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HEAT & THERMODYNAMICS

MODULE B.3.2

FEEDHEATER OPERATION

Heat & Thermodynamics

MODULE B.3.2

FEEDHEATER OPERATION

Course Objectives

1. Given a set of conditions, steam tables and a calculator, you will be able to perform simple calculations of heat transfer based on the principle that heat gained by the feedwater is equal to heat lost by the extraction steam.

2. You will be able to explain how the extraction steam is more efficiently used in feedheating than in producing further work in the steam turbine.

3. You will be able to support the rationale stated in Objective 2 using a simple numerical example.

Enabling Objectives

1. You will be able to explain how the extraction steam flow to a feedheater changes when feedwater flow conditions change.

Before we look at the feedheater as a heat exchanger, let's take a more global view of the whole system. The majority of our systems are concerned with heat transfer of one form or another. The systems are depending on each other and a change in condition in one system is reflected by changing conditions in another system.

Even in the "steady state" situation, conditions are fluctuating due to control systems, hydraulic transients, etc. How do we know what is within the normal fluctuation and what is abnormal? Are some parameters more reliable than others?

Two major questions then arise: "How do we know when we have lost control?" and secondly, "Do we know why control was lost?"

If we don't know the answers to these two questions, the chances of regaining control are very slim. You only have to examine the reports on Three Mile Island to see that this is true.

In any system, the "steady state" operation is reached when the supply satisfies the demand whether it is the supply of gold to satisfy the investor or the supply of electrical energy to satisfy the Grid requirements.

When the supply no longer satisfies the demand, conditions start to change, sometimes very rapidly. If we concentrate on the basic fluid systems within a nuclear station, there are two major parameters which will indicate changing conditions, TEMPERATURE & PRESSURE.

Let's consider these two parameters:

TEMPERATURE

Suppose we have a liquid/liquid heat exchanger; say the turbine lube oil cooler. Keep the oil flow constant and the cooling water flow constant and watch the cooler outlet oil temperature when the oil inlet temperature remains constant.

Will it change? Why doesn't the temperature change?

It will not change because the supply of cooling water and the supply of oil are constant and the steady state condition is created by the cooling water removing heat at the same rate as the cooling oil is supplying heat to the cooler.

Let's increase the flow of cooling water to the cooler.

What happens to the oil outlet temperature? Why did it start to fall?

The rate at which heat was being removed from the oil by the cooling water was greater than the rate at which heat was being added to the oil by the turbine bearings.

What happened to the outlet temperature of the cooling water?

The temperature became lower because, although overall more heat was being removed from the oil cooler; on a per kg base,each kg was removing less heat because there was less time for heat absorption in the cooler.

Did the pressure of the oil change as a result of reducing the temperature?

The pressure did not change because the pressure was being maintained by the oil pump.

B.3.2.1

Consider the following problem:

Suppose we had a closed cylinder and it was full of liquid at 300°C and at a pressure of 9 MPa. If we started to cool the cylinder, what would happen to the pressure?

Think about this and see if you agree with the response at the end of the module.

* * * * *

From this example, we can see that the first effect of cooling the cylinder was to reduce the temperature but because the temperature caused a change of volume within the system, the pressure also changed.

If the only change in the system had been the reduction of fluid temperature, then we could have measured this change by temperature or pressure measurements. A reduced pressure would lead us to deduce, quite correctly, that the temperature of the fluid was falling. Therefore, we could have used pressure to tell us that there was a mismatch in the system, ie, heat into the cylinder was less than heat out of the cylinder.

Before we move on to look at the feedheater, have a look at these two questions and compare your answers with those at the end of the module.

B.3.2.2

What happens to the pressure of the engine coolant in an automobile after the engine is shutdown? How is the effect you describe put to good use?

B.3.2.3

A tank of liquid propane is used for a period of time. The pressure in the tank falls and heavy frost forms on the outside of the propane tank. Explain why the pressure has fallen and why the frost has appeared.

* * * * *

Feedheater

The purpose of the feedheater is to raise the temperature of feedwater on its way to the steam generator. The feedwater flows through the tubes and receives its heat from steam in the heater body. The steam is extracted from suitable points on the steam turbine and may have high levels of moisture.

If the steam was condensed to saturated liquid only, then any small drop in pressure would cause the liquid to vapourize and vapour locking of drain lines would occur. Consequently, the condensate in a feedheater is sufficiently subcooled to prevent the drains flashing to vapour.

In a steady state condition, the heat gained by the feedwater is equal to the heat lost by the extraction steam and resulting condensate.

Any change in conditions on either side of the heater is going to appear as a temperature change or a temperature effect because Heat Out no longer equals Heat In.

Let's have a closer look at the conditions which exist and how they can affect heater performance.

Feedwater Side

The heat which is picked up by the feedwater is a function of the mass flow, in kg/s, and the change in enthalpy of the feedwater across the heater. This is the same as using the temperature difference except that by using the enthalpies, these values can be looked up immediately under the h_f columns in the steam tables.

Thus heat gained by the feedwater is:

flowrate (kg/s) x [Enthalpy Out ($h_{f_{out}}$)

- Enthalpy In ($h_{f_{in}}$)].

We will put some figures into this arrangement later on.

Steam Side

The heat which is lost by the steam is a function of the steam flow and the change of enthalpy of the steam entering the heater and the resulting condensate leaving the heater.

Again, we can use exactly the same approach of using enthalpies.

Thus, heat lost by the steam to the feedheater is:

flowrate (kg/s) x [Enthalpy In ($h_{steam\ in}$)

- Enthalpy Out ($h_{f_{out}}$)].

For any steady state operation, the heat gained by the feedwater will be equal to the heat lost by the extracted steam.

Heat Out Feedwater = Heat In Steam.

Feed Flow x Enthalpy Change = Steam Flow x Enthalpy Change.

Before we examine this equation in more detail, let's just consider flowrates. The feed flow requires a pump to be running; either the condensate extraction pump or the feed pump. It also requires that control valves (either the level control valves for the deaerator or the feedwater regulating valves for the steam generator) must allow the flow of feedwater.

The steam flow from the extraction steam belt on the turbine to the feedheater is not regulated by valves. The steam will only flow from the turbine to the feedheater if there is a pressure difference between the turbine and feedheater.

B.3.2.4

How is steam flow established to a feedheater? Why is the feedheater shell pressure normally lower than the turbine extraction point pressure?

B.3.2.5

How is the steam flow to the feedheater increased when the unit power changes from 50% to 100% power?

Check your responses with those at the end of the module.

Effect of feedwater conditions on extraction steam flow

Using the energy balance, heat in = heat out, we can examine the effects that changes in feedwater temperature and flowrate will have on the extraction steam flow to the feedheater.

Temperature

If the temperature of the feedwater into the heater changes, then this will affect the temperature rise of the feedwater across the heater.

The change in temperature means that the amount of heat removed from the feedheater will have changed. Assume that the feedwater flowrate is unchanged.

