pressurizer system

3. State why controlling boiler pressure is important.

4. List the three main heat sinks for the boiler in a CANDU station.

5. Briefly explain how the boiler pressure can:

    (a) remain constant as power increases
    (b) fall as power increases,

    and how this affects the PHT fluid average temperature.

Controlling the pressure of the PHT system and of the boiler is very important in the CANDU station. In this module you will be examining the reasons for controlling the pressure and you will be introduced to the means of pressure control in two areas: the primary heat transport system and the boiler.

Primary Heat Transport Pressure Control

The PHT system operates at high pressures and temperatures - in the range of 8.5 to 10 MPa(a) and 250 to 300°C. The high pressures are necessary to maintain the heavy water in a liquid state.

If the PHT pressure becomes too high, there is a possibility of rupture in the PHT system. This would be a loss of coolant accident.

If the PHT pressure becomes too low, either of two effects may occur:

(a) Boiling in the pressure tubes will begin, due to the continuing production of heat by the fuel as the pressure drops to the saturation value. If sufficient vapour is produced so that the fuel elements are covered with a vapour film, the fuel temperature will rise drastically. This will lead to fuel failure and significant releases of fission products in the PHT system.

(b) Cavitation in the main PHT circulating pumps will occur. This leads to reduction in flow (with less cooling of the fuel) and to pump damage.

———➤ Answer the following question in the space provided, then check your answer with the one in the "TEXT ANSWERS".

4.1) Describe the effects resulting from:

(a) too high PHT pressure.

(b) too low PHT pressure.

There are two main ways that PHT pressure is controlled in NGD: using a feed and bleed system or using a pressurizer system (in conjunction with a feed and bleed system).

Feed and Bleed System

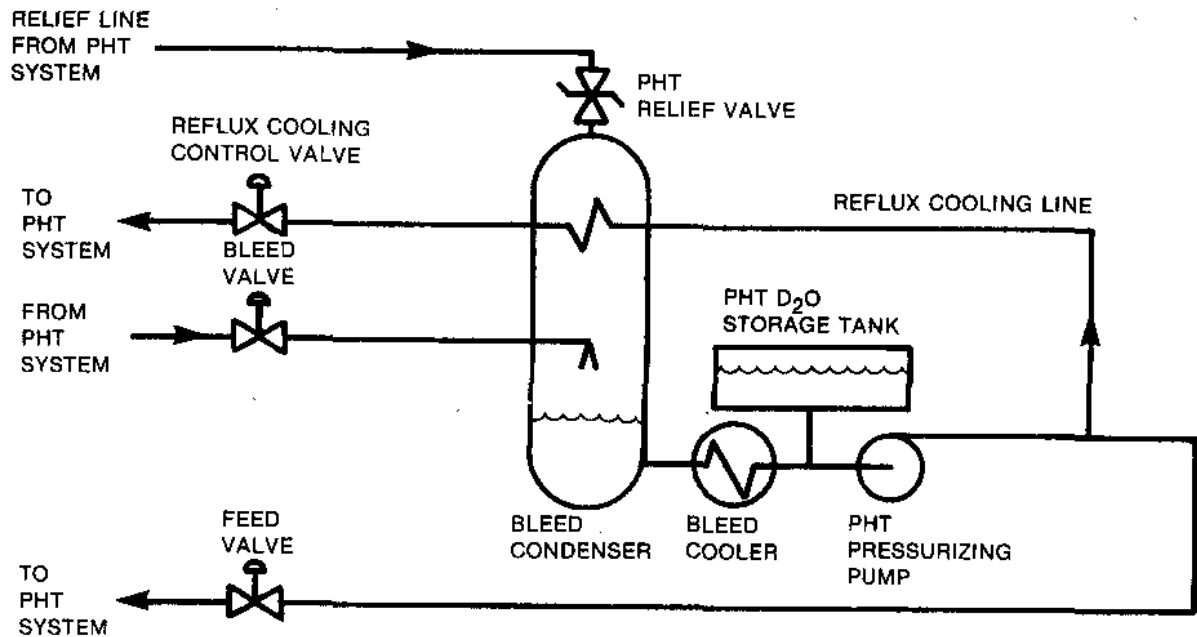A much simplified version of the feed and bleed system is shown in Figure 4.1:

Figure 4.1

The PHT pressure is controlled from becoming too high in two ways:

(a) Under normal operating conditions the bleed valve lowers the PHT pressure by admitting more D_2O from the primary heat transport system to the bleed condenser than is returned to the system. The bleed condenser is a vessel with a mixture of D_2O liquid and vapour at saturation conditions. Controlling the D_2O temperature in this vessel will also control its pressure (that is, if the vapour temperature is lowered, the pressure must drop, and if the vapour temperature is raised, the pressure must rise). The bleed condenser temperature and pressure are lowered by a reflux cooling line, which is controlled by the reflux cooling control valve. The reflux cooling D_2O is cooled by the bleed cooler.

