Thermal Operations In Food Process Engineering: Theory And Applications

Prof. Tridib Kumar Goswami
Department of Agricultural and Food Engineering
Indian Institute of Technology, Kharagpur

Lecture - 60
Drying & Multiple Effect Evaporator

Good morning. We have come to the end of this course and we will now deal the last two things like Drying and Evaporation and in that drying itself and this is the lecture number 60 we are covering Multiple Effect Evaporator as well as drying. A little more we will talk about multiple effect evaporator, but drying let me tell that already we are on the verge of the completion. So, drying and evaporation they are in many cases in many institutes, they are given very high emphasis. So, that almost half or around that of the course is covered by them.

So, it is very difficult to cover it in a single class both the things. So, that is why you will touch upon and a maybe one concentration may go a little up and drying a little less; however, in drying that is what you are that is also a separation. What you are separating? You are separating moisture from a leak solid right. So, you will see drying is always with this solid that solid which contains maybe 20%, 40%, 80% of the moisture that is being dried maybe to 20%, 10%, 5% depending on your product which you are aiming at right.

Whereas, if the other one this is a solid league solid and gas separation or solid and vapor separation. Whereas, if you are looking at you have a say a sugar concentration; you have a sugar of 10%, sugar which you want to make 50% in concentration. So, you are now separating liquid and vapor.

So, they are liquid and vapour separation; in distillation, n we have also separated there it was liquid and liquid separation from one liquidity another liquid was separated of course, via vapor formation right. However, when we are talking about drying; drying is dependent on many many factors primarily on the object which you were selecting its size, its shape.

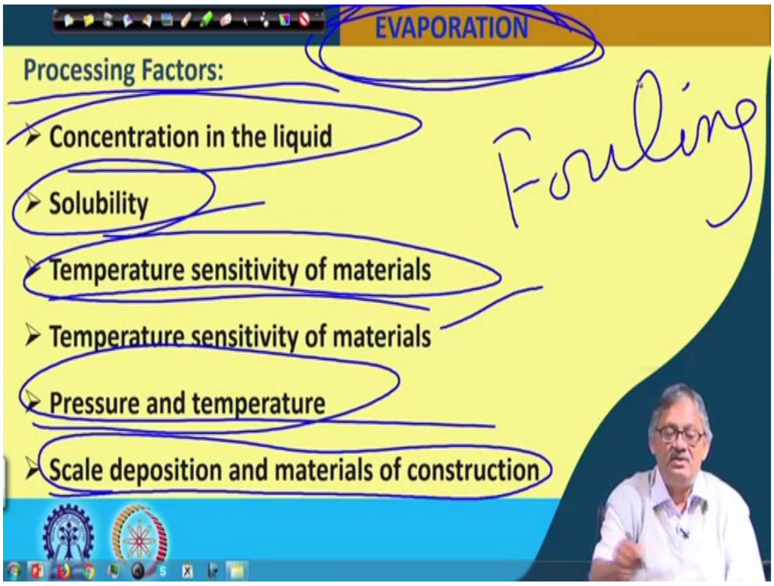
You will see that a small piece if you keep outside in the sun at least during summer hot summer that will dry up maybe in a day, but whereas, a bigger thing if you keep it that will dry up maybe for a couple of days. So, that depends on the product size, shape and the properties of the material outside properties all these. There are many types of dryers many out of which tray dryer is one of the; one of the very widely used commercial dryer.

Then another one very very much commonly used is the spray dryer that milk and the dried foods whatever milk and dried milk powders which you get mostly on the spray dryer. And there are there is also one very widely used that is called your drum dryer. There are many more like vacuum those which material are it is called heat level those which are heat level or sensitive to heat or temperature.

They are dried under vacuum drying. So, many types of they are like lyophlizer that is called your where the where you have solidified and then you have solidified the moisture and then we have sublimed right; that is life lyophilization or that is called drying or freeze drying right. So, freeze drying is obviously, a very costly affair because they are you what you are doing you are freezing the moisture first and once the moisture is frozen, then you are eliminating the middle step that is now solidized to vapor water right; eliminating the middle phase that is the liquid.

