Introduction to Abrasive Machining and Finishing processes
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Lecture- 06
Probable Solution – 2 : MQL/MQCF

So, as we are looking at the sustainable grinding solutions in order to give the good environmental effect as well as to give good health to the operators, we have already completed one solution that is the probable solution is biodegradation of cutting fluids before it is dumping in to the river body or the soil bodies and other things.

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The second solution is to reduce the quantity of cutting fluid that is nothing but minimum amount of cutting fluid using without compromising the performance of the process, ok. So, how do we go about the application of minimum quantity grinding fluid as I said cutting fluid or grinding fluid; the probable solution is minimum quantity cutting fluid.

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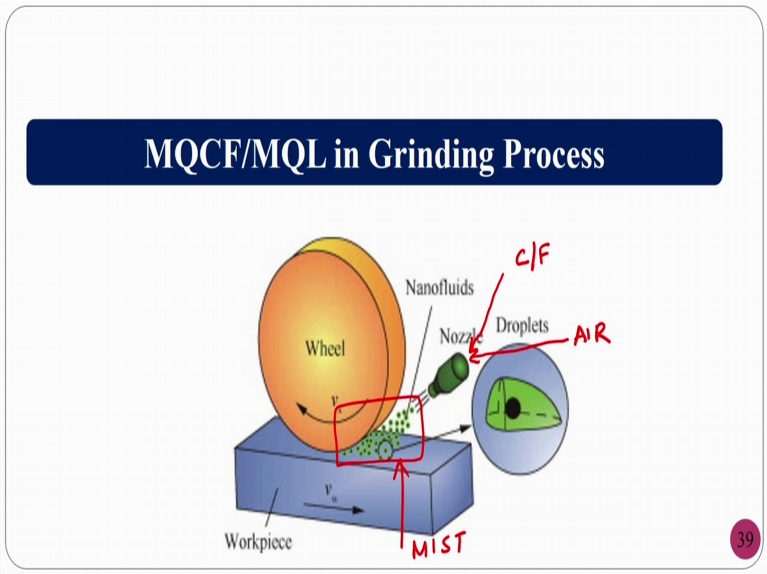

The minimum quantity cutting fluid normally will have where you will use the minimum amount of cutting fluid. Normally in the flood cooling where you just drop the cutting fluid by virtue of gravity. In that circumstances it will be 400 to 600 ml per minute. In this one, normally it ranges from 5 ml per minute to so on. It can increase or it can also decrease depend on how much air pressure that you are using because you have two nozzles whether it is internal mixing or external mixing, all these things will come up ok.

So, what you are going to do here is you are making the cutting fluid mist; that means, that you are putting a cutting fluid and your putting the highly compressed air. These two will mix compressed air you are going to put and cutting fluid you are going to put ok. This will mix and form the droplets ok. These are the nanofluid or the mist basically, mist droplet us will fall into the grinding region. This is called minimum quantity lubrication, in particular and in expansion way we will see.

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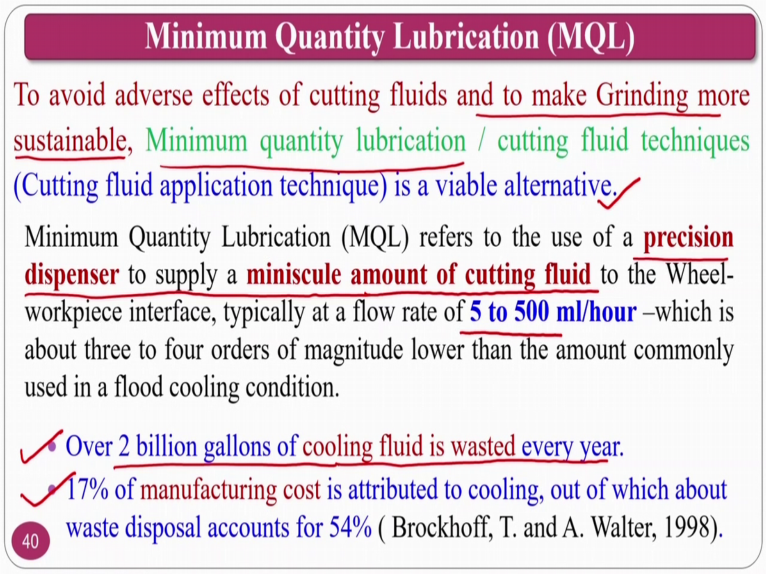

So, to avoid the adverse effects of cutting fluid and to make grinding more sustainable, minimum quantity lubrication or minimum quantity cutting fluid technique is a viable alternative; that means, that it is an alternative solution for flood cooling process.

The minimum quantity lubrication or minimum quality cutting fluid uses a precision dispenser to supply the miniscule amount of cutting fluid to the wheel work piece interface typically in the rate of 5 to 500 ml per hour. You can see here. The flood cooling normally, it will be like 500 ml per minute here. It will be 500 ml per hour; that means, that you are reducing enormously the amount of cutting fluid ok, but without compromising the mechanical performance; that means, that material removal or the surface roughness and other things.

If you see the points literature over 2 billion gallons of cutting fluid is wasted every year is across USA, across the globe normally. This amount of cutting fluid is wasted; that means, that where this cutting fluid is going they have to dump somewhere if 2 billion gallons of cutting fluid is dumping into the river or sea bodies or land fields, this is a drastic and dangerous thing that people are doing or the manufacturing industries are doing. So, you should avoid that one. 17 percent of the manufacturing cost is attributed to the cooling; that means, that cutting fluid accords approximately 17 percent; some places if you see some of the books you may find 15 percent, some of the books you find 17 percent, 18 percent and other things normally, the ranges it ranges from 15 to 17 percent the manufacturing cost attributed to the cutting fluid which is at the same time which is about waste disposal accounts for 54 percent.

That is why people what they are doing is just dumping because to avoid the additional cost of transportation to avoid the things, to make the post processing of this cutting fluid to make it biodegradable, then dumping. It also accord some amount in that circumstances to avoid and to sell the products at minimal prices, they avoid these things. So, even though you are selling at slightly higher price, if you are helping the nature, if you are helping the other people that will be good ok.

