**Cooling Technology: Why and How utilized in Food Processing and allied Industries**

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**Module No 11**

**Lecture 51**
**Freezing**

Good afternoon, my dear students, my dear colleagues, my dear friends. As you have seen that we are in the very last phase of the entire course, we have 2 more weeks left and we said that in these 2 weeks, we will try to maximize the application side, right. Because, we have already produced cooling, now, we have said in the beginning that, why cooling is needed, as you see this cool technology why and how utilized in food. So, in that why, the cooling is required, we have said, how cooling is produced, we have said, now how it can be applied, right. So, this is the third part. So, in that third part, we start with a very very common thing, which most of you, those who do boozing, of course, seniors not the juniors.

So, they know that, they need the chunks of ice, right, and this chunks of ice, they got from water, keeping it in the deep freezer, right. Now, the same thing happens, when it is also with the food system, right. So, because, our course title says that it is utilized in food. So, we will also, we have to talk about the food, also its application in food.

So, if you look at the first thing, that is, technology of preservation of food by freezing, in one go, it could be managed, right. Now, freezing preservation, let us tell some preliminary things, like it is effective for retaining colour, flavour and nutritive value and moderately effective for retention of texture. We have not said in this course, but in our another course, if you look at in NPTEL, it is there, freezing vis-a-vis cooling, that is, vis-a-vis high temperature or heating, right. So, if you keep both in comparison, then if it is high temperature, and if it is low temperature, the energy requirement for the high temperature is more compared to that for the low temperature. Number one, that is the prime thing that you need more energy, right.

And the quality of the product, which is obtained in heating, and the quality of the product which is obtained in cooling, or at the end freezing. Freezing quality is much better than that of the heating, right. So, that is why, it is being claimed that, it is very effective, for retaining colour, flavour, nutritive value and moderately effective for retaining texture. Why we are saying, we will come to that afterwards, that we will come to that, afterwards, that moderately effective for retaining the texture. Freezing process, temperature of product is reduced to minus 18 degree centigrade or below and

crystallization of the part of water and some of solutes take place.

I said in earlier class, that minus 18, hopefully, you remember that, it is equivalent to 0 Fahrenheit, not exactly equivalent to 0 Fahrenheit, is somewhere minus 17 point something, decimal. So, that is rounded up to minus 18, that is why minus 18 is taken as a datum for low temperature. Now, another thing, which we are saying, that super cooled or under cooled, that is temperature of water is lowered below its freezing point. We know, water freezes at 0 degree centigrade, this we know, perhaps, nowadays, it is also being said in the preschool, when children are around 1.5 to 2 or 2.5 year old, right. So, it is freezing at 0 degree centigrade, universally we know, but if it undergoes super cooling or under cooling below its freezing point without any occurrence of crystallization and hence no impairment of food quality then, we can say that, if there be any change during freezing then it cannot be attributed to the temperature. Temperature is not the culprit, culprit is somewhere something, somebody else, and that is the water to ice transformation is the culprit, for any reduction in quality, right. This we have to keep in mind. Now, as we said that, water freezes at 0 degree centigrade, but there are many food materials, whose initial freezing point is less than 0 degree.

One example is ice cream which has a freezing point of minus 2.5. So, which it is getting frozen it is water which is getting transformed into ice in ice cream also. So, that means, it is not universal that, water freezes at 0 degree centigrade. Scientists have made water as liquid water, even at much lower temperature.

If you just Google that, what is the minimum temperature scientists have achieved till date, keeping water as liquid, no transformation of water to ice then, you will also get, it is not 0, somewhere much lower than that, right. This, I am not able to give you, that reference of the Google. So, that is why, I am saying that, it is much lower. I am not taking the number. That means, even at minus 5, minus 10, degree centigrade, water is still liquid. We have already given one example of ice cream, where it is minus 2.5 $^{o}$C, initial freezing point. That means, till minus 2.5 $^{o}$C, no water is getting frozen, right. But, I hope, you know, Raoult's law, where it is said that, the concentration of the solutes in the liquid brings down or lowers down the freezing point or increases the boiling point, or called elevation of boiling point or in other word it is said elevation of boiling point or depression of freezing point, right. So, but how much ice cream minus 2.5 $^{o}$C, more or less this is one of the, one of the lowest freezing point with food material. All other will have minus 0.5 $^{o}$C, minus 1 $^{o}$C, things like that. So, that means, the prime thing which we would like to highlight here is that any impairment of quality during freezing is not because of temperature, whatever be the temperature, minus 5, minus 10, minus 20 $^{o}$C. It is not the temperature who is responsible for any change in quality.

