# Heat and Thermodynamics - Course PI 25

## HEAT TRANSFER CALCULATIONS

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Objectives

1. Given steam tables and values representing a feedheater or condenser with all variables but one specified, determine the unknown variable.

2. Given heavy water tables and values representing reactor channel inlet and outlet tempertures, channel flow rates of heavy water, and the number of reactor channels, determine the reactor thermal power, assuming there is no boiling in the channels.

March 1984

## Heat Transfer Calculations:

At some point in your career with Ontario Hydro you may be asked to perform calculations involving a heat balance. This module should provide you with the basic skills to do the calculations. The module also introduces some terms and situations that are common both in other initial training courses and in the stations.

## Feedheater/Condenser Calculations

In a CANDU generating station there are many heat exchangers. Two of the major types of heat exchangers are the feedheater and the condenser.

Feedheaters are generally shell and tube heat exchangers. Their function is to heat the light water (called feedwater) that is being returned to the boilers from the condensers. The feedwater flows through a number of tubes in each feedheater. Steam is extracted from the turbine set to heat the feedwater. The steam, which is usually saturated or wet, is condensed in the shell side of each feedheater. A simplified view of a feedheater is shown in Figure 3.1:

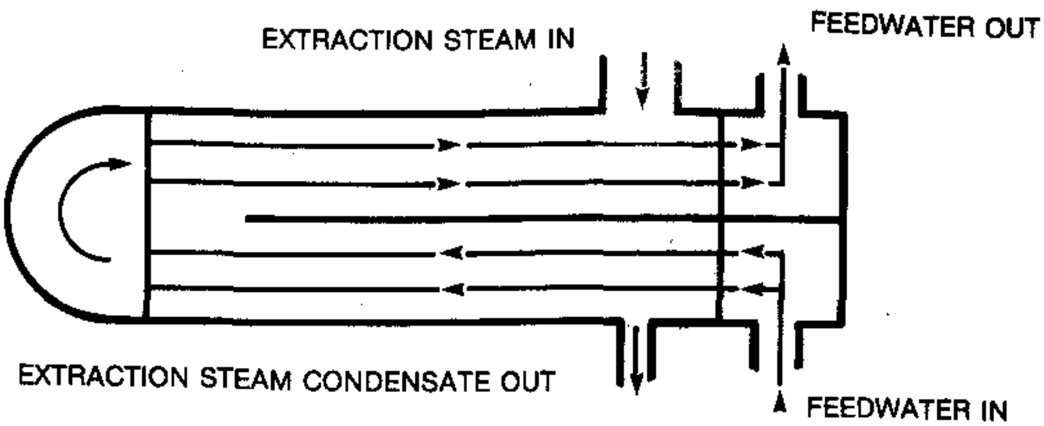


Figure 3.1

The condenser receives wet steam which is exhausted from the turbine set. This steam is condensed using cold lake water which flows through thousands of tubes in the condenser. A simplified view of the condenser is shown in Figure 3.2:

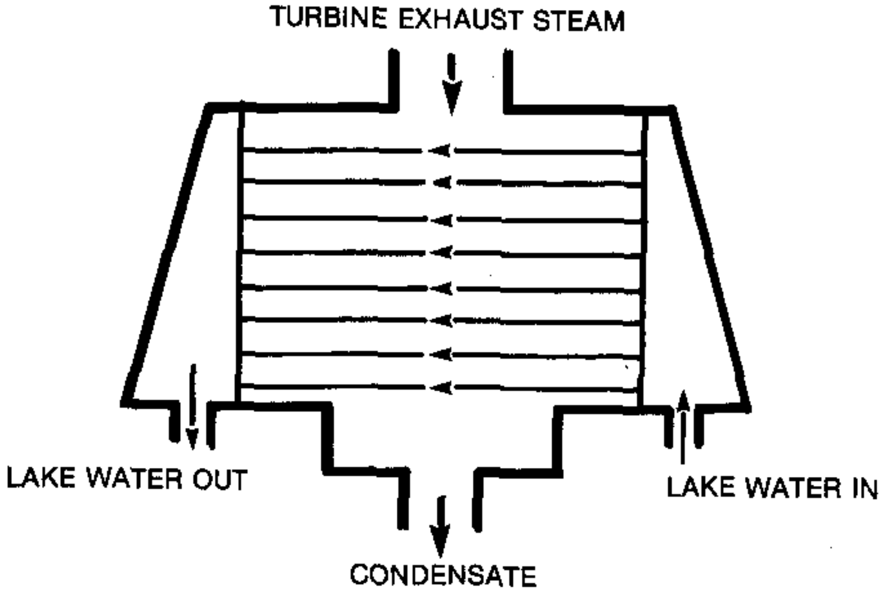


Figure 3.2

Both types of heat exchangers normally operate at steady state. Assuming no heat losses, there is thus a heat balance achieved - the rate of heat loss from the steam side is equal to the rate of heat addition to the water side.