Suppose the feedwater inlet temperature drops. The amount of heat energy which is transferred is a function of the difference in temperature between the steam side and the feedwater side of the feedheater. Because of the larger temperature difference between the steam and the feedwater, more heat is being transferred and is being removed from the heater than before. The increased rate of heat removal has the effect of lowering the temperature in the steam side of the heater.

As the temperature in the heater shell falls, so does the pressure. This provides a larger pressure difference between the turbine extraction point and the heater, and more steam flows to the heater. The energy to and from the heater come back into equilibrium with a new set of operating conditions.

The new operating conditions will be:

a) lower pressure and temperature in the heater shell.

b) higher extraction steam flow.

c) increased ΔT across the heater on the feedwater side, although the outlet temperature will be less than previously.

Similarly, if the feedwater inlet temperature had risen, there would have been less heat removed from the heaterbecause there would have been a reduced temperature difference between the steam and feedwater.

The effect of reducing the heat removed by the feedwater would be that the temperature in the steam space would start to rise. As the temperature increased, the pressure would increase and the extraction steam flow from the turbine would reduce to a new level which satisfied the feedwater conditions.

The new operating conditions will be:

a) higher temperature and pressure in the heater shell.

b) reduced extraction steam flow to the feedheater.

c) the feedwater ΔT across the feedheater will have reduced although the feedwater outlet temperature will have increased.

The effect of keeping the feedwater inlet temperature constant and changing the feedwater flow produces the same results as changes in temperature. As the heat rate removal is increased, the temperature in the shell side falls, pressure falls, extraction steam flow increases, and the system moves back into equilibrium.

Try these questions and compare your answers with those at the end of the module.

B.3.2.6

Feedwater inlet temperature to a feedheater remains constant. Assuming that the supply steam temperature at the turbine remains constant, explain how the conditions of pressure, temperature and flowrates change at the heater when the feedwater flowrate is reduced.

B.3.2.7

A turbine has three feedheaters in series. Explain the changes you would expect to find on #3 heater if heater #2 is taken out of service.

B.3.2.8

A turbine has three feedheaters. Explain what changes in operating conditions you would expect from the heaters when the turbine power output is increased from 50% to 100%.

Heat Transfer

The heat gained by the feedwater in the heater is equal to the heat lost by the extraction steam. The only points that we have to watch are:

a) the steam to the feedheater may be very wet, up to 55%.
b) the condensate to the heater drains has a significant amount of subcooling, around 15 - 20°C.

Let's look at some examples and see how we can approach a feedheater calculation.

A feedheater is supplied with saturated steam at a pressure of 270 kPa(a) in the feedheater shell. There is no subcooling of the condensate. The feedwater inlet and outlet temperatures are 90°C and 118°C respectively. The feedwater flowrate is 588 kg/s. Determine the extraction steam flowrate.

There is nothing new in the approach to this problem. The only unknown is the extraction steam flow. If we use the relationship, heat gained by the feedwater = heat lost by the extraction steam, then we can find the one unknown.

Heat gained by the feedwater

This is equal to the mass flow per second multiplied by the change in enthalpy.

Inlet temperature is 90°C h_f = 376.9 kJ/kg.

Outlet temperature is 118°C h_f = 495.2 kJ/kg.

$$\text{Change in enthalpy} = h_{f_{118}} - h_{f_{90}} = 495.2 - 376.9.$$

$$= \underline{118.3}\ \text{kJ/kg}.$$

(The enthalpy of the feedwater is effectively only a function of the temperature, because the pressure effects are insignificant.)

The feedwater flowrate is 588 kg/s heat gained per second

= flow x enthalpy

$$= 588 \times 118.3 = \underline{69560}\ \text{kJ}$$

kg x kJ/kg.

Heat lost by extraction steam

The steam is saturated and there is no subcooling. If we look at the temperature/enthalpy diagram, we can see that the heat lost by the steam is in fact the latent heat of vapourization.

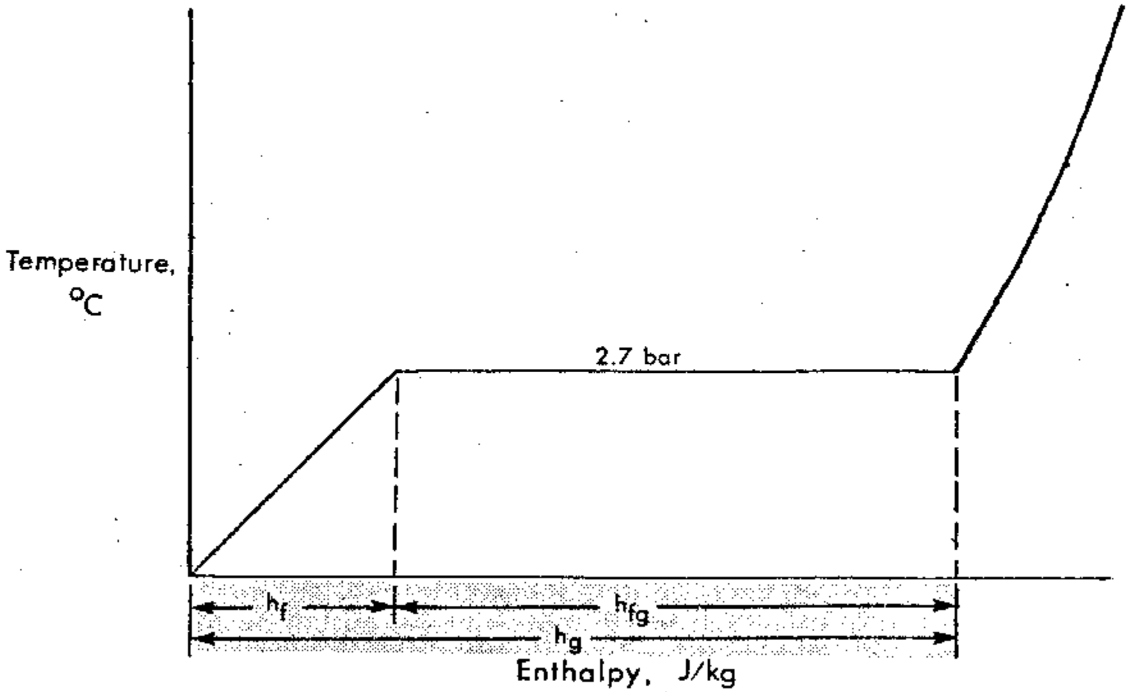

Fig. 3.2.1

At 270 kPa(a), ie, 2.7 bar, the value of h_{fg} = 2173.6 kJ/kg.

Heat lost by the steam per second is the product of the flow and the enthalpy change. Thus, heat lost by steam + $\overset{o}{m}$ x 2173.6 kJ per second, where '$\overset{o}{m}$' is the mass flowing per second.

Equating heat gained to heat lost:

$$69560 = \overset{o}{m} \times 2173.6 \text{ kJ}$$

$$\overset{o}{m} = 69560/2173.6$$

$$= \underline{32 \text{ kg every second}}.$$

In practice, the steam to the feedheater is usually 'wet' and the drains are subcooled. The only difference that this makes in the exercise is calculating the enthalpy drop of the extraction steam. Let's look at an example.