So, dried directly it is called sublimation directly subliming to the vapor that is another type, but the spray drum tray these are very widely commonly used input industries or in maybe in all many chemical industries also or many some other industries right. So, drum is normally used when you have a thick material right not thin means whose concentration is low right with thick material highly viscous those materials are dried very easily with drum right.

(Refer Slide Time: 06:26)



You have a drum and the drum is let us take this page as that you have a drum right and heating through maybe your maybe your by this steam or some other heating medium right. That is given from the inside and the material is traveling along this and the drum is rotating; drum is rotating right material is traveling along this. So, by the time this material travels through one and there is a knife that is called doctors knife.

So, that doctors knife cuts this dried material here and that is separated out; drying is like that for drum drying. Similarly spray drying is also there where you are making milk powder and many other right similar kind of materials you are doing. Spray drying tray drying fruits and residuals are easily are mostly done through tray drying there and you will see in drying there are n number of drying equations; n number of drying relations right. So, that is what drying is with right and in vacuum; obviously, the material which is very susceptible to heat.

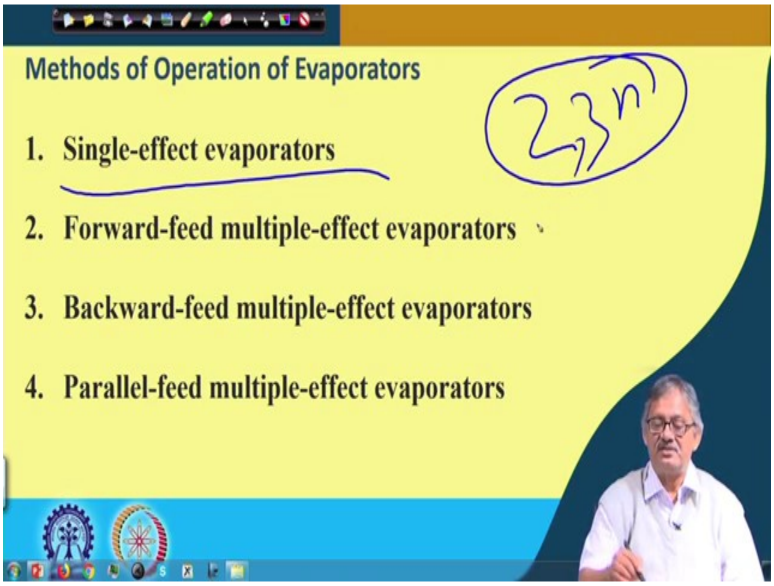
So, if you want if you need to heat at say 100 °C maybe that material may be spoiled or it is susceptible to temperature. So, you cannot raise the temperature to so high. So, what do you need you need to vaporize it how by lowering the pressure the moment, you are lowering the pressure the boiling point of that water is all is going down and you can separate too much at much lower temperature depending on the level of vacuum you are creating.

But that is also expensive because when you are making vacuum. So, it is also incurring cost however, but maybe there are some material where cost is not the primary thing, but keeping that material intact is more primary. So, there you can utilize vacuum drying. So, like that many dryings and this is basically a separation of moisture from the solid material right; from one moisture content to another moisture content right.

Similarly, if we look at another there is called liquid and vapor separation that is evaporation right. Let us tell a little more on this. So, evaporation is the process the processing factors which are associated is the concentration of the liquid that is what is the solute in the liquid at what concentration it is present, then the solubility of that solute whatever is there, then ten whether it is temperature sensitive or not that material, then temperature sensitivity of the materials ok.

Then pressure and temperature both are deep in both are influencing the process of evaporation and scale deposit if there be any which week earlier term is as the fouling right which earlier we termed it as a fouling. So, if there is any scale formation or scale deposit on the material of construction; all these factors are controlling the process of evaporation right.

