Heat and Thermodynamics - Course PI 25

BASICS

Objectives

1. Define:

   (a) Heat
   (b) Temperature
   (c) Enthalpy

2. State the meaning of each of the following as it applies to water:

   (a) Saturation temperature
   (b) Subcooled liquid
   (c) Saturated liquid
   (d) Wet steam
   (e) Saturated steam
   (f) Superheated steam
   (g) Sensible heat
   (h) Latent heat of vapourization

3. Sketch a temperature vs. enthalpy diagram for water at constant pressure. Label the following on your sketch:

   (a) Saturation temperature
   (b) Subcooled liquid region
   (c) Saturated liquid
   (d) Wet steam region
   (e) Saturated steam
   (f) Superheated steam region
   (g) Sensible heat region
   (h) Latent heat region

4. Given steam tables and values representing the temperature, pressure, and enthalpy of water, identify each set of values as one of:

   (a) Subcooled liquid
   (b) Saturated liquid
   (c) Wet steam
   (d) Saturated steam
   (e) Superheated steam

5. Given steam tables and values representing water with all but one of the initial and final conditions of temperature, pressure, enthalpy, and, if appropriate, quality specified, determine the unknown value.

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This module has two main purposes: to give you some definitions and skills which are basic to this PI 25 course, and to make you familiar with terms that you will hear in other courses here at RNTC and in the stations themselves. As you read through the module, you will come to various assignment questions.

→ Answer these questions in the spaces provided, then check your answers with those found in the "TEXT ANSWERS" section at the end of the module. If you have any questions, about either your answers or the ones in the "TEXT ANSWERS" section, please feel free to consult with the course manager.

Heat

Heat is a form of energy in a substance. The amount of heat in a substance is dependent on the temperature of the substance, on the type of substance, and its state, and on the mass of the substance.

Temperature

Temperature measures the ability of a substance to lose or gain heat energy when compared with another substance.

Are temperature and heat the same? To answer this question, imagine the small square ("A") in Figure 1.1 to be 1 kg of liquid water at 100°C and atmospheric pressure. The large square ("B") represents 1 kg of steam at 100°C and atmospheric pressure. If we allow the water and the steam to come into contact with each other, will any heat be transferred?

The answer is no - they are at the same temperature.

Do the water and the steam have the same amount of heat energy in them?

Again the answer is no - the steam must have more heat because it is in the form of a vapour, since this will be developed more fully later, the production of steam requires further addition of heat to the water.

Thus temperature and heat are not the same. Whereas heat is a form of energy, temperature is a rough indicator of the level of heat that a substance possesses.

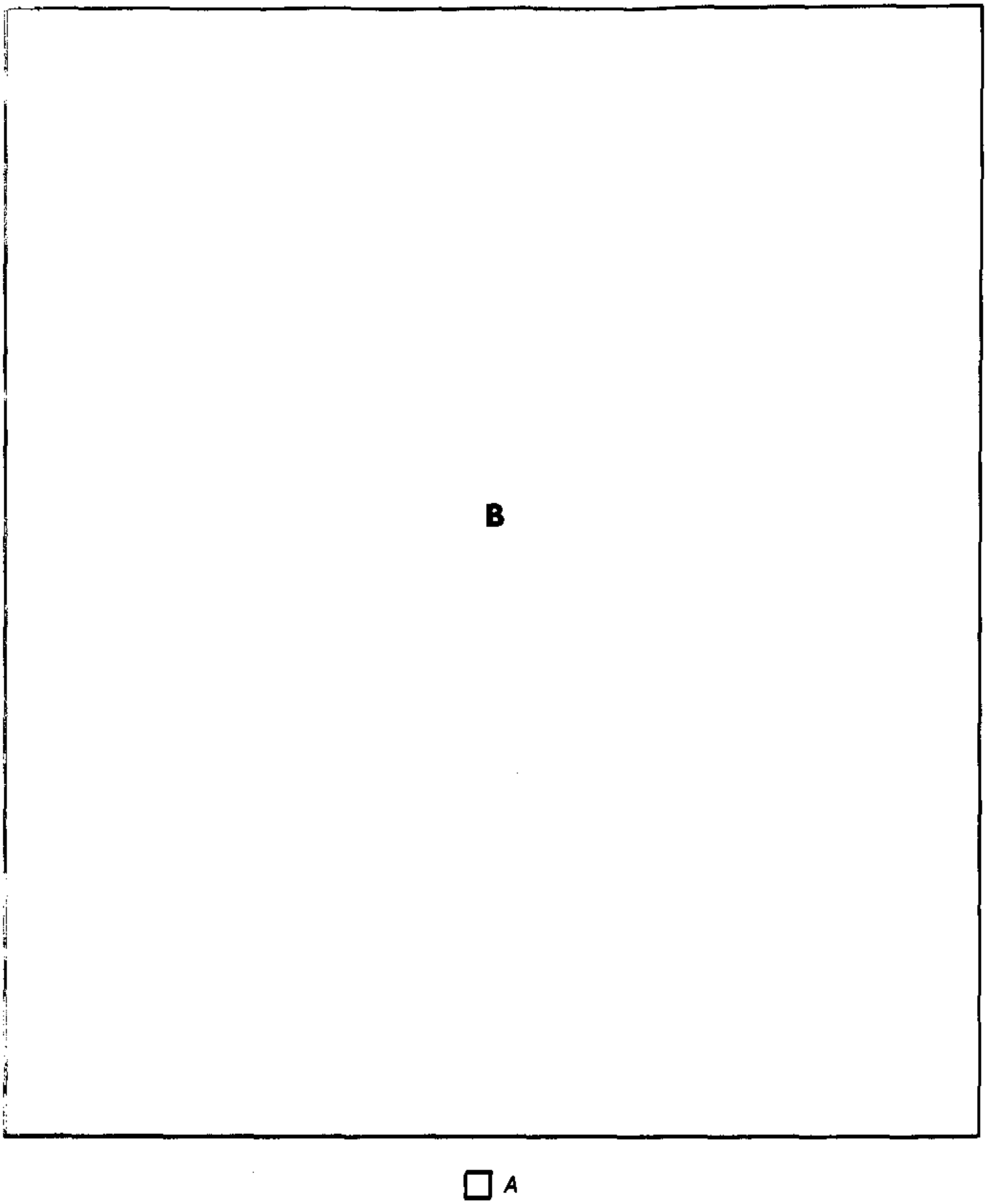

Figure 1.1

Enthalpy

For our purposes, enthalpy is defined as the total heat per kilogram of substance, measured above an arbitrary reference point. For water, the reference point is 0°C.

This definition allows us to determine quantitatively how much heat must be added to water (or how much heat can be removed from water) in various parts of the thermodynamic cycle which represents a CANDU station. The symbol for enthalpy that is used in this text is h. The unit of enthalpy is kJ kg^{-1}.

→ Answer the following questions from memory in the spaces provided, then check your answers with those in the "TEXT ANSWERS" section. Once you are satisfied with your answers, proceed to the next section, Water.

1.1) Define:

(a) Heat

____

____

(b) Temperature

____

____

(c) Enthalpy

____

____

Water

Water and heavy water are the main heat transfer media in a CANDU generating station. In the primary heat transport (PHT) system, heavy water is used to remove the heat produced by the fission of fuel in the reactor. The heavy water flows through a number of boilers, where the heat taken from the reactor is transferred through boiler tubes into light water. The light water cycle is called the secondary heat transport system. The heat added to the light water produces steam - the working fluid of the CANDU system. Some of the heat added to the steam is used in the turbine set to produce shaft mechanical power. The balance of this heat is removed in the condenser by lake water (called condenser cooling water) passing through the condenser tubes. The steam condenses and is recirculated to the boilers via a number of feedheaters, where it is heated in order to minimize thermal stressing in the boilers. The heat for this feedheating is supplied using steam and water from various parts of the secondary heat transport system.

The behaviour of water with respect to heating is thus a very important aspect of a CANDU unit. Much of the rest of this course will be concerned with this behaviour.