(b) Under abnormal conditions, i.e. if a PHT pressure rise cannot be controlled via the bleed valve, there is a relief line from the PHT system which will activate relief valves leading to the bleed condenser. If the relief valves do not control the pressure increase, reactor power will be reduced. If the power reduction does not control the pressure increase the reactor will be tripped.

The PHT pressure is controlled from dropping too low by the use of the feed valve. The PHT pressurizing pump provides high pressure D_2O at its outlet. There is a constant flow from this pump into the PHT system through the reflux cooling line. The pressurizing pump also supplies the feed valve which admits D_2O to the PHT system as necessary to maintain the PHT pressure. If the system pressure cannot be maintained using the feed valve, the reactor is tripped.

In summary, the normal variations of pressure (due mainly to PHT shrink and swell) are controlled by a balance between the operation of the bleed valve and the feed valve (taking into account the effect of flow through the reflux cooling line). The bleed condenser is used as a sink of low pressure to ensure flow through the bleed valve; the PHT pressurizing pump provides a source of high pressure to ensure flow through the reflux cooling line and feed valve.

⟶ Answer question 4.2 in the space provided before you proceed. Check your answer with the one in the "TEXT ANSWERS". If you have any questions at this point, consult with the course manager.

4.2) For the system shown below, explain how the heat transport system pressure is controlled.
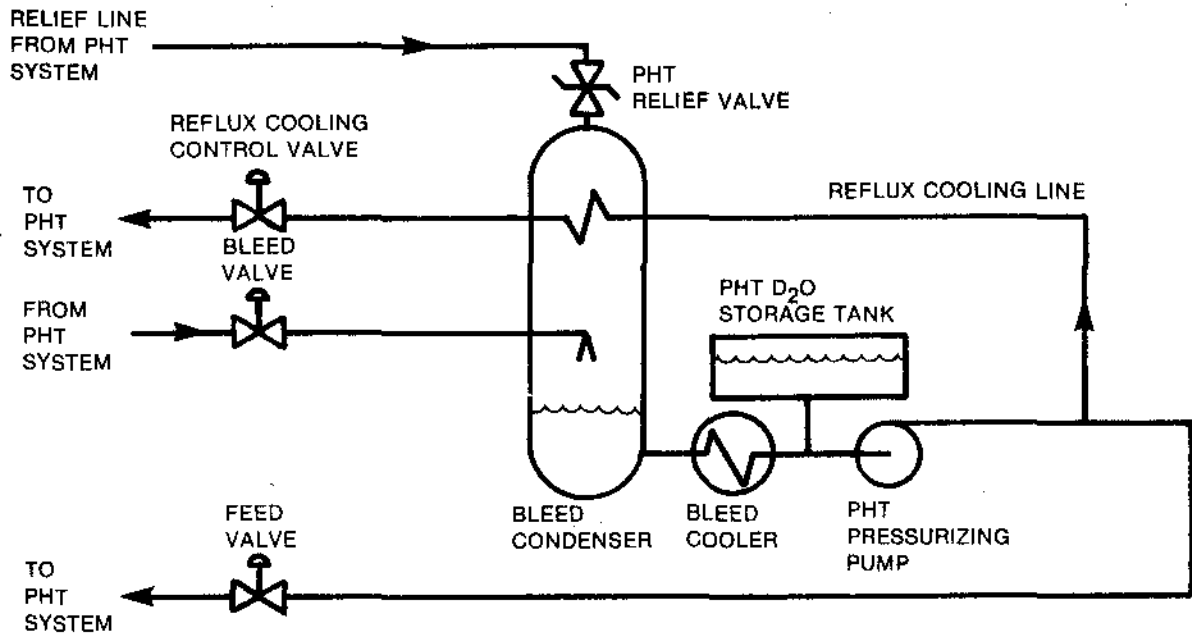
RELIEF LINE
FROM PHT
SYSTEM

