Process Integration
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Module - 5
Pinch Design Method for HEN synthesis
Lecture - 11
Low Temperature process Design – Part 02

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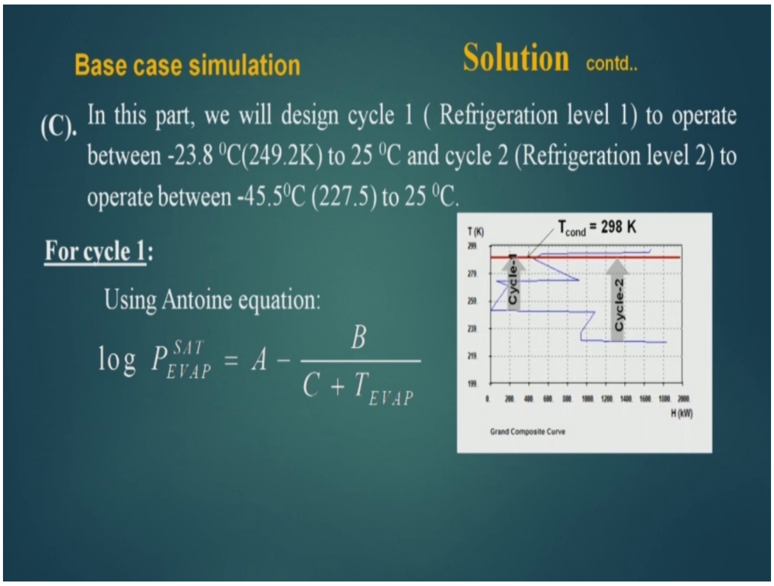

Base case simulation **Solution** contd..

(C). In this part, we will design cycle 1 (Refrigeration level 1) to operate between -23.8 ^{0}C(249.2K) to 25 ^{0}C and cycle 2 (Refrigeration level 2) to operate between -45.5^{0}C (227.5) to 25 ^{0}C.

For cycle 1:

Using Antoine equation:

$$\log P_{EVAP}^{SAT} = A - \frac{B}{C + T_{EVAP}}$$

Now, will see the base case simulation we have defined the base case, this is the base case this is the level 1 and level 2 and whatever heat is picked up in level 1 is send back to this condenser or rejected in this condenser, now for the present problem we will develop base case simulation; that means, the mathematical models through which will be able to predict the power requirement. So, for the base case simulation will design the cycle 1 the cycle 1 will be used for the refrigeration level 1, which operates between minus 23.8 degree Centigrade to 25 degree Centigrade and the cycle 2 which provides refrigeration in level 2, which provides which operates between minus 45.5 degree centigrade to 25 degree centigrade. Now, for this cycle 1 we have to calculate what is the pressure of the refrigerant which will correspond to a temperature through which we can reject heat to the cooling water.

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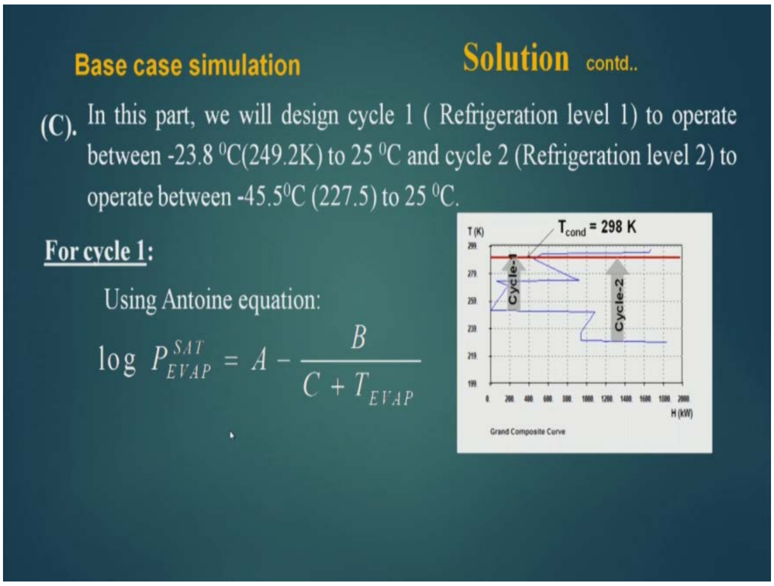

Base case simulation **Solution** contd..

(C). In this part, we will design cycle 1 (Refrigeration level 1) to operate between -23.8 ^{0}C(249.2K) to 25 ^{0}C and cycle 2 (Refrigeration level 2) to operate between -45.5^{0}C (227.5) to 25 ^{0}C.

For cycle 1:

Using Antoine equation:

$$\log P_{EVAP}^{SAT} = A - \frac{B}{C + T_{EVAP}}$$

So, the pressure is calculated using this equation.

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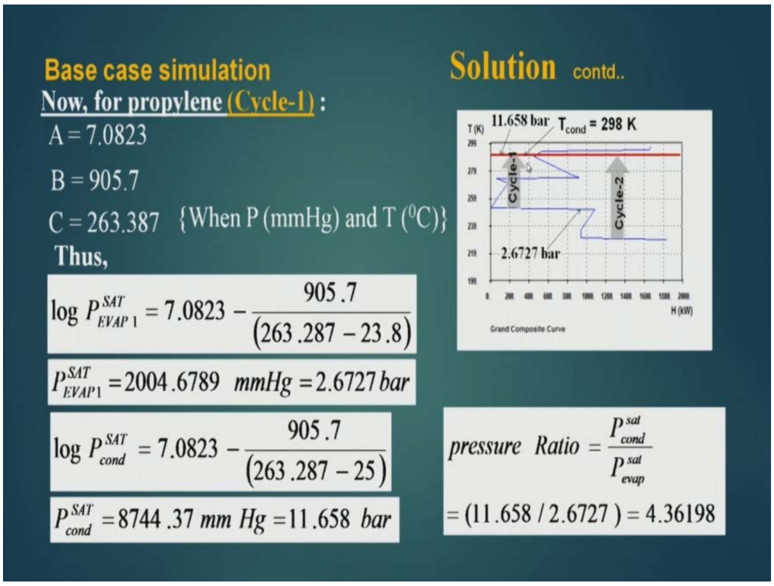

Base case simulation **Solution** contd..

Now, for propylene (Cycle-1) :

A = 7.0823

B = 905.7

C = 263.387 {When P (mmHg) and T (^{0}C)}

Thus,

$$\log P_{EVAP\,1}^{SAT} = 7.0823 - \frac{905.7}{(263.287 - 23.8)}$$

$$P_{EVAP1}^{SAT} = 2004.6789 \ mmHg = 2.6727\,bar$$

$$\log P_{cond}^{SAT} = 7.0823 - \frac{905.7}{(263.287 - 25)}$$

$$P_{cond}^{SAT} = 8744.37 \ mm\ Hg = 11.658 \ bar$$

$$pressure \ \ Ratio = \frac{P_{cond}^{sat}}{P_{evap}^{sat}}$$

$$= (11.658 / 2.6727) = 4.36198$$

And these are the values of A B C into that equation where P is written in mmHg and t degree centigrade. So, when I use this values into this equation then P saturation comes out to be two 2004.6789 mmHg, which is correspond to 2.6727 bar, and this is for evaporated and for the condenser when I use the same equation it comes out to be 11.568 bar the pressure at the evaporator would be 2.6727 bar, and the pressure required for the condenser which will satisfy the temperature levels will be 11.658 bar; that means, 2.6727 bar 11.658 bar this has to be compressed, and the pressure has to be raised. So, pressure ratio becomes 11.658 divided by 2.6727 comes out to be 4.36198 this is the pressure ratio for cycle 1, because I am talking about cycle 1. So, here the condenser is operating at 11.658 bar and this evaporator which is level 1 evaporator is operating at 2.6727 bar. So, form this pressure to this pressure the vapor has to be compressed using a compressor.

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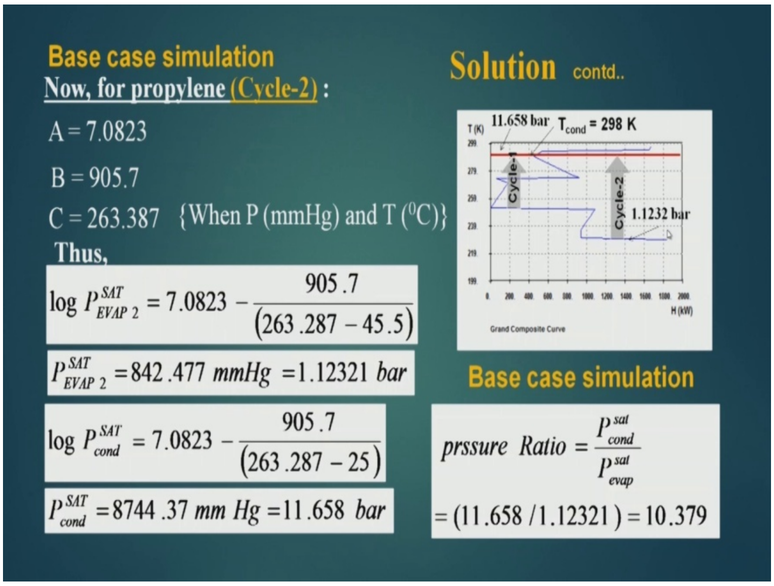

Base case simulation

Now, for propylene (Cycle-2) :

$A = 7.0823$

$B = 905.7$

$C = 263.387$ {When P (mmHg) and T (^{0}C)}

Thus,

$$\log P_{EVAP\,2}^{SAT} = 7.0823 - \frac{905.7}{(263.287 - 45.5)}$$

$$P_{EVAP\,2}^{SAT} = 842.477\ mmHg = 1.12321\ bar$$

$$\log P_{cond}^{SAT} = 7.0823 - \frac{905.7}{(263.287 - 25)}$$

$$P_{cond}^{SAT} = 8744.37\ mm\ Hg = 11.658\ bar$$

Solution contd..

Base case simulation

$$prssure\ \ Ratio = \frac{P_{cond}^{sat}}{P_{evap}^{sat}}$$

$$= (11.658 / 1.12321) = 10.379$$

So, the pressure ratio is this, similarly for cycle 2 will compute this is for cycle 2 for the evaporator the cycle 2 is operating at 1.12321 bar because cycle 2 is operating at much lower temperature. So, its pressure has to be lower. So, it is 1.12321 bar and the condenser pressure remains same has 11.658 bar. So, this is the condenser pressure. So, the pressure ratio is 11.658 divided by 1.12321 comes out to be 10.379. So, this compression ratio is very high in generally for this compression ratio is single compressor is not used because the energy consumption will be more, but for the present case will be using a single compressor for comparison purposes. So, here this is the same pressure 11.658 and this is the pressure 1.1232 bar and. So, the vapors from this pressure it is 1.12321 bar it has to be compress to a pressure of 11.658 bar then only it will be able to reject at its heat to the cooling water.