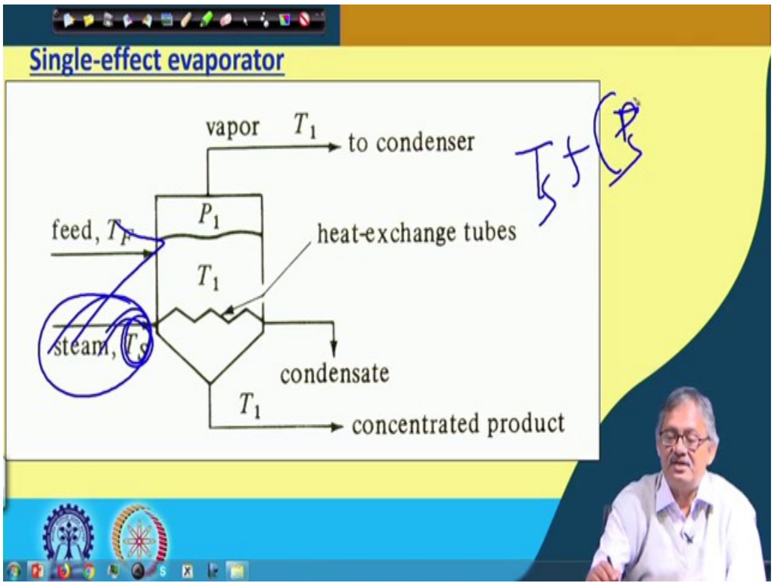
(Refer Slide Time: 11:02)



So, by enlarge it can be of two types; one is single effect evaporator normally single effect evaporator generally many are used for single effect evaporators right; why this is simple that you have a heat exchanger. So, material is coming in and going out and moisture is getting separated right. So, that is single effect evaporator, we will also discuss a little more with diagram right.

Single effect evaporators and multiple effect evaporator; multiple means more than 1; it may be 2, it maybe 3, it may be 4, it may be n number of separations right effects. So, that effect what is that meaning of effect we are also coming to that. Then in that it could be forward feed multiple effect or it can be backward feed multiple effect right and also there are parallel feed multiple effect evaporators right. So, out of which most common is the single effect and also the multiple effect. The in that multiple effect it can be one sorry 2, 3, 4, 5right.

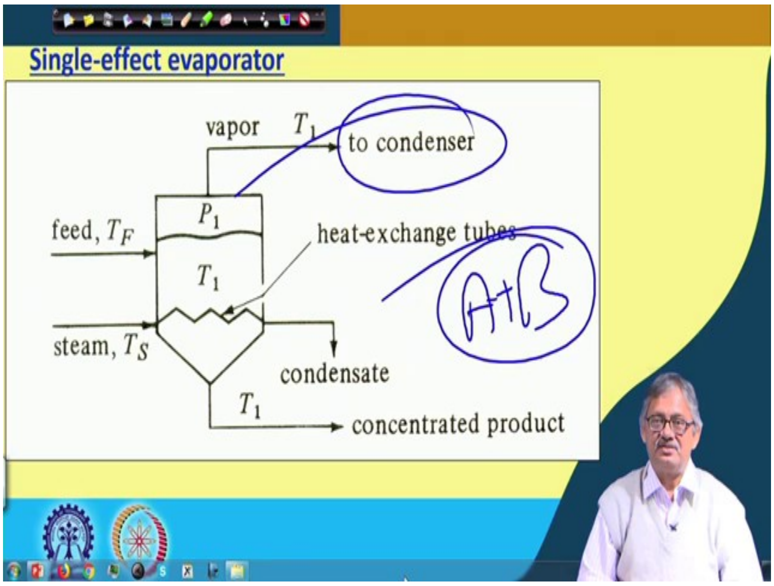
(Refer Slide Time: 12:33)



Generally 5 is very widely used one right and this is what is the single effect evaporator. As I said there will show in terms of figure. So, here you see we have an evaporator; this is how it is being denoted right, then we have a feed which is at the temperature of T_F and also we are feeding steam both the material to be evaporated is fed that is called feed and by which it is to be evaporated that is the heating medium or steam added temperature T_S.