PHT
RELIEF VALVE

REFLUX COOLING
CONTROL VALVE

TO
PHT
SYSTEM

REFLUX COOLING LINE

BLEED
VALVE

FROM
PHT
SYSTEM

PHT D_2O
STORAGE TANK

FEED
VALVE

BLEED
CONDENSER

BLEED
COOLER

PHT
PRESSURIZING
PUMP

TO
PHT
SYSTEM

Figure 4.2

Pressurizer System:

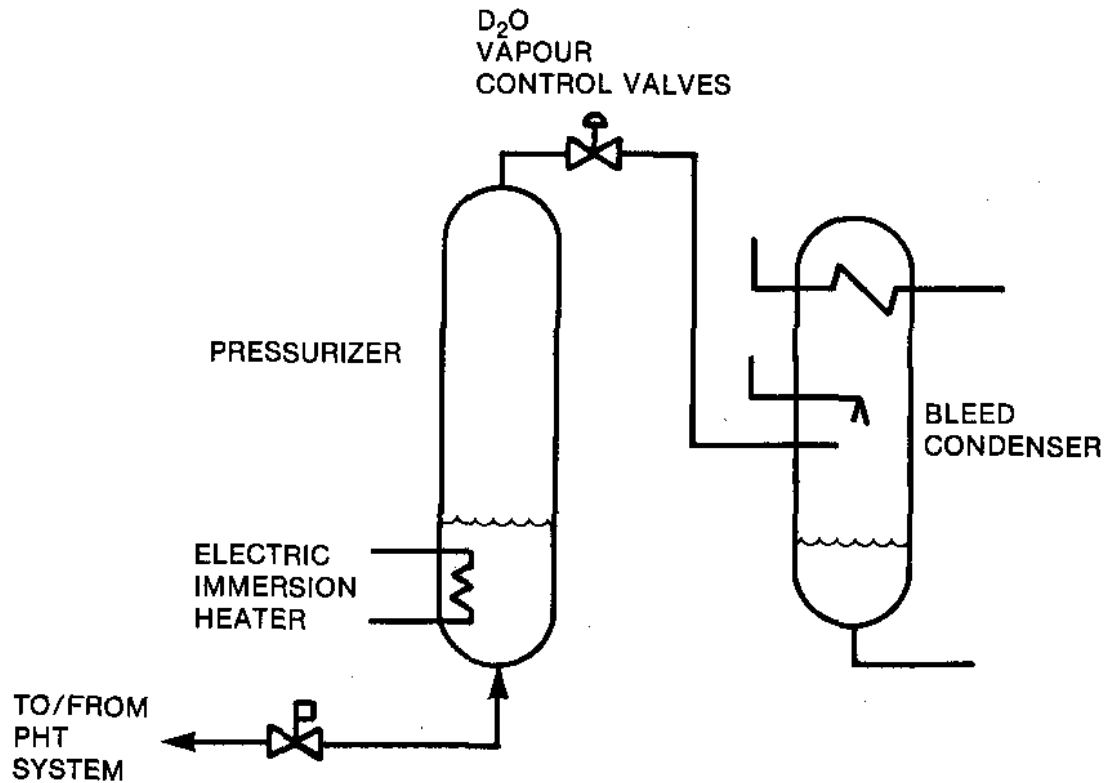A simplified version of the pressurizer sytem is shown in Figure 4.3.

Figure 4.3

The pressurizer is connected to the PHT system by a liquid line. This connection can either supply D_2O to the PHT system or remove D_2O from the system.

Under normal operating conditions, if the PHT pressure drops (say due to shrink), the immersion heater in the pressurizer will increase the temperature and thus the pressure of the D_2O vapour and liquid in the vessel. This will increase the PHT pressure via the connecting line.

If the PHT pressure increases (say due to swell) the D_2O vapour control valves will act to admit D_2O vapour from the pressurizer to the bleed condenser. This will lower the PHT pressure by removing D_2O from the PHT system to the pressurizer.

(Normally, in addition to the pressurizer, there is a feed and bleed system installed. Besides providing a low pressure sink for the pressurizer, this feed and bleed system is used to pressurize and depressurize the PHT system, from atmospheric to normal operating range.)

