

Mass Transfer Operations II
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Lecture No 30
Design of Crystallizer, Crystallization Equipment

So welcome back to mass transfer operations II and we were discussing on crystallization operation most likely today will be completing our syllabus and the last topic will be design of crystallizer and crystallization equipment. And for this crystallization design we need to follow the steps like this.

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Design of Crystallizer

Design considerations

- The function of a crystallizer is to produce crystals of a given size specification from a feed at a specified rate.
- A suitable and adequate supersaturation is created by cooling the feed or by partial evaporation of the solvent. The second method is more common in industrial practice.
- Narrow particle size distribution of the product is desired to maintain a good product quality.
- Besides the correct supersaturation and environment (i.e. agitation, pumping rate, etc.), techniques like, fine redissolution or classified product removal are helpful to achieve a better product quality.
- Batch crystallizers require seeding (i.e. addition of fine crystals that act as nuclei).

The function of a crystallizer is to produce the crystals of a given size specification from a feed at a specify rate. So we need to know the size of the crystal as well as this growth rate of the crystal also. So a suitable and adequate super saturation is created by cooling the feed or by partial evaporation of the solvent, but you see this one partial evaporation of the solvent gives the more we can say yield (()) (1:22), in the previous class we have solved the problems that with the 2 to 3 percent or even 5 percent evaporation of the total water gives this more yield of the crystallization product, crystallized product.

And a narrow particle size distribution of the product is desired to maintain a good product quality. So that is also another point in the design perspective that the narrow particle size distribution will be there. So that the, whatever the particles will be formed

in the crystallizer that can be used for a particular application. So besides the correct super saturation and environment like this agitation or pumping rate etc., techniques like fine re-dissolution or classified product removal are helpful to achieve a better product quality.

So that is another point and batch crystallizers requires this seeding or addition of fine crystals that acts as the nuclei or whenever we say that for best batch crystallizer you need crystal or lattice from the outside or we need to generate the solid phase inside the supersaturated solution, so that we can say nucleus formation. Then secondary nucleation occurs continuously in a continuous crystallizer and seeding is not generally necessary if we have the secondary nucleation process available with the crystallizer.

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Design of Crystallizer

- Secondary nucleation occurs continuously in a continuous crystallizer and seeding is not generally necessary.
- The more important parameters and quantities involved in the design of a crystallizer are:
 - (a) The feed rate and state: concentration, temperature, pressure, etc. These are specified in the design problem.
 - (b) The desired crystal size distribution (CSD) and yield:
- The percentage theoretical yield is defined as

$$\text{Yield}\% = \frac{100(Q_i C_{in} - Q_o C_s)}{Q_i C_{in}} \quad (1)$$

Where, Q_i = feed rate, Q_o = rate of outflow of mother liquor, C_{in} = feed concentration, and C_s = solubility of the solid at the exit temperature.

The more important parameters and quantities involved in the design of the crystallizers are like the two parameters are like this first one is this feed rate and the state like concentration then temperature, pressure, these are all specified in the design problem. So whatever the crystallizer will be designed so we need to maintain the concentration in the feed means then we need to make the supersaturation by changing the temperature like this soldering the temperature, lowering the temperature then we say sometimes we need to do the lowering of pressure and so that must be defined actually or specified.

And the second one is the desired crystal size distribution and the yield. So this which as we discussed that the particular size distribution should be in a narrow range so that the all the crystals will be of this similar size and shapes and the yield also. At the same time, we can say this yield is one important parameter for the crystallizer design because you see yield can dictate the, we can see economy of the process.

The percentage theoretical yield is defined as this can say the $100 \times \frac{Q_i C_i - Q_o C_s}{Q_i C_{in}}$ whereas Q_i actually is then you can say this feed rate and Q_o is rate of outflow of the mother liquor means whichever is exhausted and C_i actually is equal to C_{in} is equal to feed concentration in the beginning and C_s is the solubility of the solid at the exit temperature or where the we can say we are obtaining this mother liquor. So that is from their actually we have already solved one problem on the yield calculation, there percentage yield is defined as $100 \times \frac{Q_i C_{in} - Q_o C_s}{Q_i C_{in}}$.

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Design of Crystallizer

- In the expression for 'theoretical yield', the exit liquid is assumed to have lost the supersaturation.
- If the temperature in the crystallizer is fixed, C_s can be obtained from the solubility data.
- From the specified yield (%), Q_o is calculated using Equation 1.
- (c) The required rate of evaporation is determined by a solvent balance:**
 - Solvent evaporation rate and the heat transfer area required.
 - The evaporation rate is calculated from material balance.
 - A heat balance over the crystallizer gives the required rate of heat input.
 - Heat of crystallization should be included in the heat balance.
 - The steam or the heating fluid rate and the heat transfer area are then calculated.

So in this expression the theoretical yield, are the exact liquor actually is assumed to have lost the supersaturation. Then it is converted into mother liquor, what this one, we have already discussed this one that theoretical yield is to some extent lower than the actual yield. Because you see whenever we talk about the super saturation or actual solubility that is, this lower than the practical solubility. That is why whenever the crystal formation

takes place after that the supersaturation is lost and then that is why solubility of the solute is actually lower than the solubility in the supersaturation.

At the, this one narrow or in other words we can say the actual yield is to some extent lower than the practical yield. So if the temperature in the crystallizer is fixed means at which temperature of the crystallizer is operating then C_s can be obtained from the solubility data. So whenever we have this solubility data we can say at a particular temperature and pressure, what is the solubility of the solute in the mother liquor or exhaust liquor that would be finalized. So from specified yield percentage we can say the Q_o is calculated using this equation 1 that yield equation.

Then the third one is this is the required rate of evaporation is determined by a solvent balance like this. So the solvent evaporation rate and the heat transfer area will be requiring. And then evaporation rate is calculated from the material balance just whenever we will be doing the material balance means how much amount of feed is entering into the crystallizer and how much amount of crystal is separated from the crystallizer and how much amount of mother liquor is exhausted or is taken as the excess.

And at the same time if there is evaporation then how much amount of water is lost or evaporated during this process. So that we can get this from the heat material balance like this in is the feed rate and sometimes in will be sometime this seeding also. How much seed is added, that is also in, so in will be like feed rate pulse seeding and out will be like this all 3 like crystal, mother liquor and evaporated water vapor.

