**Thermal Processing of Food**

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**Lecture 21**

# Various Types of Heat Exchanger for Food Process Engineering

Good morning all. So, today we are going to discuss about various types of heat exchangers which are used in the food process engineering or food process industries. So we go a little introduction about the heat exchangers and what how to design a heat exchanger? And what are all the applications of heat exchangers in food process industries? And main type of for heat exchangers we are going to see in this particular lecture.

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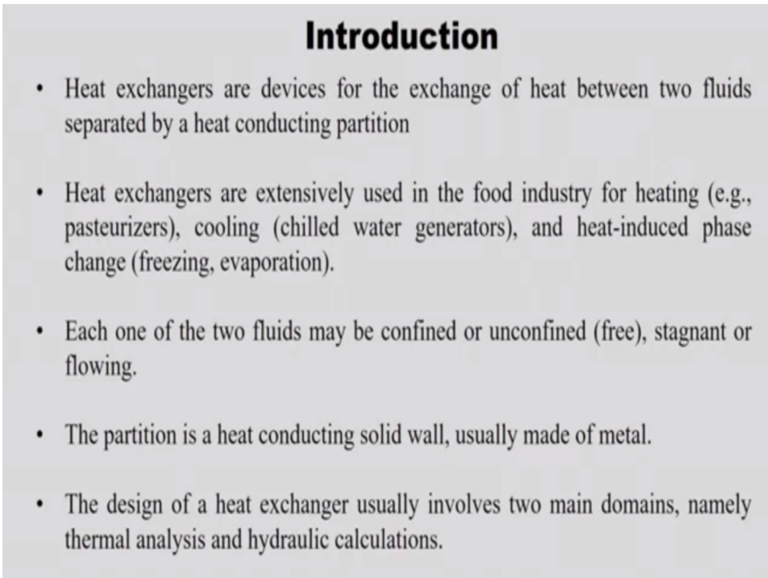


So the heat exchangers are devices for the exchange of heat between two fluids separated by a heat conducting partition. So this is nothing but a wall, right? Two fluids we have a hot fluid as well as cold fluid. So mostly cold fluid is here is you are a liquid flow food particle, sometimes with the particulate solids. Heat exchangers are extensively used in the food industry for heating, which is nothing but pasturizers, and cooling chilled water generators and heat induced phase change, so which is nothing but a freezing and evaporation.

So this evaporation we have seen in the membrane separation as well to concentrate the food material, right? So then each one of the fluids may be confined or unconfined stagnant or flowing. So, depends upon the heat exchanger we use, so each one of the two fluids may be confined or unconfined, stagnant or flowing. The partition is a heat conducting solid wall usually made of metal to give high thermal conductivity.

The design of a heat exchanger usually involves two main domains namely thermal analysis and hydraulic calculations because the heat exchanger, the food is liquid food right? So, if you remember in our aseptic processing calculations I told the same thing because in continuous thermal processing. So, we need to take care of the hydraulic calculations as well as the thermal analysis heat transfer as well as fluid flow.

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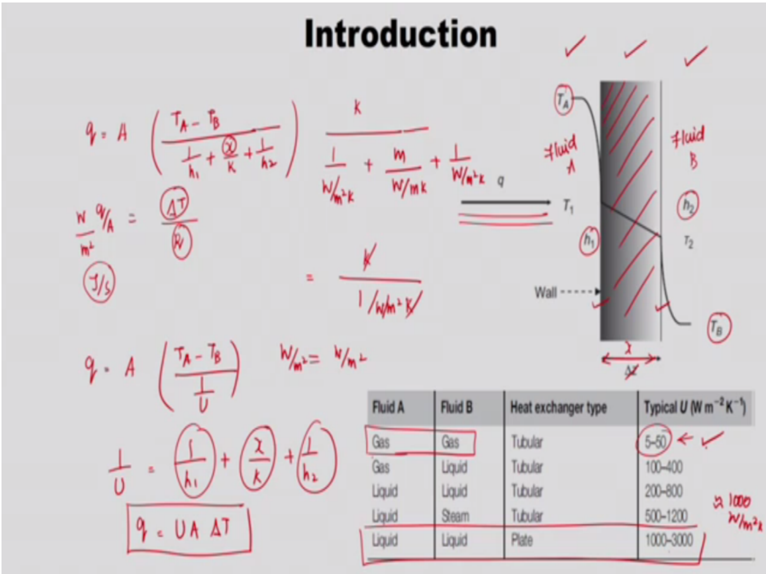


So, here is one example so this is a solid wall these two are solid walls right the heat is given here in the solid wall. So, the temperature here TA in the outside of the wall and TB in the other side of the wall, and the wall temperature is T1 and this side it is T2 and the h1 is nothing but a heat transfer coefficient h2 is a heat transfer coefficient in the other side, right? So, this is the ambient maybe we can consider, so this is also ambient or you can consider here maybe another fluid there, right?

So, now if we want to write q the heat balance q is nothing but A, TA minus TB, so flux which is nothing but a Q upon A, Q upon A is nothing but heat transfer rate upon area. So heat transfer rate is nothing but in watts and area is in meter square, so this watt is nothing but joules per second. So, that means heat transfer rate per meter square which is nothing but a heat flux. Heat flux can be written as a thermal gradient because in heat transfer it is a thermal gradient, any flux can be written as a gradient upon resistance okay?

So, in heat transfer it is a thermal gradient, the R we are going to write, so R if you see, so this is the h1, h1 is nothing but heat transfer coefficient, convective heat transfer coefficient, and this is nothing but a solid-solid material. For example, this is the wall of the heat exchanger, so this is the wall of the heat exchanger, this side one fluid resides, the other side of the wall another fluid reside, so instead of ambient you can take an example of heat exchanger itself.

So, this is the heat exchanger wall, so one fluid resides this side, another fluid resides that side. So, the h1 is the heat transfer coefficient of this particular fluid A and h2 is the heat transfer coefficient of fluid B and the temperature T1 is at the wall, near the fluid A side, T2 is the temperature in the wall near the fluid B side, right? So, TB is a temperature of the fluid B and TA is the temperature of fluid A. So, I have basically three resistance, one on the fluid A side another on the wall and another on the fluid B side, right?

So, I can combine them one upon h1, because there h is nothing but a heat transfer coefficient resistance is one upon conductance, so then your conductive resistance is nothing but X upon K, X is nothing but a thickness of the wall, okay? So, that I am taking as a X, so X upon K plus 1 upon h2, right, so this is the resistance, right. So, here the T is in Kelvin, right, so the 1 upon h is watt per meter square Kelvin, so your X is meter, K is watt per meter Kelvin. So, this is 1 upon watt per meter square Kelvin, so which is nothing but K upon 1 upon if the meter comes here it is 1 upon meter.

So, this also 1 upon watt per meter square, 1 upon watt per meter square Kelvin, so this goes above so which is nothing but K K get cancelled so this also will become watt per meter square watt per meter square unit is cancelled. So, I can write my Q as A TB minus T, TA minus TB, divided by one upon U so this one upon U is nothing but 1 upon h1 plus X upon K. So this is a conductive resistance this is convective resistance plus 1 upon h2 this is also convective resistance.