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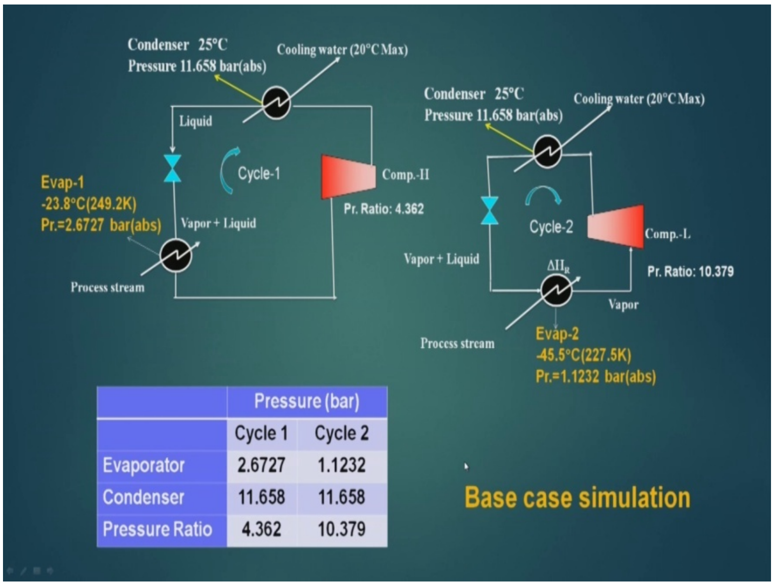

	Pressure (bar)	
	Cycle 1	Cycle 2
Evaporator	2.6727	1.1232
Condenser	11.658	11.658
Pressure Ratio	4.362	10.379

Base case simulation

Now this shows the cycles cycle 2 is this the it is operating with evaporated to which is operating at minus 45.5 degree centigrade, and pressure is 1.12321 bar here, and this is then compressed by a compressor this is to this pressure, which is 11.658 bar and the condenser temperature is 25 degree centigrade and we are using cooling water into this. So, this vapor is then condense to liquid here, and then it is expanded and a vapor liquid mixture goes to this evaporator or the pressure receiver here is 10.379, and this is cycle 2

Similarly, for cycle 1 this is the evaporator which is operating at minus 23.8 centigrade and pressure is 26727 because it is working at lower pressure its temperature is lower, and this vapor is to compressed to 11.658 bar then only it will be able to give heat to this cooling water which is at 20 degree centigrade maximum. So, the pressure ratio is 4.362 now this gives the comparison for cycle 1 the evaporator is operating at 2.6727 cycle 2 is 1.1232 and the condenser pressures are the same 11.658, and this the cycle 1 is operating at a pressure ratio of 4.362 and the cycle 2 is operating at 10.379. We are doing the base case simulation.

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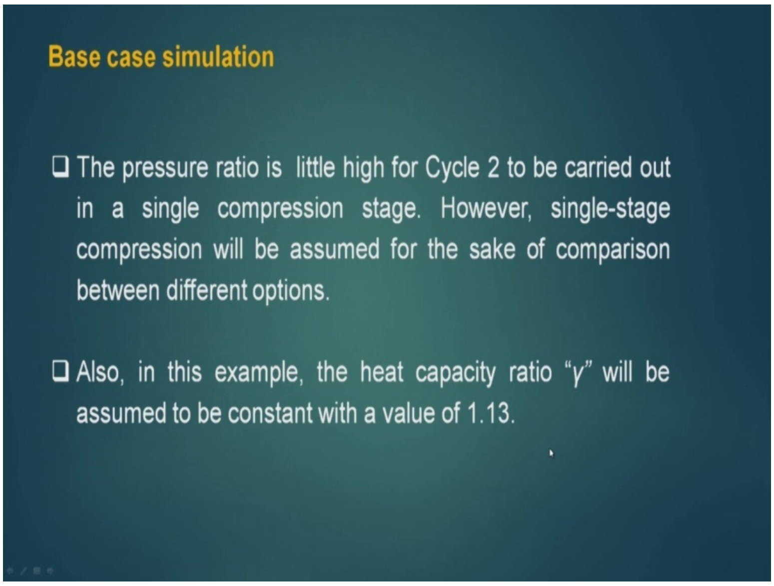

Base case simulation

- ☐ The pressure ratio is little high for Cycle 2 to be carried out in a single compression stage. However, single-stage compression will be assumed for the sake of comparison between different options.
- ☐ Also, in this example, the heat capacity ratio "γ" will be assumed to be constant with a value of 1.13.

The pressure ratio in the cycle 2 is little high for a single stage compression; however, a single stage compression will be assumed for the sake of comparison between different options, here we taking we are taking heat capacity ratio gamma to be 1.13.

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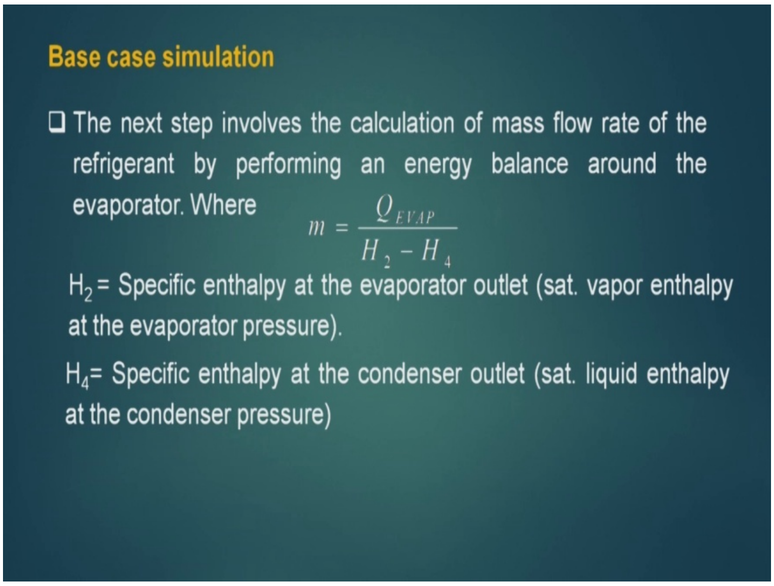

Base case simulation

- ☐ The next step involves the calculation of mass flow rate of the refrigerant by performing an energy balance around the evaporator. Where

$$m = \frac{Q_{EVAP}}{H_2 - H_4}$$

H_2 = Specific enthalpy at the evaporator outlet (sat. vapor enthalpy at the evaporator pressure).

H_4= Specific enthalpy at the condenser outlet (sat. liquid enthalpy at the condenser pressure)

Now the next step involves the calculation of mass flow rate of the refrigerant by performing a energy balance around the evaporator where mass flow rate m will be Q evaporated divided by H 2 minus H 4 and H 2 is the specific enthalpy at the evaporator outlet saturated vapor enthalpy at the evaporator pressure, and H4 is the specific enthalpy at the condenser outlet because in the condenser outlet the vapor will be condense to the liquid. So, it will be a saturated liquid enthalpy at the condenser pressure.

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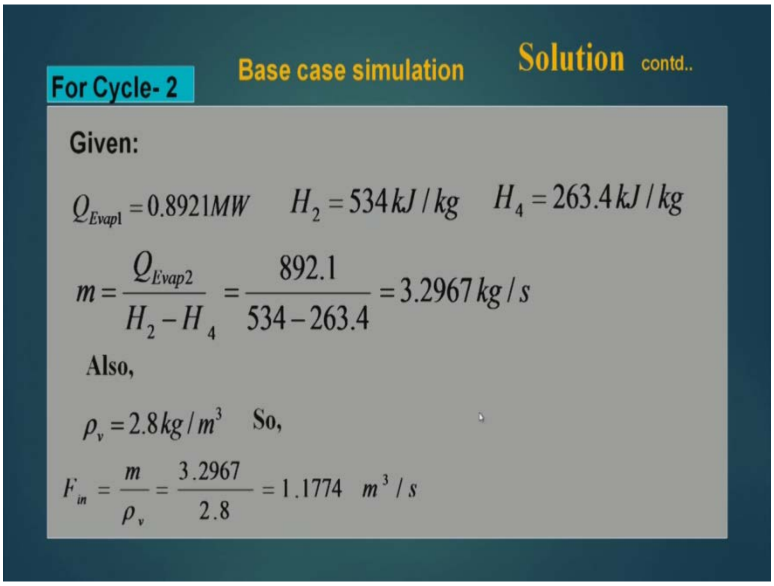

For Cycle- 2

Base case simulation

Solution contd..

Given:

$Q_{Evap1} = 0.8921MW \quad H_2 = 534\,kJ/kg \quad H_4 = 263.4\,kJ/kg$

$$m = \frac{Q_{Evap2}}{H_2 - H_4} = \frac{892.1}{534 - 263.4} = 3.2967\,kg/s$$

Also,

$\rho_v = 2.8\,kg/m^3$ So,

$$F_{in} = \frac{m}{\rho_v} = \frac{3.2967}{2.8} = 1.1774 \quad m^3/s$$

Now, Q evaporator is 9.94792 MW this we know this has come from the GCC H2 we have to calculated will I will show you a table in the last part of this lecture from where we have picked up this H2 value and H4 values then we compute m. So, m comes out to be 3.262 k g per second.

So, for this is cycle 1 cycle for the mass flow rate of refrigerant is 3.262 k g per second, and the row value for this is 5.8 k g per meter square cube this has also been taken from the data which is shown in the last part of this lecture, and we calculate f in, which is the volumetric flow rate of the refrigerant this is mass divided by the density comes out to be 0.562 zero meter cube per second. Now, for cycle 2 for similar calculations were computed this Q evaporator is taken as 0.8921 MW H2 and H4 are calculated from the data. So, m comes out to be 3.2967 k g per second density is this taken from again data table then f in is calculated as 1.1774 cube per second.

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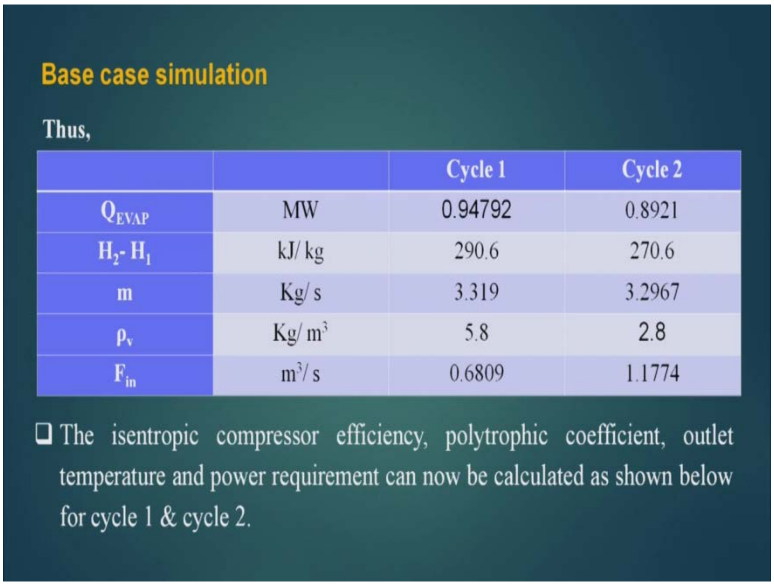

Base case simulation

Thus,

		Cycle 1	Cycle 2
Q_{EVAP}	MW	0.94792	0.8921
H_2- H_1	kJ/ kg	290.6	270.6
m	Kg/ s	3.319	3.2967
ρ_v	Kg/ m^3	5.8	2.8
F_{in}	m^3/ s	0.6809	1.1774

❑ The isentropic compressor efficiency, polytrophic coefficient, outlet temperature and power requirement can now be calculated as shown below for cycle 1 & cycle 2.

