Chemical Process Utilities

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Lecture – 5
Practice Problems Related to Power Cycle and Fuel Analysis

Welcome to the numerical problem segments here. We will discuss a couple of numerical problems attributed to the approximate and ultimate analysis and heating value. As you know that we have discussed these theoretical parts in the previous lectures.

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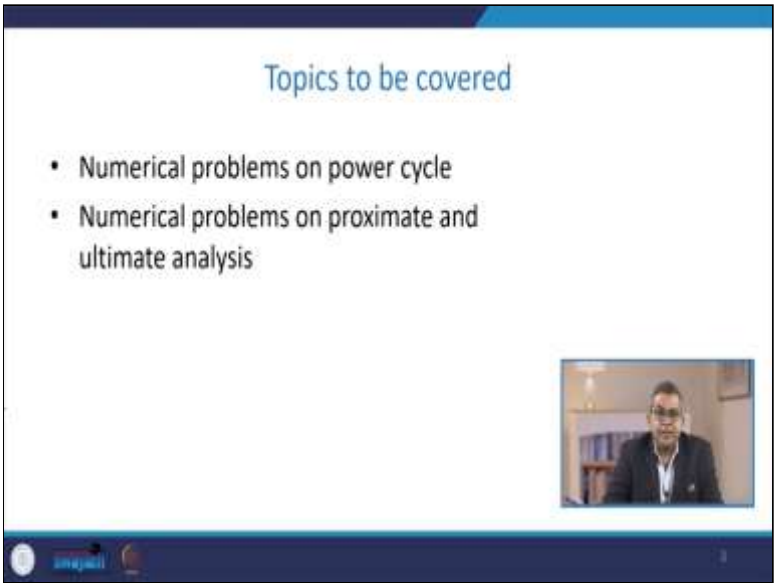

Topics to be covered

- Numerical problems on power cycle
- Numerical problems on proximate and ultimate analysis

So, the first thing, we will discuss the numerical problems pertaining to the power cycle, and in the second aspect, we will discuss the numerical problem pertaining to the proximate and ultimate analysis.

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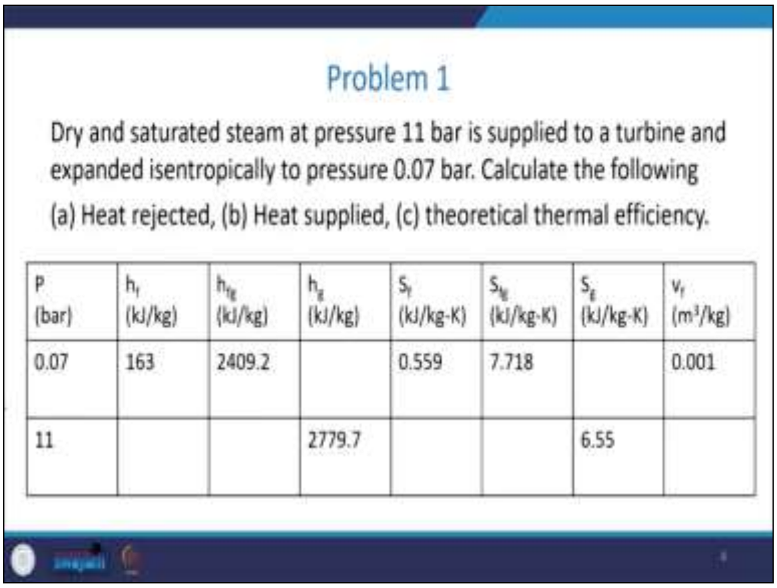

Problem 1

Dry and saturated steam at pressure 11 bar is supplied to a turbine and expanded isentropically to pressure 0.07 bar. Calculate the following (a) Heat rejected, (b) Heat supplied, (c) theoretical thermal efficiency.

P (bar)	h_f (kJ/kg)	h_{fg} (kJ/kg)	h_g (kJ/kg)	S_f (kJ/kg-K)	S_{fg} (kJ/kg-K)	S_g (kJ/kg-K)	v_f (m^3/kg)
0.07	163	2409.2		0.559	7.718		0.001
11			2779.7			6.55	

Now let us have a look at the first problem. Now, this first problem says that dry and saturated steam at pressure one eleven bar is supplied to a turbine and expanded isentropically to a pressure of 0.07 bar. Now you need to calculate the heat rejected heat supplied and theoretical thermal efficiency. Now for the ease of the business, because sometimes you may require the value which is available in the steam table, we have given the values whatever values are required for the calculation of this particular problem.

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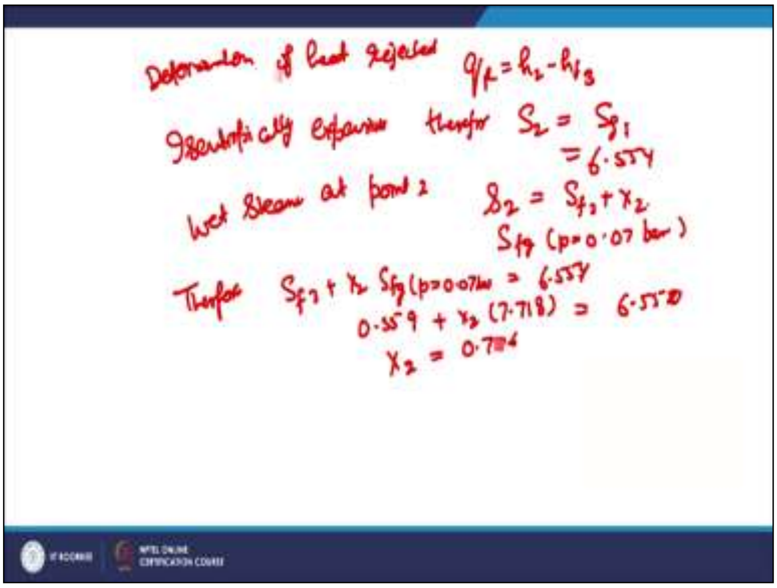

Determination of heat rejected $q_R = h_2 - h_{f3}$

Isentropically expansion therefor $S_2 = S_{g1}$
$= 6.554$

Wet steam at point 2 $S_2 = S_{f2} + x_2$
S_{fg} $(p = 0.07$ bar$)$

Therefore $S_{f2} + x_2 S_{fg} (p = 0.07$ bar $= 6.554$
$0.559 + x_2 (7.718) = 6.55$
$x_2 = 0.7$[illegible]

Now you need to determine the heat rejected. So, the determination of heat rejected given by

$$q_R = h_2 - h_{f3}$$

Now, remember we have already supplied this PV as well as the TS diagram for convenience. Now how can we find out the unknown X2. Before we go to find out, the unknown X2 let us look at what we are looking for.