A feedheater is supplied with steam having a moisture content of 28%. The temperature in the feedheater shell is 103°C. The drains from the feedheater are at 87°C. The feedwater inlet and outlet temperatures are 58°C and 85°C and the flowrate is 521 kg/s. Determine the steam flow to the heater.

The heat gained by the feedwater per second is the product of the mass and the enthalpy change.

$$h_{f_{85}} = 355.9 \text{ kJ/kg}$$

$$h_{f_{58}} = 242.7 \text{ kJ/kg.}$$

$$\text{Change in enthalpy} = 355.9 - 242.7 \text{ kJ/kg}$$

$$= \underline{113.2} \text{ kJ/kg.}$$

Heat gained by the feedwater every second

$$= \text{mass} \times \text{change in enthalpy}$$

$$= 521 \times 113.2 \text{ kJ}$$

$$= \underline{58977} \text{ kJ.}$$

The heat lost by the extraction steam which is initially 72% dry and is finally condensate, may be seen on the temperature/enthalpy diagram.

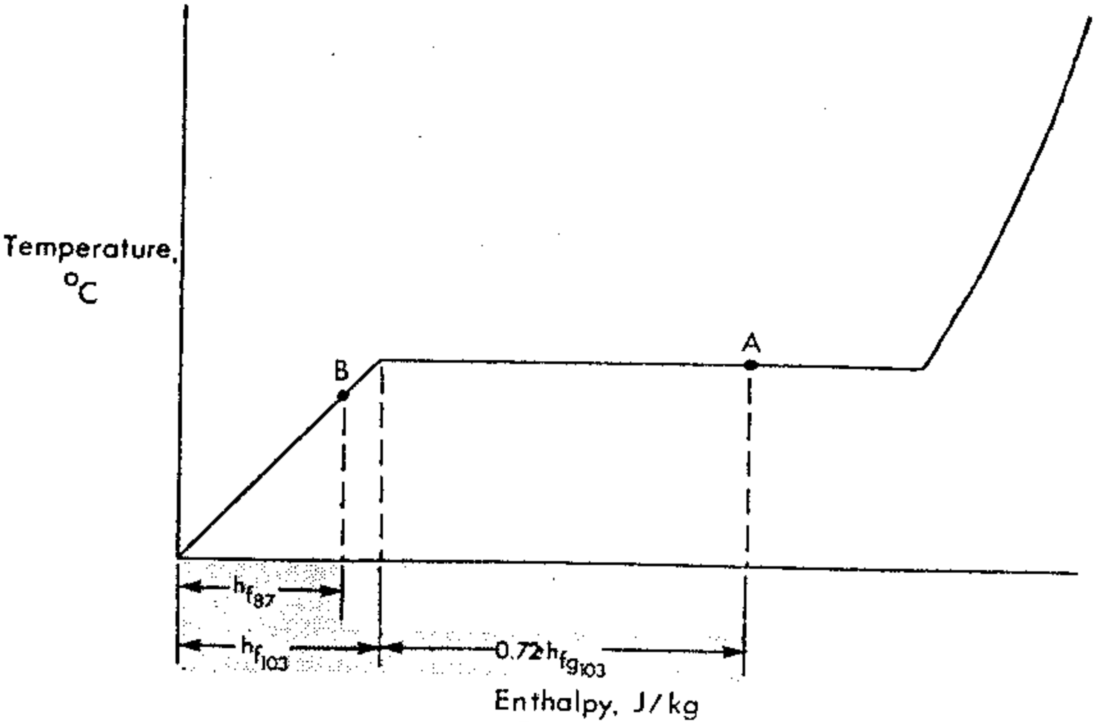

Fig. 3.2.2

$$\text{Enthalpy at point A} = h_{f_{103}} + 0.72\, h_{fg_{103}}$$

$$= 431.7 + 0.72 \times 2248.9$$

$$= \underline{2050.9}\ \text{kJ/kg.}$$

$$\text{Enthalpy at point B} = h_{f_{87}} = \underline{364.3}\ \text{kJ/kg.}$$

$$\text{Enthalpy change of steam} = 2050.9 - 364.3$$

$$= \underline{1686.6}\ \text{kJ/kg.}$$

Heat gained by feedwater = Heat lost by steam.

$$58977 = 1686.6 \times \overset{o}{m}\ \text{kJ.}$$

$$\overset{o}{m} = 58977/1686.6 = \underline{35}\ \text{kg/s.}$$

Try these problems and compare your answers with those at the end of the module.

B.3.2.9

A feedheater is fed with extraction steam from a turbine. The steam enters the heater shell at 180°C in a saturated condition. The drains from the heater are at 160°C. The feedwater inlet temperature is 150°C and the outlet is 174°C. The feedwater flowrate is 1000 kg/s.

Determine the steam flow to the feedheater.

B.3.2.10

Saturated steam enters a feedheater at 80°C and leaves as condensate at 66°C. The steam flowrate is 60 kg/s. The feedwater inlet temperature is 36°C and the flowrate is 850 kg/s.

Determine the feedwater outlet temperature from the heater.

Cycle Efficiency

The most efficient heat transfer in the steam generator occurs when the heat is transferred at constant temperature. In other words, when the steam generator is only supplying the latent heat of vapourization to change saturated liquid into saturated vapour.

In practice, this is not possible to achieve without a secondary source of heating. It follows that the greater the quantity of heat which has to be transferred in the steam generator to bring the liquid up to the saturation temperature, the more inefficient the cycle becomes.

If there was no feedheating, the steam generator would be fed with feedwater at around 35°C. This would mean that the steam generator would have to raise the temperature from 35°C to say 250°C before any latent heat could be added and therefore, before any vapour could be produced.

The feedheating system changes this picture considerably. It uses heat from the turbine to raise the temperature of the feedwater from 35°C to 175°C.

There is a second benefit in using feedheating. It is an opportunity to use thermal energy which would otherwise be rejected to the condenser cooling water system.

Around 70% of the reactor heat is thrown away in the CCW. This large quantity of heat is primarily accounted for by the remaining latent heat in the lp turbine exhaust, which must be removed to condense the large volume steam into a low volume liquid.

The steam turbine has a design limit of around 10 - 12% moisture beyond which rapid erosion would result.

The quality of steam entering a feedheater is of no significance from a heat transfer point of view. Consequently, the feedheater is able to handle moisture levels up to 50% and to raise the feedwater temperature using latent heat which is of no further use for producing work in the steam turbine.

B.3.2.11

a) If we can use the latent heat instead of rejecting it to the CCW, why don't we extract more steam from the turbine to heat the feedwater?

b) Maximum cycle efficiency occurs when the heat is added in the steam generator at 250°C. Why is the feedwater not heated to 250°C using extraction steam from the turbine?

B.3.2.12

If half of a nuclear power plant's feedheating capacity becomes unavailable, it might be necessary to reduce the electrical output. Explain two reasons why this might be necessary.

Compare your answers with the notes at the end of the module.