Now these are the for cycle 1 and cycle 2 this data is available with me for Q evaporation; that means, the evaporator load is for cycle 1 this is 0.94792 for 2 is 0. 8921 H2 minus H1 is this 29.6276 m. The flow rate of the refrigerant is 3.319 here 3.2967 here rho v is 5.8 and here 2. 8, this f in is this and this. Now, the isentropic compressor efficiency and polytrophic coefficient outlet temperature and power requirements can now be calculated as shown below for cycle 1 and cycle 2.

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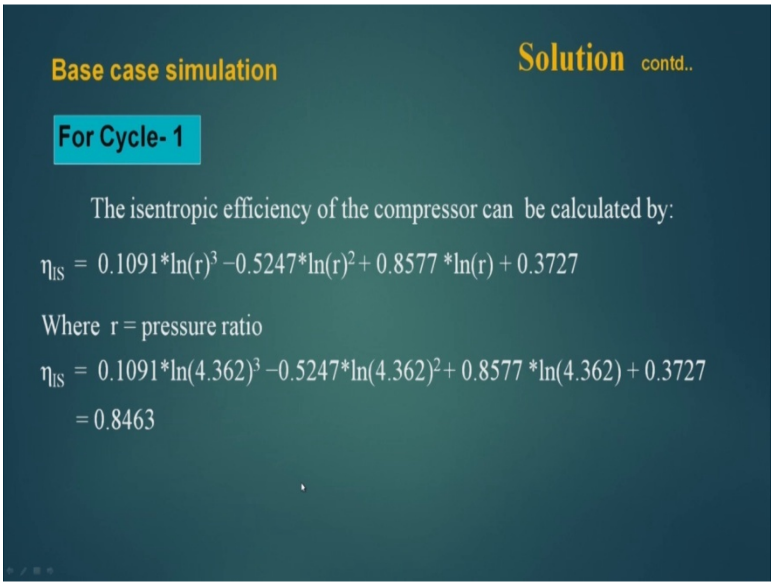

Base case simulation **Solution** contd..

For Cycle- 1

The isentropic efficiency of the compressor can be calculated by:

$$\eta_{IS} = 0.1091*\ln(r)^3 - 0.5247*\ln(r)^2 + 0.8577*\ln(r) + 0.3727$$

Where r = pressure ratio

$$\eta_{IS} = 0.1091*\ln(4.362)^3 - 0.5247*\ln(4.362)^2 + 0.8577*\ln(4.362) + 0.3727$$

$$= 0.8463$$

So, for isentropic efficiency of the compressor can be calculated by this equation where r is the compression ratio. So, we have put this values and the for cycle 1 it comes out to be 0.8463.

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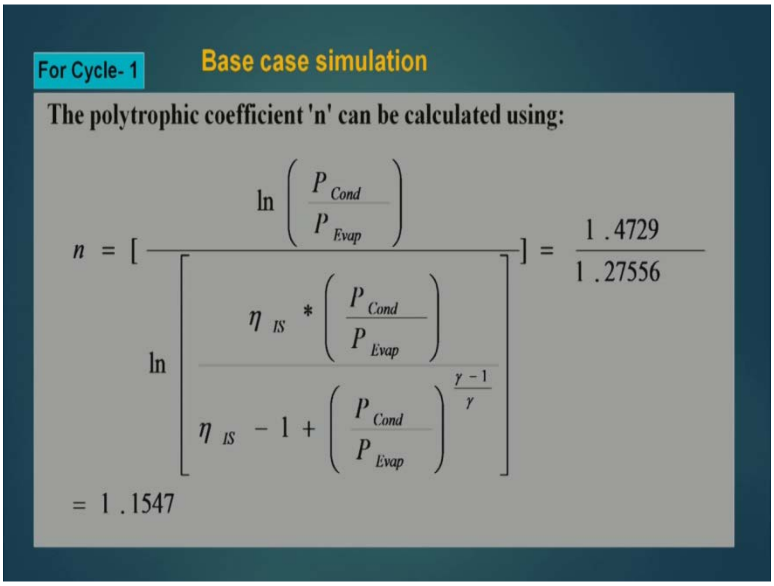

For Cycle- 1

Base case simulation

The polytrophic coefficient 'n' can be calculated using:

$$n = \left[\frac{\ln\left(\frac{P_{Cond}}{P_{Evap}}\right)}{\ln\left[\frac{\eta_{IS} * \left(\frac{P_{Cond}}{P_{Evap}}\right)}{\eta_{IS} - 1 + \left(\frac{P_{Cond}}{P_{Evap}}\right)^{\frac{\gamma-1}{\gamma}}}\right]} \right] = \frac{1.4729}{1.27556}$$

$$= 1.1547$$

Now the n is calculated by this formula for this cycle 1, and this comes out to be 1.1547 this polytrophic coefficient n.

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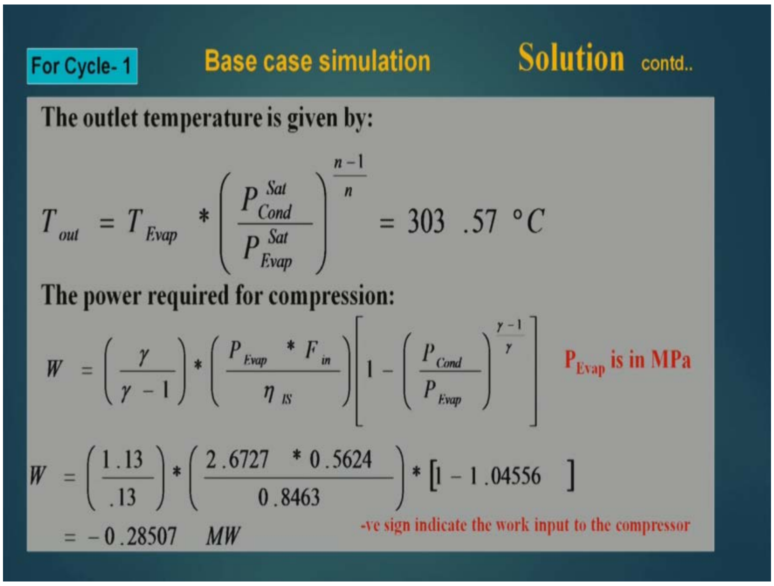

For Cycle- 1

Base case simulation

Solution contd..

The outlet temperature is given by:

$$T_{out} = T_{Evap} * \left(\frac{P^{Sat}_{Cond}}{P^{Sat}_{Evap}}\right)^{\frac{n-1}{n}} = 303.57\ {}^{\circ}C$$

The power required for compression:

$$W = \left(\frac{\gamma}{\gamma - 1}\right) * \left(\frac{P_{Evap} * F_{in}}{\eta_{IS}}\right)\left[1 - \left(\frac{P_{Cond}}{P_{Evap}}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

P_{Evap} is in MPa

$$W = \left(\frac{1.13}{.13}\right) * \left(\frac{2.6727 * 0.5624}{0.8463}\right) * [1 - 1.04556]$$

$$= -0.28507\ MW$$

-ve sign indicate the work input to the compressor

Now T out for cycle 1 is T evaporator into this equation comes out to be 303.57 degree centigrade, and the work done is calculated by this formula and this comes out to be minus 0.28507 and this has got a negative sign. So, P evaporator is in MPa we have used here and. So, this will be in MW, and the negative sign indicate the work input to the compression and that is why it is a negative sign this is a sign convention basically.

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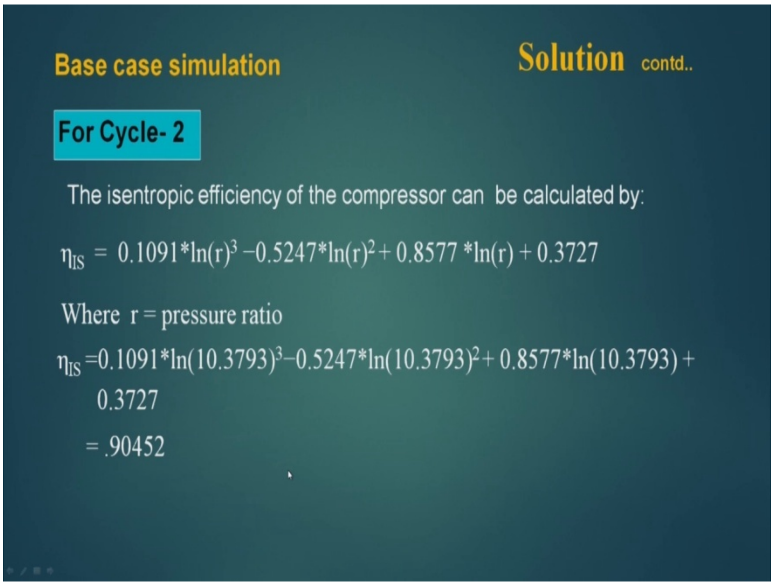

Base case simulation

Solution contd..

For Cycle- 2

The isentropic efficiency of the compressor can be calculated by:

$$\eta_{IS} = 0.1091*\ln(r)^3 - 0.5247*\ln(r)^2 + 0.8577*\ln(r) + 0.3727$$

Where r = pressure ratio

$$\eta_{IS} = 0.1091*\ln(10.3793)^3 - 0.5247*\ln(10.3793)^2 + 0.8577*\ln(10.3793) + 0.3727$$

$$= .90452$$

For cycle 2 similar computations were done the isentropic efficiency is computed as 0.90452.

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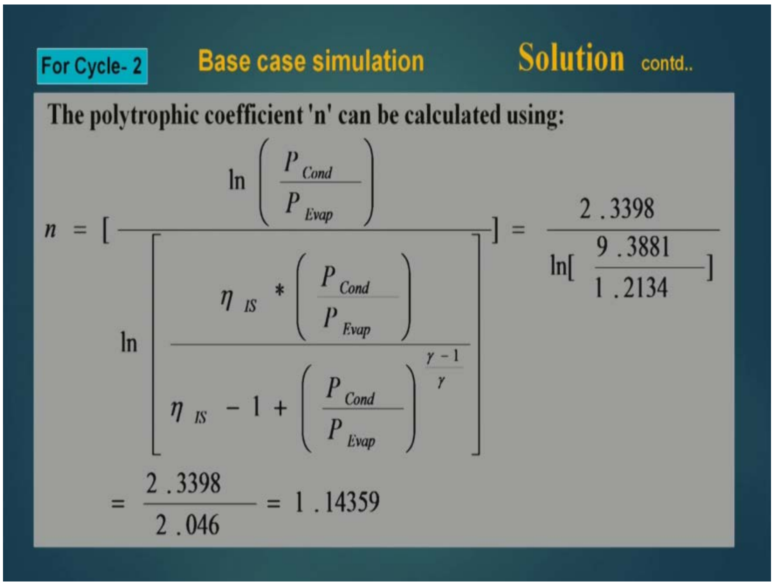

For Cycle- 2

Base case simulation

Solution contd..

