Design Practice - 2
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Lecture - 22
Micropumps

Hello and welcome to this design practice to module 22 I would be talking in this particular section about again actuators and sensor design. And we had already covered the microbial portion particularly the micro valve which is actuated with different non-conventional schemes like electrochemistry for example or thermo pneumatic, thermal or even very advanced effects like electro wetting effect or thermo capillary effect etcetera.

I will be now in today's module talking mostly about micro pumps and how actuation is done within those micro pumps. It is very important for particularly people who are in this area of you know designing of MEMS systems or small systems to understand the modalities which are associated with device design of such devices at the microscopic length scale. And so therefore intentionally this particular module has been introduced to give them the backup technical support which is needed for understanding the design at that particular small scale.

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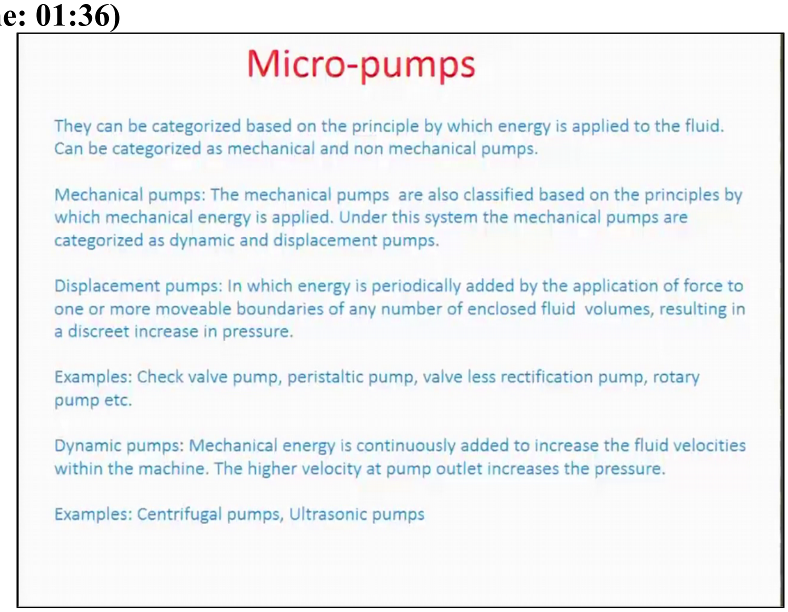

So, let us talk about micro pumps so ah obviously the first categorization which happens in micro pumps is ah based on the principle by which energy is applied to to the particular fluid it can be categorized as either mechanical energy or non mechanical energy and based on whatever is the form of energy you can have mechanical micro pumps or mechanical pumps or non mechanical parts.

So, the mechanical pumps again are classified further based on the principles by which this mechanical energy would be applied under the system the mechanical pumps are either dynamic or this tie pumps in dynamic pumps we are talking about rotary component mostly and in displacement pumps we are talking about a piston made linear movement of the actuation mechanism. The displacement pumps ah are one which in which energy is periodically added probably by application of force to one or more moveable boundaries any number of enclosed fluid volumes.

And this results in a discrete increase pressure because of which fluid is forced to go out or any medium is forced to go out many examples of the displacement pumping domains could be for example check valve pumps peristaltic pumps I am going to talk about this in detail in great detail to design them. The valve less rectification pumps the rotary pumps so on so forth. So, in the dynamic pumps mechanical energy is continuously added to increase fluid velocities within the machine the higher velocity at pump outlet increases the pressure.

And this leads to the discharge the forward discharge some examples could be for example centrifugal pump or ultrasonic pump where energy is continuously being applied okay not in discrete form.

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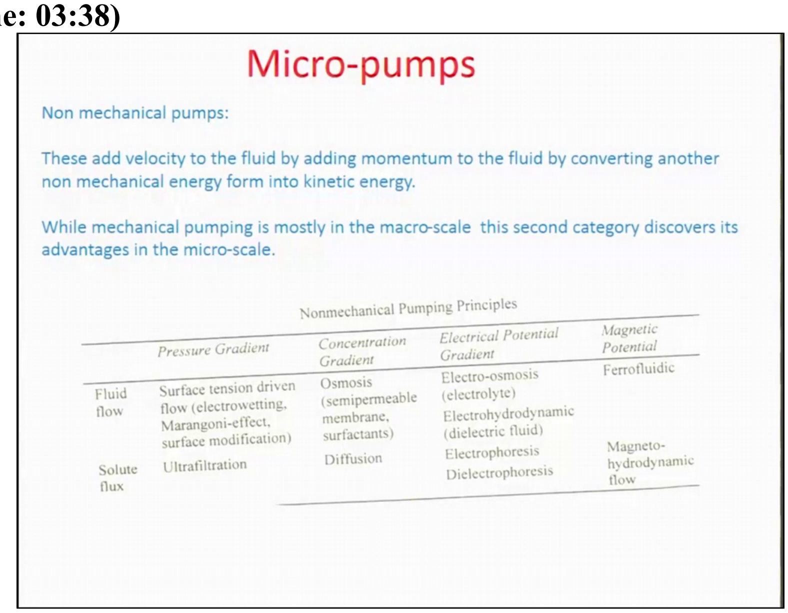