To begin, look at Figure 1.2. This graph of temperature vs. enthalpy for water represents the changes that water undergoes as it is heated at constant pressure, starting with liquid at 0°C.

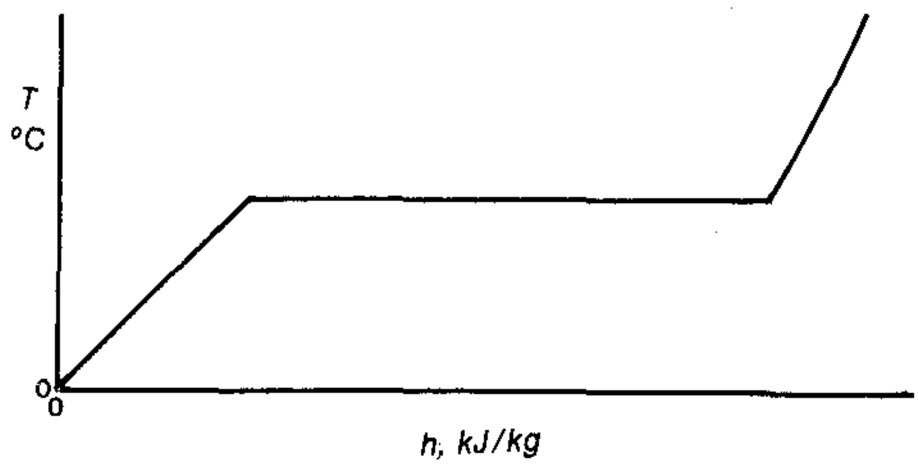

Figure 1.2

As the liquid is heated, its enthalpy increases. Initially, the liquid temperature also increases. At a certain temperature, depending on the pressure, some molecules of the water will have enough energy to change state and become vapour.

This process is, of course, boiling. The temperature at which boiling occurs for a given pressure is the saturation temperature, T_S.

Liquid that is below the saturation temperature for a given pressure is called subcooled liquid. Figure 1.3 shows the subcooled liquid region on a temperature - enthalpy diagram.

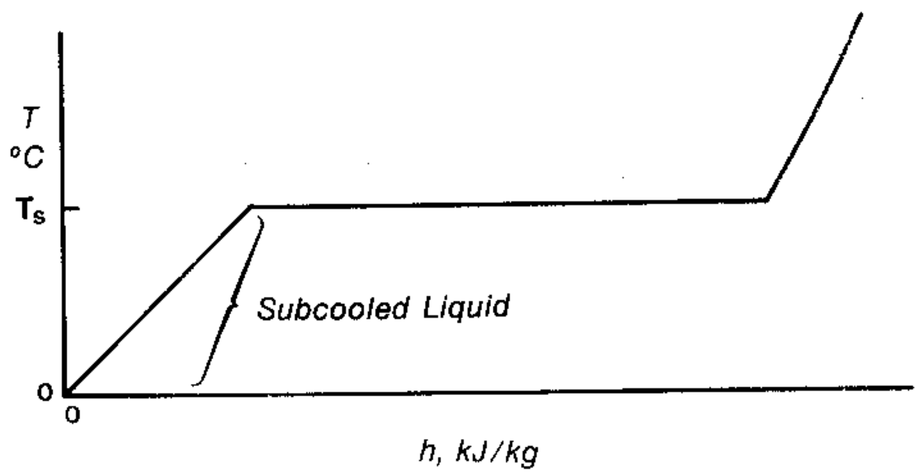

Figure 1.3

As subcooled liquid is heated, it will eventually reach the saturation temperature. If conditions are properly controlled, at this point there will be liquid at the saturation temperature, with no boiling occurring. This liquid is called saturated liquid. Figure 1.4 shows saturated liquid on a temperature - enthalpy diagram.

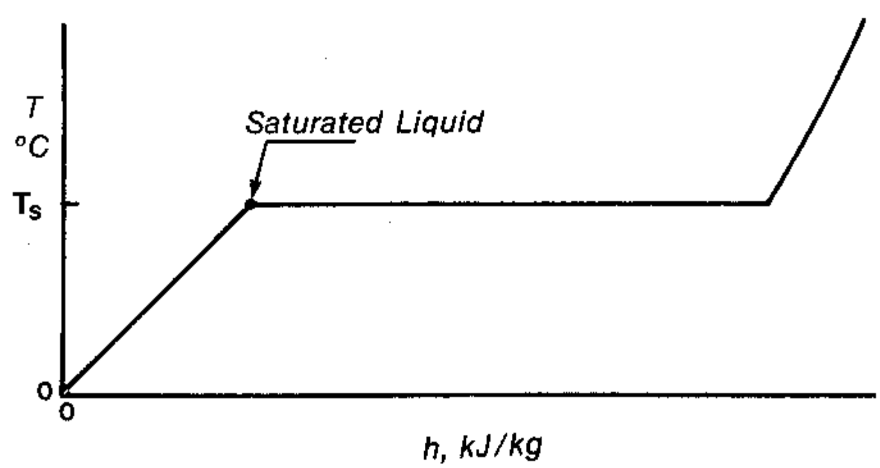

Figure 1.4

While boiling is happening, both vapour and liquid are present. Any mixture of liquid and vapour at the saturation temperature for a given pressure is called wet steam. Figure 1.5 shows wet steam on a temperature enthalpy diagram.

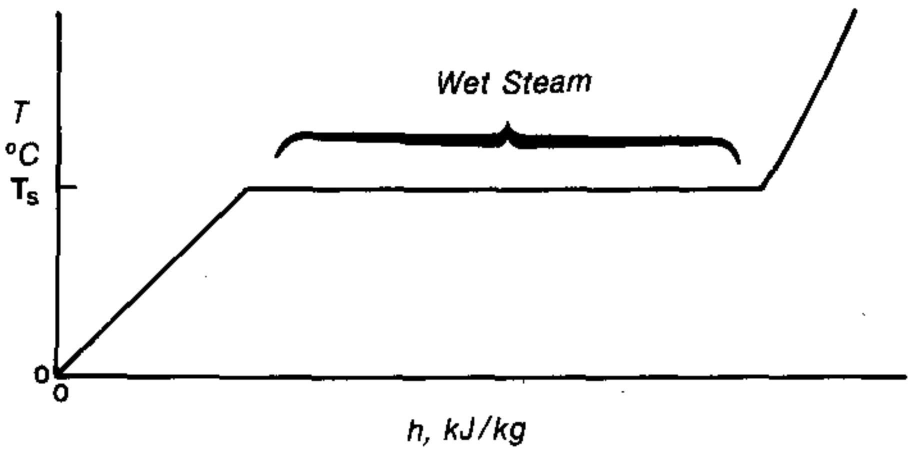

Figure 1.5

At some point all the liquid will have changed to vapour, but the vapour is still at the saturation temperature for that pressure. This is saturated steam. Figure 1.6 shows saturated steam on a temperature - enthalpy diagram.

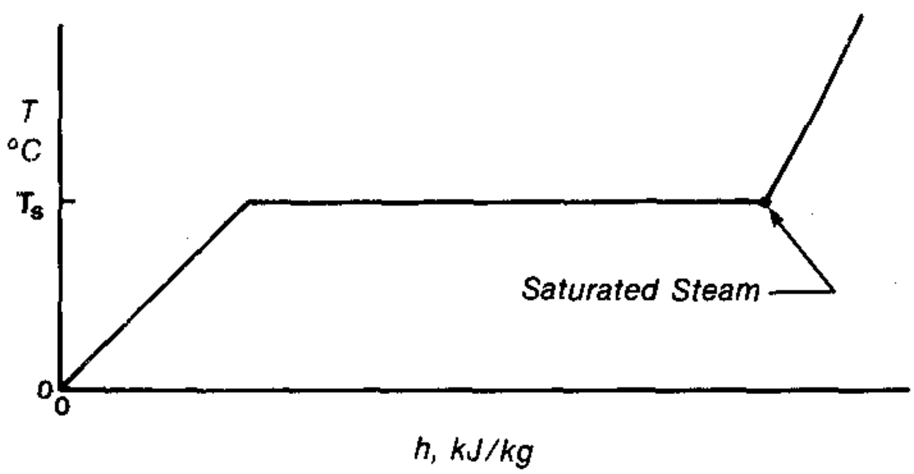

Figure 1.6

If saturated steam is heated, the temperature will rise. Any steam that is above the saturation temperature for a given pressure is called superheated steam. You can see the superheated steam region in Figure 1.7.

