BioMEMS and Microfluidics
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Lecture – 31

Hello and welcome back to this 31'st lecture on Bio Micro Electrical Mechanics System is to quick preview of what we did on the last lecture.

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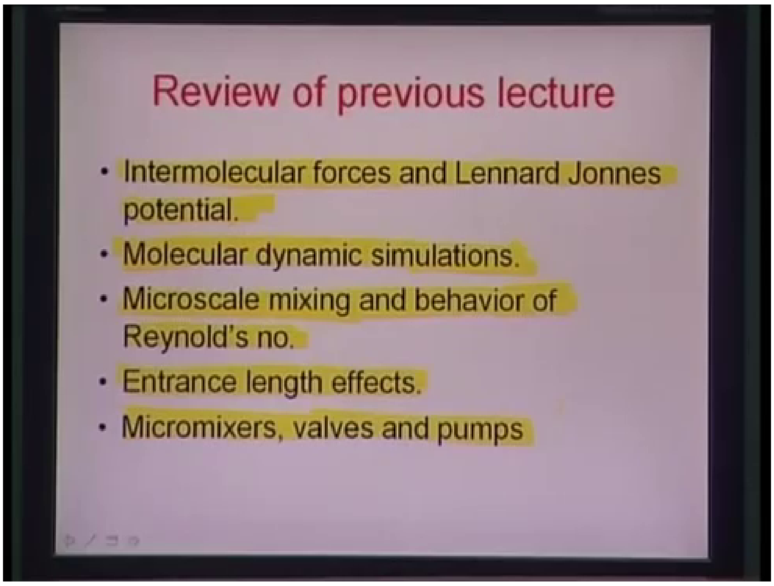

So, we talked about intermolecular forces and Lennard Jonnes potential model, molecular systems if marry call two molecular systems I and J separated by the distance R would defined, where we try to find out what the potential is between I and J in terms of an energy scale and the ratio R by sigma, where sigma is distance scale, R is the intermolecular distance or this is the separation between I and J.

And so we got an expression 4 epsilon energy scale times are value by sigma to the power minus 12 minus R by sigma to the power minus 6, where the first term would correspond to the pair wise repulsion between the electrons and the outer most cells both systems and the second term would actually be weak vendor wise forces of attraction between the nuclear another one with the electron and the other particular system.

We also try to derive the forces between the two systems I and J, where take the negative grade of potential and this would essentially be again in terms of an attractive force and repulsive force we studied in these context of several diatomic gases Some other gases systems including CO_2 and air and then try to determine the energy scales in terms of energy per unit temperature or energy per unit Boltzmann constant and distance of separation in nano meters.

And then we also saw that if we plot such systems will have typically or potentially well which exactly the repulsion and attraction would be same and beyond which the attraction would predominate over some distance until there is a reversal and the repulsion again became strong. So, we also talked about molecular dynamic simulations which means essentially trying to simulate Newton second law $m\frac{md^2r}{dt^2}$ with respect to the total amount of forces based on the negative grade of the Lennard Jones potential and there we also defined a cut of radius to simplify calculations of truncate calculation. So, that they may not just go infinitely and may have a converge solution.

So, essentially wherever the continuum assumption phase Navier stokes is replace by the empty simulation models and this was followed by a brief discussion about micro scale mixing behavior of Reynolds numbers and different scales and it is change from laminar to the transition region to fully turbulent flow, we talked about entrance length of x particularly in case of micro channels about 60 percent the hydraulic diameter and small Reynolds numbers and then we started discussing in details about micro mixers valves and pumps.

So, we like to proceed head on this node I would just like to retreat that micro scale mixing is essentially all diffusional which is based on either the interfacial area or by somehow to deducing the diffusion time. So, when we talk about reducing diffusion time there is mostly there are some mostly architectures which would come into the category of passive mixing.

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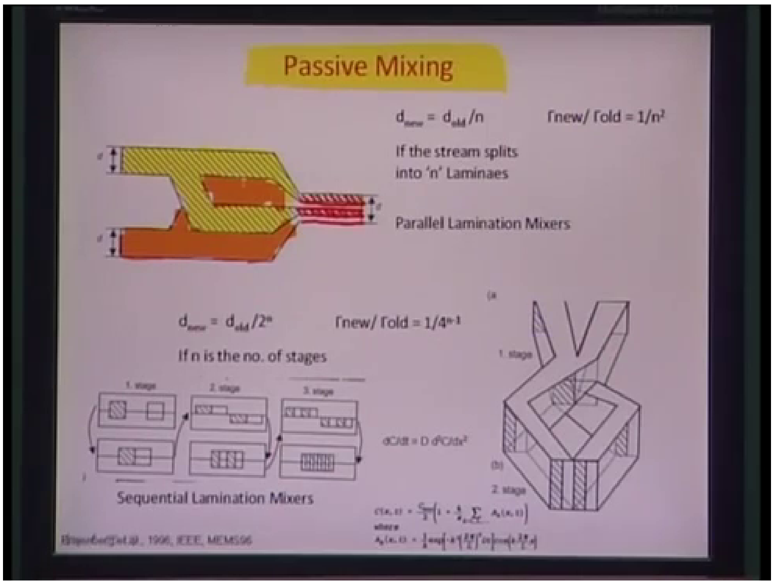

$$d_{new} = \frac{d_{old}}{n}$$

$$\frac{\Gamma_{new}}{\Gamma_{old}} = \frac{1}{n^2}$$

$$d_{new} = \frac{d_{old}}{2^n}$$

$$\frac{\Gamma_{new}}{\Gamma_{old}} = \frac{1}{4^{n-1}}$$

So, therefore, in such mixers there is no mechanical part. So, essentially it is non mechanical and passive means that there is no energy supply essentially. So, you have to just by intelligent architecture design let me flow have a reduced diffusion time and one way doing it really is lamination and as you all know from before lamination is essentially thin lamination of different type of fluids tacked against each other.

So, if you have a green die and water sample which is moving pass the channel these are two laminas essentially and if I can some house split these flows apart and bring them together in a manner that we can have 4 laminas from 2, 8 from 4 so on so forth what is reducing here is a laminas sides. So, the effective diffusion length which is between the water and the die reduces to d by 4, d by 8 so on so forth.

So, let us look at this example here, so you have a case where you are actually splitting apart at two flows. So, there is this channel here which are marking through this yellow highlighted, which is filled up with die and let me just clear this region. So, this is filled up with die it is also represented by the hatched area and we have this other channel which is represented by let say this brown color, which is essentially of a different nature. So, this goes here, this essentially goes into this region.

So, in this particular region though if you see there are four laminates, if you look at this region closely there are four laminates, there are two of the hatched sections and two plain areas so there are four laminates essentially. So, let us look at how you do that. So, you have two plains essentially, you have a plain which is flowing below and other the die here which is a shown or the in white.