So, these are the basic classifications of pumps when we talk or start talking about micro pumps. And then there are many non-conventional non mechanical processes which are related to again the fluid flow aspects the fluid behavior aspects for example surface tension again electro wetting electro osmosis ferro fluidic so on so forth. Where the nature of the particular fluid would be responsible and and its interaction with the surfaces of the devices would be responsible for the forward movement of the fluid.

So, in the non mechanical pumps we add velocity to the fluid by adding momentum to the fluid in some other term you know typically it is by converting another non mechanical energy into kinetic energy okay this is non mechanical may be electrostatic energy or for example you know surface based surface tension based energy so on so forth. So, mechanical pumping if we look at is mostly used in the macro scale because in micro scale flows micro micro scale flow control there is always a scale effect which comes and inertial effects are not so permanent because of the miniaturized size of the fluid that we are handing.

So, therefore there is a second category of non mechanical pumps which discovers and apply is very highly to the micro scale. so, again if I looked at the characterization of the different principles or classification of the different principles of the non mechanical pumps generally they are classified either as fluid flow case or a solute flux case. For example in the fluid flow case there can be a pressure gradient created by surface tension you already saw the electro wetting or thermo capillary effect.

It is also otherwise known as the Marangoni effect or by surface modification you could actually create a gradient surface you know energy surface through which increasing hydrophilicity maybe through which a water droplet can move up hill or for example the water droplet can move between one place to another at the same potential level. But it happens because of the gradient surface that has been created with different surface tension so on so forth surface energy so on so forth.

So, in the fluid flow based pumps the concentration gradient can be established you know through again osmosis processes just as you saw the movement or pressure gradient being established through surface tension. There if you have a membrane a semi permeable membrane and you have a differential concentration of a particular analyte on both sides obviously there is going to be a solvent flux from the richer side to the linear side.

So, that there is balancing of concentration on both sides so if there is at a gradient which exists and across the membrane there is always almost the possibility of mass transfer to happen so that the concentrations both sides may become equal. Again there can be diffusion driven so when we talk about solute flux we can talk about diffusion driven flux where the physical molecules will move diffusively from the higher concentration side to the lower concentrations side in a fluid path.

And it would again create equality of concentration on both sides. So, the driving factor here is the concentration and a concentration gradient. Again there can be electrical principles applied electrical potential applied to create the gradient one of the very commonly available you know effects is called the electro-osmosis effect which is about creating of a double layer on a surface by virtue of change of you know the zeta potential of the surface as it comes in contact with the fluid.

And because of the double layer by applying a perpendicular field you can migrate a particular fluid volume like a plug okay and so that becomes again electrical electrically assisted or electrically driven or electrical potential driven flow phenomena where there is fluid flow. So, there is also electro hydrodynamic you know principle which relates to a dielectric fluid which is being pushed into one particular zone of a flow stream there can be electrophoresis where there are charged particles migrating within fluid flow which are again driven through an external field and then finally die electrophoresis.

Which is because of the change in the electrical permeability of the medium with respect to ah let us say some particles or some you know two phase of a second phase for example a gas within liquid because of which there can be migration towards the higher elect lower electric field zones from the high electric field so on. So, these are different electrically applied gradients where potential difference would be the cause of movement for in some cases solute flux to happen.

Some cases fluid flows to happen again you can have just as you had all these non-conventional concentration driven electrical potential driven. You can also have a magnetic potential driven set of micro pumps in these non mechanical category where we can talk about Ferro fluidic pumps for example. I will come to these while we do explanation for each of these categories or magnetohydrodynamic dynamic flows so on so forth.

So, having classified into various types the more important question that is asked here is that what is the flow range of such pumps and what kind of volume flows can it support.