The polytrophic coefficient 'n' can be calculated using:

$$n = \left[\frac{\ln\left(\frac{P_{Cond}}{P_{Evap}}\right)}{\ln\left[\frac{\eta_{IS} * \left(\frac{P_{Cond}}{P_{Evap}}\right)}{\eta_{IS} - 1 + \left(\frac{P_{Cond}}{P_{Evap}}\right)^{\frac{\gamma-1}{\gamma}}}\right]} \right] = \frac{2.3398}{\ln\left[\frac{9.3881}{1.2134}\right]}$$

$$= \frac{2.3398}{2.046} = 1.14359$$

The polytrophic coefficient n is calculated the same formula the value is 1.14359.

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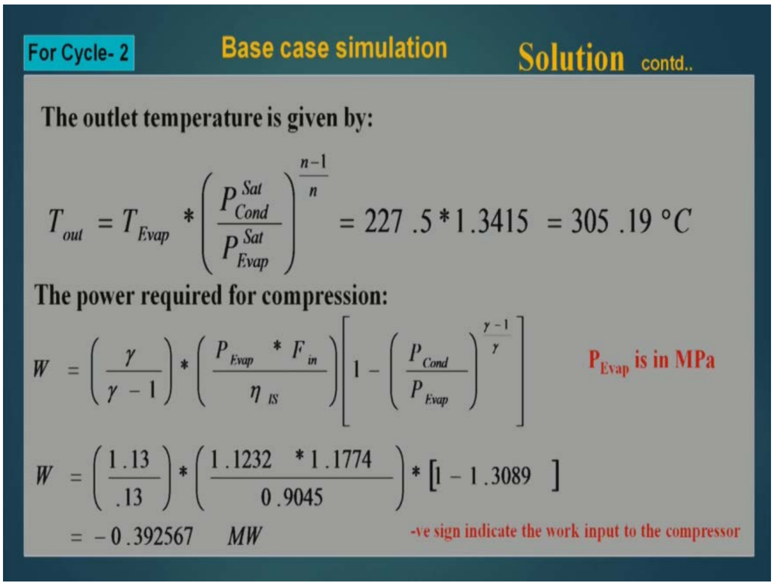
For Cycle- 2

Base case simulation

Solution contd..

The outlet temperature is given by:

$$T_{out} = T_{Evap} * \left(\frac{P^{Sat}_{Cond}}{P^{Sat}_{Evap}} \right)^{\frac{n-1}{n}} = 227.5 * 1.3415 = 305.19\ ^{\circ}C$$

The power required for compression:

$$W = \left(\frac{\gamma}{\gamma - 1} \right) * \left(\frac{P_{Evap} * F_{in}}{\eta_{IS}} \right) \left[1 - \left(\frac{P_{Cond}}{P_{Evap}} \right)^{\frac{\gamma - 1}{\gamma}} \right]$$

P_{Evap} is in MPa

$$W = \left(\frac{1.13}{.13} \right) * \left(\frac{1.1232 * 1.1774}{0.9045} \right) * [1 - 1.3089]$$

$$= -0.392567 \quad MW$$

-ve sign indicate the work input to the compressor

And this T out is computed using this formula and the work done is calculated, then it is also a minus 0.392567 MW here the P evaporator is in MPa and the negative sign indicates the work input to the compressor. So, is a sign convention again.

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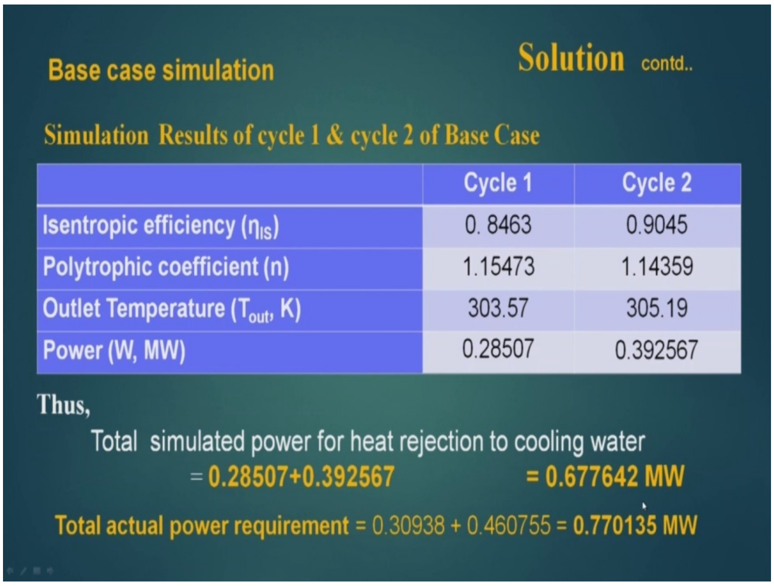
Base case simulation

Solution contd..

Simulation Results of cycle 1 & cycle 2 of Base Case

	Cycle 1	Cycle 2
Isentropic efficiency (η_{IS})	0. 8463	0.9045
Polytrophic coefficient (n)	1.15473	1.14359
Outlet Temperature (T_{out}, K)	303.57	305.19
Power (W, MW)	0.28507	0.392567

Thus,

Total simulated power for heat rejection to cooling water

= **0.28507+0.392567** = **0.677642 MW**

Total actual power requirement = 0.30938 + 0.460755 = **0.770135 MW**

So, this is the base case simulation data for us for cycle 1 isentropic coefficients are given for cycle 1 and cycle 2. Polytrophic coefficient is also given, outlet temperatures are given and power is also used here. So, through simulation what we observed that the power required to reset the heat to the cooling water from the level one as well as level 2 is 0.677642 MW. This is the ideal power and actual power which we have computed is somewhere more this is 0.770135 MW. So, there is a difference in the power here this is the simulated power and this is the actual power. Now, why we have go gone for the base case simulation, because now we will try different designs and for those different designs experimental data is not available with us. So, we have to simulate those different designs to find out what is the energy consumption of those designs, and hence we have done the base case simulation and the simulation value is this and the actual value is this.

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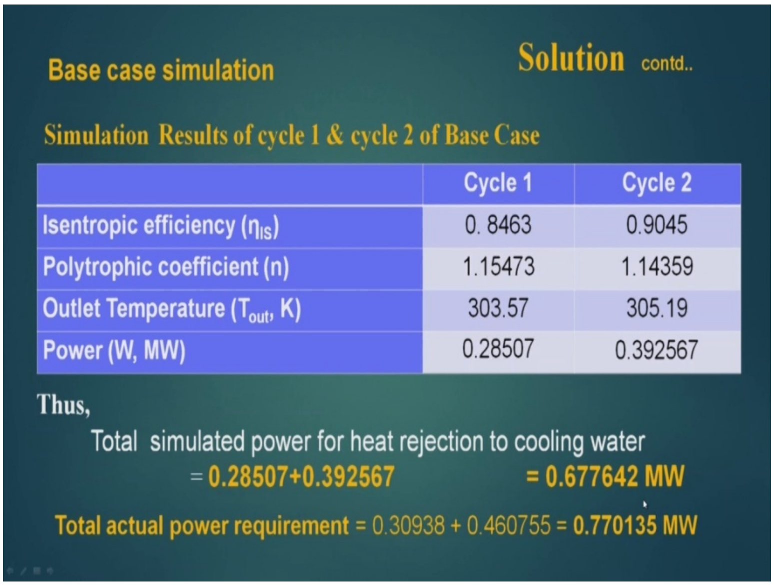

Solution contd..

Base case simulation

Simulation Results of cycle 1 & cycle 2 of Base Case

	Cycle 1	Cycle 2
Isentropic efficiency (η_{IS})	0. 8463	0.9045
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Outlet Temperature (T_{out}, K)	303.57	305.19
Power (W, MW)	0.28507	0.392567

Thus,

Total simulated power for heat rejection to cooling water

= 0.28507+0.392567 = 0.677642 MW

Total actual power requirement = 0.30938 + 0.460755 = 0.770135 MW

So obviously, the actual value will be more than the simulation value for all comparison we will be using now this value because we will take many designs and will simulate the power consumptions of those designs and hence we will compare this those values with this value, which is the base case simulation value. Now, will go for refrigeration targeting. Now how will do the refrigeration targeting this is based on alternate designs. What will be our aim to save energy of compression and hot utility this will be the two aims to save energy of a compression and hot utility. Now these are the different designs we have created design number 1 to design number 5.

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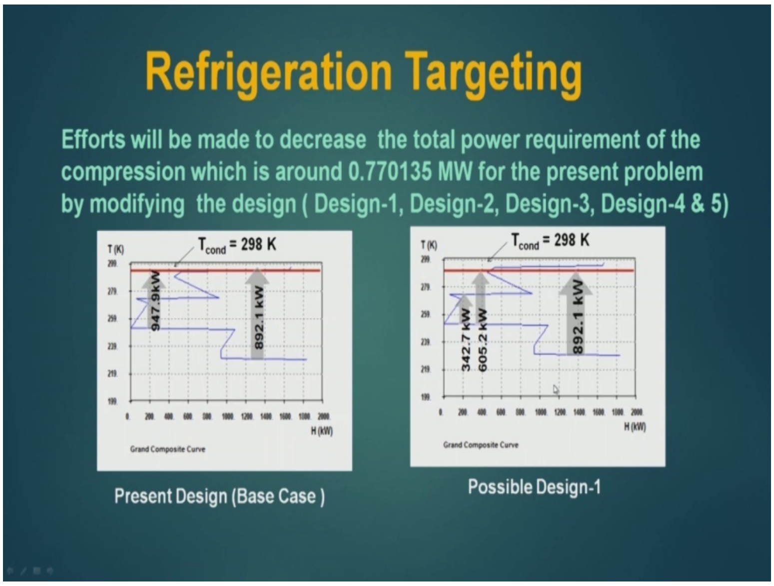

Refrigeration Targeting

Efforts will be made to decrease the total power requirement of the compression which is around 0.770135 MW for the present problem by modifying the design (Design-1, Design-2, Design-3, Design-4 & 5)

Present Design (Base Case)

Possible Design-1

Now this is the base case here the heat available with level 1 and level 2 are rejected to the cooling water this was the base case. Now in the design 1 what we are doing a part of the energy which is available in level 1 is rejected here for the process, because this demands hot utility. So, this heat is rejected here and the rest is rejected to the cooling water, similarly the heat which is available which has been consumed here by the evaporator is rejected to the cooling water. So, this is a design number 1 and we will compute the energy requirements for this and hot utility requirements for design 1.

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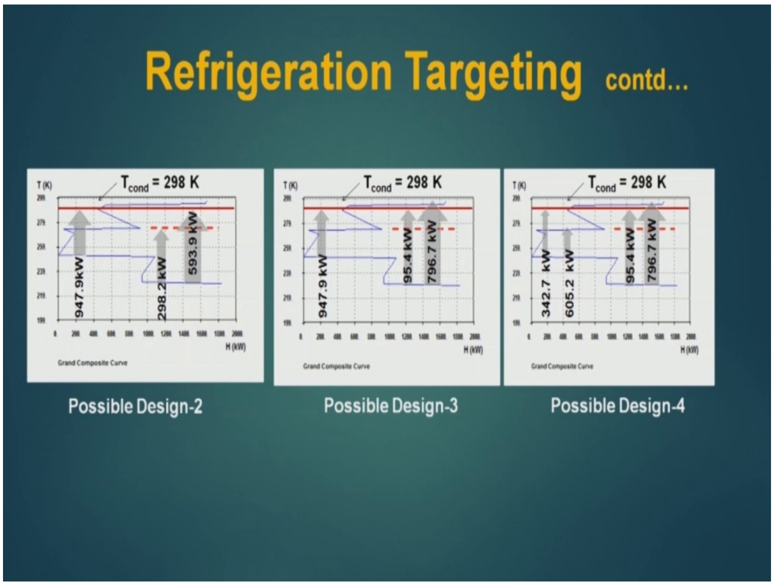

Refrigeration Targeting contd...

