Mass Transfer Operations II
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Drying: Rate of drying for continuous dryers

Welcome back to mass transfer operation 2 course and we are discussing on drying operations in the previous class we discussed on the rate of drying for batch dryers in that section we discussed on the cross circulation drying and through circulation drying.

Now, we will be discussing on the rate of drying for the continuous dryers, there are so many continuous dryers available in the actual applications the most widely used continuous dryers is the rotary dryer from one side of this rotary dryer this weight solid enters and from the opposite side the hot air enters as the drying mediums.

So, in most of the cases the continuous dryers are of counter current mode. So, we will be discussing on the rate of drying for the continuous counter currents dryers. So for that we need to do some material and energy balance and that will be like this that is integral part of the design calculation of all kinds of dryers including the continuous dryers.

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Continues drying

Material and energy balance are integral parts of design calculations of all kinds of dryers including continuous dryers.

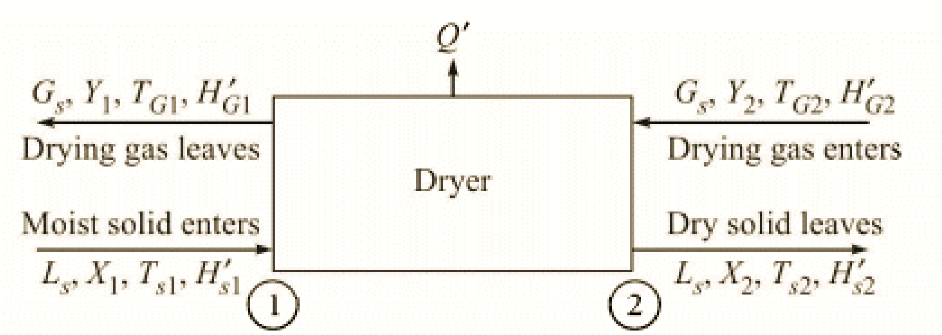

Figure: Input and output streams in a continuous dryer.

Here S_s = Flow rate of solid (kg/h, dry basin)

G_s = Flow rate of air (kg/ h, dry basin)

Q = rate of heat lost (kJ/h)

Moisture balance: $S_s X_1 + G_s Y_2 = G_s Y_1 + S_s X_2$

$S_s (X_1 - X_2) = G_s (Y_1 - Y_2)$

Enthalpy balance: $G_s H'_{G2} + S_s H'_{S1} = G_s H'_{G1} + S_s H'_{S2} + Q$

Taking to as reference temperature,

Enthalpy of solid:

$$H_{s'} = C_{ps} (T_s - T_0) + XC_{pl}((T_s - T_0)$$

$$= C_{ps} (T_s - T_0) + 4.187 + X (T_s - T_0)$$

Enthalpy of gas:

$$H_{G'} = C_{pG} (T_G - T_0) + YC_{pv}((T_G - T_0) + \mathrm{Y}\, \lambda_S$$

$$H_{G'} = 1.005 (T_G - T_0) + 1.88\, Y((T_G - T_0) + 2500\,\mathrm{Y}$$

Where, C_{ps} → Specific heat of solid

C_{pl} → Specific heat of liquid (water) = 4.187 kJ/ kg K

C_{pG} → Specific heat of dry gas (air) = 1.005 kJ/ kg K

C_{pv}→ Specific heat of vapor (water vapor) = 1.88 kJ/ kg K

λ_S → Heat of vaporization of water at reference temperature (0°C)

= 2500 kJ/kg at T_0 = 2.73.2 k

ΔH_A→ Integral heat of wetting, at T_0 kJ/kg

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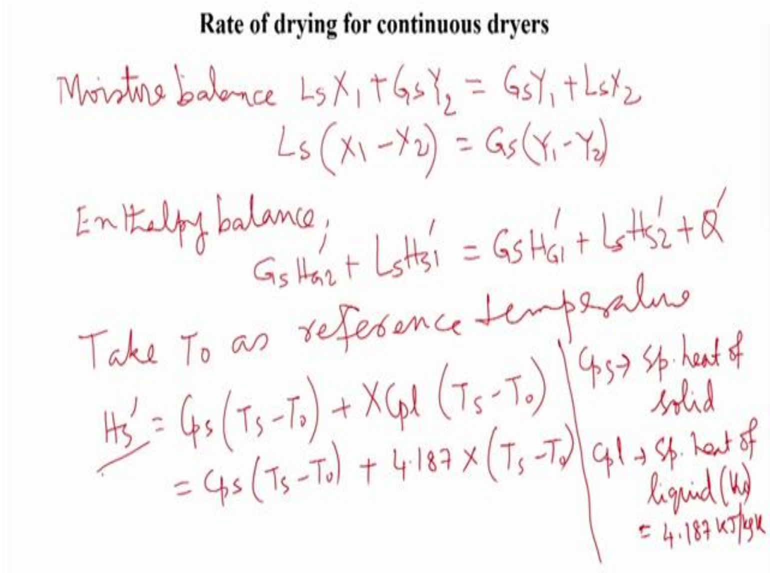

Now we need to do the moisture balance fast, so we will be doing moisture balance across the dryer, that will be say LS into X1 plus GS into Y2 is equal to GS into Y1 plus LS into X2. So from here we can say this one just by manipulation we can say LS into X1 minus X2 is equal to GS into Y1 minus Y2.