Then a heat balance over the crystallizer gives the required rate of heat input, how much amount of heat actually is require to evaporate that say 2, 3 percent or 5 percent total of the total water and how much amount of heat is required, that we can calculate from the heat balance. Then heat of the crystallization should be included in the heat balance that is how much amount of heat of crystallization is required to separate the crystal from the we can say magma. The steam or the heating fluid rate and the heat transfer area are then calculated, so from this heat balance we can say.

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Design of Crystallizer

(d) Crystallizer volume:

- The experimental data on nucleation (B°) and the growth rate (G) are required.
- These data can be obtained from a laboratory crystallizer.
- Data collected from a pilot plant crystallizer of volume around 50 litres or more can be more reliably used.
- If the product quality (in terms of the weight % of the crystals above a particular size) is specified in the design problem, Equation (2) may be solved for the dimensionless cut-off size, x .

$$W(x) = 1 - \left[1 + x + \left(\frac{x^2}{2}\right) + \left(\frac{x^3}{6}\right) \right] e^{-x} = 0.5 \Rightarrow x = 3.67 \Rightarrow L_M = 3.67 G \tau \quad (2)$$

- Where, $W(x)$ is cumulative mass or weight distribution function, L_M is median size of cumulative size distribution

And then the fourth important parameter is this crystallizer volume. So the experimental data on the nucleation that is we can say this B prime and the growth rate G are required, so that these 2 are will be getting, this growth rate you will be getting means much crystal actually is a grown per unit time and nucleation B prime actually is obtained from this theoretical equation. So these are actually required for the crystallizer volume calculation. So this data can be obtained from a laboratory crystallizer but this laboratory crystallizer must have some basis means whenever will be discussing about the laboratory crystallizer then we can say that should be of the in terms of we can say pilot plant. So that the results will be we can say acceptable.

So data collected from the pilot plant crystallizer of the volume around 50 liter or more can be more readily used. And if the product quality say in terms of we can say weight percentage of the crystals above a particular size is specified in the design problem, then we will be using this problem equation 2 may be solved for the dimensionless cut-off size of x means that is we can say the average crystal size.

Then Wx is equal to 1 minus, 1 plus x plus x square by 2 plus x cube by 6 into e to the power minus x that is coming out as 0.05 or from where x is equal to 0.36 and then we will be getting this L_m is equal to 3.67 into G into τ , where Wx is the cumulative mass or weight distribution function and L_m is the medium-size of the cumulative size

distribution. So that from the L_m we can say that what will be the average size of the crystal materials.

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Design of Crystallizer

- From the known values of G and L , the holdup time and volume can be calculated.
- The diameter of a crystallizer is frequently determined on the basis of possible entrainment of liquid with the vapour generated.

(e) Crystallizer dimension and recirculation rate:

- The recirculation rate of the slurry through the heat exchanger is important in heat transfer area calculation.
- The selected crystallizer diameter and recirculation rate should be checked so that adequate velocity is maintained to avoid settling of solid depending upon the type of crystallizer.

From the known value of this G and L that is obtained from this we can say pilot plant study or from laboratory study, the hold up time and the volume can be calculated. So the diameter of the crystallizer is frequently determined on the basis of the possible say entrainment of the liquid with the vapor generated, so that we can do. And then fifth point actually of the crystallizer design that is we can say crystallizer dimension and recirculation rate. So this recirculation rate of the slurry through the heat exchanger is important in heat transfer area calculation.

So in the crystallization study, one part actually is recycled, so whenever we will be discussing about the crystallization equipment will be showing this one that one part of the slurry is always recycled and then it is rooted through this heat exchanger to add the heat. So that some amount of water will be evaporated and supersaturation will be created again. So if whenever it is coming out from the crystallizer because you see we have learnt that whenever the mother liquor will be coming out from the crystallizer then it will be there at the solubility limit.

But whenever the material will be at the solubility limit then it cannot be this one used for the crystal formation. So we need the supersaturation for that we need to evaporate a

small part of this water and then we need to quench or we need to decrease temperature or decrease the pressure. So that the solubility values decrease and then it will lead to the supersaturation and driving force for the crystallization.

The selected crystallizer diameter and recirculation rate should be checked so that adequate velocity is maintained to avoid the settling of the solid depending upon the type of crystallizer. So that is another point also, that say adequate velocity should be maintained, recirculation rate should be high otherwise the crystals will be deposited at the bottom of this crystallizer and then it will be very tough to separate the crystals from the crystallizer or we need to say sometimes we need to break the crystallizer to bring the back the crystals from the crystallizer.

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Crystallization Equipment:

Mode of Operation

- a) Batch
- b) Continuous

Method to bring Supersaturation

- ✓ a) By cooling with negligible evaporation: Tank and batch type
- b) By evaporation of solvent with little or no cooling: evaporator-crystallizer or crystallizing evaporator
- ✓ c) By combined cooling and evaporating adiabatic evaporator: vacuum crystallization

Now we will be discussing about the crystallization equipment. This is the last topic of this syllabus of this crystal. So this depending on the mode of operation this there are 2 different types of crystallizers. One is the batch crystallizer another one is the continuous crystallizer. And depending on the method to bring the super saturation there are 3 different types of crystallization equipments are there like first is by cooling with negligible evaporation means without almost without evaporation there maybe tank or batch type evaporators.

Just by cooling we will be making the super saturation by evaporation of the solvent with little or no cooling. This only by evaporation we are will be making that supersaturation. So you have your evaporator crystallizer or crystallizing evaporators are used. And the third one is by combining cooling and evaporative this one adiabatics evaporators. So both whether will be doing the cooling as well as will be evaporating a small part of this total water. Then some like vacuum crystallizers and crystallization equipment is there. So from in this system, we will be able to make the super saturation in a very fast manner.

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Crystallization Equipment:

How crystals are brought into contact with supersaturated liquid

a) Circulating liquid method: Stream of supersaturated solution is passed through a fluidised bed of growing crystals

b) Circulating magma method: Entire magma is circulated through both crystallization and supersaturation steps without separating liquid from solids.

And then how the crystals are brought into contact with the supersaturated liquid. Suppose the say seeding is done, say there are also 2 different types like this one is the circulating liquid method, we will be discussing so in detail. That stream of the supersaturated solution is passed through a fluidized bed of growing crystals. And another one is this circulating magma method, entire magma is circulated actually through both crystallization unit and the supersaturation step without separating fluid liquid from the solids like this. So entire magma is actually will be circulating. So that is we can say circulating magma method.

