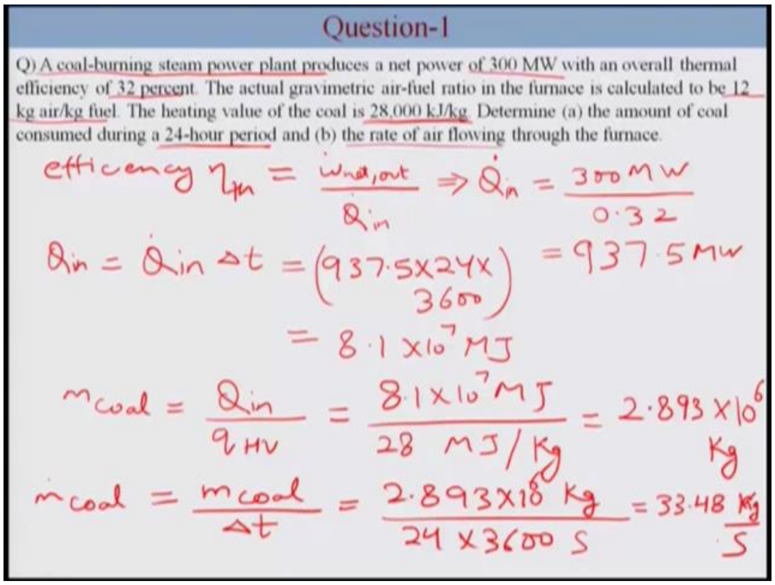
Engineering Thermodynamics
Professor Jayant K Singh
Department of Chemical Engineering
Indian Institute of Technology Kanpur
Lecture 31
Examples on second law of thermodynamics

Hello and welcome back, today we will be discussion few problems related to second law of thermodynamics, so let us begin the problems.

(Refer Slide Time: 0:26)



A cool burning steam power plant produces a net power of 300 megawatt and overall thermal efficiency of 32 percent, the actual gravimetric air fuel ratio in the furnace is calculated to be 12 kilogram of air per kg of fuel, the heating value of coal is 28000 kilojoule per kg, we have to determine the amount of coal consumed during a 24 hour period and the rate air flowing through the furnace.

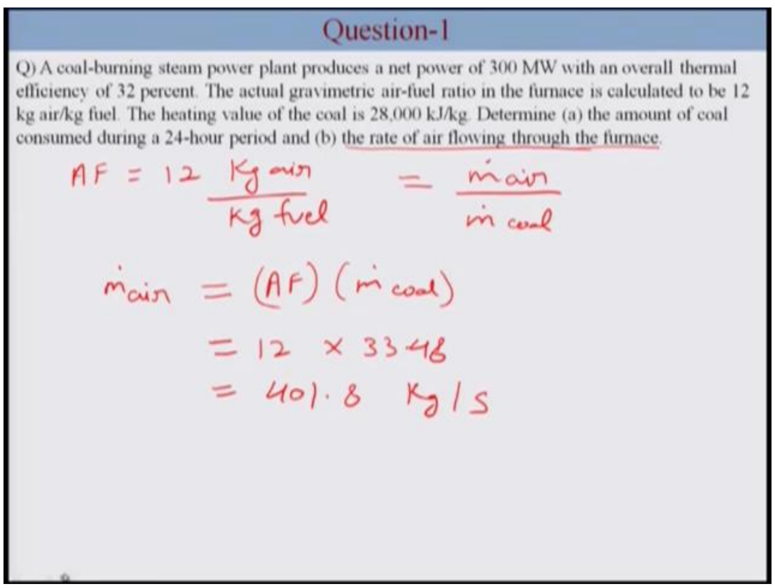
So the efficiency of a furnace is given as work output divided by the heat which is given as input. So from here we can calculate the heat given as input per unit time. This is equal to net work output which is 300 megawatt divided by the efficiency which is 0.32. So the rate of heat input is 937.5 megawatt.

From his rate we can calculate the amount of heat input given to the power plant, so this is equal to Q in lot multiplied by time that is delta T, so 937.5 multiplied by time is we have to calculate in 24 hour period, so it is 24 into 3600, so this is equal to 8.1 into 10 to power 7 megajoule.

