Upstream LNG Technology
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Lecture – 76
Tutorial on refrigeration – III

Welcome, we have done some problems on the liquefaction and refrigeration. We shall be seeking some more problems in this particular lecture.

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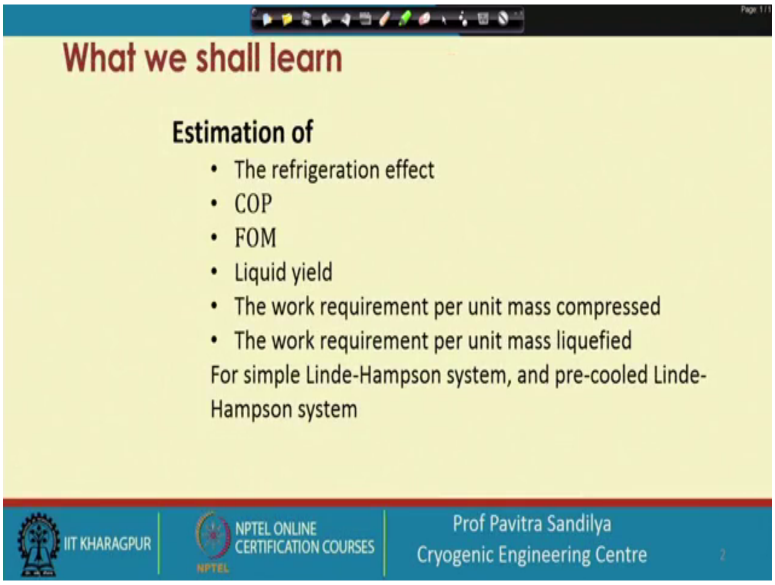

What we shall learn

Estimation of
- The refrigeration effect
- COP
- FOM
- Liquid yield
- The work requirement per unit mass compressed
- The work requirement per unit mass liquefied

For simple Linde-Hampson system, and pre-cooled Linde-Hampson system

So, in this lecture, we shall be looking into the estimation of the refrigeration effect, the COP that is the coefficient of performance, figure of merit, then liquid yield, the work requirement for simple Linde-Hampson system and pre-cooled Linde-Hampson system.

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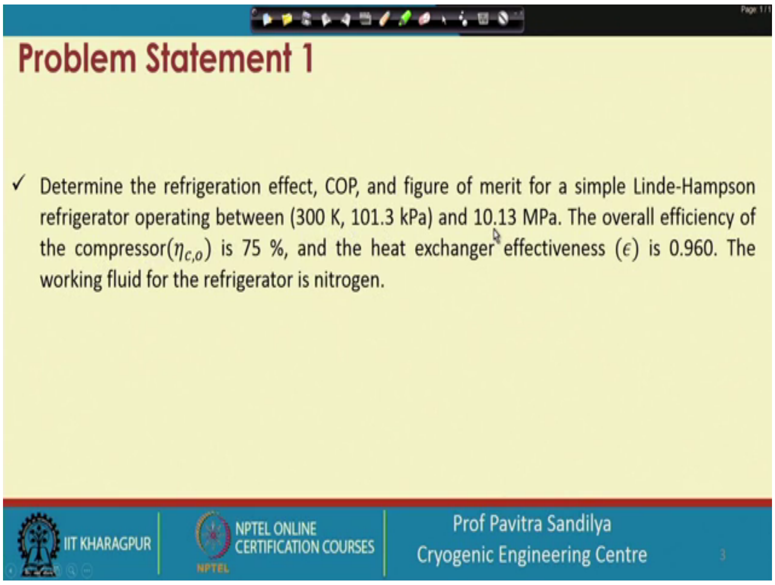

Problem Statement 1

- ✓ Determine the refrigeration effect, COP, and figure of merit for a simple Linde-Hampson refrigerator operating between (300 K, 101.3 kPa) and 10.13 MPa. The overall efficiency of the compressor($\eta_{c,o}$) is 75 %, and the heat exchanger effectiveness (ϵ) is 0.960. The working fluid for the refrigerator is nitrogen.

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So, first let us come to this problem. Here we have to determine the refrigeration effect, the coefficient of performance, the figure of merit for a simple Linde-Hampson refrigerator operating between this particular temperature pressure and compressed to this particular pressure. The overall efficiency is taken to be the 75 percent for the compressor, and the heat exchanger effectiveness is to be taken as this particular 0.96. Then the working fluid in this refrigerator is nitrogen. So, with this information, we have to find out the refrigeration effect the COP and the FOM.

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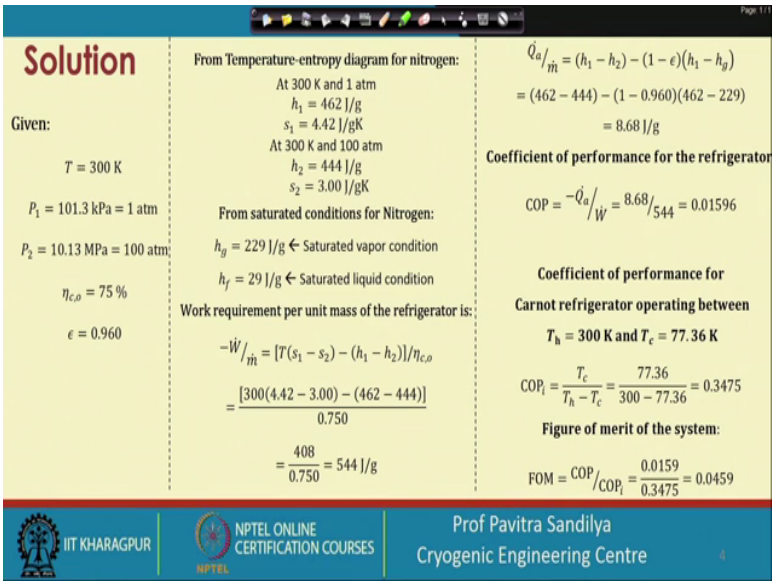

Solution

Given:

$T = 300$ K

$P_1 = 101.3$ kPa $= 1$ atm

$P_2 = 10.13$ MPa $= 100$ atm

$\eta_{c,o} = 75\,\%$

$\epsilon = 0.960$

From Temperature-entropy diagram for nitrogen:

At 300 K and 1 atm

$h_1 = 462$ J/g

$s_1 = 4.42$ J/gK

At 300 K and 100 atm

$h_2 = 444$ J/g

$s_2 = 3.00$ J/gK

From saturated conditions for Nitrogen:

$h_g = 229$ J/g ← Saturated vapor condition

$h_f = 29$ J/g ← Saturated liquid condition

Work requirement per unit mass of the refrigerator is:

$$-\dot{W}/\dot{m} = [T(s_1 - s_2) - (h_1 - h_2)]/\eta_{c,o}$$

$$= \frac{[300(4.42 - 3.00) - (462 - 444)]}{0.750}$$

$$= \frac{408}{0.750} = 544 \text{ J/g}$$

$$\dot{Q}_a/\dot{m} = (h_1 - h_2) - (1 - \epsilon)(h_1 - h_g)$$

$$= (462 - 444) - (1 - 0.960)(462 - 229)$$

$$= 8.68 \text{ J/g}$$

Coefficient of performance for the refrigerator

$$\text{COP} = {-\dot{Q}_a}/{\dot{W}} = {8.68}/{544} = 0.01596$$

Coefficient of performance for Carnot refrigerator operating between $T_h = 300$ K and $T_c = 77.36$ K

$$\text{COP}_i = \frac{T_c}{T_h - T_c} = \frac{77.36}{300 - 77.36} = 0.3475$$

Figure of merit of the system:

$$\text{FOM} = {\text{COP}}/{\text{COP}_i} = \frac{0.0159}{0.3475} = 0.0459$$

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So, first what we do that we write all the data given to us and in terms of the various notations the temperature is 300 Kelvin, and that is we are going for isothermal compression. So, this is the compressed from 1 atmosphere to about 100 atmosphere. And this is the overall compressor efficiency, and this is the heat exchanger effectiveness.