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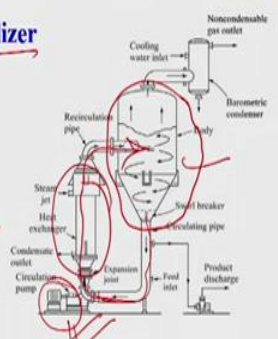
Some common crystallizers

(A) Mixed Suspension Mixed Product Removal (MSMPR) Crystallizers or Circulating Magma Crystallizers

- The growing crystals are kept in suspension by agitation; 20-40% solids in suspension is common.

(a) Forced-circulation (evaporative) crystallizer

- The slurry is pumped through an external steam-heated vertical heat exchanger to raise its temperature by 2 to 6°C.
- Heat exchanger tube size of 1.25 to 1.75 inch is common; the liquid velocity is maintained at 2-3 m/s.



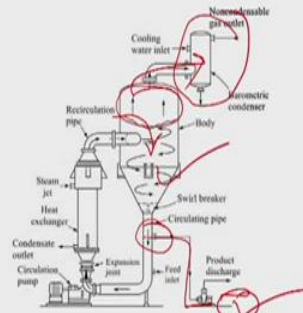
Now we will be discussing the, some common crystallizers. These are widely used in the industries. They are most widely used crystallizer that is a mixed suspension mixed product removal MSMPR crystallizer or we can say circulating magma crystallizer. So that is we can say most widely used crystallizer. So the growing crystals are kept in suspension by agitation may be 20 to 40 percent solids in the suspension that is a common. So in this actually we have 2 different types of crystallizer. The most common one is the forced circulation or evaporative crystallizer.

Suppose this is the crystallizer, so we can say this on schematic of the crystallizer is shown here. So the in this crystallizer body say one circulating pump actually is placed, so that it can circulate the same entire magma through this heat exchanger to the we can say crystallizer. The slurry is pumped through an external steam heated vertical heat exchanger to raise its temperature 2 to 6 degree Celsius. So this temperature is raised by this heat exchanger, so it will pass through this one. So this is we can say one circulation pump. And then heat exchanger tube size of this 1.25 to 1.75 inch is common. The liquid velocity is maintained at 2 to 3 meter per second. So liquid velocity is maintained in the heat exchanger.

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(a) Forced-circulation (evaporative) crystallizer

- No boiling occurs in the heat exchanger.
- The hot liquid is thrown into the crystallizer body when evaporation of the liquid occurs.
- This raises the solution concentration, reduces its temperature (because of evaporation of some liquid) and generates the supersaturation required for crystal growth.
- Many inorganic salts such as ammonium sulphate, sodium chloride, trisodium phosphate, potassium nitrate, citric acid, sugar, etc. are crystallized in an FC crystallizer.



And no boiling occurs in the heat exchanger only heating takes place because 2 to 6 degree rise in temperature does not allow this entire magma to boil. So, hot liquid is thrown into the crystallizer like this hot liquid is thrown in the crystallizer body when evaporation of the liquid occurs inside this one. And whenever the evaporation is taking place then this is actually is taken by this one we can say arrangement like this using this one exhaust system.

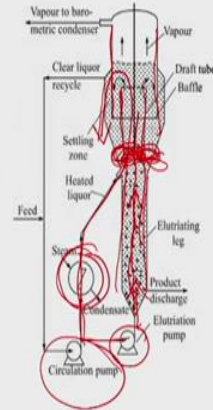
This raises the solution concentration and reduces its temperature and because of the evaporation of the some portions of the liquid and generates the supersaturation required for the crystal. So we do some preheating of the magma and it is fed into this crystallizer. So there it is, a small portion of water is evaporated, so that is again exhausted and say that is why we can say supersaturation is prevailed inside this you can say inside this crystallizer.

And many inorganic salts, such as, ammonium sulphate, sodium chloride then trisodium phosphate then potassium nitrate, citric acid, sugar or etcetera are crystallized in these that forced circulation crystallizer. So here so this product actually is obtained from the, say we can say circulating pipe, then it is taken for the final crystal formation means this cleaning followed by drawing.

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(b) Draft-tube baffle crystallizer

- The body of a DTB crystallizer is provided with an inner draft tube and also a skirt baffle.
- A long-shaft slow-moving impeller throws the liquid upwards through the baffle tube towards the boiling surface.
- This causes circulation of the magma in the crystallizer body; more circulation than in an FC unit is achieved at the same power input.
- Fouling is also less than that in an FC.
- The magma also flows out of the body through an annular zone between the skirt baffle and the wall, enters a steam-heated exchanger (the liquid flow path is shown by arrows) and recycles back to the crystallizer vessel.



Then another type of the circulating crystallizer is draft tube baffle crystallizer. So that is also widely used in the industries, the body of the draft tube crystallizer is provided with an inner draft tube like this one inner draft tube. and skirt baffle like this say, so this is the skirt baffle like this, these are all or hollow tubes.

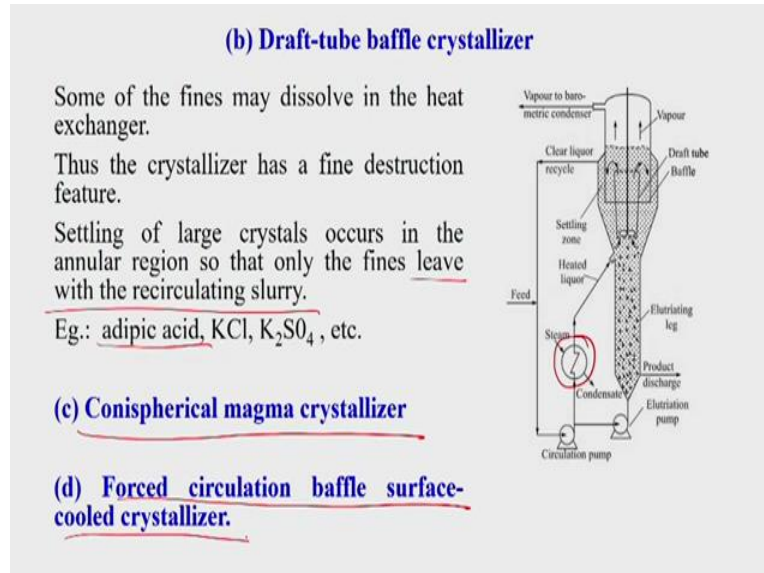
So this is special type of we can say circulating this one forced circulating crystallizer. So a long shaft slow moving impeller like this say this so impeller, impeller throws the liquid upward like this say you can say whenever we have this say we have this circulation pump say 2 parts are there. One part is actually heated and another part is used to enter the, this one magma from the bottom of the we can say the crystallizer.

