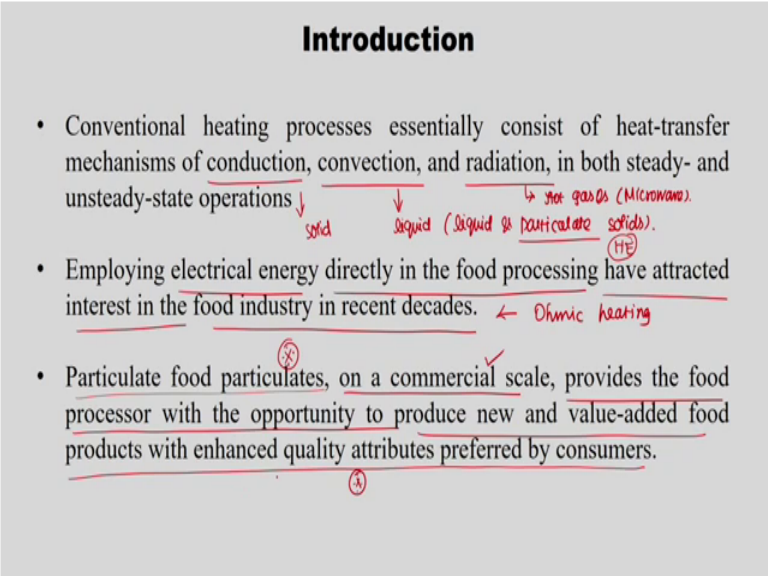
Thermal Processing of Foods
Professor R. Anandalakshmi
Chemical Engineering Department,
Indian Institute of Technology Guwahati
Lecture -16
Ohmic Heating

Good Morning all. Today we are going to discuss about Ohmic heating. So, in this lecture we are going to discuss about basics of Ohmic heating. And what are the lab and lab scale and pilot scale systems available for Ohmic heating. And what are the critical parameters one needs to consider while applying Ohmic heating for thermal processing of food. Actually, in first 10 classes we have discussed enormously about the thermal processing conventional thermal processing applied for the food materials. Then in last class, we have also discussed about the microwave as well as the radio frequency heating. So which is nothing but the normal processing food technologies

(Refer Slide Time: 01:21)



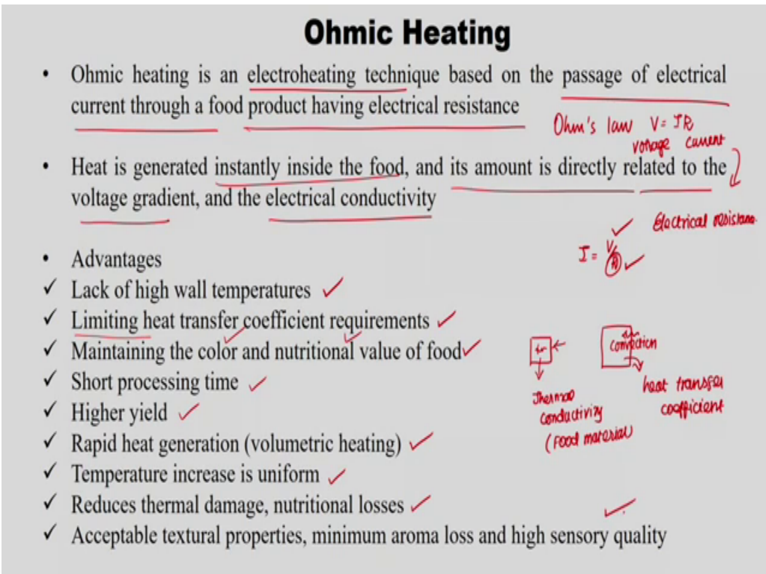
Today we are going to discuss about the Ohmic heating principle. So, if we see convention heating the major heat transfer mechanisms are Conduction, Conventional and Radiation. So, the conduction mainly applied to the solid food. Convention mostly liquid food and sometimes we may also, get liquid and particulate solids. Right the radiation comes when the heating medium is use as the hot gaseous or sometimes microwave. So both steady as well as unsteady operations steady is nothing but the time independent unsteady operation is dependent on time.

Employing electrical energy directly into the food processing have attracted interest in the food industry in the recent decades. So, instead of using the temperature so how do we do the food processing by employing directly the electrical energy that is the way the Ohmic heating concepts came up.

So, this is especially useful when particulate food particles are there on a commercial scale provide the food processer with the opportunity to produce new and value added food products with enhanced to quality attribute. So, this is very much important since we are not applying the temperature directly high temperature directly. So our quality attribute are much more higher than compare to any other conventional thermal processing.

Also it is useful when the food particles contain the particulate matters which is difficult in the thermal processing technique. Because if you remember, we have also told in the time of heat exchanger there is such limitations, on how much the size of the particulate solid should be well processing. So, this kind of restrictions can be relaxed in term of Ohmic heating. So, it is especially designed to handle the food which has particulate solids. And, also it is proven commercially to enhance the quality attributes of the food materials

(Refer Slide Time: 03:51):



Ohmic heating is an electro heating technique based on the passage of electrical current through a food product having electrical (persistent). So, it works on the principle of Ohms low so which you might have studied in your school science. So, you may be familiar with which is nothing but V equal to IR. So, V is nothing but the voltage in volts and I is nothing but a current in amperes and R is nothing but a electrical resistance.

So, the current flowing through the liquid food is nothing but the V upon R. Voltage applied across the electrodes and the resistance electrical resistance electrical conductivity of the food material. Heat is generate instantly inside the food and it has amount is directly related to the voltage gradient and the electrical conductivity. That is what I told voltage gradient applied and electrical resistant one upon R is a nothing but electrical conductivity.

So what are the advantages, one is the lack of high voltage temperature so how do we do normal convectional process, conventional thermal processing so if you have a solid food particle. You suppose to apply here a heat so thus has to penetrate through the solids. It is bases on the thermal conductivity. If it is a liquid it is a purely of convection phenomenon. So every-where the heat has to penetrate through the walls of the container.

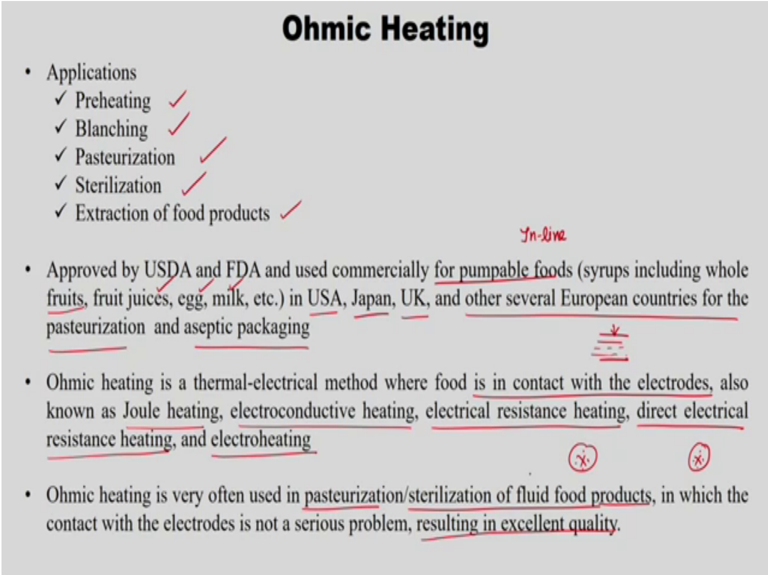
So that it is avoid here because your electrical energy is directly applying to the food material, liquid food products and limiting heat transfer coefficient requirement. So we have also seen in our earlier lectures. So, if it is a solid conduction it is mainly base on the thermal conductivity of the food or the food material. So, this thermal conductivity is only based on the material the food material what we used.

So here it depends upon the heat transfer coefficient. So one thing we should remember here is, this heat transfer coefficient, it is not only the property of the food particle the orientation of the container and the velocity of the food material which is passing through the processing system. So everything is into account with it is the function of many fact as. So in this case of Ohmic heating so I do not have the limiting or constraint of heat transfer coefficient.