And whenever will be doing the enthalpy balance, we need to consider the entire dryer. So for that we have this GS into HG2 prime plus LS into HS1 prime is equal to GS into HG1 prime plus LS into HS2 prime plus that Q prime which is lost. So we have to take this T0 as this we can say the reference temperature then we need to calculate this HS prime values like this from the specific heat values, that is we can say this one HS prime is equal to CpS into TS minus T0 plus X into Cpl into TS minus T0.

So that is nothing but we say that this one we will say is equal to CpS into TS minus T0 plus 4.187 into X into TS minus T0. Where we can say this one CpS that is specific heat of solid then Cpl that is equal to specific heat of liquid, here it is water that is we have taken as this 4.187 kilojoule per Kg kelvin and will be calculating this enthalpy of the gas that is we have say taken this one as the solid.

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Rate of drying for continuous dryers

Enthalpy of gas

$$H_G' = C_{pG}(T_G - T_0) + Y C_{pV}(T_G - T_0) + Y \lambda_w$$

$$= 1.005(T_G - T_0) + 1.88Y(T_G - T_0) + Y \times 2500$$

$C_{pV} \rightarrow$ Sp. heat of vapor (water) $= 1.88\ kJ/kgK$

So will be calculating this enthalpy of gas say, enthalpy of gas say this HG prime that is equal to CpG into TG minus T0 plus Y into CpV into TG minus T0 plus Y into lambda w. So here this CpG is equal to say 1.005 into TG minus T0 plus CpV is equal to say 1.88 into Y into TG minus T0 plus Y into lambda means Y into 2500.

So, here we can say this lambda w that is we can say this let it into vaporization of water at this reference temperature T0 means a 0 degree Celsius or 273 kelvin and this CpV actually is the specific heat of vapor, this CpV is the specific heat of water vapor, that is we can say that is equal to say 1.88 kilojoule per Kg kelvin.

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Problem 3

A non-hygroscopic filter cake is to be dried in a continuous countercurrent dryer from 30% moisture to 2% moisture (wet basis) at a rate of 1000 kg per hour. The material enters the dryer at 27°C and leaves at 52°C. Fresh air is mixed with a part of the moist air leaving the dryer and heated to a temperature of 120°C in a finned air heater using low pressure steam (4 kg/cm^2, gauge). Calculate (a) the rate of flow of fresh air, (b) the fraction of the air leaving the dryer that is recycled, (c) the theoretical steam requirement, and (d) the heat loss from the dryer, if any.

Given: temperature of fresh air: 29°C; humidity: 0.018 kg/ kg dry air; humidity of the air leaving the heater : 0.03 kg/kg; humidity and temperature of the air leaving the dryer : 0.05 kg/kg, 70°C; specific heat of the dry solid : 920 J/kg.K.

Solution: Basis of the calculation 1 h operation

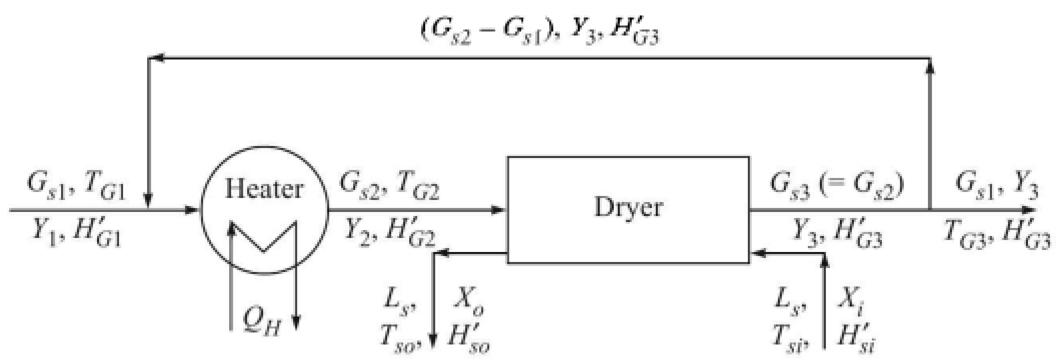

Figure: Schematic of a dryer with recirculation of air.

Now actually we will be solving on problem on the continuous dryer, so the problem is very simple like this a non-hygroscopic filters cake is to be dried in a continuous current dryer from 30 percent moisture to 2 percent moisture that is wet basis at a rate of say1000 Kg per hour. The materials enter the dryer at 27 degree Celsius and leaves at 52 degree Celsius. Fresh air is mixed with a part of the moist air leaving the dryer and heated to a temperature of 120 degree Celsius in a finned air heater using low pressure steam that is 4 Kg per centimeter square, gauge.

Now we need to calculate the rate of flow of fresh air that is required to dry this wet solid and the fraction of the air leaving the dryer that is recycled, then the theoretical steam requirement and the heat loss from the dryer, if there is any.

Now the data which are given to solve this problem are like temperature of the fresh air is 29 degree Celsius with the humidity is 0.018 Kg per Kg dry air and humidity of the air leaving the heater is 0.03Kg per Kg dry air and the humidity and temperature of the air leaving the dryer is 0.05 Kg per Kg dry air and temperature is 70 degree Celsius, specific heat of the dry solid is 920 joule per Kg kelvin and latent heat of the steam at the 4 Kg per centimeter square, gauge pressure is 2110 kilojoule per Kg.

