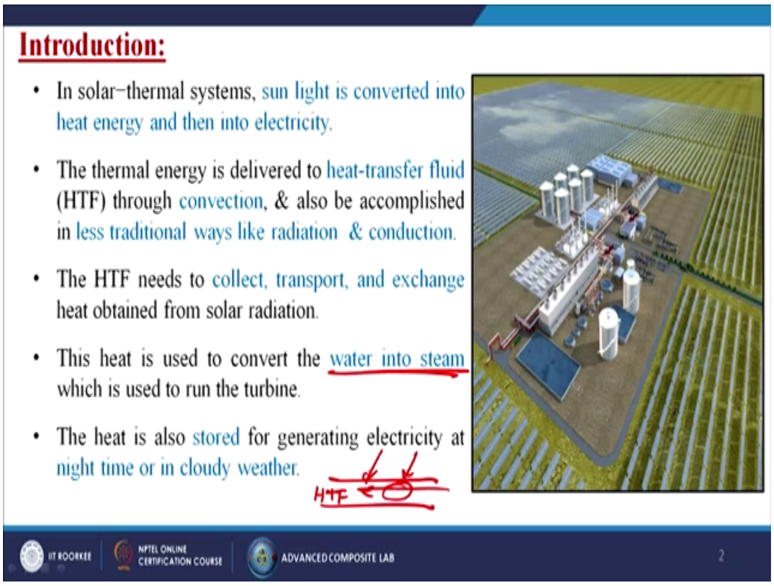
Selection of Nanomaterials for Energy Harvesting and Storage Applications
Prof. Kaushik Pal
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture – 05
Heat Transfer Fluids

Hello my friends, today we are going to discuss our new chapter that is heat transfer fluids. So, before going to start about that heat transfer fluids just let us know that actually where we are using this heat transfer fluids.

(Refer Slide Time: 00:44)



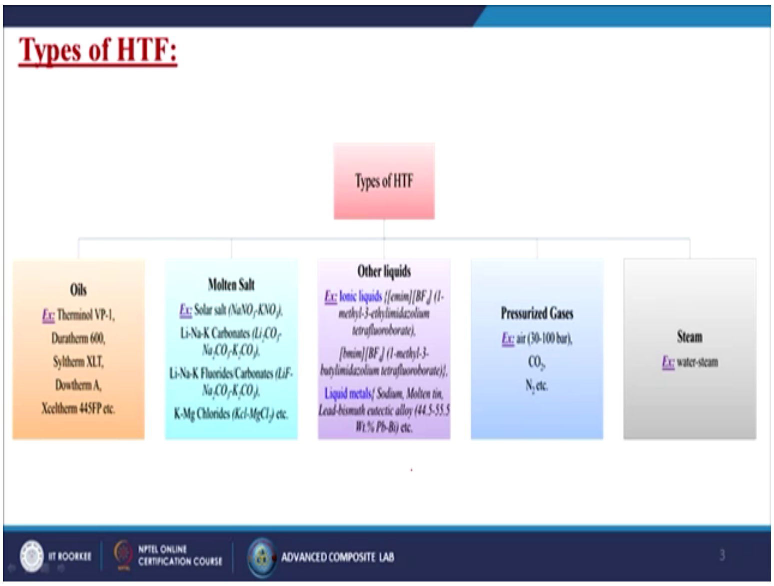
Basically you remember that I have already shown this image in my earlier lectures. So, basically in the solar thermal systems what is happening so, when the sunlight is coming to the systems that sunlight is converting into the heat energy and then into the electricity.

So; that means, if you remember in my last lecture I have discussed that when the solar energy is coming on to some panels or maybe some pipes or maybe some other containers. So, basically inside that containers either we are putting some kind of gas or maybe the air or maybe some kind of liquids. So, now, that liquid is getting heated by that sunlight and then that heated liquid we are using as a vapor and then we are running the turbines and from that we are generating the electricity.

So, basically that is the concepts so that is why today basically we are going to discuss about that particular heat transfer fluids. So, the thermal energy is delivered to heat transfer fluids in short as I told already it is HTF through convections and also be accomplished in less traditional ways like radiation and the conduction. So, basically the convection principle is working over here, the HTF needs to collect, transport and exchange heat obtained from the solar radiations.

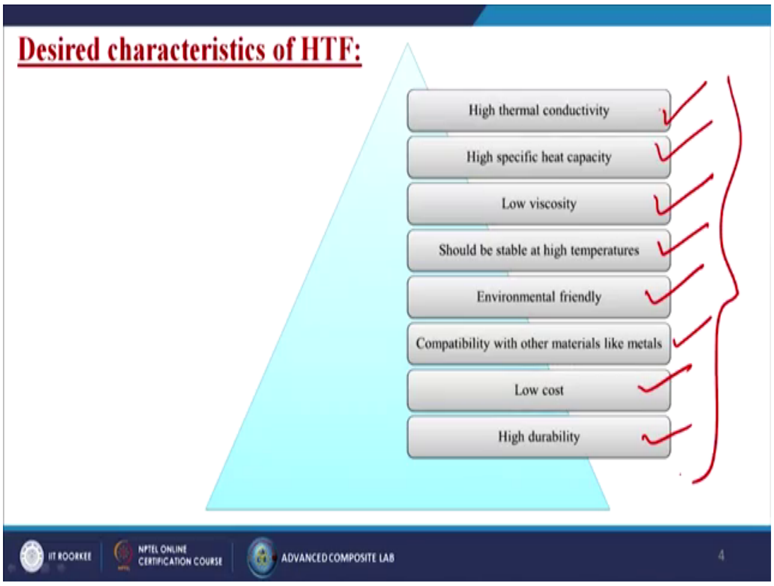
This heat is used to convert the water into steam as I told already. So, through that pipe sunlight is coming over here and then that heat transfer fluid HTF is going through this channels and through the convection process it is getting heated up and then we are increasing that heat in up to certain level. So, that this liquid is converting into the steam and then that steam directly going to the turbine and then generator is coupled with the turbine. So, when the turbine will blade will rotate. So, automatically the generator will be rotating and then from that generator we are going to get the electricity so, that is the whole concept over here. So, the heat is also stored for generating electricity at night time or maybe in the cloudy weather or maybe into the rainy season.

(Refer Slide Time: 03:01)



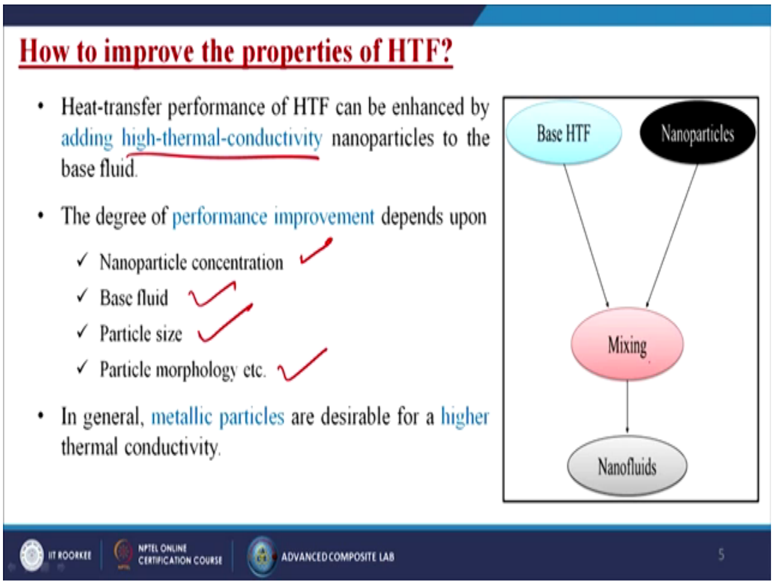
So, there are several types of heat transfer fluids are available like oils, like therminol VP, one these all are the different grades name actually basically duratherm 600, then syltherm XLT, then dowthem A. Then there are certain kinds of molten salt also available like solar salt, sodium nitrate and the potassium nitrate combinations lithium sodium, potassium carbonates, lithium potassium sodium fluorides or maybe the carbonates. So, like this way some kind of special liquids are also available like ionic liquids and the some kind of liquid metals, some kind of pressurized gas like air it is from 30 to 100 bar carbon dioxide or nitrogen and of course, the last one is the steam; that means the water steam or maybe the vapour steam.