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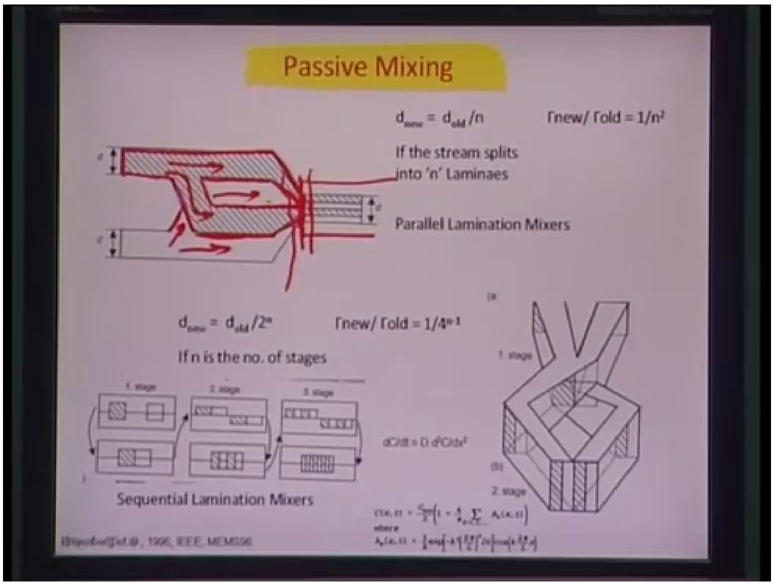

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So, the die here which is shown white is at a bottom plain is set bottom plain and the die which is shown by the hatched is at the top plain and these two dies flow on the top of each other up till an extend when they are able to converged into a small channel. So, that you make sections in a manner that let say you are split up this top region, you know split up this top region into two channels as you can see and you have similarly split up the bottom region again into two channels, one here go in this direction and another here going this direction, the top region is one here going this direction, another going this direction.

Now, what you do is you take all these together here and rapidly converge it into a smaller section in this particular region. So, you are converging rapidly into this smaller section here however you are converging into in a manner all the four channels have their die outlets getting converge here. So, what is essentially results is that you have from two from the bottom and two from the top made in a manner that you have an alternate one from bottom, one from top, one from the second one from bottom and the second one from top lay out parallel to each other.

So, you are stacking the two dies on a smaller channel so I call it lamination. So, we are trying to laminate, if you remember from your composites lectures laminates are essentially layer by layer. So, you have one layer of fluid of type one secondly, another layer of fluid of type two then another of one and another of two and you are trying to laminate the flow into pieces. So, the advantage here is many folds let us look at some of the advantages that you automatically get out of this.

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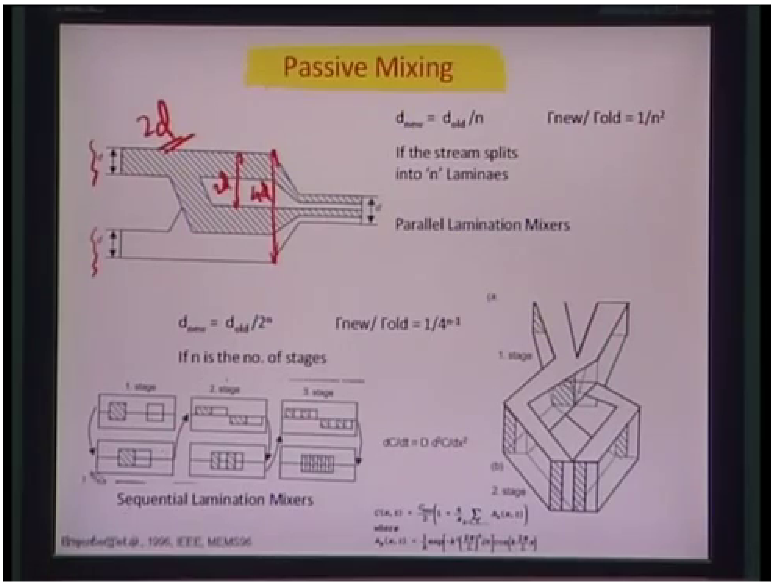

So, if you look at the diffusion length here really the diffusion length is essentially d plus d that is 2d the diffusion length here as you are seen this is d and this part is d. So, it is 2d and so basically this whole area is nothing but, 4d. So, and this particular diffusion length here is 2d.

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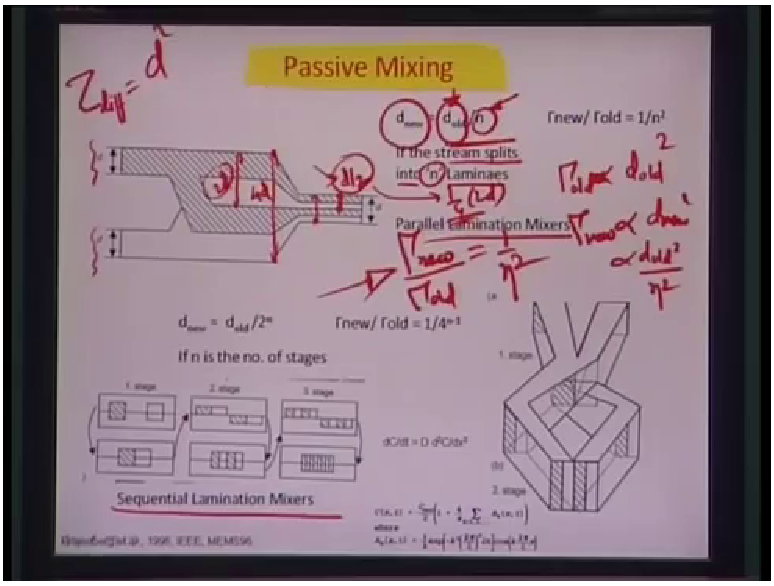

$$\Gamma_{old} \propto {d_{old}}^2$$

$$\Gamma_{new} \propto \left(\frac{d_{old}}{n}\right)^2$$

$$\frac{\Gamma_{new}}{\Gamma_{old}} = \frac{1}{n^2}$$

$$d_{new} = \frac{d_{old}}{2^n}$$

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Now, the length actually changes to d by 2. So, from 2d length you are changing to d by 2 and so effectively what is happening. So, the diffusion length which was 2d got change to d by 2 which is actually 1 4'th of 2d so this is 1 4'th of 2d. So, the diffusion length is changing as a function of laminates. So, if you are laminating four, times the diffusion gets reduced by the old length by the number of laminates, similarly if it was eight times the diffusion would get reduced by 8 and so on.

So, therefore, what you are essentially doing is you are trying to split up the streams into m laminates whereas, where the new diffusion length, where you see this is d by 2 and this is

2d. So, is equal to the 2d which is the old diffusion length divided by the number of laminates. So, very, very interesting phenomena. So, what is the conclusion of all this, the time of diffusion as you already know from our previous descriptions is proportional to this square of the diffusion length.

So, therefore, if there is a transfer length between two flows which are flowing in a channel, the cross sectional length actually is the diffusion length in that case and the flow is the diffusion time is proportional to square of that particular length. So, here if you see the time old was actually d proportional to d old Square and the time t new is not proportional to d old or d new square, which is actually proportional to d old square by n square.

So, therefore, the new time is lesser than the old time by the factor of n square. So, definitely it is an advantage, because the new time of diffusion reduces by a factor of the square or the number of laminates that you are packing in a small section of the channel. So, that is also known as a parallel lamination mixture that is how technically it is defined, because you are actually in a same plane parallel laminating the flows in to several laminate.