So, for first isentropic typically expansion occurs.

So, therefore

$$S_2 = S_{g1} = 6.554$$

Now since for wet steam at point 2

$$S_2 = S_{f3} + X_2 . S_{fg} (at\ p = 0.07\ bar)$$

x is a dryness fraction. We have taken these values from the steam table.

Therefore

$$S_{f3} + X_2 . S_{fg} (at\ p = 0.07\ bar) = 6.554$$

Now it is

$$0.559 + X_2 . 7.718 = 6.550$$

So, by this way the

X2 that is the drainer section comes out to be

$$X_2 = 0.776.$$

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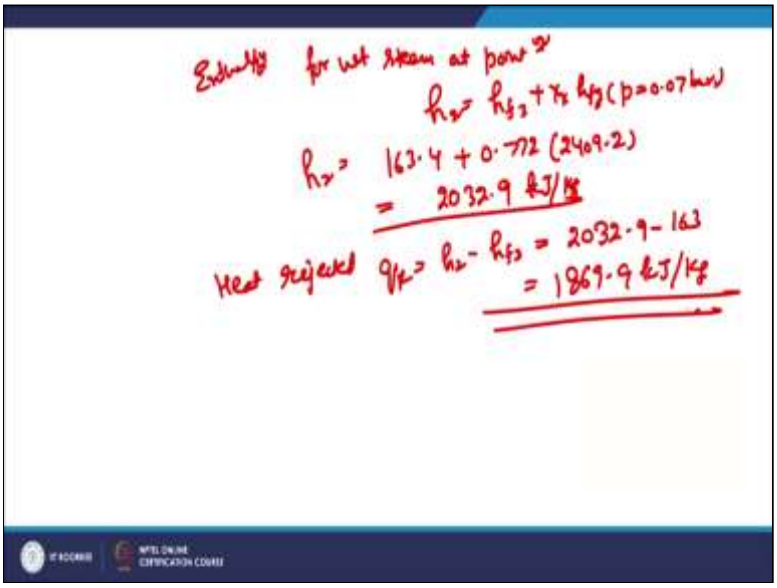

Enthalpy for wet steam at point 2

$h_2 = h_{f3} + x_2 h_{fg} (p = 0.07 bar)$

$h_2 = 163.4 + 0.772 (2409.2)$

$= 2032.9$ kJ/kg

Heat rejected $q_R = h_2 - h_{f3} = 2032.9 - 163$

$= 1869.9$ kJ/kg

So, enthalpy for wet steam at 0.2 that is

$$h_2 = h_{f3} + X_2 . h_{fg}\ (p = 0.07\ bar)$$

$$h_2 = 163.4 + 0.772(2409.2) = 2032.9\ kJ/kg$$

So, by this way we can calculate the heat rejected that is

$$q_R = h_2 - h_{f3} = 2032.9 - 163 = 1869.9kJ/kg$$

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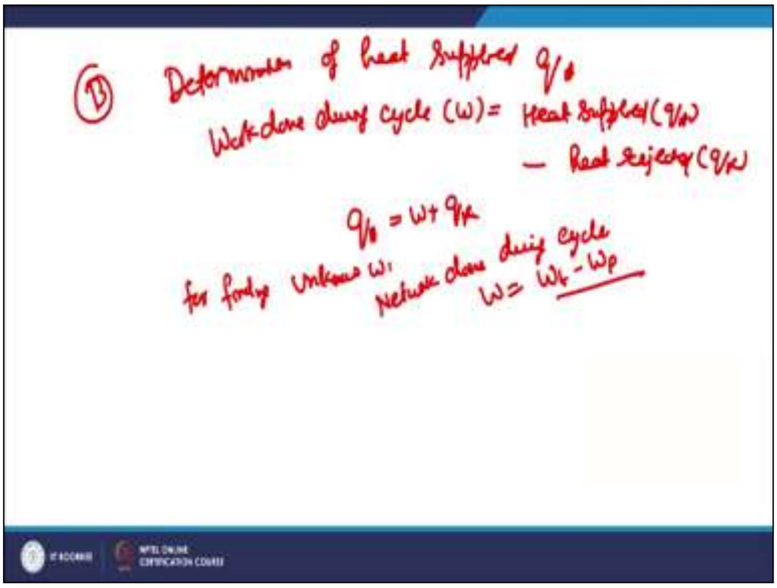

(B) Determination of heat supplied q_A

Work done during cycle $(W) =$ Heat supplied (q_A) $-$ Heat rejected (q_R)

$q_A = W + q_R$

for finding unknown W: Net work done during cycle $W = \underline{W_t - W_p}$

Now come to the next part of the problem, which is the determination of the heat supplied, q_A. Now for this we need to seek the help of mathematical relationship that is

$work\ done\ during\ cycle\ (W) = heat\ supplied\ (q_A) - heat\ rejected\ (q_R)$

or some other words

$$q_A = W + q_R$$

Now for finding the unknown w, net work done during cycle

$$W = W_t - W_p$$

So, again we need to find out the unknown W_t and W_p.

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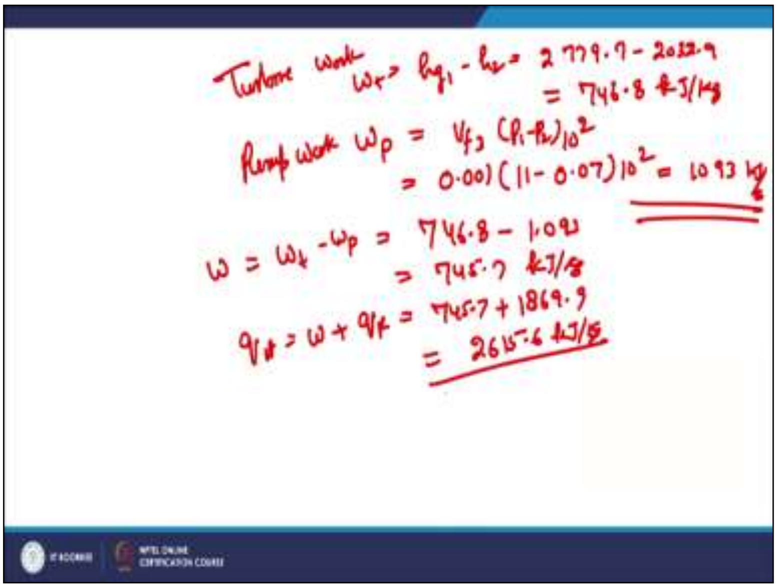