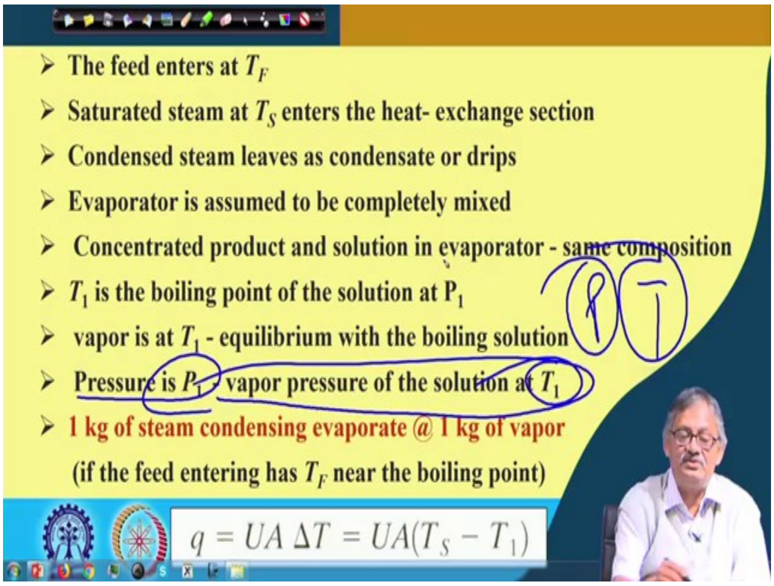
Obviously, this T_S is a function of the pressure of the steam P_S right that you know from the steam table ok. Then this internal thing is at T_{U1} where heat is being exchanged maybe in tubes or whatever this is typically heat exchanger right and the steam which has been passed is condensed right and this is at the temperature of T_1 right. It is which the concentrated product is coming out and the vapor as the pressure P_1 and corresponding to that pressure the temperature T_1 is coming to the condenser as the vapor.

(Refer Slide Time: 14:17)



So, this is also basically your one component you are separating from the other right in which say if it is a binary A and B; A is the dispersed and B is in continuous right that we can say that a is soluble or solubilized in B that is why earlier we said the solubility is also a factor right. So, this is the best way or easiest way to separate normally we do that right.

(Refer Slide Time: 14:56)



Then if we look at this separation, the feed which is dependent on the feed that enters at the temperature T_F; there is a feed temperature. So, the feed temperature again will dictate how easily or how difficult the separation is then the saturated steam and the temperature T_S that enters this heat exchanger. Basically what we draw that is nothing, but a heat exchanger right.

There is nothing, but a heat exchanger this thing is a heat exchanger sorry, then condensed team that leaves as the condensed set or a drapes then evaporator that is assumed to be completely mixed right where this thing was there sorry this thing was there. The this if this be the evaporator there it is a mixture of both liquid vapor everything right. It is a completely mix concentrated product and solution in evaporator that should have the same composition right.

Concentrated product and solution in evaporator has the same composition T_1 is the boiling point of the solution at a temperature at a pressure of P_1 and vapor is at the temperature T_1 corresponding to that equilibrium with the boiling solution and pressure also as we said P_1. There is a vapor pressure corresponding to the temperature T_1 you know both P and T are related.