Possible Design-2

Possible Design-3

Possible Design-4

Similarly, here we have three designs design 2, design 3 and design 4, in the design 2 all the heat which is available in this temperature level is rejected to the cooling water; however, here whatever the heat is available here a part of heat is rejected to this, because requires this area requires heat. So, it is being rejected this 298.2 kilowatt is rejected there in this temperature level, and rest is rejected to the cooling water. Similarly in the design three the total heat available here is rejected to the cooling water a part of it heat is rejected to the cooling water and the rest heat is rejected in this temperature level, which is a process sink this is a process sink and basically this is rejected to condenser number 2 which we have discussed in the GCC. In this design whatever heat is taken up by the evaporator, here a part of it is rejected at this level restrict rejected to the cooling water, here also a part is rejected to the cooling water and the rest is rejected to the processing which is here in the condenser number two which services gives hot utility to the process streams.

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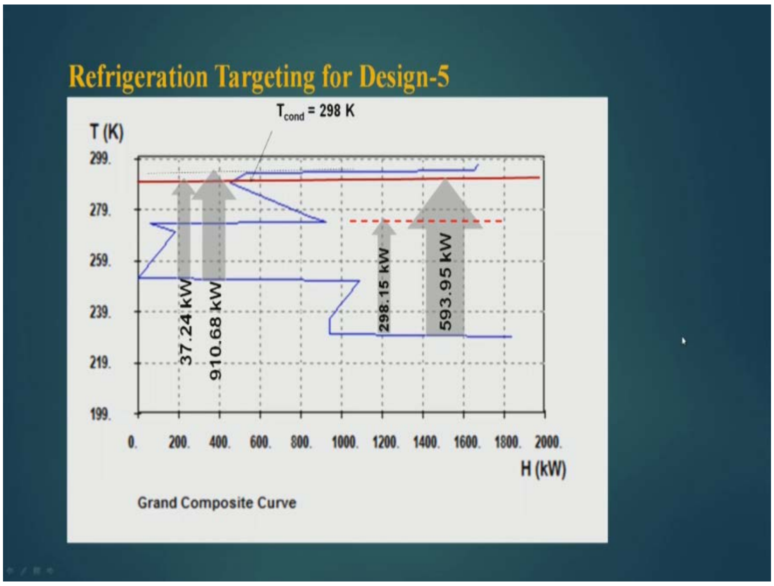

Refrigeration Targeting for Design-5

Similarly we have another design which is design number 5, here a part of heat is rejected here at this temperature level which is condenser number 2 and rest is rejected to the cooling water a part of this is rejected to this temperature level and satisfies the heat demand from here to here which is 433 KW and the rest is rejected to the cooling water. Now, you will see that when I am rejecting 298.15 kilowatt to here this is satisfies finding the heat demand of this, which is 433 how this is possible because, when I am pushing of this heat to this level a considerable amount of work is being done and that work is converted to heat and that is why whatever heat will reach here will be more than the heat, which has been lifted from here. So, we have taken 5 designs and for the each design will do the simulation and will find out what is the amount of power required to operate the refrigeration systems given in those designs plus will see that how much hot utilities they have able to decrease now let us do the refrigeration targeting for design two here what I am doing the whatever heat which is available and level one all the heats are pushed up to the water condenser and whatever heat is picked up here in the level 2 a part of heat is put here is used as a hot utility and the demand of hot utility in this reason is 0.403 MW.

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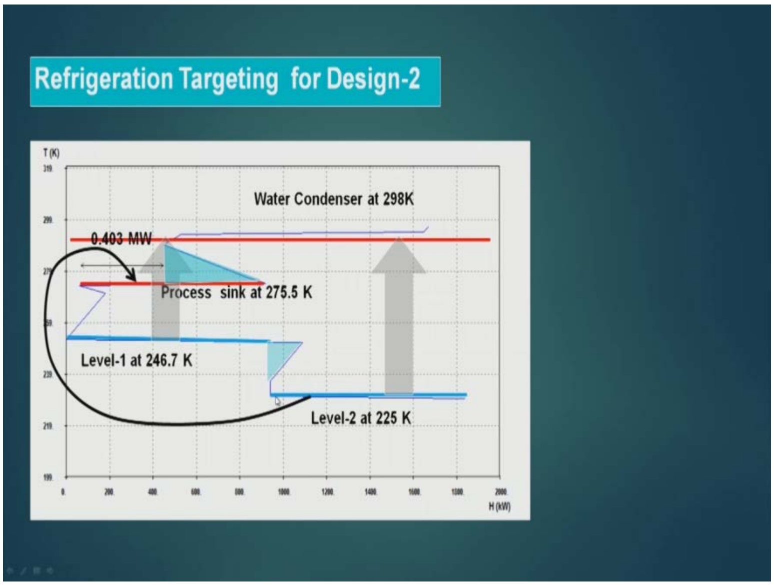

Refrigeration Targeting for Design-2

So, a part of heat is lifted here and the whole reason is satisfied; that means, 430. 43 MW is supplied here and the rest heat is put into the water condenser, which is operating at 298. Now if this is the situation then we have to simulate that how much energy is consumed for the compressors for this design two and how much hot utility it has able to saved; obviously, it is able to saved 0.403 MW of hot utility only I have to use hot utility for this reason for this case.

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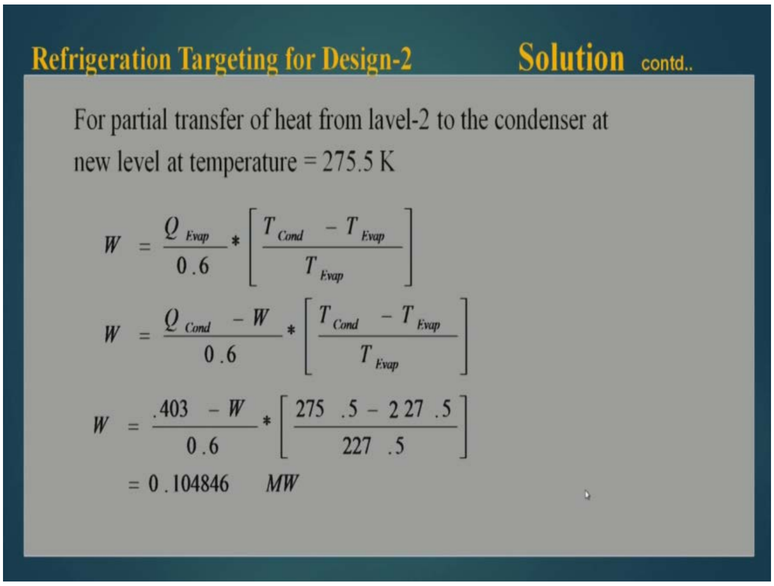

Refrigeration Targeting for Design-2

Solution contd..

For partial transfer of heat from lavel-2 to the condenser at new level at temperature = 275.5 K

$$W = \frac{Q_{Evap}}{0.6} * \left[\frac{T_{Cond} - T_{Evap}}{T_{Evap}}\right]$$

$$W = \frac{Q_{Cond} - W}{0.6} * \left[\frac{T_{Cond} - T_{Evap}}{T_{Evap}}\right]$$

$$W = \frac{.403 - W}{0.6} * \left[\frac{275.5 - 227.5}{227.5}\right]$$

$$= 0.104846 \quad MW$$

So, here we calculate what is the watt is the energy required comes out to be 0.104846 for the MW of energy required to take the heat from the level 2 and to serve it on the condenser number 3 So, here Q evaporator is not known so, but this Q evaporator is Q condenser minus W because the Q evaporator plus this W will go to the condenser and you will satisfy the 40.403 MW. So, if we calculate it we find that this is the amount of energy we should be required to push the heat if I go up. So, this heat which will satisfy to this is equal to the heat taken from this level plus the water done which will be done to glib this heat from here to here. So, the energy required is this 0.104846, now the level 2 heat will be taken up from the level 2 and pushed into two 75.5 kelvin.

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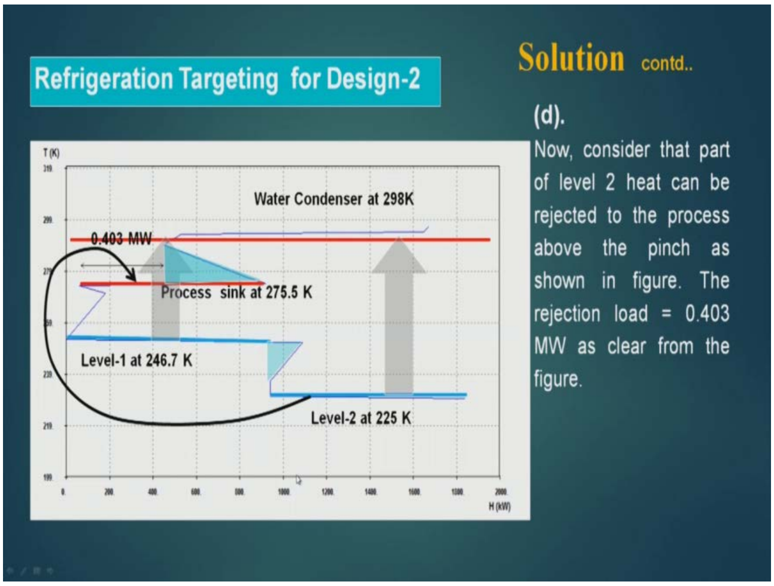

Refrigeration Targeting for Design-2

Solution contd..

(d).

Now, consider that part of level 2 heat can be rejected to the process above the pinch as shown in figure. The rejection load = 0.403 MW as clear from the figure.

So, the temperature level of this is which is a processing is 275.5 Kelvin.

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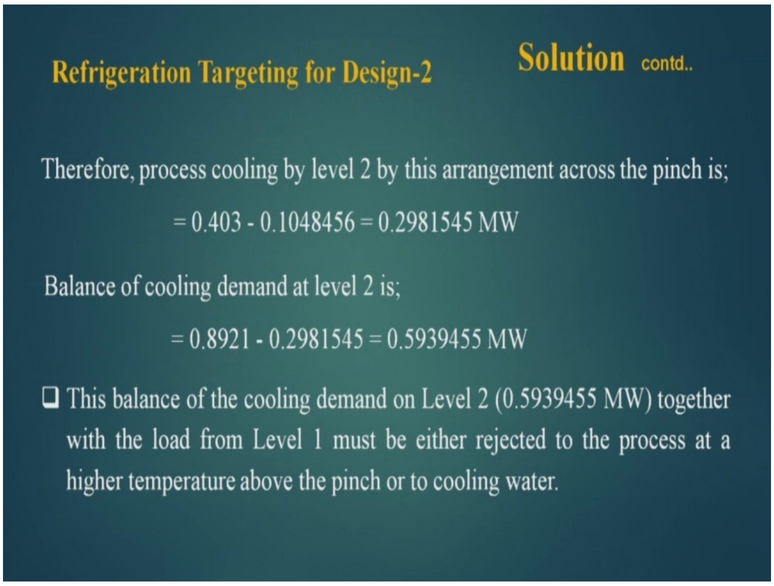

Refrigeration Targeting for Design-2

Solution contd..