So if you write q is equal to UA, TA minus TB is nothing but del T, so U is nothing but overall heat transfer coefficient AC area, del T is nothing but temperature difference between the fluids TA TB and Q is nothing but heat transfer rate. So, if you remember we have done in the pasteurization plate a type heat exchanger problem, we have also calculated number of plates required for the heating.

So, if you remember we have taken the U, the milk side heat transfer coefficient in heating cooling as well as the regeneration there we have taken around approximately thousand watt per meter squared Kelvin. So, if your fluid A is liquid and fluid B is liquid in the plate heat exchanger type you are used around thousand to three thousand watt per meter squared Kelvin.

So, that is what it is given, so based on the fluid, for example, if it is a gas gas in tubular heat exchanger, so your heat transfer coefficient 5 to 50 watt per meter squared Kelvin. So, if you remember the same pasteurization lecture, I also told in the pasturizer or sterilizer, you should not keep the air packets because air is a very low conductive medium. So, you can see from here the liquid if you have a fluid A as a liquid, fluid B as a liquid you are overall heat transfer coefficient is thousand around thousand watt per meter square.

So, if you have a gaseous heat exchanger so your overall coefficient is 5 to50 watt per meter squared Kelvin. So, if you have air packets inside the sterilizer or the pasteurizing unit, so that will lead to high temperature difference between the food material, so that leads to contamination. So this is the reason we need to avoid air in sterilizing operation, okay?

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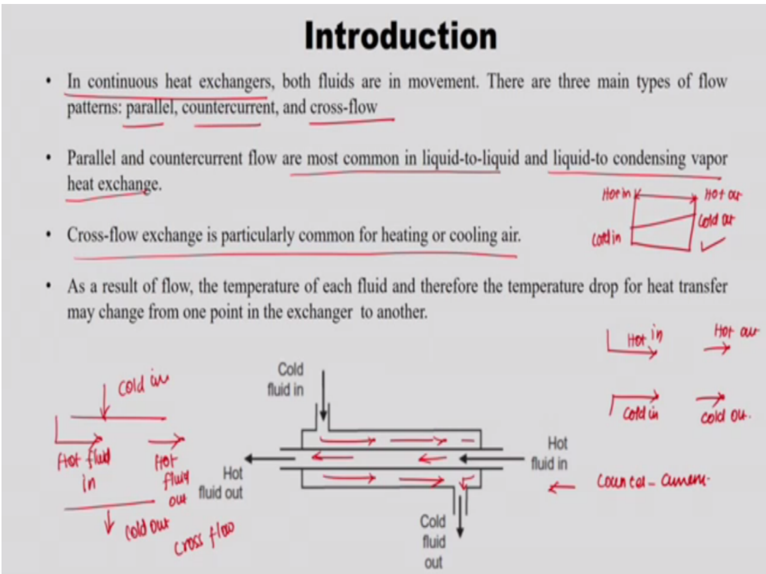


So, in introduction in continuous heat exchangers both the fluids are in movement, right? So mostly the heat exchanger we use for continuous flow. In continuous a heat exchanger both fluids are in moment. There are three main types of flow patterns, one is parallel counter current and cross flow. So, one example would be this one, so this is a counter current, counter current, your hot fluid is coming in and going this side and your cold fluid is coming here so and leaving this side of the heat exchanger.

So, this is the counter current. Co-current means your fluid, hot fluid as well as cold fluid hot fluid hot out hot in, so you are cold in and cold out, right? Cross flow is nothing but so you are hot fluid and hot fluid out. So, this is inside the tube, through your cold fluid will be perpendicular to a hard fluid direction. So, this is nothing but your cross flow, okay? So this is counter current flow, this is co-current flow. Parallel and counter flow are most common in liquid liquid as well as liquid to condensing vapour heat exchange.

So, this condensing vapour is nothing but you use the phase change heat to heat the liquid. For example, if you take heating the food material most of the time we have seen heating medium as a steam, right? So this is cold in cold the fluid in and a cold fluid out, so if you see in the latent heat exchange. So, there will not be any temperature difference so this is a steam temperature hot in and hot out, so there will not be any temperature difference in the steam.

So, it is a parallel as well as counter current flow or most common and liquid liquid or liquid to condensing vapour heat exchange, right? And cross flow exchange is particularly common for heating or cooling the air, so that is gas gas heat exchanger we have seen, right? So, there cross flow is mainly used. As a result of flow the temperature of each fluid and therefore, the temperature drop for heat transfer may change from one point to other point in the exchanger.

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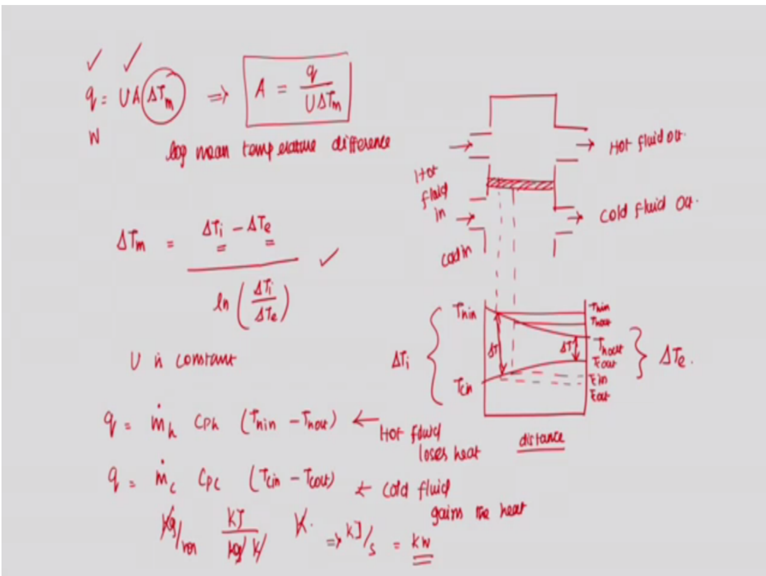

So, this is where the concept of log means temperature difference has come so LMTD. So if you remember in all the calculations we have used q is equal to UA Del Tm, all right? So this is nothing but log mean temperature difference, so what does it mean? So, it means so I am putting this as a wall. So, here is your hot fluid in, so here is your hot fluid out, so cold fluid in, I am taking co-current flow and a cold flow it out, okay?

So, if you make it in terms of X versus, distance versus temperature so that Thi Thout. So this is in, so the this is TC in and TC out, okay? So, if I take a particular area, so this would give me Th in and Th out so the same way for this particular area, TC in and TC out okay? So this Th in minus TC in we call it as a del Ti, so this we call it as a del Tem okay?

So, then finally the derivation of LMTD I am not going to do because that is not in the syllabus of this particular course. But I would like to tell you that if you really wanted to know in depth of why we need to calculate logarithmic mean temperature difference, how to derive that, you may refer some of the books given in the reference okay. So, the final the del Tm, how do we write this which is nothing but del Ti minus del te.

So, this is Inlet, this is exit. I divided by lon of del Ti divided by Del Te. So, why we are taking mean temperature difference? Because the throughout that distance my delta T is varying. So, I cannot take one particular delta T. So, if you see here so this is the delta T here, so it is there delta T here, okay. So, it is varying along the length of the heat exchanger that is the way we take mean temperature difference, logarithmic mean temperature difference.