And, maintaining the color and nutritional value of the food as, I told already so the Ohmic heating is the main requirement or the main aim of going for Ohmic heating is for two main aspects. One is for quality attribute since, we are not applying the high temperature the color and the nutritional value of food can be maintained and shorter processing time obviously. Because we are directly employing the electrical energy to heat the food. And, higher yield compare to conventional thermal technologies and rapid heat generation, Because it is also a volumetric heating phenomenon. Because you are not doing it via surface, what you do in conventional thermal processing techniques and it is a volumetric heat generation.

So that it is why, rapid heat generation would be there and temperature increases uniform due to volumetric heating principle and reduces the thermal damage nutritional losses. So, that is relate to here, the maintaining the nutritional value of food and acceptable textural properties, minimum aroma loss and high sensor quality. So, this is also one of the main advantage when we use Ohmic heating.

(Refer Slide Time: 07:53)



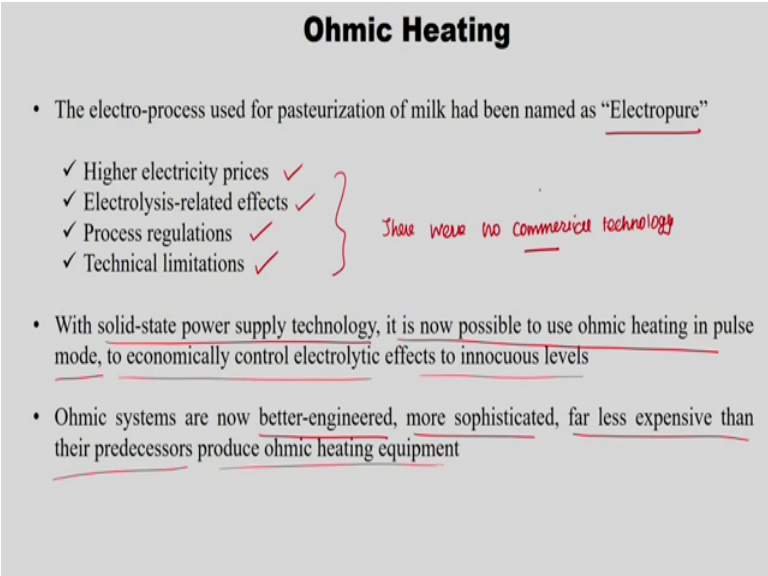
The application wise Ohmic heating is use to for Preheating, Blanching, Pasteurization, Sterilization and Extraction of food products in almost all main thermal processing of food it is a employed approved by USDA and FDA and use to commercially for pump able food so which is nothing but In-line. it is use to for pump able food, which contains syrups including whole fruits, fruit juices whole fruits in the sense pulps are high.

We have already seen it is, mainly employed for the food material, which has large food chunks. And fruit juices, egg, milk etc. so all pump able fluids it is used the commercial technologies developed in USA, Japan, UK and other several European countries, for the pasteurization as well as aseptic packaging. The Ohmic heating is the thermal electrical method where food is in contact with the electrodes also known as Joule heating, Electro conductive heating, Electrical resistance heating, Direct-electrical resistance heating, and Electro heating. So all name same Ohmic heating.

So, remember here there are two electrodes so the voltage is being applied in the electrodes the food material or the liquid food, which has to be heated passing through in between in the two electrodes. So, that is where it is told contact with the electrodes. Ohmic heating is very often use to pasteurization / Sterilization of the fluid food product, fluid food products, pump able fluids. In which the contact with the electrode is not a serious problem, resulting in excellent quality.

So some time what happens certain food material will enhanced the corrosion in the electrodes so if that is the case some of the corroded materials may also get into the food. So, it is very much employable and gives the excellent quality then such problem is not arising. Such problem in the sense, there should not be any corrosion in the electrodes due to the liquid food product to be heated.

(Refer Slide Time: 10:14):



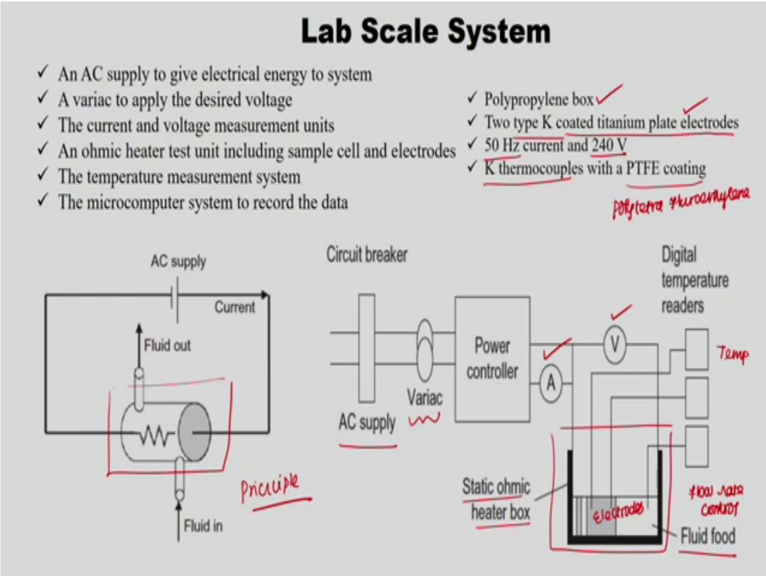
So, the electro process use for the pasteurization of a milk had been name as Electropure. The pasteurization of milk using Ohmic heating technique is call as Electropure. And after Ohmic heating got well established so there was drop using to the technology commercially due to higher electricity prices and a Electrolysis- related effects.

The electrolysis in the sense, one is the electrodes the corroded and it is comes in to the food. And sometime what happens, due to electrical heating some of the components of the food material also get denature. Because when you are using the food in presence of electrodes there may be a corrosion in the electrodes and those corroded material can also get in to food. Or, otherwise due to electrolytic reactions some of the food fragment also get denatured.

So this effects are unwanted and process regulation, there were no process regulations employed for the Ohmic heating and there were certain technical limitations were also there. So due to these reasons once it picked up there were no commercial plants, there were no commercial technology. then after that with the solid-state power supply technology, it is now possible to use Ohmic heating in pulse mode pulse Ohmic heating to, economically control electrolytic effects to innocuous levels.

And ohmic system are now better engineered, more sophisticated far less expensive their predecessors produce Ohmic heating equipment. So there was a certain dip in between but again it got picked up due to technology advancement.

(Refer Slide Time: 12:09)



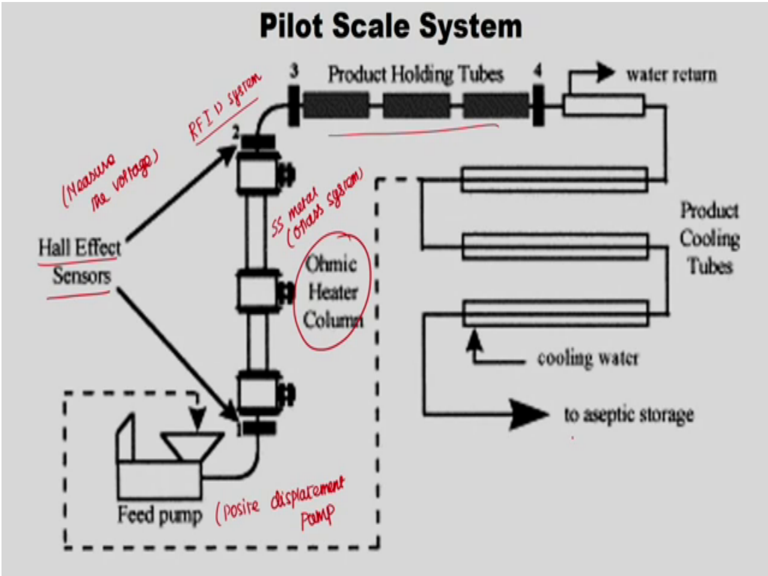
So now, we are going to see lab scale system, which is design for the Ohmic heating. So the first one is here it is a principle system so this is the principle which the Ohmic heating works. So here is you the processing system. So fluid in is this one and fluid out is this one. So, AC supplies the voltage so the current is flowing through the liquid material directly. So here is the lab scale system develop so I, have given the reference in the last slide so where you can find this Lab scale as well as a Pilot scale system.

And in the lab scale system you have a AC supplied to give electrical energy to the system. And there is Variac, so which controls the desired voltage, and it is given to the power controller. So here, you have voltage as well as a current measurement unit. So this is called Ohmic heating unit Heater tester unit. So, which is includes the sample cell as well as electrodes. So this is the static Ohmic heater box here you have your fluid food and here you have electrodes as well.