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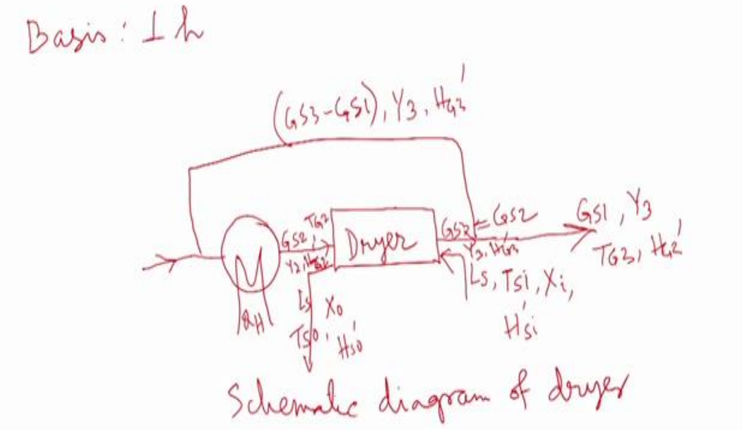
Solution



Now, we need to solve this one it is a simply we can say this counter current dryer in a continuous one. So first of all we need to draw this diagram, we can say this one we take this one just like we will take first the basis as this we can say 1 hour, let us take this for simplicity and we need to draw this total flow sheet diagram for this problem.

Like this we have this dryer and say one heater is there before this dryer so it heats the drying medium prior to entry of this dryer like this and it leaves the dryer and then if part actually is recycled a part of this we can say this one drying gas actually is recycled back to this heater. So we need to get this one and the solid is entering from here and so it will take this one that the flow rate of the solid is LS and the temperature of the solid will be TS1 and this we can say this TSi also we can take then the humidity this moisture content is Xi and enthalpy is say HSi prime.

And whenever it will be leaving the dryer so this flow rate will be say let us take this flow rate will be this LS dry basis and this temperature will be say TS out so TS out and say the moisture content will be X0 and the enthalpy will be HS out prime and this heater actually takes the QH amount of heat to heat this we can say drying medium and whenever it will be entering the drying say we can say flow rate will be like this flow rate of this hot air will be GS2 and temperature will be say TG2 and humidity will be say Y2 and enthalpy will be HG2 prime.

And whenever it will be leaving this dryer this hot air will be leaving then we can say this one, the flow rate will be say this GS3 and say we can say this one again it will be same as GS2 and say and humidity will be we can this one Y3 and say enthalpy value will be HG3 prime and one part actually will be leaving, so that will can say this one at GS1 let us take this one with this Y3 will be same and TG3 will be same also and we can say this HG3 also will be same.

So only one part say out of this one, one part actually is recycled so this part actually we can say this flow rate will be like this total flow rate is GS3 minus this GS1. GS3 minus GS1 and say humidity will be Y3 and enthalpy will be HG3 prime. So this is the one we can say this one schematic diagram of the, we can say this on dryer. So this is the important part to solve a problem, schematic diagram of continuous dryer.

So now whatever the conditions are given to solve the problem will be now noting down like this temperature of the fresh air I told this one at 29 degree Celsius then the humidity is 0.018 Kg per Kg dry air then humidity of the air leaving the heater is 0.03 Kg per Kg dry air humidity and temperature of the air leaving the dryer is 0.05 Kg per Kg dry air and 70 degree Celsius, specific heat of the dry solid that is 920 joule per Kg Kelvin. And let in heat of the steam at 4 kg per centimeter square gauge pressure. This one is 2110 Kilo Joule per Kg, So now from there actually will be calculating this one step by step will be doing this one.

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We have $T_{G1} = 29^\circ C,\ Y_1 = 0.018$

$$H_{G1}' = (1.005 + 1.88 \times 0.018)(29 - 0) + 2500 \times 0.018$$
$$= 75.13\ kJ/kg$$

$$T_{G2} = 120^\circ C,\ Y_2 = 0.03$$

$$H_{G2}' = (1.005 + 1.88 \times 0.03)(120 - 0) + 2500 \times 0.03$$
$$= 202.4\ kJ/kg$$

$$T_{G3} = 70^\circ C,\ Y_3 = 0.05$$

$$H_{G3}' = (1.005 + 1.88 \times 0.05)(70 - 0) + 2500 \times 0.05$$
$$= 201.93\ kJ/kg$$

Let us take TG1, so we have that is equal to 29 degree Celsius and Y1 is equal to 0.018. Now we can calculate the what will be the enthalpy value at a HG1 prime so that will be calculating just using this simple formula HG1 prime is equal to say 1.005 plus 1.88 into Y prime 0.018 into TG1 that is we can say 29 minus reference temperature 0 plus 2500 into Y1 that 0.018. So this is coming out to be as 75.13 kilojoule per Kg.

So then we need to calculate, the HG2 prime for that we have this TG2 we have is equal to 120 degree Celsius and Y2 is giving as 0.03. So from there will be calculating in the same way will be calculating HG2 prime that is equal to 1.005 plus 1.88 into 0.03 into 120 minus 0, here also reference temperature is 0 degree Celsius plus 2500 into 0.03. So it comes out as 202.4 kilojoule per Kg.

Similarly, this TG3 is equal to 70 degree Celsius and Y3 is equal to 0.05. So from here will be calculating HG3 prime is equal to 1.005 plus 1.88 into 0.05 into 70 minus 0 plus 2500 into 0.05, so that is coming out as 201.93 kilojoule per Kg. So we have now HG1 prime, HG2 prime and HG3 prime.