This can be expressed as follows:

$\dot{Q}_L = \dot{Q}_G$,

where $\dot{Q}_L$ is the rate of heat lost, in kW.

and $\dot{Q}_G$ is the rate of heat gained, in kW.

The rate of heat transfer, $\dot{Q}$ is the product of the mass flow rate, $\dot{m}$ (in kg/s), and the change in enthalpy, $\Delta h$ (in kJ/kg), that occurs.

The heat balance can be rewritten as:

$$(\dot{m}\,\Delta h)_L = (\dot{m}\,\Delta h)_G$$

→ *Locate your copy of "Steam Tables in SI Units".* *Answer* question 3.1 in the space provided before you proceed, then check your answer with the one in the "TEXT ANSWERS".

3.1) A feedheater heats feedwater from 85°C to 120°C. 80 kg/s of extraction steam (saturated at 125°C) is used to heat the water. The extraction steam condensate exits the feedheater at 125°C.

(a) Sketch a temperature vs. enthalpy diagram to show the feedwater heating process.

(b) Sketch a temperature vs. enthalpy diagram to show the extraction steam condensing process.

(c) Determine the flowrate of feedwater heated.

Question 3.1 represents the least complicated heating situation - where water is heated solely by condensation of saturated steam. Generally, the steam entering the feedheater or condenser is wet steam.

→ Answer question 3.2 in the space provided and check your answer with the one in the "TEXT ANSWERS" before you proceed.

3.2) 750 kg/s of steam (12% wet at 30°C) is exhausted from the turbine set to the condenser. The steam is condensed, and the condensate leaves at 30°C. 37,000 kg/s of lake water is used to condense the steam. If the water enters the condenser at 15°C, determine the temperature of the water leaving it.

Question 3.2 deals with a condenser. In CANDU stations the main condensers are designed to prevent subcooling of the condensate. The feedheaters, however, normally operate with subcooled extraction steam condensate.

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

3.3) 71.2 kg/s of extraction steam (66.6% wet at 60°C) is used to heat feedwater from 27°C to 59°C. If the extraction steam condensate leaves the heater at 28°C, what is the feedwater flowrate?

3.4) At 25% power, heater #5 at BNGS-A is designed to use 29.4 kg/s of extraction steam (71.3% wet at 132°C). If 335 kg/s of feedwater enters the heater at 118°C and the extraction steam condensate leaves the heater at 119°C, what is the outlet feedwater temperature?

→ You should now be able to do the first objective of this module. If you feel you need more practice, please consult with the course manager.

## Reactor Thermal Power Calculations

Most of the heat output of the reactor is transferred to the boilers. This is done by the PHT heavy water. This heavy water flows through a number of pressure tubes which contain the fissioning fuel. The $D_2O$ then flows through the boiler and is pumped back to the reactor.

The amount of heat that is transferred to the boilers is called the reactor thermal power output. The purpose of this section is to provide you with the skill of estimating this output.

If you knew the power output of one pressure tube and the number of pressure tubes, you should easily be able to determine the total power. This determination will be an estimate since conditions vary from one pressure tube to another.

Certain pressure tubes are fully instrumented - that is, the flow of $D_2O$ and the inlet and outlet temperatures are measured. Using these values, the thermal power of one pressure tube, $\dot{Q}_{PT}$, can be calculated.

Here, $\dot{Q}_{PT}$ will be the product of the mass flow rate, $\dot{m}$, and the change in enthalpy, $\Delta h$, of the $D_2O$:

$$\dot{Q}_{PT} = \dot{m}\,\Delta h$$

⟶ Locate your copy of the "Heavy Water Steam Tables". Use them to answer the following questions, then compare your answers with those in the "TEXT ANSWERS".

3.5) $D_2O$ enters a pressure tube at 251°C and exits at 296°C. The flow of $D_2O$ in the tube is 24 kg/s.

(a) What is the change in enthalpy of the $D_2O$ as it goes through the pressure tube?