And we have a temperature measurement system and if you have fluid food then you may be having flow rate control as well. And to record all the data and temperature of flow and you will have a microcomputer system as well. And, so this is insulated completely using the polypropylene box and two type K coated titanium plate electrodes are used. The electrodes use to here is the titanium plate electrodes.

And the frequency applied is 50Hz current and 240 voltage 240 voltage and K type thermocouple with a PTFE coating is using to measure the temperature within the cell. Which is nothing but the Ohmic cell. So PTFE is nothing but the Poly-Tetra-Floro-Ethylene. So this coatings are use in order to avoid the corrosion when it is directly facing the fluid food products.

(Refer Slide Time: 14:50)



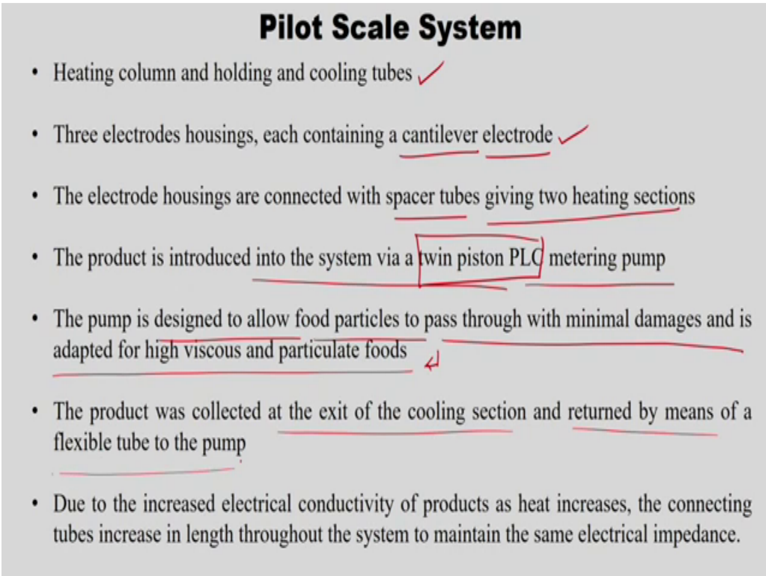
So this is the pilot scale system. So, if you see over here this the feed pump so mostly positive displacement pump. So this is your Ohmic heater column, so you have a three different sections. So this is the all hall effect sensor. So hall effect sensor is just to measure the voltage. So as I told already there are lot of technology improvement so even now they were using RFID system.

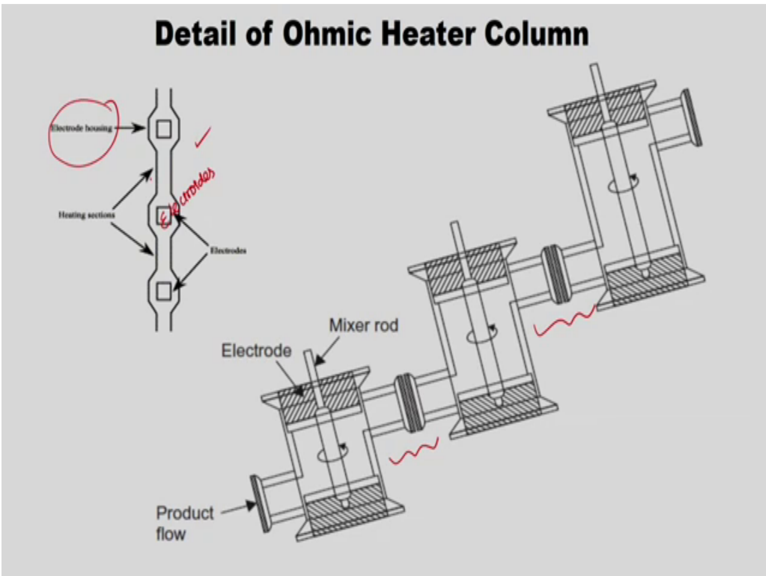
RFID system is used to measure the voltage, so earlier it was using the Hall Effect Sensors. Hall Effect is nothing but so when the magnetic field is applying to the perpendicular to the current then you can measure the voltage across the section through which the current is flowing. So, now they are using RFID system but, when you use the sensor depends upon that you supposed to define column as well.

The Hall Effect Sensor this may be metal column for example- SS metal can be use. If you use the RFID system there may be a frequency interferences between the stainless still material and RFID system so in that case you may be using the glass system. So thus is up to the choice of the production unit whatever you wanted to use you can use but it should be design carefully.

Here you have three Ohmic heater column then, after that it goes to product holding tube. So, what we have seen in the previous lectures how the inline pasteurization and sterilization are conducted. We have a heater we have a holding tube and after that cooling section. So here the heater column is nothing but the Ohmic heater column except that then everything else is same so you have a product holding tubes here, and here you have a cooling sections where your cooling water is use to cool the product. Then after, that it goes to aseptic storage or packaging.

(Refer Slide Time: 17:05) reference slide 19:31





So heating column holding and cooling tubes and three electrodes housings, each containing a cantilever electrode. The electrode here is cantilever electrode the electrode housings are connect with the spacer tubes which gives to heating sections. So, if you see here then you will understand better so this is the thing. So there are three heating sections so this is nothing but the electrical housing so here you have the electrode.

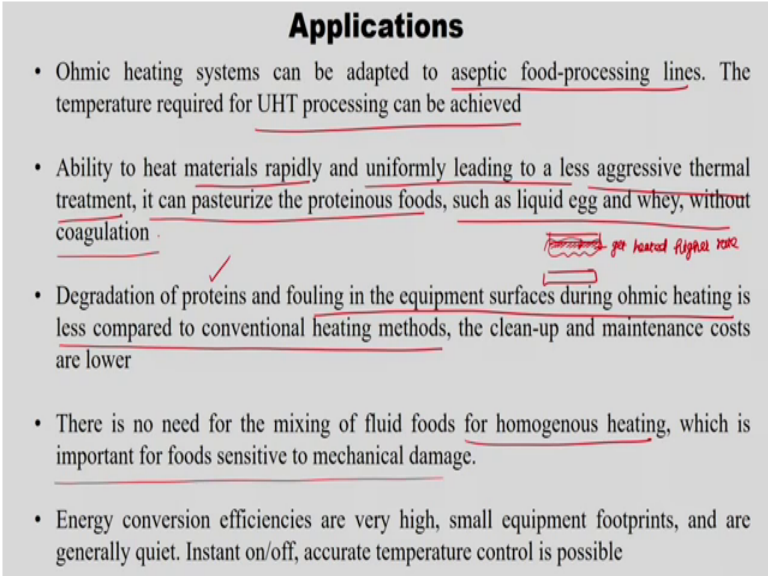
So, electrode so here is the spacer tube gives the two different heating sections and the product is introduce into the system via twin piston PLC metering system. As I said earlier this pump is on your choice so this the based on fluid product what you use for the Ohmic heating. The pump is design to allow the fluid particle to pass through with minimal damages and is adapted for high viscous and particulate foods. So as we told already the mainly ohmic heating is employed for high viscous and particulate foods.

So we need to design the pump accordingly, which should allow fluid food particles to pass through with minimal damage and the product was collected at the exit of the cooling section and returned by means of a flexible tubes to the pump. And due to increase the electric conductivity of the products as the heat increases, the connecting tube increase in length throughout the system to maintain the same electrical impedance. So you must be wondering so why you have at the connecting tubes, here right so that is the purpose here.

So, due to increase the electric conductivity of the product as heat increases the connecting tube so also increases in length throughout the system, to maintain the electrical impedance. So in all section the electrical impedance should be same so this is simple same thing what we have seen here so as I told earlier, so this system can be system in the sense the Ohmic heater column can be design based on once own choice. So, which housing you wanted to provide, which sensors you wanted to provide and which kind of heating column you wanted to provide it is based on our choice. So I have given two different systems. One is the system where you have a heating sections here and you have electrodes in between and electrode housing is nothing but this whole set up.

And here another one you can see so this is vertical to take care of upward flow so this is slanting sections. So here you will find two electrodes here, and also here you have a mixer rod will give the agitation to give the proper mixing for the fluid. So this is the product flow. so here you will get It at the exit so other than that there is not much difference in between them you can have a mixer of or you cannot have so it depends upon the requirement of the industry or the requirement base on the fluid food product.