Now, we for these kind of problems, we have to take the help of the T s diagram. And in, in this case we shall choose the T s diagram of nitrogen; and from that we have learned earlier how to look at T s diagram and from there we can find out that what are there are enthalpy and entropy at the inlet and outlet of the compressor. So, these are the values we read out from the T s diagram.

And then we know that from the, because nitrogen is saturated after the isenthalpic expansion at theJT valve. So, we shall be getting the saturated nitrogen and saturated oxygen at 1 atmosphere. So, this is a, so there we are reading from the T s diagram, the values of the saturated vapor enthalpy and saturated liquid enthalpy g is for the vapor, and f is for the liquid.

So, from the expression we have derived earlier for the work per unit mass of the gas compressed. So, here we are writing the expression and we are plugging in the values of temperature entropies, enthalpies and the overall efficiency of the compressor. And we find that this is the work required for this a refrigerator.

And from now we come to this expression for the how much heat is absorbed, and this is the expression. And in this we have the heat exchanger efficiency. And we again plug in the values of the various variables, and we get this value this is the refrigeration effect that means, this particular gas under this particular situations will be taking out this much amount of energy from the space to be cooled.

Now, to find the coefficient of performance we know it is equal to what is equal to the amount that is heat absorbed and the work done on the system. So, we are again plugging in the values and we are finding the coefficient of performance coming to be this value.

And now to compare that how good or how bad it is what we do we compare it with the ideal value of the COP and that is for the Carnot refrigerator, and here we put these values of this COP ideal that is T c by T h minus T c, we put this valves and we find this is the value of the COP. And we can easily compare that the real refrigerator has much less COP than the ideal 1. And to assess further we find out the figure, figure of merit and we find the figure of merit is coming to a very, very low value this is about only 4.6 percent that means, it is a very, very it is not a very good refrigerator it is, because it is giving a very small value of the FOM.

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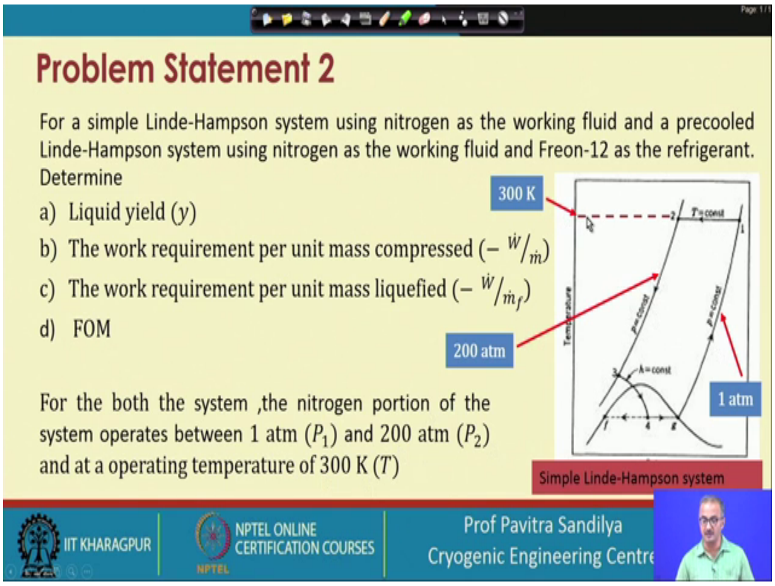

Problem Statement 2

For a simple Linde-Hampson system using nitrogen as the working fluid and a precooled Linde-Hampson system using nitrogen as the working fluid and Freon-12 as the refrigerant. Determine

a) Liquid yield (y)

b) The work requirement per unit mass compressed ($-\dot{W}/\dot{m}$)

c) The work requirement per unit mass liquefied ($-\dot{W}/\dot{m}_f$)

d) FOM

For the both the system ,the nitrogen portion of the system operates between 1 atm (P_1) and 200 atm (P_2) and at a operating temperature of 300 K (T)

Now, we come to the second question. In this question, we have been asked to come consider a symbol Linde-Hampson system using nitrogen as the working fluid. And also a pre-cooled Linde-Hampson system using the same nitrogen as the working fluid and Freon-12 as a refrigerant, because in the pre-coolant pre-cooling system, pre-cooled system we need a separate refrigeration circuit.

So, there that is why we are finding in the refrigerator refrigerant circuit system for this particular pre-cooled Linde-Hampson, we are using their Freon-12. And with this information, we have to determine the liquid yield the work requirement per unit mass of gas compressed and work requirement for the unit mass of the gas that is liquefied. So, these are the ones we have to find out and we have to also find out the figure of merit.

Now, here on in this particular diagram what we see we are showing the T s diagram for the simple Linde-Hampson which we saw earlier. So, here we are finding that that pressure is increasing at constant temperature and that constant pressure this is the cooling. And then at certain point we are making the isentropic expansion get evolve and we are getting the two phases and the vapor phase is taken back after heating to the inlet condition of the compressor at a constant pressure.

Now, as the problem these are the various values given to us, so it is from 1 atmosphere to 200 atmosphere it is being pressurized at 300 k. So, this is 300 k Kelvin line.

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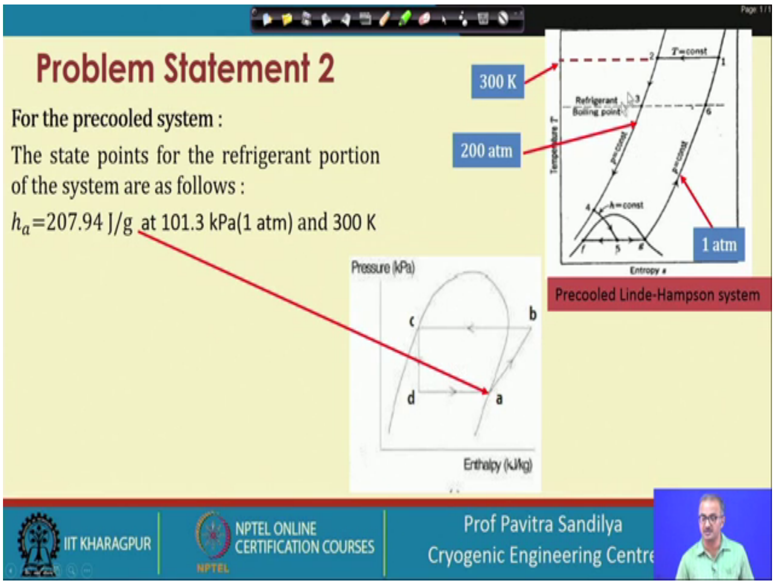

Problem Statement 2

For the precooled system :

The state points for the refrigerant portion of the system are as follows :

h_a=207.94 J/g at 101.3 kPa(1 atm) and 300 K

Precooled Linde-Hampson system

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And for the pre-cooled system what we have been given that we are asked that we are taking the Freon as the pre-coolant. And from for this system we have been given this is the, understand this is the actual refrigeration cycle and this is the pre-cooling cycle. So, first let us see in the actual 1 we have the 300 k same as earlier, and 200 atmosphere, this is 1 atmosphere and only thing modification is this. There is another thing; this is coming for the pre-coolant ok; this 3, 6 we showing the pre-coolant circuit.