Turbine work $W_t = h_{g_1} - h_2 = 2779.7 - 2032.9$
$= 746.8$ kJ/kg

Pump work $W_p = v_{f_3}(P_1 - P_2)10^2$
$= 0.001(11 - 0.07)10^2 = 1.093$ kJ/kg

$W = W_t - W_p = 746.8 - 1.093$
$= 745.7$ kJ/kg

$q_A = W + q_R = 745.7 + 1869.9$
$= \underline{2615.6 \text{ kJ/kg}}$

So, turbine work work W_t is equal

$$W_t = h_{g1} - h_2 = 2779.7 - 2032.9 = 746.8\ kJ/kg$$

Similarly if you talk about the pump work W_p

$W_p = V_{f3}(P_1 - P_2)10^2 = 0.001(11 - 0.07)100 = 1.093\ kJ/kg$

W is equal to turbine work minus pump work and that is

$$W = 746.8 - 1.093 = 745.7\ kJ/kg$$

So,

$$q_A = 745.7 + 1869.9 = 2615.5\ kJ/kg$$

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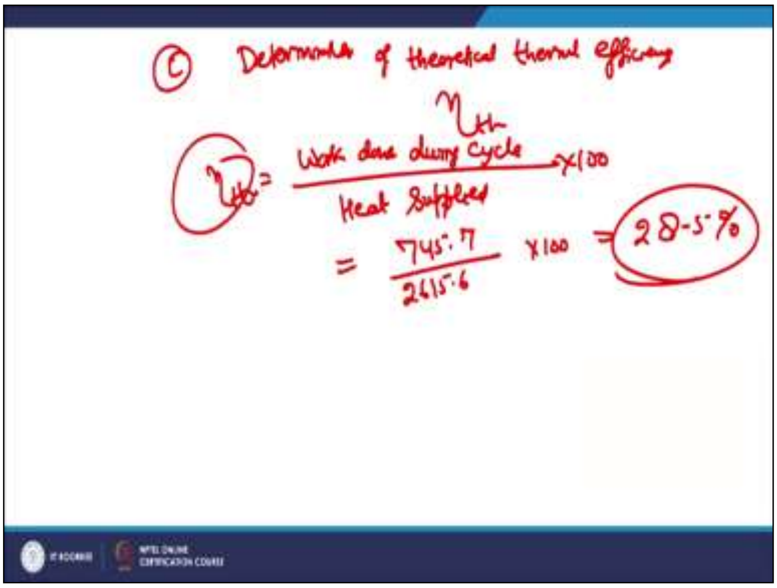

ⓒ Determination of theoretical thermal efficiency

η_{th}

$$\eta_{th} = \frac{\text{Work done during cycle}}{\text{Heat supplied}} \times 100$$

$$= \frac{745.7}{2615.6} \times 100 = 28.5\%$$

At last, that is the third point we are looking to determine theoretical thermal efficiency. Now this can be calculated by work done during cycle divided by heat supplied multiplied by one.

$$\eta_{th} = \frac{work\ done\ during\ cycle}{heat\ supplied} \times 100 = \frac{745.7}{2615.6} \times 100 = 28.5\%$$

So, this is the desired result we have calculated by this wave.

Now let us move to another problem.

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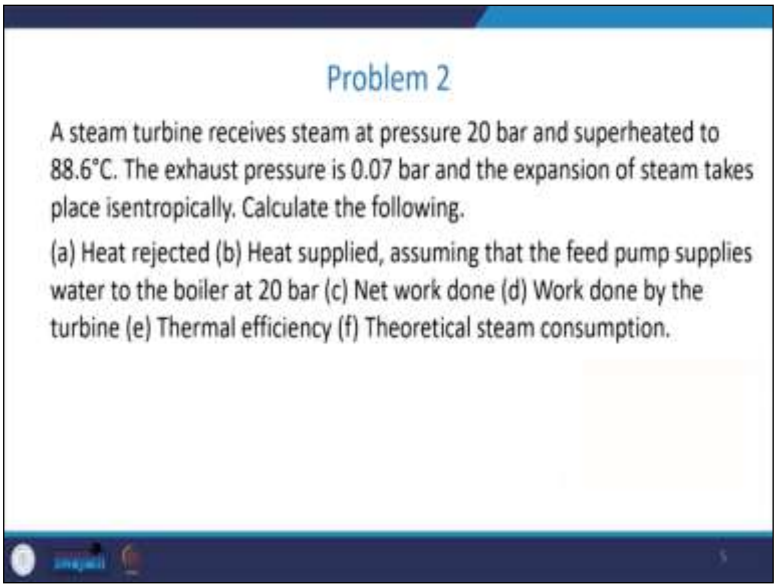

Problem 2

A steam turbine receives steam at pressure 20 bar and superheated to 88.6°C. The exhaust pressure is 0.07 bar and the expansion of steam takes place isentropically. Calculate the following.

(a) Heat rejected (b) Heat supplied, assuming that the feed pump supplies water to the boiler at 20 bar (c) Net work done (d) Work done by the turbine (e) Thermal efficiency (f) Theoretical steam consumption.

This problem suggests that a steam turbine receives steam at a pressure of 20 bar and is super heated to 88.6 degrees Celsius. The exhaust pressure is 0.07 bar, and steam expansion takes place isentropically. So, we need to calculate the heat rejected heat supplied. For this, we need to assume that the feed pump supplies the water to the boiler at 20 bar and we need to calculate the net work done by the turbine thermal efficiency and theoretical steam consumption.

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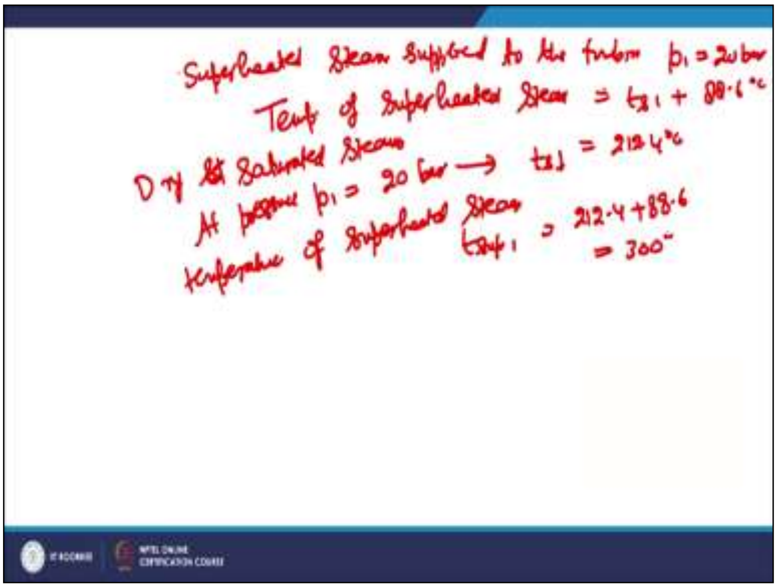

Superheated Steam Supplied to the turbine $p_1 = 20$ bar

Temp of Superheated Steam $= t_{s1} + 88.6$ °C

Dry ~~St~~ Saturated Steam

At pressure $p_1 = 20$ bar → $t_{s1} = 212.4$ °C

Temperature of Superheated Steam $t_{sup1} = 212.4 + 88.6 = 300°$

Now here, the superheated steam supplied to the turbine at pressure $P_1 = 20$ bar.