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A numerical demonstration of the benefit of feedheating consists of making a comparison of the heat used in heating the feedwater compared with the heat lost as work from the turbine.

In this exercise, we have to make some assumptions and this is more easily done by trying to use conditions you would reasonably expect to find in a power plant. Let's have a look at a question of this type.

Demonstrate the benefits of using extraction steam. Compare the heat recovered with and without feedheating using saturated steam extracted from a turbine at 120°C. State any assumptions that are made.

Assumptions

1. Turbine exhaust temperature is 35°C.
2. 10% of the steam flow in the turbine is extracted for feed heating.
3. Assume turbine exhaust is 10% wet.
4. Assume no subcooling in the condenser.

In this question, we have two conditions to examine:

a) with no feedheater
b) with feedheating.

In both cases, we **must consider the turbine work as recovered heat.**

Case 1 No feedheating

In this case, we have the turbine work of 100% steam flow with saturated steam at 120°C expanding to 10% moisture at 35°C PLUS the heat in the condensate.

The change in enthalpy of the steam may be seen by looking carefully at the temperature enthalpy diagram. I say 'carefully' because you can save a lot of work by identifying the heat which is rejected from the system and the heat which is recovered.

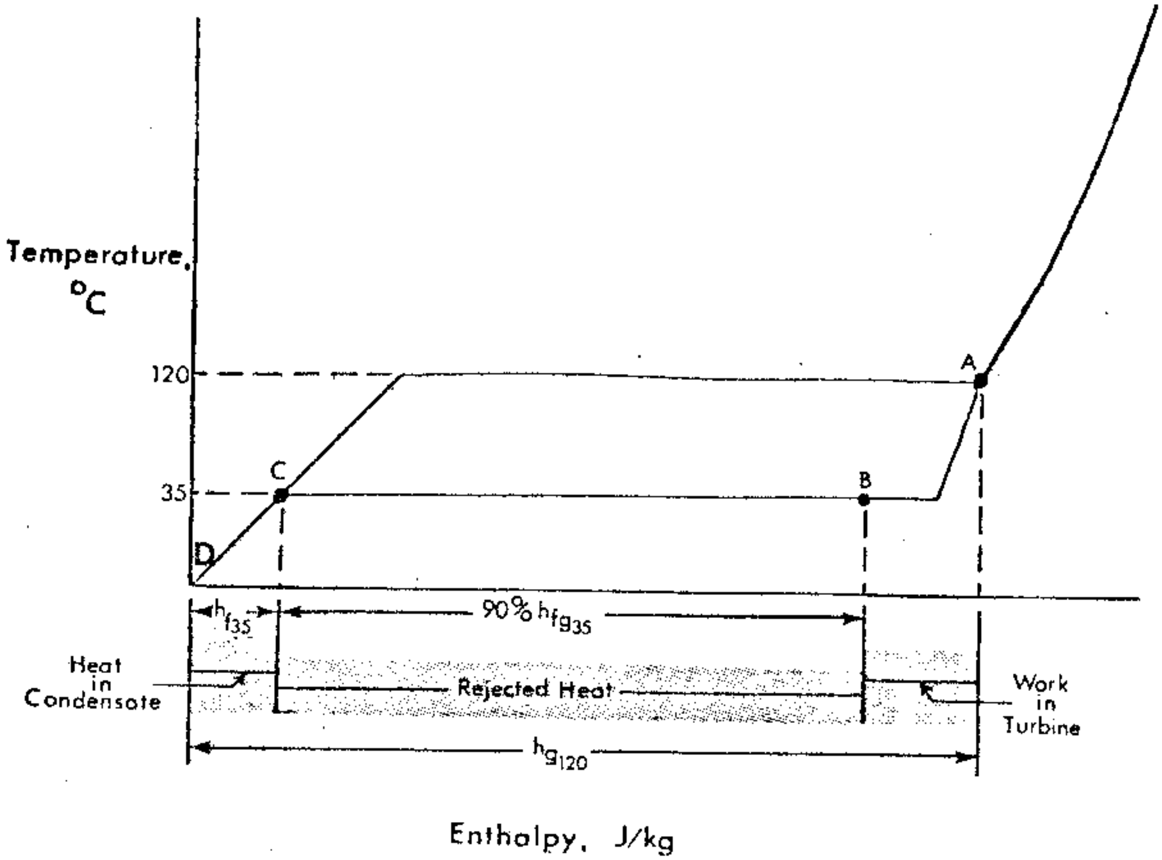

Fig. 3.2.3

The steam in the turbine at point A is saturated and expands to 10% moisture at point B. This change in enthalpy is recovered as work in the steam turbine. From point B to point C, heat is being rejected at constant temperature in the condenser as the remaining latent heat of vapourization is being removed. From point C to point D, nothing happens and this heat is returned to the feed system via the hotwell.

So you can see, the only heat which is lost from the system is the remaining latent heat of vapourization.

If we consider 1 kg of steam, the recovered heat is

$$h_{g_{120}} - 0.9\ h_{fg_{35}}$$

$$h_{g_{120}} = 2706 \text{ kJ/kg,}$$

$$h_{fg_{35}} = 2418.8 \text{ kJ/kg.}$$

$$\text{Recovered heat} = 2706 - (2418.8)\ 0.9 \text{ kJ/kg}$$

$$2706 - 2176.9$$

$$= 529.1 \text{ kJ/kg of steam at } 120°\text{C.}$$

Case 2 With feedheating

This case is slightly more complicated because we have to consider 10% of the steam flowing to the feedheater and the remaining 90% to the turbine. We have already done the turbine portion so let's get that out of the way.

Still using 1 kg of steam, if we reduce the turbine steam to 90%, we will only get 90% of the recovered heat.

Heat recovered from turbine with feedheating is 90% of that recovered without feedheating.

Heat recovered = 0.9 x 529.1 kJ/kg

= 476.2 kJ/kg of steam at 120°C.

Consider the feedheater to which 10% of the steam is now flowing from the turbine. Again look at the temperature/enthalpy diagram for heat recovered.