(b) Determine the power output of the pressure tube.

3.6) 25 kg/s of $D_2O$ flows through a pressure tube. The inlet and outlet $D_2O$ temperatures are 248°C and 290°C. If there are 388 pressure tubes in the reactor, determine the reactor thermal power output.

→ Once you have completed question 3.6 satisfactorily, you should be able to do the second objective of this module. If you are confident you can do this, obtain a criterion test and complete it. If you feel you need more practice before you attempt the test, please consult with the course manager.

3.1) (a)

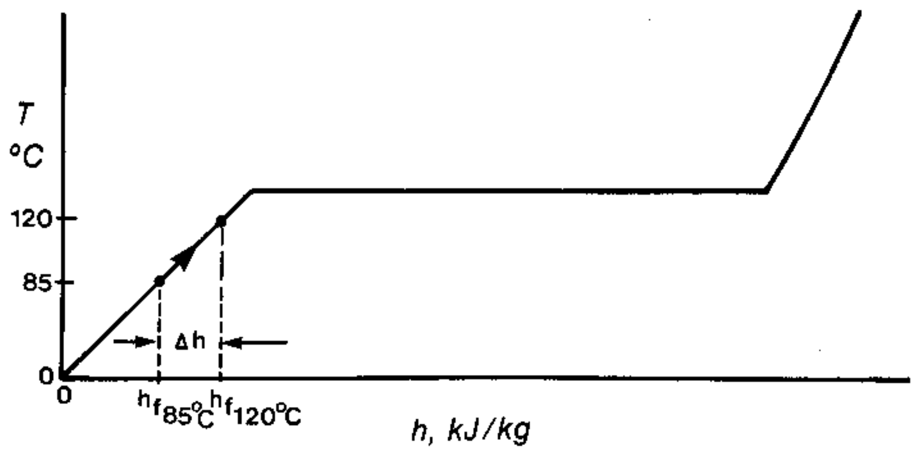


Figure 3.3

(b)

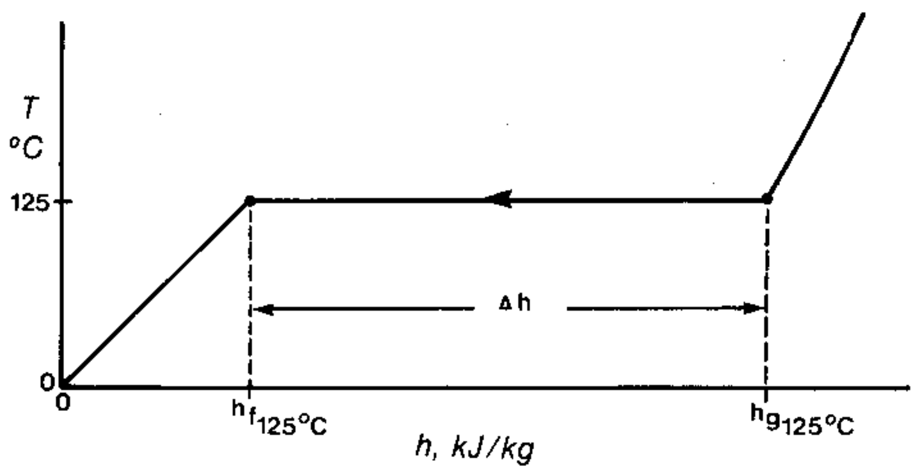


Figure 3.4

(c) As shown in (b), $\Delta h$ for the steam side is:

$$h_{g_{125°C}} - h_{f_{125°C}}$$

This is the same as $h_{fg_{125°C}}$.

As shown in (a), $\Delta h$ for the feedwater side is:

$$h_{f_{120°C}} - h_{f_{85°C}}$$

Thus,

$$\dot{m}_L(h_{fg_{125°C}}) = \dot{m}_G(h_{f_{120°C}} - h_{f_{85°C}}),$$

where $\dot{m}_L$ is the mass flow of extraction steam,

and $\dot{m}_G$ is the mass flow rate of the feedwater.

$$80(2188.0) = \dot{m}_G(503.7 - 355.9)$$

$$\dot{m}_G = \underline{1180\ kg/s}$$

3.2) In this question, the steam side of the condenser can be shown as on Figure 3.5:

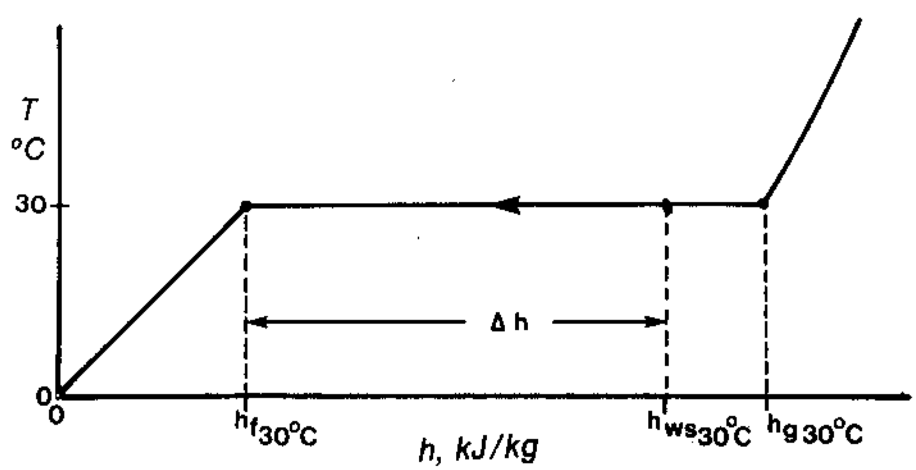


Figure 3.5

Here $\Delta h = h_{ws30°C} - h_{f30°C}$

For the lake water side, $\Delta h = h_{f?} - h_{f15°C}$, as shown on Figure 3.6:

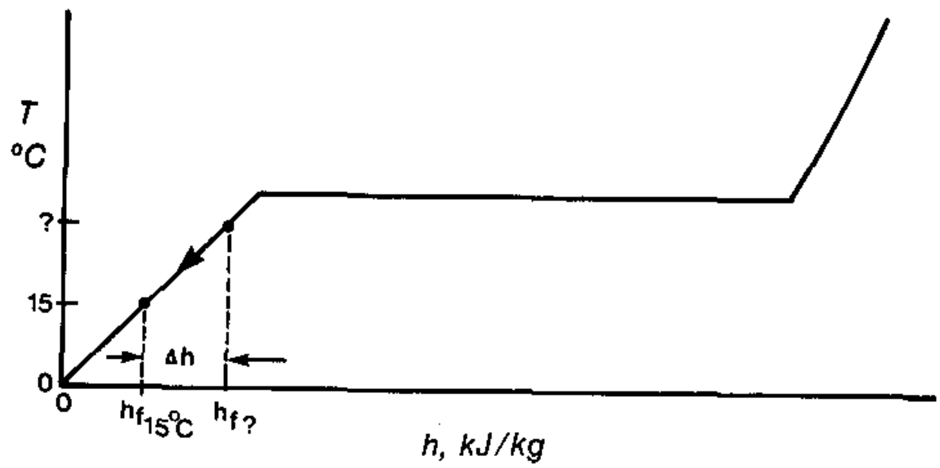


Figure 3.6

Thus, $\dot{m}_L(h_{ws30°C} - h_{f30°C}) = \dot{m}_G(h_{f?} - h_{f15°C})$

$h_{ws30°C}$ must be determined:

$h_{ws30°C} = h_{f30°C} + qh_{fg30°C}$ where $q = 1 - 0.12 = 0.88$

$\dot{m}_L(h_{f30°C} + 0.88\ h_{fg30°C} - h_f\ 30°C) = \dot{m}_G(h_{f?} - h_{f15°C})$

$\dot{m}_L(0.88\ h_{fg30°C}) = \dot{m}_G(h_{f?} - h_{f15°C})$

$750(0.88 \times 2430.7) = 37{,}000(h_{f?} - 62.94)$

$h_{f?} = 106.3$ kJ/kg

How can you use $h_{f?} = 106.3$ kJ/kg to find the water temperature?

*The answer: Use enthalpy and look in either Table 1 or Table 2 of "Steam Tables in SI Units".*

From Table 1, $h_{f25.5°C} = 106.9$ kJ/kg. There is no value near 106.3 kJ/kg in Table 2. Thus the outlet water temperature is about 25.5°C (assuming that the enthalpy of water varies little with pressure).