The temperature of superheated steam = $t_{s1} + 88.6$ degrees Celsius.

Now for this we need to seek the help of a steam table that is the dry saturated steam.

At pressure $P_1 = 20$ bar; $t_{s1} = 212.4$ degree Celsius.

So, therefore the temperature of superheated steam $= 212.4 + 88.6 = 300$ degree Celsius.

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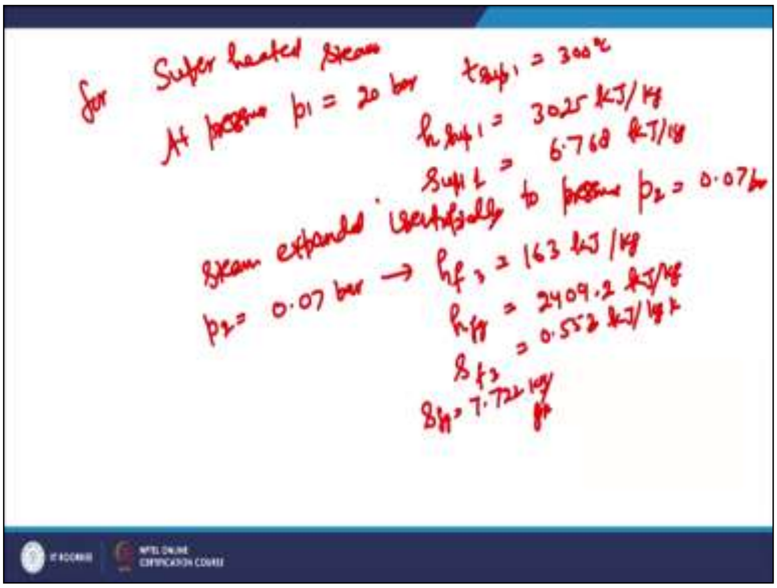

For Super heated steam

At pressure $p_1 = 20$ bar $t_{sup1} = 300°C$

$h_{sup1} = 3025$ kJ/kg

$s_{sup1} = 6.768$ kJ/kg

Steam expanded isentropically to pressure $p_2 = 0.07$ bar

$p_2 = 0.07$ bar $\rightarrow$ $h_{f3} = 163$ kJ/kg

$h_{fg} = 2409.2$ kJ/kg

$s_{f3} = 0.552$ kJ/kgK

$s_{fg} = 7.722$ kJ/kgK

For a superheated steam at pressure P_1 = 20 bar and we have find out the temperature t_{sup1} = 300 degree celsius.

So, enthalpy is equal to $h_{sup1} = 3025\ kJ/kg$

And entropy $s_{sup1} = 6.768 \frac{kJ}{kg}.K$

Now we have already given that steam expanded isentropically to pressure P2 = 0.07 bar. So, again we need to seek the help of steam table for the dry saturated steam.

So, at pressure P_2 = 0.07 bar;

the enthalpy $h_{f3} = 163\ kJ/kg$

$h_{fg} = \ 2\ 2409.2 \frac{kJ}{kg}$

Entropy $s_{f3} = 0.552 \frac{kj}{kg}.K$

$S_{fg} = 7.722 \frac{kJ}{kg}.K$

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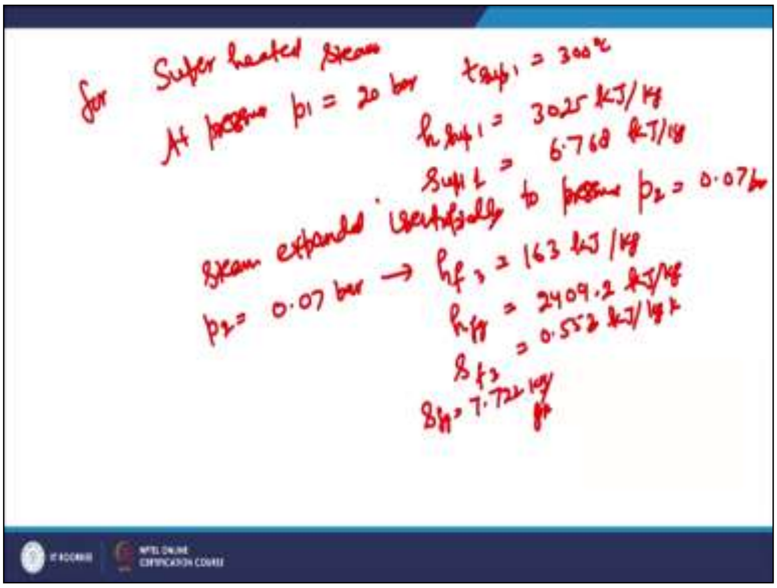

for Super heated steam

At pressure $p_1 = 20$ bar $t_{sup1} = 300°C$

$h_{sup1} = 3025$ kJ/kg

$s_{sup1} = 6.768$ kJ/kg

Steam expands isentropically to pressure $p_2 = 0.07$ bar

$p_2 = 0.07$ bar $\rightarrow$ $h_{f3} = 163$ kJ/kg

$h_{fg} = 2409.2$ kJ/kg

$s_{f3} = 0.552$ kJ/kgK

$s_{fg} = 7.722$ kJ/kgK

And V volume specific volume is equal to 0.001 meter cube per kilogram.

Now we are having the data with us.