We know the heating value of the coal, from this we can calculate the amount of coal consumed, so the mass of coal would be heat which is given as input and the heating value of coal, so which is Qhb, so 8.1 into 10 to power 7 megajoule divided by heating value of coal is 28000 kilojoule, so it can be written as 28 megajoule per kg. This is equal to 2.893 10 to the power 6 kg.

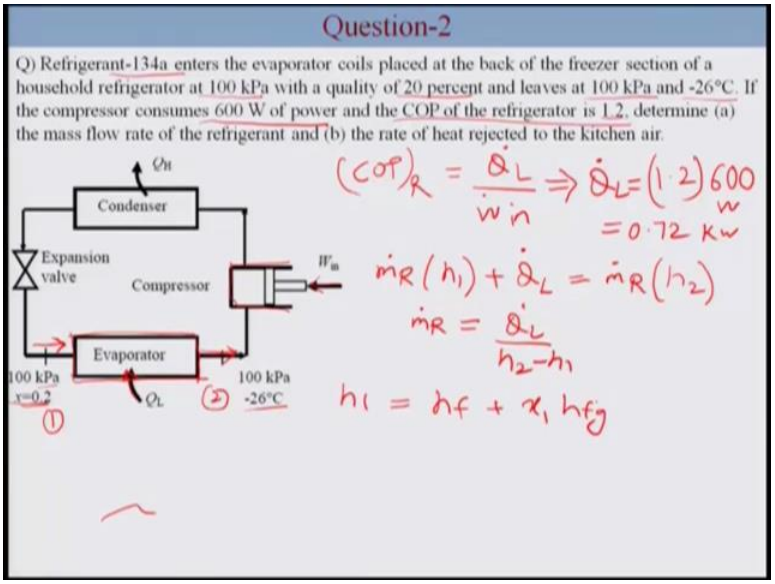
From this we can also calculate the rate of coal which should be given as input by dividing the mass of the coal by time, so this is rate of coal which should be given as input is mass of coal divided by time, so this is 2.893 into 10 6 kg divided by time which is 24 hours, so 24 into 3600 seconds so it is equal to 33.48 kg per second.

(Refer Slide Time: 3:38)



In the second part we need to calculate the rate of air flowing through the furnace, so as we know the air fuel ratio is 12 kg air per kg of fuel as it is given in the question, so this air fuel ratio is equal to mass flow rate of air divided by mass flow rate of coal. From this we can calculate the mass flow rate of air or rate of air flowing through the furnace, so M dot air is equal to air fuel ratio multiplied by M dot 4, so this we have already calculated in the previous part this is equal to 12 multiplied by 33.48 which is equal to 401.8 kg per second.

(Refer Slide Time: 4:35)



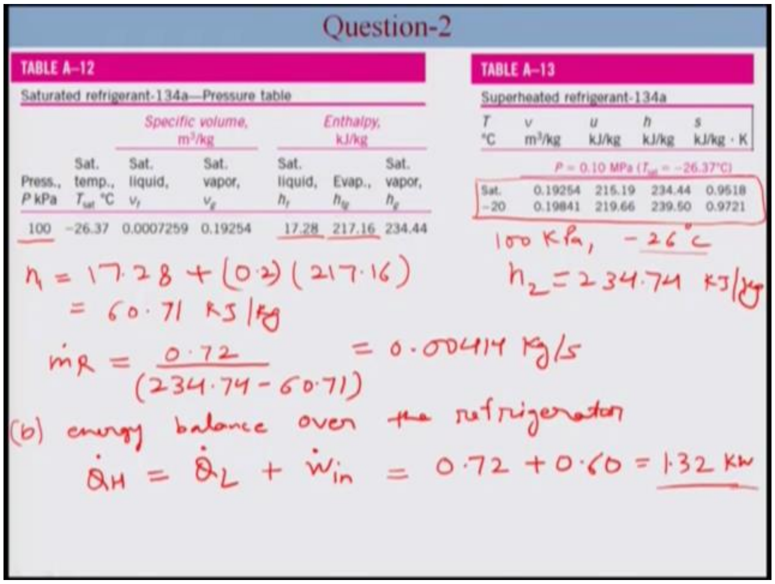
Moving on to the next question, in this a refrigerant 134 A enters the evaporated coil, so this is an evaporator, refrigerant enters the evaporator coil placed at the back of the freezer section of a household refrigerator at 100 kilopascal, so it is entering at 100 kilopascal with the quality of 0.2 that is 20 percent and leaves at 100 kilopascal and minus 26 degree Celsius from here it is leaving at 100 kilopascal and minus 26 degree Celsius.