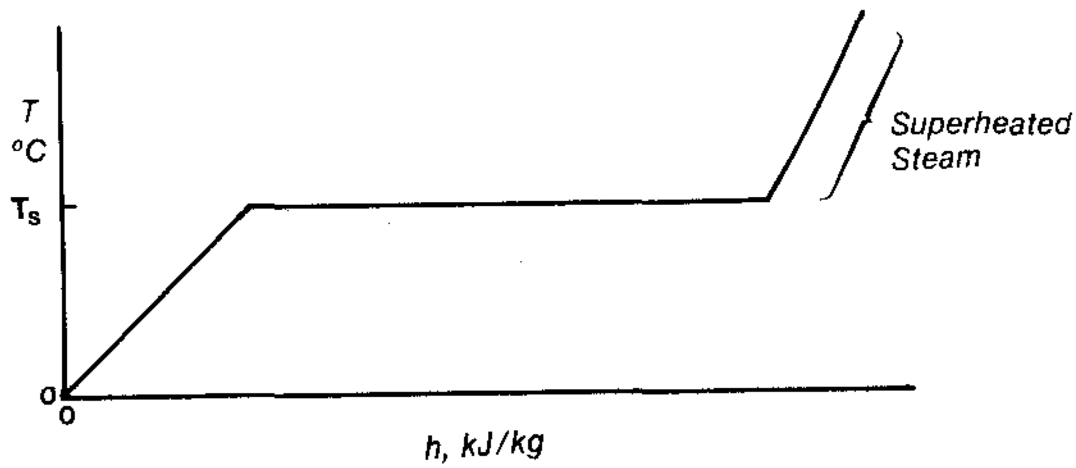

Figure 1.7

On these diagrams, any heat added that produces a temperature change is called sensible heat. The sensible heat regions are shown in Figure 1.8.

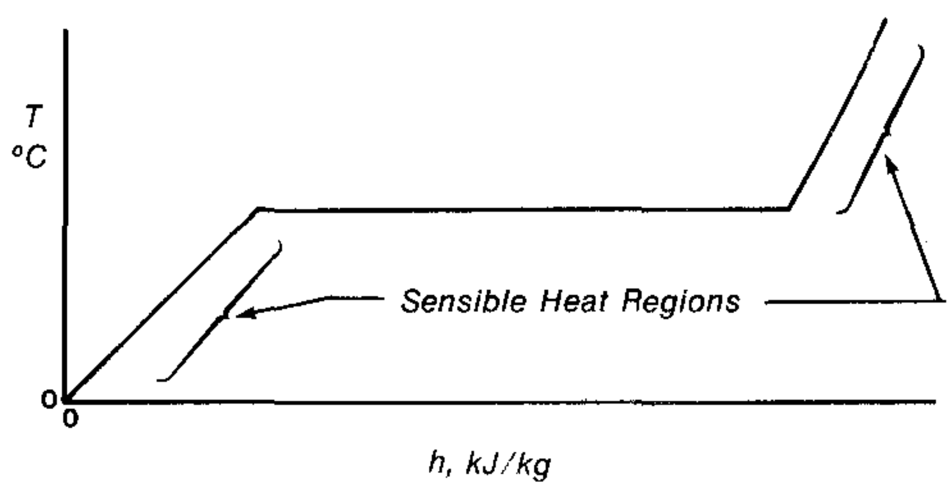

Figure 1.8

The heat added to completely boil one kilogram of fluid at constant temperature is called the latent heat of vapourization, L_V. This is shown in Figure 1.9.

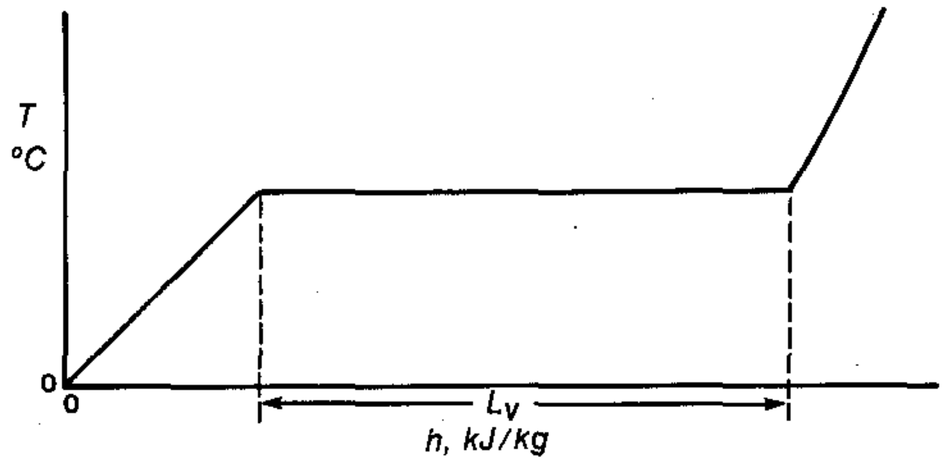

Figure 1.9

→ Try these assignment questions. Answer from memory in the space provided, then check your answer with those in the "TEXT ANSWERS" section.

1.2) State the meaning of each of the following as it applies to water:

(a) Saturation temperature: ______________________

____

(b) Subcooled liquid: ______________________

____

(c) Saturated liquid: ______________________

____

(d) Wet steam: ______________________

____

(e) Saturated steam: ______________________

____

(f) Superheated steam: ______________________

____

(g) Sensible heat: ______________________

____

(h) Latent heat of vapourization: ______________________

____

____

1.3) Sketch a temperature vs. enthalpy diagram for water at constant pressure, starting at 0°C. Label the following on your sketch:

(a) Saturation temperature
(b) Subcooled liquid region
(c) Saturated liquid
(d) Wet steam region
(e) Saturated steam
(f) Superheated steam
(g) Sensible heat region
(h) Latent heat region

Steam Tables:

This section deals with identifying the "states" of water (i.e. subcooled liquid, saturated liquid, wet steam, saturated steam, and superheated steam) given values that represent water at a certain temperature, pressure, and enthalpy. In order to be able to identify these states, you must be able to read the steam tables and to use the information presented in them.

→ Locate the copy of "Steam Tables in SI Units" and turn to page 1.4 in Table 1. The information you will be using is contained in the first five columns on the left side of the page.

The extreme left hand column lists saturation temperatures in even increments. The units are °C. Next to each saturation temperature is listed a pressure in bar (1 bar = 100 kPa(a)). This is the pressure at which water will boil for the given saturation temperature, or the saturation pressure.

1.4) For example, look at the 100°C entry. What is the saturation pressure for water to boil at 100°C? ________

→ Answer this question in the space provided and check your answer with the one in the "TEXT ANSWERS" section before proceeding.

The third column from the left is headed "h_f", which stands for the enthalpy of saturated liquid at the given saturation temperature. Find h_f for water at 100°C. The enthalpy is 419.1 kJ/kg. This means that 1 kg of water at 1.013 bar must have 419.1 kJ of heat added to it to raise it from 0°C to 100°C.

The fifth column from the left is headed "h_g" - this is the enthalpy of saturated steam at the given saturation temperature. Thus, to change 1 kg of water at 0°C to saturated steam at 100°C (and 1.013 bar) it is necessary to add 2676.0 kJ of heat.

The fourth column from the left, headed "h_{fg}", is not strictly an enthalpy. It is a difference of enthalpies: $h_g - h_f$. This is the latent heat of vapourization at the given saturation temperature.

1.5) What is the latent heat of vapourization of water at 100°C? ____________________

→ Answer this question in the space provided before proceeding and check your answer with the one in the "TEXT ANSWERS".

