Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part- 2

Module- 22
Determination of Electrolyte flow velocity in ECM

by
Prof. Shantanu Bhattacharya
Department of Mechanical Engineering,
IIT, Kanpur

Hello and welcome to this manufacturing process technology part 2 module 22 we were talking about how to design the electrolyte flow velocity in ECM process and for doing that I would like to assume this following.

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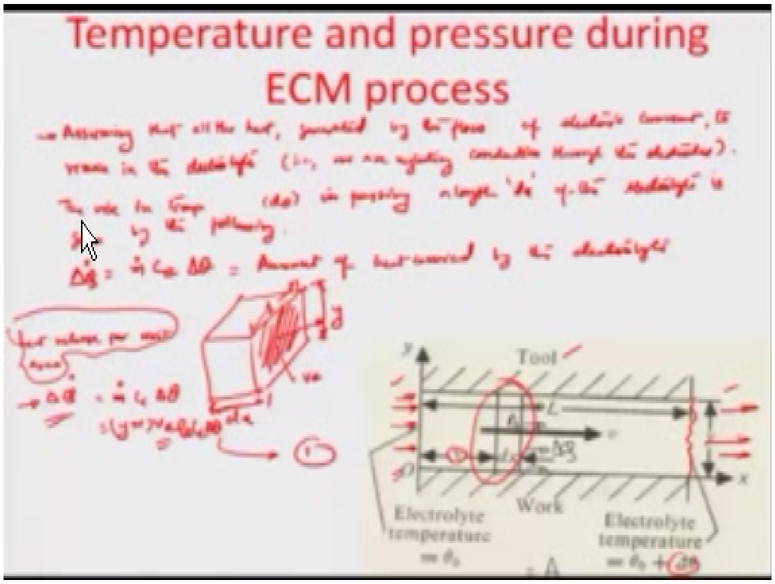

Temperature and pressure during ECM process

So we have now a tool and a work piece as has been shown here and we can assume that we have let us say the electrolyte entering the system from this direction at the zero Y plane and exiting in this from this other plane formulated here at the other end of the tool electrode combination we assume all the heat generated by the flow of the electric current to remaining the electrolyte.

So let us just write that here so assuming that all the heat generated by the flow of electric current to remain in the electrolyte that is we are neglecting in our preposition the heat flow through the electrodes which is a big issue because of the high conductivity of the metal electrodes so we are neglecting conduction through the electrodes so the rise in temperature dθ in passing a length dx of the electrolyte is given by in the following Δq° the rate of increase of heat equals to the rate of mass flow.

m° times of the specific heat capacity of the electrolyte CE times of Δθ which is the temperature rise which has happened because of this movement of the electrolyte from one side of the electrode to the other side of the electrode so if I wanted to just try to so let us just write this down here as the amount of heat carried by the electrolyte.

So if we assume this particular section here that we are referring to as a cuboids where this really is the phase across which the heat gets transferred so that is the area and if you assume that the equilibrium gap the gap at a point of time key where we are considering the Z transfer to take place is why okay further we are assuming a dx element width in this particular case at a distance X from one side where the electrolyte really enters or maybe one side of the electrode consider.

So here if we assume the width to be let us say because it is a one dimensional case we are just assuming the width here to be unity so this is 1 okay whatever be the units so this is me one dimensional case but nanny even you can also assume L it does not really matter it cancels out later on in the analysis so here the heat release per unit area is given by Δq° equals m°ce Δθ as you know m° being equal to y times of 1 times of the velocity of the electrolyte flow.

Let us assume the electrolyte is flowing at a constant velocity VE okay times of the density of the electrolyte row e times or specific heat capacity times of Δθ okay so you can think of the heat so this is the amount of heat carried by the electrolyte and the you can you can say that the heat released per unit area of the electrode is just dividing this with respect to the area of the electrode which is involved in this particular case it is dx x 1 okay.

So that is how you can predict the amount of heat that comes into the electrolyte so let us now try to keep this as such the total amount of heat rate that the electrolyte is carrying represented in equation 1.