———► Answer the following question, then compare your answer to the one in the "TEXT ANSWERS".

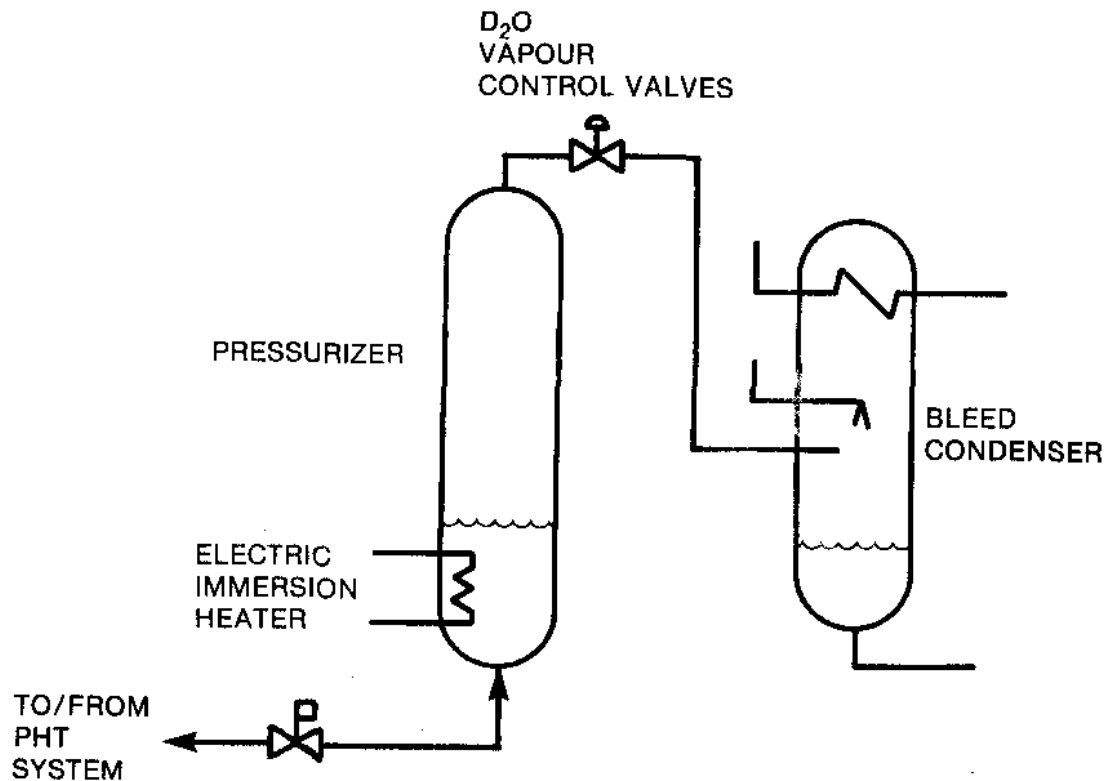4.3)   For the pressurizer system shown below, explain how the PHT system is controlled.

D₂O
VAPOUR
CONTROL VALVES

PRESSURIZER

BLEED
CONDENSER

ELECTRIC
IMMERSION
HEATER

TO/FROM
PHT
SYSTEM

Figure 4.4

Boiler Pressure Control

The boilers are the main heat sink for the heat generated in the reactor. This heat is added to the water in the boilers by the PHT system to produce steam. The steam removes heat from the boilers as it flows out.

It is very important to match the addition of heat to the boilers with the removal of heat from them. If the reactor power (ie, the heat input) is greater than the heat removed by the steam flow, then boiler temperature and pressure both increase. The opposite happens if the reactor power is less than the heat removed by the steam. Either temperature or pressure can be used to indicate conditions in a boiler because the boiler is operating <u>at saturation</u>. Pressure is a variable that can be measured easily and quickly; thus boiler <u>pressure</u> is used to control the match between heat input to the boiler and heat output from the boiler.

The boilers in turn must have heat sinks in order to continue to function as the main reactor heat sink. The three main heat sinks for the boilers are:

(a) the turbine set

(b) the condenser

(c) the atmosphere

Note that under normal circumstances heat is removed from the boilers via steam to the turbine set and condenser. If the turbine set or the condenser are unavailable, the steam can be rejected to atmosphere to allow heat removal from the boilers.

⟶ Answer the following questions before you proceed. Check your answers with those in the "TEXT ANSWERS".