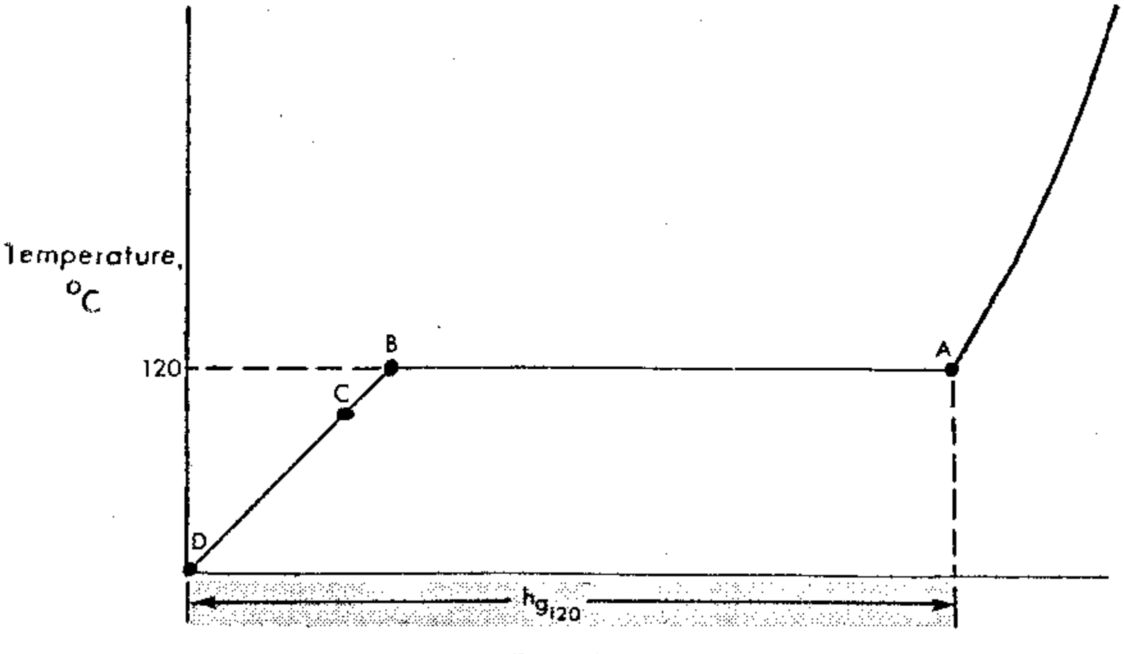

Fig. 3 2.4

The steam enters the heater at A and is condensed to point B if no subcooling or point C if subcooling occurs. The heat in the heater drains C-D remains in the feedwater system. So no heat is lost. All the heat sent to the feedheater is recovered. The heat in the steam is $h_{g_{120}}$ which is 2706 kJ/kg. If we consider one kg, we only have 10% of this heat. Consequently, the heat recovered in the feedheater is 270.6 kJ/kg.

Total recovered heat with feedheating is the turbine work plus heat recovered in the feedheater.

ie, 476.2 + 270.6

= 746.8 kJ/kg of steam at 120°C.

Primarily, we have gained on latent heat of vapourization which would otherwise have been rejected to the CCW. Heat recovered from turbine operation was reduced by 52.9 kJ/kg but the feedheating showed a recovered heat value of 270.6 kJ/kg.

If your immediate reaction is that we should do a lot more feedheating, remember my earlier remarks concerning numbers of heaters with increase in efficiency and use of high quality steam for heating. There is an optimum level above which an increase in feedheating capacity shows no increase in efficiency but the numerical exercise uses the thermodynamic principles upon which feedheating is based.

Try these questions and compare your answers with the notes at the end of the module.

B.3.2.13

Explain why steam is extracted for feedheating and not allowed to do further work in the steam turbine.

B.3.2.14

Saturated steam is supplied to a feedheater at 180°C. Demonstrate the benefit of feedheating by considering two cases:

a) a steam turbine without feedheating
b) a steam turbine with one feedheater and compare the heat recovered in each case. Use a temperature/enthalpy diagram to explain your reasoning.

Consider this one heater to utilize 20% of the steam entering the turbine. State all other major assumptions made.

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When you feel that you are ready for the Criterion Test, obtain the test from the Course/Shift Manager. Upon completion of the test, request the self evaluation sheet and compare with your test. Finally, have the Manager review your work so that you may identify areas to be reinforced or progress to Module B.3.1.

Answers

MODULE B.3.2

FEEDHEATER OPERATION

B.3.2.1

The pressure in the cylinder would start to fall. The reason for this is that as the temperature of the liquid falls, so does the volume that the liquid occupies. The molecules do not vibrate so rapidly as the temperature decreases and they effectively occupy a smaller volume.

This is exactly the situation that we have with the PHT system and to overcome the problem of changing pressure, we remove some mass of D_2O when the temperature rises and we add some mass of D_2O when the temperature falls. This is done with the feed and bleed system.

B.3.2.2

If you said that the pressure increases or decreases you could be right but with qualification.

If you really thought about this from the moment you shut the engine down, you would have this sequence of events:

a) Initially, hot engine and then loss of coolant flow as water pump and fan are shut down.

b) Short term imbalance occurs due to the heat from the engine not changing dramatically whilst the heat rejection from the cooling water via the radiator decreases significantly. As a result, the temperature starts to rise.

c) As the temperature rises, the liquid expands and the system pressure increases until the pressure relief valve allows the system pressure to force the excess fluid into a reservoir.

d) As the engine starts to cool down, the coolant system is losing more heat than is being supplied because the engine is no longer supplying heat, being shutdown. As the temperature falls, so does the pressure. Eventually, the pressure in the coolant system becomes below atmospheric and atmospheric pressure is able to force fluid back into the coolant circuit to make up for the fluid contraction which has taken place.

This is a familiar pattern of events when looking at a closed fluid heat transfer system. How many closed fluid heat transfer systems could you come up with?!

B.3.2.3

In this example, the pressure is falling because heat is being removed from the system.

The propane vapour is generated by adding latent heat to the saturated liquid in the tank. The heat that vapourizes the liquid, flows into the tank from the outside. If the rate of vapour production uses latent heat at a greater rate than the heat is available from the atmosphere, then the temperature of the tank contents start to fall and of course, so does the pressure. If the usage is heavy, then the temperature will fall down to the dew point when condensation will appear on the tank and then down to the frost point when the moisture on the outside of the tank freezes. At this point, the system pressure is rapidly approaching atmospheric pressure when no gas flow would be available at all because there would be no pressure difference.

B.3.2.4

Consider a feedheater that is pressurized with steam from the turbine but has no feedwater flow. In this situation, no heat is being transferred from the extraction steam to the feedwater.

If the feedwater flow is established, the extraction steam will condense on the feedheater tubes as the latent heat is removed. This condensation process results in a local reduction in pressure around the tubes and initiates some steam flow.

This process of condensation continues to lower the heater shell pressure and temperature until the extraction steam reaches a flowrate when the heat provided by the steam from the turbine matches the heat removed by the feedwater.

At this point, the temperature and pressure in the feedheater will be at lower values and the feedwater temperature will have increased.

This process is happening all the time creating a self regulation effect so that the heat removed always balances the heat supply.

B.3.2.5

As the unit power is raised from 50% to 100%, two major changes take place on the feedheater. As the steam flow through the turbine increases so do the extraction steam pressures which means that the temperatures in the shell of the heaters have also increased.

Secondly as the steam flow increases, so does the feedwater flow to the steam generator and so heat is being removed at a greater rate than before.

Both these causes will create a larger extraction steam flow to the heaters together with a significant increase in feedheating.

B.3.2.6

It is probably easier to draw up a table of heater conditions and then write an explanation for the changes.

	Feedwater	Steam
Flowrate	Decrease(G)	Decrease
Inlet Temp	1 Same(G)	Increase
Outlet Temp	2 Increase	N/A
Feedwater ΔT(2-1)	Increase	N/A
Pressure	N/A	Increase

(G) Information Given

The rate of heat removal from the feedheater decreases with the reducing feedwater flowrate. The effect is an energy imbalance because the extraction steam is providing more thermal energy than is being removed.