Therefore, process cooling by level 2 by this arrangement across the pinch is;

= 0.403 - 0.1048456 = 0.2981545 MW

Balance of cooling demand at level 2 is;

= 0.8921 - 0.2981545 = 0.5939455 MW

- ❑ This balance of the cooling demand on Level 2 (0.5939455 MW) together with the load from Level 1 must be either rejected to the process at a higher temperature above the pinch or to cooling water.

So, if I deduct it 0.403 minus the work, which has been done it comes out to be 0.2981545 MW; that means, this much amount of heat if from level 2 is pass to the process sink, which is condenser number 3 then it will satisfy the whole requirement of the condenser 3 which is 0.403 MW. So, balance it which will come out to be 0.8921 minus this much amount is comes out to be 0.5939455 MW this will go to the cooling water from level 2. So, the balance of the cooling demand on level 2 is 0.5939455 MW together with the load from level 1 must be either be rejected to the process at a higher temperature above the pinch or the cooling water, and in design two we are servicing the cooling water; that means, we are passing up this heat to cooling water now to reject the heat from level 1.

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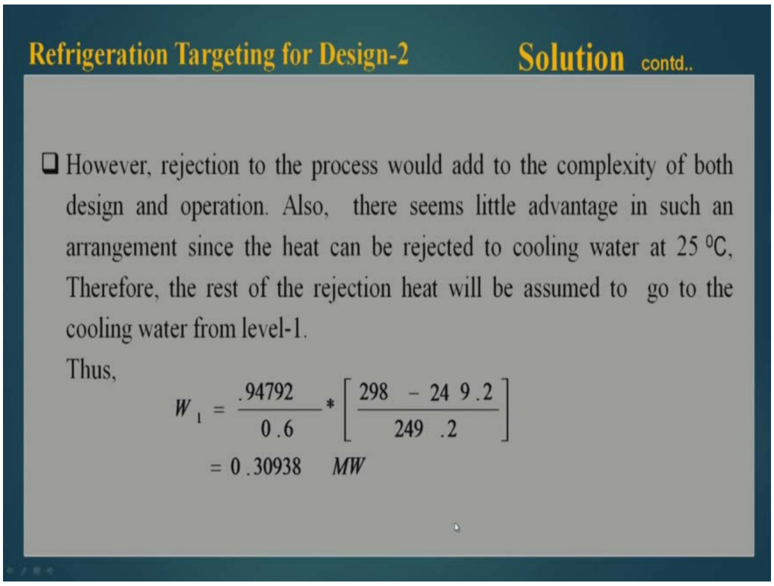

Refrigeration Targeting for Design-2 **Solution** contd..

- ☐ However, rejection to the process would add to the complexity of both design and operation. Also, there seems little advantage in such an arrangement since the heat can be rejected to cooling water at 25 ^{0}C, Therefore, the rest of the rejection heat will be assumed to go to the cooling water from level-1.

Thus,

$$W_1 = \frac{.94792}{0.6} * \left[\frac{298 - 249.2}{249.2}\right]$$

$$= 0.30938 \quad MW$$

One thing we should note that the this rejection to the process would add to complexity both in the design and operation, also that seems little advantage in such an arrangement since heat can be rejected to cooling water 25 degree centigrade therefore, the rest of the rejection heat will be assume to go to the cooling water from level 1. So, what we are doing from level 1, I am rejecting the heat totally to the cooling water and to do.

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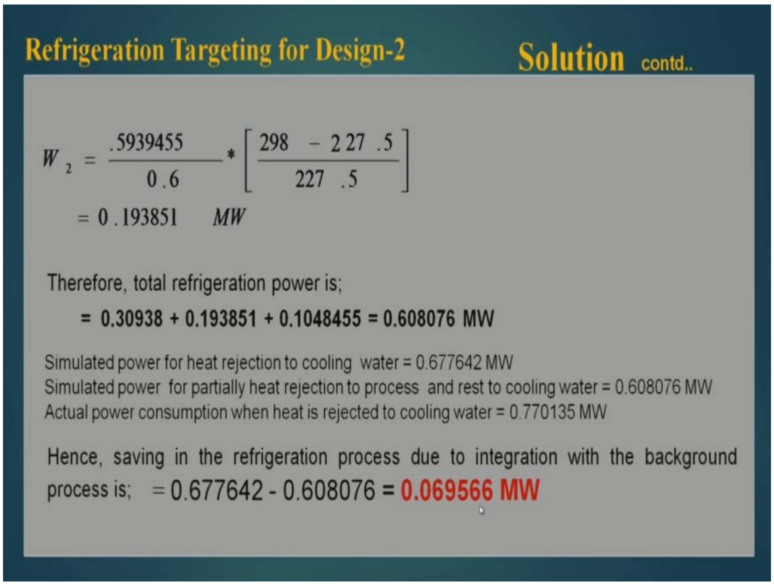

Refrigeration Targeting for Design-2 **Solution** contd..

$$W_2 = \frac{.5939455}{0.6} * \left[\frac{298 - 227.5}{227.5}\right]$$

$$= 0.193851 \quad MW$$

Therefore, total refrigeration power is;

= 0.30938 + 0.193851 + 0.1048455 = 0.608076 MW

Simulated power for heat rejection to cooling water = 0.677642 MW
Simulated power for partially heat rejection to process and rest to cooling water = 0.608076 MW
Actual power consumption when heat is rejected to cooling water = 0.770135 MW

Hence, saving in the refrigeration process due to integration with the background process is; = 0.677642 - 0.608076 = **0.069566 MW**

So, I will be needing 0.30938 MW and the rest amount of heat which is available in level 2, if I take that to the cooling water then my requirement will be 0.193851 MW. So, if I add them together. So, total energy requirement will be this, this is the partial heat from level 2 to the condenser number 3 and this 2 heats are to push to the cooling water the heat from evaporators to push to the cooling water. So, total is 0.608076 MW and this is the simulated power for heat to cooling water, that is base case was 0.677642 MW and this is the value here now for the design 2 and the actual value was this. So, saving is 0.069566 MW. So, if I go for design two I will be able to save 0.069566 MW of energy.

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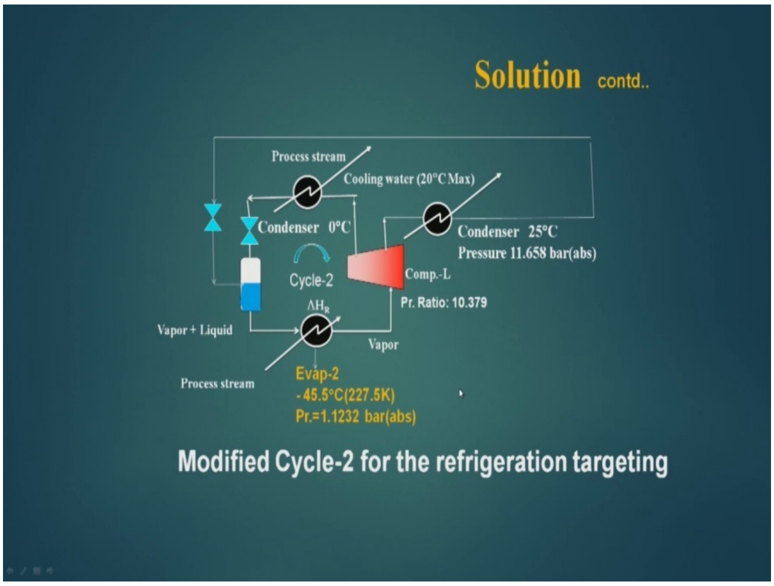

Modified Cycle-2 for the refrigeration targeting

Similarly and if I see what sort of a refrigeration cycle will meet design 2. So, this shows a refrigeration cycle it is a multistage compressor where vapors are coming out to at 2 different temperatures and pressures. So, this is at one pressure this forms cycle 2 and this forms cycle 1.

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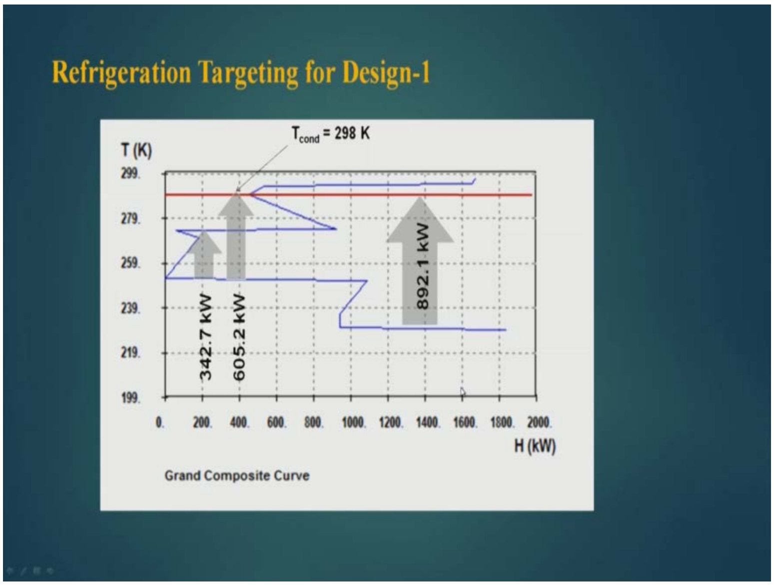

Refrigeration Targeting for Design-1

Grand Composite Curve

Now let us go for the refrigeration targeting for design one here what we are doing were taking a part of heat, which is available here in this evaporated to this level which is a process level and this is operated by condenser number 3 and the whole heat available at this level is put to the cooling water. So, here we have in the level 1 to compression energy is required in two compressor energy for this and compression energy for this. So, here 342.7 kW is lifted from here to here for this. I have to use some energy and 605.2 kilowatt is lifted from here to this cooling water. I need some energy and for here 892.1 energy is lifted from this to cooling water. So, three energies are required. So, here I get W one a and W one B is this and in the W 2 this is this in the level two which I am in resting energy. So, if I add up this 3 energy is comes out to be 0.7185623 MW.