If the compressor consumes 300 water power, so this is the compressor and it consumes 600 watt of power and the COP of the refrigerator is 1.2 for this refrigerator the COP is 1.2 determine the mass flow rate of refrigerant and the rate of heat rejected to the kitchen air. COP of refrigerator is the amount of heat which is removed from the refrigerator divided by the work which is given as input to remove that heat. So from here Ql is equal to COP that is 1.2 multiplied by work input which is 600 watt. So Ql dot is equal to 0.72 kilowatt.

Now if we apply energy balance so refrigerant is entering form here, some of heat is added, it takes some of heat and then it comes out of the evaporator, so and the energy balance will be MR, this is mass of the refrigerant, it is entering the evaporator multiplied by its enthalpy, so this point we take as 1 and here it is 2, so MR into enthalpy at the point 1 plus Ql which the is the heat it is removing is equal to mass flow rate of the refrigerant and it is multiplied by H2 enthalpy when it is leaving the evaporator.

So this gives mass of the refrigerant or mass flow rate of the refrigerant as Ql dot dived by H2 minus H1. Now we need to know H2 an H1, so for H1 P1 is 100 kilopascal and X is 0.2, it is a mixture of liquid and vapour, so H1 will be Hf plus X1 Hfg at the conditions of 1.

(Refer Slide Time: 7:29)

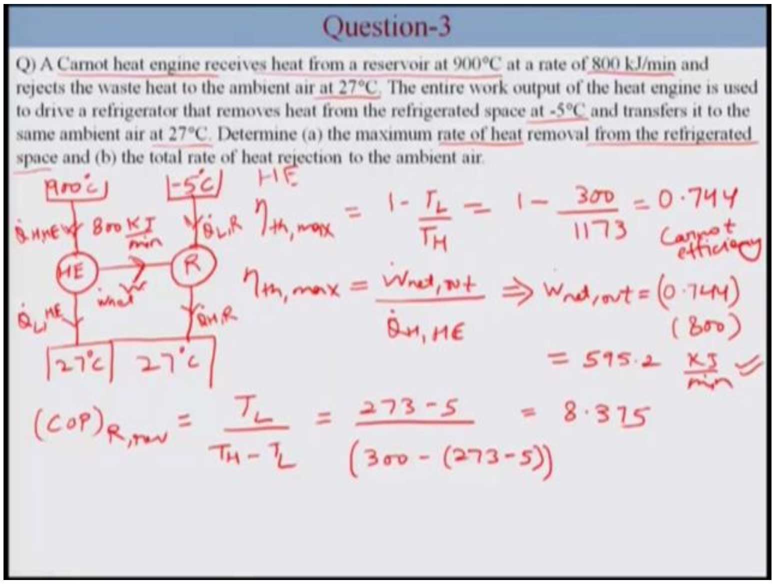


So if we see from the steam table of saturated refrigerant at 100 kilopascal, Hf is 17.28 and Hfg is 217.16, so value of H1 will be 17.28 Hf plus X 1 is point 2 multiplied by Hfg 217.16, so this is equal to 60.71 kilojoule per kg.

Similarly for second state it is superheated refrigerant, it is at 100 kilopascal and temperature is minus 26 degree Celsius, so for getting the value of H we need to interpolate between these two as saturation temperature is minus 26.37 and we need to know the values is at minus 26 degree Celsius. So from here the H2 is after interpolation 234.74 kilojoule per kg.

So mass of refrigerant will be obtained from the previous equation by putting all the values H2 minus H1 uh this is equal to 0.00414 kg per second. The second part is, we have to calculate the rate of heat rejected to the kitchen air, so if we apply energy balance over the refrigerator, so heat which is given out or rejected from the refrigerator or its rate is equal to rate of heat removed from the refrigerated space plus power which is given as input, so we know all the values expect Qh dot, so 0.72 plus 0.60, this is equal to 1.32 kilowatt. So this much amount of heat is rejected to the kitchen air.