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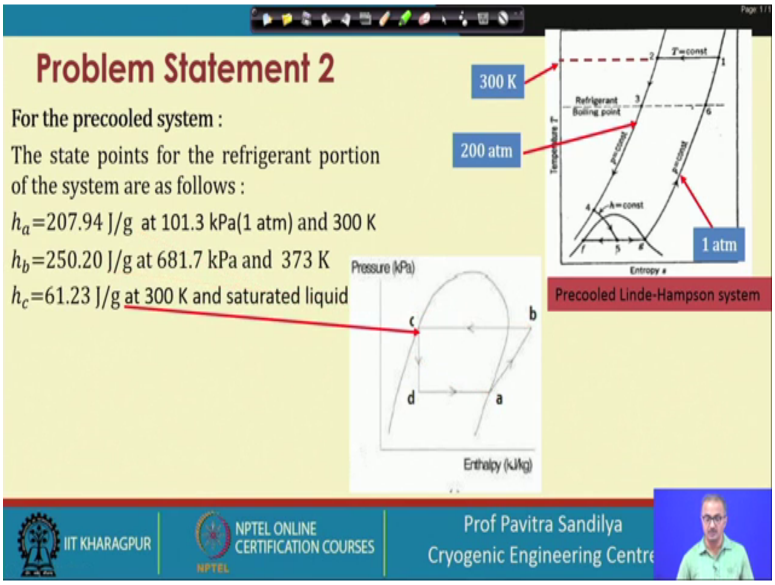

Problem Statement 2

For the precooled system :

The state points for the refrigerant portion of the system are as follows :

h_a=207.94 J/g at 101.3 kPa(1 atm) and 300 K

h_b=250.20 J/g at 681.7 kPa and 373 K

h_c=61.23 J/g at 300 K and saturated liquid

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Now, this is a pre-coolant heat exchanger and here we have been given all the values of this h a, h b and h c etcetera as per our earlier you can refer for this one.

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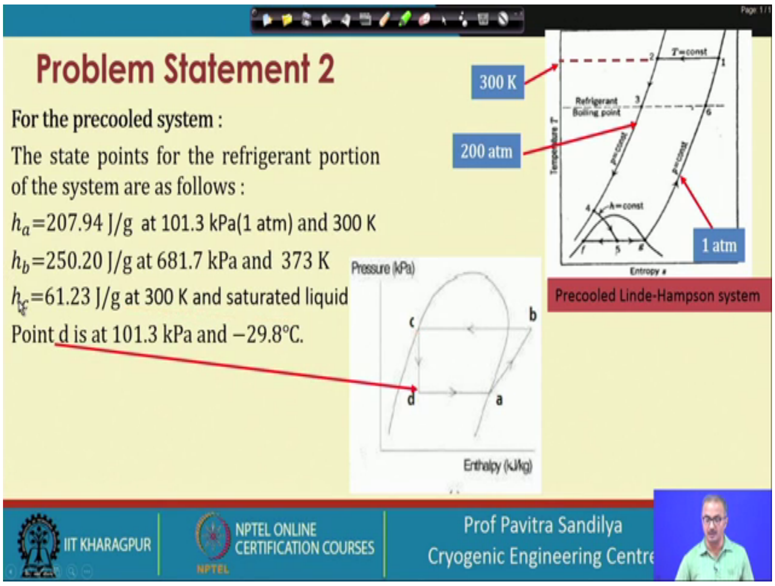

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h_c=61.23 J/g at 300 K and saturated liquid

Point d is at 101.3 kPa and −29.8°C.

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You can refer to the system we have shown in the lecture. So, there you can find out what is a, b, c, d. And you can also make out from here that what is a, b, c, d, from a you are isothermally compressing it. So, a must be this 0.21 all these things the similar kind of thing there for this my pre-coolant. So, you can see that if you can plot this one also in a T s diagram for the pre-coolant. Here we are showing on the pressure enthalpy diagram, but you can make a similar kind of diagram on this T s diagram also for the pre-coolant.

So the, this is please understand this, you can solve these problems by taking in consideration any of the thermodynamic phase diagram, it is not that you have to use T s diagram only. You can use any thermodynamic diagram only thing is this, if you choose one particular diagram you may find that the solution becomes easier, to do; otherwise there is no restriction that you have to use the T s diagram or P h diagram only to solve this kind of problems.

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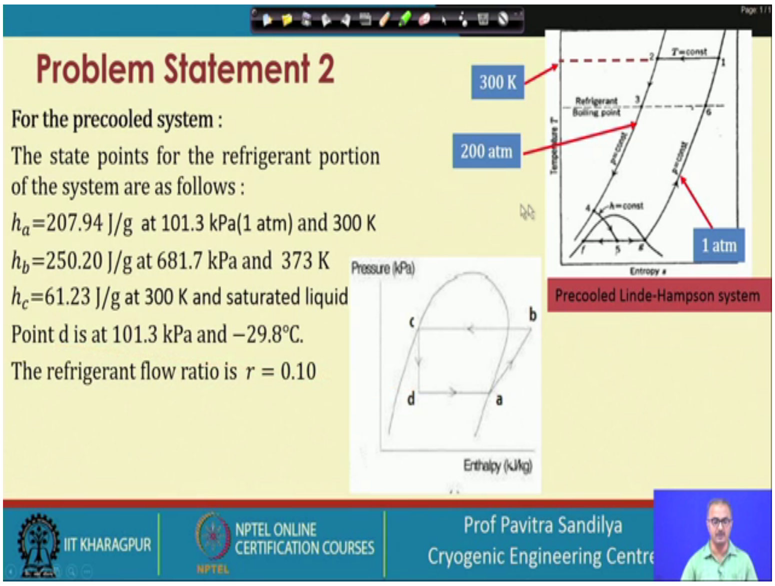

Problem Statement 2

For the precooled system :

The state points for the refrigerant portion of the system are as follows :

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h_b=250.20 J/g at 681.7 kPa and 373 K

h_c=61.23 J/g at 300 K and saturated liquid

Point d is at 101.3 kPa and −29.8°C.

The refrigerant flow ratio is $r = 0.10$

300 K

200 atm

1 atm

Precooled Linde-Hampson system

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And now we do, we find that this is the refrigeration of flow ratio which is given as 0.10, this is and this ratio means this is a ratio of the refrigerant flow rate to the flow rate of the gas in the actual nitrogen system. So, in this case, it is the ratio of the flow rate of the Freon to the flow rate of the nitrogen.

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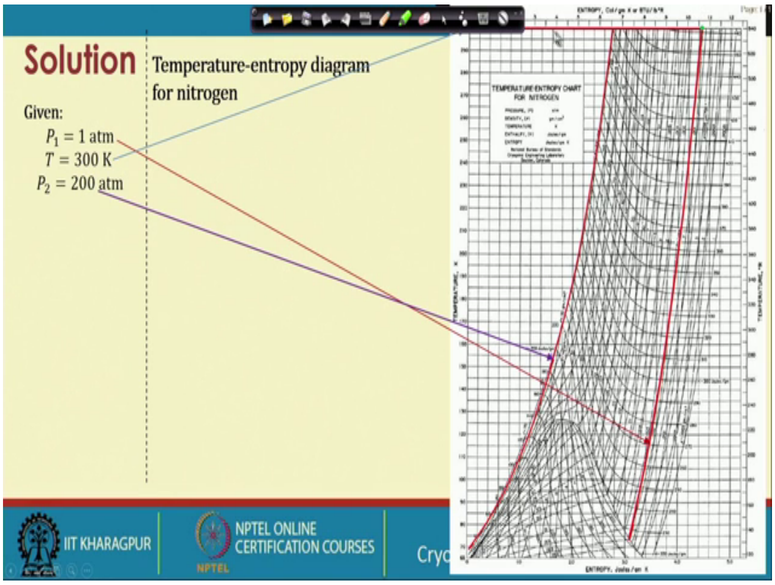

Solution

Given:

$P_1 = 1$ atm

$T = 300$ K

$P_2 = 200$ atm

Temperature-entropy diagram for nitrogen

Now, here first we see this T s diagram of nitrogen here, and here this diagram will be used to find out the various values of the enthalpy and entropies. So, here first we locate the 1 atmosphere line 300 k and then also the 200 atmosphere isobaric line. So, this is the 1 atmosphere isobaric line is the 200 atmosphere isobaric line and here we have the 300 Kelvin isothermal line ok.