As a result, the temperature in the steam space starts to rise. As the temperature rises, so does the pressure. The effect of the rising pressure is to reduce the pressure differential between the turbine and the feedheater and the extraction steam flow is reduced as a result.

Why does the feedwater outlet temperature rise in this situation? There are two reasons, one more significant than the other. In any heat transfer operation, the amount of heat which is transferred is a function of temperature difference and time.

At the lower flowrate, the feedwater velocity is slightly reduced which means that there is slightly more time available for the feedwater outlet temperature to move towards the feedheater steam temperature.

More significantly, as the temperature in the steam side of the feedheater rises, there becomes a larger difference between the steam temperature and the average feedwater temperature and more heat is transferred. In this way, the ΔT for the feedwater has increased across the heater although the inlet temperature remained constant and the feedwater flowrate decreased.

B.3.2.7

In this exercise, the feedwater flowrate is going to remain constant. If we remove the number two heater, the number 3 heater will receive feedwater at a temperature much lower than normal. The effect of this low inlet temperature will be that heat energy will be transferred at a higher rate from the high temperature in the steam space to the lower temperature feedwater.

There is now an energy imbalance where more heat is being removed from the feedheater than is being supplied and the temperature in the steam space starts to fall. As the temperature in the steam space drops, so does the pressure and more extraction steam flows from the turbine to the heater.

In summary conditions on #3 heater will be as follows:

1. Heat transfer and extraction steam flow will increase.
2. Temperature and pressure in the steam space will decrease.
3. Feedwater outlet temperature will fall.
4. Feedwater temperature rise across the heater will increase.

B.3.2.8

Some significant changes occur with the extraction steam and the feedwater when the turbine power is raised from 50% to 100%.

As the governor steam valves open up, less and less throttling takes place until the point is reached when the GSVs are fully opened and there is no throttling at all across the GSVs.

At this point the steam pressure at the emergency stop valves is being evenly dropped across the whole of the turbine down to condenser pressure instead of having a major pressure drop across the GSVs.

As a result of this change, all the stage pressures in the turbine have increased including those at the extraction steam points.

A higher pressure differential now exists to the feedheaters. More extraction steam flows to the heaters which means that more heat is being supplied to the feedheaters than is being removed by the feedwater and the shell temperature rises which means that the shell pressure also rises.

The higher temperature in the steam space increases the heat transfer to the feedwater and the feedwater outlet temperature on all the heaters increases.

As a result of increasing the steam flow through the turbine, there will be a demand for higher feedwater flow into the steam generator.

The effect of increasing the feedwater flow through the heaters will further increase the rate of heat transfer and the extraction steam flow will increase further to match this new thermal load.

In practice, these two conditions are happening at the same time. Probably the only parameter which does not change dramatically is the condensate temperature from the condenser.

In summary, the extraction steam flows will increase, the feedwater flow will increase, the feedwater outlet temperatures from the heaters will increase, the feedwater temperature rise across the heaters will increase, the pressure and temperature in the steam space of the heaters will increase.

B.3.2.9

Using the temperature/enthalpy diagram, we can see that the heat lost by the steam is the difference between $h_{g_{180}}$ and $h_{f_{160°C}}$.

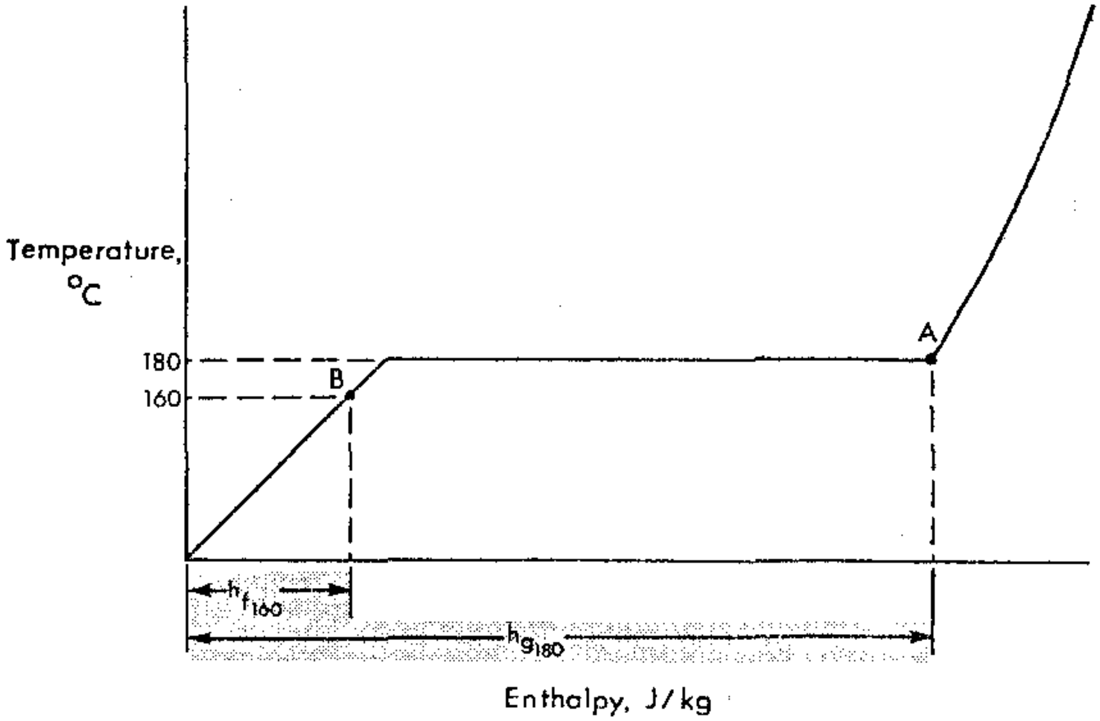

Fig.3.2.5

Enthalpy difference of the steam $= h_A - h_B$

$$= h_{g_{180}} - h_{f_{160}}$$

$$= 2776.3 - 675.5$$

$$= \underline{2100.8}\ \text{kJ/kg.}$$

Heat lost by steam $= \underline{\overset{o}{m} \times 2100.8}$ kJ per second.

Heat gained by the feedwater $= h_{f_{174}} - h_{f_{150}}$

$$= 736.7 - 632.1$$

$$= \underline{104.6}\ \text{kJ/kg.}$$

Heat gained per second = Mass x enthalpy change

$$= 1000 \times 104.6$$

$$= 104600\ \text{kJ.}$$

The heat lost by the steam = heat gained by the feedwater

$$\overset{o}{m} \times 2100.8 = 104600 \text{ kJ}$$

$$\overset{o}{m} = 104600/2100.8$$

$$\overset{o}{m} = \underline{49.8} \text{ kg/s.}$$

B.3.2.10

In this example, we know everything about the steam and have to find the feedwater temperature.