The information in the above example can be shown on a temperature-enthalpy diagram:

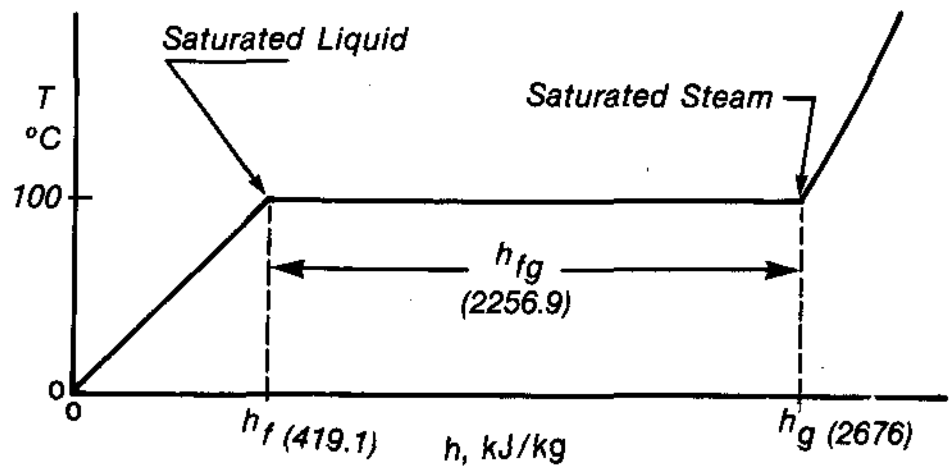

Figure 1.10

Now, compare Table 2 with Table 1.

1.6) What is the difference between the two tables?

____

→ Answer this question and check your answer with the "TEXT ANSWERS" section before you proceed.

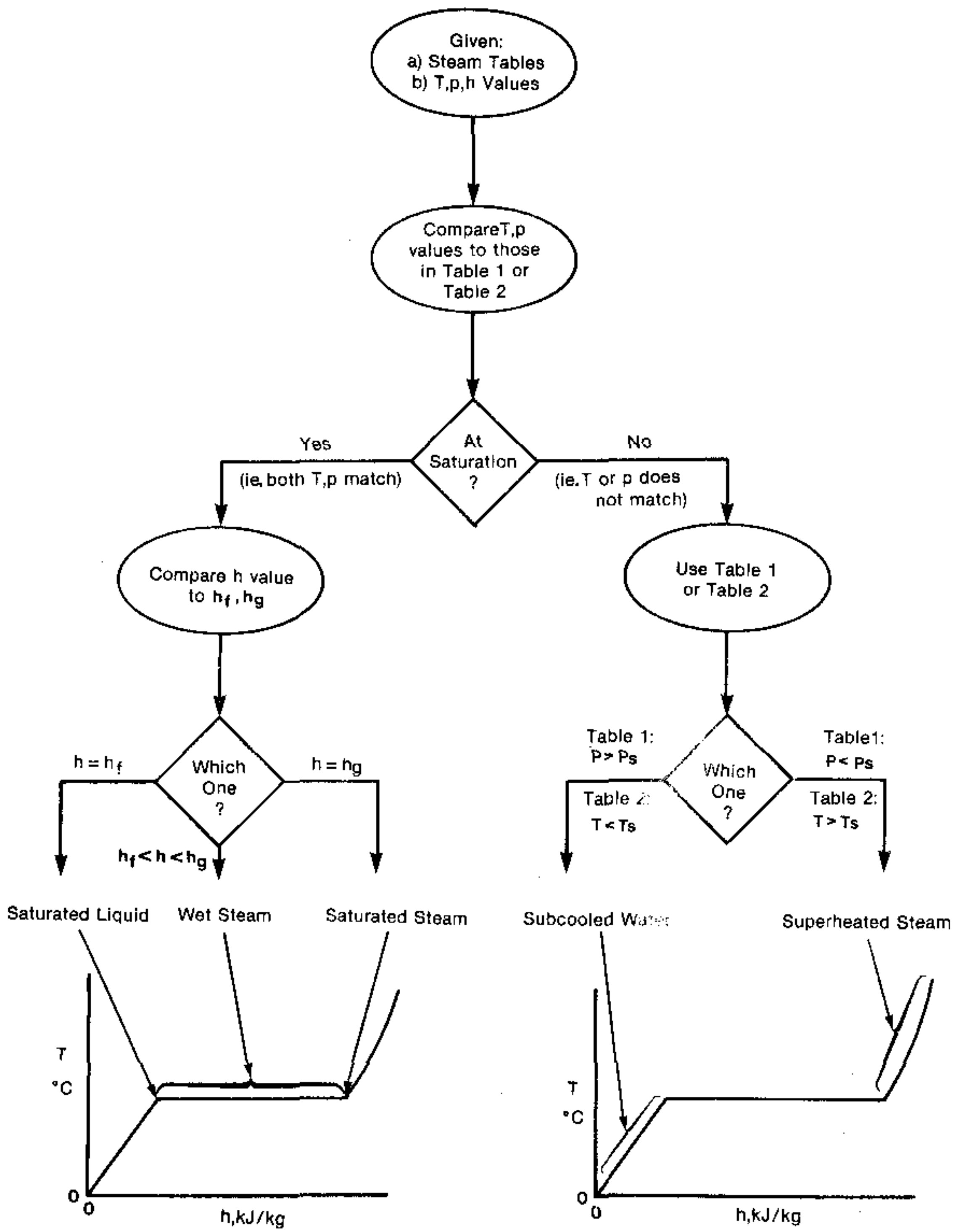
Given:
a) Steam Tables
b) T,p,h Values
CompareT,p values to those in Table 1 or Table 2
At Saturation ?
Yes
(ie, both T,p match)
No
(ie.T or p does not match)
Compare h value to h_f, h_g
Use Table 1 or Table 2
Which One ?
$h = h_f$
$h = h_g$
$h_f < h < h_g$
Table 1: P > Ps
Table 2: T < Ts
Table1: P < Ps
Table 2: T > Ts
Saturated Liquid
Wet Steam
Saturated Steam
Subcooled Water
Superheated Steam
T °C
0
h,kJ/kg

Figure 1.11

Identifying States:

If you are given a set of temperature, pressure and enthalpy values that represents water, how could you use the steam tables to go about identifying the state of water?

You can use a decision making process which is represented by Figure 1.11.

⟶ Use this diagram and your steam tables to follow these examples:

Identify the following as one of subcooled liquid, saturated liquid, wet steam, saturated steam, or superheated steam:

(A) 100°C, 1.013 bar, 1575.0 kJ/kg

The first thing to do is decide whether the example is at saturation or not. Look at the given temperature and pressure. Compare these values to those given in either Table or Table 2. (In this first example, since the given temperature matches an entry in Table 1, and since the given pressure does not match an entry in Table 2, you should use Table 1.) If both the given temperature and pressure match the saturation values in the appropriate table, then the example is at saturation.

⟶ Answer these questions now, then compare your answers with those in the "TEXT ANSWERS" section.

1.7) Look at 100°C in Table 1 and compare the given pressure to the saturation pressure. Is this example at saturation? ______________________

1.8) Of the 5 states of water, 2 can now be eliminated.

Which two? ____

Why? ____

1.9) You now have 3 choices, each at 100°C and 1.013 bar. How can you choose between them? ____________________

____

Since the given enthalpy (1575.0 kJ/kg) is greater than h_f but less than h_g, the water in this example has more heat added to it from 0°C than saturated liquid but less than saturated steam. In other words, the water must be boiling but it cannot be completely vapour. This example represents wet steam.

(B) 225 °C, 8 bar, 2894.5 kJ/kg

1.10) (a) Is this example at saturation? ______________

(b) Why? ______________________________

1.11) Which of the 5 states of water can now be eliminated?

____

→ Answer questions 1.10 and 1.11 before proceeding, then check your answers with those in the "TEXT ANSWERS".

There are two ways to proceed from this point - use Table 1 or Table 2. Either way can be used, depending on your preference.