(Refer Slide Time: 20:46)



The application of the Ohmic heating system can be adapted to aseptic food processing lines so we have already told pump able fluids and temperature require for UHT processing can be achieved using Ohmic heating. Ability to heat material rapidly so we have just a seen in the advantages and uniformly leading to a less aggressive thermal treatment so my temperature is not that high, and it can pasteurize the proteinous food, such as liquid egg and whey without coagulation.

So since my temperature is not increasing that much there is no aggressive thermal treatment so it can pasteurize proteinous product, which may be difficult using the conventional thermal processing technology. So, especially whey without coagulation and degradation of proteins and fouling in the equipment surfaces during Ohmic heating is less compare to conventional heating method. So, here due to degradation of proteins so it will not form a layer near the electrode.

So if it forms the layer near the electrodes then may be overheating near the electrodes because the formed layers for example so you have electrode here. So if my fluid particle forms the fouling or scaling near the electrode so then here it will get heated fast get heated higher rate. Why it is higher rate? Because this may not be able to move so in that case it get heat at higher rate so this may be the problem.

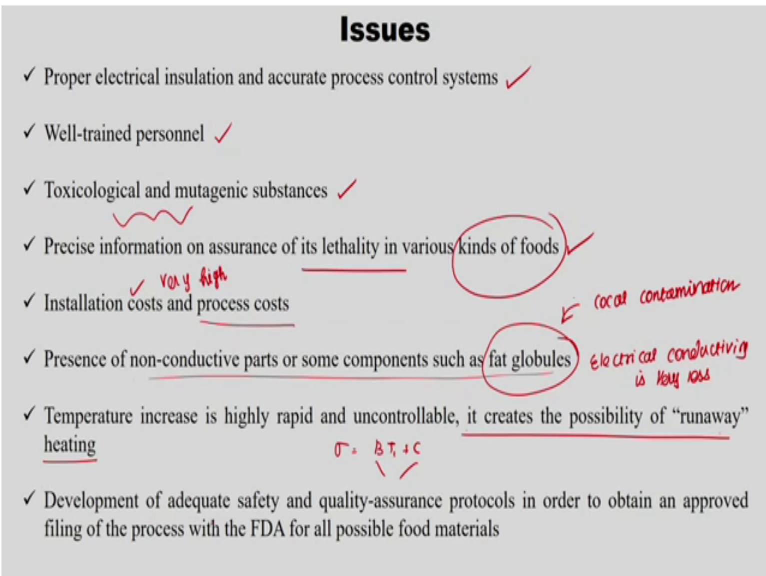
Degradation of the proteins and fouling in the equipment surface during Ohmic heating is less compare to conventional heating method. So, the overheating near the heating surface is less in Ohmic heating compare to conventional heating method. There is no need for mixing of fluids fluid for homogeneous heating which important for food sensitive to mechanical damage.

So normally what are the conventional thermal processing methods available so there if I use the agitation so you might have seen also right there are couple of lectures we have also specifically given weightage to the agitation principle. Right so if I do the agitation so my heat transfer will be enhance, but in the food side, this would be the disadvantage because there are some foods, which are sensitive to mechanical damage.

So to avoid the agitation I can also employ Ohmic heating because it gives me homogeneous heating without any agitation. Because it works on the principle of volumetric heating phenomenon. Energy conventional efficiencies are very high of course and small equipment footprints and are generally quiet. And, it will not make any noise due to thermal stresses and Instant on off his possible. If you have seen somewhere in a previous lecture that come up with time.

So once I switch on so how long it takes to heat the container and heat the food so that can be avoided here because it is an instant on off and also system can be shut down instantly. If any problem occurs and accurate temperature control is possible using proper process control system.

(Refer Slide Time: 24:21)



And, the issues wise, we need to take care of proper electrical insulations and accurate process control system. So, when I was mentioning here itself I told where the accurate temperature control is possible only when, if you use to accurate process control system. And Well-trained (person are) personnel are needed and Toxicological and Mutagenic substances production. So, this is the area which not much explode.

As, I say already told, so there may be possibility for electrolysis as well as the corrosion of electrodes. And which is directly because of we are heating food products directly using the electrodes. So, there may be transfer of Toxicological as well as Mutagenic substance which goes in to food. And precise information on assurance of its lethality in various kind of foods is also area which needs to be explode in terms of Ohmic heating.

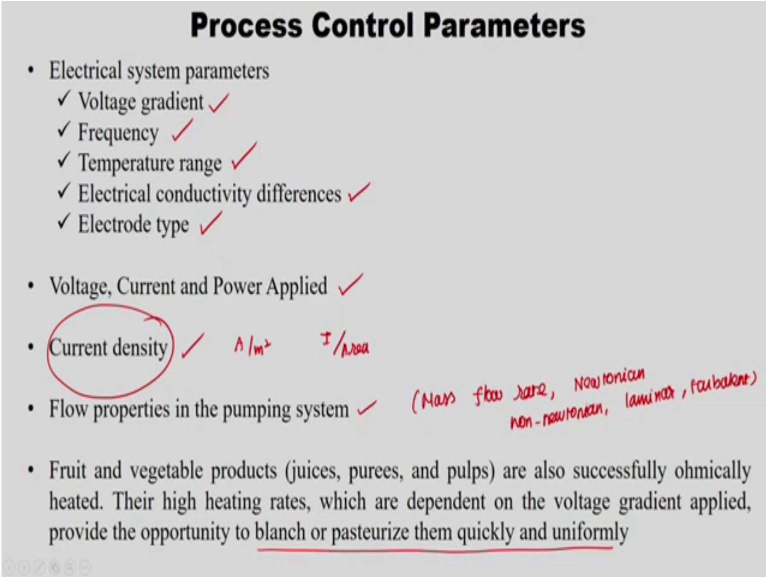
Because the property of the food is extensively affects the Ohmic heating we will see in subsequent slides so why it so. And installation cost are very high we told in all non-conventional thermal processing technologies but processing cost is almost comparable with any of the thermal processing technology. And presence of non-conductive parts are some components such as fat globules.

So if it there so it is electrical conductivity is very less. So if your food products contain the fat globule, what happens is that particulate place will not be heated much. So if it is not heated much there will not be contamination, local contamination. So this is the serious issue in ohmic heating. So presence of non-conductive parts. And temperature increases highly rapid and uncontrollable. It crerates the possibility of runaway heating.

So this is also important because, the time verses electrical conductivity that relation is almost linear relationship BT1 plus C. So B and C are constants. So almost the temperature increases linearly with the electrical conductivity. So in that case if it increases the rapidly, so it becomes uncontrollable then there is a possibility of runaway heating.

So, that is also one of the issue of Ohmic heating. And development of adequate heating safety and quality- assurance of protocols in order to obtain an approved filing of the process with the FDA for all possible food materials. So this is very much Important it is not only true for Ohmic heating per any process for any food processing technology. So we need to take care of the safety and quality assurance protocols because it is of public health significance. So this is true for almost non-thermal or thermal technologies. So which are going to be applied commercially.

(Refer Slide Time: 27:40)

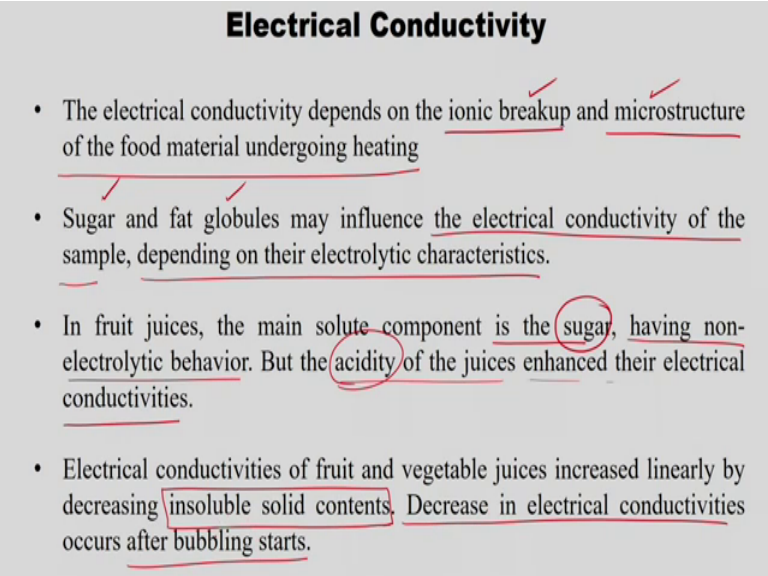


And what are all the main process control parameters to be consider in Ohmic heating Is the voltage gradient, what we applied the frequency and the temperature range and the Electrical conductivity differences and the electrode type.So this is the on the electrical system parameters. And voltage current and power applied across the electrode. And the current density, Current density is nothing but the ampere per meter square which is nothing but a current upon area.