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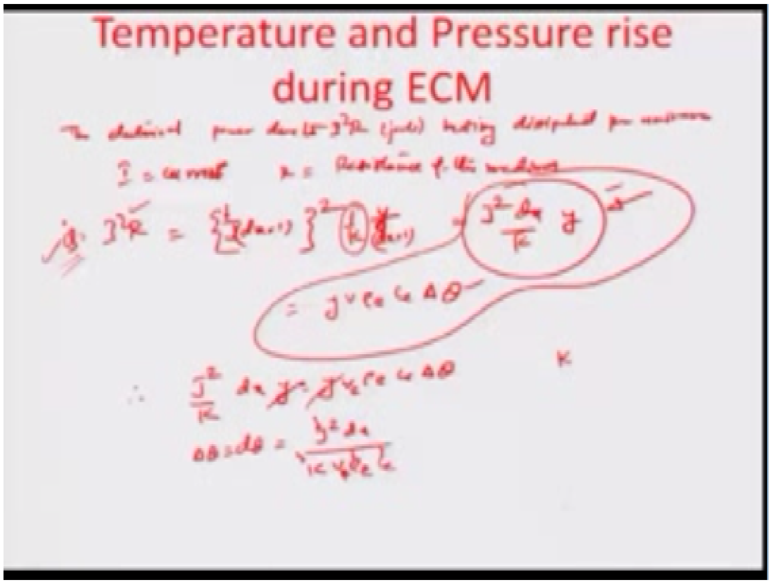

Temperature and Pressure rise during ECM

And let us now try to find out the electrical power due to the I^2R or you can call it joule heating okay dissipated parent area so obviously I is the current and R is the resistance of the medium so I^2 R in this particular case can also be referred to as J times of dx times of unity which is the area square okay obviously J is the current density which is current per unit area and if you look at in the previous example is the current is coming in this direction from the electrode the total area that is being considered here is really this dx times of unity or dx x 1.

So that times of the resistance which is one by conductivity times of the distance of both electrodes across which the whole current is flowing the current actually just let me recall flows from this face the top face right here to the bottom phase this distance being why the total length the current would take or the path length of the current is why and obviously the area across which the current is flowing is the X x1

So we can compare this or we can write it as ρ which is one by conductivity times of length of movement of the current y divided by area which is dx x 1 so that is how you can develop the I^2 R it dissipated and if I wanted to look at the final values it is J^2dx by K times of y that we are considering and so obviously the heat dissipated of the electrode is going to no other means but into the electrolyte medium at is being transported by the electrolyte medium.

So if we assume these two heat rates to be equal so this is the rate of dissipation you can say you know the dq/dt so the electrical power which is also nothing but the heat added if we assume that there are no other conversions of heat so what power is basically applied gets converted into heat so this $q^\circ R$ rate of change of heat a rate of transfer of heat is basically related to $I^2 R$ in that case which is given by this $J^2 dx/ Ky$ and you already know that this heat is getting pumped into the electrolyte.

And the rate at which the electrolyte is being heated is given by $y V\rho ECE \Delta \theta$ so this is just a complete sort of a you can say power balance between the electrical power and the way that the electrolyte is being heated up and if we just convert this into more realistic equation we can have J^2/K times of dx times of y equals $yV \rho e \Delta\theta$ let us cancel this y or $d\theta$ can be represented as you know $\Delta\theta$ or $d\theta$ can be represented as $J^2 x\, dx/k v \rho e c e$.

ρ is the electrolyte density see is the specific heat capacity J is the current density in the medium k is the conductivity and v is basically the electrolyte flow velocity you could to get the call it VE okay in this particular case so having said that now I would like to just seek your attention to the fact that conductivity K really and so does the resistivity is not invariant with respect to temperature because if you increase the temperature obviously the conductivity is going to be changed substantially.

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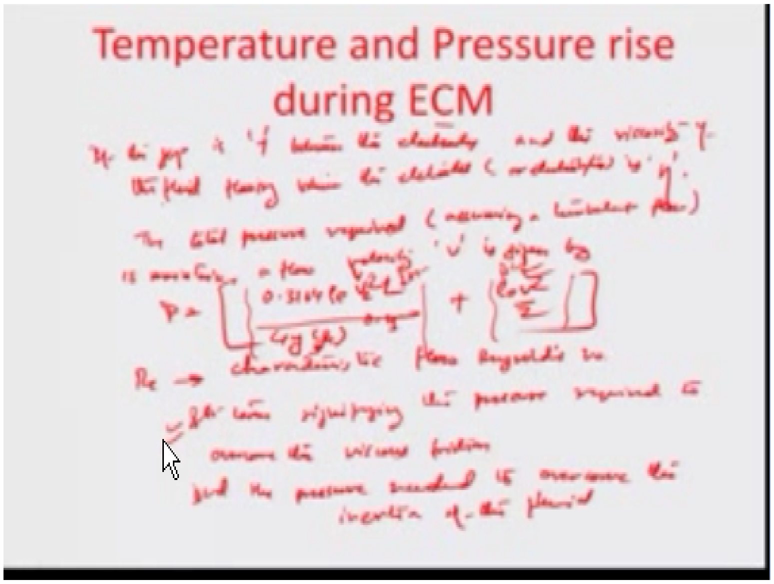

Temperature and Pressure rise during ECM

And so in this event we could actually write the temperature dependence of conductivity as below where K can be recorded as K_0 [1+α θ-θ_0] K_0 where obviously is the room temperature value of the conductivity and θ_0 is the room temperature θ is whatever is above the room temperature the computer above the room temperature so θ - θ_0 is the differential okay temperature differential and α is basically the specific conductivity per unit temperature what would be the rise factor associated with k_0.