3.3) In this question the extraction steam condensate is subcooled:

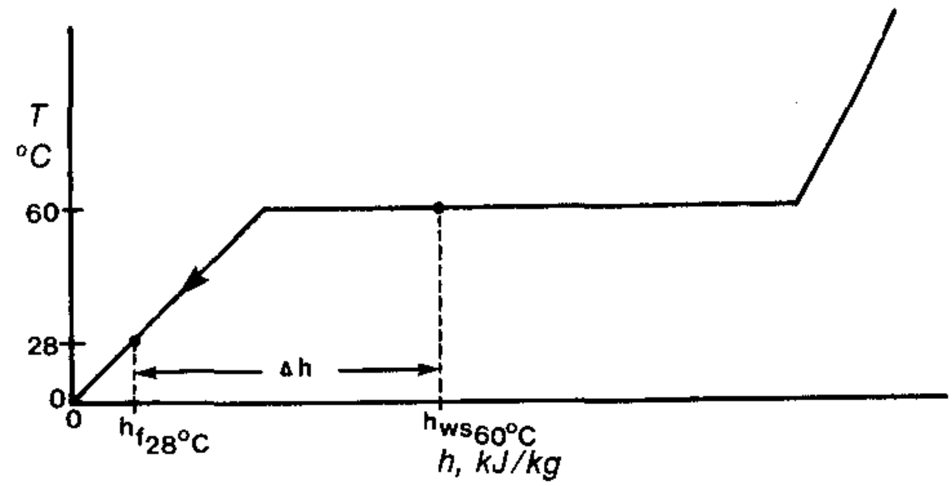


Figure 3.7

Here, $\Delta h = h_{ws_{60°C}} - h_{f_{28°C}}$

On the feedwater side,

$\Delta h = h_{f_{59°C}} - h_{f_{27°C}}$, as in Figure 3.8

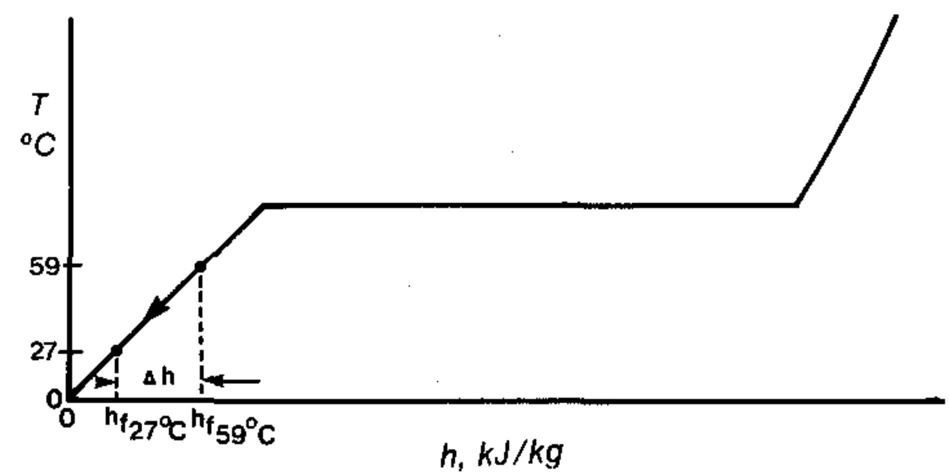


Figure 3.8

Thus, $\dot{m}_L(h_{ws60°C} - h_{f28°C}) = \dot{m}_G(h_{f59°C} - h_{f27°C})$

$h_{ws60°C} = h_{f60°C} + (1 - 0.666)h_{fg60°C}$

$= h_{f60°C} + 0.334\ h_{fg60°C}$

$\dot{m}_L(h_{f60°C} + 0.334\ h_{fg60°C} - h_{f28°C}) = \dot{m}_G(h_{f59°C} - h_{f27°C})$

$71.2(251.1 + 0.334 \times 2348.6 - 117.3) = \dot{m}_G(246.9 - 113.1)$

$\dot{m}_G = \underline{490\ kg/s}$

3.4)