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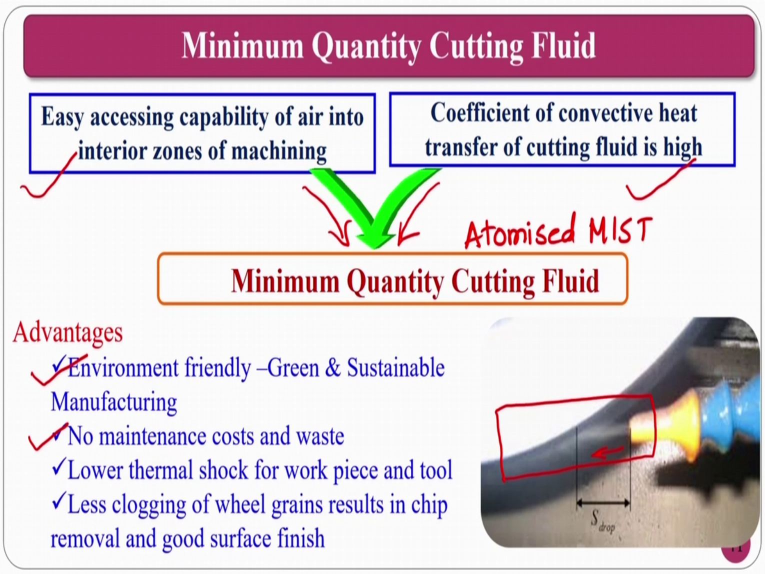

What is minimum quantity cutting fluid? minimum quantity cutting fluid is nothing but you have a cutting fluid, you have a highly compressed air ok, both mixes and comes in a droplet or nano size droplet or micro size droplet atomised mist ok. Why you are mixing? The convective heat transfer coefficient of the cutting fluid is very high. At the same time, convective heat transfer coefficient of air is very less. So, but air is a gas, it can enter or penetrate into the seashore zones of metal cutting or the grinding, but as a liquid, cutting fluid cannot. So, now, we have one advantage, one disadvantage in the cutting fluid; one advantage, one disadvantage in the air.

So, now, we have to mix the two advantages; this cutting fluid if you see the cutting fluid convective heat transfer coefficient is very high that is a positive. At the same time, easy accessing capability of air being a gas is a positive. So, what we are going to do? We are going to mix forcibly and making the atomised mist; that means, that whatever I am going to get out of these is a atomised mist; that means, that high convective heat, the convective heat transfer coefficient of cutting fluid is carried by these droplet us and is this droplet us or in the gaseous form ok, atomised mist ok.

In this atomised mist, what will happen, convective heat transfer coefficient is retained. At the same time, it can penetrate being a gas into the intricate joules of machining or grinding process ok. So, as we can see, the cutting fluid mist is coming out of the nozzle and it is going in between the work piece and the grinding wheel. So, you are forced convection will be a in these circumstances, what will happen in this circumstances, the forced convection will takes place and the heat transfer will be better so that the performance of this finishing or machining in terms of minimum quantity cutting fluid will be much better compared to flood cooling.

The advantages if you see environmental friendly and green sustainable because you are using very minute quantities of a cutting fluid, no maintenance cost or the waste because here mist goes off. There is no recycling or you accumulating in the cutting fluid tank so that, you have to dump after sometimes. So, there is no maintenance cost because one time use so, you are using it. So, lower thermal shock for the work pieces and tool; that means that since it is a uniform mist which is a gas, since there is no cutting fluid impinging or something in that circumstances, there is no shock and less clogging of wheel grains because the gas is forcibly impinging on to the grinding wheel. In that circumstances if there is a clogging of the material because of this force and because of the lubricity and because of the cooling nature what will happen, this clogged work piece material will come out of the wheel.

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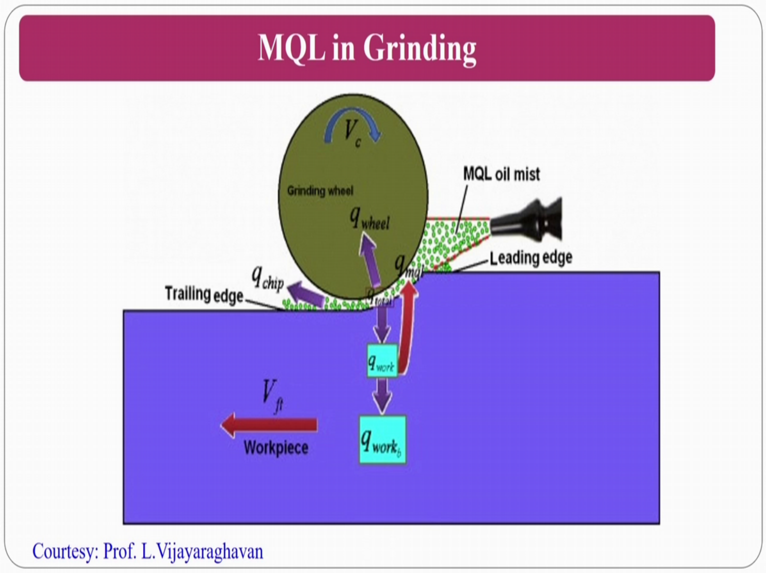

So, if the abrasives are very active because of the clogged material taking out by the cutting fluid, what will happen? The good surface finish and material removal will be taken place. As you can see here, the MQL in grinding, the minimum quantity cutting fluid is coming and it is falling so that the heat which is going out, it will be taken wheat in the chip as well as work and other things. Normally, the basic advantage that you are going to get is the chip loading will be minimum and the active abrasive particles will retain it is original sharpness and the surface roughness and MMR will be much better.

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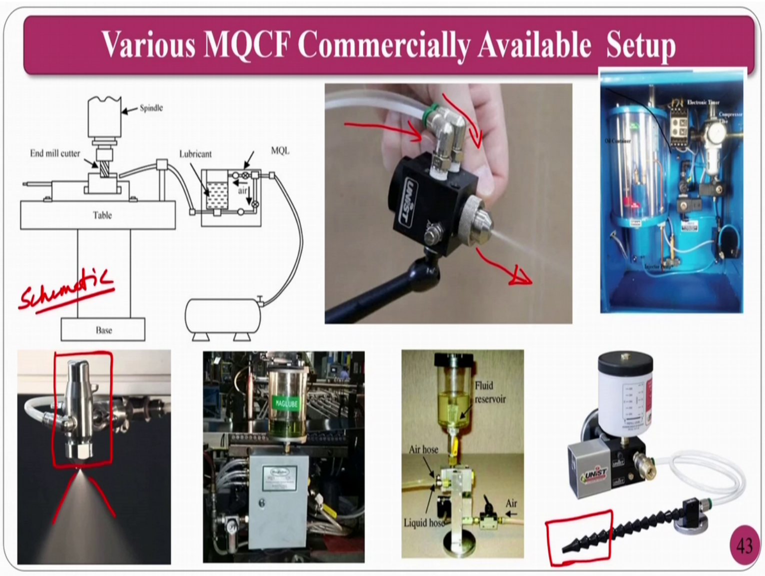

So, commercially available setups; if you see the commercially available setups, this is the schematic diagram ok. So, you can see the mist. How this is a internally mixed mist system is there where you can see the mist is coming in this region ok. So, the cutting fluid as well as the air compressed air is mixing inside the chamber. This is a chamber inside it is mixing, then it is forming a mist, then it is forcefully sent out and now you can direct your nozzle at certain distance as per your requirement and certain angle as per your requirement. These are the some other flexible type of nozzles, you can have the cutting fluid as well as the air and you can mix it and you can send the atomised mist so that you can have a gas that consist of convective heat transfer coefficient of a liquid because you are atomising the liquid ok.

These are another set ups where you can use the systems. It some are externally mixed, some are the internally mixed and different setups. These are commercially available at economic prize excluding the compressor. You have to purchase a compressor, then these are these MQL that is Minimum Quantity Lubrication nozzles are commercially available in the market. Normally in India, you can get at the prize around 10000 or something. So, you can if somebody has interested for doing MQL system for grinding or machining or some other things, you can go ahead with it ok.