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Mass of solid (L_s) : $L_s = 1000(1-0.3) = 700 kg$

$$X_i = \frac{1000 \times 0.3}{700} = 0.429$$

$$X_o = \frac{0.02}{0.98} = 0.0204$$

$$C_{ps} = 920\ J/kgK = 0.92\ kJ/kgK$$

$$T_{si} = 27^\circ C,\ T_{so} = 52^\circ C$$

$$H'_{si} = (C_{ps} + 4.187 \times X_i)(T_{si} - T_0)$$
$$= (0.92 + 4.187 \times 0.429)(27-0) = 73.29\ kJ/kg$$

$$H'_{so} = (0.92 + 4.187 \times 0.0204)(52-0) = 52.28\ kJ/kg$$

Now, we will be calculating this mass of the solid and then from there actually we will be calculating the, we will be doing this we can say this one moisture balance and enthalpy balance, so first of all will be getting this mass of the solid say LS, so mass of the solid that is will be finding out LS. So LS is it is giving that 30 percent is there, 30 percent moisture is there so in the dry basis will be LS is equal to this 1000 into 1 minus 0.03. So we can say this one say it is 700 Kg. Then whatever the Xi will be out of this we can say this one moisture is 30 percent, so this one will be we can say 1000 into 0.3 divided by 700 so this is nothing but 0.429.

And this X out that is only 2 percent so we can say this one that is the desired one so we can say 0.02 by 0.98 so that will be like this 0.0204, so we have this one Xi and X out and CpS is also given that is supplied solid that is 920 joule per Kg kelvin. So this is nothing but 0.92 kilojoule per Kg kelvin. And say TSi is given that in which temperature the solid is entering TSi that is we can say (())(22:47) entering at 27 degree Celsius and TS out also is given as 52 degree Celsius.

So we will be calculating now the enthalpy of the solid, so say we can say this one will be calculating this HS in whatever the solid actually is entering with the enthalpy value that is we can say this CpS plus 4.187 into Xi that is into TSi minus say T0, so it is coming out as say we can say this one 0.92 plus 4.187 into 0.429 into this TS(())(23:51) in 27 degree Celsius minus 0 degree Celsius. So it is coming out as 73.29 kilojoule per Kg.

Now whatever the enthalpy of the solid which will be leaving the dryer HSo prime that is on the same way but the moisture quantity is different the will be calculating like this 0.92 plus 4.187 into 0.0204 that is the X out into temperature is 52 minus 0 so that enthalpy value will be like this 52.28 kilojoule per Kg.

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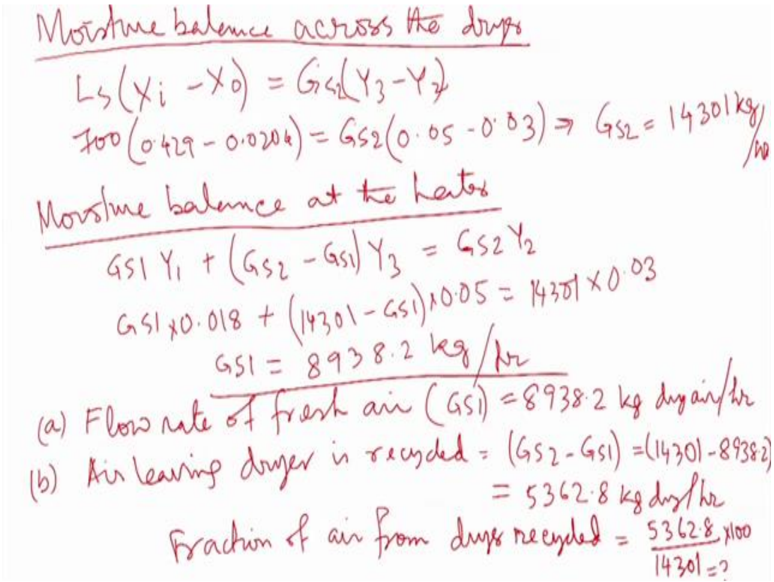

Now we need to do the moisture balance across this dryer, so we can do this moisture balance across the dryer like this a, that will be doing as a like LS into Xi minus X out is equal to GS into Y3 minus Y2, here actually GS is GS2 so this LS is equal to this 700 and xi is equal to 0.429 and X out is equal to 0.0204 this is GS2 we do not know but we know the moisture content of Y3 and Y2 that is we can say this one 0.05 minus 0.03. So from here will be getting this GS2 that is equal to say we will be getting by manipulation will be getting 14301 Kg. So we can say this one dryer.

So now we need to do the moisture balance at the heater will be doing this moisture balance at the heater, that is just by doing the moisture balance is GS1 into Y1 plus GS2 minus GS1 into Y3 is equal to GS2 into Y2. So if we put all the values here then we will be getting the GS1 that is not known actually. So we will be putting this, this GS1 into Y1 we know this one 0.018 plus GS2 just we have knowing found out this one 14301 minus GS1 we need to find out into Y3 is equal to 0.05 is equal to GS2 is 14301 into Y2 is equal to 0.03.

So from here we will be getting this there GS1 actually GS1 is equal to will getting that 8938.2 Kg dryer. So all this one as we have taken the basis at this 1 hour, so it will be like that is also per hour, that I also we can say Kg dryer per hour we can say this one per hour.

Now we will be doing this calculation like this a first flow rate of the fresh air that actually nothing but this one. So we can say this one the first answer of this first problem that is the flow rate of fresh air, so that is flow rate of fresh air that is we can say this one GS1 that is we have got this one as 8938.2 Kg dry air per hour.