So this this narrow part is called say Elutriating leg through this one actually it is pumped and as the draft this one fan type thing is operating here. It tries to move this magma in the upward direction. So this causes the circulation of the magma in the crystallizer body and more circulation then in an FC unit is achieved at the same power input like this as the this elutriating leg is very thin and as this there is one we can say exhaust fan is there. That is why all entire feed actually is circulated very efficiently and it is flowing in this direction. So fouling is less also than that in the FC.

So the magma also flows out of the body through an annular zone between the skirt baffle like this one and the wall of this crystallizer. And enter such steam heated exchanger like

this steam heat exchanger, the liquid flow path is shown by just arrow and recycles back to the crystallizer vessel. So that is now one part actually it is entering through this one so the to preheat the we can say this magma.

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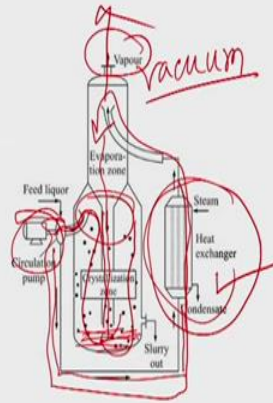


So some of the fines may dissolve actually in the heat exchanger. So in this heat exchanger some fine this one particles will dissolve. Thus the crystallizer has the fine distribution feature. So in draft tube baffle type crystallizer, so the particle size or crystal size distribution is very precise so you can say. And the settling of large crystals occur in the annular region so that only the fines leave with the circulating slurry. Say the examples of the crystal formation in the draft tube baffle crystallizers will be adipic acid then potassium chloride then potassium sulphate etcetera. And the other types of we can say the crystallizers are like Conispherical magma crystallizer then forced circulation baffle surface cooled crystallizers.

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(B) Circulating Liquor Crystallizer

- The crystals are retained in the crystallizer vessel and only the liquor is circulated through an external heat exchanger.
- the liquor is either heated by steam or cooled by a suitable cooling medium to generate supersaturation.
- Vacuum is also sometimes provided to enhance evaporation.
- Crystals are kept in suspension in the vessel by the up flowing liquid.
- The liquid velocity is so maintained that there is hardly any crystal present in the top region of the liquid in the vessel.



Now the at circulating liquid crystallizer, the crystals are retained in the crystallizer vessel and only the liquor is circulated through an external heat exchanger. So this one actually the we can the this one very simple this one crystallizer. So we can say the crystals will be settled at the bottom of this one and say whenever we have the circulating pump, it will be actually we can say it will feed this mother liquor or sorry this magma to this crystallizer through this heat exchanger and in the evaporation zone and throws in the evaporation zone.

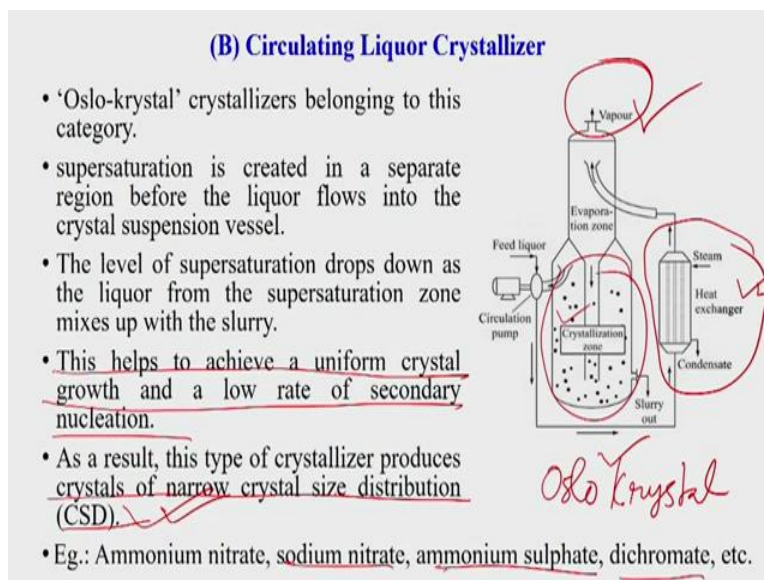
So the liquor is either heated by the steam by this in the heat exchanger or cooled by suitable cooling medium to generate the super saturation. So both are available, so maybe in the heat exchanger, maybe it is heated then whenever it will be thrown in the evaporation zone then huge amount of say vapor water vapor will be generating and then this supersaturation will be prevailed here or sometimes it is cooled down. Then it will say supersaturation is created.

So vacuum is also sometimes provided this one to enhance the evaporation. So here actually say sometimes this vacuum actually is created. And crystals are kept in suspension in the vessel by up following the liquid this one say the arrangement is like this whenever it will be coming through the narrow tube. It will be circulating like this

one and whenever it will be circulating, it will be sucked whatever is not crystallized or whatever the mother liquor will be there that will be at the top of this crystallizer.

Then it is actually sucked through this circulation pump and it is again circulated this heat exchanger. The liquid velocity is so maintained that there is hardly any crystal present in the top region of the liquid in the vessel. So that is why crystals will be formed at the bottom of this crystallizer and at the top only exhaust mother liquor will be there. That will be circulated through the heat exchanger.

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So say this one, one example of this Oslo-Krystal like this, this is the Oslo crystallizer. Oslo crystallizer belongs to this type of category. So supersaturation is created in the separate region before the liquor flows into the crystal suspension. So supersaturation is created here or by here also by using vacuum or by heating or cooling. The level of supersaturation drops down as the liquor from the supersaturation zone mixes up with the slurry like here. So whenever it is coming, the saturation will be dropping down.

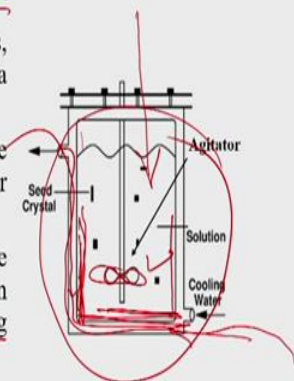
This is obvious because you see this one in the crystallization zone whenever the crystals will be separated so supersaturation will go on decreasing. Because, the supersaturation is the driving force for the crystallization to be taken place. This helps to achieve a uniform crystal growth and a low rate of the secondary nucleation. So as a result, this type of crystallization produces crystal with narrow crystal size distribution, so using this

circulating liquid crystallizer will be here also we will be getting this narrow crystal size distribution. Some examples are like this ammonium nitrate then sodium nitrate then ammonium sulphate, dichromate, etcetera. these are created by circulating liquid liquor crystallizer.