And you can actually try to introduce these flows in a manner, where you can do it sequentially. So, if you try to split it a part n times and take it back again in a three dimensional manner the new can do it sequentially. And so that is how sequential, lamination, mixture comes out to be as you see the ratios there between the diffusion new the time of diffusion new and the time of diffusion old would be quite different than that in the parallel lamination case.

So, let see what the sequential lamination mixer you look like. So, here let suppose you have two flows and this flows are parallel if flowing through a small channel like this. So, what you do is you divide the section of these two flows half and half and one half you take up the plane and another half you take down the plane. So, is now a three dimensional situation and then you mix them together back into a similar plain that in a different manner. So, let me just look at in this way. So, let just look at through a more clear illustrations.

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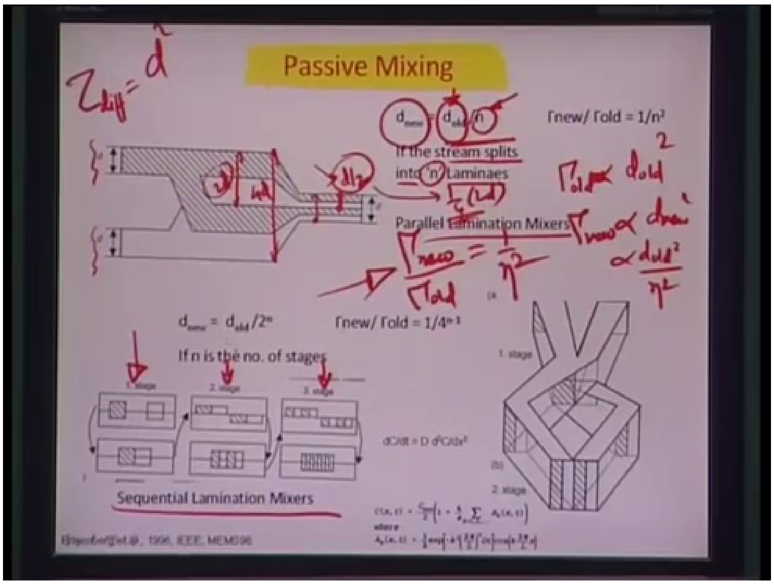

So, let suppose you have a case here, where you have a one channel cross section in the center with two flowing dies let say you have a hatched die, which is probably by green die and water here. So, what you do is, you split this flow into two parts so this part you take up here on this particular plain, this is a different plain. So, you have half and half here and this other part you take in a different manner in a plain which is at the bottom.

So, as I told you we essentially taking one on the top side and another on the bottom like this and here this again is hatched and a plain die and then what you do is, you take these back into the same plain and mix them together. So, you have partly flows coming like this, in partly flows coming back from here into the same plain. And so essentially you have a half hatched half water and other half at hatched and other half water, but now what you have done is from an initial two laminates i you have spitted into four laminates at this sequence carries on. So, you have one channel which is half of the main channel which goes in the plain down another half of the channel being protected in the plain up and then you are coming back again into the same area, where you are actually laminating these half and half into 4 and then 4 into 8 and 8 into 16 and so and so forth. So, this called a sequential lamination mixture.

So, here you can see the difference stages at stage 1 you have from two which generates into 4 in stage 2 you have splitted up and you are mixing it together this 4 in stage 3 or mixing it again and into 8 so on so forth. So, here if you consider at the way this the lamination happens then the d new.

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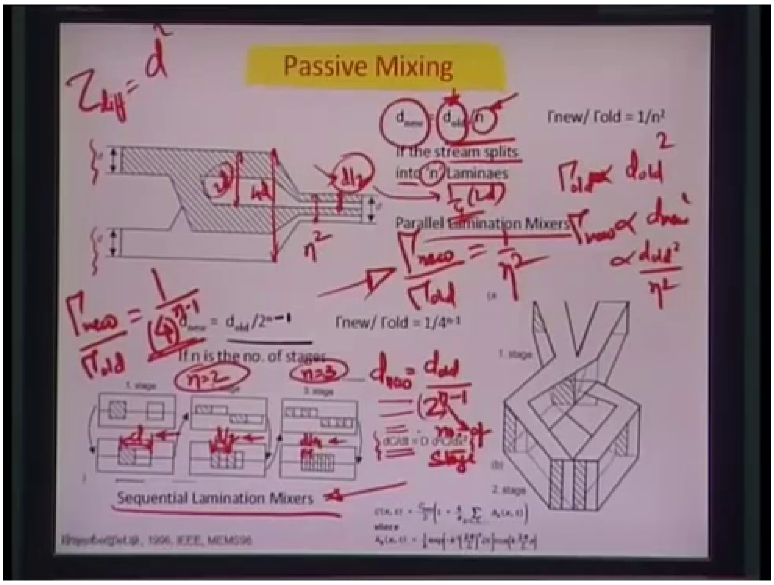

$$\Gamma_{old} \propto d_{old}{}^{2}$$

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So, the d new is equal to the d old and divided by 2 to the power n minus 1 let me just explain this little bit more here. So, that for the common you know reference say. So, let say we beginning this here with let say the diffusion length d here if you see here the diffusion length between these two hatched die and the water sample if d, if you see here in this particular instant after that second stage has been crossed. So, n is equal to 2 here in the second stage, the d actually becomes d by 2 the diffusion length is only related to half the length between the two hatch dies and water sample so d by 2.

In the third case when n equal to 3 and then the diffusion length actually further becomes d by 4. So, the equation which can fit all this that the d new is actually equal to the d old divided by 2 to the power of n minus 1, where n is the number of stage. So, essentially if n is 2 here d new should be d old by 2, 2 minus 1 n minus 1 is 2 minus 1 is 1, if it is 3 here d new becomes d old by 4 so on so forth.

So, it pretty much matches with or the physical dimensions that we have been showing the different stages of mixing. One more interesting thing here is that of course, if d new and d old are related by this 2 to the power n minus 1 are relationship the time new in this case should be actually 1 by 4 to the power of n minus 1 times of the time old. So, for the initial n's the one which earlier kind of mixers the parallel lamination mixtures showed n square relationship changes to 4 to the power of n minus 1.

So, in the concept and the fabrication mechanism and the whole mechanism of laminating the flow is totally different in both the cases. So, this is also known as sequential lamination mixes. So, the idea is that was the d smaller the rate kinetics and the diffusion model can be represented by the temporal variation of concentration dc by dt being proportional to this second derivative of concentration with respect to x. So, you have this relationship dc by dt equal to diffusion constant d times of d2 c by d x2, where x is the diffusion path length, the cross length of the two flows, the cross sectional length of the two flows. So, there is was sequential lamination mixes typically do. Now, micro mixers based on the way that they are able to promote mixing can be classified into passive and active mixers.