So this is another critical parameters which is to be consider in the Ohmic heating. And flow properties in the pumping system, because it is use to for pump able foods so we need to take care of the flow properties. Because the for example the mass flow rate is a main critical factor. And which type of food material we use. So one of the lectures I mention about the Newtonian and Non-Newtonian.

And also, which type of flow we are encountering for example, laminar or turbulent so that is also matters. So all this to be taken care. And the fruit and the vegetable products for example- juices, purees and pules are also, successfully Ohmiccaly heated. Their high heating rates, which are dependent on the voltage gradient applied. Provide the opportunity to blanch or pasteurize them quickly and uniformly compared to conventional thermal technologies.

(Refer slide time: 29:18)



So one of them main parameter how we have solid conventional thermal processing of solid foods thermal conductivity was the main parameters and in terms of liquid food products, And in terms of liquid food products the heat transfer coefficient so here in Ohmic heating the electrical conductivity is the critical factor. So it depends upon the ionic breakup and the microstructure of the food material undergoing heating. So if you remember the current which is flowing through the food is nothing but a flow of electrons. So how much it depends upon the ionic breakup as well as the microstructure of the food material, which is undergoing heating.

For example If I have heating food product which has a sugar as well as the fat globules may influence the electric conductivity of the sample depending on their electrolytic characteristics. For examples for sugar and fat globules so my electrolytic characteristics may be different. So based on that only it shows up the electrical conductivity when voltage has applied between the electrodes. In fruit juices, the main solute component is the sugar which is having a non-electrode behavior but, the possibility of the juices enhanced there electrical conductivity.

For example, sugar has non-electrolytic behavior but, that will be compensated if your juices having acidity in nature. Because the acidity in nature enhanced the electrical conductivity. So, basically it is an example. So, you cannot determine or you cannot generalize the food material by saying wherever the sugar component is there. So, it will have non-electrolytic behavior so it also depend on the other component of the food material for example if the sugar and acidity contents both are there.

So the non-electrolytic behavior of the sugar can be compensate using the acidity of the fruit juice. Electrical conductivity is of fruit and vegetable juices increase linearly by decreasing the insoluble solid contents. So if there are high amount of insoluable solid contents then you were electrical conductivity may be reduced. So decrease in electrical conductivities occurs after bubbling starts. Actually, this bubbling is the phenomenon when you have a water so there may be a bubbling phenomenon. So we are going to see this in next slide. So if that is bubbling is occurs there may a decreasing electrical conductivity.

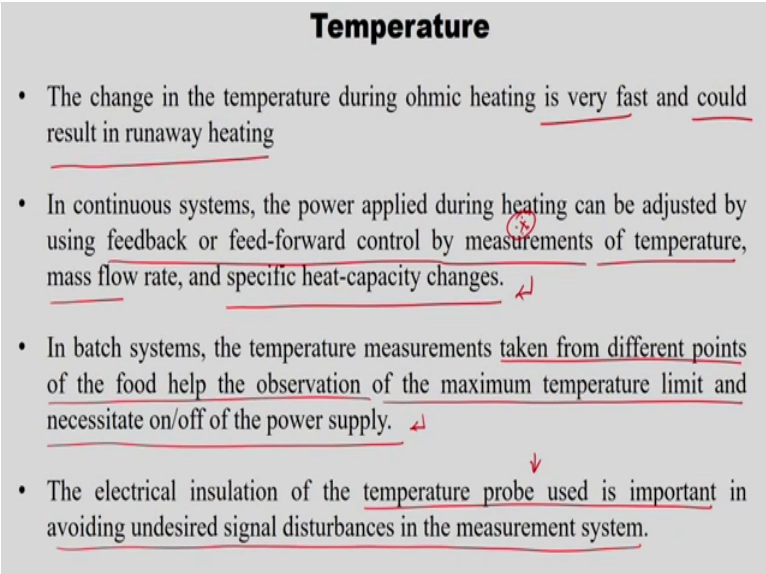
(Refer slide time: 31:56)

Fluid Food	Temperature Range (°C)	Voltage Gradients Applied (V/cm)	Concentration Range	Electrical Conductivity (S/m)
Salt solutions	25–80	20	0.2–0.8% w/v NaCl	0.40–3.20
Sugar solutions	30–60	20–70	13–14% w/v	0.10–0.20
Apple juice	30–80	20–60	20–60% v/v soluble solids	0.30–1.00
Sourcherry juice	30–75	20–60	20–60% v/v soluble solids	0.70–1.60
Orange juice	25–80 30–60	42.42 20–60	0–21% solid 0.2–0.6 mass fraction	0.50–1.25 0.15–1.15
Grape juice	20–80	20–40	Fresh, not reported	0.38–0.78
Strawberry pulp	20–80			
Pulp 1		32–70	Brix 14.5°, 2.5% w/w starch	0.20–0.50
Pulp 2		40–80	Brix 26.5°, no starch	0.10–0.35
Strawberry topping	20–100	55–100	Not reported	0.005–0.06
Strawberry filling	20–100	55–100	Not reported	0.03–0.25
Strawberry–apple sauce	20–100	25–70	Not reported	0.11–0.34

So, this is the table which talks about the different fruit, food and the temperature ranges. And the voltage gradient applied across the electrode and the concentration range in the food material and electrical conductivity. So this you can get in the reference itself. For example I will just would like to highlight few.

Orange juice the temperature range is 25-80 and 30-60. And the voltage gradient applied is 42.42 voltage per cm and if it a temperature ranges between 30-60, then you suppose to applies 20-60 voltage per cm. And also it is depend on the mass fraction. So here you have a 0-20% solid contents here, 0.2-0.6 mass fraction. And also the electrical conductivity is high in terms of when you apply 42.42 volts per cm. It contain 21% solids but if you 0.2 to 0.6 mass fraction. So your electrical conductivity is decreased 0.15 to 1.15 semens per meter. So, you can see such kind of the tables in reference material given.

(Refer slide time: 33:16):



So the next important parameter is temperature we have seen about the electrical conductivity. Because the Ohmic heat to Ohmic heating to applied the food material should have electrical conductivity so that what is we have seen so the second one is the temperature

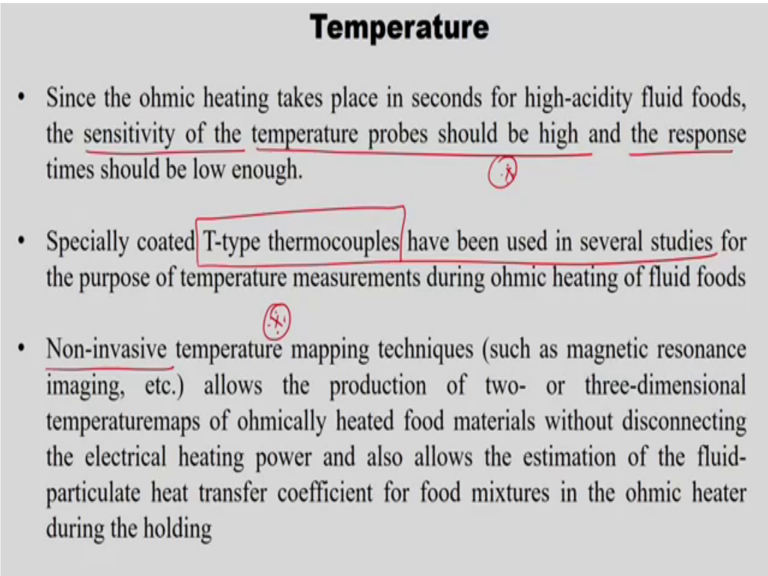
The change in the temperature during Ohmic heating is very fast we have just a seen and could resultant run away heating. And in continuous system the power applied during heating cam be adjusted by using feedback or feed-forward control this is very much important. Because if it heats rapidly there may be a runaway heating. Measurements of temperature mass flow rate and specific heat capacity.