(Refer Slide Time: 03:58)



Now, let us discuss about what will be the characteristics of that HTF so, that we can choose that particular HTF for this kind of operations. So, first is that it should have high thermal conductivity, it should have high specific heat capacity, it should have low viscosity, should be stable at high temperatures, environmental friendly, compatibility with other materials like metals, low cost and high durability means the longevity of life. So, now, basically suppose I am having that particular liquid so, how to improve the properties of that particular liquid so that it can satisfy all this properties.

(Refer Slide Time: 04:49)

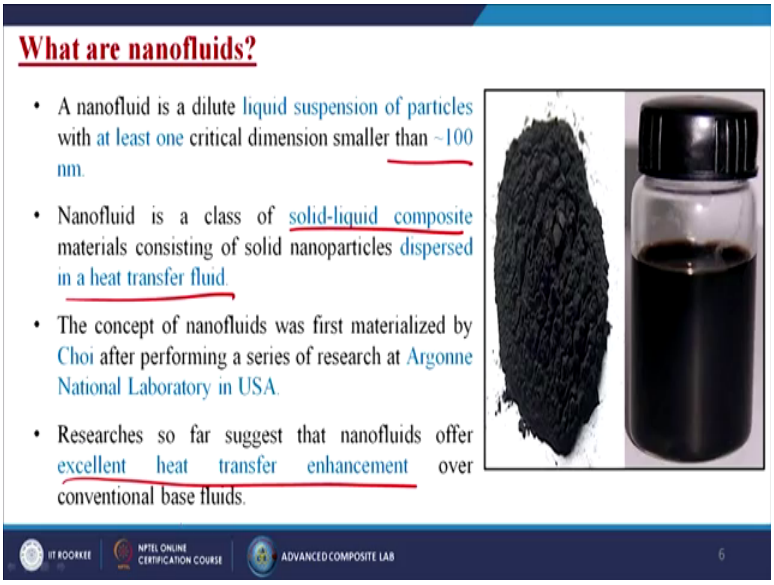


So, basically heat transfer performance of the HTF can be enhanced by adding high thermal conductivity nanoparticles to the base fluid, because as I told already that in a single fluid without mixing or adding anything it cannot provide this all kind of properties. So, just to enhance that other properties also we are going to add certain kind of nanoparticles which can enhance certain particular properties. So, either that nanoparticles maybe a single one means is from a single particular compounds or maybe a combinations of different compounds, because as we know that when there is certain nanoparticles it will enhance certain properties, but not all the properties.

Sometimes it may happen that it is enhancing on particular properties simultaneously it is decreasing another properties, but in that particular case we need increase of that particular properties also. So, what will do, we are going to add another types of nanoparticles which will increase that particular properties also. So, the degree of performance improvement depends upon nanoparticle concentrations, base fluid, particle size and the particle morphology.

So, basically we are having the base HTF and nanoparticle we are mixing together and we are making the nanofluids. Why you are calling it the nanofluids, because the fluid containing the nanoparticles in general metallic particles are desirable for a higher thermal conductivity.

(Refer Slide Time: 06:27)

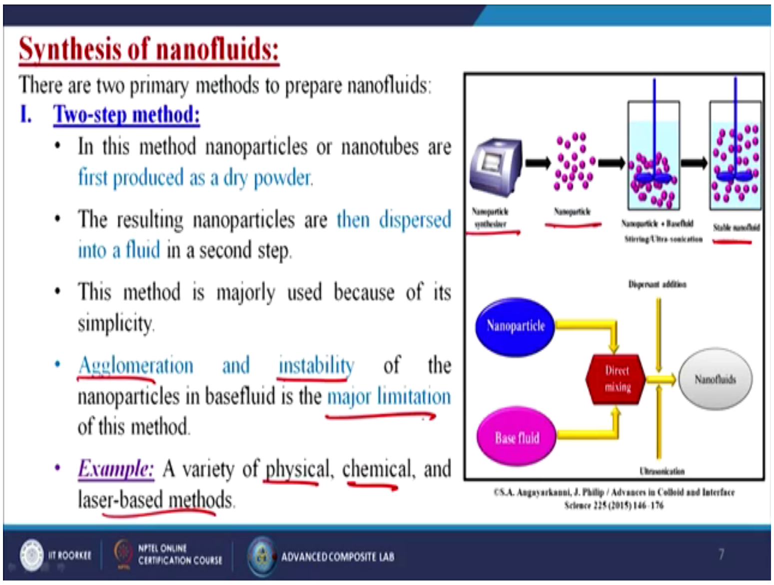


What are nanofluids basically? So, just let us know a nano fluid is a dilute liquid suspension of particles with at least one critical dimension smaller than 100 nano meter. So, if you remember that from the nanotechnology point of view there are so many types of nanomaterials designation like 0 d, 1 d, 2 d, 3 d so, like this. That means, when we are talking about the nanoparticles that ones dimension should be into the nanoscale. So, basically in this particular case when we are talking about the nanoparticles one dimension from 1 nanometer to 100 nanometer then that kind of particles basically we are using over here.

So, nano fluid is a class of solid liquid composite materials consisting of solid nanoparticles dispersed in a heat transfer fluid. So, the concept of nanofluids was first materialized by Choi it is a name of an scientist, after performing a series of research at Argonne National Laboratory in USA. Researches so far suggest that nanofluids offer excellent heat transfer enhancement over conventional base fluids, yes of course, because when I am adding third any kind of third party materials. So, of course, it is going to increase certain kind of properties.

So, in this particular imagery you can see simple I am having that powder, I am having the base fluids and I am putting that powder into the base fluids. of course, up to certain concentration it is not that I am going to add 100 percent, maybe 5 percent, 10 percent, 20 percent depending upon that the performance enhancement. If I had more nanoparticles sometimes it may happen that it can reduce all the properties due to the agglomerations or maybe some other problems.

(Refer Slide Time: 08:21)



Now, how we are going to make this kind of nanofluids, there are 2 primary methods generally we are following one is called the two- step method. In the two- step method first we are having the nanoparticle synthesizer where we are synthesizing our nanoparticles. So, we are having that nanoparticles, then simple I am having one beaker or maybe any kind of flask where I am putting the base fluids and then I am slowly adding the nanoparticles under the continuous steering of by magnetic stirrer or maybe any kind of mechanical stirrer. So, we are getting one stable nanofluids over there.

So, first we are synthesizing the nanoparticles then we are adding into the systems that is why it is called the two step method. So, example a variety of physical, chemical and laser based methods, but this method is having certain problems. What is that, agglomerations and instability of the nanoparticles in base fluid is the major limitation of this particular method.

(Refer Slide Time: 09:24)

And the second method is of course, of one step method. So, in this method the production of nanoparticles and their dispersion in a base fluids are done simultaneously. So, if I want to discuss in this particular image so, just let me explain that we are having that heated crucible over there right.

So, where I am putting my materials that materials means, what materials I am going to add with my base fluids. Now I am having the liquid circulated throughout it so, what happened when I am giving the heat the vapor is generating and that vapor is directly going or maybe come into the contact with the liquids and the nanoparticle is adding into the system. So, simultaneously both process are taking place in a single step.