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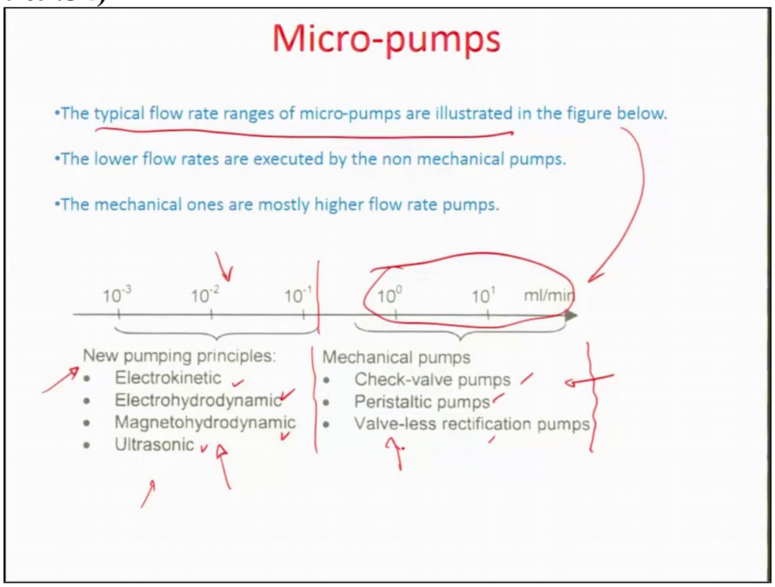

So, typically the flow rates in micro pumps are ranged between what is illustrated here in the mechanical case you can see peristaltic pumps or valve less rectification pumps or check valve pumps which I will describe design-wise in the subsequent slides. Having a flow rate close to 1 to 10 milliliter per minute in this particular zone and when we talk about these other so-called non mechanical forms of energy being applied like electro kinetic pump or electro hydrodynamic pump or magnetohydrodynamic pump or ultrasonic pump.

They fall in a much lower flow range category between 0.001 to .1 milliliter per minute so it is about again a tenth of the minimum flow rates that can be obtained through mechanical systems. But then what is the reason why such new pumping principles and such innovative actuation schemes are initiated and one of the major reasons is that in microfluidic flows particularly when we are talking about applying these two human Diagnostics clinical Diagnostics etc.

And the volume is very low and you have to have a very controlled motion of a very small amount of fluid within chip size platforms so that they can have everything including signal transduction the recognition of the element the signal readability aspects, interpretation aspects in a very small area. So, therefore energy needed for such movements of minuscule amount of flows may be minimalistic and mechanical pumps may not satisfy that kind of a range of flow requirements.

So, therefore new pumping principles are quite essential and you will learn some actuation schemes from looking at some of these principles.

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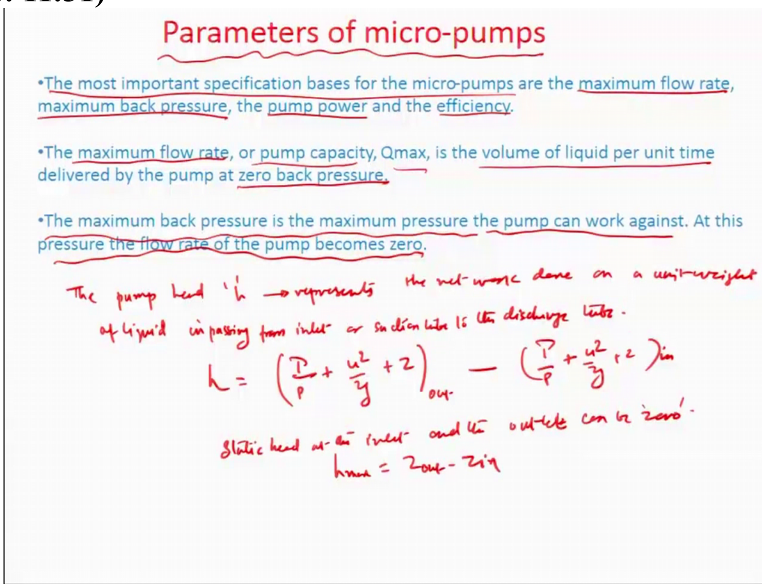

So, how do you justify what kind of parameters are needed for controlling flows of micro pumps in defining flows within micro pumps the most important specification basis for micro pumps for the micro pumps are the maximum flow rate the maximum backpressure against which the pump has to deliver and ultimately the pump power and the pump efficiency. So, these are you can call the for indicated parameters for categorizing or classifying a certain micro pump in different ranges.