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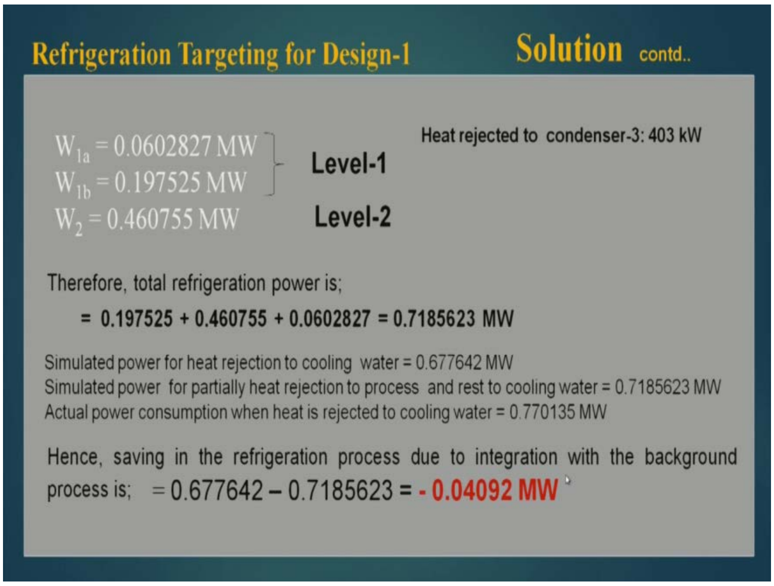

Refrigeration Targeting for Design-1 **Solution** contd..

$W_{1a} = 0.0602827$ MW
$W_{1b} = 0.197525$ MW } **Level-1**
$W_2 = 0.460755$ MW **Level-2**

Heat rejected to condenser-3: 403 kW

Therefore, total refrigeration power is;

= 0.197525 + 0.460755 + 0.0602827 = 0.7185623 MW

Simulated power for heat rejection to cooling water = 0.677642 MW
Simulated power for partially heat rejection to process and rest to cooling water = 0.7185623 MW
Actual power consumption when heat is rejected to cooling water = 0.770135 MW

Hence, saving in the refrigeration process due to integration with the background process is; = 0.677642 – 0.7185623 = **- 0.04092 MW**

So, we see that the energy has increased and what we are doing we are able to reject heat to through condenser 3403 KW; that means, we are able to reduce 403 kilowatt of hot utility of the process and will be investing this much of amount of energy for compression which is more than the earlier one. So, the savings is minus; that means, I have to use more energy than my base case in this.

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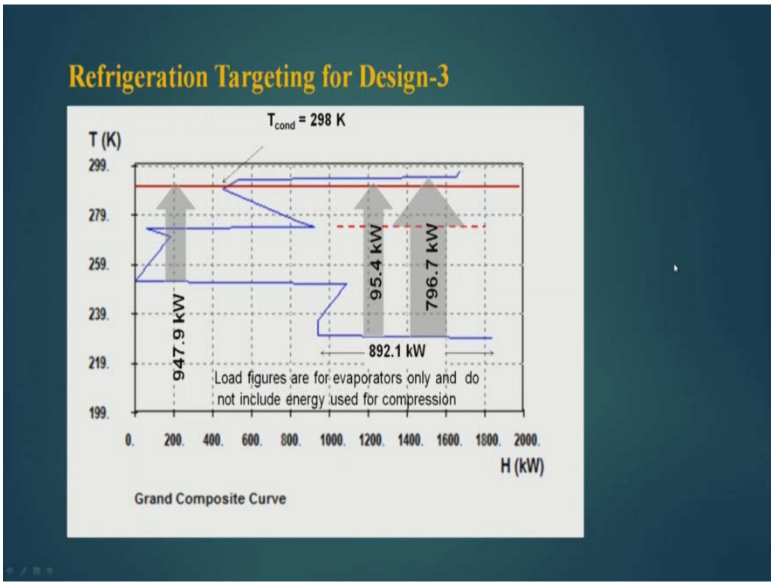

Refrigeration Targeting for Design-3

So, we go for design three now what do we are doing the whole amount of heat which is available in this level 1 we are rejecting into the cold water a part of heat which is available here in level two is being served here in this level. So, the hot utility requirement of this level is satisfied by taking heat from level 2 to this level and this will be done through condenser number two now these values are whatever mean you are seeing here this is the amount of heat which is his lifting, but when it reach here the heat will increase because this will then it will be added with the the heat which will be generated due to compression. So, here whatever values we are seeing here the energy used for compression is not included into this and that is why this plus this is this value 892. 1 which is the heat picked up into this invert evaporator.

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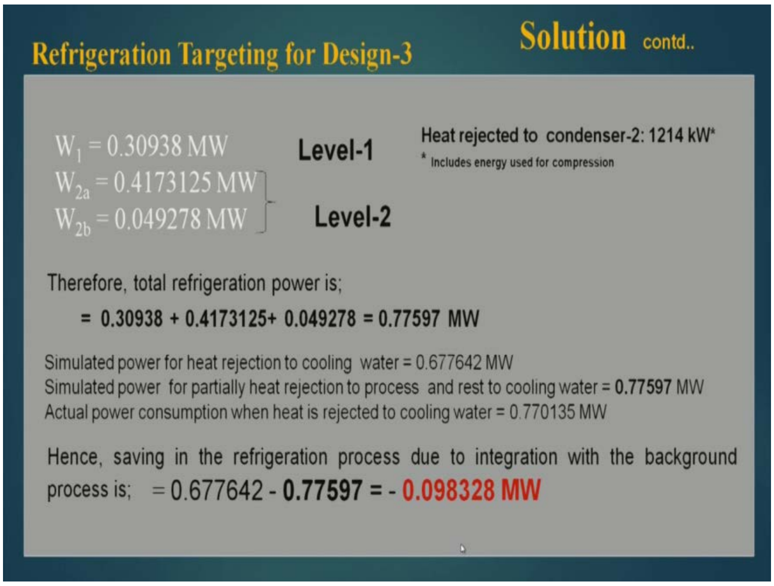

Refrigeration Targeting for Design-3

Solution contd..

$W_1 = 0.30938$ MW **Level-1**

$W_{2a} = 0.4173125$ MW

$W_{2b} = 0.049278$ MW **Level-2**

Heat rejected to condenser-2: 1214 kW*

* Includes energy used for compression

Therefore, total refrigeration power is;

= 0.30938 + 0.4173125+ 0.049278 = 0.77597 MW

Simulated power for heat rejection to cooling water = 0.677642 MW

Simulated power for partially heat rejection to process and rest to cooling water = **0.77597** MW

Actual power consumption when heat is rejected to cooling water = 0.770135 MW

Hence, saving in the refrigeration process due to integration with the background process is; = 0.677642 - **0.77597** = - **0.098328 MW**

So, if I do this simulation for design 3 I get this now in level 2 there will be 2 requirement of energy this is W two a w two b these are this values 0.4173125 megawatt and 0.049278 megawatt and for the level 1 it will be 0.30938 megawatt and heat rejection to the condenser two will be 1214 kilowatt; that means, I will be able to satisfy the whole requirement of condenser two; that means, this much amount of hot utility will be saved, but I will be using a higher amount of power 0.77597 MW. So, my saving will be in negative; that means, I have to use this much of power more than the base case, but I will able to save this much of hot utility lets go for design 4.

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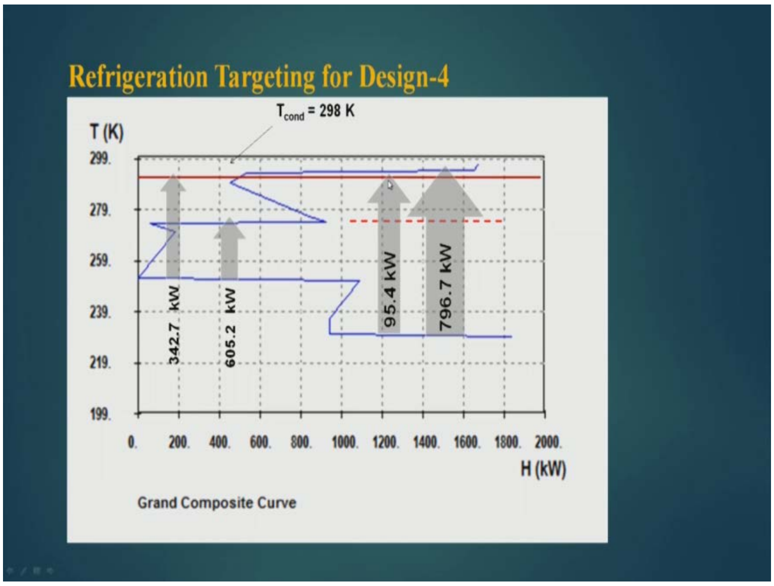

Refrigeration Targeting for Design-4

Grand Composite Curve

In design 4 what is being done the heat, which is available here is being pumped a part of it is pumped to this level which is a process level and is operated by condenser three and the rest is send to the cooling water. So, when this much of amount of heat is pumped it satisfies this. In fact, this will should 342.7 kilowatt and this will be 605.2 kilowatt and here a part of this is pumped to this energy level to satisfied the what utility requirement of this and the other part is put into the cooling water.

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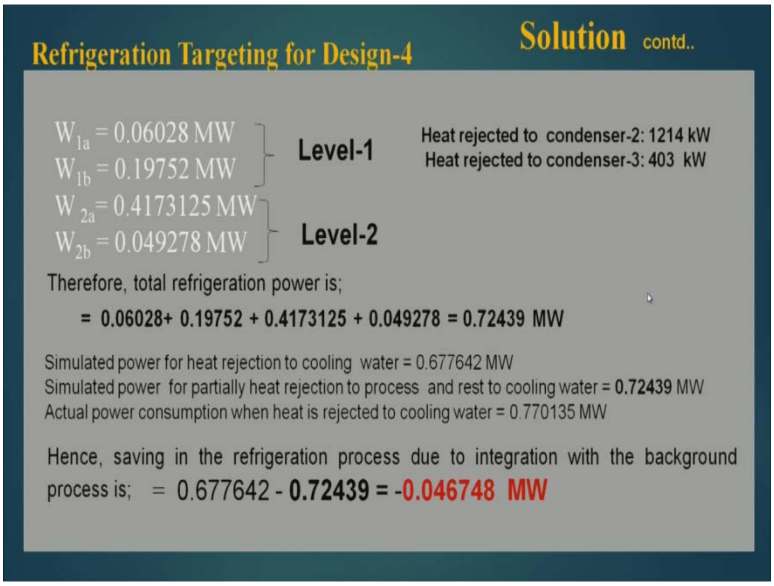

Refrigeration Targeting for Design-4

Solution contd..

W_{1a} = 0.06028 MW
W_{1b} = 0.19752 MW } **Level-1**

W_{2a} = 0.4173125 MW
W_{2b} = 0.049278 MW } **Level-2**

Heat rejected to condenser-2: 1214 kW
Heat rejected to condenser-3: 403 kW

Therefore, total refrigeration power is;

= 0.06028+ 0.19752 + 0.4173125 + 0.049278 = 0.72439 MW

Simulated power for heat rejection to cooling water = 0.677642 MW
Simulated power for partially heat rejection to process and rest to cooling water = **0.72439** MW
Actual power consumption when heat is rejected to cooling water = 0.770135 MW

Hence, saving in the refrigeration process due to integration with the background process is; = 0.677642 - **0.72439** = -**0.046748 MW**

So, if we simulate this design then we see that for the level 1 will be consuming 0.6028 MW and here 0.19752 MW and for level 2 will be consuming point 4173125 MW and 0.049278 megawatt and, but we will be able to satisfy the total hot utility requirement through this. So, we do not have to purchase any hot utility requirement for the process. So, total energy requirement is this 0.72439 MW here also this is negative; that means, I have to use more power than my base case, but I am able to satisfied my total hot utility requirement.