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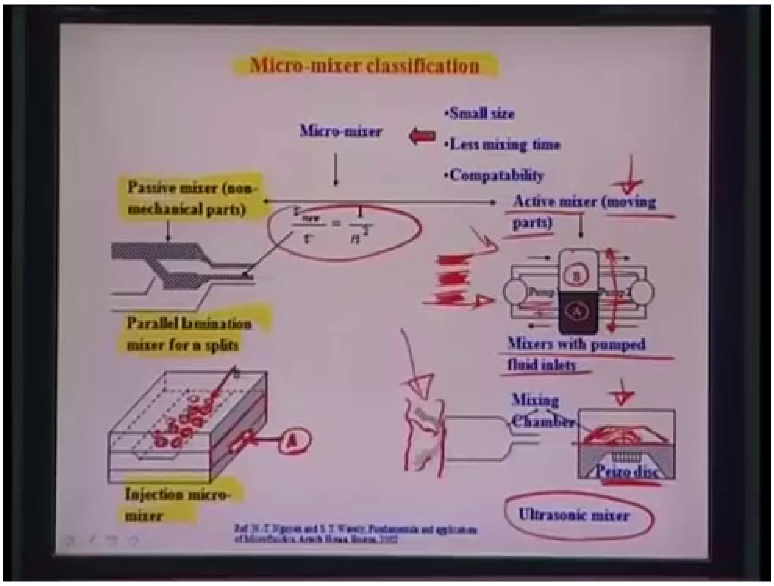

Passive mixers are essentially by intelligent design, where there are absolutely no mechanical parts or no energy that is being supplied. So, several different types of mixtures coming this category or the parallel and lamination mixtures, where either you split the flows using you know parallel sequence and stack the laminates close to each other whether by going in plain out of plain or going in the same plane that could be one mechanism of mixing and another mechanism could be injection based mixture here as very simple mechanism as you are seeing there are two channels. So, there is a channel which is pointed out by this area in the lower stack or lower layer of the stack, which is called A, this is one channel and the top channel is in the second portion of the stack which is called channel B and there are these small capillaries drill in this channel B. So, that when you flow material A there is an oozing out of A into the channel B.

So, essentially you are forming micro globalize of by A within the flowing die d and all you are doing here is increasing the cross sectional area. So, that the mass transport goes up at a certain flux level and because of the higher mass transport and more prominent diffusion mixing happens quicker. The other category is mixture or active micro mixtures, where you supplied some kind of energy by either mechanically moving part or as we see in some illustrations and we have been seen before also some electrically induced mixing in scattered out or magnetic field in the use mixing scattered out.

So, some of energy has to be supplied to active micro mixtures that is the way they are defined let suppose this particular illustration is an example of mixtures with pump fluid inlets. So, you have fluids A and B here and this also known as a kinetic mixture. So, what you do is you take two pumps here, pump one and two and then pump excepts from fluid A into this field of B and excepts from fluid B back into the stream of A. So, you are essentially creating laminates so this is the black layer, this is again the white layer, this is the black layer again this is the white layer and so on and so forth.

So, you are creating laminates throughout this cross section here as you are seen by repeated pumping and that again creates smaller length of diffusion and the time of diffusion again reduces, because of smaller length of diffusion. So, that is kind of kinetic mixture which comes in to the activeness category, the other kind of mixture is ultrasonic mixer as you seeing here is another active mixture.

So, here there is a channel at the top which has two fluids flowing past each other, like mentioned here. So, this channel here is showing the two fluids inlets of different colorations, passing through somewhere in this particular channel and there is a peizo desk at the bottom which vibrates and that is creates perturbations and deformations between this two layers. So, that there is a mass transport enhanced by this peizo effect the thousands of bubbles actually generated and this principle is also known as cavitation.

So, whenever there is a vibrating surface which is vibrating at a very high frequency and there is a fluid in contact with this surface that is a tendency of the fluid to lag the motion of the plates, the plates moves forward and backward much more rapidly than the fluid can actually respond. And therefore, there are almost always vacuum traps which are created and the air from the diffused air of the diffused mass of air in the liquid actually comes into this trap and this results in formation of thousands of bubbles that is called cavitation.

And the bubbles come upwards and then try to because they are lighter in way because of the Archimedes' principles they would come to the top and so this bubbles are essentially responsible for all the transportation, because this bubbles would create differential pressure zones within this small interface of two mixtures that would create a huge amount of mass transport based on that. So, that is what another kind of active mixture be categorized as this called ultrasonic mixer. So, primarily again the basic classification of micro mixtures or a basis of whether they have energy supplied for mixing of they not have energy supplied mixing.

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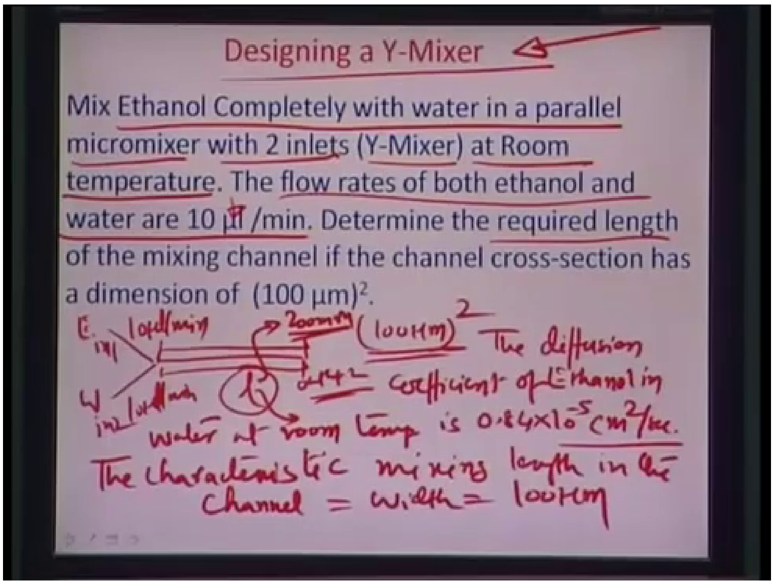

So, I would like to now do a small example numerical example we want to design a wide mixture. And here the task is to mix ethanol completely with water in a parallel micro mixer with two inlets and this Y mixer. So, you have ethanol coming from one water coming from another let say is mixing along this channel here length and this mixing is totally taking place at room temperatures. So, you do not need to consider the energy equation here and the flow rates both ethanol and water are both 10 micro liters per minute each 10 micro liters per minute from both sides.

And so we have to determine the required length here l of mixing channel if the cross section has 100 microns square; that means, it is actually you are 100 micron by 100 microns square section, which is the cross section of this channel and we need to determine the length. So, what do we have to really consider here, one is the critical factor of what is the time of diffusion and with this kind of a velocity, the idea is the fluid should be able to contain it is self at least for time equal to the time of diffusion for you know the diffusion to happen properly before the fluid manage from the other end of the micro mixer. So, these are the various inlets, inlet 1, inlet 2 and this is outlet.

And so therefore, the length also which is traverse by the fluid is diffusion time times of the velocity of the fluid and let see what this would be. So, the diffusion coefficient of ethanol in water at room temperature is 0.84 times 10 to the power of minus 5 centimeter square per second and the characteristic mixing length in the channel with is w equal to 100 micro meters, this also the diffusion length is essentially the width in this case which is 100 micro meters.