And the maximum flow rate or pump capacity that is Q max is the volume of liquid which comes out and is disturbed by the pump per unit time at zero back pressure okay. So, that is how you are defining it. So, the maximum backpressure is the maximum pressure the pump can work against and at this pressure the flow rate of the pump becomes zero. So, basically the pump is just able to sustain no backward movement at a certain maximum level of pressure which is then the back pressure.

So, let us now compute the pump head how we can estimate some of the parameters which are needed for actuation design or actuator design. So, the pump head h kind of represents the network done on a unit weight of liquid in passing from inlet or suction tube to the discharge tube. So, let us say if P were the outlet pressure so this can be represented as P / Rho + u square by 2g + z the potential energy at the outlet - a similar aspect at the inlet.

So, if we assume that the the gauge pressure is zero and pump operates from atmosphere and Prosperic condition and delivers R again into the atmospheric condition so the static head at the inlet and outlet can be 0 and h max then becomes equal to z output minus z input.

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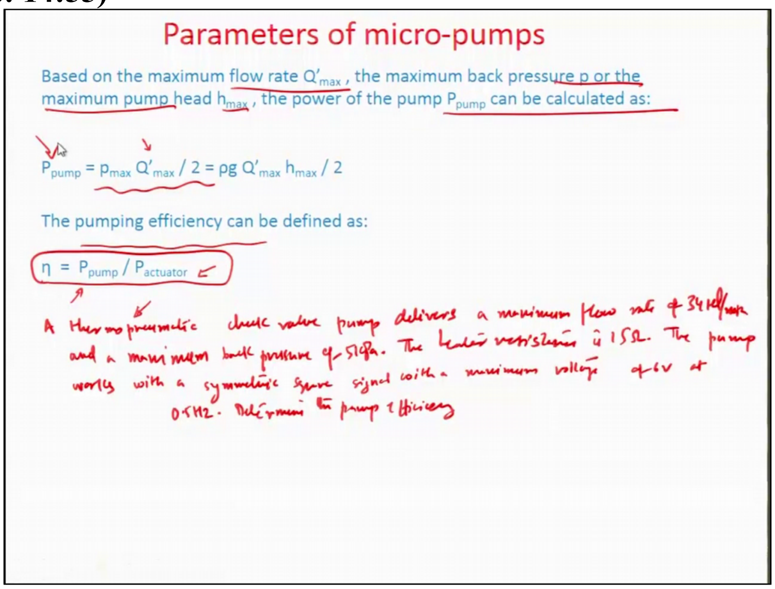

So, based on the maximum flow rate Q dot max the maximum backpressure P or the maximum pump head h max, the power of the pump can be calculated it is basically the pressure discharge volume product divided by 2 it is assumed that the volume flow rate picks up from 0 and goes to Q dot Q Q dash max which is the maximum flow rate and so therefore the average flow rate can be taken to be just half of Q dash maximum.

So, the pumping efficiency now can be defined as the total power needed by the pump divided by the power needed to actuate the pump ok. So, that is how you talk about what is the inlet energy given per unit time versus the what is the the the pumping energy that is actually needed to maintain the discharge at a certain rate okay per unit time. let us let us understand this through an example problem that will be probably better so that you can think of the you know the actuation scheme design.

So, let us say there is a thermo pneumatic check valve pump, check valve pump really delivers on the basis of whether the valve is switched on or whether the valve is switched off maybe there is a gravity flow in the way of a valve and if the valve seat is open then flow continues if it is closed the flow does not I mean the flow stops. So, the thermo pneumatic check valve pump delivers a maximum flow rate of 34 micro liters per minute and the maximum backpressure of 5 kilo Pascal's.

So, we had to actuate the thermo pneumatic mechanism we have already seen this while designing the static valve example in one of the lectures. So, here we are actuated a heater with a certain resistance to go up to a certain temperature so that it heats up a hermetically sealed cylinder with let us say an air confinement and the air expands because of charges law and creates a membrane deflection okay.

And so if we can do it multiple number of times by making let us say or feeding the electrical heater with the square wave signal where there is a heater on heated off mode and there is some kind of a pulse width modulation scheme where you can control the duty cycle and the frequency at which the square signal is being generated. You can multiply close and open the valve in a manner so that you can have an average flow generate across the valve okay.

So, this is how check valve pumps are really operating okay. So, it is you have to first understand the basic principle before again starting the design okay. So, there is a well again I am just illustrating that there is a heater the heater is fed with the signal of an on so you switch off or switch on and then change the switch off switch on times at a certain frequency so that you can have delivery of the pump at a certain rate.