Now we need to calculate that how much air actually is leaving the dryer that is recycle so that is the second question that how much air actually we can say this one GS2 minus GS1 which we can say this. That air leaving dryer that is recycled that is we can say this one is equal to we can say this one GS2 minus GS1.

So it is like this 14301 minus 8938.2 that is coming out to be as 5362.8 Kg dry air per hour. And then the question is that the fraction of the air that is from the dryer that is fraction that is recycled, fraction of air this one from dryer that is recycled is equal to we can say this one 5362.8 divided by total this one entry is 14301 into 100 so that is coming out to be 37.5 percent. So this is another answer.

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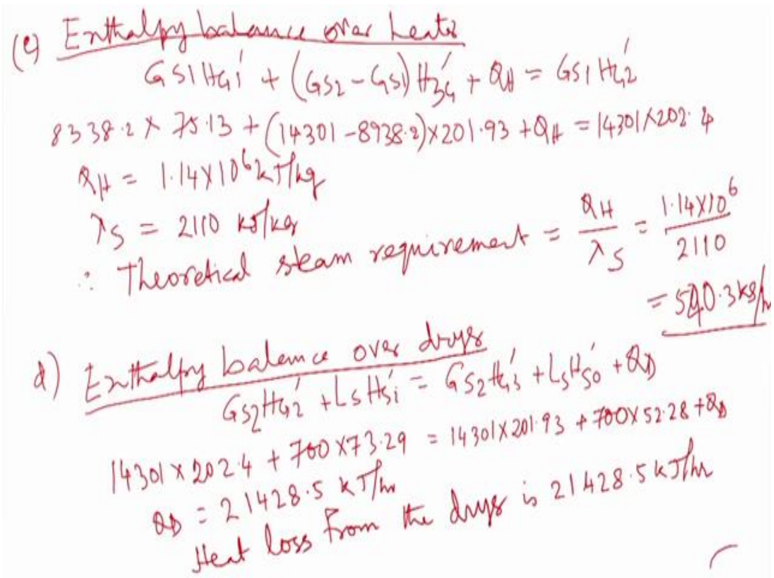

Now we need to do the enthalpy balance over the heater so that is we can say this one for problem c, so that is we can say theoretical steam requirement so for that we can do the enthalpy balance over heater. So there will be doing this GS1 into HG1 prime plus that whatever recycled back that is GS2 minus GS1 into HG3 prime plus which is lost actually we can say this QH amount that is nothing but we can say this one what is entering actually that is say GS1 into HG2 prime.

So we will putting all this to get whatever the amount of heat is lost, so that actually will find out from here we will be putting these 8938.2 into this enthalpy value is 75.13 plus that is 14301 minus 8938.2 into 201.93 plus this QH we need to find out is equal to 14301 into 202.4, so from here actually after manipulation will be getting QH is equal to 1.14 into 10 to the power 6 kilojoule per Kg.

So this amount heat is actually is lost and we know this one this latent heat this lambda S is actually is given for this one lambda S or at this 4 Kg per centimeter square, gauge pressure that is given as 2110 kilojoule per Kg.

So we can this theoretical steam requirement is equal to we can say this one from this basic formula QH by lambda S we will be getting QH got this one the 1.14 into the 10 to the power 6 divided by 2110. So from here will be getting like this 540.3 Kg per hour. So that is we can say the theoretical steam requirement will be 540.3 Kg per hour.

Now we will be getting how much heat is lost actually from the dryer that we need to find out, so we can say this one will doing again the enthalpy balance over the dryer. Suppose we initially done the enthalpy balance over the heater.

Now we will be doing this enthalpy balance over this dryer. So here will be doing like this a GS2 into HG2 prime plus LS into HSi prime is equal to GS2 into HG3 prime plus LS into HSo prime plus this we can say this one how much load actually we are giving to this heater. So all the value actually will be getting like this that is 14301 into HG2 prime is 202.4 plus LS is equal to 700 into HSi prime is equal to 73.29 is equal to say GS2 is equal to 14301 into HG3 prime is equal to 201.93 plus LS is equal to 700 into HS out that is we can say this one only 52.28 plus QD.

So from here we can say this one QD will equal to 21428.5 kilojoule per hour. So we can say this one from the dryer heat loss is, so heat loss from the dryer is 21428.5 kilojoule per hour. So that way actually can calculate this performance of the continuous dryer.

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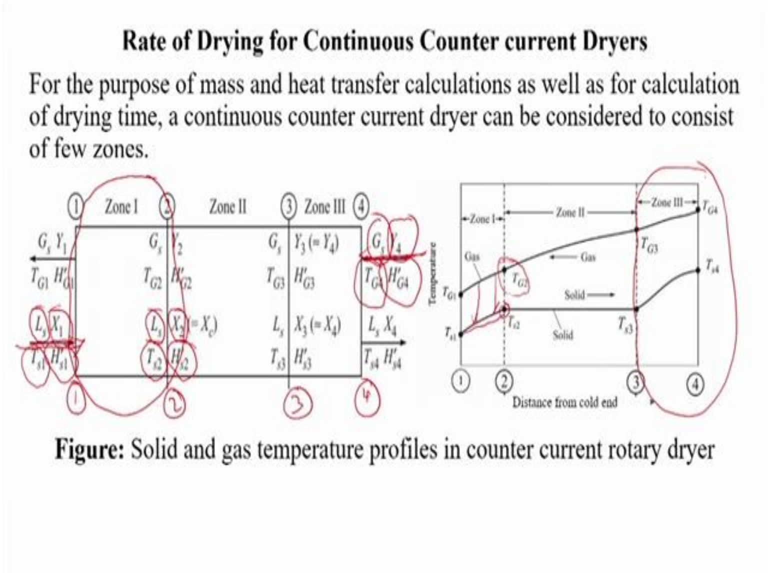

Now, we will be discussing on the rate of drying for continuous counter current dryers and will calculating the drying time and for that actually will be dividing this we can say total dryer into so many segments like this for the purpose of the mass and heat transfer calculations as well as for the calculations of drying time, a continuous counter current dryer can be considered to consist of few zones.