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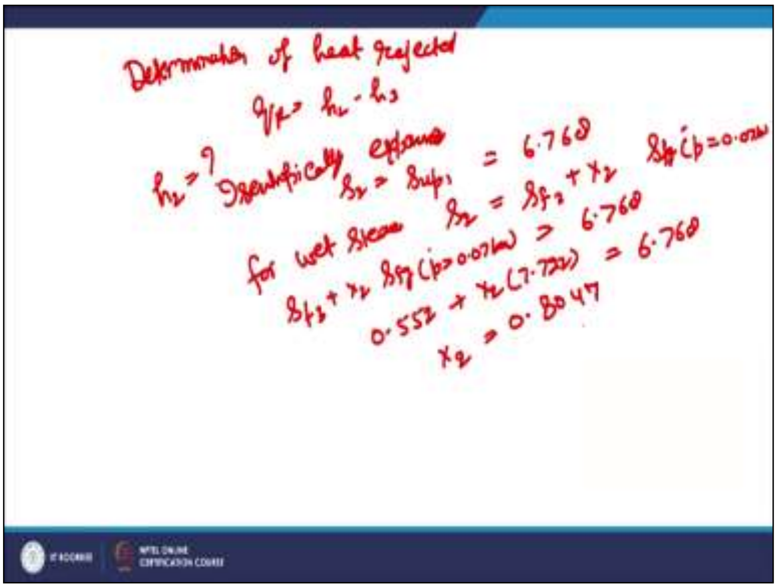

Determination of heat rejected

$q_R = h_2 - h_3$

$h_2 = ?$ Isentropically expans

$s_2 = s_{sup1} = 6.768$

for wet steam $s_2 = s_{f3} + x_2$ $s_{fg}(p = 0.07bar)$

$s_{f3} + x_2 s_{fg}(p = 0.07bar) = 6.768$

$0.552 + x_2(7.722) = 6.768$

$x_2 = 0.8047$

So, the determination of heat rejected

$q_R = h_2 - h_3$.

So, we need to find out the h_2.

So, isentropically expansion.

So, therefore $S_2 = S_1 = 6.768$.

Now for wet steam S_2 at 0.2, $S_2 = S_3$ + dryness friction S_{fg} (p = 0.07 bar) therefore

$$S_{f3} + X_2 S_{fg}(p = 0.07\ bar) = 6.768$$

$$0.552 + X_2 7.722 = 6.768$$

$$X_2 = 0.8047.$$

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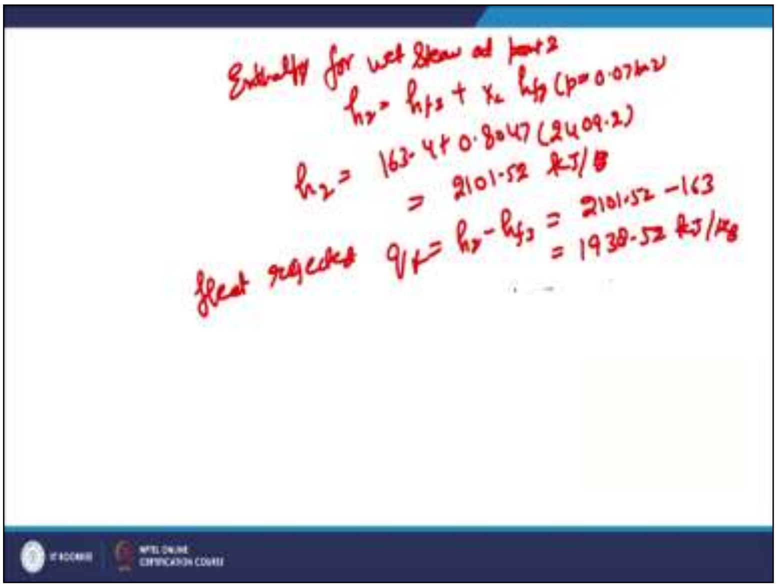

Enthalpy for wet steam at point 2

$h_2 = h_{f3} + x_2 h_{fg} (p = 0.07 bar)$

$h_2 = 163.4 + 0.8047 (2409.2)$

$= 2101.52$ kJ/kg

Heat rejected $q_r = h_2 - h_{f3} = 2101.52 - 163$

$= 1938.52$ kJ/kg

So, enthalpy for wet steam at point 2

$$h_2 = h_{f3} + X_2 h_{fg} (p = 0.07\ bar)$$

Now in this way we can calculate h 2

$$h_2 = 163.4 + 0.8047(2409.2) = 2101.52\ kJ/kg$$

So, heat rejected $q_R = h_2 - h_{f3} = 2101.52 - 163 = 1938.52\ kJ/kg$

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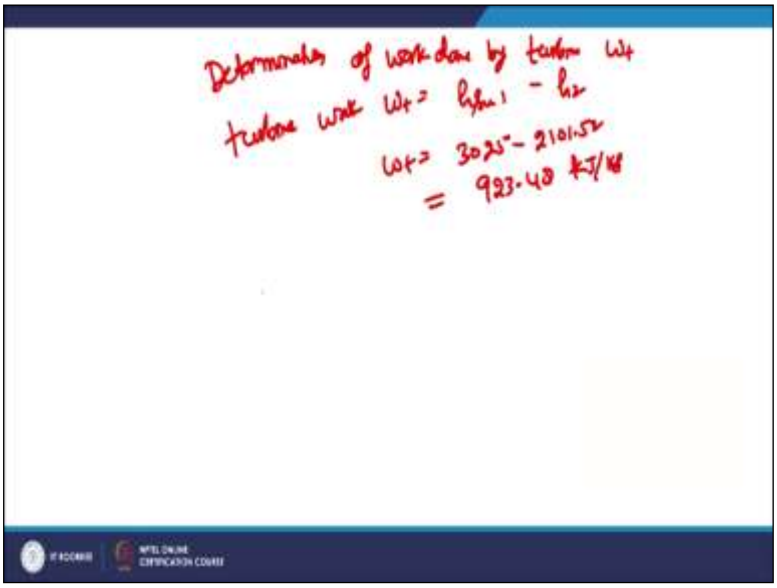

Determination of work done by turbine W_t

turbine work $W_t = h_{sup 1} - h_2$

$W_t = 3025 - 2101.52$

$= 923.48$ kJ/kg

Now another thing that is the determination of work done by turbine W_t.