So, in this particular case the heater resistance for the particular design of this particular pump is around 15 ohms and as a designer of these kind of small systems you must when you are designing actuation at this particular scale you must be very, very careful about the different parameters which are there to define the performance or operability of the architecture that you are designing for.

So, the pump works with the symmetric square signal with the maximum voltage of 6 volts at 0.5 Hertz frequency that means you know it is operating exactly once in two seconds this voltage signal and we know we now want to determine the pump efficiency. So, the mode the modus operandi that would be there to calculate the efficiency is given in the equation right here. So, we want to calculate what is the power that the pump delivers in terms of flow? And what is the power that is needed for the actuation signal. And then just simply compare them ratio metrically to see what is the efficiency.

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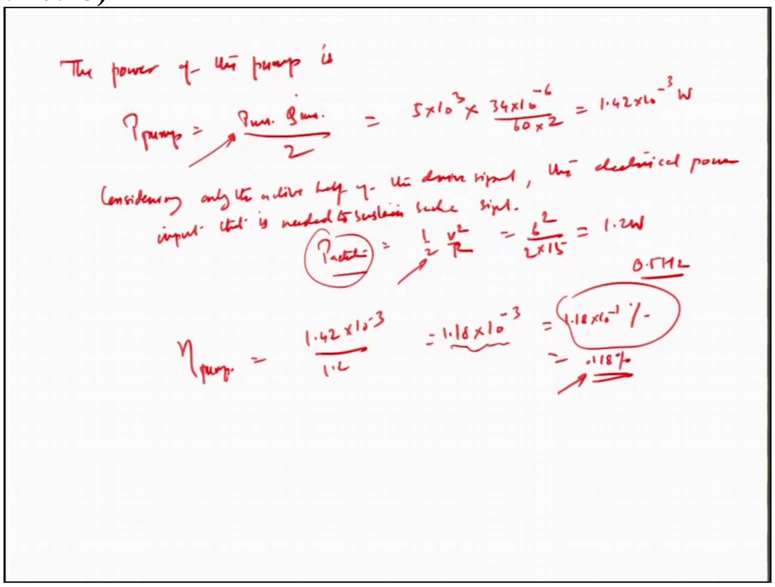

So, the power of the pump will be calculated a priori this is the maximum power that the pump can develop is obviously equal to the maximum backpressure against which the pump can flow times the average maximum flow that the pump has that is Q rod / 2. In this particular case the pump operates against the back pressure of 5 k pa so 5 * 10 to the power of 3 and the total maximum flow rate that the pump can provide is 34 micro liters per minute.

So let us compute that so 34 10 to the power of -6 liters and this is per minute so we divided by 60 to make it per second times 2 obviously it is Q dot max / 2 and so this comes out to be equal to so this makes it 1.4 to 10 to the power of minus I am sorry -3 watts. If we consider only the active half of the drive signal which is a square wave as I told you the electrical power input that is needed to sustain such a signal across a resistance which is given our input that is needed to sustain such a drive signal okay will actually be what is needed for the actuation of the pump.

So, P actuator so this is exactly half V square / R because you know I mean when we are talking about 0.5 Hertz it means that the powering happens exactly once in 2 seconds and so does the de powering okay. So, you have exactly 2 seconds of powering followed by that of de powering. So, when we talk about one such square signal which has been given the total amount of power that is consumed here is 6 square / 30, so, that is 1.2 watts.

And therefore in this particular case if such a signal given has produced this kind of a back pressure or you know pumping power then the efficiency of the thermo pneumatic pump or actuator is actually equal to 1.42 10 to the power of -3 / 1. 2 that is 1.18 10 to the power of -3 or even better -1% okay so it is .118 % so this is how the efficiency of a thermo pneumatic pump is. So, as you know that the efficiency figures in this particular case is quite unreasonably low.

But again you have to understand that because there are scale effects at these scales that we are talking about it is almost always important for more power to go in the system in order to actuate or create different effects. So, I think I have made sure that I gave you some of the non-conventional ways in which non mechanical pumping is carried out I am going to also talk about peristalsis in some level of detail in the next class.

And then discuss some schematics or designs of what kind of actuation mechanisms can happen for again initiating micro flows and different levels followed by maybe some introductory you know research grade material presentation in the area of gas sensing design. So, till here until then I would like to end this module thank you very much for being with me, thank you.