Using Table 1: The saturation pressure for water to boil at 225 °C is 25.501 bar.

1.12) (a) What effect does raising the pressure have on the saturation temperature for water? ______________

____

(b) What effect does lowering the pressure have on the saturation temperature for water? ______________

____

→ Answer these questions, then check them before proceeding.

Since the given pressure, 8 bar, is less than 25.501 bar, the saturation temperature of the example must be less than 225°C. This example is thus above the saturation temperature for the given pressure, that is, it is superheated steam.

Using Table 2: The saturation temperature for water at 8 bar is 170.415 °C. Since the given temperature, 225 °C, is higher than the saturation temperature at the given pressure, this example must be superheated steam.

Now it's time to practice for yourself.

→ Using steam tables and Figure 1.11 answer question 1.13 in the spaces provided, then check your answers against those in the "TEXT ANSWERS".

1.13) State whether each of the following represents sub-cooled liquid, saturated liquid, wet steam, saturated steam, or superheated steam:

(a) 54°C, 0.15 bar, 2599.2 kJ/kg ____________________

(b) 210°C, 20 bar, 897.9 kJ/kg ____________________

(c) 170°C, 7.92 bar, 1241.2 kJ/kg ____________________

(d) 179°C, 9.8 bar, 758.7 kJ/kg ____________________

(e) 300°C, 30 bar, 2995 kJ/kg ____________________

Basic Calculations Using Steam Tables

In this section you will be given sets of values representing water as it is heated or cooled from one set of conditions to another. Using the steam tables, you will be asked to do simple calculations to determine an unknown variable.

→ Locate your copy of the steam tables and use them to follow the worked examples and to try some practice questions:

Example 1:

Water at 60°C is heated to produce water at 95°C. Determine the heat that must be added per kilogram of water heated.

Answer:

If we can find the enthalpy of the water at the initial and final conditions, we can say that the difference in enthalpies, Δh, between the two conditions is the amount of heat that must be added per kilogram.

Liquid water is an incompressible fluid. As such, its enthalpy will not vary significantly with pressure. Thus, if we know the water temperature, we can assume that the enthalpy of the liquid is essentially the same as that of saturated liquid at the same temperature.

The enthalpy of water at 60°C can be assumed to be the same as h_f at 60°C, or 251.1 kJ/kg from Table 1, and the enthalpy of water at 95°C can be assumed to be h_f at 95°C, or 398.0 kJ/kg.

The amount of heat added in this case is:

$$\Delta h = h_{f_{95°C}} - h_{f_{60°C}}$$
$$= 398 - 251.1$$
$$= 146.9 \text{ kJ/kg}$$

This can be represented on a temperature vs. enthalpy diagram as follows:

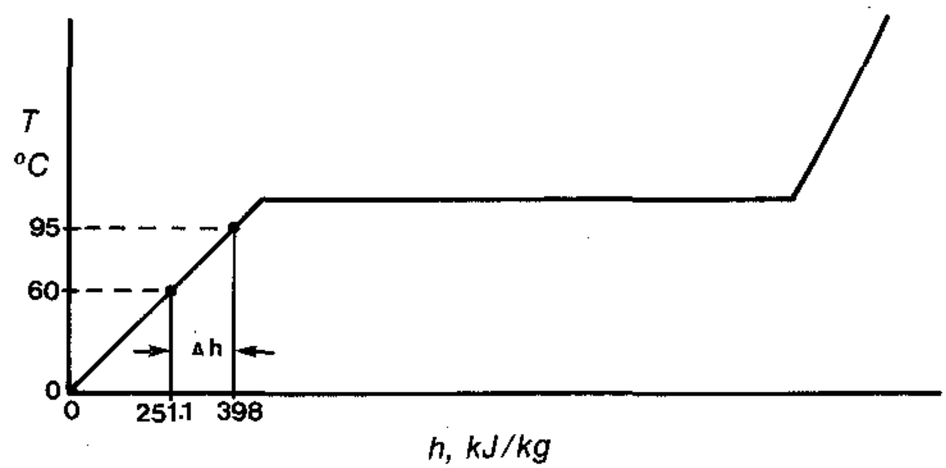

Figure 1.12

Example 2:

Water at 176°C enters a boiler. The boiler produces 1000 kg/s of saturated steam at 254°C. What is the rate of heat addition in the boiler?

Answer:

The process is represented by Figure 1.13:

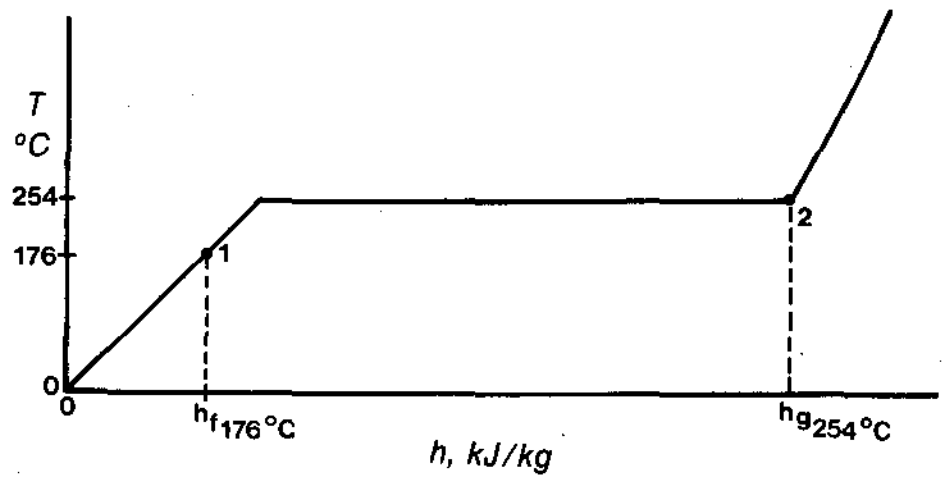

Figure 1.13

Here, condition 1 is water at 176°C and condition 2 is saturated steam at 254°C.

Δh is the difference between $h_{g_{254°C}}$ and $h_{f_{176°C}}$

$$\Delta h = h_{g_{254°C}} - h_{f_{176°C}}$$

$$= 2799.1 - 745.5$$

$$= 2053.6 \text{ kJ/kg}$$

Since there are 1000 kg/s of steam generated, the rate of heat addition is 1000 x Δh, or

$$1000 \times 2053.6$$

$$= 2{,}053{,}600 \text{ kJ/s}$$

1 watt is equal to 1 J/s by definition. Thus the rate of heat addition may be expressed as 2,053,600 kW or 2053.6 MW.

⟶ Before you proceed, try the following questions. Answer them in the space provided, then check your answers with those in the "TEXT ANSWERS".

1.14) How much heat must be added per kilogram to raise the temperature of liquid water from 60°C to 250°C? (Assume that the liquid is pressurized sufficiently to remain liquid).

1.15) What is the heat removal rate if 33.0 kg/s of saturated steam at 120°C is condensed to form water 103°C?

Wet Steam

→ Use Figure 1.14 to answer the following questions. Write your answers in the space provided, then check them with the "*TEXT ANSWERS*" before you proceed.

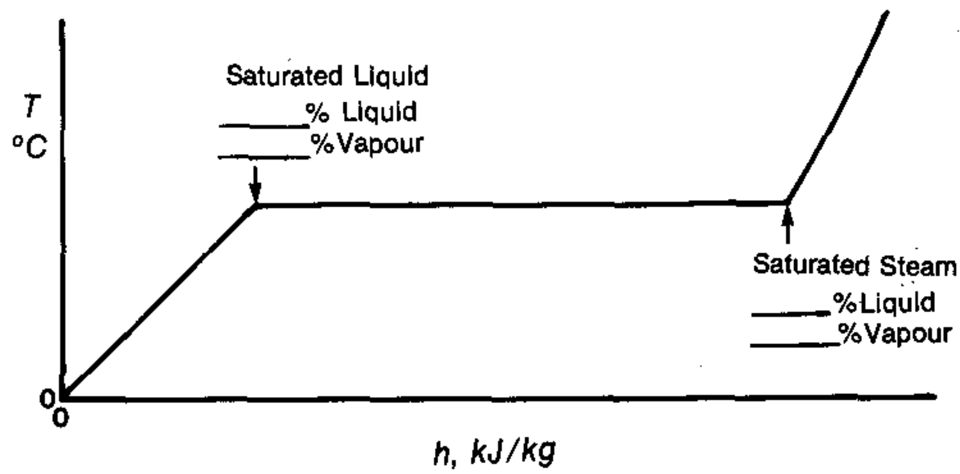

Figure 1.14

1.16) For saturated liquid, what percentage of the fluid is:

(a) liquid?