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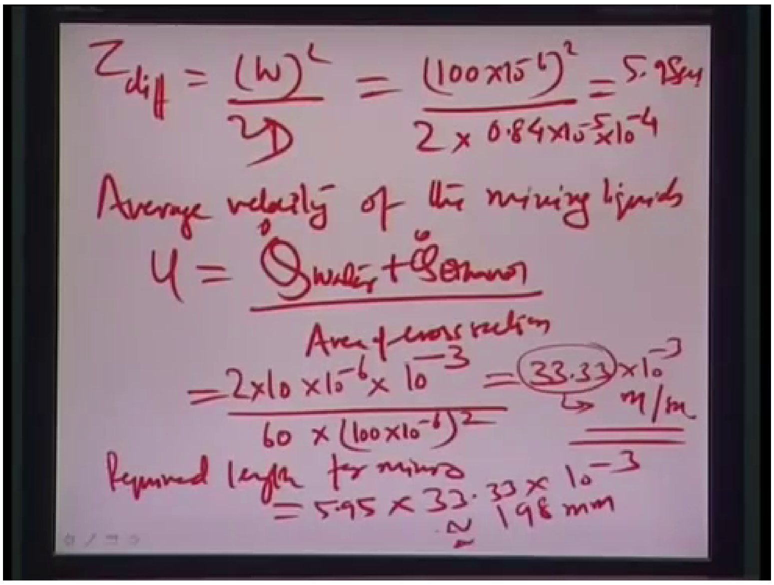

$$\tau_{diff} = \frac{w^2}{2D}$$

$$u = \frac{Q'_{water} + Q'_{ethanol}}{area\ of\ cross\ section}$$

So, the time of diffusion tau dif can be also represented as square of w by twice D this case it is 100 10 to the power minus 6 square divided by 2 times of 0.84 into 10 to the power minus

5 times and this essentially is centimeters square per second. So, if you want to convert the centimeter squared add a multiply with minus 4 10 to the power minus 4 . and so this comes out to be equal to 5.95 seconds and if we consider the average velocity of flow of the mixing liquids. So, essentially u in this case is equal to the flow rate of water is flow rate ethanol by the area of cross section of the channel velocity of flow again equal to is equal to the volume rate of flow divided by the cross sectional area, this meter per second in which fluid move.

And so here essentially both the flows are flowing at rate of 10 micro liters per minute, which means it is 2 time of 10 10 to the power minus 6 liters which is 10 to the power minus 6 in to 10 to the power minus 3 meter cube and this is per minute. So, you have divided by 60 and then the area of cross section is of course, 100 micron square. So, 100 10 to the power minus 6 square. So, this effectively comes out to be equal to flow velocity 33.33 into 10 to the power of minus 3 meters per second.

I would just like to draw you are attention to fact that the velocity only about 33 millimeters per second, which is a not very high considering the other flow rate etcetera which you have seen here that is primarily, because you know the cross section of the channel. So, the required length for the mixing in this case is nothing but, the diffusion time which is 5.95 times of the velocity of the fluid flow and that comes out to be equal to about 198 millimeters. So, the length of the channel here which you need is really about 200 millimeters for the flow to mix completely. So, that is how you do these problems of designing Y mixers. So, let us actually go on to another numerical problem.

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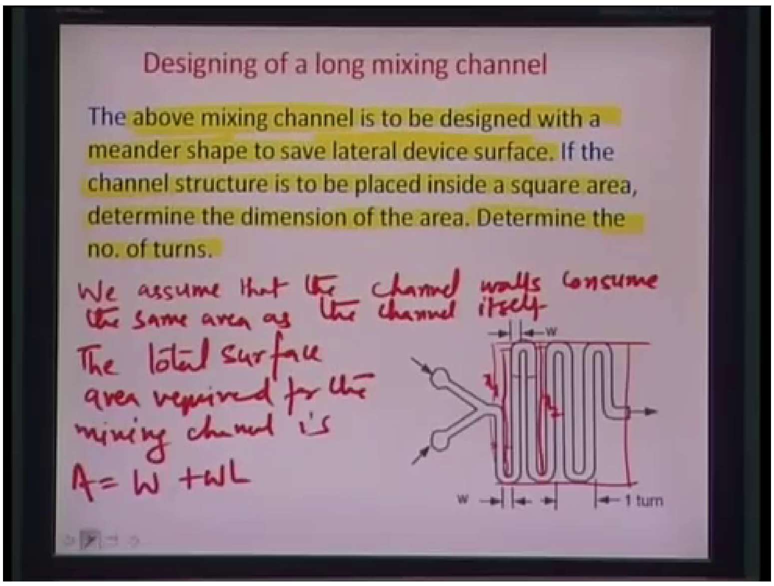

$$A = W + WL$$

So, the problem is pretty much similar you have to actually find out this time that suppose you know the above mixing channel whatever we found out is to be designed with meandering shape or S shape just to say lateral device surface area, MEMS is all about integrating into a small platform. So, let say if this channel structure is placed inside a square area we had determine the dimensions of the area and also the number of terms that it would take for this channel to meander in this small area.

So, let us actually see this as the figure illustrated here the bottom. So, you have a width an empty with each channel as a width of W and in between the channels also there is a width of W. So, in between the channel is a death zone essentially where there is just flats surface the channels are in grade within the flats surface. So, the channels of thickness W and between two such between one meandering channel the inter channel spacing is about W. So, W is kind of an island here in this region. So, we need to find out the dimensions of this particular square platform over which this channel have been kind of integrated and also we need to determine how many turns of this channels would take in this square platform.

So, we assume the channel was consume the same amount of area is the channel itself. So, now, something interesting can be done here, let suppose that this dimension here all the way to here is x 1 similarly you have another dimension x 2 here so on so forth. So, the total surface area required for the mixing channel is W L of the channel area plus W L of the wall area or W x 1 and W x 1 W x 1 for this particular one term.

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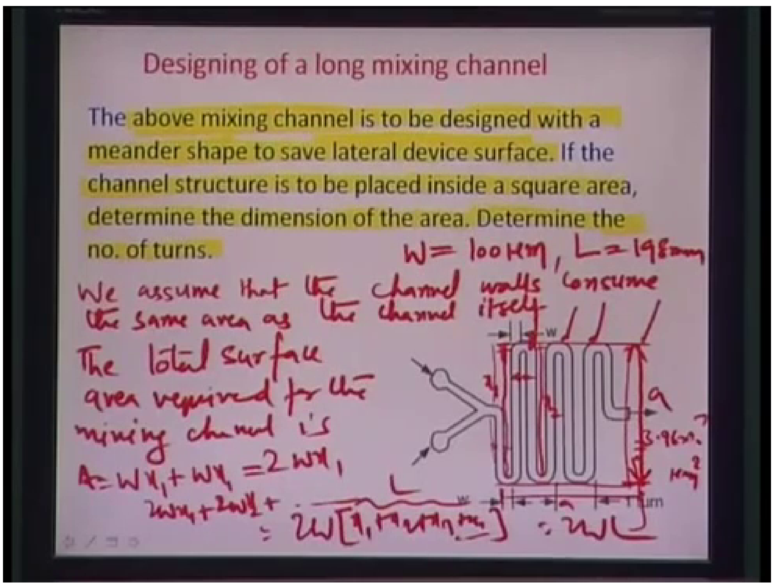

$$A = W x_1 + W x_1 = 2 W x_1$$

So, essentially let me just retried this point again that for this particular channel with one length equal to x1 let say from here to here and one length equal to x2 from here to here, the total amount of area that this channel would need is essentially W the width times of x1 plus the width of the wall times of again that x1. So, for each of these runs the total area is twice W x1. So, there are several such x1's, x2's, x3's so on so forth determine the whole channel.