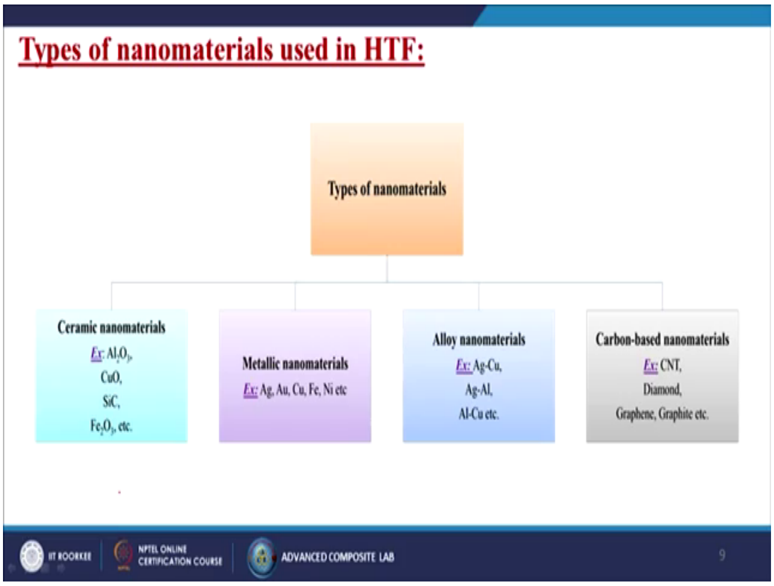
So, in this method, agglomerations of nanoparticles can be minimized and stability of fluids can be increased. Here is also another good examples like that suppose you are having that liquid, the liquid may be anything; that means, that liquid is basically your base materials or maybe the base liquid and then you are having one electrode is made by the copper and another electrode is made by the graphite.

So, now when you are giving the potential difference in between to what will happen the spark will be generated, due to that spark or maybe the electrochemical process what will happen this copper ion will come into the systems. That means, into the liquid now you are purging the gas what will be the gas say suppose if you purge the oxygen gas. So, automatically that copper will react with the oxygen and it will form the copper oxide and then automatically that copper oxide particle will be inside your system. So, that is also the another advantage or maybe you can say that another approach for making in a single step method.

So, in this method, the residual reactants like impurities are left in the nanofluids due to incomplete reaction which are difficult to remove that is also a one kind of drawbacks, but this method is more convenient than the two- step method. Examples like direct evaporation and condensation, chemical vapor condensation and submerged arc synthesis etcetera.

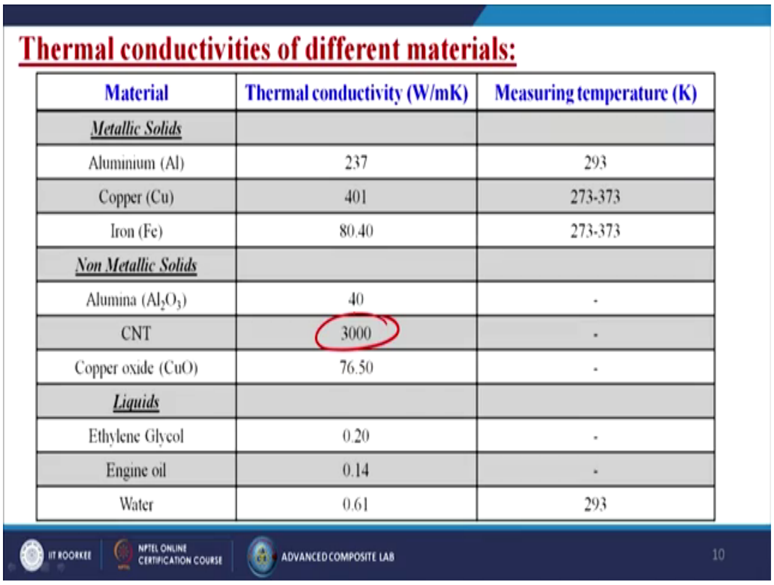
Till now we are discussing about what type of process we can make the materials or maybe we can make the HTF. Now in this particular case we are going to discuss that what kind of nanomaterials basically we can add.

(Refer Slide Time: 12:09)



So, like we can add like ceramic nano materials like alumina Al 2 O 3, copper oxide, silicon carbide, Fe 2 O 3, metallic nano materials like silver, gold, copper, iron, nickel. If we talk about the alloy nanomaterials like silver copper combinations, like silver aluminium combinations, like aluminium copper combinations. If I talk about the carbon based nanomaterials we can add the carbon nanotubes, we can add the diamond of course, this is the artificial diamonds and graphene or maybe the graphite. So, these kind of nanomaterials basically we are adding to the HTF.

(Refer Slide Time: 12:49)

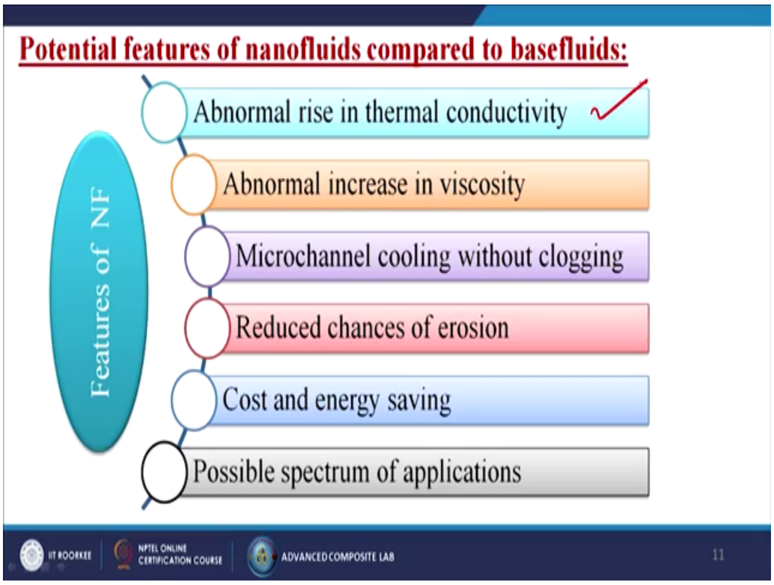

Thermal conductivities of different materials:

Material	Thermal conductivity (W/mK)	Measuring temperature (K)
Metallic Solids		
Aluminium (Al)	237	293
Copper (Cu)	401	273-373
Iron (Fe)	80.40	273-373
Non Metallic Solids		
Alumina (Al_2O_3)	40	-
CNT	3000	-
Copper oxide (CuO)	76.50	-
Liquids		
Ethylene Glycol	0.20	-
Engine oil	0.14	-
Water	0.61	293

Now, why, we are adding this kind of materials because as I told already, of course we are going to increase certain kind of properties right. So, basically our main aim for making the HTF is that it should have very high thermal conductivity then only the heat can come from directly to the sunlight to the systems so, these conductivity because this nanoparticle will make a path so that the heat can come directly into the system.

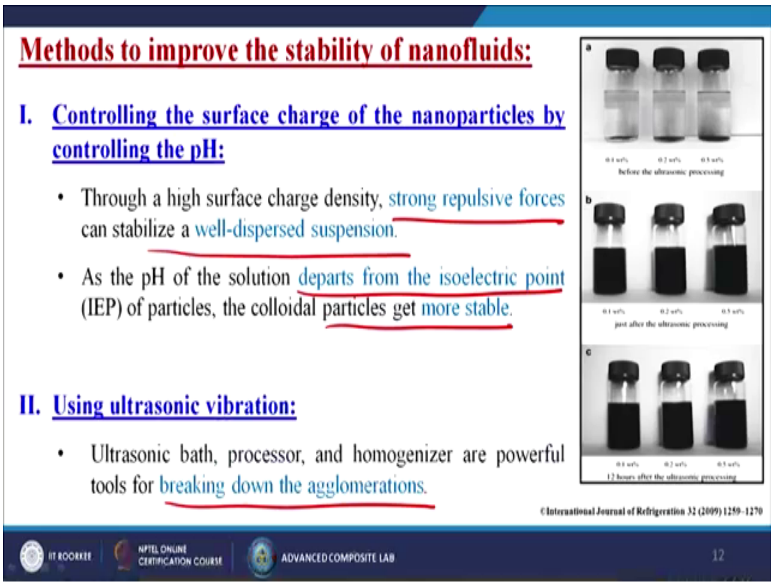
So, the thermal conductivity is the prime factor over here so, now, based on the higher thermal conductivity we are choosing the different types of nanomaterials over here. Say suppose if we talk about the aluminium it is having the 237 watt per meter kelvin the thermal conductivity and measuring temperature is 293 kelvin. If we talk about the carbon nanotubes now you can understand what is the difference, it has gone up to 3000. So, the maximum k maximum one we are getting from the carbon nanotubes. So, that is why people are nowadays using the carbon nanotubes, maybe in some recent days maybe some new material will come which will overcome these value also or maybe it will go for the higher thermal conductivity.