(b) vapour?

1.17) For saturated steam, what percentage of the fluid is:

(a) liquid?

(b) vapour?

→ (Write the percentages on Figure 1.14 in the appropriate spaces.)

1.18) On Figure 1.14, mark the point that represents wet steam with 75% vapour and 25% steam by mass.

1.19) How much of the latent heat must be added to the saturated liquid to produce the wet steam in question 1.18? ______________________

1.20) *How could you determine the enthalpy of the wet steam* from question 1.18? ______________________

____

Note: The steam from question 1.18 is commonly referred to in a variety of ways. It could be called wet steam (quality = 75%); 25% wet steam, wet steam with moisture content 25%, or wet steam with dryness fraction 0.75.

Generally, to determine the enthalpy of wet steam (h_{ws}) add the enthalpy of saturated liquid (at the same temperature) to the fraction of the latent heat of vapourization (again at the same temperature) that corresponds to the steam quality:

i.e. $h_{ws} = h_f + q\, h_{fg}$

where q = steam quality, represented as a fraction.

⟶ Answer the following questions in the space provided before proceeding, then check your answers with those in the "*TEXT ANSWERS*".

1.21) Determine the enthalpy of 25% wet steam at 130°C.

1.22) Wet steam at 50°C has enthalpy 2450 kJ/kg. Determine the moisture content of this steam.

1.23) Saturated liquid at 14 bar is heated to produce 10% wet steam. How much heat is added per kg of wet steam produced?

1.24) How much heat is removed from 5 kg of wet steam (moisture content = 21%) at 140°C to produce water at 110°C?

1.25) If 2.28×10^4 kJ of heat are added to 10 kg of water at 65°C to produce wet steam at 95°C, what is the quality of the steam produced?

→ The first module is now complete. Read the objectives for this module again. If you are confident you can perform the objectives, obtain the PI 25-1 Criterion Test and complete it. If you feel you need more practice in any area, see the course manager.

PI 25-1 TEXT ANSWERS

1.1) (a) Heat:

A form of energy in a substance, depending on the temperature, type, state and mass of the substance.

(b) Temperature:

A measure of the ability of a substance to lose or gain heat when compared with a second substance.

(c) Enthalpy:

The total heat per kg of substance, measured above an arbitrary reference point.

1.2) (a) Saturation Temperature:

The temperature at which boiling occurs for a given pressure.

(b) Subcooled Liquid:

Liquid water below its saturation temperature.

(c) Saturated Liquid:

Liquid water at the saturation temperature. No boiling has yet occurred.

(d) Wet Steam:

A mixture of liquid and vapour at the saturation temperature.

(e) Saturated Steam:

100% vapour at the saturation temperature.

(f) Superheated Steam:

Vapour at a temperature above its saturation temperature.

(g) Sensible Heat:

Heat added that results in a change in temperature.

(h) Latent Heat of Vapourization:

Heat added to boil 1 kg of water at constant temperature.

1.3)

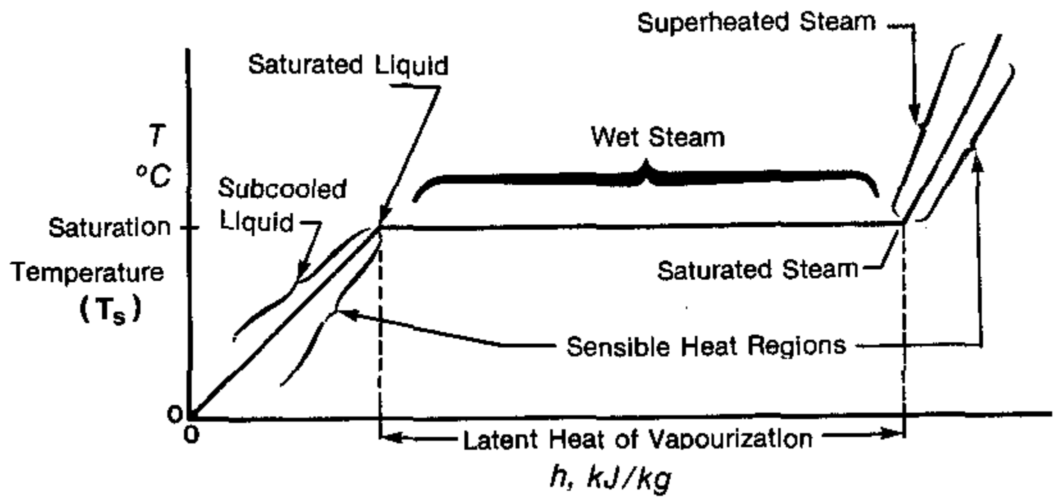

Figure 1.15

1.4) The saturation pressure for 100°C is 1.013 bar, or 101.3 kPa(a).

1.5) The latent heat of vapourization for water at 100°C is 2256.9 kJ/kg.

1.6) Table 1 has even increments of temperature as the initial variable, while Table 2 has even increments of pressure as the initial variable.

1.7) Yes, this example is at saturation - that is, the given temperature and pressure (100°C, 1.013 bar) match values in Table 1. (Note: On Figure 1.11, you have now picked the left branch).

1.8) (a) Subcooled liquid and superheated steam can be eliminated.

(b) These two states cannot be at saturation by definition, thus they can be eliminated.

1.9) Compare the given enthalpy to h_f and to h_g. Since the given value states the amount of heat added to water from 0°C, it can be compared to the saturated liquid and saturated steam enthalpies to fix the state.

1.10) (a) No.

(b) In this case either Table 1 or Table 2 is appropriate, since there is an entry to match 225°C in Table 1 and an entry to match 8 bar in Table 2.

From Table 1, the saturation pressure for 225°C is 25.501 bar (not 8 bar).

From Table 2, the saturation temperature for 8 bar is 170.415°C (not 225°C).

Looking at Figure 1.11, you have now picked the right hand branch.

1.11) Since saturated liquid, wet steam, saturated steam are at saturation, they can now be eliminated.

1.12) (a) Raising the pressure increases the saturation temperature.

(b) Lowering the pressure decreases the saturation temperature.

1.13) (a) Saturated Steam

In either Table 1 or 2, 54°C and 0.15 bar match saturation values (53.997°C can be rounded off to 54°C). Thus this example is at saturation. Comparing the given enthalpy, 2599.2 kJ/kg, to h_f and to h_g in Table 1 or 2, you will find the given enthalpy equals h_g. This must be saturated steam.

(b) Subcooled Liquid

Comparing 210°C and 25 bar to either table should indicate that this example is not at saturation.

PI 25-1 TEXT ANSWERS

If you used Table One:

The saturation pressure for water to boil at 210°C is 19.007 bar. The given pressure, 20 bar, is greater than 19.077 bar; thus the saturation temperature for the example must be more than 210°C. Since the example is at 210°C at 20 bar, the state must be subcooled water.

If you used Table Two:

The saturation temperature for water at 20 bar is 212.375°C. The given temperature, 210°C, is less than the saturation temperature. This must be subcooled liquid.

(c) Wet Steam:

Table One is the best choice for this example, since Table 2 does not have 7.92 bar listed. When you compare the given temperature and pressure, 170°C, 7.92 bar, to the values in Table 1, you should find they match. This example is thus at saturation. The given enthalpy, 1241.2 kJ/kg, is more than h_f (719.1 kJ/kg), and less than h_g (2767.1 kJ/kg). This means the correct answer is wet steam.