So, essentially the total amount of area is suppose there are several of these different terms inside is twice W x1 it is there are all different lengths plus twice W x 2 plus twice W x3 so on so forth. So, 2 W can be taken common and then this is x1 plus x2 plus x3 plus x4, so this can be taken so on so forth as the total length of the channel L. So, total area of the channel would need is 2 WL .

So, as we know here the W essentially the width of the channel is given as 100 micrometers and the length we found out from the earlier equation was 198 mm for the diffusion time to be good enough for the time for the diffusion time to be smaller than the smaller than equal to the resistance time. And so therefore, 2 W L here comes out to be equal to 3.96 times of 10 to the power of 7 micrometers square. So, if you assume this dimensions of this particular area to be A square, because it is square area. So, you have A here and A here.

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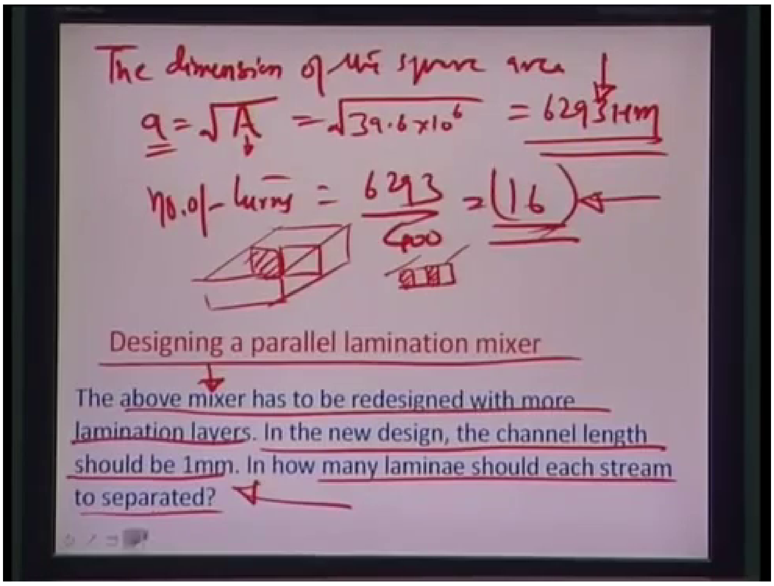

$$a = \sqrt{A}$$

So, you are left with the dimensions of the square area, which is root of this A, where A is the total length, total area that of the mixing channel that the mixing channel would occupy. So, essentially it is equal to root over 39.6 into 10 to the power of 6 micron square which is about 6293 micro meters. So, this essentially is the area 6.3 millimeters by 6.3 millimeter over which you can pack this serpentine and meandering channel, also there is a question about the number of turns that this channel would take. And so assuming that we have each turn compressing of about four different bits and this I would like to retreat by just rubbing of some of the line work here made particularly here.

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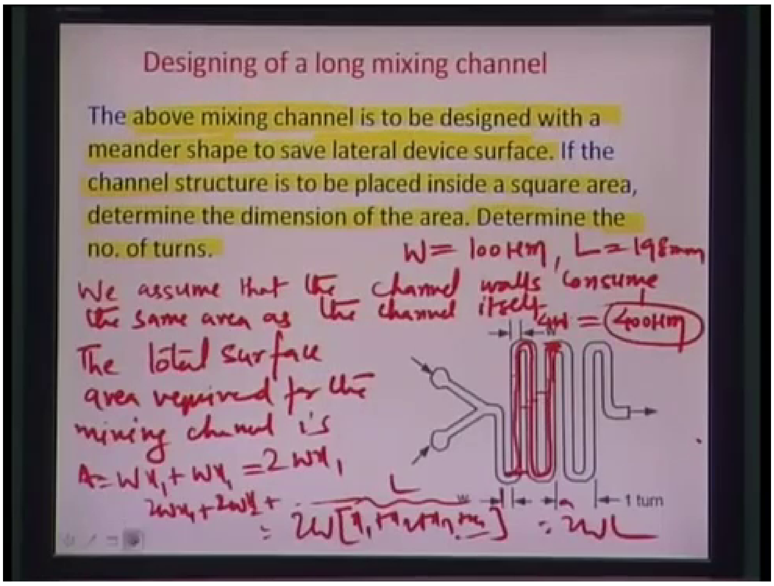

. So, if you look at this particular case you can find out the that you know in one particular turn which starts from let say point here all the way to point here there about 4 W's W plus W plus W. So, it is starts from here. So, there is about 4 W's which starts from and let me just retreat this again W plus W plus W plus W. So, from here to here of the channel which is one complete turn, essentially the total width that the channel would move is about 4 W and so this is equal to about 400 microns.

So, if one turn corresponds to 400 microns, the total 6293 microns would have exactly 6293 by 400 terms which is equal to about 16. So, the whole channel can be meander in to a 16 term architecture with an area of about 39.6 times 10 to the power of 6 microns square and one side equal about 6.3 millimeters.

So, you can see this scale what is important for me to tell you is that the scale essentially is very small I mean 6 by 6 millimeter by 6 millimeter by 6 millimeter is probably close to the size of 25 paisa coin. And so in this particular area you can always create 16 terms and make the length of the channel to be good enough for as long as about close to about 198 millimeters for the diffusion times to be equal to the resistance of two flows.

Let us do another numerical example here we want to design is now a parallel lamination mixer and let say the upper mixer has to be redesign with more lamination layers. So, instead of just green dye and white dye mixing on one particular channel as the part of the y, you know are wanting to laminate in to several different cross sections.

So, you want to find out that in the new design, the channel length has been constraint to be 1 millimeter that has been given in the question. So, how many laminar would be needed for doing the same think as this two laminar set was doing in a 198 millimeter long channel. So, essentially this is what the question is.