As I told in previous slide the temperature mass flow rate as well as specific heat capacity changes during Ohmic heating should be measure then and there to have a precise control of the system. In, back system the temperature measurement taken from the different points of the food help the observation of the maximum temperature limit. And associate the on off the power supply in the back system we employ the thermocouple and get the temperature measurements.

Then and their using the digital display so if we feel it goes to the maximum temperature limit then we can switch of the power supply. And electrical insulation temperature probe is used is important in avoiding undesired signal disturbance in the measurement system. So what we are using is, electrical energy to heat the flood in such case the temperature probe what we use also should be insulated properly otherwise it will have an undesired signal disturbance.

Because this is also electrical and that is also electrical so it is signal disturbance would be there. So insulation of the electric probe whatever we use for the temperature measurement should be insulate properly.

(Refer Slide Time: 35:16)



And a since the Ohmic heating in second for high-acidity fluid foods, the sensitivity of the temperature probes should be high and response times should be low enough. So this is also another important criteria where we are use thermocouple to measure the temperature inside the food material. Because the probe should be high, that is nothing but a sensitivity. Sensitivity is how fast it measure the temperature and give the digital display.

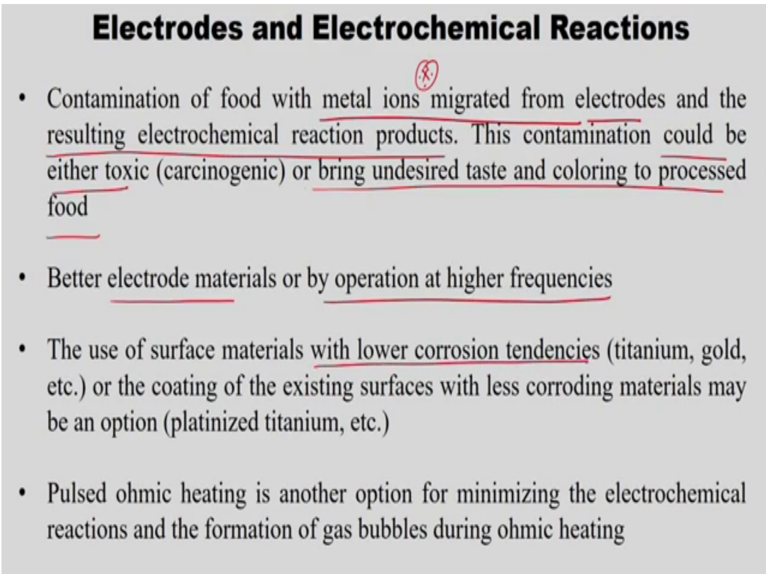
Right and also there are ((35:49)) for example if I keep the thermocouple how fast it respond to the temperature difference and how fast I will be able to get that the data recorder. This two are important parameters and specially coated T-type thermocouple have been use in several studies for the purpose of temperature measurement during Ohmic heating. So that T-type thermocouple so this the same thermocouple we have seen to be used in variation purpose also right so validation temperature distribution test.

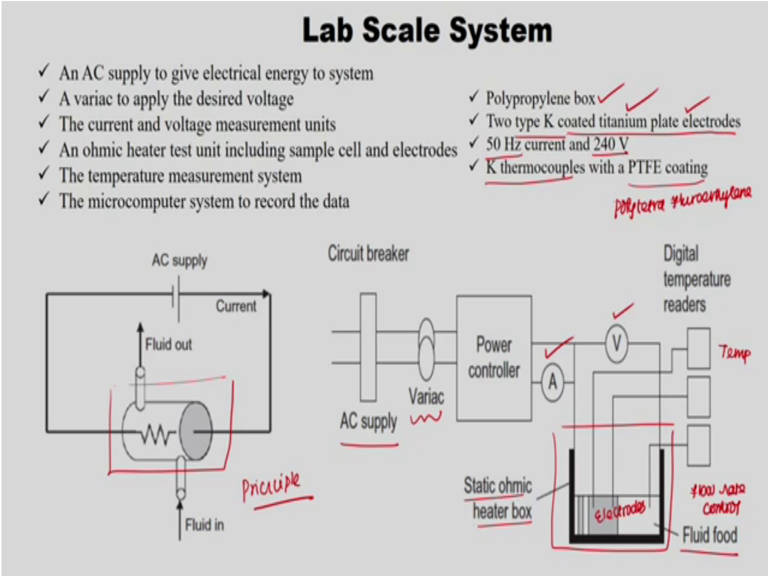
So there also be use the T-type thermocouple and one more the picking up the recent technology is non-invasive. Non-invasive is in the sense, the both are electrical systems thermocouple whatever the thermocouple we get in terms of distance signals right so since both are involving the electrical signals there may be a disturbance so due to which the non-invasive temperature mapping techniques were developed.

So such as magnetic resonance imaging which allows the production of two-or three-dimensional temperature map of Ohmically heated food Materials without disconnecting the electrical heating power and also allows the estimation of fluid-particulate heat transfer coefficient for food mixtures in the Ohmic heater during the holding period . So, this is what they do is they employ the magnetic particle so which nothing but a traced particle.

So this is use as a traced particle to measure the temperature inside the holding tube. So this also will be sent with along the fl and it is further use to for a temperature measurements. So this helps me as alternative to the normal conventional thermocouple temperature thermocouple measurement system.

(Refer Slide Time: 37:47)



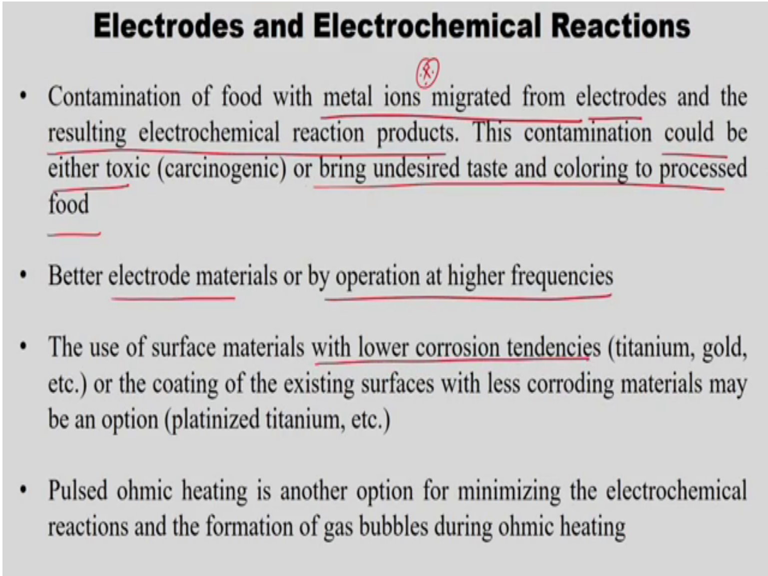


And another important critical factor is that electrochemical reaction the contamination of food with a metal ions migrated from the electrodes and the resulting electrochemical reaction products. So this is the critical thing when we use the Ohmic heating so the contamination of the food by the metal ions migrated from the electrodes so this contamination of the food by the metal ions migrated from the electrodes.

So this contamination could be either toxic which is nothing but a (carcinogenic) or being undesired taste and coloring to processed food. That is another problem while most of the consumer not prefer electrically heated food. The better electrode materials or by operational high frequency so we can avoid such electrochemical reactions in the electrodes and use of surface electrodes with a lower corrosion tendency so that is nothing but titanium, gold so if you see in our pilot scale so here we use a two type K coated titanium plate electrode.