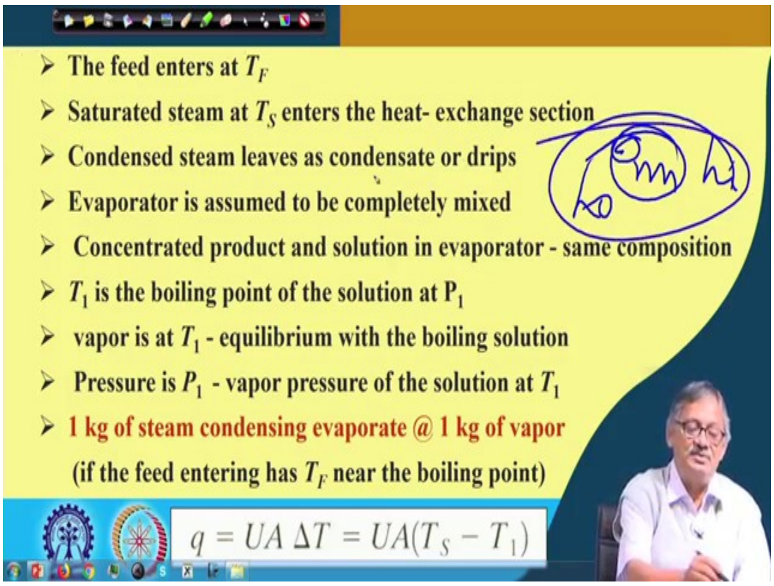
So, if one is known other is also automatically known right, but this is the vapor pressure right of the solution at the temperature T_1 and normally it is seen that 1 kg of steam condensing that is the fundamental how many paddy, how many rice right how much energy you are giving and how much you are getting. So, you are giving 1 kg of steam.

So, if 1 kg of steam is utilized, then roughly 1 kg of vapor you are producing 1 kg of vapor means that if you remember that evaporator which you drew right from there you are giving steam here feed was there and this is the bottom which is coming out and from the top we have that condenser right. So, these vapor is that 1 kg of the vapor is coming out that is being separated from the solution right.

So, 1 kg vapor is getting separated per kg of the steam utilized right. If the feed entering is nearly its boiling point that is if the temperature of the feed is near to its boiling point, then only it can be like that right. Otherwise, if the T_F is much lower than the boiling point, then you have to heat it to its boiling point then the vapor will go; then it will separate. So, lot of things are involved.

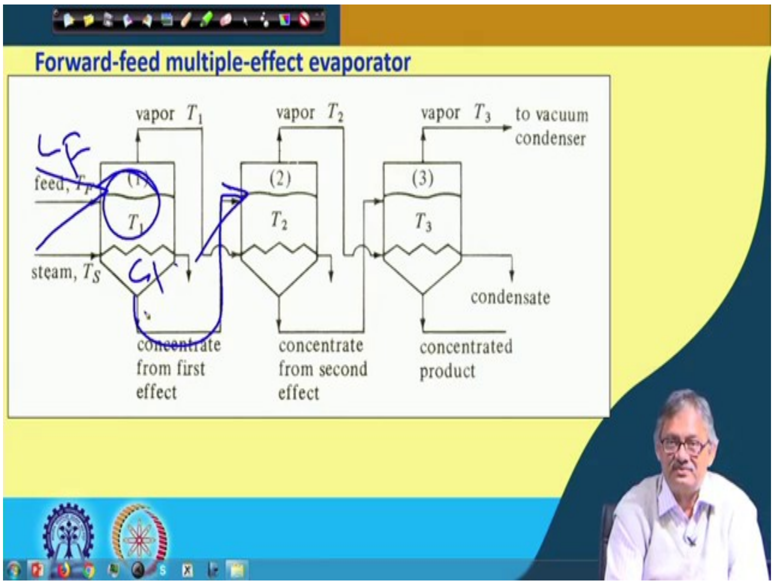
So, there it may not be 1 kg to 1 kg means 1 kg steam utilized and 1 kg vapor separated that may not be possible. And in all the average heat transfer equation used is $q = UA\,\Delta T$ where delta T is that TS minus T 1 right T S we said that is the temperature of the steam and T_1 that is the temperature which is in equilibrium at the boiling point or boiling solution right. So, this delta T and U; U is the overall heat transfer coefficient that depends on as we said if this is the material. So, you are giving heat by the steam.

(Refer Slide Time: 20:08)



So, if there are some tubes or whatever inside so, that will have one outside that is outside heat transfer coefficient ho one metallic heat that conduction or resistance due to the metal and another inside of the tube where your material is there. So, these three will make as we said the other day overall heat transfer coefficient. So, overall heat transfer coefficient can be determined on that basis right and that heat transfer is; obviously, as $q = UA\Delta T$ right.