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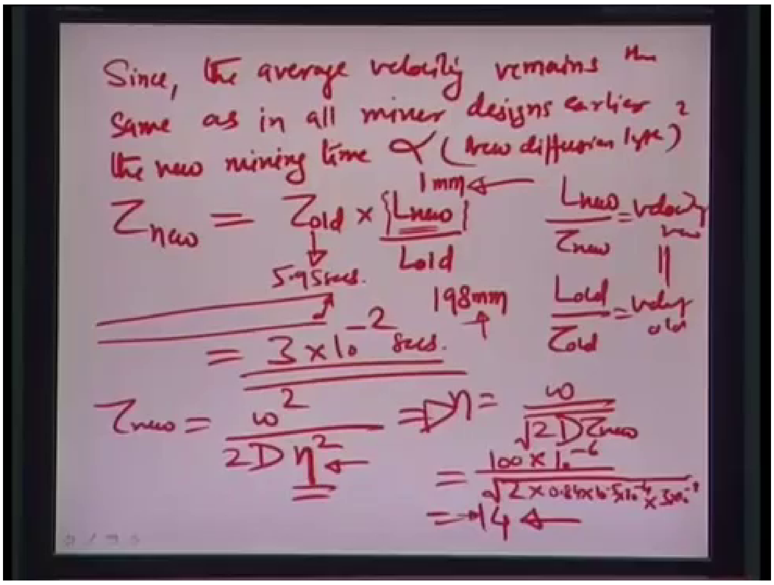

$$\tau_{new} = \tau_{old} \times \frac{L_{new}}{L_{old}}$$

$$\tau_{new} = \frac{W^2}{2D\eta^2}$$

So, let us assume that since the average velocity remains this same as in all the other mixer designs earlier, the new mixing time we will be propositional to in the square of the new diffusion length. And therefore, really the t new is equal to t old times of L new by L old and the L new is as we know about 1 millimeters, which is the requirement and old is about 198 millimeters, let me just retreat one thing here that this L new is essentially the length of the channel, it is not the length of the cross section, so this is not the diffusion length, this is the length of the channel. So, if you are assuming that the velocity of flow is same in both the cases, you have the ratio between L new tau new giving the new velocity, similarly ratio between L old and tau old as the old velocity and their same these two are same.

So, therefore, it is a inverse ratio which you can calculate the t new by t old is a same ratio, is the ratio of different length cell new by L old and we have said in the question that the L new has to be about 1 millimeters when the L old is about 198 millimeter as we calculated before. So, this brings out if you assume this t old to be 5.95 seconds, remember from the first example then this t new time would require a value 3 10 to the power minus 2 seconds.

So, as we know that the time of new is also propositional to square off the cross section length and essentially inversely propositional to 2D and in this case they would be a number of lamina n square. So, therefore, this n value can be derived here as W divided by twice D tau new and essentially if you put the value of W has 100 microns give me minute here 100 10 to the power minus 6 and the diffusion coefficient to be the same as we took earlier 0.84 times 10 to the minus 5 times 10 to the minus 4 meter squared per second times of tau new which is 3 10 to the power minus 2 seconds we left with value of n which is equal to about 14. So, they have to be 14 lamina for the micro fluidic mixer to have similar performance as the in 1 mm length as happens 198 mm length with only one lamina of each kind. So, that is how you do some of this problems like to another numerical example in the shake of clarity.

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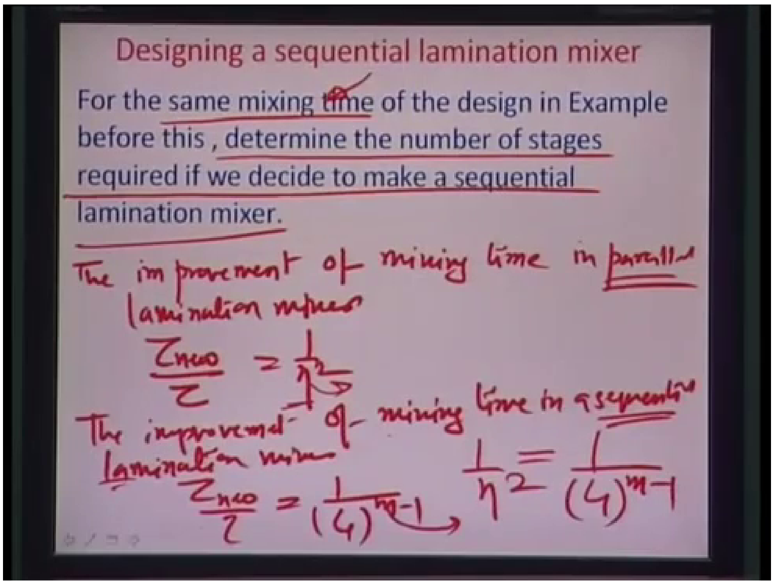

$$\frac{\Gamma_{new}}{\Gamma_{old}} = \frac{1}{n^2}$$

$$\frac{\Gamma_{new}}{\Gamma_{old}} = \frac{1}{4^{n-1}}$$

$$\frac{1}{n^2} = \frac{1}{4^{m-1}}$$

So, let us suppose now that we want to design the same mixing time of the example before this is about 3 10 to the minus 2 seconds. So, you have to determine the number of stages required if we decide to make a sequential lamination mixer instead of parallel lamination mixer. So, what improvements to be need to make here so the improvements of a mixing time in parallel lamination mixer case are given by the equation what t new by tau equals 1 by n squared.

The improvement in time for a sequential one is given by t new by tau equal to 1 by 4 to the power m minus 1, where m is the number of stages here mind you this n and m n not same, n is a number of stages in the parallel lamination mixer and m is the number of stages in the sequential lamination mixer. So, for similar kind of a improvement what is being retreat in the question here that for the same mixing time of the design an example before this determine the number of stages required, if we decide to make the sequential instead of parallel. So, you know that for that 1 by n square has to be equated to 1 by 4 to the power of minus m minus 1.

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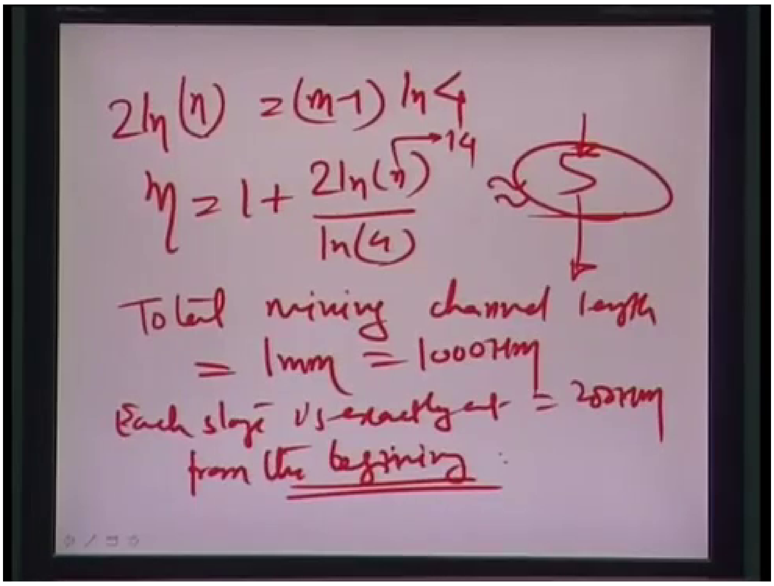

$$\frac{1}{n^2} = \frac{1}{4^{m-1}}$$

$$2\ln(n)=(m-1)\ln 4$$

$$m=1+\frac{2\ln(n)}{\ln 4}$$

And if we take natural log both sides we have twice ln of n equals m minus 1 l n 4 or m comes out to be 1 plus twice ln n by ln 4, you know n is 14 which we calculated last example and therefore, the m value comes out to be equal to 5. So, there are only about 5 stages in a parallel sequential laminar in mixer which corresponds to about 14 stages in the parallel lamination mixer of 14 laminates in the parallel lamination mixer.