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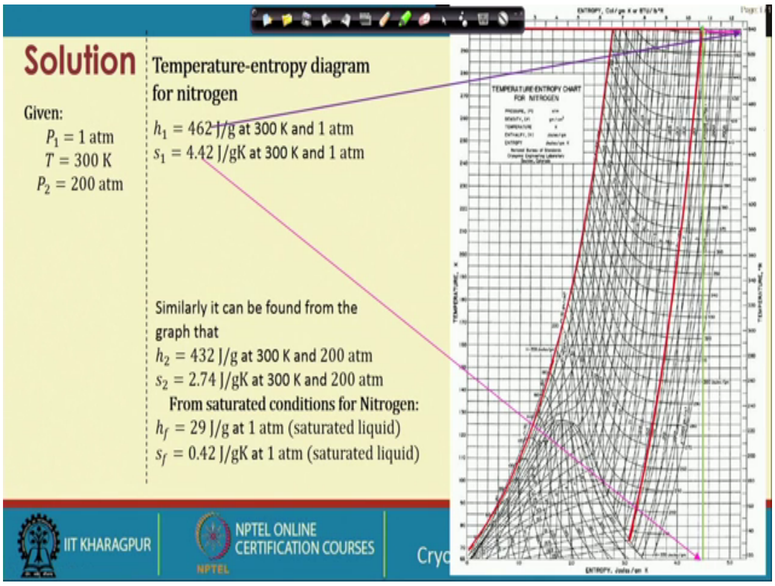

Solution

Given:

$P_1 = 1$ atm

$T = 300$ K

$P_2 = 200$ atm

Temperature-entropy diagram for nitrogen

$h_1 = 462$ J/g at 300 K and 1 atm

$s_1 = 4.42$ J/gK at 300 K and 1 atm

Similarly it can be found from the graph that

$h_2 = 432$ J/g at 300 K and 200 atm

$s_2 = 2.74$ J/gK at 300 K and 200 atm

From saturated conditions for Nitrogen:

$h_f = 29$ J/g at 1 atm (saturated liquid)

$s_f = 0.42$ J/gK at 1 atm (saturated liquid)

And at these points whatever they are intersecting we can now find out the value of the h 1 and the s 1, this s 1 is coming from the x-axis, and h 1 is coming from the value of this isenthalpic lines are there. So, wherever this line is there you can see from here top is very near to this axis. So, here somewhere here the isenthalpic line will come, so this isenthalpic value you have to take as the x 1 value. And here we can do the same exercise for the other h 2 s 2 for the 200 atmosphere also. So, once we do this with this a second with time we do with this particular isobaric curve.

So, now then also we find out the value of the h f s f that is the enthalpies of the saturated liquid. Now, here that is from this particular line here we find out this isenthalpic this isobaric line. So, wherever this is in the two phase zone this under dome we have the two phase zone. So, this particular value will be giving us the enthalpy of the saturated vapor and if you extend it on the other hand you will get the value of the enthalpy of the saturated liquid.

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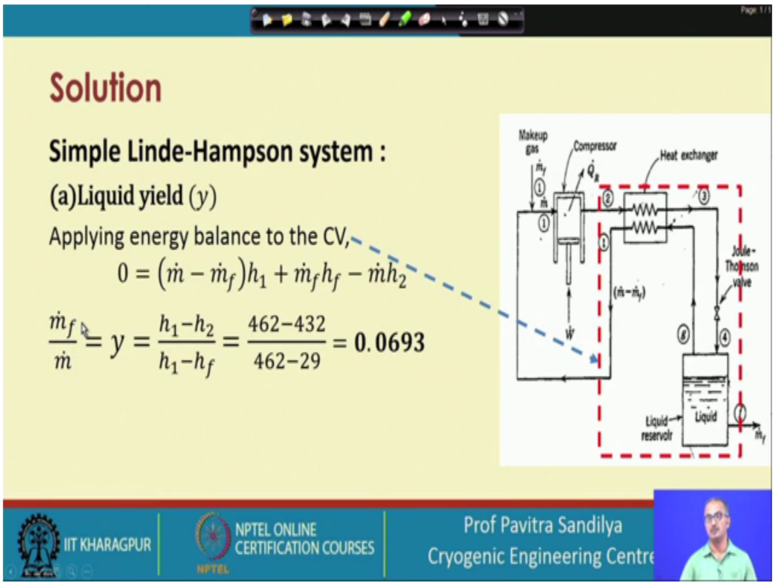

Solution

Simple Linde-Hampson system :

(a)Liquid yield (y)

Applying energy balance to the CV,

$$0 = (\dot{m} - \dot{m}_f)h_1 + \dot{m}_f h_f - \dot{m}h_2$$

$$\frac{\dot{m}_f}{\dot{m}} = y = \frac{h_1 - h_2}{h_1 - h_f} = \frac{462-432}{462-29} = \mathbf{0.0693}$$

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Now, this is now we go to the solution. So, till before this we just find out the values of the entropies and enthalpies which we shall required to find out the various parameters asked in the problem. So, we first go for the liquid yield. And for this we make an energy balance around this particular control volume which consists of the this liquid reservoir and the heat exchanger and the Joule-Thomson valve. And we find this is the energy balance at steady state and rearranging, we get this particular expression for the yield of the liquid in terms of the enthalpies. We plug in the values of enthalpies and we find this is the liquid yield that is about 6.9 percent; that means, the amount of; that means, out 6.9

percent of the total gas supplied is converted to liquid. So, it is a very, very small value ok.

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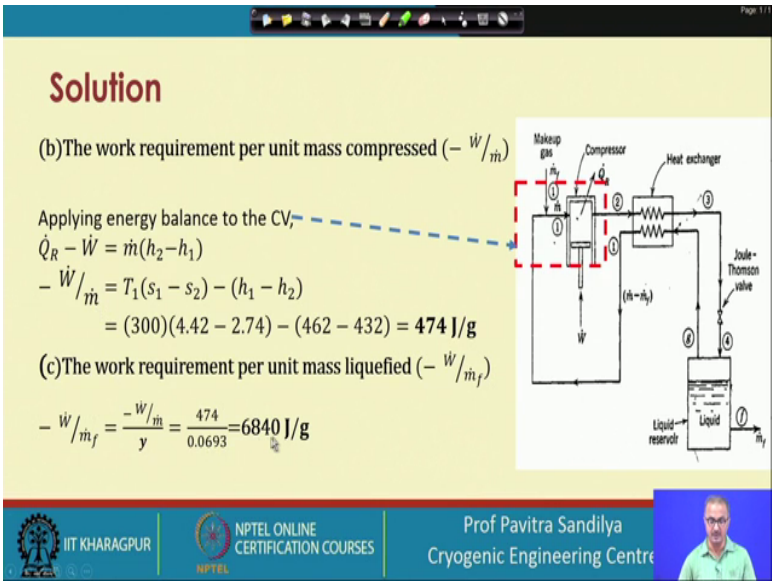

Solution

(b)The work requirement per unit mass compressed $(-\dot{W}/\dot{m})$

Applying energy balance to the CV,

$\dot{Q}_R - \dot{W} = \dot{m}(h_2 - h_1)$

$-\dot{W}/\dot{m} = T_1(s_1 - s_2) - (h_1 - h_2)$

$= (300)(4.42 - 2.74) - (462 - 432) = \mathbf{474\ J/g}$

(c)The work requirement per unit mass liquefied $(-\dot{W}/\dot{m}_f)$

$-\dot{W}/\dot{m}_f = \frac{-\dot{W}/\dot{m}}{y} = \frac{474}{0.0693} = 6840\ \text{J/g}$

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And now we go for the work requirement again work, because work is associated with the compressor only. So, we take the control volume to the compressor and not any, any other thing. Even you cans, if somebody wants to take the other things also into construction that is not going to give a different result, only thing you will find that you will get some other variables to be considered to find out the work done. So, you can this choice of the controls volume is arbitrary you can choose any control volume, but you have to be careful whenever you are writing all the balance or the conservation laws. So, for ease we are choosing only the compressor as the control volume.

Now, we see that this is the expression for the work. And we again plug in the values we find the value of the work done by the compressor. And this is the work done by the compressor per unit mass of the gas liquefied. This is for the, per unit mass total mass is compressed it is the only for the mass of the gas liquefied and we find these values. So, these are the two values we obtain.