(Refer Slide Time: 20:51)



Then we come to another that is forward feed multiple effect evaporator right because we saw that there are two types; one is forward feed, another is backward feed right. So, forward feed means your steam is entering also the direction of flow of the steam and the feeder are integral or same right. This feed is coming to this evaporator which is at the temperature T_1 like a single effect evaporator where you are passing steam at T_S right and this steam is getting condensed here as the condenser.

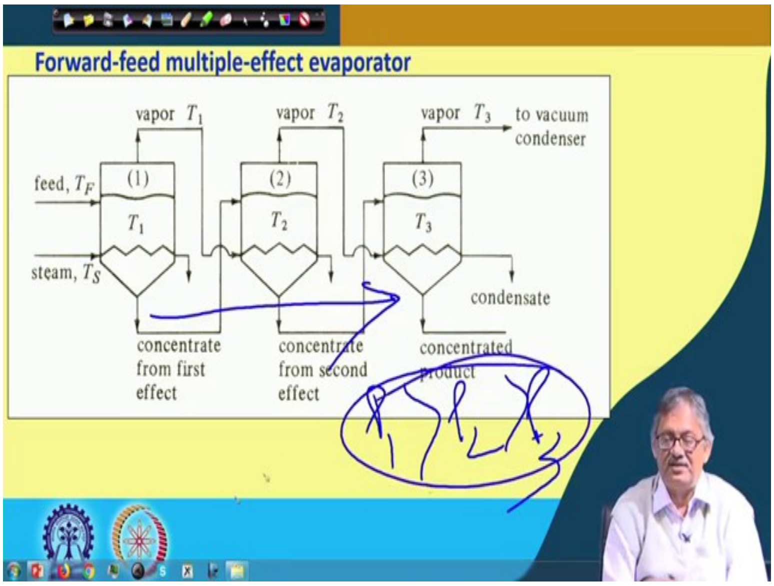
Then some portion of the liquid which came here with a concentration of say C_1 has come out to b or C feed has come out to b as C_1 and that is being fed to the second effect for further concentration right. Whereas, the steam came here only and it get condensed here right, but the steam which has produced in the 1^{st} effect we said 1 kg steam produces almost 1 kg vapor right.

So, if that be true that 1 kg 1 kg, then that vapor is coming and that is at the temperature T_S steam temperature right corresponding the pressure P_1 right. So, that is being fed instead of steam to the second effect right. This is the effect that this effect has made steam has made vapor which is being fed as steam or vapor to the second effect right and higher concentrated solution, then the 1st effect is fed to the second effect right. And there by this pressure is less than this pressure right that is why this vapor is getting a ΔP and it is being then supplying or to fill it up right.

So, high pressure to low pressure it is going and this concentrated through may be some device you are feeding it to the second effect right. And after this second effect again the same thing happens, this whatever vapor you have made it in the heat exchanger that is this is the condensed and this over C_1 now has become much more concentrated as C_2 and this concentrate is being fed to the third effect right and this is being fed whereas, the vapor which is coming out from there as now is being fed to the third effect right.

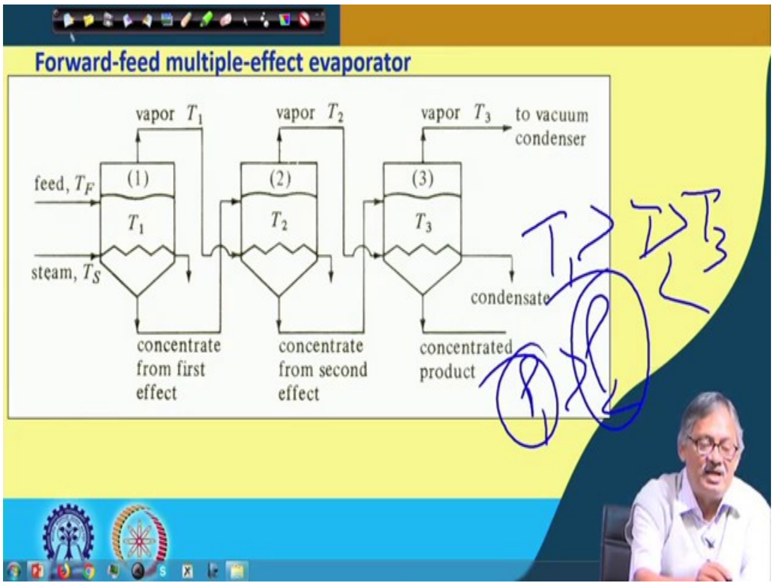
So, that means, you see the temperature here it was T_1 corresponding to the pressure P_1, here the temperature is T_2 corresponding to the pressure P_2 and here the temperature is T_4 corresponding to the pressure P_3 right.