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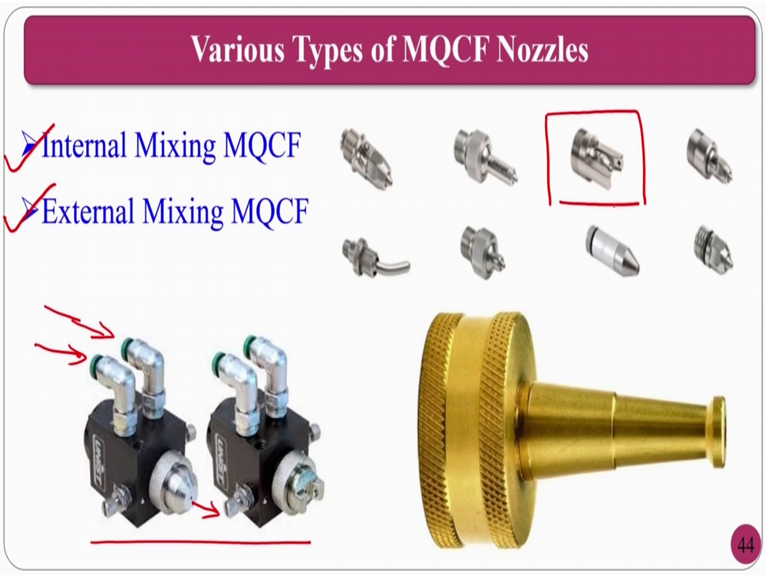

There is other types normally, internal mixing as I said external mixing, what is internal mixing? If the cutting fluid as well as the compressed air mixes within the chamber then comes out. That is called internal mixing. If the cutting fluid and the compressed air is mixing outside the nozzle by the virtue of pressure difference and other things, that is called external MQL or external mixing systems ok.

So, these are the internal mixing systems. You can see here; one input is coming here, another input is coming here, both will mix and come out. This is called internal and some other places you can see here two things are externally like this, they may and they may pass on. So, externally mixed internally mixed and other things can be, this may not be external also because just to explain you, I have taken this particular example.

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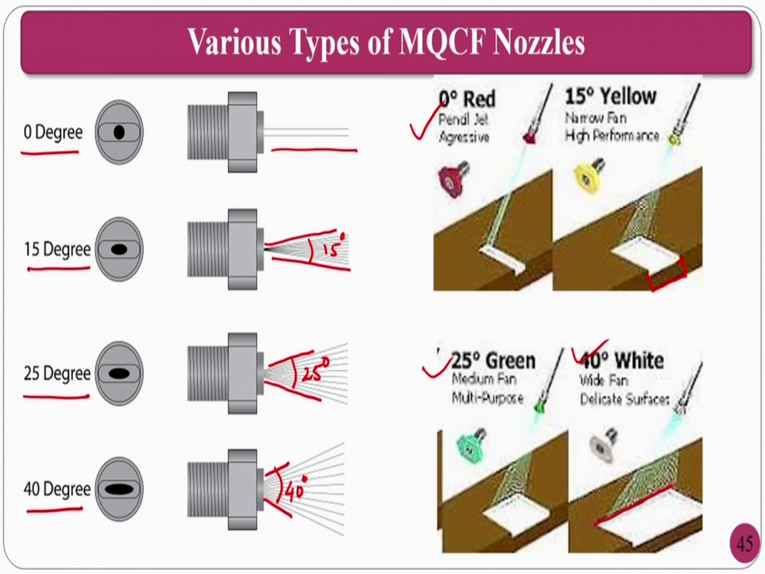

So, you can have your divergence and other things ok. If you see the d 0 Degree; that means, that if I want at a point cooling or a small area cooling, then you can go for 0 degree divergence, then the 15 degree divergence you can have a elliptical type of hole where you can see the maximum range of this will be approximately 15 degrees, then you can go for 25 degrees. The angle of divergence you can go for 25 degrees ok, then you can also go for 40 degrees and other thing.

So, you can have as per your requirement. If you are going for a metal cutting operation, you have to choose one type of nozzle. If you are going for a grinding operation because grinding wheel has it is own width ok; if that width you have to cover, then you have to go for certain shape where it should occupy complete width the thickness will vary. Assume that the thickness he is approximately 20 mm ok. So, you have to cover 20 mm, if it is 40 mm, you have to cover 40 mm. According to your requirement, you can go for the nozzle divergence and other things. Some other things are there normally, 0 red where you can go for a small region, then 15 degrees if you have then you can cover approximately this much region and 25 degrees and 40 degrees. What will happen if you can see at their one stretch, how much space you can cover ok this is the beauty about different.

See, now I am giving you knowledge of this type of nozzles because you have to choose your own nozzle as per your requirement. You may be working on milling, somebody working on grinding, somebody may be working on some other thermal processes and others. I am not talking about laser machining or something. Some of you may be from the design department, some of you may be thermal specialization, some of you may be computational mechanics, if you want to validate the simulations that you have done. So, your requirements person to person will vary as you know taste is varies from person to person, similarly your requirements also vary from person to person.

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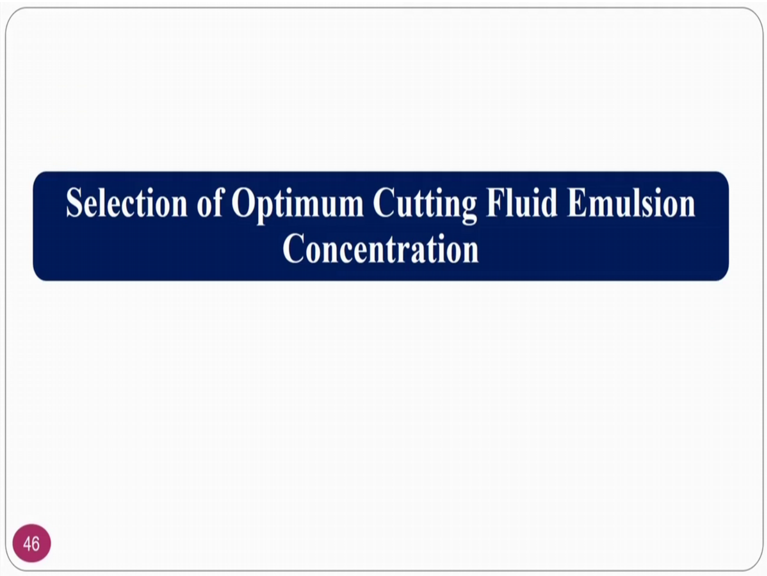

The selection of optimum cutting emulsion concentration ok; so, these also one of the thing; many people, normally you bought it ok I bought in the cutting fluid, just mix with water, no. How much water you want to mix, water is a better coolant; cutting fluid mineral oil is a better lubricant. You have to optimize, you should as an engineer you should have quantity to value, you cannot go for a qualitative things.