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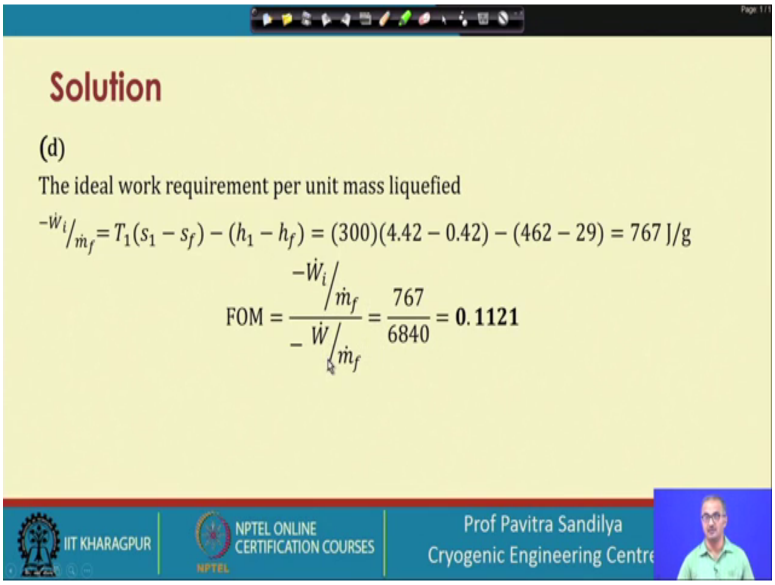

Solution

(d)

The ideal work requirement per unit mass liquefied

$-\dot{W}_i/\dot{m}_f = T_1(s_1 - s_f) - (h_1 - h_f) = (300)(4.42 - 0.42) - (462 - 29) = 767\ \text{J/g}$

$$\text{FOM} = \frac{-\dot{W}_i/\dot{m}_f}{-\dot{W}/\dot{m}_f} = \frac{767}{6840} = \mathbf{0.1121}$$

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And then now we want to go for the FOM. So, for FOM we need to know what is the ideal work. And for the ideal work, we find this particular expression. Again, this can be obtained easily from the thermodynamic energy balance, the first law and we find this is the ideal work. And then we take the ratio of the actual work to the sorry the ideal work to the actual work why because actual work will always be more than the ideal work. So, we choose this kind expression and we get this particular value of the FOM. So, it is not a very high FOM we are getting.

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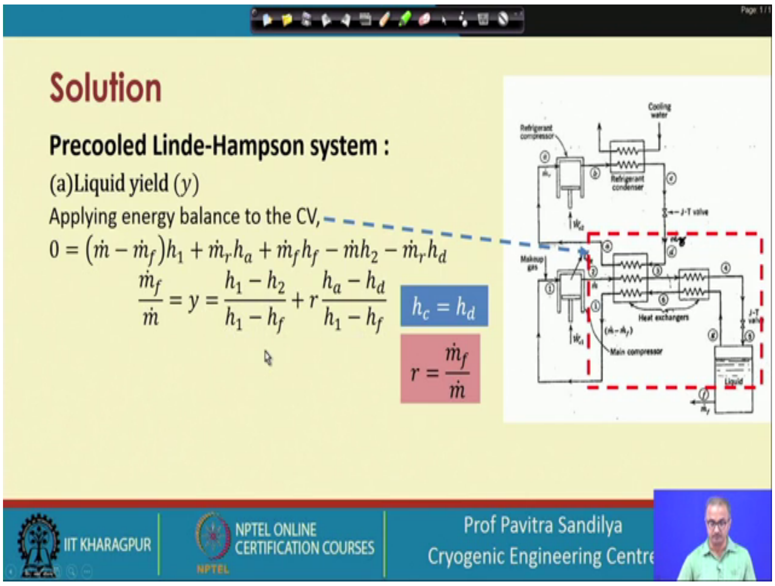

Solution

Precooled Linde-Hampson system :

(a)Liquid yield (y)

Applying energy balance to the CV,

$0 = (\dot{m} - \dot{m}_f)h_1 + \dot{m}_r h_a + \dot{m}_f h_f - \dot{m}h_2 - \dot{m}_r h_d$

$$\frac{\dot{m}_f}{\dot{m}} = y = \frac{h_1 - h_2}{h_1 - h_f} + r\frac{h_a - h_d}{h_1 - h_f}$$

$h_c = h_d$

$r = \dfrac{\dot{m}_r}{\dot{m}}$

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Now, for the pre-cooled Linde-Hampson, if this is the particular some system we are they are learned that here this is the Freon's system. So, this Freon system is pre-cooling this nitrogen system ok. So, this here we have this a, b, c, d; the we found those a, b, c, d and those corresponding enthalpy and entropy values. And now with those we find the expression from the first law of thermodynamics, we make an energy balance under in this particular control volume and we get this particular expression.

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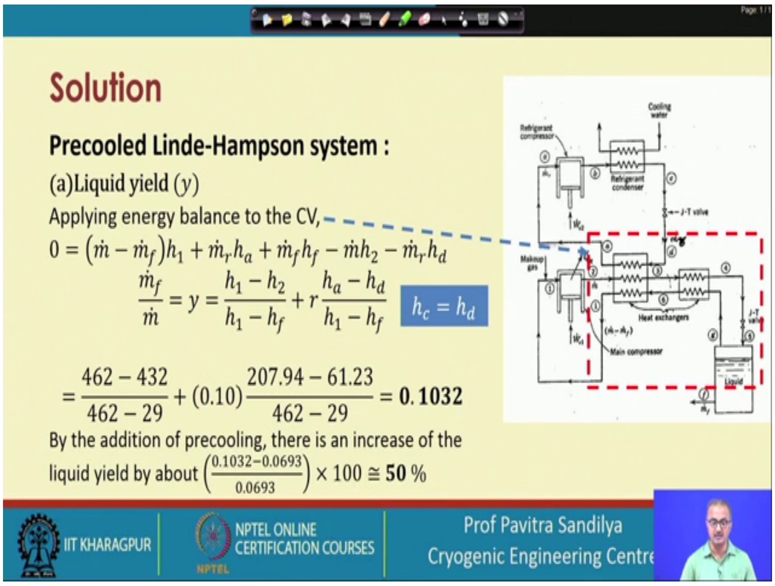

Solution

Precooled Linde-Hampson system :

(a)Liquid yield (y)

Applying energy balance to the CV,

$$0 = (\dot{m} - \dot{m}_f)h_1 + \dot{m}_r h_a + \dot{m}_f h_f - \dot{m} h_2 - \dot{m}_r h_d$$

$$\frac{\dot{m}_f}{\dot{m}} = y = \frac{h_1 - h_2}{h_1 - h_f} + r\frac{h_a - h_d}{h_1 - h_f}$$

$$h_c = h_d$$

$$= \frac{462 - 432}{462 - 29} + (0.10)\frac{207.94 - 61.23}{462 - 29} = \mathbf{0.1032}$$

By the addition of precooling, there is an increase of the liquid yield by about $\left(\frac{0.1032 - 0.0693}{0.0693}\right) \times 100 \cong \mathbf{50}\ \%$

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And here we see that h c and h d are same because there is a isenthalpic expansion, this is h c this is h d and they are same, because the isentropic expansion. And we plug in the values and we find that the, this amount of the liquid yield. And we what we find that now the liquid yield has increased from a value of about 6 percent to about 10 percent, so that is the advantage of having pre-cooling in the Linde-Hampson cycle.