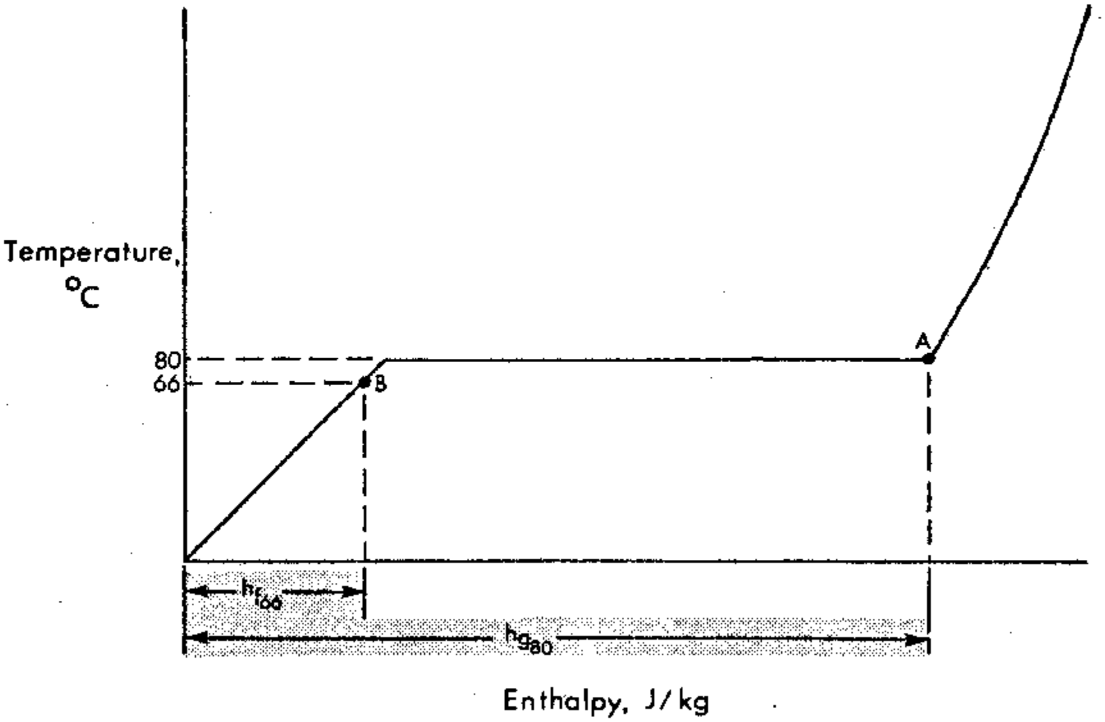

Fig. 3.2.6

Change in enthalpy of steam to condensate is $h_{g_{80}} - h_{f_{66}}$

$$h_g = 2643.8 \text{ kJ/kg}$$

$$h_{f_{66}} = 276.2 \text{ kJ/kg.}$$

$$\text{Change in enthalpy} = 2643.8 - 276.2$$

$$= \underline{2367.6} \text{ kJ/kg.}$$

Heat lost by steam per second

$$= \text{mass x enthalpy change}$$

$$= 60 \text{ x } 2367.6$$

$$= \underline{142056} \text{ kJ.}$$

Heat gained per second by the feedwater

$$= \text{mass x enthalpy change}$$

$$= \text{mass x } (h_{f_x} - h_{f_{36}})$$

$$= 850 \text{ x } (h_{f_x} - 150.7) \text{ kJ.}$$

$$\text{Heat lost by steam} = \text{Heat gained by feedwater}$$

$$142056 = 850 \text{ x } (h_{f_x} - 150.7) \text{ kJ}$$

$$142056/850 = h_{f_x} - 150.7 \text{ kJ}$$

$$167.1 = h_{f_x} - 150.7$$

$$\therefore h_{f_x} = \underline{317.8} \text{ kJ/kg.}$$

'x' is temperature corresponding to a liquid enthalpy value of 317.8 kJ/kg.

From table 1, x = 76°C when h_f = 318 kJ/kg.

B.3.2.11

a) Although there is a lot of low temperature heat available that would normally be rejected to the CCW, it is of little use in heating the feedwater. The reason for this is simply that the temperature of the steam is very close to that of the condensate so the amount of heat which may be transferred is extremely limited.

*To obtain better heat transfer, we can use higher temp*erature steam but as steam is extracted at higher and higher temperatures, the turbine work lost to feedheating increases. There is an economic point beyond which feedheating is of no further benefit. In the Candu system, this optimum occurs when the feedwater temperature is around 175°C.

b) Before we examine this principle any closer, let's make a statement of fact.

"It is impossible to raise the temperature of the feedwater to 250°C using heating steam which is also at 250°C."

So, why can't we heat the feedwater to 240°C? In practice, the feedwater outlet temperature is roughly 4°C *below the extraction steam temperature to the heat*er. If we wanted feedwater at 240°C, then we would have to use steam at 244°C.

This situation creates a conflict of interest. We want to maximize the cycle efficiency by raising the feedwater temperature but we also want to use the high temperature steam in the turbine where it is of most benefit in producing work.

B.3.2.12

The action that would follow a significant loss of feedheating capacity depends largely upon where in the feedheating cycle the loss occurs.

If the loss occurs in the early part of the feedheating system, then it is possible for a large proportion of the heat loss to be picked up in the following heaters.

It should be realized that this will dramatically change the extraction steam flow distribution and more high quality steam will be used for feedheating instead of turbine work. Thus, it may be possible to maintain a reasonable feedwater temperature into the steam generator but at the expense of power in the higher pressure end of the turbine and consequently, electrical power would be reduced.

The main point to consider is the thermal shock to the steam generator feedwater nozzles. When the temperature difference is large between the steam generator temperature and the feedwater temperature, the thermal stresses become an *overriding parameter. An operating limit, of temperature* difference, ensures that permanent damage does not result. A reduction in steam flow and hence feedwater flow is the only way to reduce the temperature difference at the feedwater nozzles. This reduces the feedwater flow through the feedheaters which raises the feedwater temperature.

If the feedheating was unavailable at the high temperature end of the system and temperature differences in the boiler were not a problem, the loss of heating would have to be provided by the PHT system in the steam generator. The average temperature and pressure in the steam generator would fall, assuming reactor power is constant and in a reactor leading program, the BPC program would sense a mismatch and reduce the turbine load.

The loss of feedheating would provide more steam flow to the condenser and would cause a mismatch between the heat lost by the steam and the heat gained by the CCW system. Even if the vacuum deloader did not operate, an increased pressure in the condenser would reduce the steam flow through the turbine. Would the turbine power level change?!

B.3.2.13

When the steam is exhausted from the turbine, it still possesses around 80% of its heat, the majority of which will be rejected to the CCW in the condenser and the rest will be returned to the system in the feedwater.

If we can use some of the heat which is going to be rejected to the CCW, then the savings are obvious. We can show by simple calculation that although a small amount of turbine work is lost, a considerable amount of heat is gained from the extraction steam.

As the steam temperature increases, the penalty in lost turbine work also increases when using high temperature steam for feedheating.