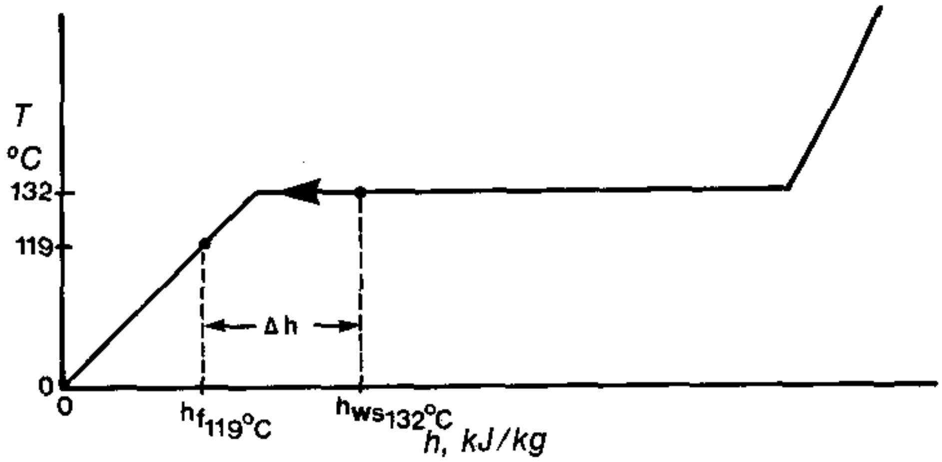


Figure 3.9

The enthalpy difference on the steam side is:

$h_{ws132°C} - h_{f119°C}$

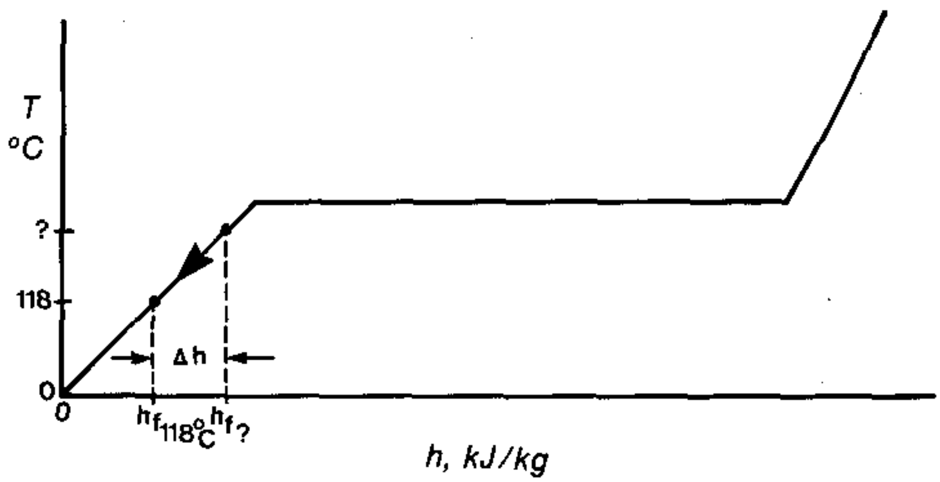


Figure 3.10

The enthalpy difference on the feedwater side is:

$h_{f_?} - h_{f_{118°C}}$

Thus, $\dot{m}_L(h_{ws_{132°C}} - h_{f_{119°C}}) = \dot{m}_G(h_{f_?} - h_{f_{118°C}})$

$h_{ws_{132°C}} = h_{f_{132°C}} + (1 - 0.713)h_{fg_{132°C}}$

$= h_{f_{132°C}} + 0.287\ h_{fg_{132°C}}$

$\dot{m}_L(h_{f_{132°C}} + 0.287\ h_{fg_{132°C}} - h_{f_{119°C}}) = \dot{m}_G(h_{f_?} - h_{f_{118°C}}$

$29.4(554.8 + 0.287 \times 2167.8 - 499.5) = 335\ (h_{f_?} - 495.2)$

$h_{f_?} = 554.5$ kJ/kg

From Table 1, using 554.5 kJ/kg, the outlet feedwater temperature is <u>132 °C</u>.

3.5) (a) From the "Heavy Water Steam Tables", Table 1,

$h_{f_{251°C}} = 1057.07$ kJ/kg

$h_{f_{296°C}} = 1287.07$ kJ/kg

Thus $\Delta h = 1287.07 - 1057.07$

$= \underline{230 \text{ kJ/kg}}$

(b) The power output of the pressure tube is the product of the mass flow rate and the $\Delta h$ of the $D_2O$:

$\dot{Q}_{PT} = 24 \times 230$

$= \underline{5520 \text{ kW}}$

3.6) From the "Heavy Water Steam Tables",

$\Delta h = h_{f_{290°C}} - h_{f_{248°C}}$

$= 1254.49 - 1042.68$

$= 211.81$ kJ/kg

The power output per channel, $Q_{PT}$,

$25 \times 211.81 = 5295.25$ kW

The reactor thermal power output is:

$388 \times 5295.25 = \underline{2.05 \times 10^6 \text{ kW}}$

(or 2050 MW)