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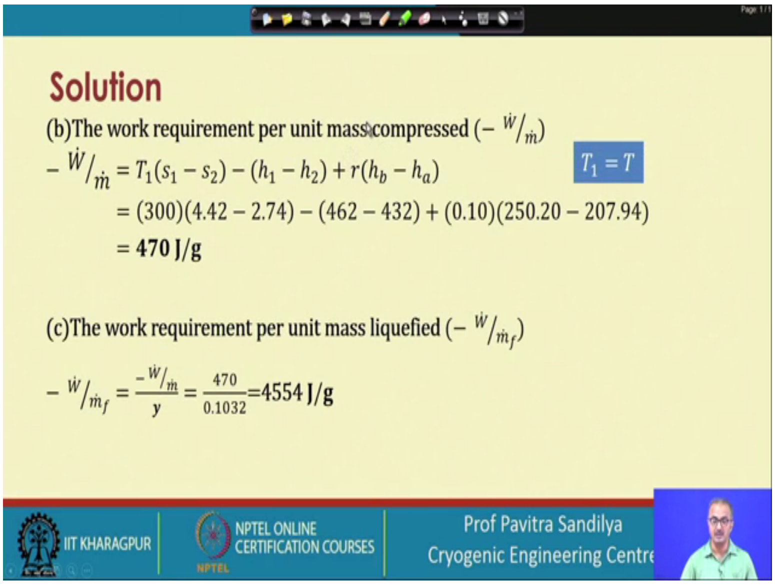

Solution

(b)The work requirement per unit mass compressed $(-\dot{W}/\dot{m})$

$\boxed{T_1 = T}$

$$-\dot{W}/\dot{m} = T_1(s_1 - s_2) - (h_1 - h_2) + r(h_b - h_a)$$
$$= (300)(4.42 - 2.74) - (462 - 432) + (0.10)(250.20 - 207.94)$$
$$= \mathbf{470\ J/g}$$

(c)The work requirement per unit mass liquefied $(-\dot{W}/\dot{m}_f)$

$$-\dot{W}/\dot{m}_f = \frac{-\dot{W}/\dot{m}}{y} = \frac{470}{0.1032} = 4554\ \mathbf{J/g}$$

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Now, you see that let us see that we are getting this 50 percent increase. And now, so let us look at the work done. So, we this is the expression for the work done. And what we find this is the work done for the unit mass of the gas compressed, and this is the work done per unit mass of the gas liquefied.

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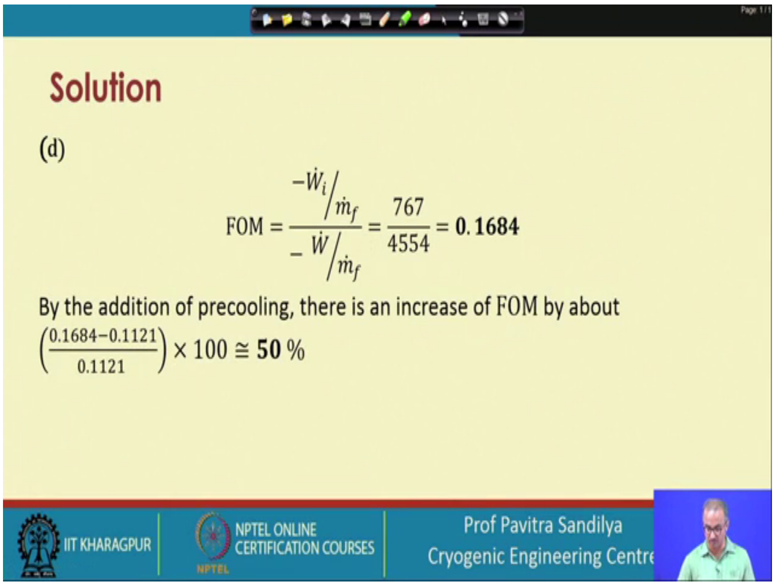

Solution

(d)

$$\text{FOM} = \frac{-\dot{W}_i/\dot{m}_f}{-\dot{W}/\dot{m}_f} = \frac{767}{4554} = \mathbf{0.1684}$$

By the addition of precooling, there is an increase of FOM by about

$$\left(\frac{0.1684 - 0.1121}{0.1121}\right) \times 100 \cong \mathbf{50}\ \%$$

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Again, if we find this FOM, we find the FOM has now increased to about 16 percent. And this is the increase in the FOM due to this pre-cooling.

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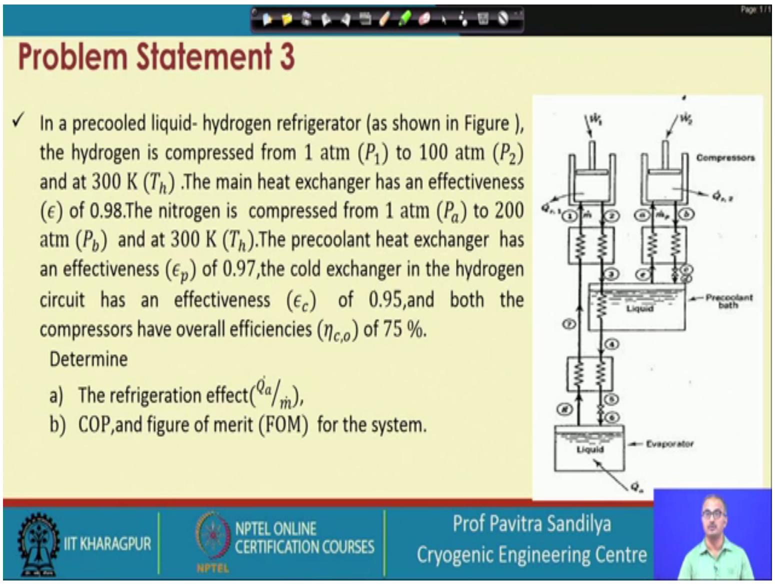

Problem Statement 3

- ✓ In a precooled liquid- hydrogen refrigerator (as shown in Figure), the hydrogen is compressed from 1 atm (P_1) to 100 atm (P_2) and at 300 K (T_h) .The main heat exchanger has an effectiveness (ϵ) of 0.98.The nitrogen is compressed from 1 atm (P_a) to 200 atm (P_b) and at 300 K (T_h).The precoolant heat exchanger has an effectiveness (ϵ_p) of 0.97,the cold exchanger in the hydrogen circuit has an effectiveness (ϵ_c) of 0.95,and both the compressors have overall efficiencies ($\eta_{c,o}$) of 75 %.

Determine

a) The refrigeration effect($\dot{Q}_a/\dot{m}$),
b) COP,and figure of merit (FOM) for the system.

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Now, we come to the next part in the next part what we find that the pre-cooled liquid hydrogen refrigerator we have. And here we have been given the inlet pressure as 1 atmosphere the outlet pressure at the compressor to be the 100 atmosphere at 300 k, and we are assuming that the compressor is isothermal. Then the mean heat exchanger effectiveness is about this. The nitrogen is compressed from 1 atmosphere 200 atmosphere at 300 k the pre coolant heat exchanger has an effectiveness this much. And the cold heat exchanger in the hydrogen circuits and if it we know this much. And both the compressors have overall efficiencies of the 75 percent. And we have determined the refrigeration effect and the COP and figure of merit for the system.

Now, here you see this representation that this is the mains main system and this main system is being pre-cooled by this particular auxiliary system. So, we again, because it is again we are going for this T s diagram and we will find the values of this various pressure and enthalpies and entropies and as earlier. So, here we have all these values from here.