(Refer Slide Time: 14:06)



Now, what are the potential features of nanofluids compared to base fluids, first is that abnormal rise in thermal conductivity, abnormal increase in viscosity, microchannel cooling without clogging, reduced chances of erosions, cost and energy saving and the possible spectrum of applications. So, these all are the features for nanofluids.

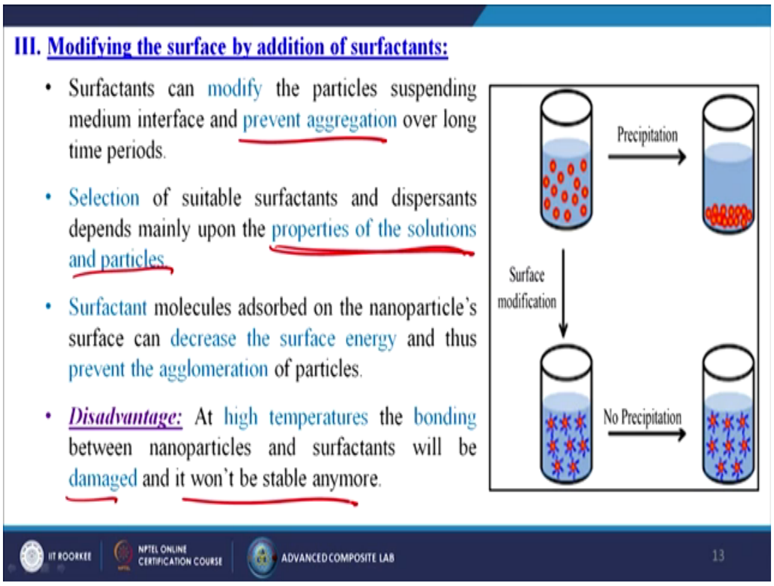
(Refer Slide Time: 14:34)



Now, how to improve the stability of the nanofluids so, there are several methods the first one is that controlling the surface charge of the nanoparticles by controlling the pH. So, basically through a high surface charge density, strong repulsive forces can stabilize a well - dispersed suspension. As the pH of the solution departs from the isoelectric point of particles the colloidal particles get more stable so, that is the number one conditions.

If we talk about the number 2 conditions then basically sometimes you are using the ultrasonic vibrations by the sonicator right. So, ultrasonic bath, processor and homogenizer are powerful tools for breaking down the agglomerations. Agglomerations means jolting of the nanoparticles in a certain particular points, then that vibration will go and it will break that particular jolting and the nanoparticles will be dispersed into the system.

(Refer Slide Time: 15:35)

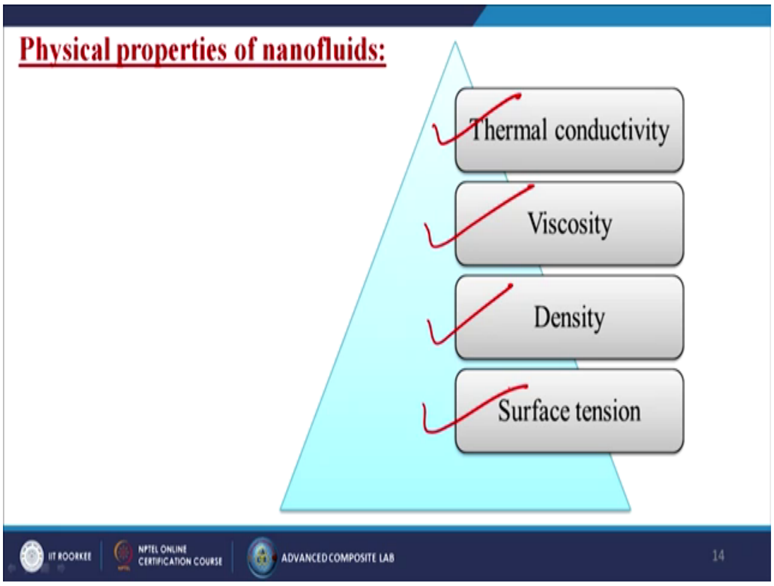


Next third one is the modifying the surface by adding of the surfactants, simple we are doing certain kind of coatings over there. So, nanoparticles due to that high surface energy there is a affinity that they can stick together, then if I add certain kind of lubrication, kind of materials or maybe certain kind of emulsion or may be certain kind of nonstick materials so, automatically the nanoparticle will come closer, but they will not stick together so, that is also the another methods.

So, surfactants can modify the particles suspending medium interface and prevent agglomeration over long time periods. So, selection of suitable surfactants and dispersants depends mainly upon the properties of the solutions and the particles. Surfactant molecules absorbed on the nanoparticle's surface can decrease the surface energy and thus prevent the agglomeration of particles, as I told already. So, simple the surfactant will attached on to the nanoparticle surface so, it is non sticky. So, it will not allow to stick the nanoparticles together.

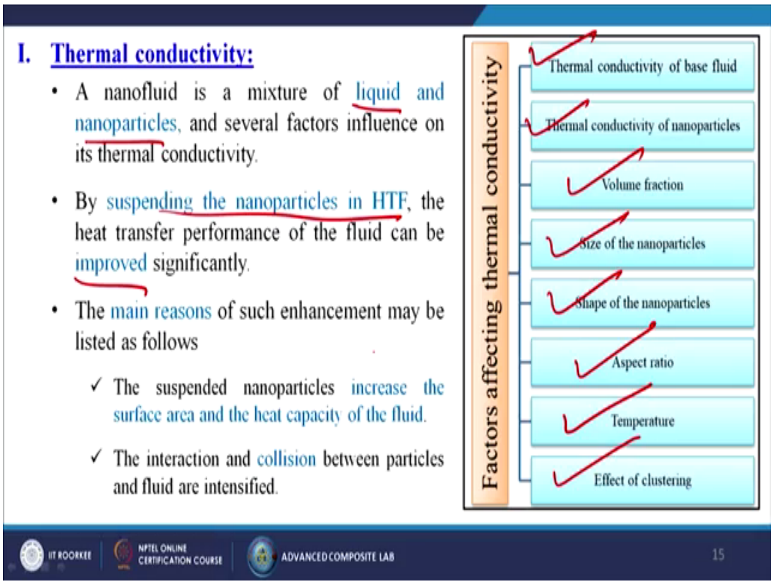
Disadvantages, at high temperatures that is also the another thing, because this is a coating kind of things. So, if you increase or maybe at the high temperature at maybe high working temperature rather I say so, in that particular case what happened maybe that surfactants can come out from the nanoparticles, that is a one of the disadvantage of this particular process. So, it will damaged and it would not be stable anymore or maybe that surfactants can degrade. So, that is also the problem.

(Refer Slide Time: 17:16)



Now, what are the physical properties generally we expect from the nanofluids, first one is called the thermal conductivity, then viscosity, density and the surface tension. So, these all are the 4 properties generally we need for choosing any kind of nanofluids.