And also remember here I have taken U is constant along the length because though my temperature is varying, my overall heat transfer coefficient is constant. So, from this I will calculate the log mean temperature difference, then substitute in the q formula which is nothing but UA del T. Here you can substitute your U and Q you will be able to know, Q is nothing but for hot fluid, mass flow rate of hot fluid, CP of hot fluid and del T del T in the sense Th in minus Th out okay.

So, if you write for cold fluid it is a mass flow rate of cold fluid CP of cold fluid, this is TC in minus TC out, okay. So, remember one hot fluid loses heat losses heat and cold fluid gains the heat. So, this is the way we calculate and design the heat exchanger right. So, if I want to know how much heat transfer area is needed to heat my fluid the food or liquid food. So, I will get to know from Q by U del Tm.

So the Delta if I know Inlet outlet temperature if I know flow configuration whether it is a counter flow or cross flow or co-current flow, then I will be able to calculate my del Ti, del Te and from there I will calculate the log mean temperature and from the log mean temperature. I will be able to calculate the area provided U is given, and q I will be able to calculate from mass rate of the hot fluid, this is mass rate which is nothing but in kg per second or hour so this is kilo joules per kg Kelvin so this is in Kelvin.

So, this Kelvin Kelvin gets cancelled, kilo joules per hour, so you if you convert into joules kilo joules per second so that is nothing but kilo, so what I told you is here, this is also in watts, right? So, unit, you can calculate the Q and substitute in the formula so that is the way you design the heat transfer area for liquid to food to be heated in the heat exchanger.

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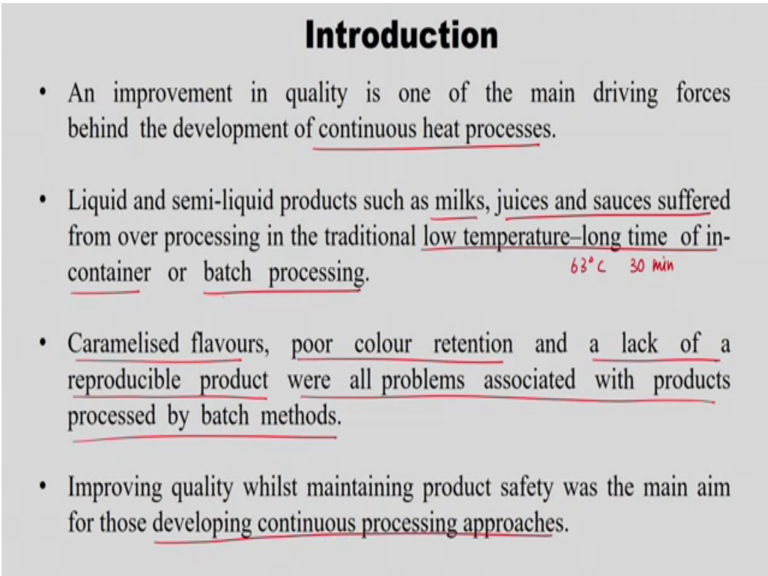


So, then intro about the heat exchanger, why we need to study? An improvement in quality is one of the main driving forces behind the development of continuous heat processes. So the liquid, semi-liquid products such as milk juices and sauces suffered from over processing in traditional low-temperature long time of an in container or batch processing. Batch processing in one of the lectures also we have discussed an enormously so I just to put it and forget it. For example, if you see the temperature for the pasteurization 63 degree centigrade about 30 minutes.

So, this causes the lower processing, so due to which the continuous process came into existence. So caramelized two flavours poor colour retention and a lack of a reproducible product where all the problems associated with the products processed by batch method. So, to overcome these disadvantages then to keep product safety in mind the continuous processing approaches were developed.

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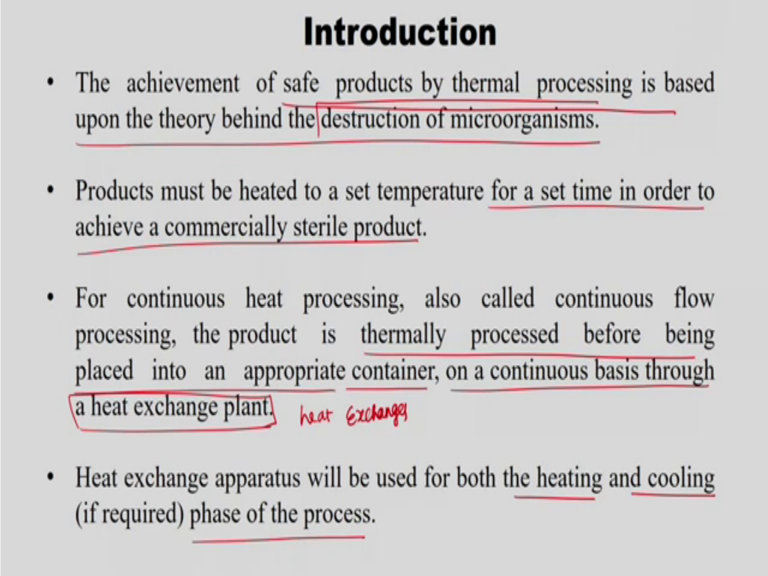


The achievement of safe products by a thermal processing is based upon the theory behind the destruction of microorganisms. So why we are thermal processing it the, for the reason for destruction of microorganisms. The products must be heated to a set temperature for a set time in order to achieve a commercially sterile product, in continuous heat processing also called continuous flow processing, the product is thermally processed before being placed into an appropriate container on a continuous basis through a heat exchanging plant.

So, the main part of the continuous thermal processing is nothing but a heat exchanger, okay. So, the heat exchanger apparatus will be used to for both heating as well as cooling, cooling phase of the process, this we discussed in our earlier lectures itself, so heating as well as cooling and if you see in the aseptic process, regeneration also in between heating regeneration and cooling.

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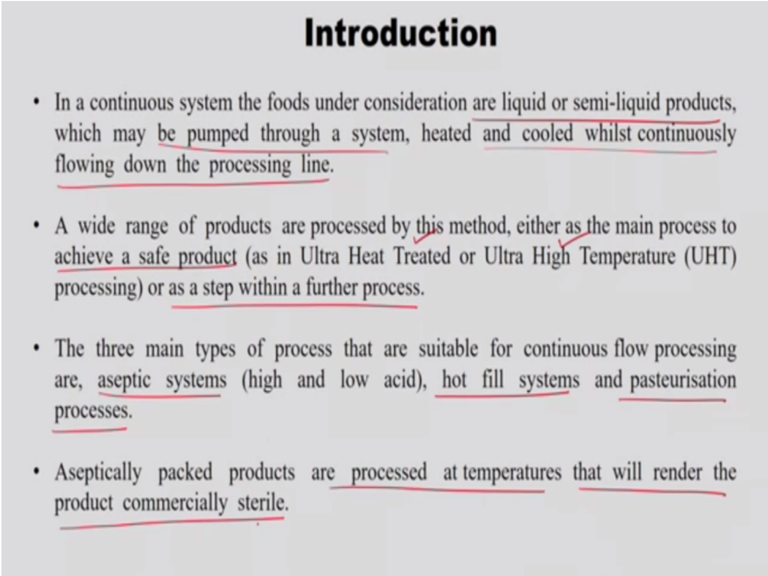


In continuous system the foods under consideration are liquid or Semi-liquid products which may be pumped through a system heated and cooled while continuously flowing down the process line a wide range of products are processed by this method that means the continuous flow process, either the main process to achieve a safe product.