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(C) Tank Crystallizers

- A tank crystallizer, as the name suggests, consists of a cylindrical tank provided with a cooling jacket or a cooling coil.
- The hot feed is pumped into the tank and the cooling liquid is passed through the jacket or the coil at a predetermined rate.
- The temperature differential between the liquor and the cooling fluid should be low in order to reduce deposition on the cooling surface.
- Use of an agitator to keep the crystals in suspension and to prevent excessive fouling of the heat transfer surface is pretty common.



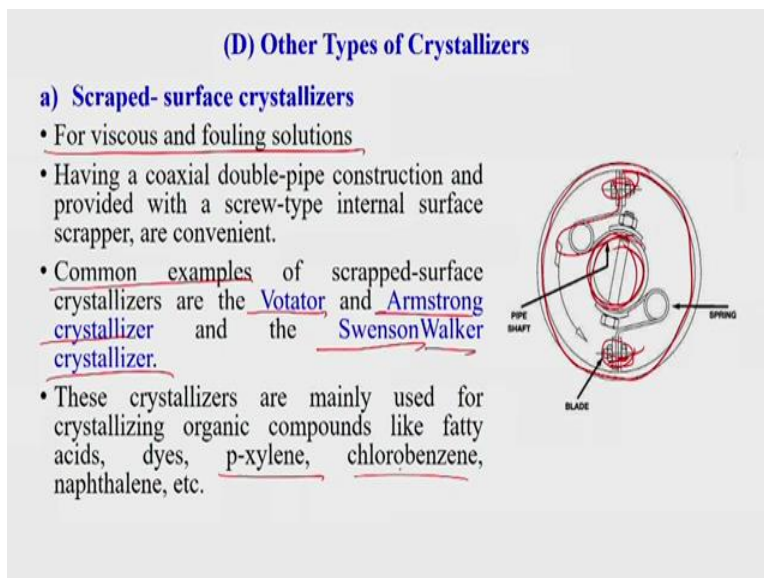
The diagram illustrates a tank crystallizer. It consists of a cylindrical tank with an internal agitator. A cooling jacket surrounds the tank, with cooling water circulating through it. A hot feed is pumped into the tank, and the cooling liquid is passed through the jacket at a predetermined rate. The diagram also shows a seed crystal being added to the solution. Red handwritten circles and arrows highlight the agitator and the cooling jacket area.

Then third one this is very common one that is say tank crystallizers. This is a simple tank we can say this one, only this we can cooling water circulation is taking place. A tank crystallizer as the name suggest that it consists of a cylindrical tank only provided with a cooling jacket or cooling coil. So this cooling arrangement is provided only to generate the supersaturation. The hot feed is pumped into the tanks suppose is a pump the top of this tank say hot magma is placed there and this one. And the cooling liquor liquid is passed through the jacket or coil at a predetermined rate.

The temperature differential between the liquor and that cooling fluid suppose a cooling fluid is flowing through this one should be low in order to reduce the deposition on the cooling surface like the so it should be difference should be low otherwise if there is a huge difference in the temperature between this magma and this solution and this cooling solution then this one on the inner surface of this tank the crystals will be deposited as a result this fouling will be taking place and then effective heat transfer will be decreasing.

So use of an agitator like this agitator actually keeps the crystal in the suspension and to prevent the excessive fouling of the heat transfer surface is pretty common. So that is actually done and agitation is done throughout this cooling crystallization process.

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And the other types of crystallizers which are also not so famous but there are some few crystallization units are there. The one is this scraped surface crystallizer say this scraping is done by this one. For viscous and fouling solutions, like this having a coaxial double pipe construction like this one. This is the outer cell and this a inner cell if these are coaxial pipe shaft is there with a screw type this one internal surface scraper like this one this using this screw type thing like these are called say common examples are like Votator or Armstrong crystallizer or we can say Swenson Walker crystallizer.

So these are the common names of this one. Whenever the crystals will be deposited on the inner surface of the crystallizer, then it will be scraped and then it will be thrown to this collection basket. These crystallizers are mainly used for the crystallizing organic compounds like fatty acids, dyes, paraxylene then chlorobenzene, naphthalene, etcetera.

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- b) Fluidized bed crystallizers
- c) Surface cooled crystallizers
- d) Direct-contact refrigeration crystallizers

✓ **Application of ultrasound has been found to be effective for controlled nucleation and has the potential of improving CSD and product quality of industrial crystallizers**

The other types are fluidized bed crystallizers then surface cooled crystallizers then direct contact refrigeration crystallizers. So at the end application of this ultrasound has been found to be effective for control nucleation means ultrasound will this one enhance the nucleation. And has the potential of improving this crystal size distribution and product quality of the industrial crystallizer. So that is, nowadays these are all widely used.

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Problem 2

A batch crystallizer receives 2500 kg of a saturated solution of sodium chromate (Na_2CrO_4 , 10 H_2O ; MW=342) at 80°C . The solution is seeded with 1.2 kg sodium chromate crystals of 70 μm average size and cooled to 30°C . About 3% of water present in solution evaporates out during cooling process. What are the (a) quantity and (b) average size of product crystal? (c) If the crystallization process takes 6 h, calculate the average growth rate, $G=(L-L_s)/t$ where L is average size of product crystal, L_s is seed size.

Given:

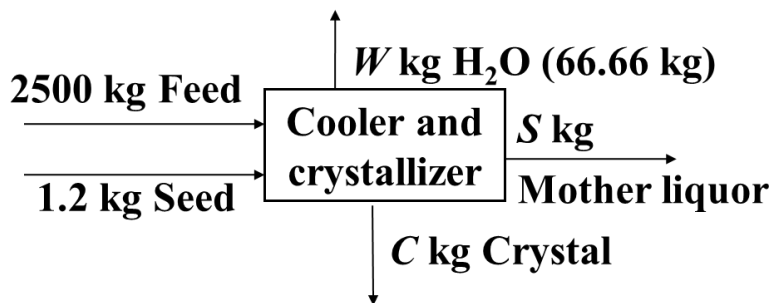
✓ $\rho_c = 1480 \text{ kg/m}^3$; volume shape factor, $\phi_v = 0.45$; $C_s = 125 \text{ kg salt per 1000 kg water at } 80^\circ\text{C}$ and $88.7 \text{ kg salt per 1000 kg water at } 30^\circ\text{C}$, mass of a seed $\phi_v L_s^3 \rho_c \text{ kg}$

✓ *It may be noted here that the number of product crystals are equal to the number of seed crystals.*

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A batch crystallizer receives 2500 kg of a saturated solution of sodium chromate (Na_2CrO_4 , 10 H_2O ; MW=342) at 80°C . The solution is seeded with 1.2 kg sodium chromate crystals of 70 μm average size and cooled to 30°C . About 3% of water present in solution evaporates out during cooling process. What are the (a) quantity and (b) average size of product crystal? (c) If the crystallization process takes 6 h, calculate the average growth rate, $G=(L-L_s)/t$ where L is average size of product crystal, L_s is seed size. Given: $\rho_c=1480 \text{ kg/m}^3$; volume shape factor, $\phi_v=0.45$; $C_s=125 \text{ kg salt per } 1000 \text{ kg water at } 80^\circ\text{C}$ and $88.7 \text{ kg salt per } 1000 \text{ kg water at } 30^\circ\text{C}$, mass of a seed= kg.