(Refer Slide Time: 17:36)

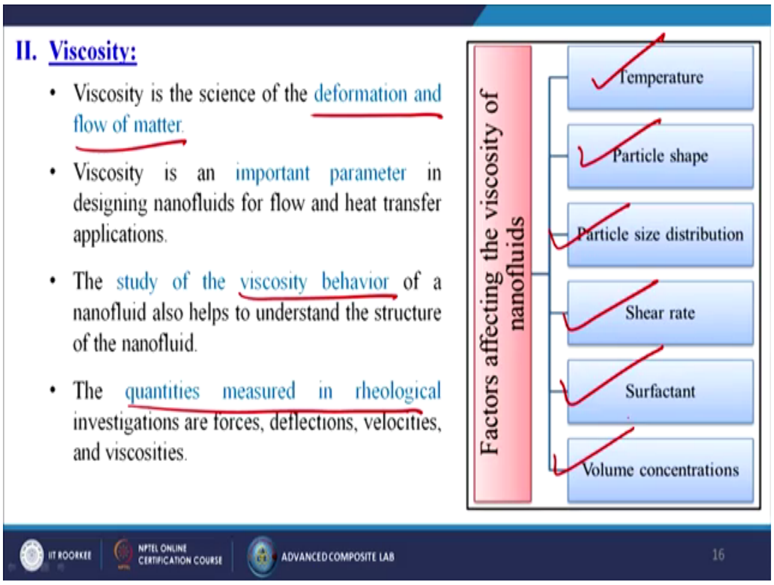


So, what is thermal conductivity, a nanofluid is a mixture of liquid and nanoparticles and several factors influence on it is thermal conductivity. So, factors affecting the thermal conductivity basically what are those, first is that thermal conductivity of base fluid, thermal conductivity of nanoparticles, volume fraction, size of the nanoparticles, shape of the nanoparticles, aspect ratio, temperature and the effect of clustering. So, these all are the factors which basically affecting the thermal conductivity of that particular nanomaterials or may be the nanofluids.

By suspending the nanoparticles in HTF, the heat transfer performance of the fluid can be improved significantly. The main reasons of such enhancement may be listed as follows like, the suspended nanoparticles increase the surface area and the heat capacity of the fluid. Yes because when you are making that particular materials into the nano size so, aspect ratio which is nothing, but the surface to volume ratio is very high. So, surface area is increasing surface energy is increasing so, due to that automatically the more heat absorption will be taking place.

Next the interactions and collisions between the particles because you are using number of particles so, they are suspended. So, when they are moving inside the liquid so, at the time of movement they are colliding each other, either maybe the Brownian emotions or maybe by some other means. So, the fluids are intensified, so these are the first conditions.

(Refer Slide Time: 19:20)

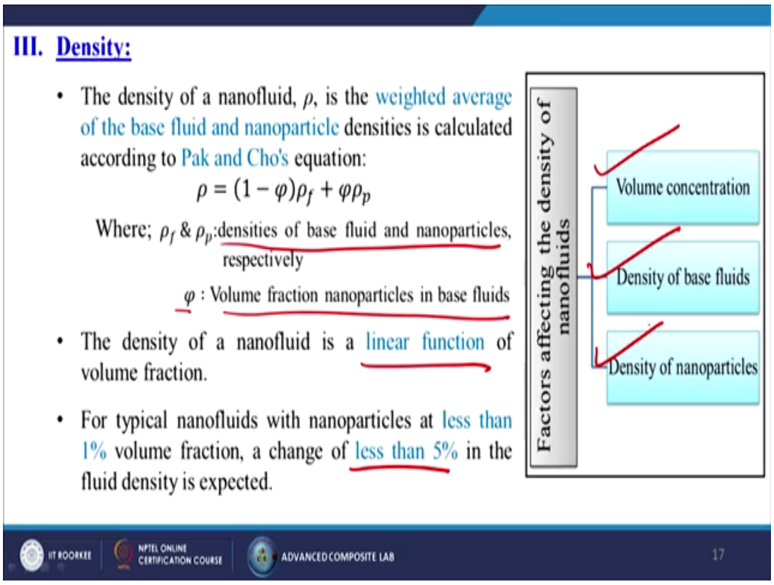


Next viscosity so, in this particular case viscosity is the science of deformations and the flow of matter right, this is a simple Layman description. So, viscosity is an important parameter in designing nanofluids for flow and heat transfer applications.

So, the study of the viscosity behaviour of a nanofluid also helps to understand the structure of the nanofluid. Yes of course, because viscosity is one kind of parameters because when the liquid is flowing through the pipe, suppose there is a certain kind of critical joints or maybe some kind of narrow joints, if we I am using certain kind of viscous fluids maybe that viscous fluids cannot enter into that particular joints or maybe be into that particular shapes. So, I need the material which is having the moderate viscosity.

The study of the viscosity behaviour of a nanofluid also helps to understand the structure of the nanofluid. The quantities measured in rheological investigations are forces, deflections, velocities and the viscosities. Now what are the factors basically affecting the viscosity of that particular nanofluids like temperature, particle shapes, particle size distribution, shear rate, surfactant and the volume concentrations.

(Refer Slide Time: 20:43)



Next third one is called the density. So, the density of a nanofluid which is nothing, but the universal nomenclature rho is the weighted average of the base fluid and nanoparticles densities is calculated according to the Pak and Cho's equations. What is that particular equations, rho is equal to 1 minus sigma rho f plus sigma rho p.

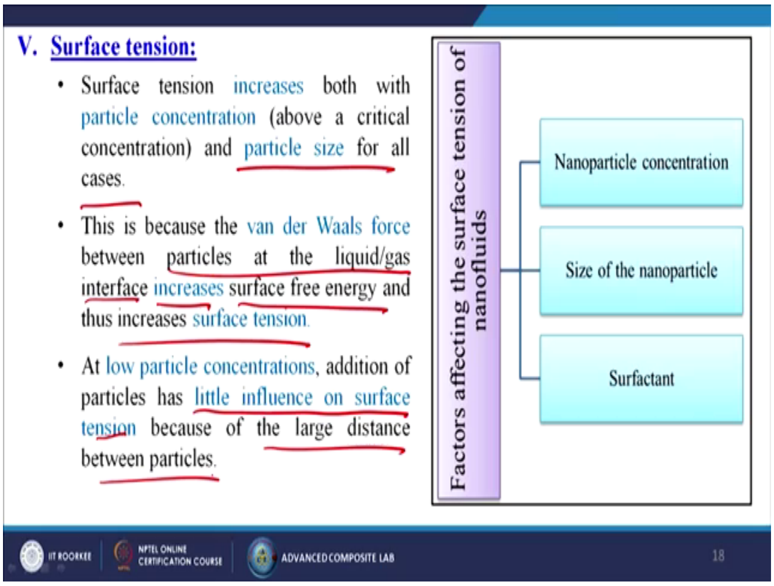
So, where rho f and rho p are the densities of base fluid and nanoparticles sigma is the volume fraction of nano particles in the base fluids. Yes of course, because now here in this particular case we are having 2 systems one is the liquid, one is the nanoparticles. So, you have to calculate both the densities join together then only you are going to get the overall densities of that particular nanofluids.

So, the density of a nano fluid is a linear function of volume fractions because if you increase the quantity of the nanoparticles automatically the density will change. If you add more liquid to the systems automatically the density will change so, that is why it is called the linear function. So, for typical nanofluids with nanoparticles at less than 1 percent volume fraction a change of less than 5 percent in the fluid density is expected, now you can see that little bit changing how much change in the density so, this is basically the thumb rule.

Now what are the factors which affecting the density of the nanofluids like volume concentrations, density of base fluids and the density of the nanoparticles so, these 3 factors.

Now we are going to discuss about the surface tensions that is also an important parameter.

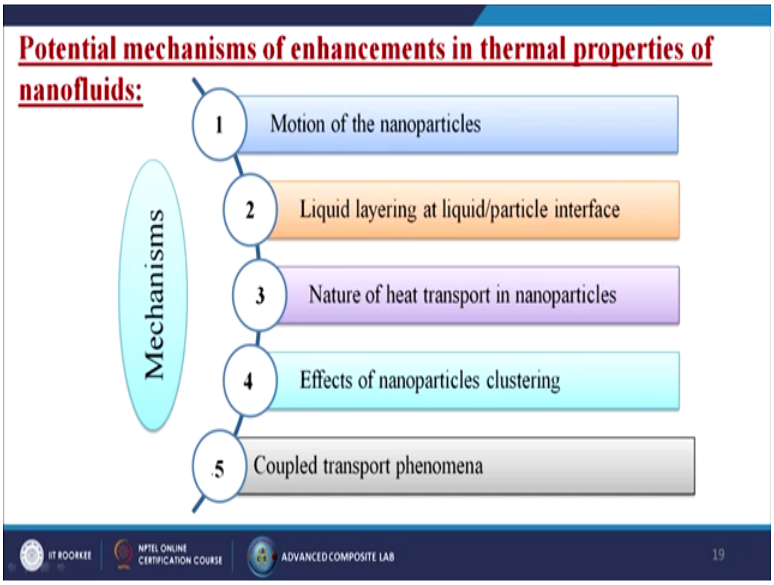
(Refer Slide Time: 22:29)



So, surface tension increases both with particle concentration above a critical concentration and particle size for all the cases, yes what is surface tension. I can give you one examples suppose if you dip your finger into some milk or maybe into some oil. So, what will happen after taking it out you can see that milk or maybe the oil is attached with your finger? So, that is basically due to the surface tensions in between your finger and in between your oil or maybe the milk. So, that phenomena basically is known as a surface tension.