The main process itself a heat exchanging process which is nothing but ultra-heat treated or ultra-high temperature are a step with enough further processing the heat exchanger may be used as an intermediate step to heat. The fluid or the main process itself a heat exchanging process which is happening in the ultra-high temperature or even aseptic processing.

The three main types of process are suitable for continuous flow processing or aseptic systems, which is high and low acid foot and hot fill systems, pasteurization process so everything comes under this continuous flow process category. Aseptically packed products or process two temperatures that will render the product commercially sterile, so aseptic processing we have already seen in maybe three lectures I guess.

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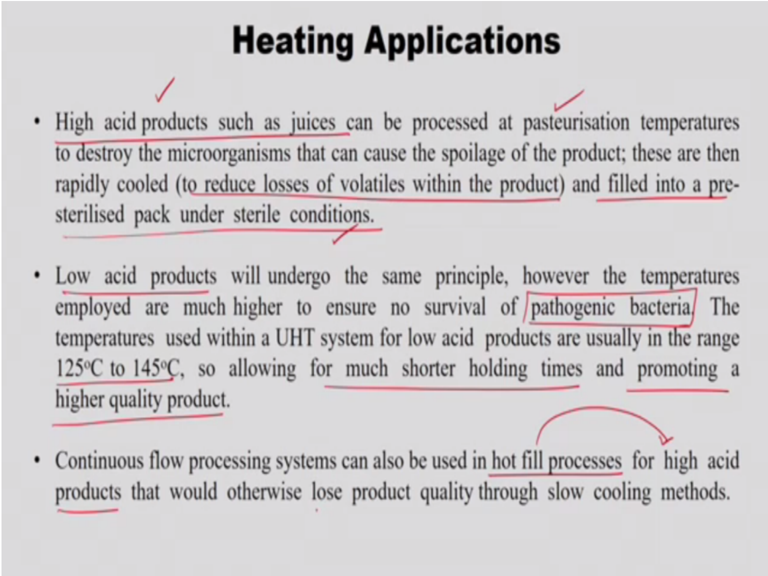


So then heating applications so this also we have discussed if it is a high acid products such as juice can be processed at pasteurization temperature to destroy the microorganism that can cost the spoilage of the product. There are then rapidly cool to reduce the loss of volatiles within the product also to reduce the contamination of thermophilic bacterias, right, because when you slowly cooling there may be a chance for the recontamination. So the cooling is done very rapidly and filled into a presterilized pack under sterile conditions.

So hot acid products we do pasteurization and a packet under sterile conditions in a sterilized packaging the low acid products which undergo same principle. However, the temperature employed is much higher to and should no survival of the pathogenic bacteria. So that is why we go for a sterilization the temperature applied here at 125 to 145 degree so allowing for much shorter holding times and promoting a higher quality product. The continuous flow processing system can also be used in a hot fill processes for high acid products again hot fill processes for high acid products that would otherwise lose product quality through slow cooling methods.

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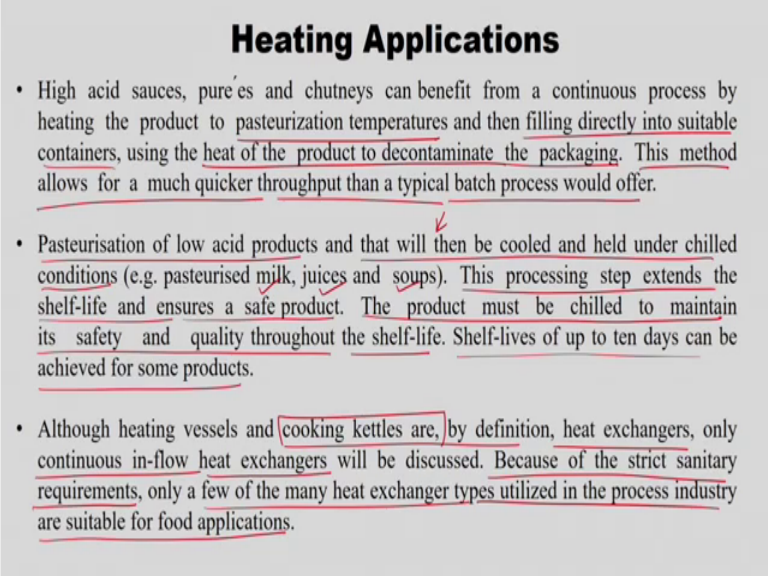


And high acid choices again high acid food comes under pasteurization category. They are filling directly into suitable containers using the heat of the product to decontaminate the packaging. So sometimes this also tried so this method is this method allows a much quicker throughput than a typical batch process would offer the high acid certain high acid foots pasteurized and filled in the normal containers not in a sterile containers.

So the product heat itself further decontaminate the packaging so this also another heating applications. Where heat exchanging systems are used and pasteurization of low acid products that will then be cooled and held under chill the conditions so this is where we do not so we need to refrigerate them, even low acid products, so pasteurized milk juices soups everything comes under this category.

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This processing step extends the shelf life and ensures the safe product the product must be chilled to maintain its safety and quality throughout the shelf life shelve lives up to ten days can be achieved for some products. So these are all some of the heating up applications furnace high acid products which are pasteurized and part-owner sterilized to packaging under sterile condition low acid products which are to be sterilized to kill the pathogenic bacteria and hot fill processes. Where high acid products are processed and these high acid products are processed and filled in the packaging.

So that temperature of the products itself will take care of the decontamination of the packaging system then further pasteurization of low acid products. Here we did sterilization so if you do pasteurization that has to be chilled to extend the further shelf life, okay. So, although heating vessels are cooking kettles by definition heat exchanges, so whatever we use in day-to-day life those also called as a heat changer. Because the heat exchanger is one which exchanges the heat right through a solid one they themselves cooking kettles themselves as a heat exchanger.

Even one of the lectures I mentioned whatever we do in normal day-to-day process which is nothing but a pasteurization of milk. So, whenever we are heating the milk we are doing pasteurization but that is not the case with the industry they have to handle the large volume and they have supposed to store and distribute for further use. So in that case GMP regulations were to be followed right good manufacturing practices to be followed.

Here also the heat exchangers, cooking kettles also by definition heat exchangers but the only continuous inflow heat exchangers which are used in the food processing industry which we will be discussed in this lecture. Because of strict sanitary requirements, right, so only a few of the many heat exchanger types utilized in the process industry are suitable for food applications.

So the same thing I will be telling in the dryers as well so we are also going to have a lectures on dryers various dryers used in the food processing industry there. There are lot of dryers are there and even normal chemical industry also uses various dryersm but these dryers which are used in food industry should be hygienic, right.

The dehydration plant should be contamination free for the dryers to be used in the food industry the same thing here. Even though there are lot many varieties of heat exchangers are available in the processing industries. But food processing industry strictly follows the sanitary requirements so because of which very few types of heat exchangers are used.