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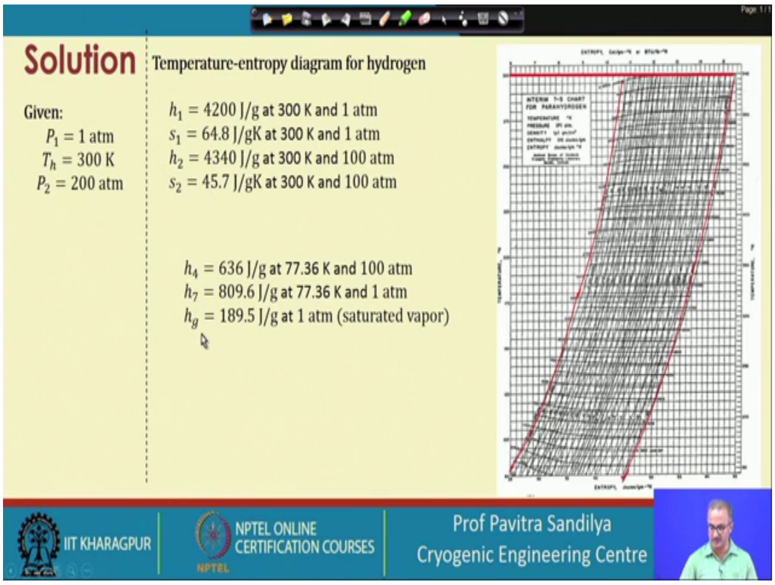

Solution

Temperature-entropy diagram for hydrogen

Given:
$P_1 = 1$ atm
$T_h = 300$ K
$P_2 = 200$ atm

$h_1 = 4200$ J/g at 300 K and 1 atm
$s_1 = 64.8$ J/gK at 300 K and 1 atm
$h_2 = 4340$ J/g at 300 K and 100 atm
$s_2 = 45.7$ J/gK at 300 K and 100 atm

$h_4 = 636$ J/g at 77.36 K and 100 atm
$h_7 = 809.6$ J/g at 77.36 K and 1 atm
$h_g = 189.5$ J/g at 1 atm (saturated vapor)

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So, it is I am not going skipping it, I am going fast, because we know already how to do this. And now we are considering the temperature enthalpy entropy diagram for the hydrogen. So, earlier we did it for nitrogen, now we are going to the hydrogen. And here we are choosing the para hydrogen as, we learned earlier why para hydrogen not ortho hydrogen, because we learned earlier that, whenever we are storing hydrogen. We start we do this ortho para conversion earlier, because otherwise what happens with ortho to para being exothermic, it will release energy and it will revaporize the liquid hydrogen.

And, so we first convert the ortho to para hydrogen. And then store it so that in with this logic what we are doing we are considering the enthalpy or the thermodynamic diagram for the para hydrogen and not the ortho hydrogen. So, we locate all the values of the pressure temperature and we get these values of the enthalpies and entropies.

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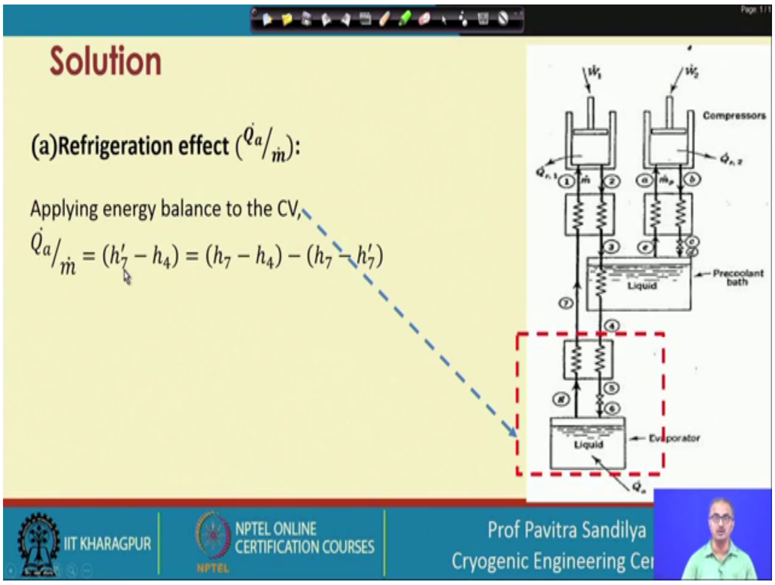

Solution

(a)Refrigeration effect $(\dot{Q}_a/\dot{m})$:

Applying energy balance to the CV,

$$\dot{Q}_a/\dot{m} = (h_7' - h_4) = (h_7 - h_4) - (h_7 - h_7')$$

Now, going for the refrigeration effect; so, here we have the refrigeration effect. So, this Q a is this is expression and this is the h s h 7 prime represents the actual enthalpy due to the in effectiveness of the heat exchanger.

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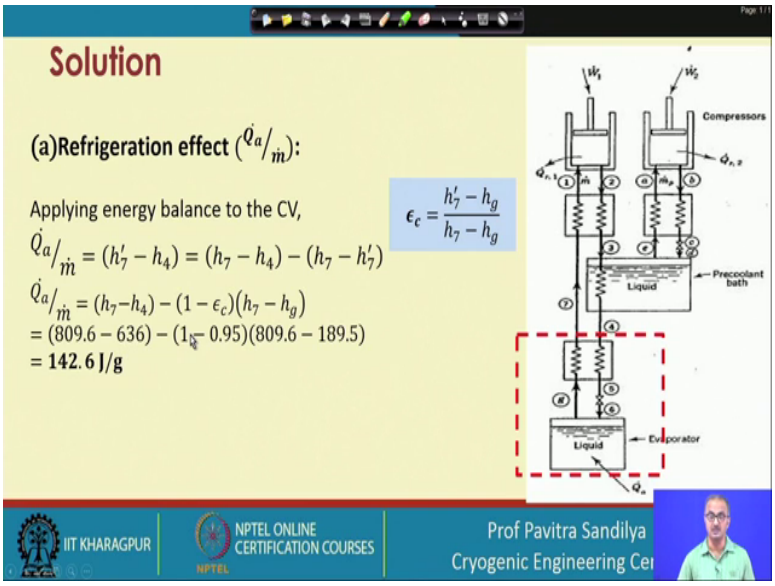

Solution

(a)Refrigeration effect $(\dot{Q}_a/\dot{m})$:

Applying energy balance to the CV,

$$\dot{Q}_a/\dot{m} = (h_7' - h_4) = (h_7 - h_4) - (h_7 - h_7')$$

$$\dot{Q}_a/\dot{m} = (h_7 - h_4) - (1 - \epsilon_c)(h_7 - h_g)$$

$$= (809.6 - 636) - (1 - 0.95)(809.6 - 189.5)$$

$$= \mathbf{142.6\ J/g}$$

$$\epsilon_c = \frac{h_7' - h_g}{h_7 - h_g}$$

So, here we are finding this particular thing. This is the expression, we are getting from the in by considering the effectiveness. And here we find that this is the value of the of the heat effect that is that this, this much of the energy will be taken up from the refrigerated space by the liquid. And here we find also due to the ineffectiveness, this amount of heat is coming down. And you can see very easily, if this is 100 percent effective that is this epsilon c is 1 then we find that this expression will not be there. So, this value this evaporation effect will be increasing this; so, this cooling effective decreasing because of the ineffectiveness of the heat exchanger.

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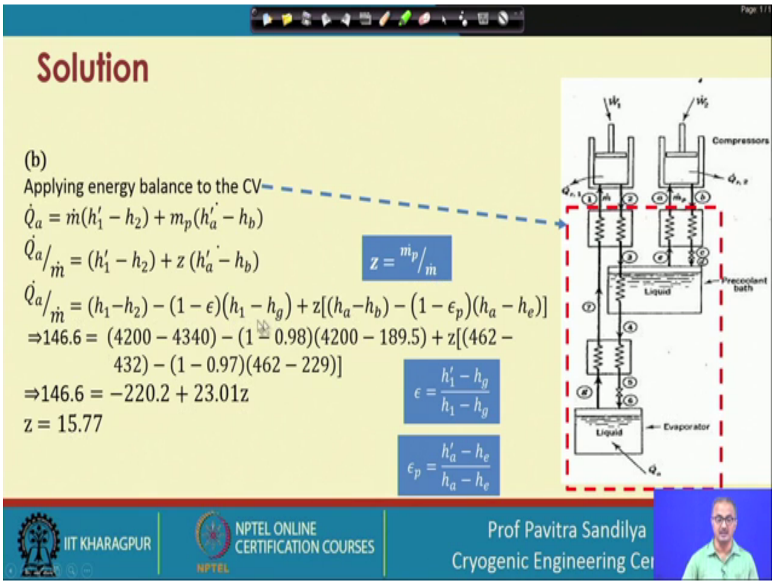

Solution

(b)