So, this is because the van der Waals force between particles at the liquid or maybe the gas interface increases surface free energy and thus increase the surface tension. At low particle concentrations, addition of particles has little influence on surface tension because of the large distance between the particles. Yes of course, because low concentration means particle is getting free area for movement, but if we increase the particle concentrations so, automatically the particles will come closer so automatically the surface tension will change. Now what are the factors that affecting the surface tensions like nano particle concentrations, then size of the nanoparticles and last one is the surfactant; that means, if you are going to use any kind of coating materials or not.

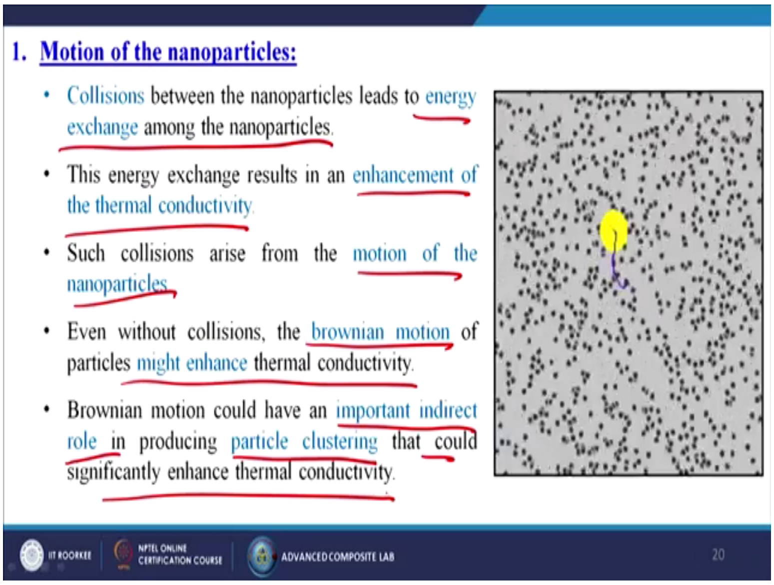
(Refer Slide Time: 23:52)



Now, what are the potential mechanisms of enhancement in thermal properties of the nanofluids. So, first is called the motion of the nanoparticles, because in the liquid systems you are having the nanoparticles so, movement of the nanoparticles inside the fluid.

Second liquid layering at liquid particle interface so, you are having the nanoparticles then how the liquid is coming into the contact with your nanoparticles. Third nature of heat transport in the nanoparticles how the heat is moving inside the system from one particle to the another or maybe particle to the liquid. Next effects of the nanoparticle clustering; that means, the agglomerations of the nanoparticles in this particular case. So, last one is the coupled transport phenomena which is nothing, but depends upon the heat transfer and the mass transfer of that particular fluid with the nanoparticles one.

(Refer Slide Time: 24:53)



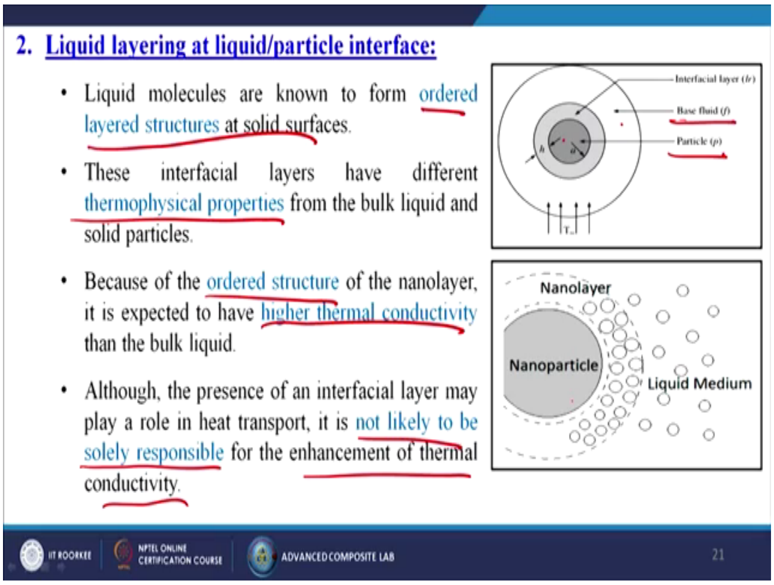
Now, first one we are going to discuss about the motion of the nanoparticles.

So, as I told already when you are increasing the concentrations of that particular nanoparticles so, automatically there will be a collisions in between the nanoparticles what you are seeing in this particular image. So, collisions between the nanoparticles leads to energy exchange among the nanoparticles. So, suppose the heat is coming from this sides so, automatically this side nano particle will be more heated up and this sides when they are colliding each other. So, from higher temperature nanoparticles the heat is going into the lower heat affected nanoparticles. So, like this way the true collisions the heat is transferring from one nanoparticles to the another.

This energy exchange results in an enhancement of the thermal conductivity of the whole system. Such collisions arise from the motion of the nanoparticles. Even without collisions, the Brownian motion of particles might enhance the thermal conductivity. So, the Brownian motion is taking place Brownian motion could have an important indirect role in producing the particle clustering that could significantly enhance the thermal conductivity.

So, that is also the another important indirect role of the Brownian motions of the nanoparticle, which produce the particle clustering; that means, one particle tries to go to another place. So, like this way the heat is moving from one place to the another.

(Refer Slide Time: 26:27)

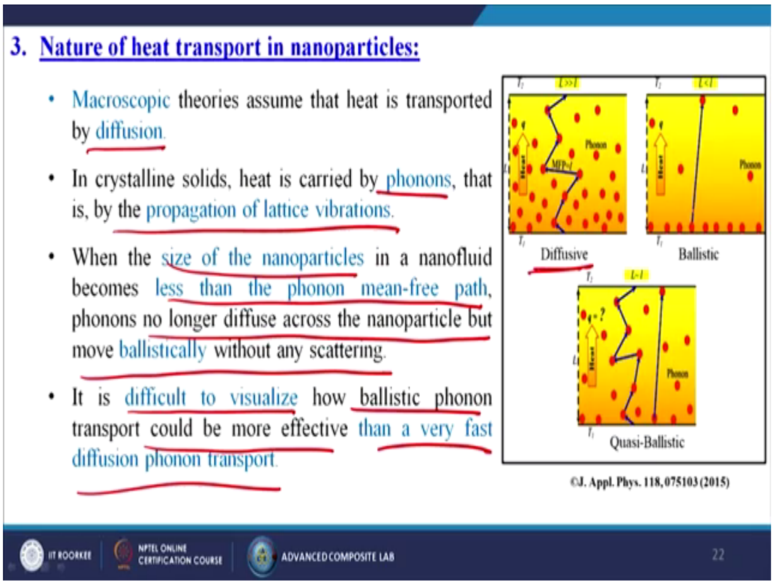


Next second one is the liquid layering at liquid particle interface. So, basically liquid molecules are known to form ordered layer structures at solid surfaces. These interfacial layers have different thermo physical properties from the bulk liquid and the solid particles. Because of the ordered structure of the nanolayer, it is expected to have higher thermal conductivity than the bulk liquid.