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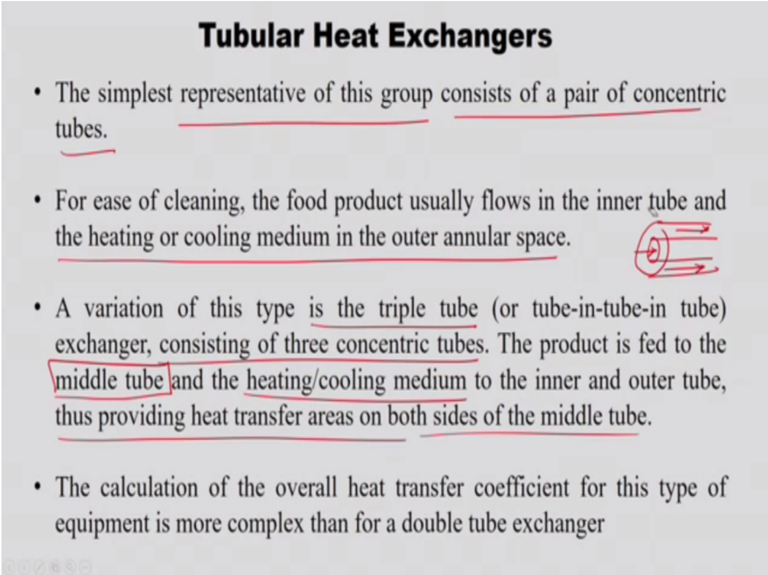


The first one is tubular heat exchanger the simplest representative of this group consists of a pair of concentrating tubes for ease of cleaning the food product usually flows in the inner tube and the heating or cooling medium in the outer annular space. The variation of this type is the triple tube right, so which has three tubes as a concentric tube, in the middle tube your product would be flowing the other two inner and outer tube your heating and cooling medium.

If it is a heating process it is a heating medium, if it is a cooling process it is a cooling medium the product is fed into the middle tube and the heating or cooling medium to the inner and outer tube which provides the heat transfer areas on both side of the middle tube. So, if you have a tube in concentric double pipe heat exchanger, so you will have the hot fluid flowing in here, so if you have one more tube.

So probably we will see in the here, what is tube in tube, as well as tube in tube in tube heat exchanger. First, we will see the theory. So, the product is fed to the middle tube and that heating and cooling medium to the inner and outer tube thus providing heat transfer areas on both side of the middle tube. The calculation of overall heat transfer coefficient for this type of equipment is more complex.

So, whatever I told here so here fluid is flowing other side of the wall one heat exchanger wall is there one fluid is flowing this side another fluid is flowing this side. So that is the way we calculated the overall heat transfer coefficient but if you have a three tubes. Then you need to further calculate the heat transfer coefficient that is not that easy or straightforward method to calculate the overall heat transfer coefficient for the triple tube heat exchanger than the double tube heat exchanger.

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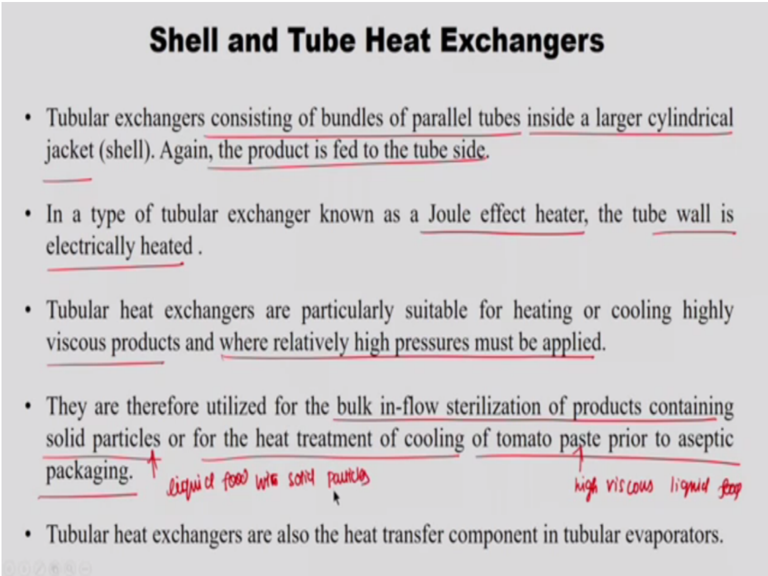


So the next one is shell and tube the tubular heat exchanger consists of a bundles of parallel tubes inside a larger cylindrical jacket. Again the product is fed into the tube side, so in a type of tubular exchanger known as a Joule effect heater. The tube wall is electrically heated, so it is not to be necessarily the cold fluid will be heated through the hot fluid, so here in the certain type of tubular exchanger which is called as a Joule effect heater.

The tube wall is founded with the electrical coils, they can be heated electrically as well the tubular heat exchangers are particularly so trouble for heating or cooling highly viscous products. Where relatively high pressures must be applied or therefore, heat realized foreign bulk inflow sterilization of the products containing solid particles and for the heat treatment of cooling of tomato paste prior to aseptic processing.

So, these are used to for bulk inflow sterilization of the products which has certain solid particles as well or for the heat treatment of cooling of tomato paste prior to aseptic processing. So that means high viscous, high viscous liquid food or so they can also be used with the liquid food with the solid particles, food with solid particles. So, the tubular heat exchangers are also the heat transfer component in tubular evaporators.

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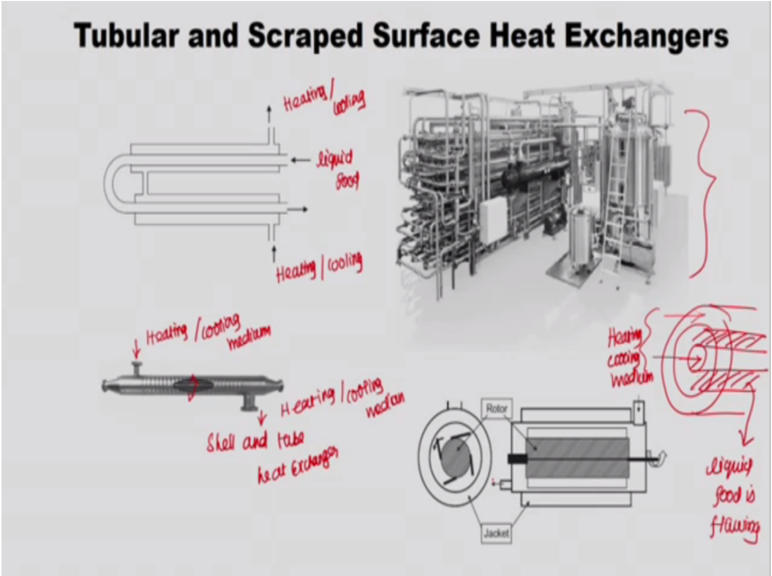


So, here is what your double pipe heat exchanger so which is nothing but a tubular heat exchanger. So your hot fluid goes in here or you can say your liquid food material is inside the tube liquid food. So, your heat medium or heating medium in terms of heating or cooling medium in terms of cooling flows this side, heating or cooling medium, okay.

So, this is the shell and tube, shall and tube, this is the shell and tube heat exchanger where number of tubes. So, if you see number of tubes are put together in a bundle, so then the shell side your normal heating or cooling medium will be flowing. So this is heating or cooling medium, heating or cooling medium, so this is heating or cooling medium, so inside the tube your food material is flowing.

So, this is where in the industry where tubular heat exchanger looks like, right. And one more thing what we have seen the triple pipe is, right. So triple pipe is something like this, right? So we told so the inner pipe as well as the outer pipe, right? So in the both places your heating or cooling medium is flowing in the middle of the pipe, in the middle pipe so your liquid food is flowing.