(Refer Slide Time: 10:10)



In the next question a Carnot heat engine receives heat from a reservoir at 900 degree Celsius at a rate of 800 kilojoule per minute and rejects the waste heat to the ambient air at 27 degree Celsius. The entire work output of the heat engine is used to drive a refrigerator that removes heat from the refrigerated space at minus 5 degree Celsius and transfers it to the same ambient air at 27 degree Celsius. Determine the maximum rate of heat removal from the refrigerated space and total rate of heat rejection to the ambient air.

So in this question there is a heat engine which receives heat from the reservoir at 900 degree Celsius so this is at 900 degree Celsius and at a rate of 800 kilojoule per minute and rejects the waste heat to the ambient air at 27 degree Celsius. The entire work output so some work is being produced and this work output of the heat engine is used to drive a refrigerator, so this mug output is given as input to a refrigerator that removes heat from the refrigerated space.

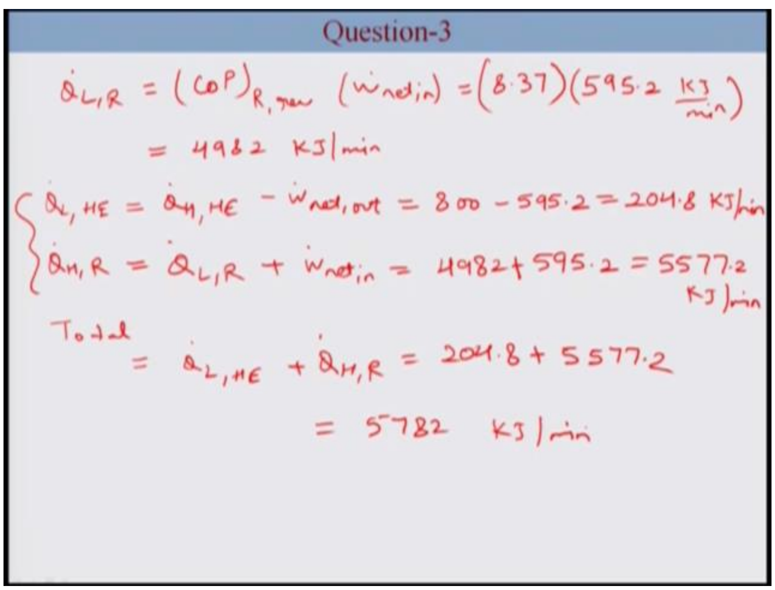
So this removes heat from the refrigerated space which is maintained at minus 5 degree Celsius and transfers it to the same ambiance, so it transfers it to same ambient air which is at 27 degree Celsius. Now this is the overall schematic diagram of what is said in the question. Now we have to determine the maximum rate of heat removal from the refrigerated space.

So assuming that all the process operates steadily, for heat engine maximum thermal efficiency is equal to 1 minus Tl by Th. So for heat engine, Tl is 27 degree Celsius and Th is 900 degree Celsius, so this will be 1 minus 300 divided by 1173. So it comes around to be 0.744. So this is the carnot efficiency of the heat engine. Writing this in terms of work and heat so work net output, this is the work output divided by Qh.

So this is Qh for heat engine Q dot h dot heat engine from this, we will get work output from the heat engine and this is equal to efficiency 0.744 multiplied by Qh dot for heat engine that is 800 so this is equal to 595.2 kilojoule per minute. Now this work is given as input to the refrigerator. The rate of heat removal from the refrigerated uh space will be maximum if the Carnot refrigerator is used. The COP of refrigerator is Tl divided by TH minus Tl and this is equal to per head.

Refrigerator I will be 273 minus 5 divided by this 300 minus 273 minus 5 so this is equal to 8.375. Marking all the notation, so here the heat which heat engine is taking from a source at 900 degree Celsius, it is Q dot H or heat engine. It is rejecting heat to the (sur) ambient air which is Ql dot of heat engine. For refrigerator it is taking heat at minus 5 degree Celsius, so this is marked as Ql dot for refrigerator and it is rejecting to the ambient air which is marked as Qh dot of refrigerator.