Although the presence of an interfacial layer may play a role in heat transport it is not likely to be solely responsible for the enhancement of the thermal conductivity, yes of course. Now the problem is that suppose you are having that nanoparticles you are having that liquid now the layers are forming on to the surface due to the interactions of that nanoparticles with the liquid. So, now, in this particular image you can see the inside one is a particle, then we are having that base fluids and in between the base fluids and particles one interfacial layer is forming basically so, which is nothing, but called the nanolayer.

Also if you are using any kind of surfactants on top of that also that can acts as an interfacial layer also. So, now, how the heat will move from your liquid to the particles or may be particle to the liquid that also depend upon this intermediate facial layer which is nothing, but you are surfactants. So, that is also an important considerations.

(Refer Slide Time: 28:05)



Next third one is called the nature of heat transport in the nanoparticles means which way the heat is transferring into the systems. Macroscopic theories assume that heat is transported by the diffusion method. Basically in crystalline solids, heat is carried by phonons, that is by the propagation of lattice vibrations. So, simple the vibration is taking place in between the phonons so, due to that vibration the heat is producing.

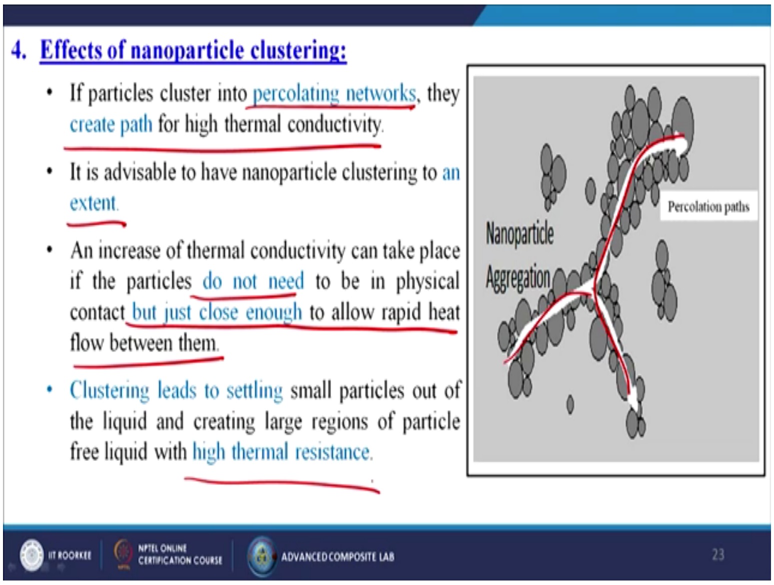
When the size of the nanoparticles in a nanofluid becomes less than the phonon mean free path, phonons no longer diffused across the nanoparticle, but move ballistically without any scattering. So, it will run away in a very high speed. So, it is difficult to visualize how ballistic phonon transport could be more effective than a very fast diffusion phonon transport.

So, in this particular case in this case you see the heat is increasing to the top right so, it is called the diffusive process so, these all are red dot all are the phonon. So, basically you see the heat it is following certain path; that means, it is having some nanoparticles. So, one particle to another, then this particle to this particle, this particle to this particle so, it is making one kind of path by the diffusive. Actually that another way I can say that diffusive is the bulk phenomena and the ballistic is the nano phenomena.

So, in this particular case what happened, when we are talking about the nanofluids or may be the nanomaterials that time the nanomaterial size is too small. So, it is getting some free path in between the particles to go through from one place to another. So, if it is having suppose I am having 2 balls, one is the bigger football and one is the smaller ping pong ball, now I am having so many balls over there. So, which ball will be easier to go from one place to another of course, the small ping pong ball. So, in this case also the same thing is happening in the ballistic case. So, the phonon it is very easy to triggering out and go to another place due to it is small size.

So, if we talk about the quasi ballistics it is nothing, but the mixing of the diffusive process as well as the ballistic process. So, both phenomena the heat is transferring.

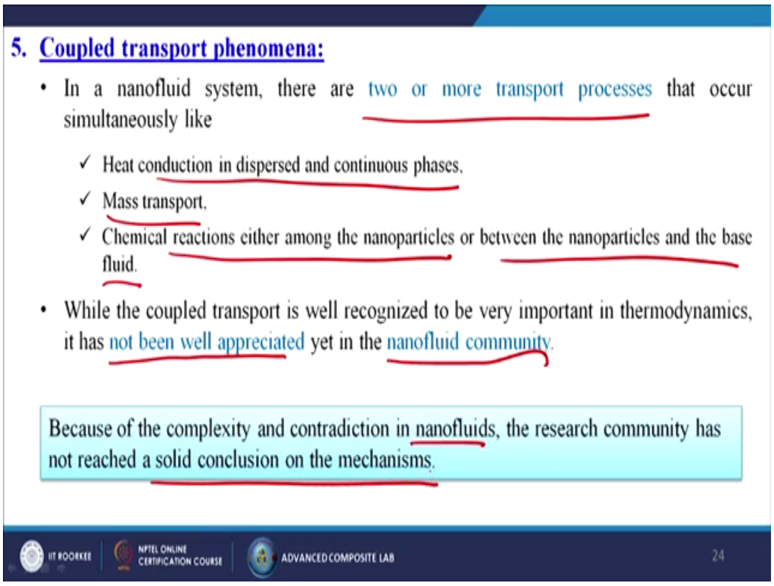
(Refer Slide Time: 30:27)



Next, effects of the nanoparticle clustering, so if particle cluster into percolating networks so, basically this is following the percolation theory or maybe the percolation networks sometimes you are calling it, they create path for high thermal conductivity. So, it is advisable to have nanoparticle clustering to an extent, mean sometimes it may require that nanoparticle can stick together, but not all. A few nanoparticles in to different places generally we expect that it should cluster and generally it happens actually that without knowingly or unknowingly also we cannot destroy that particular agglomerations it will be always there inside the systems.

An increase of thermal conductivity can takes place if the particles do not need to be in physical contact, but just close enough to allow rapid heat flow between them. So, in this particular case you see the nanoparticles with different size, has been agglomerated together and how the heat path actually is generating in between that. Clustering leads to settling small particles out of the liquid and creating large regions of particle free liquid with high thermal resistance.

(Refer Slide Time: 31:39)

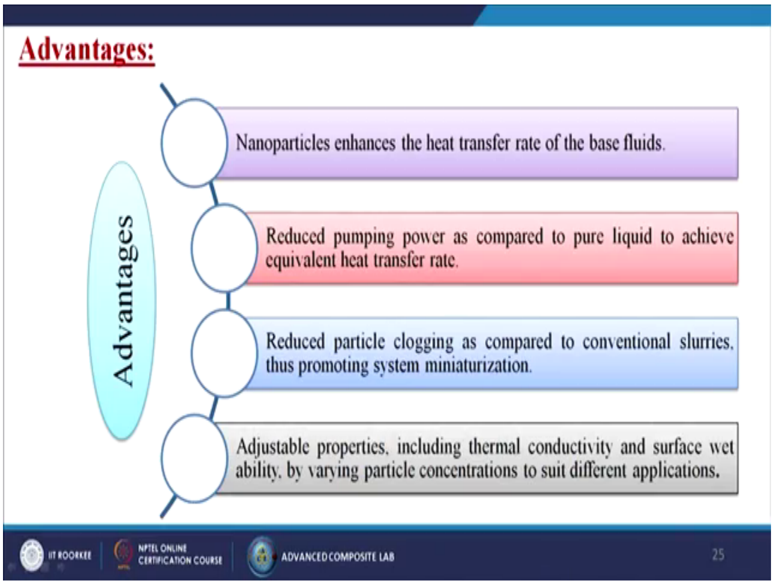


Next is the last one that is called the coupled transport phenomena.

So, basically in a nanofluid system there are 2 or more transport process that occur simultaneously like, heat conduction in dispersed and continuous phrases, mass transport and the chemical reaction either among the nanoparticles or between the nanoparticles and the base fluids. Yes of course, sometimes it may happen that nanoparticles can react with the base fluid and make some new compound. So, while the coupled transport is well recognized to be very important in thermodynamics it has not been well appreciated yet in the nanofluid community. So, scientist actually basically do not expect that this kind of coupled transport phenomena because it is very complex one and also it needs lots of research.