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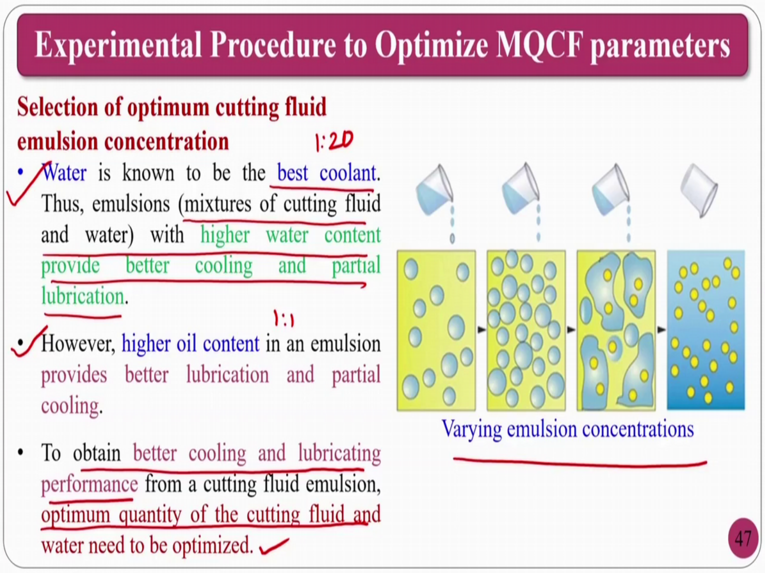

If you see here water, how do you select? Water is well known to be a the best cooling agent, thus emulsions that is a mixing of cutting fluid and water with a higher water content provide better cooling and partial lubrication. If you are going to mix 20 litres of water with 1 litre of cutting fluid, what will happen? Dominating cooling properties will come. If you high have higher oil content in an emulsion, assume that 1 is to 1; 1 litre of cutting fluid, 1 litre of water in that circumstances, you will have dominating characteristics of lubrication.

So, you should not go like that ok in that circumstances, what you have to do is you have to do some preliminary test to find optimum composition ok. To obtain better cooling and lubricating performance from the cutting fluid emulsion, optimum quantity of cutting fluid and water mixing should be done at optimum quantities ok. So, varying emulsion concentrations you cannot go for go by 1 is to 1, you can cannot go by 1 is to 20 so, you have to go for the optimum. How do you find that optimum value? For that purpose, there are sent some standard procedures, see.

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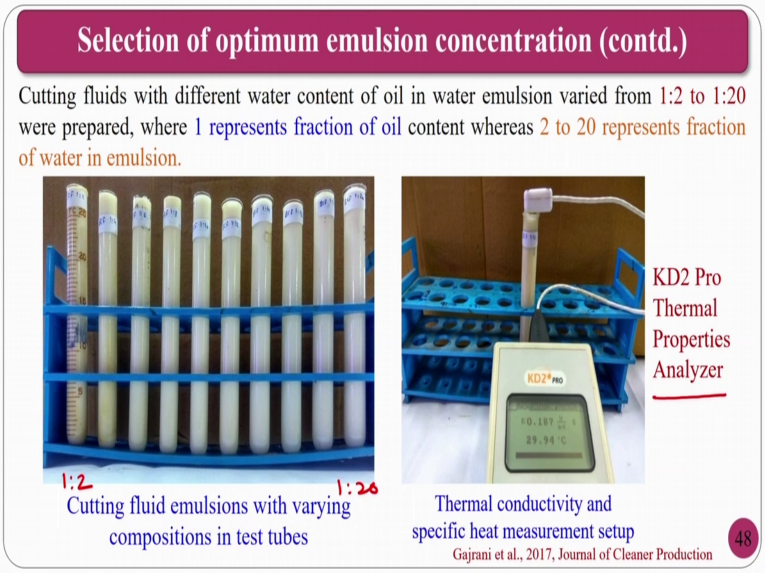

In this particular thing, this is particularly what we have done for metal cutting in the lathe process, but my intention is to show you how you have to optimize. What we have done in this particular thing is, we have varied from 1 is to 2 to 1 is to 20, ok. So, one litre of cutting fluid we have mixed with 2 litre, 4 litre, 6 litre, 8 litre, 10, 12, 14, 16, 18 and 20. With the basic idea, what you can understand, basic concept shows that water is a better coolant. So, 1 is to 20 will be a dominating cooling characteristics at the same time, 1 is to 2 will have better lubricating properties, but do I go for it? No, you have to choose.

For that purpose, what you have to do is first thermal property analyser, what is a thermal conductivity measurement? There is a KD2 pro thermal properties analyser is there where you can find the thermal conductivity of a cutting fluid. Why you have to measure the thermal conductivity? Thermal conductivity if it is very high. Assume that I am doing a machining operation or a grinding operation, if the thermal conductivity of my fluid is very high; that means, that it can conduct more temperature or heat from the machining region or the grinding region.

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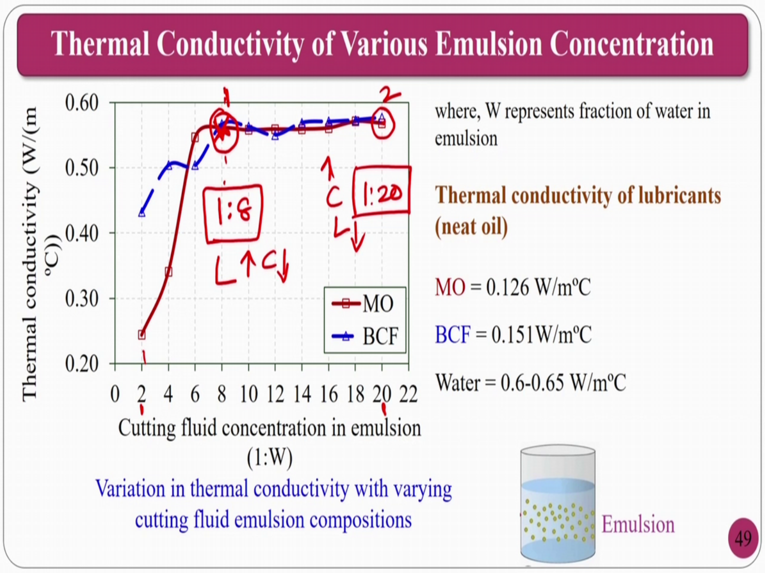

So, you can see the thermal conductivity versus cutting fluid concentration. As the concentration increases from 2 to 20 ok, this is the region 2 to 20 in this particular region what will happen? Once it reaches to 8, this particular point ok, what it is happening? This is the point, what is happening? The thermal conductivity is now stabilized; that means, if you take any cutting fluid composition after 1 is to 8, it is approximately same value of thermal conductivity.

So, from this particular graph, I can say I can go for 1 is to 8 or 1 is to 10 1, anything I can go, but only thing is that if you use 1 is to 8, you will get better lubricating properties because you have 8 litres of water instead of 1 is to 20, if you take this particular point, instead of this point 1.2 here, 1 is to 8, it will be having better lubricating properties. Here 1 is to 20, what will happen? Here, it will have better cooling properties. Here, cooling properties are less, lubricating properties here all less, that is the beauty. So, you can choose any value in between 1 and 2.