(Refer Slide Time: 24:43)



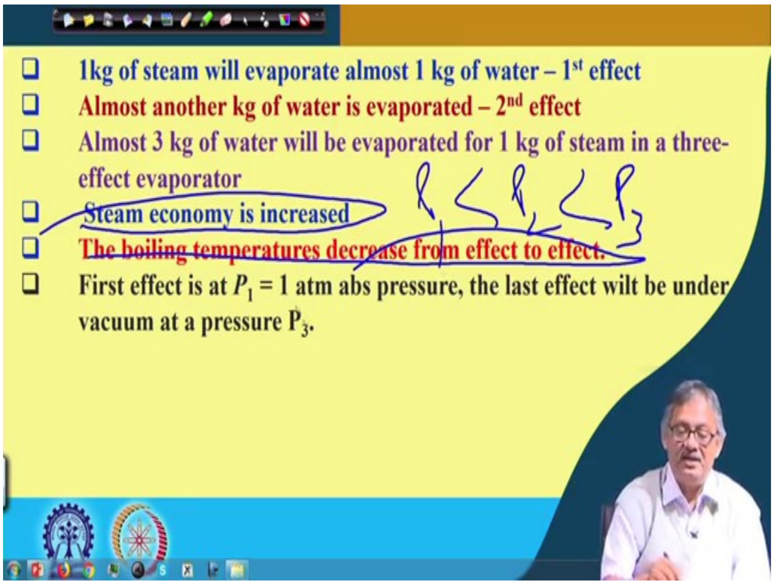
But in all the cases P_1 is greater than P_2 is greater than P_3. So, as the effect is increasing your pressure is getting decreased.

(Refer Slide Time: 25:00)



Similarly the temperatures are also getting decreased because the moment $P_1 > P_2$; that means, $P_2 < P_1$; that means, T_1 will be higher than T_2 right or similarly is higher than T_3 right like that things are happening ok. So, this is what and the vapor is coming out to T_3 to a vacuum condenser and that this steam condenser comes out and concentrated product you are getting at the end right.

(Refer Slide Time: 25:42)

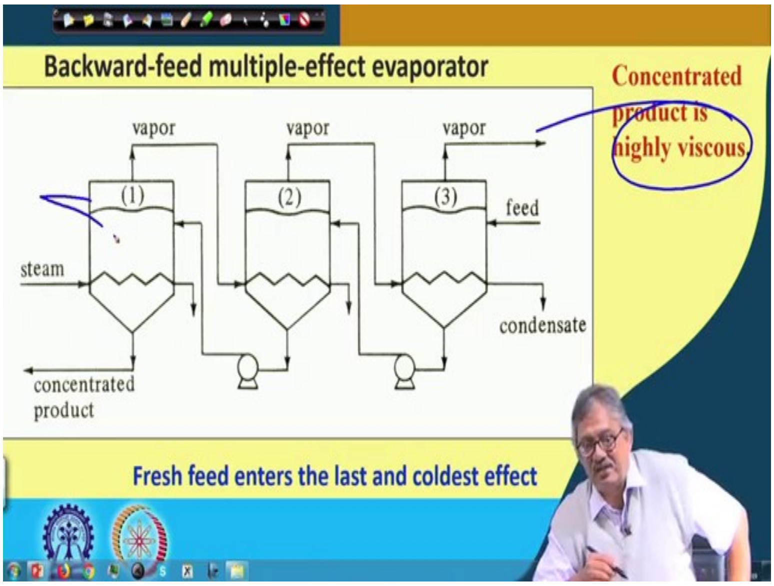


So, if you see that analyze it, then you know that 1 kg of steam in the 1st effect you are getting and similarly in the 2nd effect is also roughly 1 to 1 kg roughly, but overall almost