So, turbine work is equal to superheated enthalpy at point number one minus enthalpy at point number 2

So this turbine work

$W_t = 3025 - 2101.52 = 823.48\ kJ/kg$

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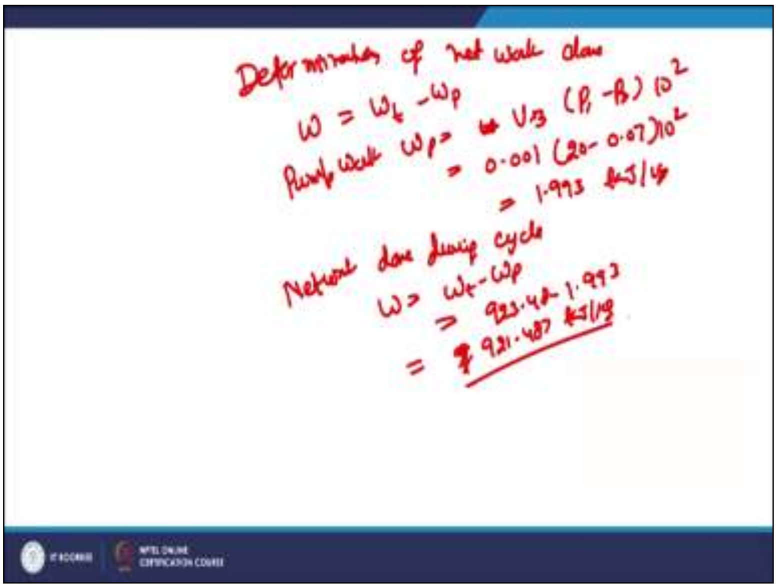

Determination of net work done

$W = W_t - W_p$

Pump work $W_p = V_{f3} (P_1 - P_2) 10^2$

$= 0.001 (20 - 0.07) 10^2$

$= 1.993\ kJ/kg$

Net work done during cycle

$W = W_t - W_p$

$= 923.48 - 1.993$

$= 921.487\ kJ/kg$

Now next step is the determination of net work done that is w. So, the net work done during the cycle can be given as w is equal to turbine work minus pump work.

Now since we do not have any clue about the w p that is the pump work. So, pump work

$$W_p = V_{f3}(P_1 - P_2)10^2 = 0.001(20 - 0.07)100 = 1.993\ kJ/kg$$

So, net work done during cycle

$$W = W_t - W_p = 923.48 - 1.993 = 921.487\ kJ/kg$$

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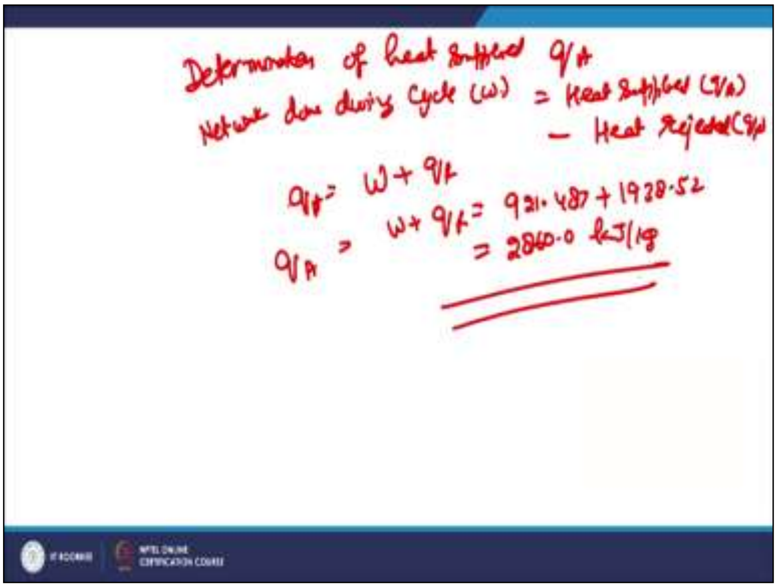

Determination of heat supplied q_A

Net work done during cycle (W) = Heat supplied (q_A) − Heat rejected (q_R)

$q_A = W + q_R$

$q_A = W + q_R = 921.487 + 1938.52$

$= 2860.0\ kJ/kg$

Now next determination of heat supplied that is sometimes referred as q A. So, it is given as net work done during cycle is equal to heat supplied q A minus heat rejected q R or q A is equal to w plus q R w we have already determined. So, q A is equal to w plus q R and that is 921.487 plus 1938.52 this is 2860.0 kilo joule per kilogram.

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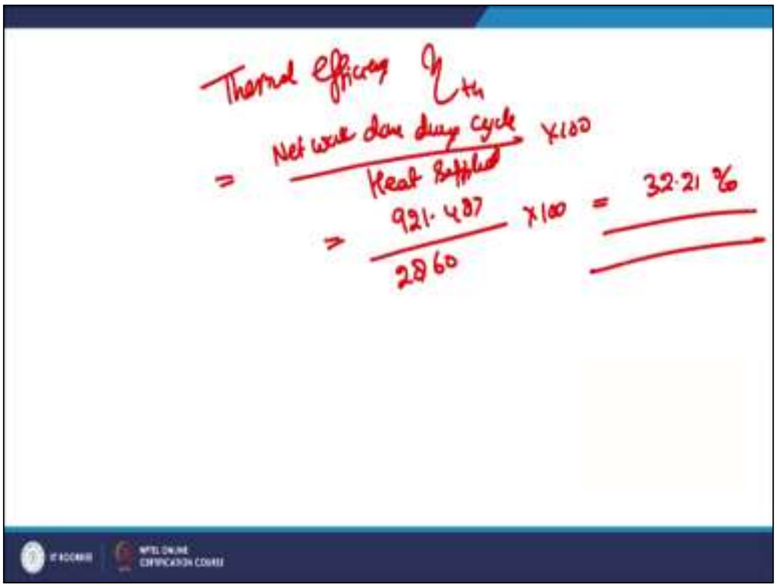

Thermal efficiency η_{th}

$$= \frac{\text{Net work done during cycle}}{\text{Heat supplied}} \times 100$$

$$= \frac{921.487}{2860} \times 100 = 32.21\ \%$$

Now let us talk about the thermal efficiency. Now this is equal to net work done during cycle divided by heat supplied multiplied by 100. So, we have already calculated the relevant information that is 921.487 divided by 2860 into 100 it comes out to be 32.21% this is the thermal efficiency of the system.