The closer the feedwater is to the saturation temperature in the steam generator, the more efficient the cycle becomes. Typically, the saturation temperature is 250°C but it is not only impossible to heat the feedwater to 250°C using steam at 250°C but is is not economically viable to heat it above 175°C. The temperature of 175°C represents the economic cut-off temperature above which the penalty of using high temperature steam becomes unacceptable.

B.3.2.14

First of all, state your assumptions - all of them!

a) Turbine exhaust temperature is 35°C.

b) Turbine exhaust moisture is 10%.

c) No subcooling occurs in the condenser.

d) 20% of the steam flow in the turbine is extracted for feedheating.

Case 1 No feedheating

The conditions may be shown on a temperature/enthalpy diagram showing saturated steam at 180°C expanding to 10% moisture at 35°C.

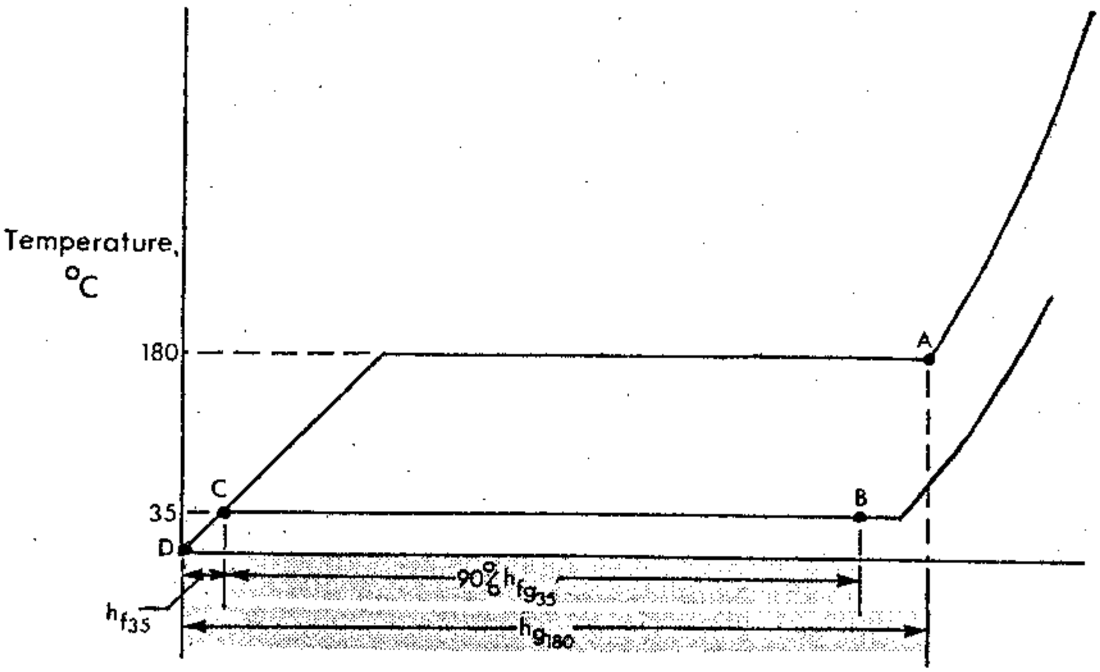

Fig. 3.2.7

The enthalpy change from point A to point B represents the work done in the turbine. The enthalpy drop from point B to point C is the heat rejected to the CCW system and the enthalpy C-D is the heat energy remaining in the condensate in the hotwell and is returned to the feedwater system.

The loss of heat is the 90% of the latent heat at 35°C. So the recoverable heat is $h_{g_{180}} - 0.9\ h_{fg_{35}}$

$= 2776.3 - 0.9\ (2418.8)$

$= 2776.3 - 2176.9$

$= \underline{599.4}$ kJ/kg of steam at 180°C.

This represents both the heat in the condensate and the work done in the turbine.

Case 2 With feedheating

There are two areas to cover:

a) the turbine work and condensate.
b) the feedheater operation.

a) Turbine Work and Condensate

If the flow through the turbine is reduced by 20%, then the work and condensate will show a 20% reduction of recoverable heat.

Recoverable heat from the turbine and condensate with 20% extraction steam = 0.80 x 599.4

$= \underline{479.5}$ kJ/kg of steam at 180°C.

b) The Feedheater

We can see how much recoverable heat is available from the feedheater by drawing the temperature/enthalpy diagram.

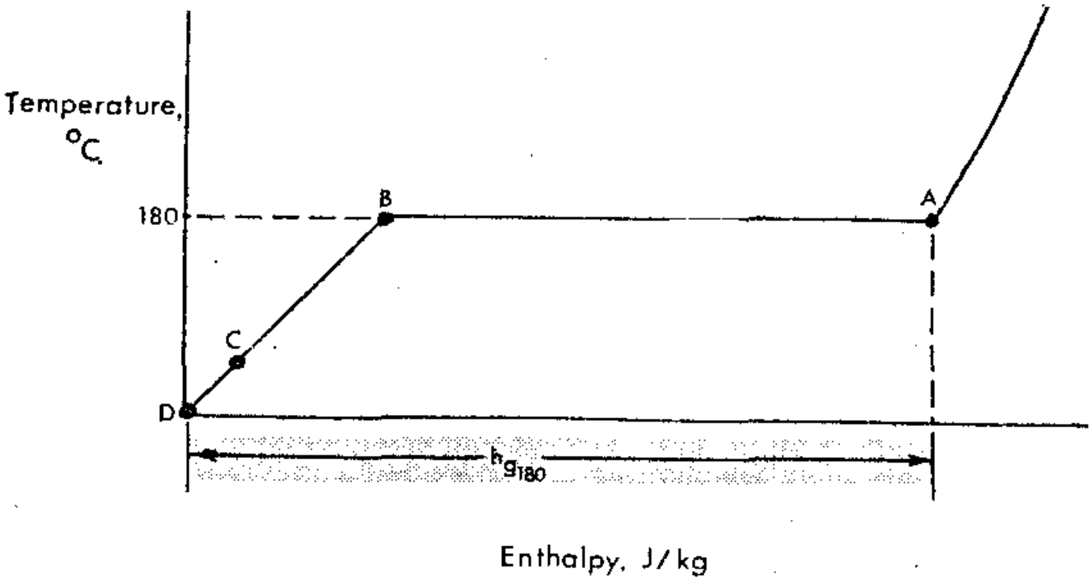

Fig. 3.2.8

The enthalpy change from point A to point B is the heat gained by the feedwater and lost by the steam. The enthalpy change from point B to C represents the heat given to the feedwater and subcooling the heater drains. The enthalpy C-D is the remaining heat in the drains from the heater and this remains in the system. So the total heat in the steam is recovered.

$$h_{g180} = \underline{2776.3} \text{ kJ/kg.}$$

The heat gained for 20% of 1 kg is

$$0.20 \times 2776.3 = 555.3 \text{ kJ.}$$

Thus the total recoverable heat with feedheating per kilogram of steam entering the turbine is

$$479.5 + 555.3 = \underline{1034.8} \text{ kJ}$$

compared with 599.4 kJ without feedheating.

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