So, because of the complexity and contradictions in nanofluids, the research community has not reached a solid conclusions on this particular mechanisms.

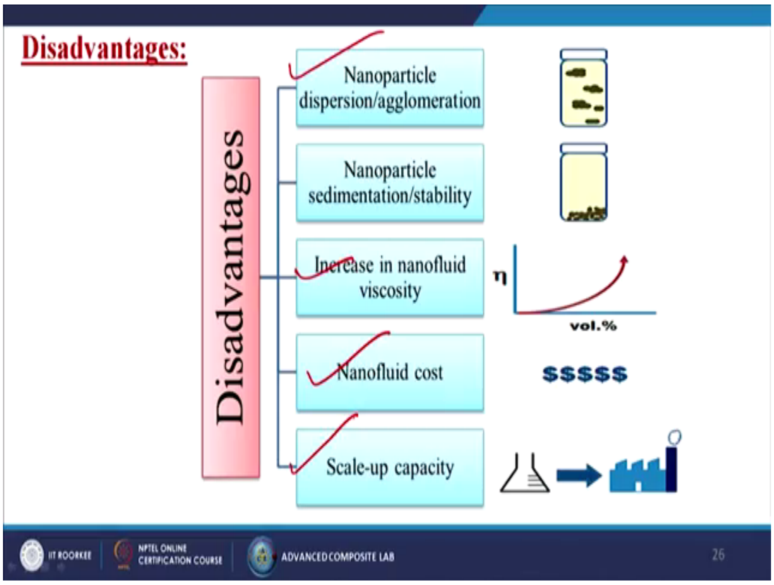
(Refer Slide Time: 32:44)



Then what are the advantages. So, basically nanoparticles enhance the heat transfer rate of the base fluids, till now we have discussed all this points. Second it is going to reduced pumping power as compared to pure liquid to achieve equivalent heat transfer rate, because it is consuming the more heat by applying the nanoparticles into the system. Third one it reduced particle clogging as compared to conventional slurries thus promoting system miniaturization.

So, the problem is that in this particular case we are using certain kind of surfactants so, that nano particles cannot stick. So, it is giving the better heat conductivity or maybe better heat flow into the system than the macro or maybe the micro particle. Last, adjustable properties including thermal conductivity and surface weight ability by wearing particle concentration to suit different applications, over there.

(Refer Slide Time: 33:49)



Now, of course, there are certain disadvantages what are those, first is that nano particle dispersion and agglomerations already we have discussed, nanoparticle sedimentation stability yes of course, after certain time due to the gravitational force that if it is very heavier than that particular liquid so, automatically the nanoparticles will come down and settle at the bottom.

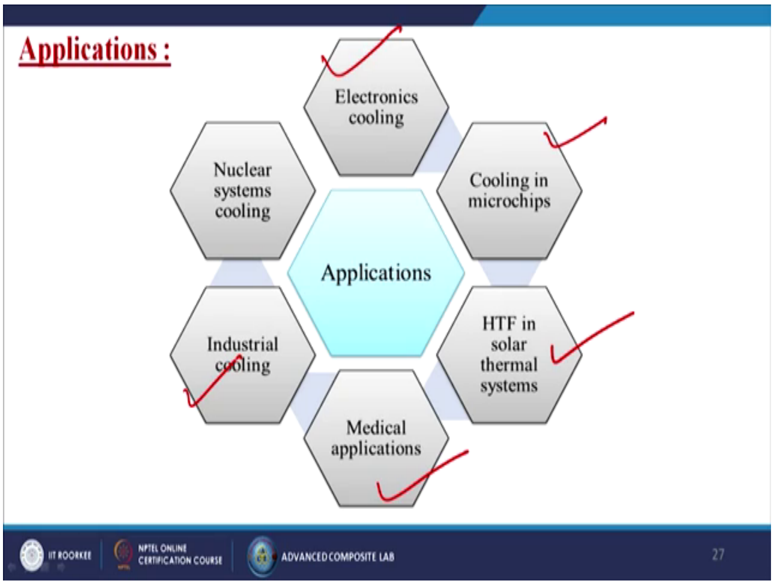
Third increase in nanofluid viscosity that is also a one kind of disadvantages over there it should not be because if it will be more viscous then after certain time, it will be very difficult to pass through the pipe or may be the channels. Nanofluid cost of course, we are adding certain kind of nanomaterials also we are pulverizing the nanoparticles into the small parts for make it more effective. So, automatically the operating cost for making that nanofluid is increasing tremendously.

And last one is the scale up capacity, because if it is very less for the research purpose we can make the nano fluid adding the nanoparticles very easily and the cost will be cheaper, but from the industrial point of view when I am increasing the quantity of the nanofluid. So, automatically same percentage of the nano materials I am going to add into the systems automatically the overall cost is going to be increased. So, these all are the different disadvantages that choosing of the nanomaterials for adding into the nanofluids.

So, basically people are trying to work on this things and hope in near future they are going to solve all these kind of problems or may be some newer materials will come which will be give the better properties and will solve this kind of problems.

Now what are the applications.

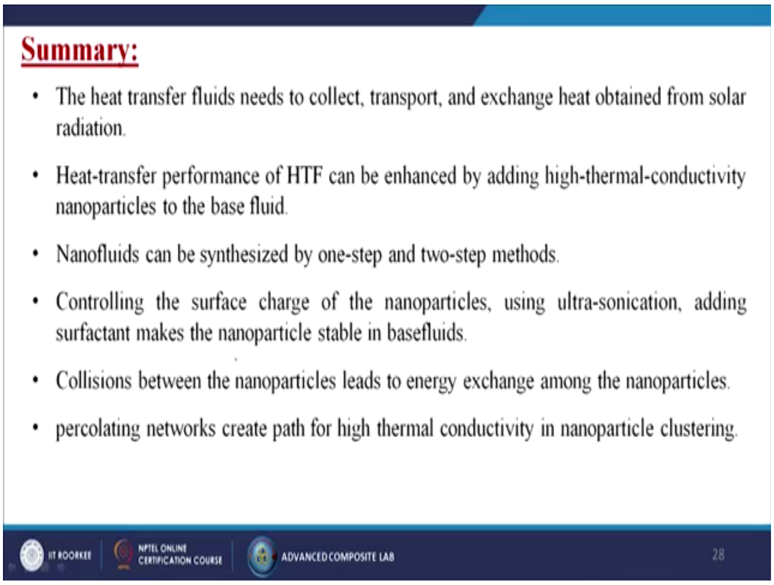
(Refer Slide Time: 35:33)



So, basically we can apply this kind of nanofluids into the nuclear systems cooling, electronics cooling, cooling in microchips, HTF in solar thermal systems, medical applications and industrial cooling, but still there are also some possible areas where the scientist are now a days using this HTF.

So, basically this is good for exchanging the heat from one system to another, now we have come to the last part of this particular lecture. So, in summary we can say that heat transfer fluids needs to collect transport and exchange heat obtained from solar radiation, heat transfer performance of HTF can be enhanced by adding high thermal conductivity nanoparticles to the base fluid.

(Refer Slide Time: 36:24)



Nanofluids can be synthesized by one - step method or maybe the two - step method, controlling the surface charge of the nanoparticles, using ultra-sonications, adding surfactant makes the nanoparticle stable in base fluids also it will make a barrier in between the agglomerations of the nanoparticles.

Collisions between the nanoparticles leads to energy exchange among the nanoparticles because it is transfering the heat from one place to another or may be one nanoparticle to the another nanoparticle. Percolating networks create path for high thermal conductivity in nanoparticle clustering, but still I am telling that so many research is going on basically onto the nanofluids for making it more stable less agglomerations of the nanoparticles and more heat conductivity. So, that it can absorb the more heat so that the overall efficiency of the system can be increased.

Thank you.