It is the transformation of water to ice, that is, formation of ice is the prime culprit for any change in quality during freezing, ok. Therefore, the transformation of water to ice, there is a nucleation, right. There is a term called nucleation and unless a nucleus is formed there will not be any formation of ice crystal. There are two types of this nucleation, one is homogeneous and the other is heterogeneous, or catalytic, and this occurs in food materials that homogeneous, not non homogeneous, or heterogeneous, occur in food material, which involves formation of nuclei, adjacent to suspended foreign particles, right, like surface film, foreign particles or on the walls of the containers, with that necessitates, some super cooling temperature, and for that the temperature is lowered to some critical value, where nucleation begins, and further decrease in temperature results in abrupt increase in nucleation rate. So, if you just follow properly, then you see that, we have said already, some information, which are very critical or crucial, that is, which involve, that is, formation of nucleus, are adjacent to suspended foreign material, surface film, or walls, right.

So, these are minimum requirement for the formation of water to ice, as well, we are also saying necessitates some super cooling, that is, by lowering the temperature to some critical value, where nucleation begins, and if we decrease the temperature further, it results in abrupt decrease in nucleation rate, or rather abrupt increase in nucleation rate, right. So, here you have come to know, one very important thing, that it is not the temperature, which, if you lower down automatically, you will get ice to, water to ice transformation. Now, so, if we assume that, say, this is a container, and there is some water, right, and if we lower down the temperature, from both the sides, if it is one dimensional heat transfer. So, if you apply, or subtract Q quantity of heat from here, then the temperature of this will go on decreasing, say T1, then T2, then T3 etc. right. And if this water is pure like $H_2O$ only, there is no other thing, like there is no suspended foreign material, there is no surface films, and the wall, I am talking about wall now, right.

So it is pure water $H_2O$ only, other things are not available. Then, if you lower down the temperature, still further, there will not be any formation of nucleus, because, as we have seen, for formation of nucleus, either one or more than one of these are required, that is, suspended foreign material, or some surface films, or some walls of the containers, right, where, the nucleation will begin. But if we have already removed these things, then we have only pure water, $H_2O$, right, pure water, $H_2O$ is there. So, if we still decrease the temperature, and while doing that, I hope, you have seen thermo flux, right, thermo flux. This you have seen, perhaps at home, or outside, and you have seen that, it is a container in which, there is another container like one in a one, like if this is the container, obviously, of this size, that is in another container, like this, one, right, and the wall of this is so polished, that you can see your face, it acts like a mirror, and that is also having a cap, and if you open the cap and see inside, then also you see, like the outside inside is

also so much, like outside it is polished, right.

So depending on the polishing the one which we said that wall, this we said wall normally again in this case let me tell though this is not part of it, but still if you have read fluid flow, then there was one chart, that is called Moody's chart, M O O D I, Moody's chart, right. How the chart is look like? The chart looks like, this, that you have log log graph, this is f, this is $N_{Re}$ and the curves are like this, for different epsilon by D, where this is called relative roughness, relative roughness, right. So, if it is relative roughness, epsilon by D, for a given epsilon by D, you can find out beforehand, you have found out, $N_{Re}$ and then, you can find out the friction factor. Why it has come? Because, normally we think, what, if this is a pipe and if this is the L of the pipe, right, but Moody's said that if we think, like this, that, this is the L, through which a fluid has to move, it is not so. What he said, if you take the inside of the pipe, take a section, and see under microscope, right, then you will see the pipe, which was supposed to be like this, but is not, it is like this.

So, instead of the liquid or fluid moving from this end to that end, as L, it is moving from here to there, like this, like this, like this, like this, much more than L. So, what we are talking about, L is not the L, because the fluid has to move much more than L, as the wall is rough. So, depending on the roughness we said epsilon by D, that is, the relative roughness that came up. We are not going into more in detail of this, but if you look at that if we can do our this container that roughness is absolutely 0, it is policed in such a way that the roughness is absolutely 0. Then we said that, walls, that is one of the criteria to form the nucleus.