Like this the zone set for this simplicity we have taken the, there is three different zones are there in the continuous dryer say this first zone will be like this so that is we can say this one cold zone, so where this we can say this one cold to we can say this one moist solid is entering with LS flow rate and with the moisture content is X1 with temperature TS1 and the enthalpy is HS1 prime and this one the hot air actually is entering from the this one from the zone 4, so here you see this one the stations are like this station 1, station 2, station 3 and station 4. So from station 4 this we can say this one at the end of this zone 3 this we can say drying air is entering with the humidity with Y4 and temperature is TG4 and the enthalpy value is HG4 prime.

So it is entering here and in that zone actually were this hot air or drying air is entering there we can say the whatever the temperature is supplied to this drying solid it is used to heat the drying solid at the desired temperature only. No drying actually takes place in this zone like this.

So that we will be discussing in detail, so in the zone 1 say it is whenever it is entering in the beginning so the drying air which will be entering in the zone 1 with this we can say this one low temperature because you see in zone 2 and 3, the hot air is used to separate the we can say this moisture and during this process the temperature is decreased.

So whenever it will be entering this zone 1 with this minimum temperature we can say this one at TG2 so it is entering here and then it will come in contact with this we can say this one (())(38:27) solid like this so this (())(38:29) solid temperature will go on increasing from TS1 TS2 in zone 1 and this is that we can say this on flow rate is LS and this moisture content actually will be definitely will be decreasing.

That will be X2 that is we can say this critical moisture content and then temperature will be increase from TS1 to TS2 and enthalpy will also go on increasing from HS1 to HS2, and then whenever it will be this one maintaining its critical moisture content then you will see temperature of the solid will remain constant.

So that is why from TS2 to TS3 the temperature is constant so we can see this one TS2 is equal to TS3. Because at that condition the critical moisture content is already arrived, but at the same time the whatever the drying gas which is entering at TG4 at a high temperature in this zone 3 we can say where only the heating of this solid takes place that is decreasing is temperature from TG4 to TG3 again in zone 2 this (())(39:40) moisture we can say this one is removed this, sorry. Bound moisture content up to critical moisture content will be decreased from TG3 to TG2. And then in zone 1 this temperature of the gas will be decreasing from TG2 to TG1

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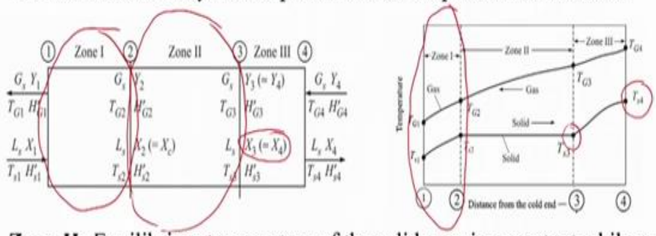
Zone I: Preheat zone → solid is heated by the gas until the rate of heat transfer to solid is balanced by heat requirements for evaporation of moisture.



Zone II: Equilibrium temperature of the solid remains constant while surface and unbound moisture are evaporated. The critical moisture content X_c is reached at boundary 3. Dry patches appear on the surface. Unsaturated surface drying and evaporation of bound moisture occur.

Zone III: Heated to the desired outlet temperature.

So we can say this one, the zone 1 that is in this zone or we can say this one in this zone the same, this is called actually the preheat zone solid is heated by the gas until the rate of the heat transfer to the solid is balanced by heat requirements for evaporation of the moisture.

So we can say this is a preheat zone and I discussed this also earlier that in this preheat zone the temperature of the drying gas is minimum means when it enters it, its temperature was maximum then when it enters the zone 1 that time its temperature is decreasing to a greater extent.

And in zone 2 which is we can say this one just after this zone 1 and before this zone 3, so it is we can say this equilibrium temperature of the solid remains constant because while surface and unbound moisture are evaporated. The critical moisture content Xc is reached at this boundary 3, or we can say this one critical moisture content actually now is here this critical moisture content actually that here the critical X3 or we can say this whatever X4 also both are same means that we can say critical moisture content because after that the moisture is not removed from the system only the temperature increases from here you see temperature increases from TS3 to TS4 and then it supposed to be desired temperature, what is the desired temperature based on that we can say this one where the station 4 will be.

But you see the moisture content will not change, so there dry patches appeared on the surface and unsaturated surface drying in evaporation of the bound moisture also occur. And zone 3 is nothing but this heated to the desired outlet temperature.