So, parallel of course, may be a little faster, because you are bringing all the 14 together assuming that you have a split a part these flows 7 times and you know bringing them together back again, the parallel would be a little faster than this sequential practical stamp point. So, for a 1 mm mixing channel each mixing stage of the new design only occupies about 200 microns or so.

So, you have the total mixing channel length in case of the parallel lamination mixer about 1 mm about 1000 microns and so each stage is exactly a 200 microns from the beginning that is how you categories these kind of mixers. So, in an nutshell now you probably have seen or now you can do some calculations by yourselves and have a good idea about the different forms of mixers be parallel or sequential or why shape a meandering any other geometric.

So, let us looking to some practical examples after this as to how the macro scale intuition can play have a when you translate the information on to the micro scale. So, I would like to look at a problem which we kind of experimentally did back in our graduate days, where we talk about Y type or T shape mixer with the flow controlling valves some both arms of the T. So, there is a case where now there are two streams which are coming on both arms of the T and mixing along the stream of the t and then you have control valves on both sides of the arms. So, you can control the fluorides from both these streams one at a time and then try to investigate what happens with in the time of t.

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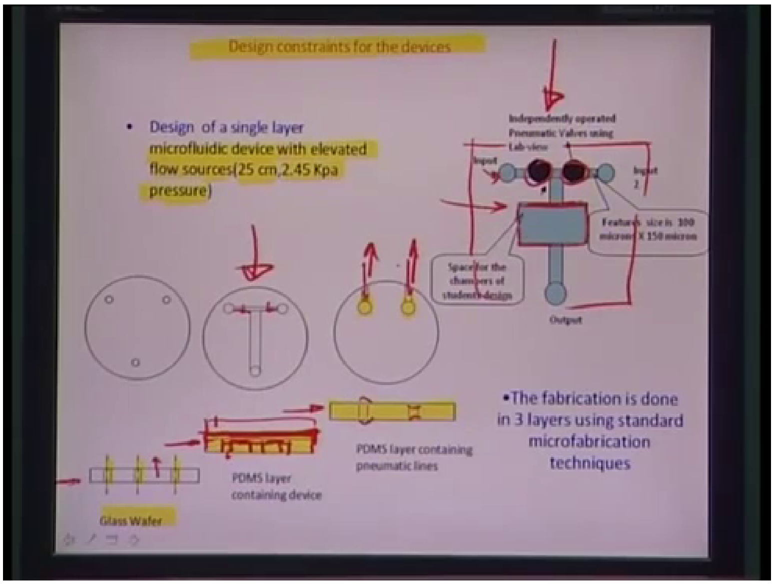

So, the problem is some would like this as illustrate here in the figure as you can see here the constraint for this device is that it is actually a micro fluidic device flow sources, which are placed about 24 centimeter above as like gravity driven flow and the pressure that it creates at the entries about 2.45 kilo Pascal's, the devices essentially comprises of three layers. So, there is a glass layer here, which has these small drilled holes cylindrical holes which cannot do the inlet outlet of the fluids and there is a PDMS layer which has this t feature micro channels in between which does the mixing action and then and the top there is another PDMS layer with these two blister pockets.

So, there is a tendency of this pockets to be filled in and out with compressed here. So, that you can act them as valves so there is an small opening and the top in the PDMS which kind of in flats and when it is inflates the lower layer, which is this is particular layer here channel layer gets squeezed and the valves gets closed, so the flow reduces all the way to about very negligible on both sides.

So, you assemble this by putting layer 1 on the bottom of the layer 2 on the bottom of layer 3 and then plasma bond all these three layers together as you can see illustrate here in this particular figure. So, you have a layer at the bottom here which are not zone the glass layer. So, transparent layer then layer at the top here which is again transparent, but contains the channel essentially in the PDMS.

The upper portion of the layer here as you can see is an all PDMS the upper portion is all PDMS. So, you have a channel only embedded at the between this glass and the PDMS surface, this part is solid PDMS and then you have another layer of PDMS which comes and sits at the top of this layer which are this blisters pocket here you can see and the blisters can be fitted in with the scientific tubing at 1 by 21 gage made up of still and then peek and you can proxy the manner that the air can flow in and out and that is inflate and deflate this blisters like this and this.

And so therefore, as the inflate they kind of quizzes the channel which is below it here and here and this channel kind of bends and blocks the flow, because of this blisters. So, now, you have to find out what happens by giving different designs here to the mixing rate, this was actually a student experiment and it was graduate glass and then when they start in doing this experiment they realize that whatever intuition they were carried caring forth from the macro scale as and really translate very well to the micro scale.

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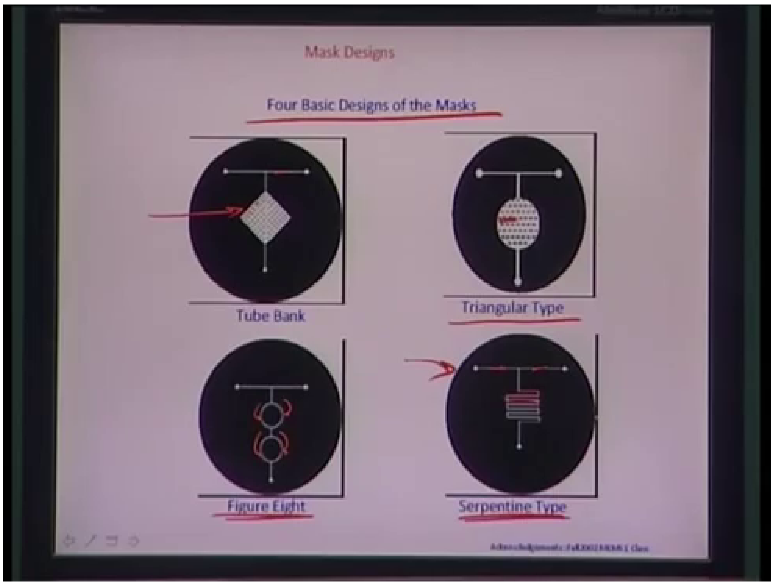

So, they were about four basic designs of structure which were investigated in this black box region, one was as you see here we call it a tube bank kind of structure. So, these are small perturbation these are small dots which are kind of in the PDMS is like small cavities and we expected that when you flow these two fluids, one from this end another from this end there should be at least some twisting and turning, because of the small, small cavities locally local eddies would be created.

In the second case we talked about a triangular type of design, where this cavity is now actually essentially triangular in nature like this they are small try angles and the third was a figure 8 kind of design, where we are splitting apart the flow and putting it back again and then again splitting apart and putting it back and then we have this serpentine time type of design where you had a meandering channel and the two flows coming from both and c r mixing along this particular channel.

So, we are kind of towards the end of the lecture. So, what I would like to illustrate next time is how when we flow fluid across this different structures, different patterns are formulated and which are the most, which are the best designs which can promote rabid mixing supposing the result are very, very contribute intuitive in this case and then once you finish this then will start with micro valves and micro pumps and try to round it often the next two lectures.

Thank you I will see you next time.