Applying energy balance to the CV

$\dot{Q}_a = \dot{m}(h_1' - h_2) + m_p(h_a^{'} - h_b)$

$\dot{Q}_a/_{\dot{m}} = (h_1' - h_2) + z\,(h_a^{'} - h_b)$

$z = {}^{\dot{m}_p}/_{\dot{m}}$

$\dot{Q}_a/_{\dot{m}} = (h_1 - h_2) - (1-\epsilon)(h_1 - h_g) + z[(h_a - h_b) - (1-\epsilon_p)(h_a - h_e)]$

$\Rightarrow 146.6 = (4200 - 4340) - (1 - 0.98)(4200 - 189.5) + z[(462 - 432) - (1 - 0.97)(462 - 229)]$

$\epsilon = \dfrac{h_1' - h_g}{h_1 - h_g}$

$\Rightarrow 146.6 = -220.2 + 23.01z$

$z = 15.77$

$\epsilon_p = \dfrac{h_a' - h_e}{h_a - h_e}$

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Now, for to find out this for the next problem this how much heat has been derived taken off. So, we are considering this with a pre-cooling system, if you are doing a pre cooling system, so we are finding this is the expression for the heat to be absorbed. And again here we are finding this h 1 prime and h a prime these are representing the actual enthalpies. And again this is coming due to the ineffectiveness. So, we are so that means, we are considering the ineffectiveness of all the three heat exchangers 1, 2, 3. So, we are considering all the heat exchangers, how this thing is effect affecting the heat to be taken up by this is a particular refrigerant.

So, after this we find that again we can see it here easily that if this epsilon and this epsilon p r 1, then we find that this amount of heat that can be absorbed will increase. So, because of the ineffectiveness of the heat exchanger, the amount of heat to be absorbed is not is decreasing. So, just we are plugging in the values and we find this is the value of the z. So, this z is nothing but this m p by m dot that is the ratio of the pre-coolant flow rate to the flow rate of the actual process gas. So, this is the value of this z, we are obtaining after plugging in the values of the various enthalpies and the heat exchanger effectiveness.

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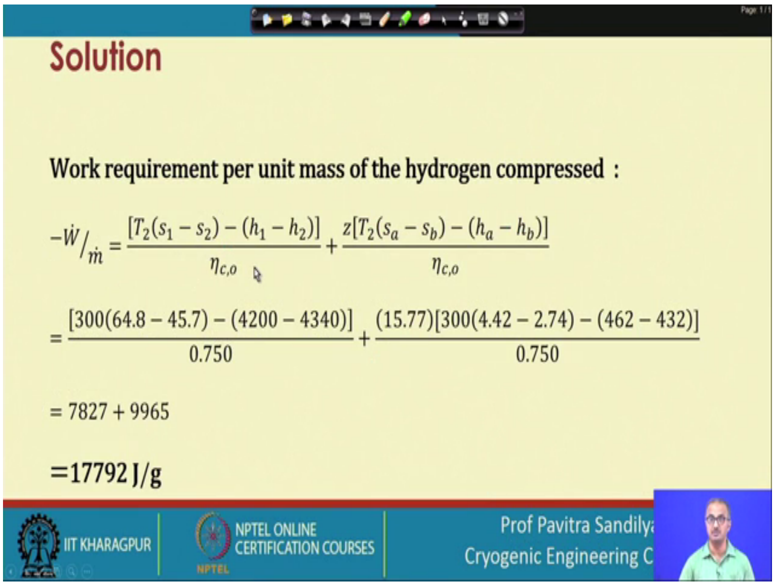

Solution

Work requirement per unit mass of the hydrogen compressed :

$$-\dot{W}/\dot{m} = \frac{[T_2(s_1 - s_2) - (h_1 - h_2)]}{\eta_{c,o}} + \frac{z[T_2(s_a - s_b) - (h_a - h_b)]}{\eta_{c,o}}$$

$$= \frac{[300(64.8 - 45.7) - (4200 - 4340)]}{0.750} + \frac{(15.77)[300(4.42 - 2.74) - (462 - 432)]}{0.750}$$

$$= 7827 + 9965$$

$$\mathbf{= 17792\ J/g}$$

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Work requirement is now simple. We are just considering the two systems because total work will be for the actual system as well as for the auxiliary system. So, we have to consider both these systems. And looking into taking to account there are compressor efficiencies we are finding this is the amount of work done.

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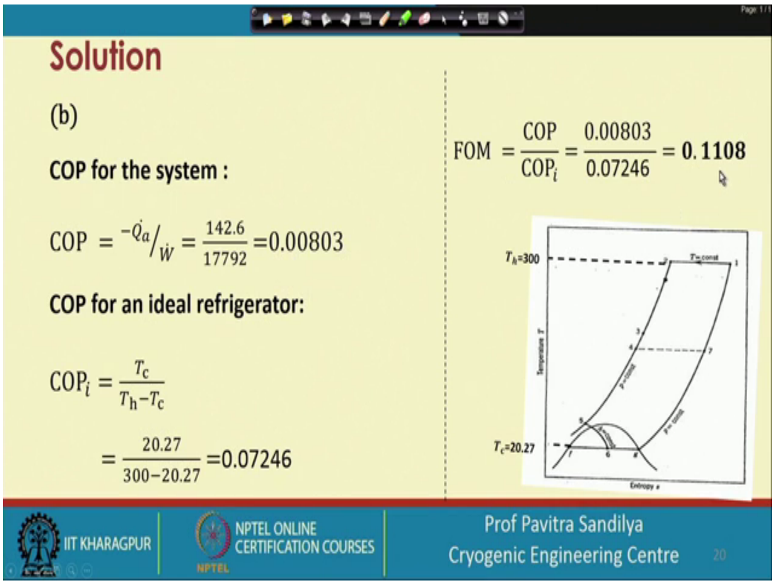

Solution

(b)

COP for the system :

$$\text{COP} = {}^{-\dot{Q}_a}/_{\dot{W}} = \frac{142.6}{17792} = 0.00803$$

COP for an ideal refrigerator:

$$\text{COP}_i = \frac{T_c}{T_h - T_c}$$

$$= \frac{20.27}{300 - 20.27} = 0.07246$$

$$\text{FOM} = \frac{\text{COP}}{\text{COP}_i} = \frac{0.00803}{0.07246} = \mathbf{0.1108}$$

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And the COP can, now easily found out by doing this particular expression and we are getting a COP to be very, very small. So, and the ideal COP is coming to this. So, if you want to find out the FOM, we just take these ratios of these 2 COP s and we get the FM to be FOM to be about 11 percent.

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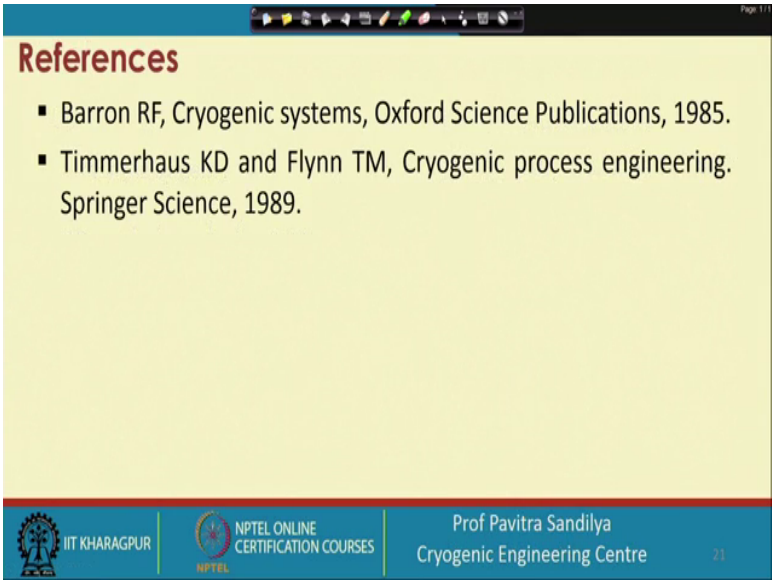

References

- Barron RF, Cryogenic systems, Oxford Science Publications, 1985.
- Timmerhaus KD and Flynn TM, Cryogenic process engineering. Springer Science, 1989.

And to know more about this, you can refer to these two books

Thank you.