If we have already removed suspended foreign material, we have removed surface films nothing is there. So, we have also made the inside so nicely polished that there is no roughness, it is really L is equals to L because this turbulence or rather this roughness we have removed and it has become 1 L that can be done by polishing right. And under this situation if it is so good material where there is no roughness then the liquid will remain as liquid. If we even go down to minus 5, or minus 10, or some that is what I said that scientist have brought the temperature much lower, by taking care of all these right. So, for the formation of the nucleus you need a site right that site which we call that you need a site, that site could be suspended foreign materials, suspended film or any other or wall, right.

Now, then, we also said, there are two ways of forming the, sorry, there are two ways of forming, or two types of nucleation, as one is heterogeneous, and other is homogeneous, right. Then if we look at the formation of the nucleus, then you see that, it is a function of either of the three singly, or in combination, that is, the temperature, here you see, it is

minus 50, and if that means, it is not to a scale, it is an indicative, this is, if this is 0, and if we go right, normally, we go with temperature, as you proceed, the temperature goes up, but it, since, it is lowering. So, we are saying that, as we are proceeding, temperature is going down, and say, this is minus 50 $^{o}$C, and this is the rate of nucleation, for that you see, it is 0,0. So, this is the origin, and the line which we have drawn, for the formation of nucleus, or rate of nucleus formation is not passing through this 0,0 or origin. It is some less than 0 temperature, which we have said sub cool, where, the formation of nucleus begins. Now, once the nucleus is formed, then it is the rate of nucleation is proceeding more or less, as of course, we have to we have to keep this temperature difference, initial super cooling, rate of heat removal either singly or in combination, right.

So, that we have to keep and then the nucleus formation is exponentially increasing. I hope, this curve is exponential, that you know, exponential, right, that you know. This type of curve is called exponential, right. So, once we have this, then the rate, either again, we say that either the temperature difference delta T, between the material and the cooling medium, that has to be high, or it has to have an initial super cooling, or the rate of heat removal, either singly or in combination of them, anything may do. This job that instead of passing it through the origin it will have a lowering of temperature, and at that temperature, where the nucleation will start, but that is not 0,0, that is somewhere lower than 0, at any temperature, since, it is a schematic one, not calibrated one. So, we cannot say that, what is the temperature? Obviously, different for different materials, right. Now, with this, once you have the formation of nucleus, then it comes, how the nucleus? That means, you have one nucleus, say here, and if we assume this to be a food material, and you know that, in all food materials, there are cells, there are tissues, there are dissolved solids, or D S dissolved solids, etc. right. So, if we assume that, say one nucleus has formed, this is an enlarged one, right, that nucleus, size of the nucleus can be as small as you can think of, right number 1. Then what will happen? So, this is a another water molecule, this is another water molecule, this may be another water molecule.

Now, under given condition of this temperature difference, initial super cooling, or rate of heat removal, under this condition, this is all produced by obviously, lowering of temperature, right, by lowering of temperature, this is happening. So, under that condition, which is prevailing already, one nucleus has formed, surrounding water molecules, they will then have the option, either form another nucleus under this same situation, or if they are not capable, then they will go and join this already formed nucleus. So, the size of the nucleus now will be little more, and then if this one also joins there, then that will be even more, then if this one also joins there, then that will be even more right. So, instead of forming another nucleus, if these water molecules surrounding, they think or they have not that energy to form a nucleus, they will join to the already formed nucleus, and the size of the nucleus will go up, or this is called crystal, size of the

crystal will go up, right. Then, this is of course, in black, should have been in white. The same for the growth of the crystal, that means, that from nucleus N, it has now formed a crystal, or ice crystal, we say ice, see ice crystal.

There also, you see that, the temperature difference, initial super cooling, and rate of heat removal, all these are factors to have the growth of the nucleus, right, and growth of the nucleus rate, it is passing through origin 0,0, unlike that formation of nucleus, it was N, from there it was like this, right. So, it is passing through the origin and the nature of the curve is curvilinear, means as these factors are imposing, the size of the crystal is also, or growth of the crystal size is also increasing, but not exponentially. It is a curvilinear, right. So, with this our time is over today. So, let us stop and we have understood why nucleation is important, right, and how it is affecting, it will affect the quality, we will come to that afterwards. Thank you very much.