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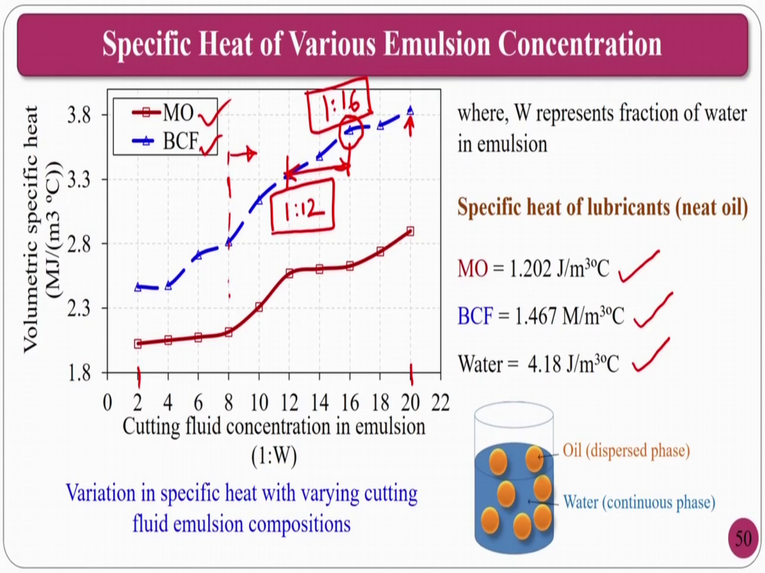

The second thing is to measure volumetric specific heat. This also will give you how much specific heat is it is taking out from the machining region. So, the same composition 2 to 20, we have done and you see for the bio cutting fluid and mineral oil which you have seen in the previous class, the compositions mineral oil is basically the petroleum product, bio cutting fluid is basically a vegetable oil which is commercially available ok. So, in this circumstances, the maximum amount of what you can observe is 1 is to 20 because water is a better cooling ability.

At the same time, if you take 16, so it is approximately after 16 there are change in specific volume rate; volumetric specific heat is very less. That is means of from the previous curve, what you can understand is thermal conductivity curve after 8, you can take any particular value ok. So, you have to compromise lubrication, you have to compromise cooling in that circumstances, if you can go for 1 is to 16, that will be a better composition because you can go for 1 is to 20, but the thing is that lubricating properties will be less.

For example, this is particularly for the single point cutting cooler, machining process. If at all people want to go for the grinding operation, they can go approximately 1 is to 12 or something because you require better lubricating properties also. So, a person can go in between 1 is to 12 to 1 is to 16. That is best range for a grinding operation. You can see here, specific heat of the lubricants mineral oil is 1.2 and bio cutting fluid is 1.4, water is 4.2 approximately. In that circumstances obviously, water is a better one, but you have to compromise or you have to optimise cooling and lubricating properties. That is why, you should go in between 1 is to 12.

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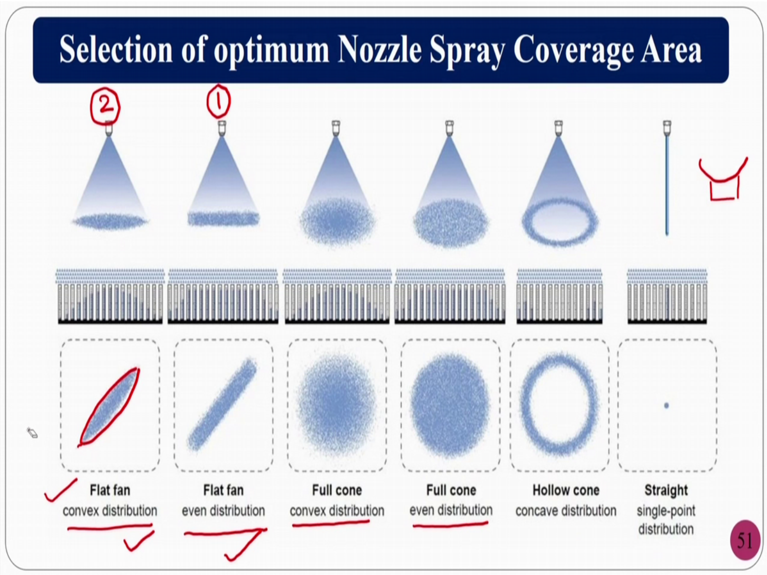

Now, you have optimised the nozzle internal mixing or external missing, both are good. So, you have optimised the composition. Now, you have to choose which type of nozzle you required for covering for your application. The flat pan normally, you will have a elliptical type of thing. Flat fan, even distribution, normally flat fan convex distribution, you will have convex distribution. In the in the other case, you will have a even distribution, then can full cone with the convex distribution, full cone with even distribution and other things.

Since we are bothered about grinding process, grinding process will have a wheel like this which you will have a contact approximately this type of things. So, you always go for flat fan even distribution or if it is not available, you can go for flat fan convex distribution also you can go. But, preferably second one is a first preference first one is a second preference, ok. So, flat fan if you can go and it will give you better results. For single point cutting tool, people should go for the flat fan with convex distribution because your area of contact in the machining region or in the in the cutting tool normally chip tool interface and other things will have a elliptical shape and other things.

If at all you want more details about this one, I have already taught an another course, introduction to machining and machining fluids where this also is explained and I am just giving glimpse here ok. You can go through that course it is available on MOOCS which is recorded at IIT Guwahati. I am very thankful for IIT Guwahati giving me that opportunity. So, in a metal cutting, you should your option should be the first one that is for metal cutting or single point cutting tool, you have to go for convex distribution in the grinding, you have to go for even distribution.

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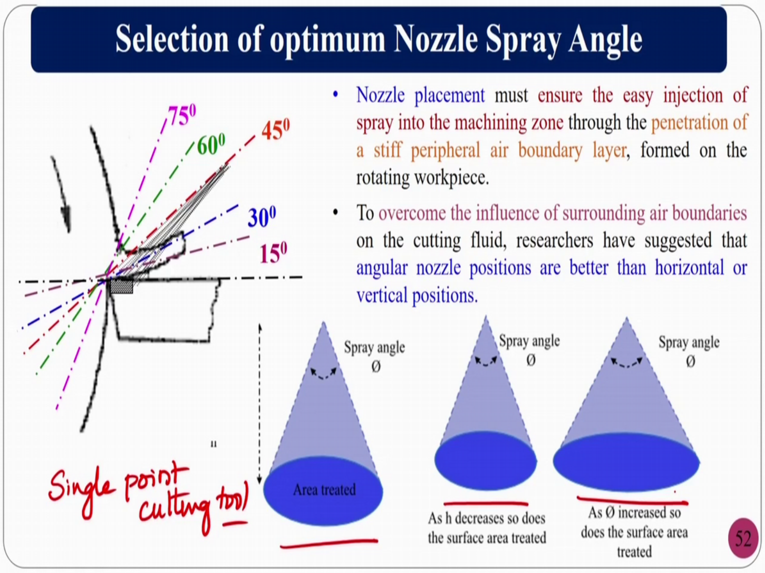

The selection of optimum nozzle, spray angle for a machining you can go for approximately 45 will be the better as you can see single point cutting tool here where you require always elliptical type of per area you which has to cover and if at all you want to go for the grinding operation, the grinding wheel structure will be completely different from the single point cutting tool. So, the better would be like 30 degrees or even you can go for 15 degrees, you can go for 45 degrees, but if this may lose some of the velocity that is carrying. That may help you in terms of the dressing the wheel; that means, that you taking out of the loaded work piece material in the form of chips, if the structure is open, ok.