(Refer Slide Time: 15:27)

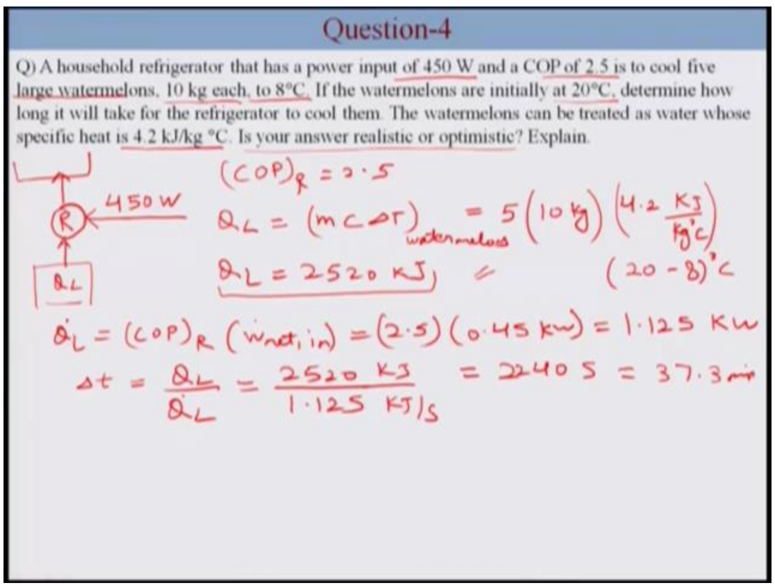


And the work is work net which is given out from the heat engine and is taken as input by the refrigerator. The rate of heat removal from the refrigerated space becomes Ql dot R is equal to COP of the refrigerator multiplied by net input work and this is equal to 8.37 multiplied by 59512 kilojoule per minute. So this value comes out to be 4982 kilojoule per minute.

Second we need to calculate total rate of heat rejection to the ambient air, so from both heat engine and refrigerator, some heat is being rejected to the ambient air, so from the heat engine Ql dot of heat engine is Qh dot minus net work which is given as output. This is equal to 800 minus 595.2, so this comes out to be 204.8 kilojoule per minute and from refrigerator, Qh dot R is equal to Ql dot plus work which is given as input.

So this is equal to 4982 plus 595.2, so this is equal to 5577.2 kilojoule per minute. The total amount will be sum of these tow, so this is equal to heat engine where Qh dot of refrigerator and this is equal to 204.8 plus 5577.2 this is equal to 5782 kilojoule per minute. So this is the amount of heat which is rejected to the ambient air.

(Refer Slide Time: 17:50)



In the next question a household refrigerator that has a power input of 450 watt and a COP of 2.5 is to cool 5 water lemons, 10 kg each to 8 degree Celsius. If the watermelons are initially at 20 degree Celsius determine how long it will take from the refrigerator to cool them. The watermelons can be treated as water whose specific heat is 4.2 kilojoule per kg degree Celsius. And after that we also need to explain is our answer realistic or optimistic.

For refrigerator it takes some heat from a space maintained at low temperature and it gives it to a space at high temperature and some work is given as inputs. So it is given in the question power input is 450 watt. Now COP is given which is 2.5, we we can calculate the total amount of heat which needs to be removed to cool the watermelon, so that heat which is to me removed is Ql and that is equal to Mc multiplied by delta T for watermelons.

And this is equal to there are 5 watermelons, so for each multiplied by mass of each is 10 kg, specific heat is 4.2 kilojoule per kg degree Celsius and the temperature difference is it is cooled from 20 to 8 degree Celsius so 20 minus 8, this Ql is equal to 2520 kilojoule. So this is the amount of heat which needs to be removed, total amount and the rate of heat removal from the refrigerator is Ql dot which is equal to COP of the refrigerator multiplied by the rate of work which is given as input.

So this becomes equal to 2.5 multiplied by 0.45 kilowatt, so rate of heat removal from the refrigerator is 1.125 kilowatt, so from this we can calculate the time needed to remove this Ql amount of heat, so time will be total heat which is to be removed and the rate of heat removal, so 2520 divided by 1.125 this is in kilojoules and this is kilojoule per second, so it gives 2240 second or 37.3 minutes.

And this answer is optimistic since the refrigerator space will gain some heat during the process from the surrounding air which will increase the work load, thus in reality it will take longer to cool the watermelons. So we will end this lecture, thank you.