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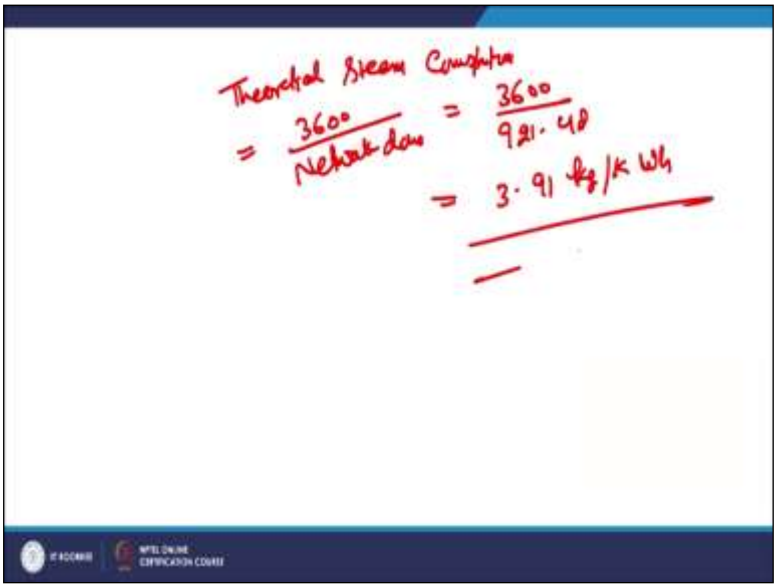

Theoretical Steam Consumption

$$= \frac{3600}{\text{Network done}} = \frac{3600}{921.48}$$

$$= 3.91\ \text{kg/kWh}$$

Now at last we can calculate the theoretical steam consumption. This is given by 3600 divided by net work done 3600 divided by 921 which we have already calculated this is given as 3.91 kilogram watt hour. So, this is the desired result.

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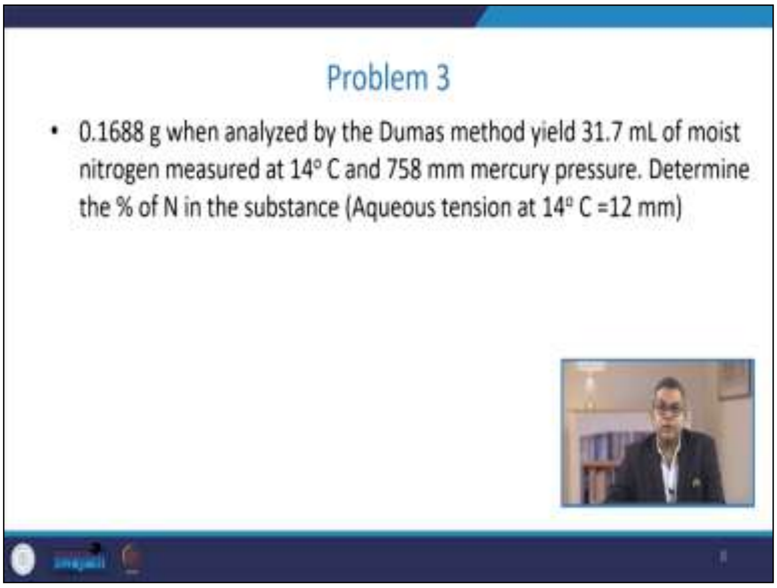

Problem 3

- 0.1688 g when analyzed by the Dumas method yield 31.7 mL of moist nitrogen measured at 14° C and 758 mm mercury pressure. Determine the % of N in the substance (Aqueous tension at 14° C =12 mm)

Now let us take another problem that is related to the Dumas method. So, 0.16 double eight gram when analyzed by the Dumas method yields 31.7 ml of moist nitrogen measured at 14 degree Celsius and 758 mm of mercury. Now you need to determine the percentage of nitrogen in the substance it is given that the aqueous tension at 14 degree Celsius equal to 12 millimeter.

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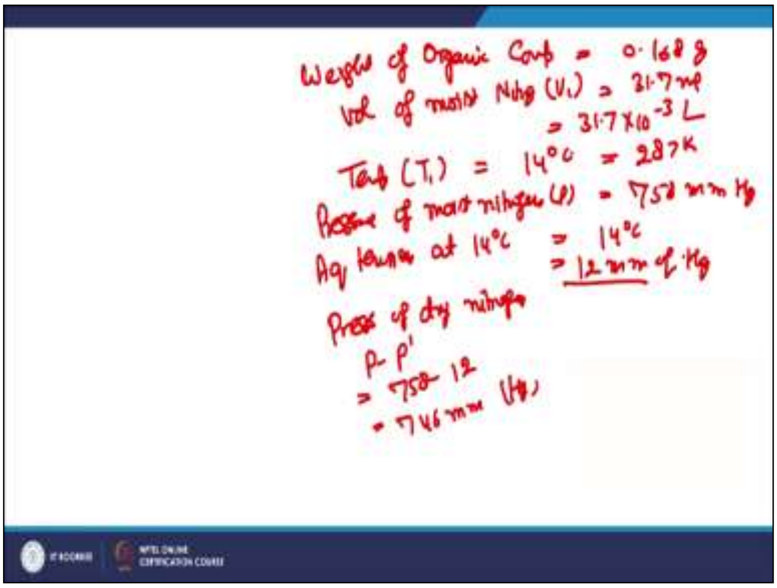

Weight of Organic Comp = 0.168 g
Vol of moist Nitg (V_1) = 31.7 ml
= 31.7×10^{-3} L
Temp (T_1) = 14°C = 287K
Pressure of moist nitrogen (P) = 758 mm Hg
Aq tension at 14°C = 14°C
= 12 mm of Hg
Press of dry nitrogen
P - P'
= 758 - 12
= 746 mm (Hg)

Now weight of let us solve this problem. Now it is weight of organic compound that is 0.168 gram volume of moist nitrogen v 1 is equal to 31.7 ml or 31.7 into 10 to the power minus 3 liter the temperature given is T 1 14 degree Celsius or 287 Kelvin. Now pressure of moist nitrogen p that is 758 mm of mercury, the pressure of moist nitrogen is 758 mm. Now aqueous tension at 14 degree Celsius is 12 mm of mercury this is given the problem.

So, the pressure of dry nitrogen that is p minus p 1 which is equal to 758 minus 12, 12 which this is given here and that is 746 millimeter of mercury.