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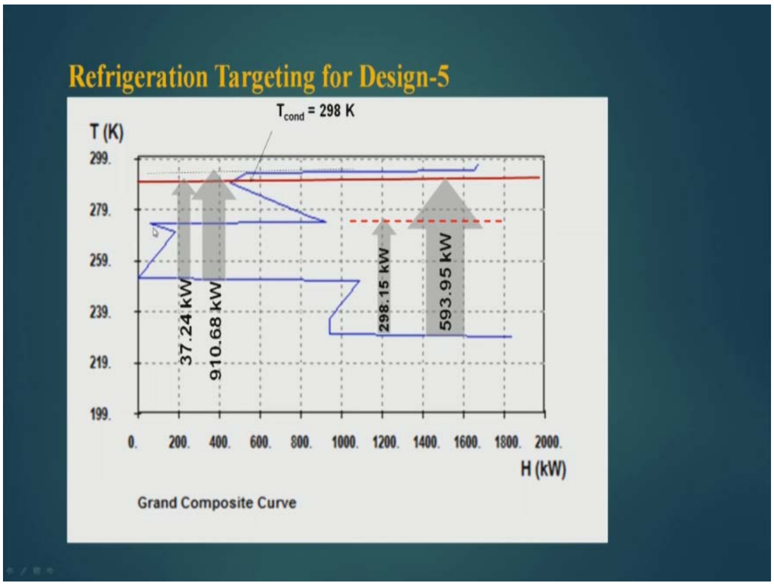

Refrigeration Targeting for Design-5

Now, let us go to the design 5 here what I am doing a part of this of this energy which we have received here in the evaporator is pumped to satisfy the hot utility requirement of this area and this is done through condenser two and the remaining part is put to the cold water similarly a part of heat here 298. 15 is put into this energy level to satisfy the demand hot utility demand here which is 403 and rest of it is put to the cold water.

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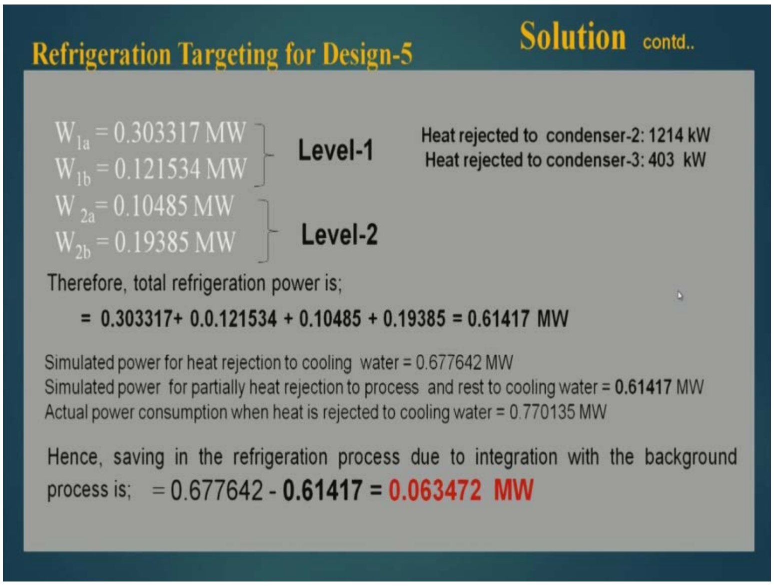

Refrigeration Targeting for Design-5

Solution contd..

W_{1a} = 0.303317 MW
W_{1b} = 0.121534 MW } Level-1

W_{2a}= 0.10485 MW
W_{2b} = 0.19385 MW } Level-2

Heat rejected to condenser-2: 1214 kW
Heat rejected to condenser-3: 403 kW

Therefore, total refrigeration power is;

= 0.303317+ 0.0.121534 + 0.10485 + 0.19385 = 0.61417 MW

Simulated power for heat rejection to cooling water = 0.677642 MW
Simulated power for partially heat rejection to process and rest to cooling water = **0.61417** MW
Actual power consumption when heat is rejected to cooling water = 0.770135 MW

Hence, saving in the refrigeration process due to integration with the background process is; = 0.677642 - **0.61417** = **0.063472 MW**

So, this is another arrangement and if you simulate it we see that for level 1 will be consuming point 30317 MW and 0.121534 MW and for level 2 will be consuming 0.10485 megawatt and 0.19385 MW for level 2 and here also in this case we are satisfying the total hot utility requirement of the process. So, total energy requirement is this 0.61417 MW and here we are able to do the saving this much saving than the base case base case is this 0.677642 MW and we are also able to serve the hot utility requirement.

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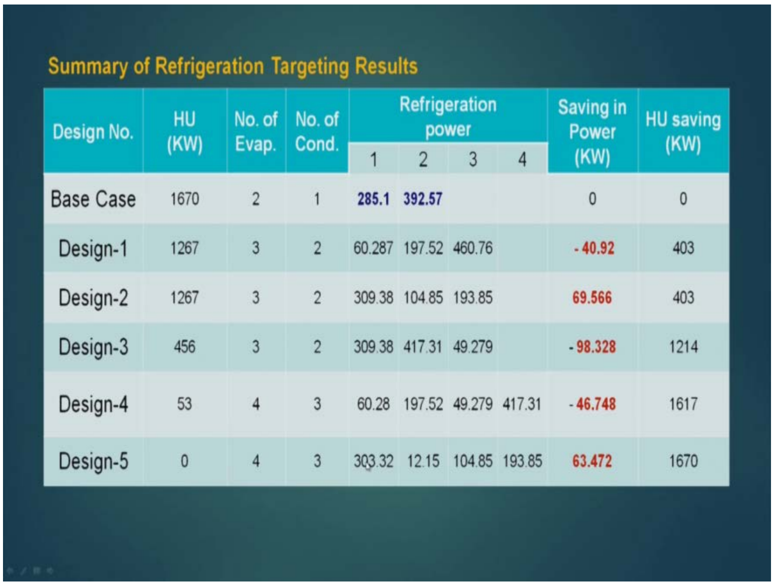

Summary of Refrigeration Targeting Results

Design No.	HU (KW)	No. of Evap.	No. of Cond.	Refrigeration power				Saving in Power (KW)	HU saving (KW)
				1	2	3	4		
Base Case	1670	2	1	**285.1**	**392.57**			0	0
Design-1	1267	3	2	60.287	197.52	460.76		**- 40.92**	403
Design-2	1267	3	2	309.38	104.85	193.85		**69.566**	403
Design-3	456	3	2	309.38	417.31	49.279		**- 98.328**	1214
Design-4	53	4	3	60.28	197.52	49.279	417.31	**- 46.748**	1617
Design-5	0	4	3	303.32	12.15	104.85	193.85	**63.472**	1670

So, summary here this is our base case here I was using one 670 hot utility and this is the power requirement of this case in design one the hot utility requirement has reduced to one 267 here I am using 3 evaporators and 2 condensers in the base case I am using two evaporators and one condenser and this is the requirement of the energy. So, energy saving is minus 40.92 and hot utility saving is 403 in the design 3 design two I am using 1267 hot utility here there are 3 number of evaporator 2 number of condensers and energy saving is 69.566 what I am only saving 433 kilowatt of hot utility in the design 3 hot utility requirement is reduce to 456 here three number of evaporators 2 number of condensers, but there is no saving.

That means, I am using more power than the base case pressure saving is minus, but I am able to save one two one four kilowatt of hot utility here design number four the hot utility requirement is 53 only this is 4 evaporators and 3 condensers and here also saving is negative; that means, I am consuming more energy than my base case and there is a saving of 161617 hot utility kilowatt of hot utility and design 5 here the hot utility requirement is 0, I am using 4 number of evaporators and 3 number of condensers and I am there is a saving in the energy of 63.472 kilowatt and the energy saving in hot utility is maximum.

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Refrigeration Targeting

Decision will depend on:

1. Design complexities

(No. of evaporators, condensers, heat exchangers, etc.)

2. Saving in Power
3. Saving in Hot Utilities(HU)

For the present case the cost of hot utility will below and thus will not affect the TAC much. Nevertheless, the present example offers a method to analyze And target Refrigeration systems

So, this appear to be design 5 appears to be the best design, but we as for as energy conservation is concerned, but the design has to be checked through other yardsticks, also now let us see the decision will depend upon the design complexities number of evaporators condensers and heat exchangers etcetera because a complex design with more number of units are not good designs the second consideration will be the saving in power and third consideration will be the saving in hot utility, but in this case in the present case the cost of hot utility will be low and thus will not affect the t a c much nevertheless the present example offers a method to analyze and target refrigeration system though here the hot utility cost will be very less and it will not going to affect the t a c much, but this problem or this solution method gives a method to analyze the refrigeration targeting value and that is why we have taken up this.

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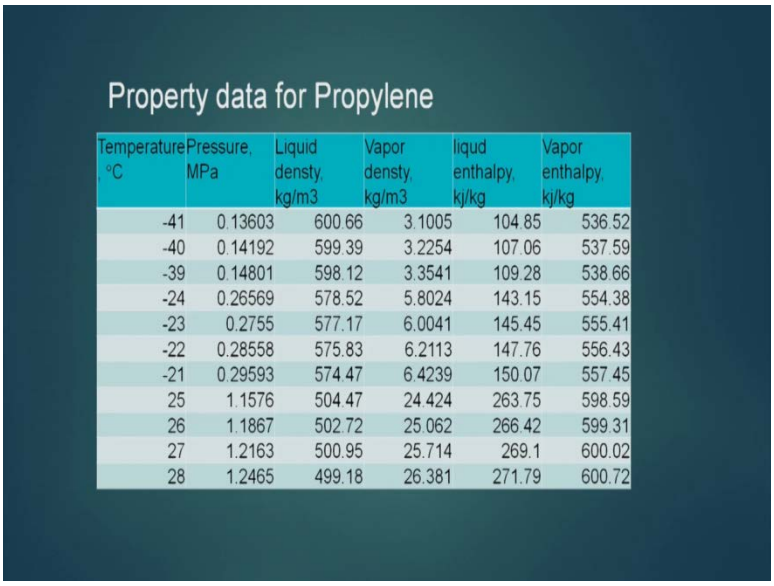

Property data for Propylene

Temperature, °C	Pressure, MPa	Liquid densty, kg/m3	Vapor densty, kg/m3	liqud enthalpy, kj/kg	Vapor enthalpy, kj/kg
-41	0.13603	600.66	3.1005	104.85	536.52
-40	0.14192	599.39	3.2254	107.06	537.59
-39	0.14801	598.12	3.3541	109.28	538.66
-24	0.26569	578.52	5.8024	143.15	554.38
-23	0.2755	577.17	6.0041	145.45	555.41
-22	0.28558	575.83	6.2113	147.76	556.43
-21	0.29593	574.47	6.4239	150.07	557.45
25	1.1576	504.47	24.424	263.75	598.59
26	1.1867	502.72	25.062	266.42	599.31
27	1.2163	500.95	25.714	269.1	600.02
28	1.2465	499.18	26.381	271.79	600.72

Now, this is a property data for polypropylene and the enthalpies and the densities where calculated based on this data now.

Thank you.