It may be noted here that the number of product crystals are equal to the number of seed crystals.



Now we will be solving one problem on the say crystal size distribution. The problem is that a batch crystallizer receives a 2500 kg of a saturated solution of sodium chromate Na_2CrO_4 , 10 H_2O molecular weight of 342 at 80 degrees Celsius, so this is a magma. The solution is seeded with 1.2 kg sodium chromate crystal of 70 micron average size, so that so whenever we have this one 1.2 kg sodium chromate crystal so that is we can say this is we can this is another input also. So one input is 2500 kg saturated solution and another, the first one is this 2500 kg saturated solution and second input is 1.2 kg sodium chromate crystals.

As this high is given that 75 micron, so from here we can get that how many numbers of crystals are present and for crystallization we may assume or this is the common practice that the number of crystals will not alter in the say the crystallization system. Whenever

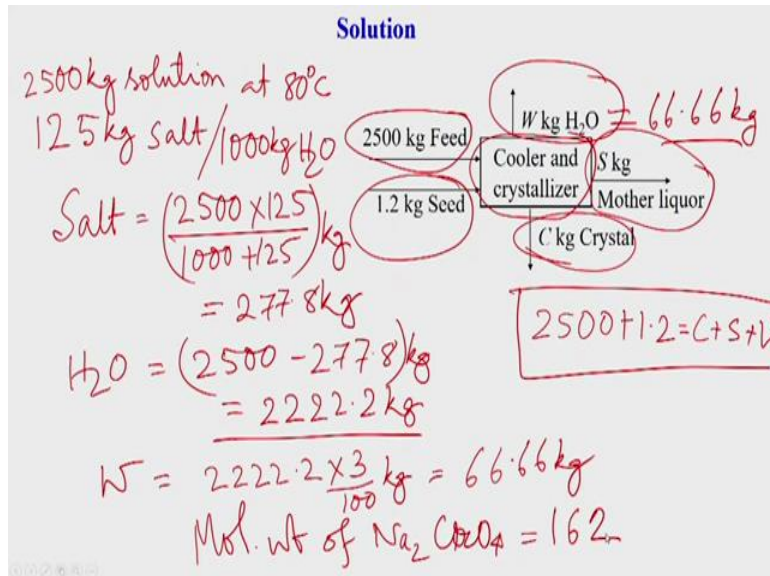
we will be putting the seeds, the in the from the beginning to the end the number will remain same but the size will be different.

It depending on the we can say supersaturation then how much temperature is dropped and we can say this is how much time actually we are allowing these two make the crystals okay. About 3 percent water present in a solution evaporates out during this cooling process. What are the quantity then average size of the product crystal? We need to find this one, if the crystallization takes place for 6 hours calculate the growth rate? Growth rate is G is equal to L minus L_s by t where L is the average size of the product and L_s the seed size.

Whatever the seed size is a given like this say 70 micron average seed size. And these are the given like this a density of the mother liquor or magma is given as 1480 kg per meter cube. Volume shape factor ϕv is equal to given as 0.45 and C_s is given as 125 kg salt per 1000 kg at 80 degrees Celsius and 88.7 kg per 1000 kg at where is the 30 degrees Celsius, so definitely solubility will be minimum at 30 degrees Celsius and mass of the seed is given as $\phi v L_s^3$ into ρ_c that we have already discussed this one in the previous class. So now we need to remember or we need to take a note that it may be noted here that the number of product crystals are equal to the number of the seed crystals.

So there, during this crystallization process, the new crystals will not be created whatever the seeds are added there or new phases are incorporated inside this crystallization system. This will be actually increased from L to, L_s to L not the number.

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Problem 2

A batch crystallizer receives 2500 kg of a saturated solution of sodium chromate (Na₂CrO₄, 10 H₂O; MW=342) at 80°C. The solution is seeded with 1.2 kg sodium chromate crystals of 70 μm average size and cooled to 30°C. About 3% of water present in solution evaporates out during cooling process. What are the (a) quantity and (b) average size of product crystal? (c) If the crystallization process takes 6 h, calculate the average growth rate, $G = (L - L_s)/t$ where L is average size of product crystal, L_s is seed size.

Given:

✓ $\rho_c = 1480 \text{ kg/m}^3$; volume shape factor, $\phi_v = 0.45$; $C_s = 125 \text{ kg salt per 1000 kg water at } 80^\circ\text{C}$ and $88.7 \text{ kg salt per 1000 kg water at } 30^\circ\text{C}$, mass of a seed $\phi_s L_s^3 \rho_c \text{ kg}$

✓ *It may be noted here that the number of product crystals are equal to the number of seed crystals.*

So we will be solving this problem like this one, sorry, two inputs are there say 2500 kg feed and 1.2 kg seed and then W kg water and say from this crystallizer C kg crystal will be separated, S kg magma will be separated. So we can say say 2500 plus 1.2 is equal to C plus S plus W. So this is overall mass balance. Now we will be doing this all these step-by-step firstly say we can say 2500 kg solution at 80 degree Celsius and here 125 kg salt is present per 1000 kg water.

So that is given in the problem, so salt will be amount of salt will be like this 2500 into 125 by total is 1000 plus 125 that is equal to 277.8 kg. So water will be 2500 minus 277.8 kg is equal to 2222.2 kg. Say out of this water 3 percent water is evaporated. So W is

equal to say 2222.2 into 3 by 100 kg that is 66.66 kg. So we can say W is equal we can say 66.66 kg. So that amount of water actually is evaporated during this process. Now you see this molecular weight of sodium chromate that is we can say is equal to of Na_2CrO_4 is equal to 162.