So if we wanted to now solve for this equation between let us say 0 and Δθ from one side to the other side of the hole electrolyte transfer process as it gets into the inter electrode gap and goes out okay so this can be recorded if we assume this length here right here to be L as you can see you know the whole length of the tool surface tool electrode surface so I can easily allow this we convert into 0 to L J^2 dx / k_0 [1 +α θ - θ_0] times of ρ CeV in other words the velocity of the electrolyte Ve can be written down as J^2l /k k 0 times of Δθ + α x 2x of $\Delta\theta^2$ x of ρ ECE.

So that is how you can find out what is the velocity of the electrolyte VE in this particular case so if the gap is why between the electrodes and the viscosity of the fluid flowing between the electrode or the electrolyte you can say is η the total pressure required assuming a turbulent flow behavior to maintain a flow velocity V is given by P = 0.3 164 ρe V^2 L/ $4yRe^{0.25}$ +$\rho eV^2/2$ so obviously Re here is the characteristic flow Reynolds number and I can classify these two terms.

Here as the first term signifying the pressure required to overcome the viscous drag or a better term would be a better terminology here would be viscous friction between the plate and the electrolyte moving electrolyte and the second term that you can see right here this is the first term this is the second term is basically the inertial component okay it is basically the pressure needed to overcome the inertia of the fluid.

So obviously the first term because of the scale factor becomes more significant in comparison to the second term because the gap is very small and the inertial effects may not be that predominant in comparison to the surface effect which would happen more in this case and so therefore we would like to predict this value of the pressure that the electrolyte would apply corresponding to a certain velocity again you please record this very carefully that you know it is really a function of this Ve^2 okay.

And also somehow a hidden component of velocity within the Reynolds number so in a way this would be able to sort of let us estimate what is going to be the overall pressure rise because of a certain flow velocity that we are introducing in the electrolyte so let us actually look at a numerical design example where we talked about designing such a such a flow velocity within the limits and bounds of the ultimate yield strength of the materials that are being used as electrodes in this particular case.

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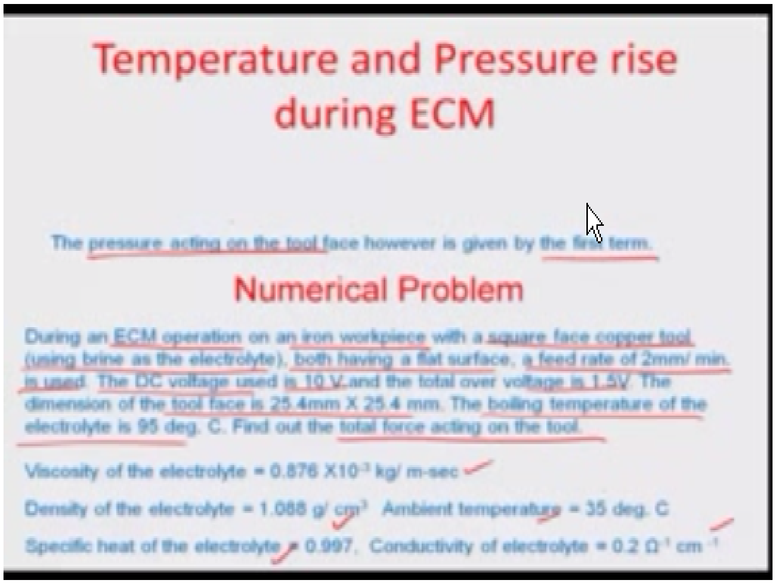

Temperature and Pressure rise during ECM

The pressure acting on the tool face however is given by the first term.

Numerical Problem

During an ECM operation on an iron workpiece with a square face copper tool (using brine as the electrolyte), both having a flat surface, a feed rate of 2mm/ min. is used. The DC voltage used is 10 V and the total over voltage is 1.5V. The dimension of the tool face is 25.4mm X 25.4 mm. The boiling temperature of the electrolyte is 95 deg. C. Find out the total force acting on the tool.