So, this is tube in tube in tube heat exchanger. So, this is shell-and-tube, this is tubular exchanger, which has two concentric tubes. So, this is scraped surface so we will see about the theory and come back. So, this is a clear, right, like shell and tube as well as tubular exchanger. This is the basic types, so in the tube your liquid food material is going, so other tubes you are, or tube or shell side you are heating or cooling medium is flowing.

So, it is not necessary I need to heat or cold my liquid food with the hot fluid or cold fluid. So, there may be electrically wounded tubular exchanger also there, so in that case it is called as Joule effect heater. And these shell and tube heat exchangers are used or tubular heat exchangers are used to for liquid food which contain solid particles as well as the high viscous liquid food also can be handled in the tubular heat exchangers.

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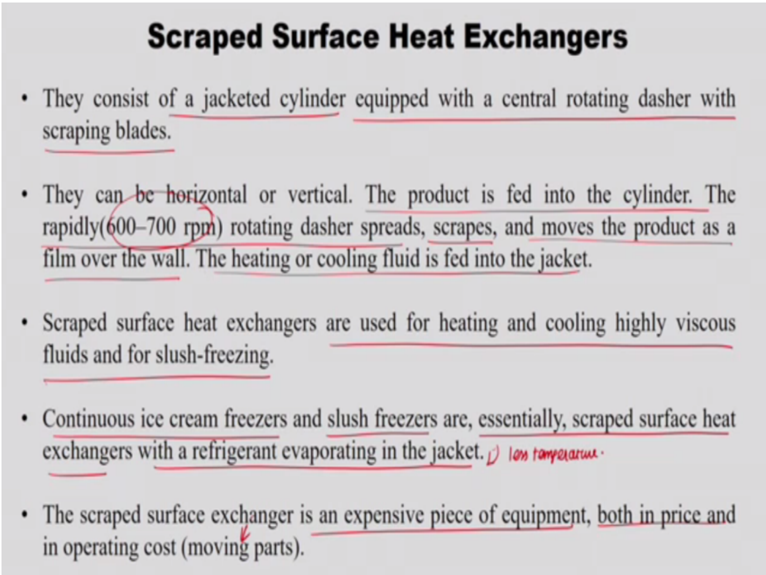


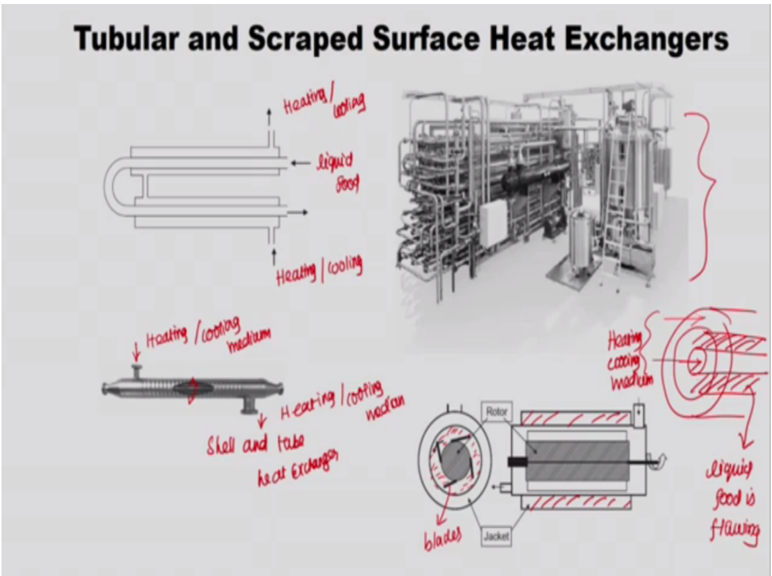


So, the scrap the surface heat exchangers, so which has a, they consist of a jacketed cylinder equipped with the central dasher with scrapping blades, so that is right here. Here, so this is your jacket so in the middle you have a rotor right so the rotor has blades. So this is the side view, so this is blades, so this is a rotor, so at this place your liquid food with the high amount of solid particles stays there okay.

So they consist of a jacketed cylinder equipped with the central rotating dasher with scrapping blades. So they can be horizontal or vertical the product is fed into the cylinder they rapidly rotating the rotating speed is about 600 to 700 rpm and they spread scraps and moves the product as a film over the wall the heating or cooling medium is fed into the jacket. So here you have your heating or cooling medium.

So, these rotors helping the products because it has high amount of solids because the scrapped surface heat exchanger is mainly used to for high viscous fluids or liquid food contains a large amount of solid particulates. So, for this application only the scrapped surface heat exchangers are used so in that case. So, these blades are helping the solids liquid food with the high amount of solids to form a film layer near the jacketed one in the other side of the jacketed one you are heating or cooling medium is flowing.

So, the scrap surface heat exchangers are used to for heating cooling highly viscous fluids and for slush freezing the continuous ice cream freezes and slush freezes or essentially scrapped surface heat exchanges with the refrigerant evaporating in the jacket. So one thing is as I said earlier, it need not be always hard fluid or cold fluid here the refrigerant is also used as a heating or cooling medium because it gets evaporated the less temperature okay.

So the scrapped exchanger is an expensive piece of equipment both in price as well as in operating cost because it has got many moving parts. So the exchanges are expensive.

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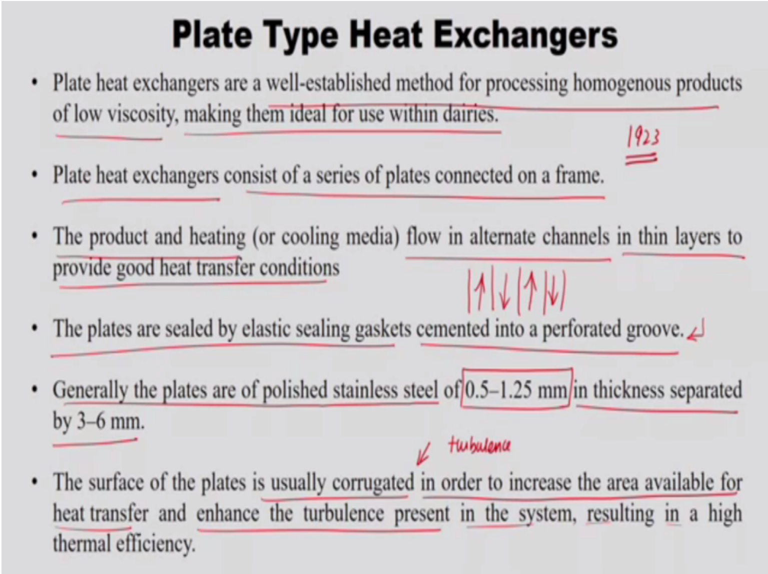


So the next one is very important heat exchangers in the food industry so it is almost came into existence in 1923. And in most of the pasteurizing or a aseptic processing the plate type heat exchangers are used. So the plate type heat exchangers are well established method for processing homogeneous products of low viscosity making them ideal for use within dairies, mostly in the pasteurization or aseptic processing of milk. The plate heat exchangers consist of a series of plates connected on a frame. The product and heating or cooling media flow in alternate channels in thin layers to provide good heat transfer conditions.