So that is to avoid the corrosion are electrochemical reactions. So normally the lower corrosion tendency materials which is nothing, but the titanium or gold is used or the coating of the existing surface with the less corroding materials may be also an option platinized titanium. So this also can be used and pulsed to Ohmic heating is another option for minimizing the electrochemical reactions and the formation of gas bubbles during Ohmic heating. So the formation of gas bubbles as well as the minimizing electrochemical reactions can be taken care by the pulse to Ohmic heating. So pulse Ohmic heating I suppose to use one more pulse generator to create the current

(Refer Slide Time: 39:34)

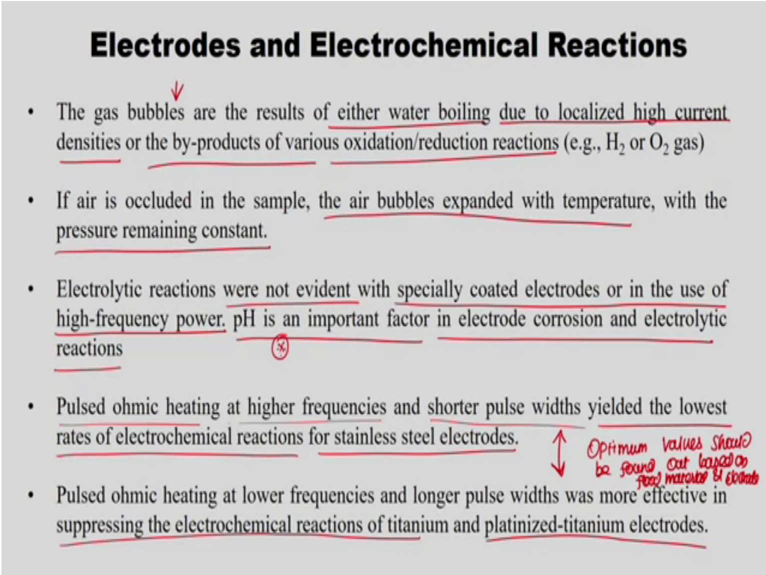


So the gas bubble so we have seen if there is a bubbling, there may be a reduction in the electrical conductivity right, this gas bubbles where from there are coming, so are the results of either water boiling due to localize high current densities or the by-product of various oxidation and reduction reactions for example .H2 or O2 gas. So due to which also there may be a bubble formation or naturally the water boiling also creates the bubble formation.

So whatever be but it is undesired in the Ohmic heating if the air is occluded in the sample, air bubbles expanded with the temperature with the pressure remaining constant. So this is also a problem so it is starts growing and it collapse with each other. So that is also a problem and the electrolytic reactions were not evident with specifically coated electrodes or in the use of high frequency power. So this we have seen here as well either I need to use better electrode materials or by operation at higher frequency.

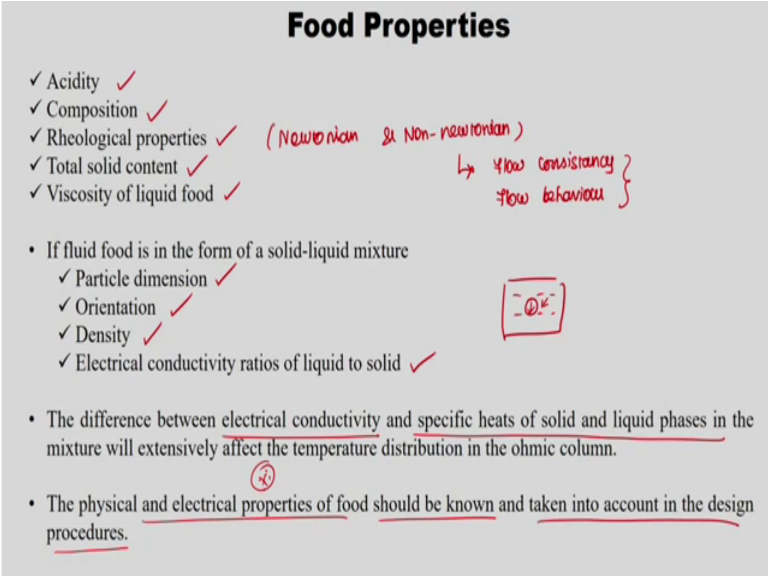
So ph is an another important factor in the electrode corrosion and the electrolytic reaction so this is very much important ph and temperature which also enhance the electrode corrosion. And electrolytic reactions, So this is just to give two examples so we cannot generalized anything here. So that is what I wanted to tell you this the pulse ohmic heating at higher frequencies that is what we have told.

(Refer Slide Time: 41:11)



Right, so if we take care of higher frequency then the electrode reactions may be avoided so pulse Ohmic heating at higher frequencies and shorter pulse width yielded the lowest rates of electrochemical reactions for stainless steel electrodes. But, pulse Ohmic heating at lower frequency and longer pulse width was more effective in suppressing the electrochemical reactions of titanium as well as platinized-titanium electrodes.

So we cannot generalized but optimum value should be found out, optimum value should be found out based on the food material and electrode. So we cannot generalized. So in general that is the case means the better electrode materials at a higher frequencies will avoid the electrochemical reactions but certain food material should not be true as well. There are exceptional cases always ss(Refer Slide Time: 42:22)



And, the food properties which are also very much important when we apply the ohmic heating the acidity so we have already seen acidity increase the electrical conductivity. The composition of the food material for example we have told if my fluid food has the fat globules so then it shows the non-electric behavior. So because of that there may be cold spot in the food material.

So, because which it cannot conduct the electricity in that as it may not get heated to the optimum level so there may be cold spot in the food material Rheological properties as example, I have told you right Newtonian and Non-Newtonian food. So Non-Newtonian food there are two important criteria so we need to take care, one is flow consistency another one is flow behavior.

So in one of the lectures also we have told right most of the food materials are behaving with the Non-Newtonian food behavior so this two important parameters we suppose to consider so that is where the Rheological properties of the food is very much important for the Ohmic heating. And total solid content one of the point is we have seen if we increase the solid contents there may be s reduction the electric conductivity.

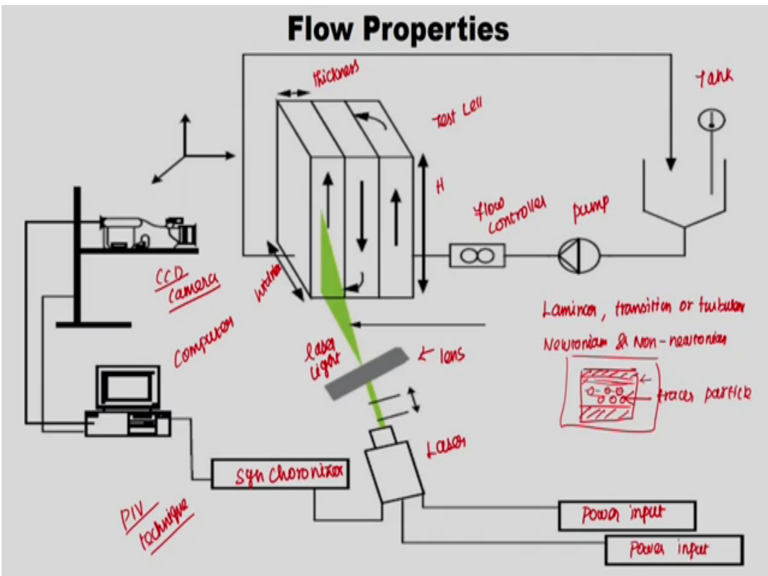
And the viscosity of the liquid food this is also related to the rheological property behavior if the food is in the form of solid liquid mixture so I we need to take care of the particle dimension. Because it is pump able fluid and need to employ the pump also based on the characteristics of the flood product what we used.

And the orientation and the density of the solids in the liquid mixture and electrical conductivity ratios of the solid and liquid so this is the very much important because when you have a liquid as well as the solid particle in the thermal processing technology we might have told the heat transfer coefficient. And the thermal conductivity of the solid material should be far match otherwise the convection may be very fast and conduction will be very slow.

Then in such case we have the overheating at the surfaces the same thing here when we use the solid particulate in the liquid the electrical conductivity ratios between the solid and liquid is also very much important when we employ Ohmic heating. The difference between the electrical conductivity and specific heats of the solid and the liquid phases in the mixture will extensively affect the temperature distribution in the Ohmic heating column so this is the difference between the electrical conductivity and specific heats of the solid and liquid phases.

So this we have seen in the previous slide itself so how it effects the Ohmic heating. The physical and the electrical properties of the food should be known and take into account. In the design procedure so this is very much important. The electrical properties as well as the physical properties which is nothing but the density, dimension etc. also to be taken care when we use the design procedure

(Refer slide time: 45:44)



So then, there are Flow Properties. Flow properties in the sense, I have already mention so we suppose to know which type of flow it is encountering whether laminar or transition or turbulent. And also important thing is the Newtonian and Non-Newtonian. So When we use such a cases I have also mention. So, for example you have electrode here so based on the flow consistency intakes here what means to be happen is the flood layer which is next to the electrodes.