(d) Saturated Liquid:

The given temperature and pressure, 179°C, 9.8 bar, match the values in Tables 1 and 2 (rounding 9.798 bar to 9.8 bar). This example is at saturation. The given enthalpy, 758.7 kJ/kg, equals h_f - so the state is saturated liquid.

(e) Superheated Steam:

Comparing 300°C and 30 bar with the values in either table should indicate that the example is not at saturation.

If you used Table One:

The saturation pressure for water to boil at 300°C is 85.927 bar. Since the given pressure, 30 bar, is less than 85.927 bar, the saturation temperature must be less than 300°C. Since the water is above the saturation temperature at the given pressure, this is superheated steam.

If you used Table Two:

The saturation temperature for water to boil at 30 bar is 233.841°C. Since the given temperature, 300°C, is greater than the saturation temperature for 30 bar, the state is superheated steam.

1.14) This process can be represented as shown in Figure 1.16.

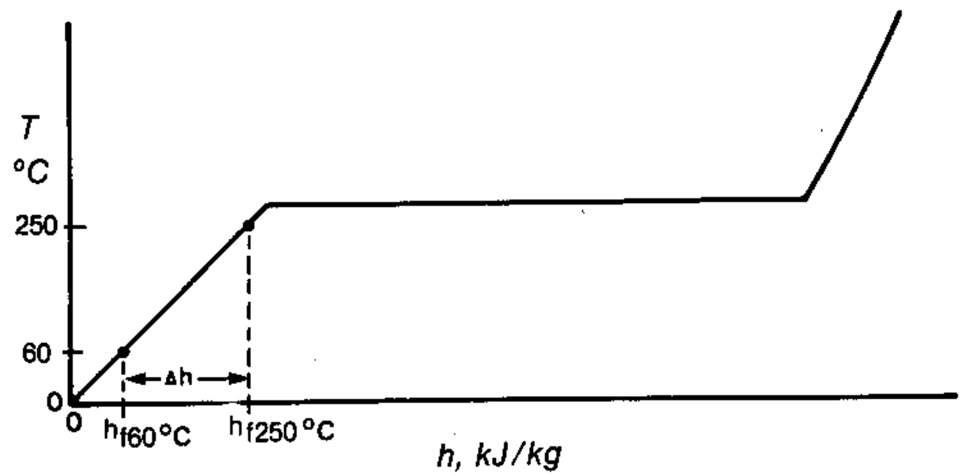

Figure 1.16

Here $\Delta h = h_{f_{250°C}} - h_{f_{60°C}}$

From Table 1, $h_{f_{250°C}} = 1085.8$ kJ/kg

and $h_{f_{60°C}} = 251.1$ kJ/kg

Thus, $\Delta h = 1085.8 - 251.1$

$= 834.7$ kJ/kg

PI 25-1 TEXT ANSWERS

1.15) The process can be represented as shown below:

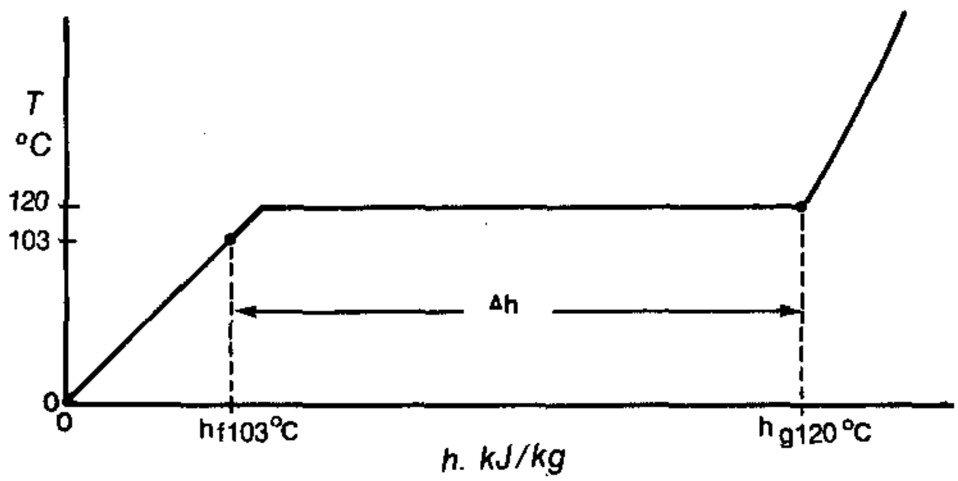

Figure 1.17

In this case, $\Delta h = h_{g120°C} - h_{f103°C}$

From Table 1, $h_{g120°C}$ = 2706.0 kJ/kg

and $h_{f103°C}$ = 431.7 kJ/kg

Thus, Δh = 2706.0 - 431.7

= 2274.3 kJ/kg

For a 33.0 kg/s flow, the heat removal rate will be 33.0 x 2274.3 = 7.51×10^4 kW.

1.16) (a) 100% is liquid.

(b) 0% is vapour.

1.17) (a) 0% is liquid.

(b) 100% is vapour.

1.18)

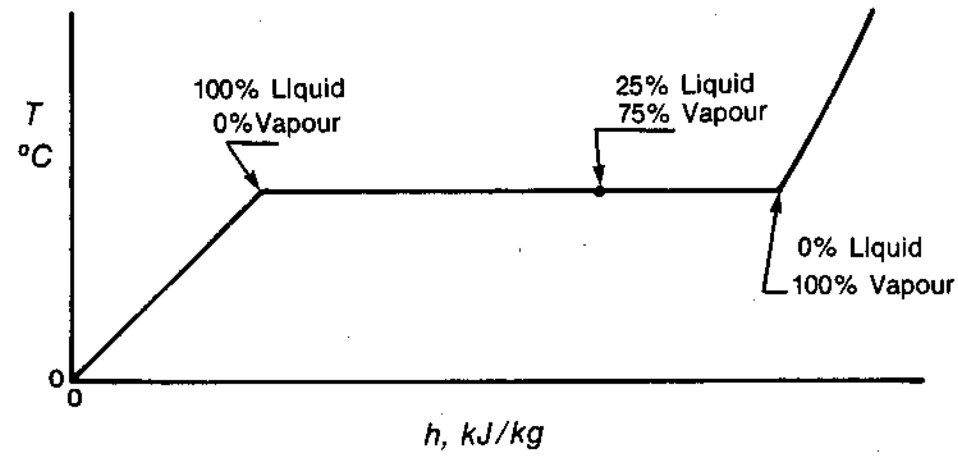

Figure 1.18

1.19) To change saturated liquid to wet steam (75% vapour and 25% liquid), 75% of the latent heat must be added.

1.20)

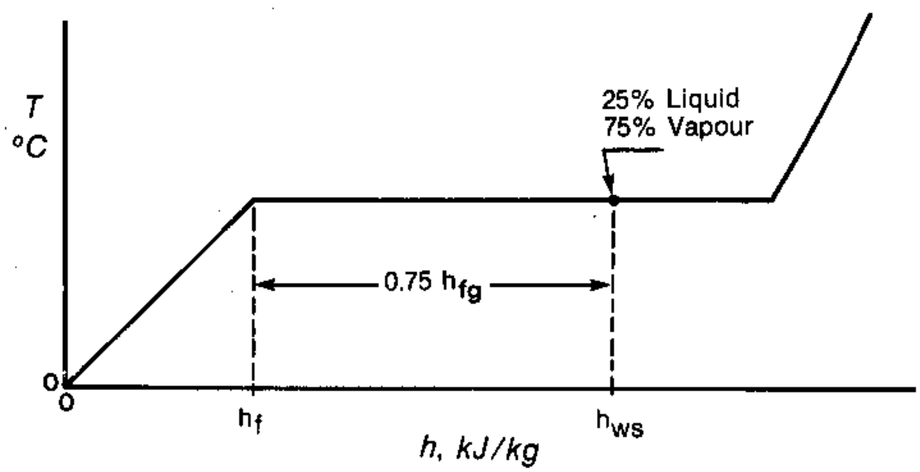

Figure 1.19

To obtain the enthalpy of the wet steam (h_{ws}), consider the following:

First, the water must be heated from 0°C to produce saturated liquid. The heat added can be expressed as h_f.