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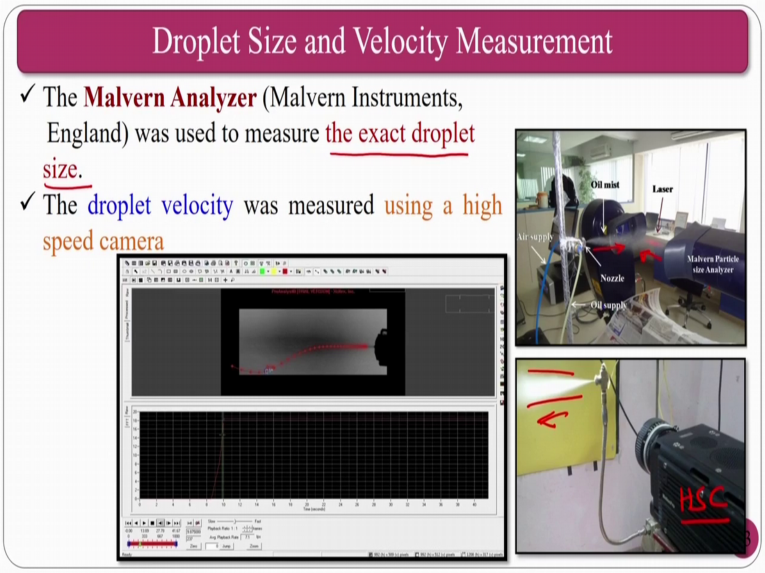

So, people nowadays doing some of the simulations, experiments on how whenever compressed air and cutting fluid both are mixing, both in that circumstances or the droplet is for, what is the droplet size, what is the droplet velocity and other things. We have taken some of the things from our colleagues who are from IIT Madras professor I Vijaya Raghavan. So, courtesy to him for sharing his slides so, what they have done is Malvern Analysis is one of the used use to measure the exact droplet size and the droplet velocity was measured using high speed camera.

In this particular thing, what they have do is Malvern particle size analyzer is kept here, this is the Malvern particle analyzer you can see, you can see a laser light is coming here, laser light is coming. And the particles oil mist particles are coming so, it can measure the droplet size. At the same time, high speed camera is there and it will measure what is the velocity of the jet ok. So, at the same time, they have already simulated what is this is experimental measurement is there, then also people can do computational fluid dynamics to measure various things that required or to validate the experiments.

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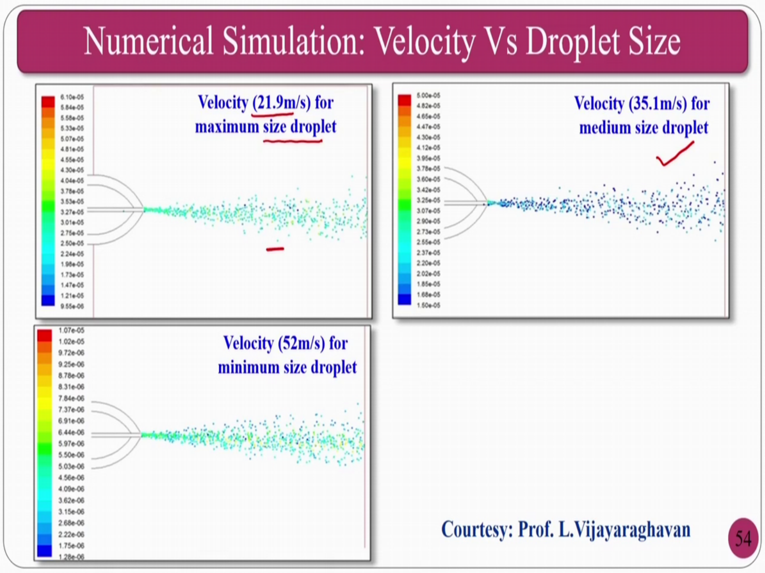

So, numerical simulation, the people they have done velocity versus droplet size. If the velocity is approximately 21.9 meter per second, the maximum size of the droplet, you can see the droplet size. Here is the droplet size is this much, if you are increasing to 31 point, 35 approximately you are going to get a medium size. If you are going to increase the velocity that means, that how we increase the velocity, your cutting fluid is constant, your supplying cutting fluid.

So, you are increasing the velocity of your pressurized jet. If you are increasing the pressurized jet, mist formation is taking place. As the pressure increases what will happen, it will shear the cutting fluid into droplets micro droplets nano droplets and other things. So, at the same time it will send that is how the pressure in the velocity increases, at the same time droplet size decreases.

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Grinding Fluid Mist Droplet size on Forces and Temperature

Pressure (bars)	Flow rate (ml/hr)	Droplet Diameter (µm)	Cutting Force (F_x)	Normal Force (F_z)	Surface Roughness (R_a)	Temperature (°C)
2	60	23.7	25	143	0.507	533
2	80	12.9	23	117	0.327	423
2	100	7	21	103	0.337	273
4	60	18.3	27	121	0.349	406
4	80	7.5	28	72	0.23	201
4	100	4	27	105	0.345	167
6	60	16.3	26	42	0.128	210
6	80	6.8	43	133	0.323	485
6	100	2	30	93	0.371	156

Courtesy: Prof. L.Vijayaraghavan

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You can see here the pressure is 2 bar and flow rate is flow rate means cutting fluid how much you are pumping per unit time. So, you are 60, 80, 100 similarly, droplet diameter if you see 23. If the flow rate is increasing, it is also decreasing ok. It is same, similarly 4 and the same thing they have increased 60, 80, 100, similarly 60, 80, 100 for 6 per pressure. The cutting forces, normal forces, surface roughness improvement at the same time temperature.

In the better temperature is achieved in the this condition where if you are achieving the minimum temperature; that means, that the metallurgical changes of that work piece is very less; that means, that it is very good for the proper machining is taking place in that particular region.