4.4) State why controlling boiler pressure is important.

4.5)   List the three main heat sinks for the boiler in a CANDU station.

Boiler pressure is controlled in the large stations using the Boiler Pressure Control (BPC) program of a digital control computer. There are two different types of BPC program:

(a)   boiler pressure is held constant as power is increased

(b)   boiler pressure is lowered as power is increased

In the first case, the pressure in the boilers is held constant at all power levels. Power is increased by increasing steam flow from the boiler. Effectively, reactor power becomes less than the heat removed by the steam which causes the boiler pressure to drop. In order to keep it constant, the BPC program increases reactor power so that heat input matches heat output.

The result of this power increase is a change in the PHT D_2O average temperature. The amount of heat transferred from the PHT D_2O to the light water in the boiler is a function of the temperature difference between the average temperature of each of the two substances. In order to increase power, more heat must be transferred. Since boiler pressure (and thus temperature) is maintained constant, the average PHT temperature must rise as power is increased.

In the second case, the pressure in the boilers is lowered when power is increased. This is done to keep the PHT D_2O average temperature constant through the whole power range and thus, to reduce PHT D_2O shrink and swell. When the reactor power increases (which tends to increase the D_2O temperature, and boiler temperature and pressure), the BPC program increases steam flow from the boiler. This flow is increased so much that boiler pressure can be lowered. This is associated with a decrease in boiler temperature so that the temperature difference between the PHT D_2O and the light water can be increased. Therefore, more heat can be transferred despite the constant temperature of the PHT D_2O.

━━━▶ Answer the following in the space provided, then check your answers with those in the "TEXT ANSWERS".

4.6) Briefly explain how boiler pressure can remain constant as power increases, and how this affects the PHT D_2O average temperature.

4.7) Briefly explain how boiler pressure can fall as power increases, and how this affects the PHT D_2O average temperature.

➤ You have now completed PI 25-4. If you feel confident you can do the objectives for this module, obtain a criterion test and answer the questions on it. If you feel you need more practice before attempting the test, consult with the course manager.

4.1) (a) The main effect of a very high pressure in the PHT sytem is the possibility of a rupture, which would cause a loss of coolant accident.

(b) The first effect of too low a pressure in the heat transport system is boiling of D_2O in the pressure tubes. *This could lead to fuel failure and release of fission products if the boiling becomes enough to lead to vapour film formation around the fuel.*

The second effect is cavitation in the main heat transport circulating pumps. This will cause reduction in PHT flow and in fuel cooling, and it may lead to pump damage.

4.2) The PHT pressure is controlled in this feed and bleed system by a balance in flow through the bleed valves and the feed valves (and including the reflux cooling flow).

The bleed valves act to lower the PHT pressure by admitting D_2O from the heat transport system to the bleed condenser. The bleed condenser will lower the temperature and pressure of any bleed flow that occurs. Condensing action is maintained by the reflux cooling line. The bleed cooler acts to maintain the reflux cooling line temperature low.

The feed valves act to raise the PHT pressure by admitting high pressure D_2O to the heat transport system. The PHT pressurizing pump is the source of high pressure D_2O.

4.3) The pressurizer acts to raise or to lower PHT pressure through the same connecting line.

In order to raise the pressure, electric immersion heaters heat the liquid in the pressurizer vessel. The PHT pressure is increased via the connecting line.

In order to lower the pressure, D_2O vapour is admitted from the pressurizer to the bleed condenser by the D_2O vapour control valves. Liquid D_2O will be removed from the heat transport system to the pressurizer and the PHT pressure will be lowered.

4.4) Boiler pressure is used to control the match between heat input to the boiler from the reactor and heat output from the boiler in the steam. This match is critical; thus boiler pressure control is important.

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4.5)   The three main heat sinks for the boiler in a CANDU station are the turbine set, the condenser, and atmosphere.

4.6)   At stations where boiler pressure is maintained constant, power is increased by first increasing steam flow from the boilers. This would tend to lower boiler pressure. The BPC program increases reactor power to maintain constant boiler pressure, while the PHT D_2O average temperature changes.

4.7)   At stations where boiler pressure changes, power is increased by first increasing reactor power. This would tend to increase boiler pressure. The BPC program increases steam flow so much that boiler pressure and temperature in fact decrease, allowing an increase in power while at the same time keeping PHT average temperature constant.