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Solution

Mol wt $\text{Na}_2\text{CrO}_4 \cdot 10\text{H}_2\text{O} = 342$
 $\therefore$ Mol. wt of $10\text{H}_2\text{O} = 180$

Water balance

2500 kg Feed
 1.2 kg Seed
 W kg H_2O (66.66 kg)
 Cooler and crystallizer
 S kg Mother liquor
 C kg Crystal

$$S x_{\text{seed}} + F x_f = S x_g + C x_c + W x_w$$

$$1.2 \times \frac{180}{342} + 2222.2 = S \frac{91.85}{100} + C \frac{180}{342} + 66.66$$

$$\Rightarrow 0.9185 S + 0.526 C = 2156.15 \quad (1)$$

Mother liquor
 $\frac{88.7}{1000 + 88.7} \times 100\%$
 $= 8.15\% \text{ (crystal)}$
 $\text{water } (100 - 8.15)$
 $= 91.85\%$

Problem 2

A batch crystallizer receives 2500 kg of a saturated solution of sodium chromate ($\text{Na}_2\text{CrO}_4 \cdot 10\text{H}_2\text{O}$; MW=342) at 80°C . The solution is seeded with 1.2 kg sodium chromate crystals of $70\text{ }\mu\text{m}$ average size and cooled to 30°C . About 3% of water present in solution evaporates out during cooling process. What are the (a) quantity and (b) average size of product crystal? (c) If the crystallization process takes 6 h, calculate the average growth rate, $G=(L-L_s)/t$ where L is average size of product crystal, L_s is seed size.

Given:
 $\rho_c = 1480\text{ kg/m}^3$; volume shape factor, $\phi_v = 0.45$; $C_s = 125\text{ kg salt per } 1000\text{ kg water at } 80^\circ\text{C}$ and $88.7\text{ kg salt per } 1000\text{ kg water at } 30^\circ\text{C}$, mass of a seed $\phi_v L_s^3 \rho_c\text{ kg}$

It may be noted here that the number of product crystals are equal to the number of seed crystals.

And then molecular weight of molecular weight of the salt $\text{Na}_2\text{CrO}_4 \cdot 10\text{H}_2\text{O}$ that is equal to given as 342. So therefore molecular weight of $10\text{H}_2\text{O}$ that is 18 into 10, so 180. Now we will be doing this material balance for water whatever we did for the previous problem also we will be following the same thing, water balance we will be doing the

water balance means say we have water from here, here and then water here, water here and water here, so water balance we will be doing.

So will we say seed into x seed plus feed into x_F is equal to, so mother liquor that we can say then a it will be seed s double e d , xS double e d , so mother liquor also S and so xS plus C into x_C plus W into x_W . So here 1.2 kg into water will be total 180 by 342 plus F means total 1000 kg, as say 2500 into how much percentage, total amount is say 125 kg salt per 1000 kg means 875 kg per 1000 kg. So total water is like this 2222.2, so will be 2222.2 kg.

So is equal to S into xS in the mother liquor, so that will be say we can say in the mother liquor it is mentioned that the how much amount of will be there say in mother liquor will be (finer found) we will found out in mother liquor. So 88.7 percent water is there by 88.7 percent the salt is there so per 1000 kg. 1000 plus 88.7 into 100 percent, so it is coming out as 8.15 percent crystal this is.

So this water is in mother liquor water will be 100 minus 8.15 so that is coming out as 91.85 percent. So it will be S into 91.85 percent means by 100 plus C into 180 by 342 plus water whatever water will go out this one 66.66. So from here actually we will be getting like this is 0.9185 S plus 0.526 C is equal to 2156.15, so this is we can say equation 1.

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Solution

Na₂CrO₄ balance

$$277.8 + 1.2 \times \frac{162}{342} = S \frac{8.15}{100} + C \frac{162}{342}$$

$$\Rightarrow 0.0815S + 0.474C = 278.3 \quad (2)$$

$C = 203.67 \text{ kg}$

Crystal size calculation

Seed size = 70 μm

Mass of seed = $\phi_0 L_s^3 \rho_c = 0.45 (70 \times 10^{-6})^3 \times 14803$

$$= 2.284 \times 10^{-10} \text{ kg}$$

```

graph LR
    Feed[2500 kg Feed] --> Unit[Cooler and crystallizer]
    Seed[1.2 kg Seed] --> Unit
    Unit --> Water[W kg H2O 66.66 kg]
    Unit --> ML[S kg Mother liquor]
    Unit --> Crystal[C kg Crystal]
  
```

Solution

Mol wt Na₂CrO₄ · 10H₂O = 342

∴ Mol. wt of 10H₂O = 180

Water balance

$$S_{\text{seed}} x_{\text{seed}} + F x_f = S x_s + C x_c + W x_w$$

$$1.2 \times \frac{180}{342} + 2222.2 = S \frac{91.85}{100} + C \frac{180}{342} + 66.66$$

$$\Rightarrow 0.9185S + 0.526C = 2156.15 \quad (1)$$

Mother liquor

$$\frac{88.7}{1000 + 88.7} \times 100\%$$

$$= 8.15\% \text{ (Crystal)}$$

$$\text{Water } (100 - 8.15)$$

$$= 91.85\%$$

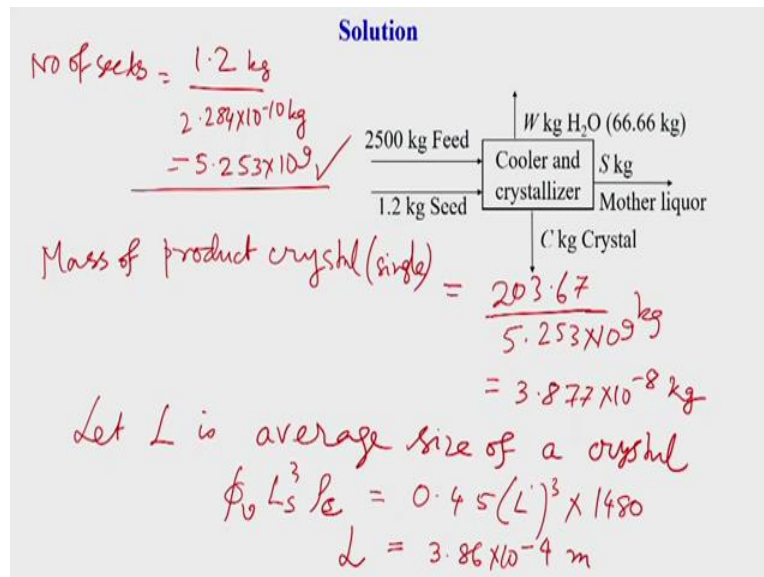
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graph LR
    Feed[2500 kg Feed] --> Unit[Cooler and crystallizer]
    Seed[1.2 kg Seed] --> Unit
    Unit --> Water[W kg H2O 66.66 kg]
    Unit --> ML[S kg Mother liquor]
    Unit --> Crystal[C kg Crystal]
  
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Now we will be doing the, this sodium chromate balance, we will be doing Na₂CrO₄ balance. The way we did this one for the other solid also, we will be doing like this in this out of this 2500 kg feed we have this already we have calculated that the 277.8 kg is there from the feed. And out of this 1.2 kg seed say we can say this is 1.2 into 162 by 342 that is only we can say sodium chromate is there. Then it will be like this S into in this one say it 8.15 percent, so 8.15 by 100 plus C into 162 by 342. So from here we will be getting like this from here actually we will be getting 0.815 into S plus 0.474 C is equal to this plus this then it will be 278.3, so this is equation 2.