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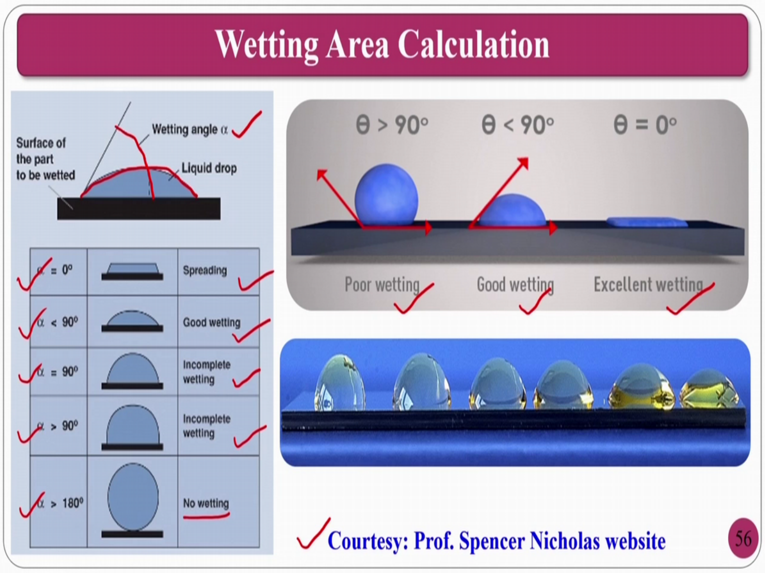

Wetting area calculations; wetting means normally you might have seen super hydrophobic. I have already explained you what is super hydrophobic, hydrophilic where hydrophobic means fearing. So, when I have the leaf lotus leaf is there particle will be there and it will goes off because it will assume that it will fear ok, to understand in a better way where alpha is 0 that is wetting angle is 0 which is it is called spreading. Alpha is less than 90, good wetting, alpha equal to 90, incomplete wetting and again greater than 90, it is incomplete and if it greater 90, no wetting.

So, this is how you can make normally, whenever you have a droplet like these, this particular angle which is making with respect to surface is nothing but the wetting angle. As I said, if it is angle is theta is above 90 in the figure 2, poor wetting and the good wetting and excellent wetting if theta is 0 degrees ok. This is taken from professor Spencers and where a graded he has done some texturing on the surfaces with a grading wet ability ok.

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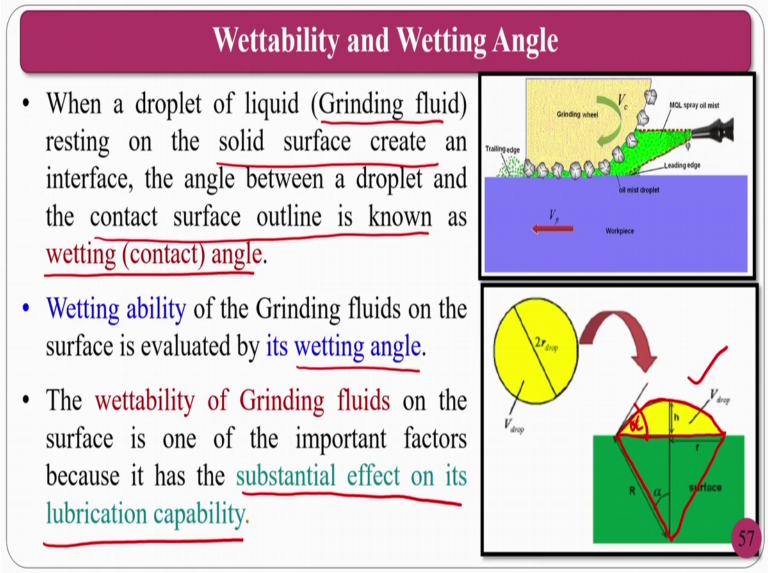

The wetting angle will be calculated when the droplet of a liquid which is nothing but a grinding fluid resting on a solid surface to create an interface, the angle between droplet and contact surface outline is known as wetting angle or contact angle. This is the droplet and this is the contact angle, alpha.

So, wetting ability of grinding fluid on the surface is evaluated by wetting angle and the wet ability of grinding fluids on the surface is one of the important factors because it will substantially effect on it is lubrication capability because if you see, if this much is occupied what will happen? This is the how you can calculate the area contact area of that particular fluid whenever it is spread on a surface or whenever you are putting on a work piece surface. If the wetting ability is very good, it is spreading is very good; that means, that it can easily cover the surface so that the lubrication will be proper.

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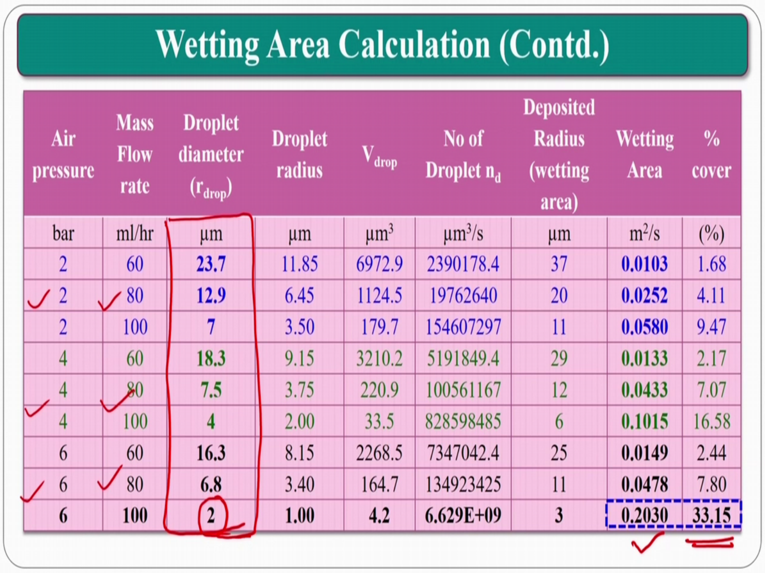

Wetting Area Calculation (Contd.)

Air pressure	Mass Flow rate	Droplet diameter (r_{drop})	Droplet radius	V_{drop}	No of Droplet n_d	Deposited Radius (wetting area)	Wetting Area	% cover
bar	ml/hr	µm	µm	μm^3	$\mu m^3/s$	µm	m^2/s	(%)
2	60	23.7	11.85	6972.9	2390178.4	37	0.0103	1.68
2	80	12.9	6.45	1124.5	19762640	20	0.0252	4.11
2	100	7	3.50	179.7	154607297	11	0.0580	9.47
4	60	18.3	9.15	3210.2	5191849.4	29	0.0133	2.17
4	80	7.5	3.75	220.9	100561167	12	0.0433	7.07
4	100	4	2.00	33.5	828598485	6	0.1015	16.58
6	60	16.3	8.15	2268.5	7347042.4	25	0.0149	2.44
6	80	6.8	3.40	164.7	134923425	11	0.0478	7.80
6	100	2	1.00	4.2	6.629E+09	3	0.2030	33.15

And you can here clearly see here same thing, 2 bar pressure and mass flow rate 4 bar pressure mass flow rate, 6 bar pressure mass flow rate, the wetting area droplet diameters, you can see the droplet diameters. If you are going to increase the pressure of the air normally, droplet us size will go down and mass flow rate also increases this. The droplet diameter is minimum in 100 millilitre per hour and 6 bar pressure, at the same time wetting area is high; that means, that percentage of wetting area is 33 percent ok. As I said if the droplet size is very less, it can enter it can penetrate at the same time, it can spread easily on the surface.