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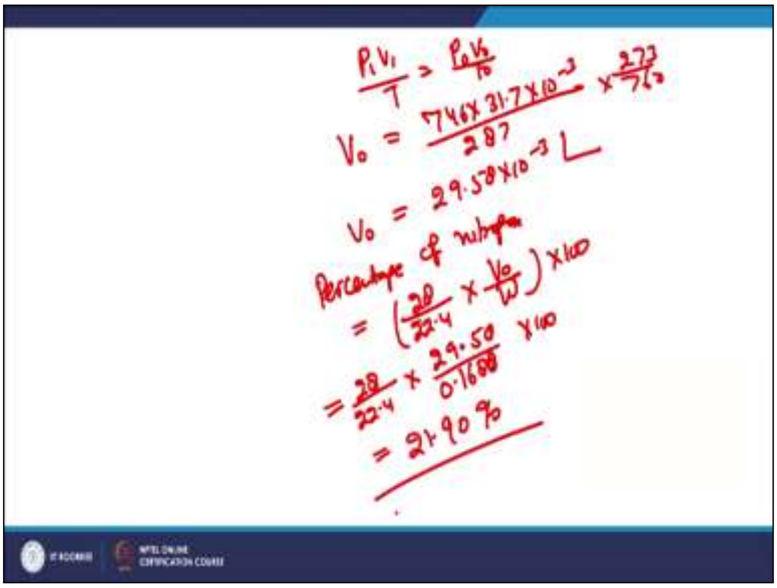

$$\frac{P_1V_1}{T} = \frac{P_0V_0}{T_0}$$

$$V_0 = \frac{746\times 31.7\times 10^{-3}}{287}\times\frac{273}{760}$$

$$V_0 = 29.58\times 10^{-3}\ L$$

Percentage of nitrogen

$$= \left(\frac{28}{22.4}\times\frac{V_0}{W}\right)\times 100$$

$$= \frac{28}{22.4}\times\frac{29.50}{0.1680}\times 100$$

$$= 21.90\%$$

Now let us take our bellowed formula P 1 V 1 upon T 1 is equal to P naught V naught upon T naught. So, need to calculate the V naught. So, 746 into 31.6 into 10 to the power minus 3 divided by 287 into 273 upon 760. So, V naught is equal to 29.58 into 10 to the power minus 3 liter. So, percentage of nitrogen is comes out to be 28 divided by 22.4 into V naught upon w into 100 and that is 28 upon 22.4 liter 29.58 divided by 0.168 into 100 and that comes out to be 21.90%. So, this is our desired result.

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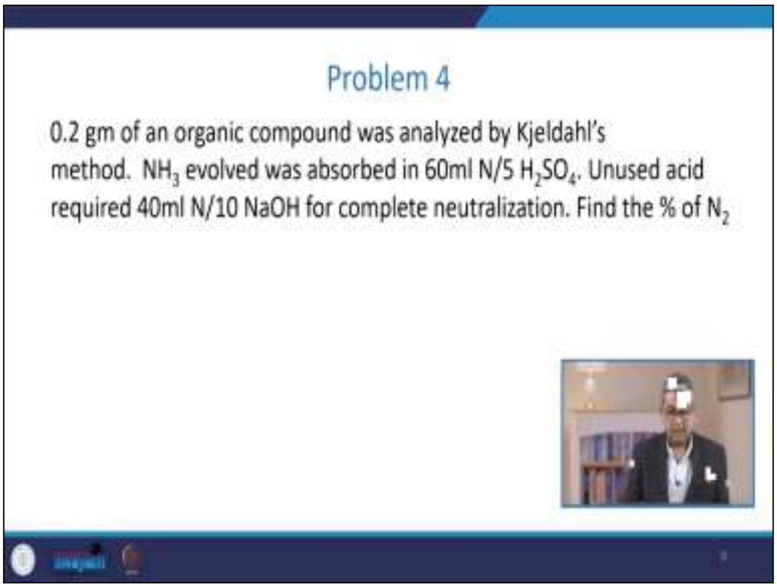

Problem 4

0.2 gm of an organic compound was analyzed by Kjeldahl's method. NH_3 evolved was absorbed in 60ml N/5 H_2SO_4. Unused acid required 40ml N/10 NaOH for complete neutralization. Find the % of N_2

Let us take the another problem in this problem that is a problem number four the point 2 gram of an organic compound was analyzed by Kjeldah's method. Ammonia evolved was absorbed in 60 ml n by 5 H 2 So 4 and unused acid this required 40 ml of n by 10 NAOH for complete neutralization. Now your objective is to find out the percentage of nitrogen.

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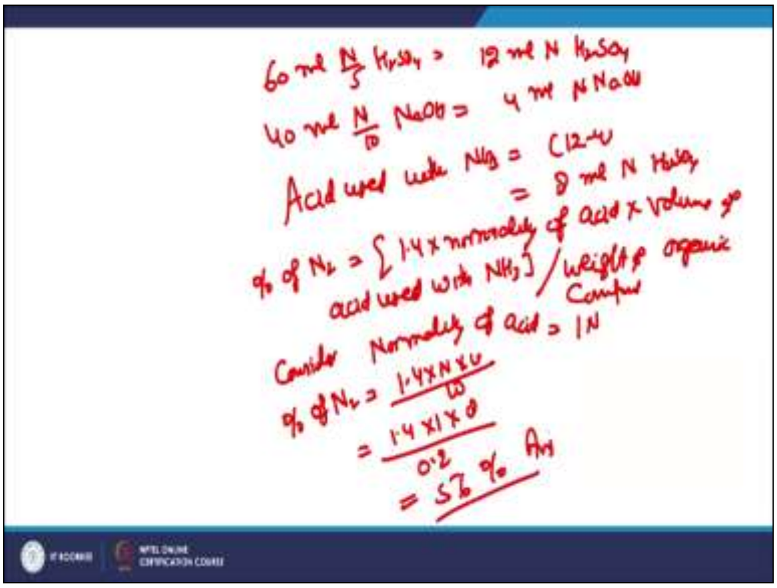

$60\text{ ml } \frac{N}{5} H_2SO_4 = 12 \text{ ml } N\ H_2SO_4$

$40\text{ ml } \frac{N}{10} NaOH = 4 \text{ ml } N\ NaOH$

Acid used with NH_3 = (12−4)

= 8 ml N H_2SO_4

% of N_2 = {1.4 × normality of acid × volume of acid used with NH_3} / weight of organic compound

Consider Normality of acid = 1N

$\% \text{ of } N_2 = \frac{1.4 \times N \times V}{W}$

$= \frac{1.4 \times 1 \times 8}{0.2}$

= 56 % Ans

Now here the 60 ml n by 5 H 2 SO 4 that is 12 ml if we convert this to H 2 SO 4 and 40 ml n by 10 NAOH equivalent to 4 ml and NAOH. Now acid used with ammonia that is 12 minus 4 or 8 ml normal H 2 SO 4. So, therefore the percentage of nitrogen is equal to 1.4 into normality of acid into volume of acid used with NH 3 divided by weight of organic compound. Now we can consider normality of acid 1N.

So the percentage of nitrogen is equal to 1.4 into N into V upon w and that is 1.4 into 1 into 8 divided by 0.2 and that comes out to be the 56% and that is the answer. So, in this particular segment we have carried out some sample example of the theory which we have carried out in the previous chapters. And I hope that all of you have gone through this the concept of ultimate and proximate analysis as well as the other concepts by this way thank you very much for paying attention.