3 kg water will be evaporated per kg of the steam right. Because you have originally fed with a steam in the 1st effect and afterwards you have not fed any steam. So, steam economy is increased and the boiling temperature decreases as the effect is increasing right because the Ps are getting less right $P_3 < P_2 < P_1$ right.

So, it is gradually decreasing. So, temperature is also decreasing. First effect P_1 is the at most roughly 1 atmosphere absolute pressure and the last effect will be under vacuum corresponding to the pressure P_3 right much lower than P_1 much much lower than P_1 right.

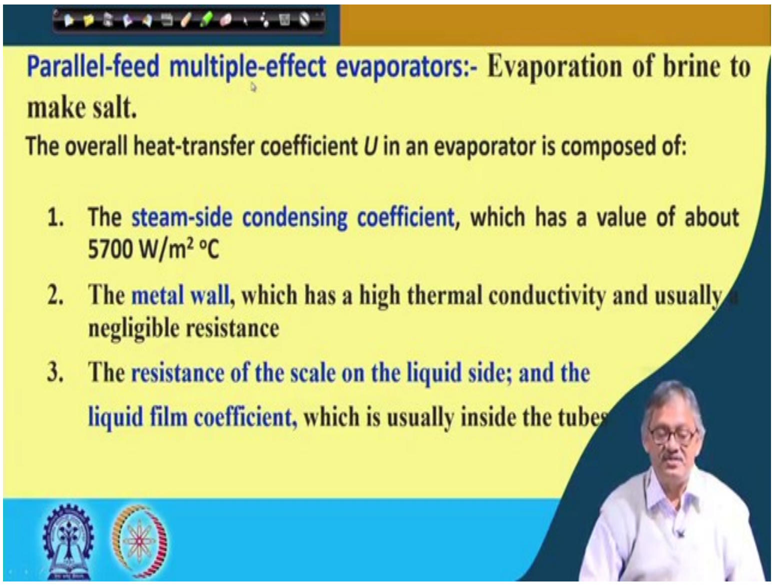
(Refer Slide Time: 27:00)



So, if we look at the other one backward feed; backward feed is also similar to forward, but only the things team enters in from one end and the feed enters from the other end right. So that means, if the feed is at low temperature means it is not at boiling at low condition low temperature, then that is concentrated product is highly and if it is highly viscous then it is entering.

So, the what is happening? As it is progressing the viscosity temperature is increasing so, viscosity is decreasing. So, from only high viscous to low viscous and ultimately it is coming out from the other end right.

(Refer Slide Time: 27:54)



This way the backward feed is being utilized for maybe a viscous or maybe a cold fluid which is coming in right. Similarly a parallel flow could be there the overall heat transfer coefficient U for the evaporator that roughly for steam, it is condensing coefficient is 5700 $W/m^2.°C$ metal wall that will have high thermal conductivity of the metal.

Usually the resistance is negligible and the resistance of the scale on the liquid side that could be due to the resistance of if there is any scale and the corresponding heat transfer coefficient will be the inside internal or inside heat transfer coefficient right. So, with this let us come to the end of this course. Hope you have enjoyed the course, but most vital is that you should understand and you should try to follow that as much problems you can solve right.

You will see the basic thing is as many problems you can solve on your own; that means, you are understanding the subject, you are understanding the topic more and more right. It is it was not possible to deal with the all unit operations because of the time constraint and not or the purview of the course also because many other courses are dealing with these unit operations. So, there it you may get more in detail, but we have highlighted many of them. So, that is what I wish that you enjoyed this class and get the best out of it.

Thank you and all the best.