So, I have a plates one side my hot fluid is flowing other side cold fluid, other side hot fluid other side cold fluid. So this is the way the alternative channels are arranged. The plates are sealed by elastic sealing gasket cemented into a perforated groove, right? So generally the plates are of polished stainless steel which is of about 0.5 to 1.25 mm in thickness separated by 3 to 6 mm right.

So, these plates are of stainless steel, the thickness of them is 0.5 to 1.25 mm they are separated by the distance 3 to 6 mm, okay. So, these plates are separated by 3 to 6 mm and they are sealed by elastic sealing gasket cemented into a perforated groove, so this we will see in picture. So, the surface of the plates is usually corrugated in order to increase the area available for heat transfer as well as enhance the turbulence present in the system resulting in a high thermal efficiency. So, these are corrugated to promote mainly the turbulence and also sometimes it also gives the strength to the plates which are stacked together okay.

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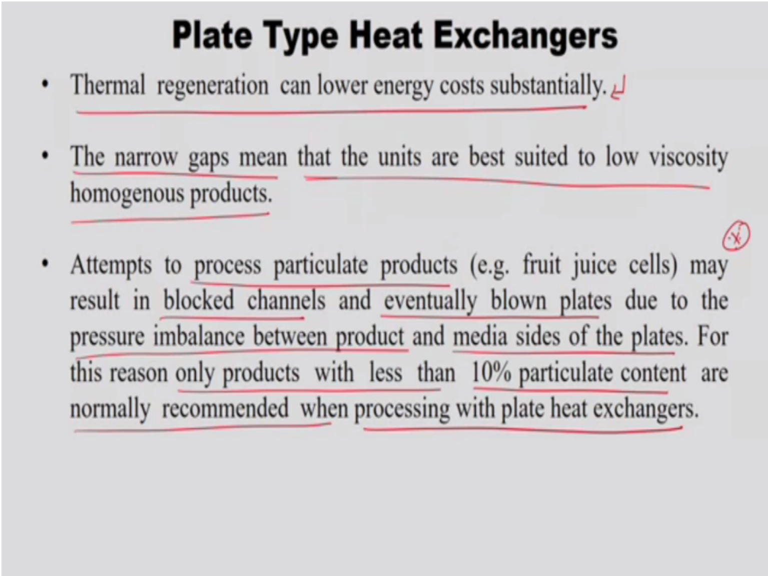


So, the thermal regeneration can in the plate type exchanges as we have seen in many of our lectures. The thermal regeneration is possible which can lower the energy cost substantially, then narrow gaps mean that the units are best suited for low viscosity homogeneous products because the gaps between the plates are very-very narrow.

So, we cannot handle the liquid food with the large amount of particulate solids because it gets in between the plates and further fouling can occur. So attempts to process particulate products, which is example is nothing but the fruit juices with the pulp, right. That cell may result in blocked channels and eventually blown plates due to the pressure imbalance between the product and the media sides of the plates.

So, for this reason only products with less than 10 percentage particulate content or normally recommended, when processing with plate type heat exchanger, so this has to be kept in mind, so we cannot process the liquid foot with more than 10 percentage of the particulate content. And the regeneration is possible in plate type heat exchangers which lowers the energy cost.

And there are many variations of the plate type heat exchanger. So, how to take care of each and every plate? And which type of groove should be there and based on the product we can select them, so which way we want the plate type heat exchanger to be designed.

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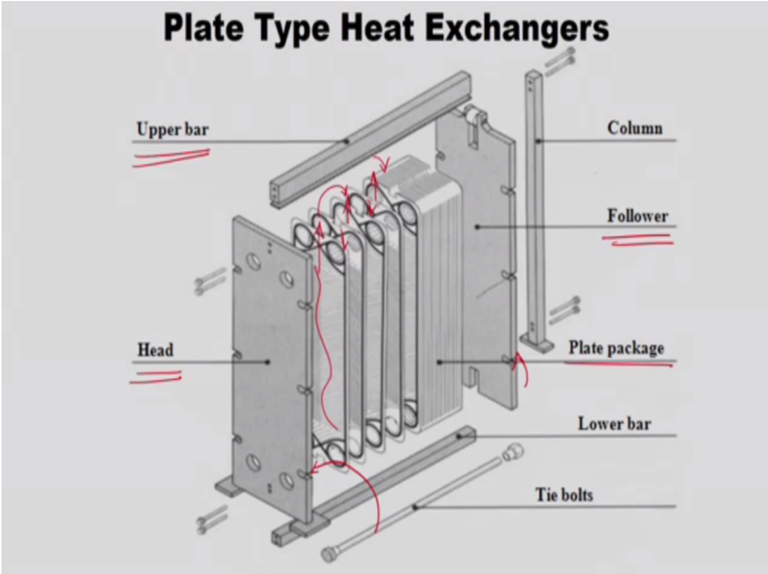


So, here we see, so this is the plate type heat exchangers looks like. So this is your upper bar so, this is your head plate, head plate in the sense header and this is the follower, right? So in between the header and follower your plates were arranged. So, as I said so here your hot fluid is flowing and here your hot fluid is flowing, here your hot fluid is flowing, so there is a mechanism which transfers this hard fluid to here and so here your cold fluid is flowing, right.

So that means so this flows through the plate, okay, so this is the lower bar this is upper bar. So, in which there are two mechanism one is the plates you can remove via bars or it can be hanged in the bar, so if it is hanged in the bar it can be easily taken out because one of the advantage for this plate type heat exchanger is this is a module type, right, so in future if I want to increase the protection, so I can just add one more module in the plate type heat exchanger.

So, in that way the module can be easily added or removed based on the need of the process industry, so that is the way we have seen number of plates requirement, right? So for regeneration section how many number of plates or heating section how many number of plates, or cooling section how many number of plates, so we have estimated as a number of plates in the each section.

So, in that way the plates can be hanged or the plates can be welded in the bar so that it can be removed in the later stage, but hanging would give me advantage if I want to remove or add the plates. And so this is the plate package and this bolts so this will come here, so to stack the plates, right? To keep them intact between the header and follower, so these are various categories of plate configuration.

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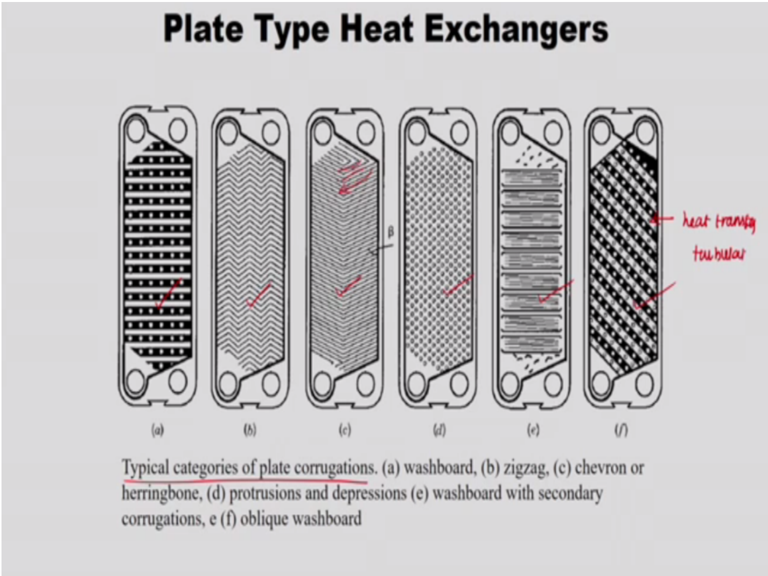


So, this configuration is washboard, so this is zigzag and this is chevron or herringbone, the (c) type, the (d) type is protrusions and depressions and (e) type is washboard with secondary corrugations and (f) is oblique washboard. There are different varieties, right. So, that is what I told, so when the fluid is passing through, so it is designed in such a way to increase the heat transfer and to give further turbulence to the, turbulence to the fluid, okay. So, that is the way it increases the heat transfer.