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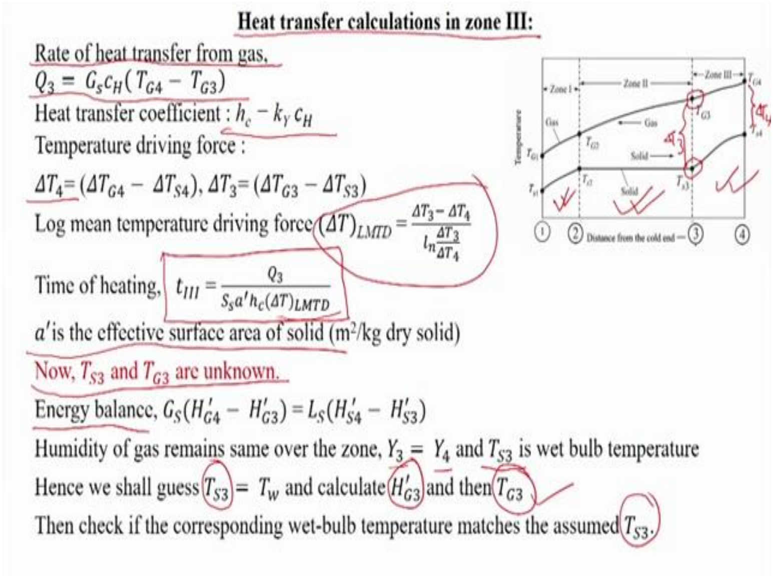

Now we will be this one doing systematic calculation of the drying time this, for this three zones but the convenient way of calculation of this first will be calculating this zone 3. Then will be calculating this zone 1 and finally will calculating zone 2.

So this, for this we can say this one we need to find out the rate of the heat transfer from the gas. This Q3 will be like this GS into CH into TG4 minus TG3, then we have a heat transfer coefficient is equal to kY into CH and this temperature driving force will be like this, this one we can say this one temperature driving force in the station 4 that is nothing but we can say T4 minus TS4 and here the temperature driving force in this we can say this one is station 3 will be TG3 minus TS3 ok.

So this we can say this one delta T4 this is delta T3. Now, as the temperature driving force is not linear or not we can say uniform or is not same. So that is why we need to get this log mean temperature driving force that is simply we are getting delta T3 minus delta T4 by ln delta T3 by delta T4.

And here actually (())(43:18) time of heating this how much time actually is required in the zone 3 that is we can say that will be getting by Q3 by SS into 'a' prime into hc into delta T driving force.

Where this 'a' prime is nothing but we can say this one effective surface area of the solid so that will be meter square per Kg dry solid.

Now we see here, TS3 and TG3 both are unknown. So this in this case we can say this one both these TS3 and TG3 are not known. We need to find out this TS3 and TG3 this one will be doing this one.

Now we need to the energy balance this one in this zone that will be GS into HG4 prime minus HG3 prime is equal to LS into HS4 prime minus HS3 prime. So, humidity of the gas remains same over the zone because we told that this Y3, Y4 all this are this one same because after that no drying actually takes place and TS3 is we can take as we can take as a wet bulb temperature.

Hence we shall guess this TS3 now we can say that is a wet bulb temperature and then will be calculating this HG3 prime and then TG3 prime whether we are getting this wet bulb temperature is matching with this assume TS3 or not we need to find out this one. If it is matching, then our guess was correct.

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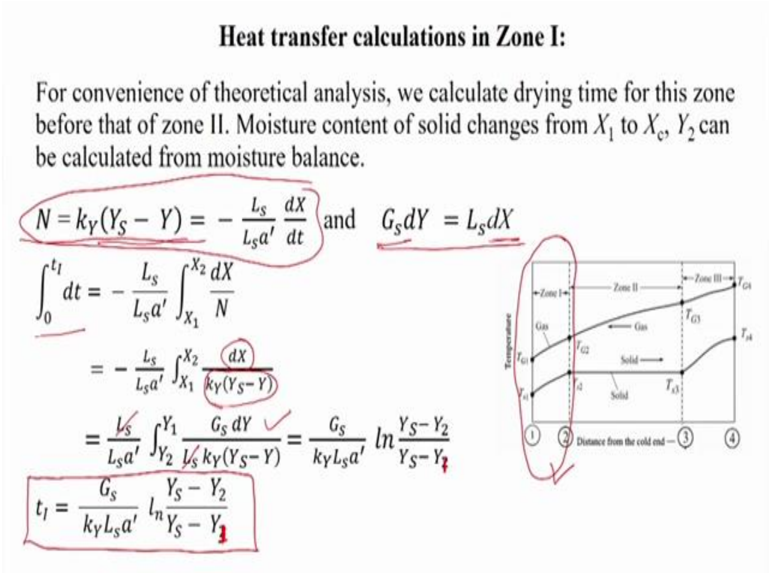

Now, we see this will be the heat balance in the zone 1. Because we say this one for convenience of the theoretical analysis we calculate the driving time for this zone because, before this zone 2 because of the moisture content of the solid changes from X1 to Xc, then Y2 can be calculated from the moisture balance, Okay.

Now we know this one this, in this zone because this is simply we can this one whatever the drying will take place up to we can say this one we can say, critical moisture content that will be N is equal to KY into YS minus that is nothing but say we have already derived this one is equal to minus LS by LS into ‘a’ prime into DX Dt so and we know this one that for this type of this one system if we take the slice also we will be getting GS into dY is equal to LS into dX.

So, we will be putting this two in this equation If we put this in just after manipulation if we put this and say in place of we can say GS or in case of this LS, if we put this one so dt will be nothing but this dt will be nothing but LS by LS into ‘a’ prime and so will be interrogating from 0 to t1 time.