Secondly, 75% of the latent heat is added to produce the wet steam. This can be expressed as 0.75 h_{fg}.

Thus, the enthalpy of the wet steam is the sum of h_f and 0.75 h_{fg}:

$$h_{ws} = h_f + 0.75\ h_{fg}$$

(Remember that enthalpy for water is by definition the heat added from reference point <u>0°C</u>.)

1.21) "25% wet steam" is steam with quality 75%.

At 130°C, h_f = 546.3 kJ/kg

and h_{fg} = 2173.6 kJ/kg

Thus h_{ws} = 546.3 + 0.75 x 2173.6

= <u>2176.5 kJ/kg</u>

1.22) In this question you are asked to calculate the moisture content of the steam. You can use the enthalpy of the wet steam to determine the steam quality, and then find the moisture content using the quality:

$$h_{ws} = 2450 \text{ kJ/kg}$$

At 50°C from Table 1 h_f = 209.3 kJ/kg

and h_{fg} = 2382.9 kJ/kg

Thus, 2450 = 209.3 + q x 2382.9

$$\text{and } q = \frac{2450 - 209.3}{2382.9} = 0.940$$

The quality is 94.0%; the moisture content must be 100 - 94.0 = <u>6.0%</u>.

1.23) In this case, Δh is $h_{ws} - h_{f_{14bar}}$. Since there is no mention of temperature change, we will assume the wet steam to be at 14 bar. This is shown on Figure 1.20:

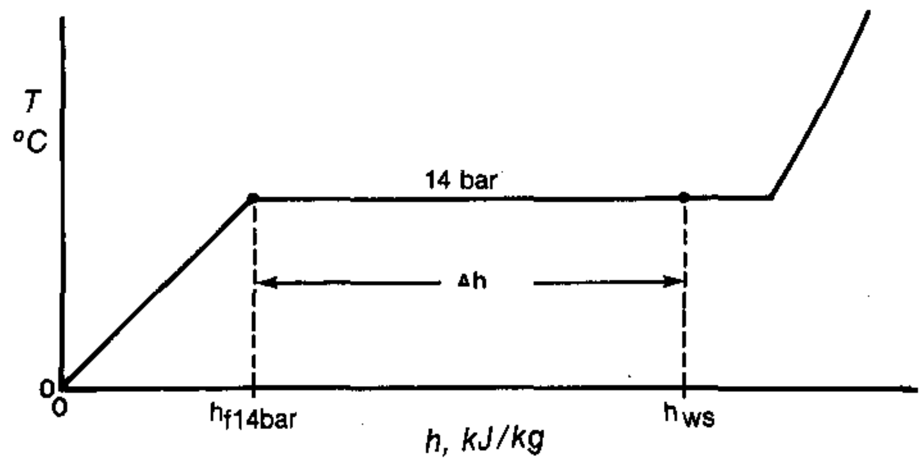

Figure 1.20

By inspection of Figure 1.20, you will see that Δh is the same as the percentage of latent heat added to the saturated liquid. Since the steam is 10% wet, 90% is the percentage of latent heat added.

From Table 2, $h_{fg_{14\ bar}} = 1957.7$ kJ/kg

Therefore, $\Delta h = 0.90 \times 1957.7$

$= \underline{1761.9\ kJ/kg}$

1.24) This example involves condensing steam and cooling it. The change in enthalpy, Δh, is:

$$h_{ws_{140°C}} - h_{f_{110°C}}$$

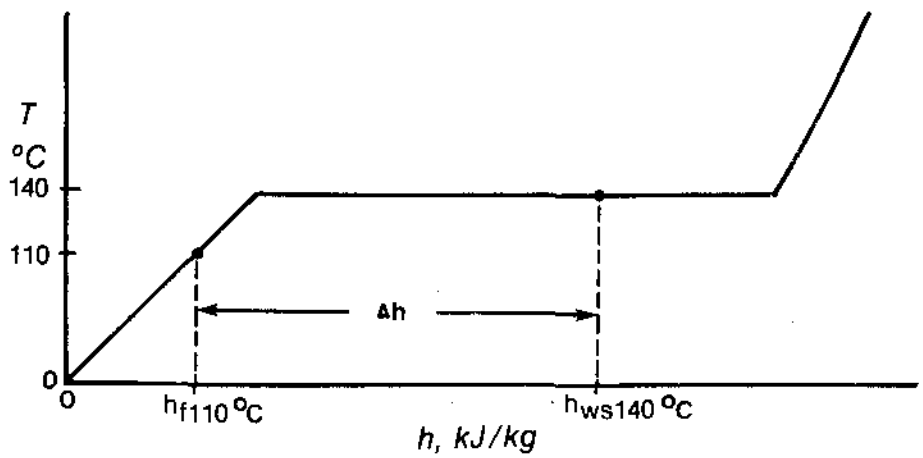

Figure 1.21

From Table 1, $h_{f_{140°C}} = 589.1$ kJ/kg

and $h_{fg_{140°C}} = 2144.0$ kJ/kg

Since the moisture content is 21%, the dryness will be 79%.

Thus $h_{ws_{140°C}} = 589.1 + 0.79 \times 2144.0$

$= 2282.86$ kJ/kg

From Table 1, $h_{f_{110°C}} = 461.3$ kJ/kg

Thus, $\Delta h = 2282.86 - 461.3$

$= 1821.56$ kJ/kg

The heat removed from 5 kg of steam is

$5 \times 1821.56 = \underline{9.11 \times 10^3 \text{ kJ}}$.

1.25) This example is somewhat different than the others, in that the unknown variable is the steam quality.

The process can be represented as in Figure 1.22:

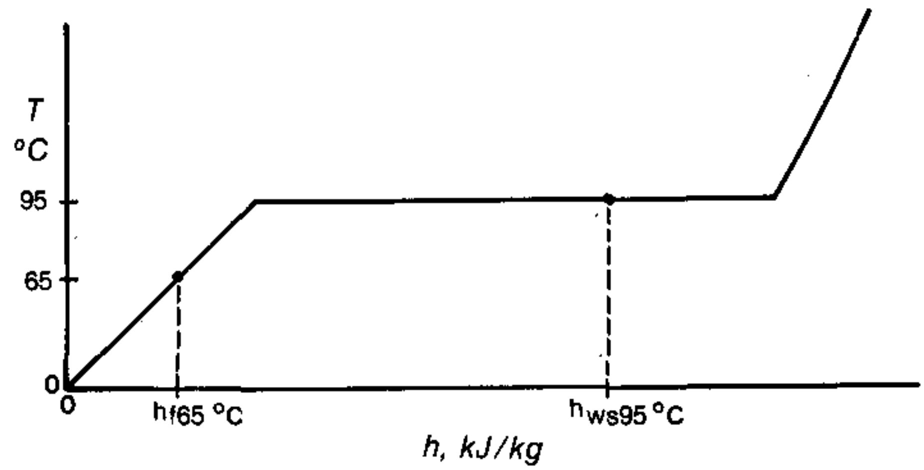

Figure 1.22

The quantity of heat added for 10 kg of water is 2.28×10^4 kJ. Thus the change in enthalpy is (Δh) is:

$2.28 \times 10^4 \div 10 = 2.28 \times 10^3$ kJ/kg.

Δh can also be expressed as $h_{ws_{95°C}} - h_{f_{65°C}}$

This can be expanded:

From Table 1, $h_{f_{65°C}} = 272.0$ kJ/kg

$h_{f_{95°C}} = 398.0$ kJ/kg

$h_{fg_{95°C}} = 2270.2$ kJ/kg

Thus, $\Delta h = (398.0 + q \times 2270.2) - 272.0$ kJ/kg

Substituting, $2.28 \times 10^3 = (398.0 + q \times 2270.2) - 272.0$

So $q = 0.949$,

or the steam quality if 94.9%.