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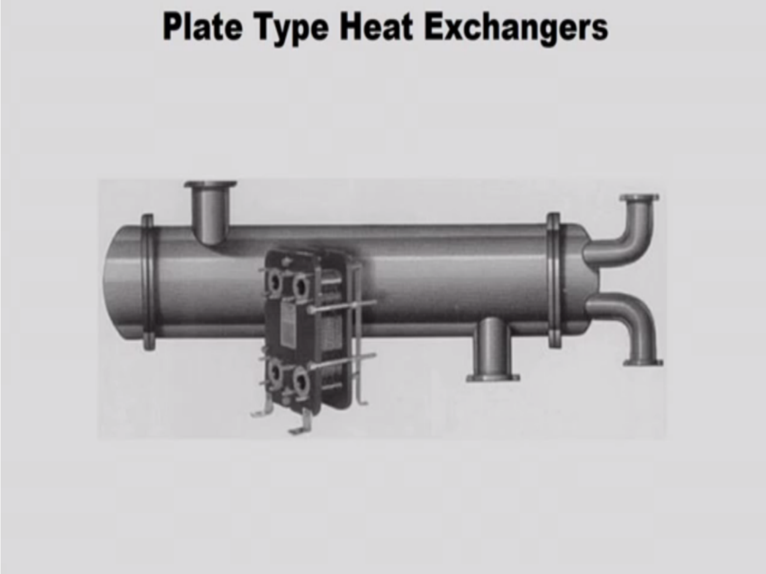


And if you compare your shell-and-tube module and plate module this is the way it looks like so in that way it is very compact compared to shell and tube heat exchanger.

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**Advantages and Disadvantages**

- Flexibility: The capacity can be increased or decreased by adding or removing plates.
- Sanitation: By opening the stack, both sides of the entire exchange area are made accessible for cleaning and inspection.
- High heat transfer coefficient, due to increased turbulence in the narrow flow channel
- Compactness: High exchange surface to volume ratio.
- On the other hand, the narrow size of the flow channels results in high-pressure drop and limits its use to low-viscosity fluids not containing large suspended particles. The need for gaskets.

So, the advantage wise the capacity can be increased or decreased by adding or removing plates, this I already discussed, so that flexibility I have in the plate type heat exchanger, the sanitation by opening the stack both sides of the entire exchange area are made accessible for cleaning and inspection. So, it is just the plate, in the plate the fluid is flowing, so I can remove the plate very easily and clean them and inspect them when needed right.

So, the sanitation wise it is very much advantageous and high heat transfer coefficient, due to increased turbulence in the narrow flow channel. That is the way the corrugations were made and a compact heat exchange surface to volume ratio is very high. So, that is the way it is compact. On the other hand, disadvantage sight, it is a narrow size of the flow channels results in high pressure drop and limits is used to only low viscosity fluids, which does not contain large suspended particulates. This is the disadvantage and also their need for gaskets.

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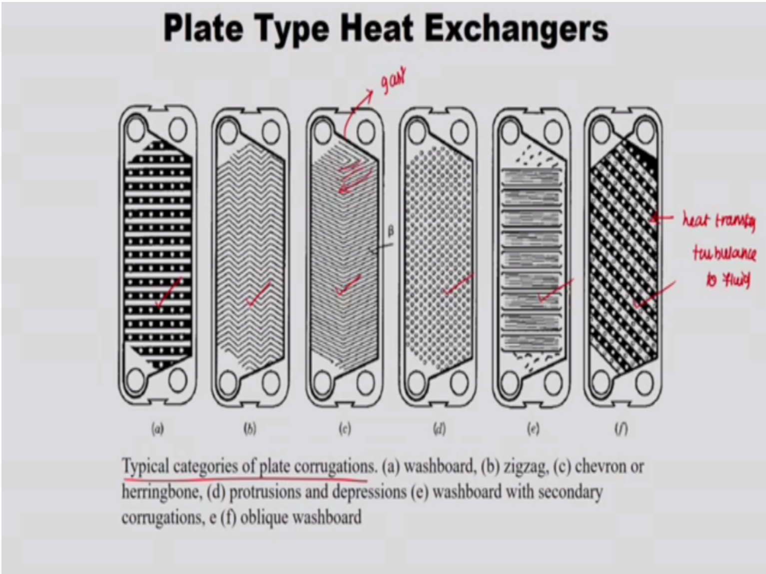


Gaskets in the sense, so here if you see in this, so this is nothing but an gaskets okay. So, which prevents the further leaking of the fluid, right? So the need for gaskets is very much disadvantageous one. As I discussed there are many improvements made in these kind of heat exchanges. For example, there is something called double plate security system. So that means the both the plates where welded and formed as a channel then after that these formed channels were further made together in the module by gaskets, right.

So, if there is any leakage between the plates then obviously it is known, because it is kept as a channel, so in that way the security system can be improved to avoid the leakage of the liquid foot product when it is heated. So, there are many improvements and also I said earlier so all to be performed in the contamination free area. So, that one has to ensure while using any of the heat exchange equipment in the food processing industry.

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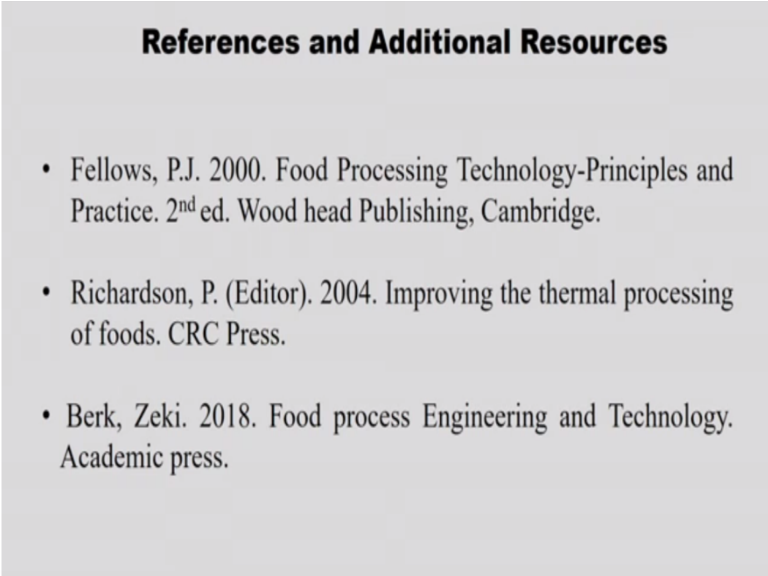


So, that is all for heat exchanges. So, these are the references and additional resources what I have used in this particular lecture. Thank you.