So from this equation 1 like $0.9185 S$ plus $0.526 C$ is equal to 2156.15 and equation 2, $0.0815 S$ plus $0.474 C$ is equal to 278.3. From there we will be getting that C is equal to crystal is equal to say 203.67 kg thus amount of crystal is equal to 203.67 kg. Now we will be doing the crystal size calculation, the third part actually we have this crystal size calculation. So we have this seed size is given that is 70 micrometer and mass of seed is equal to say ϕ_v into L_s cube into ρ_C that is already given like 0.45 into 70 into (10 to the) this 70 micron into 10 to the power minus 6 to the power 3 and ρ_C is equal to that is already given 1480 that is we can say in terms of kg. So it is coming out as 2.284 into 10 to the power minus 10 kg. So mass of the seed actually is this one. So we have this total 1 kg and mass of 1 seed is equal to 2.284 into 10 to the power minus 10 kg.

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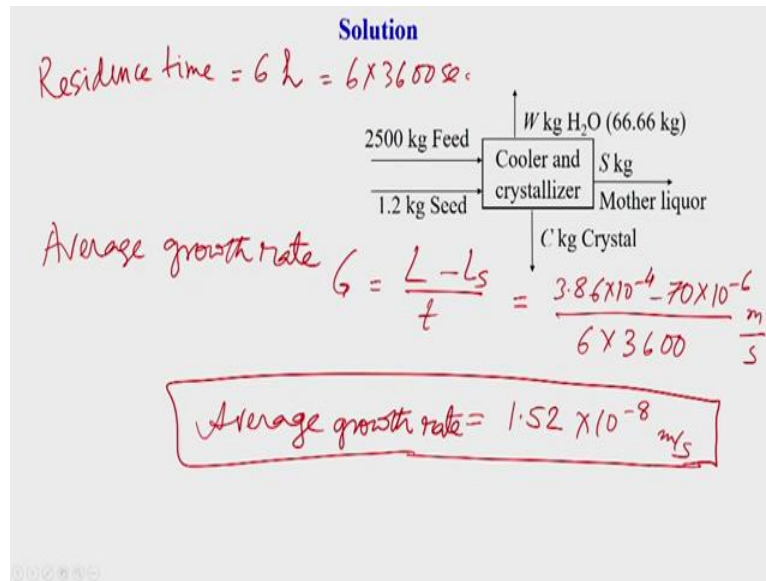


So number of seeds we can say, so number of seeds will be 1.2 kg by this 2.284 into 10 to the power minus 10 kg. So it is coming out as 5.253 into 10 to the power 9. And the mass of actually this total mass of the crystal after the crystallization is obtained as 203.67, 203.67 kg. So mass of product crystal because we have this the number of seeds actually will not change and mass of product crystal (()) (43:46) single one that is will be equal to you can say 203.67 divided by 5.253 into 10 to the power 9 that is in terms of kg.

So that is coming out as say 3.877 into 10 to the power minus 8 kg. Now we have this say let L is the average size of a crystal. So we have this ϕ_v into L_s cube into ρ_S sorry

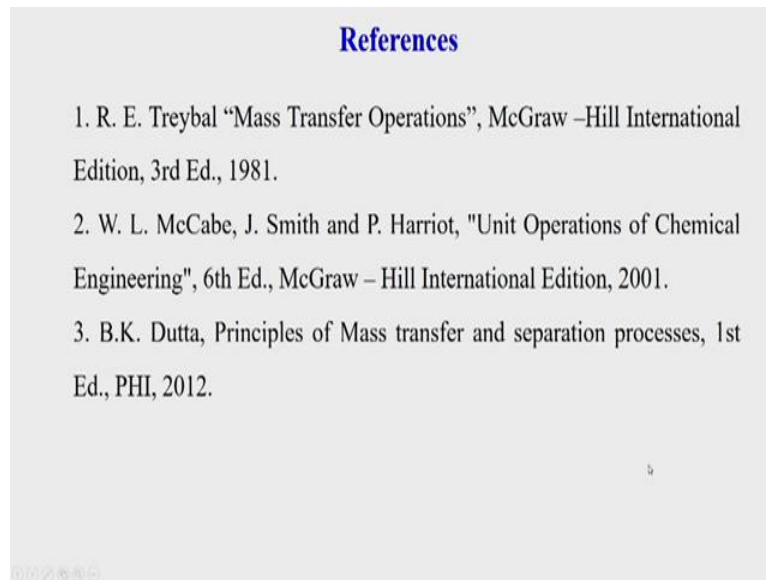
rho crystal that is equal to 0.45 into say L cube, Ls cube into 1480. So we have this one, so we can say, sorry this one is, so this is coming out as we can say is equal to, so L will be equal to 3.86 into 10 to the power minus 4 meter. So from here actually we are getting this L is equal to 3.86 into 10 to the power minus 4 meter.

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And a residence time is equal to 6 hour is equal to 6 into 3600 second. So average growth rate G is equal to you can say L minus Ls by t that is L is equal to whatever we got this one 3.86 into 10 to the power minus 4 and whereas it is 70 micron, 70 10 to the power minus 6 by 6 into 3600, so that is we can say meter per second. So this is coming out as 1.52 into 10 to the power minus 8 meter per second. So this is the growth rate, average growth growth rate. So this is the average growth rate of the crystal.

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So the references we can follow for the further studies will be like this R. E. Treybal's book that is Mass Transfer Operations by McGraw Hill International Edition and McCabe Smith Book of this 2001, this McGraw Hill International Edition book and Principal of Mass Transfer and Separation Processes by B. K. Dutta.

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So thank you, good luck and any suggestions feedback.