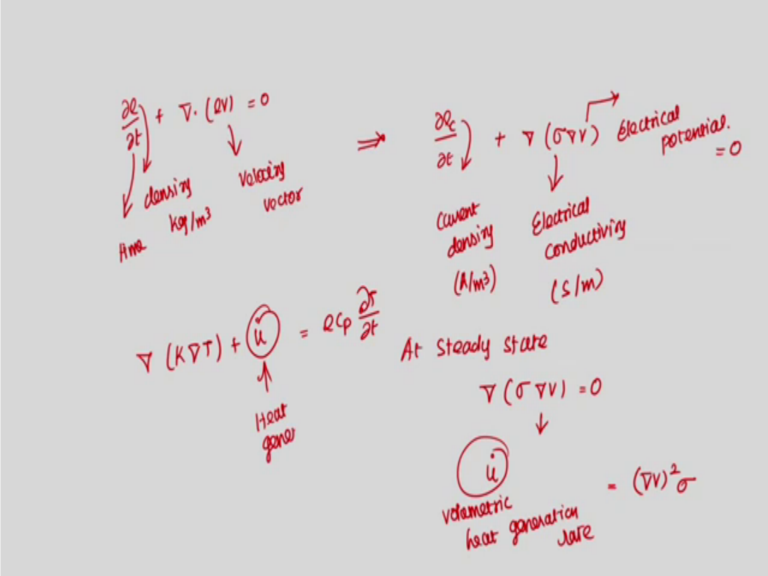
So will not move fasters in that case it may get heated at higher case and it will cost the overcooking or over processing so this can be avoid at if we know the flow properties inside the Ohmic heating column well. So one such technique is this is nothing but a PIV technique so which is use to see the local velocity variations inside the cell so this technique uses image processing to get to know the velocity. So this is normal computer system so this is CCD camera. So which has higher pixel rate as well as pulse seconds how many shorts it can take also it is very much higher so this is the high end camera.

So this is the computer system so this is the synchronizer. So this lesser so this is lens so this is the laser light, this is the test cell, which is having proper high thickness and width. And this is the flow controller this is pump so this is the tank from here fluid is pumped and the using the flow controller it goes to test cell and it come to the back. So here we are using it we are using the lesser light so this test cell also has carrier particle so as I told earlier so this is my fluid I also employ the tracer particle in the fluid material.

So what happens is this lesser light so follow the tracer particle so which is called a tracer particle so this is also moves in per with the fluid velocity. Right so this lesser light or get the tracer particles so this is taken as the image using the CCD camera then it is image processed and we will get to know what is the power input. So what happen is I employ the lesser light in to the teste cell the test cell also contain the tracer particle, so the tracer particle movement will be also capture by the camera.

Then after that, eye image process and get to know the velocity of the tracer particle so the velocity of the tracer particle is nothing but the liquid velocity. So if I know the localized liquid velocity then I may get an idea about the distribution of the temperature inside the test cell.

(Refer Slide Time: 50:06)

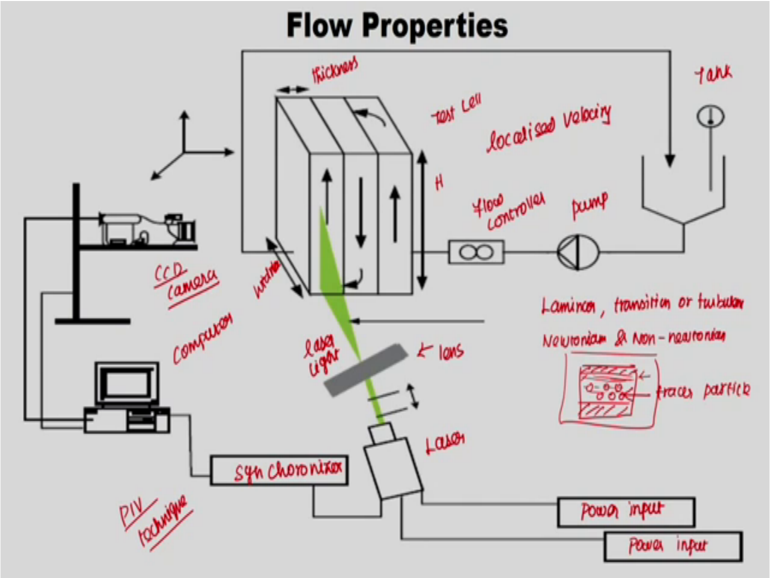


Right, so for example how it can be modeled this we already know the continuity equation in any system so this is grad dot Rho V. Right so this is the density this is the fluid density which is the kg per meter cube So this is the time with respect to time. So this is nothing but a density to the velocity v is nothing but the velocity vector. So if you write the same principle using the Ohmic heating Dow Rho c upon do t this is nothing but the current density here.

So plus grad sigma grad v. so this is sigma nothing but a electrical conductivity which is in siemens per meter and this v is nothing but a electrical potential s it is nothing but a voltage which here. So this is in ampere per meter cube so if we combine the Ohmic heating principle with the continuity equation so this is the equation which is equal to the zero so at steady sate there is no time dependency. so I can say grade sigma grade v which is equal in to zero.

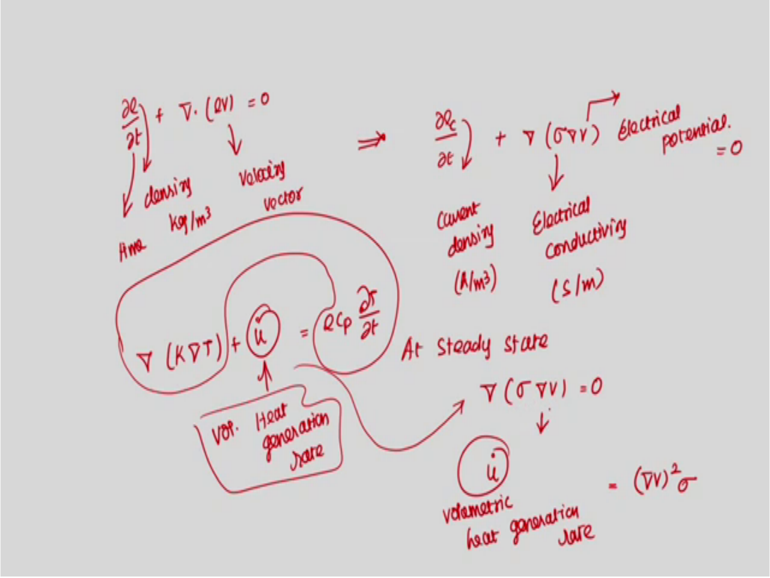
So some from this I, can calculate the heat generation rate. So which is nothing but a volumetric heat generation. Volumetric heat generation rate, so which is equivalent to grad v square into sigma. So this further u dot is taken into account so when we use a normal energy balance equation so normal energy balance equation for the solid food K grad T which is equal in to rho cp dow t upon t so here you will take the heat generation as well. This is the heat generation rate.

(Refer slide time: 52:40)



So get to know this for liquid food so we suppose to get the localized velocity. So this will give me how the temperature because in conventional system so your temperature alters your velocity and velocity alters to your temperature. So this would give me localized velocity from that I can model the system better.

(Refer Slide Time: 53:03)



References and Additional Resources

- Fellows, P.J. 2000. Food Processing Technology-Principles and Practice. 2nd ed. Wood head Publishing, Cambridge.
- Goullieux, A., Pain, J.P. 2005. Ohmic heating. In: Sun, D.W. (Ed.), Emerging Technologies for Food Processing. Elsevier Academic Press, United Kingdom.
- Richardson, P. (Editor). 2004. Improving the thermal processing of foods. CRC Press.
- Cullen, P.J., Tiwari, B.K., Vasilis, P.V. 2012. Novel Thermal and Non-Thermal Technologies For Fluid Foods.

So normal thermal processing will have only this component. but, here you have a volumetric heat generation so that can be relate to the Ohmic heating principle using this equation.

So you can refer this further this further references and additional resources so I have taken the tables from the particular reference so you may like to refer more for further in depth knowledge about the electrical conductivity and how much voltage difference to be applied electrode based on the food products. Thank You.