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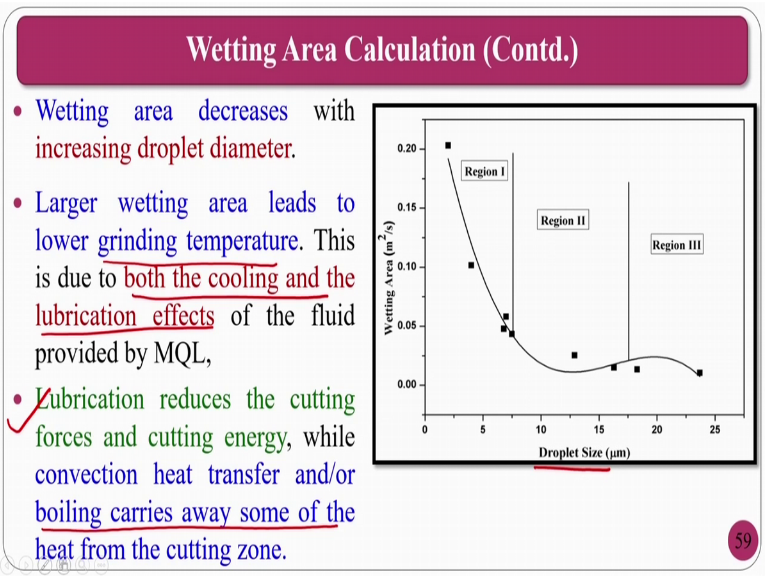

You can see here, droplet size variation with respect to wettings are wetting area as the droplet size decreases, the wetting area increases. The larger wetting area leads to lower leads to lower grinding temperature because it can easily take out the temperature. Not only based on the wetting, it also because of it is size ok. Surface area of the droplet will increase if it goes to nano size, both. Then, what will happen? The cooling ability as well as penetrating ability will increase at the same time, if it is nano believe me that it can penetrate between the loaded chip in the abrasive successive abrasive grains so that, it can deload the chips.

The lubrication reduces the cutting forces and cutting energy while the convective heat transfer and boiling carries the some of the heat from the cutting zones; that means, that it will improve the performance in all respects; on the temperature point of view, from the surface roughness point of view and cooling point of view, lubricating point of view, all point of view. It will be very good ok.

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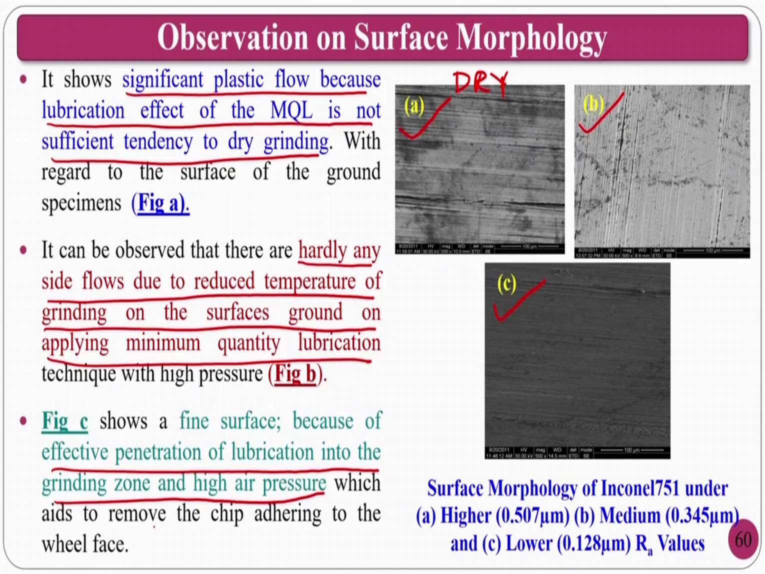

Now, we will see the practically what is happening in the figures ok. Whenever, you are going to give better cooling or the big droplets, whenever you are going to give the small droplets or minimal droplets minimal size droplets, what will happen? Significant plastic flow because of the lubrication effect of MQL is not sufficient tendency in the dry grinding because a will show the dry grinding of inconal surface. It is observed in the b, this is one done because it is done the dry grinding.

In the second one, hardly any side flow is due to reduced temperature of grinding surfaces on applying the minimum quantity lubrication, figure b is completed; figure c because of the effective penetration of lubrication into the grinding zone and the high pressure, it is aids remove the chips adhering and other things ok.

That means that compared to dry grinding your minimum quantity and the cutting fluid utilization will be always good. That is what the conclusion from the practical point of view. These are the scanning electron micro surfaces which are done on a inconal surface which is a super alloy for a in a grinding application and they are observing how the grinding marks are there, how the morphology is changing the dry wet and MQL.

Summary of this class, what all we have done? We have two solutions; one is biodegradation of the cutting fluid, another one is using the minimum quantity cutting fluid ok.

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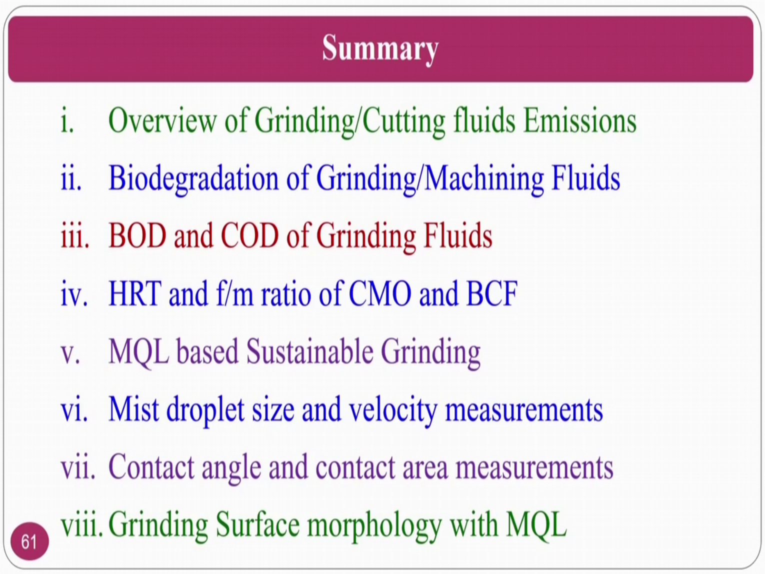

This is we have studied in this particular class and overview of grinding and cutting fluid emissions, Biodegradation of Grinding fluids, BOD, COD, HRT and f by m ratio that is food to microbes ratio and other things, we have done for the commercial mineral oil as well as bio cutting fluid, MQL based sustainable grinding, we have seen and mist droplet size velocity measurements and simulations, we have measured the contact area by the cutting fluid in the form of mist and other things, we have seen and grinding surface morphology in minimum quantity cutting fluid and grinding.

This is about the sustainability of grinding process, ok. So, hope you understand what is a importance of cutting fluid positive side, but it has also negative side. So, to avoid this negative sides we have to find some solutions as an engineers and these solutions are two; one is biodegradation that means, that you have to treat with cutting fluid before you are dumping into the landfills or before you are dumping into the nearby water bodies. Otherwise, if you cannot do that one, you can go for minimum quantity grinding fluids where you use minimum amount which is required and you are pressurizing with high pressure jets.

So, force convection will takes place and particle sizes are very small and contact area is very good. So, lubrication and cooling will be done and forced convection will be done compared to your conventional flood cooling where free convection will be taken. So, forced convection is better than free convection. So, the heat transfer in the grinding zone will be very high. This is about the sustainability and some of the basics of the grinding, ok.

Thank you for your kind attention and I will see you in the next class.