This is how much time actually t1 means we can say in this zone 1, how much time will be taking this one where the moisture content will be increasing from x1 to x2. Moisture content will be decreasing from x1 to x2. So that is the dX by N, this N will be replaced by this KY into YS minus Y.

So will be putting this N is equal to KY into YS minus Y and then we can again do this one dX we can keep this one in the form of dX actually we can keep in the form of Y also GS by LS into dY just will be putting this one GS into dY by LS into KY, then this LS is actually will be going.

That is why we kept this LS from the beginning, so ultimately what will happen this after this interrogation we will be getting this GS into KY into LS into ‘a’ prime into ln YS minus Y2 by YS minus this Y1.

So, t1 will be like this GS into kY into LS into 'a' prime into ln into YS minus Y2 by YS minus Y1. So this is the, we can say that this one time requirement in we can say this one zone 1. So this is we can say this one in the zone 1.

So now we will be calculating this one in the zone 2, here actually we are assuming one this one what parameters like this the moisture content of the solid is below Xc. If it Xc it reaches Xc then we will not be able to calculate the, we can say this one drying time in this zone. Because that after that nothing will happen this only here also what will be there, there will be no drying actually (())(47:58).

If with a moisture content of the solid below Xc then only we can say this one there will be some drying time.

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Heat transfer calculation in Zone II: ($X < X_c$)

The moisture content of solid is below X_c.

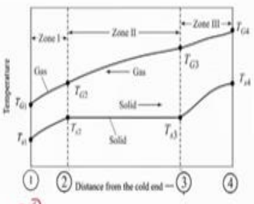
We assume that drying rate is proportional to free moisture

$$N = \frac{N_c\,(X - X^*)}{(X_c - X^*)} = \frac{k_Y(Y_S - Y)(X - X^*)}{(X_c - X^*)}$$

$$t_{II} = \frac{L_s}{L_s a'}\int_{X_3}^{X_2}\frac{dX}{N} = \frac{L_s}{L_s a'}\int_{X_3}^{X_2}\frac{dX(X_c - X^*)}{k_Y(Y_S - Y)(X - X^*)}$$

$$= \frac{L_s}{L_s a'}\,\frac{(X_c - X^*)}{k_Y}\int_{X_3}^{X_2}\frac{dX}{(Y_S - Y)(X - X^*)}$$

$$= \frac{G_s}{L_s a'}\,\frac{(X_c - \overset{0}{X^*})}{k_Y}\int_{Y_3}^{Y_2}\frac{dY}{(Y_S - Y)(X - \overset{0}{X^*})}$$



If $X^*=0$, $t_{II} = \frac{G_S}{L_s a'\,k_Y}\,\frac{X_c}{\left(X_4 + \left(\frac{G_S}{L_S}\right)(Y_S - Y_4)\right)}\,ln\,\frac{X_c(Y_S - Y_3)}{X_4(Y_S - Y_2)}$

as [$G_s(Y_s - Y_4) = L_s(X - X_4) \rightarrow X - X_4 + \left(\frac{G_S}{L_S}\right)(Y_s - Y_4)$]

Here also we can say this in the same way we can this one we assume, here also this we assume that drying rate is proportional to free moisture just here like this if it is not proportional if it is proportional to the square of the we can say this one moisture content then the expression will be to some extend different.

Otherwise it will be like this we have already derived this, N is equal to Nc into X minus X star by Xc minus X star that is after manipulation we will be getting kY into YS minus Y into X minus X star by Xc minus X star.

So for that case we will be getting this same way will be getting t will be equal to LS by LS into ‘a’ prime into x3 to x2 dX by N and will be putting this N formula this one N like this part we will be putting here in this here will be getting LS by LS into ‘a’ prime into x3 to x2 dX into say this one Xc minus X star by kY into YS minus Y into X minus X star.

So just after manipulation and which are the constant parameters will be taking out this one from this enter expression LS by LS into ‘a’ prime into Xc minus X star from here and kY from here then will be getting this x3 to x2 dX by YS minus Y, this into X minus X star.

Now, for this X actually we can say this one we need to do another thing, just we need to do one this one what is called moisture balance like this. For this zone, GS into YS minus Y4 that is Y4 means that is also Y3 is equal to nothing but LS into X minus X4. From there will be getting X is equal to X4 plus GS by LS into YS minus Y4.

We will be putting this value actually in here, this in X will be putting, now you see if the X star is 0 we can say if the equilibrium moisture content is negligible, means if it is 0 then this part will go, this we can say this one is 0 and this is also 0, then we have this one for tII just by interrogation we will be getting that X actually will be coming out here like this this X part actually will be coming here like X4 plus GS by LS into YS minus Y4 and we have GS by LS into ‘a’ prime into kY is there and then this part said dY by YS minus this Y like this will be that Xc into YS minus Y3 by X4 into YS minus Y2.

So from here actually will be getting that tII will be GS by, GS into Xc by LS into ‘a’ prime into kY into X4 plus GS by LS into YS minus Y4 and into ln Xc into YS minus Y3 by X4 into YS minus Y2.

Now actually will be able to calculate the total drying time in the continuous dryer also in this we can say zone 1, zone 2, and zone 3.

So in the next class we will be discussing on the drying time calculation from the drying rate curve, so there will be discussing different situations and will be calculating the total drying time.

Thank you.