Viscosity of the electrolyte = 0.876×10^{-3} kg/ m-sec

Density of the electrolyte = 1.088 g/ cm^3 Ambient temperature = 35 deg. C

Specific heat of the electrolyte = 0.997. Conductivity of electrolyte = 0.2 Ω^{-1} cm^{-1}

So let us say that although the pressure acting on the tool phase would typically be given by this first term we assume when we try to find out actually numerically how these two terms would be different so in this numerical example we have an ECM operation being carried out on an iron work piece and it is so carried out with the square phase copper tool using common kitchen salt solution as electrolyte okay.

And they are both having a flat surface and a feed rate of two millimeter per minute is used the DC voltage that is applied is about 10 volts the total over voltage is 100 1.5 volts again and the dimension of the tool phase is given out to be25.4 mm into 25.4 mm so it is a square tool phase we also know the boiling temperature of the electrolyte which is of significant concern in our case it's95 degrees Celsius we should not be able to go to that level that is how the velocity has to be planned so higher is the velocity greater is the possibility of the temperature to be lower because the heat transfer.

Now is getting faster but we have to really limit ourselves to the boiling point because we do not really want the electrolyte to start boiling because of more heat accumulation and lesser flow velocity so there is a trade-off optimal trade-off between the flow velocity at the temperature state that the electrolyte would be inside the working zone in an ECM process so we find out the total force acting on the tool by this mythology.

We have been given some parameters here like viscosity of the electrolyte density specific heat capacity of the electrolyte also the overall conductivity of the electrolyte and the ambient temperature which is 35degree Celsius.

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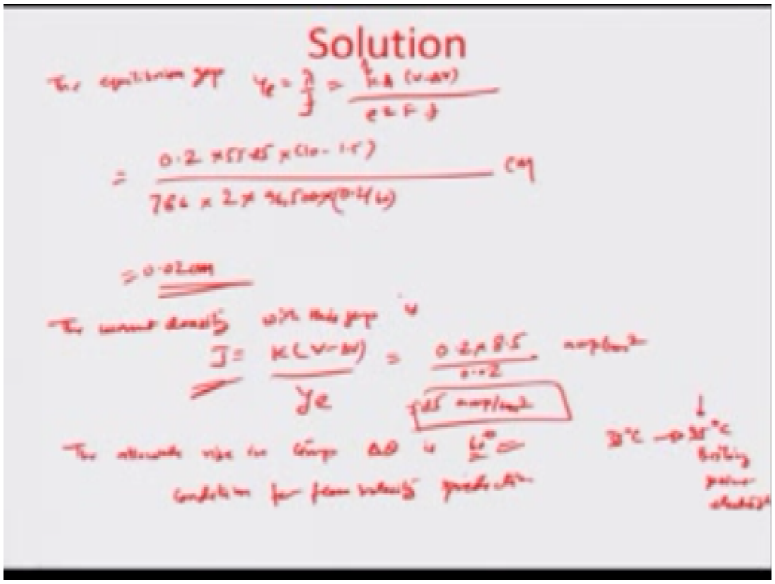

Solution

So let us now first compute the equilibrium gap which can be given by y = λ / F so obviously λ can be again calculated by using the expression ka V- ΔVρ at f times of small f I have already derived this expression many times so let us look at what would be the equilibrium gap in this case the k value is 0.2 were in centimeter inverse RN iron assuming iron work piece here so 55.85 times of voltage minus over voltage is about a 2.5 volts and this is divided by the density of the iron that we are moving which 7.86 g /cm^3 times of the smallest resolution valiancy which is the F is state +2 the faraday constant 96500 Coulomb and times of the feed rate which is really 0.2 / 60 cm/sec.

So this much centimeters is what the equilibrium gap is going to be so in this case it comes out to be about 0.02centimeters okay and the current density with this gap is going to be J equals K times of V - ΔV /ye so in this case current density would be the conductivity 0.2 Ω inverse centimeter inverse times of V- ΔV is 8.5/ 0.02 Aper cm^2 so this happens to be equal to about 85 amperes /cm^2.

So that is how the current density J is going to be the allowable rise in temperature Δθ is around 60° because we are operating at about you know 30 to 35 ° and we can at the most go up to 95°

C which is the boiling point of the electrolyte okay so we do not want to surpass this point because then the finish is lost completely because of the two-phase electrolyte coming into the work zone so Δ θ allowable is about 60 ° in this particular case so this is the condition for flow design flow velocity friction maybe you can say and now we want to do that flow velocity V.

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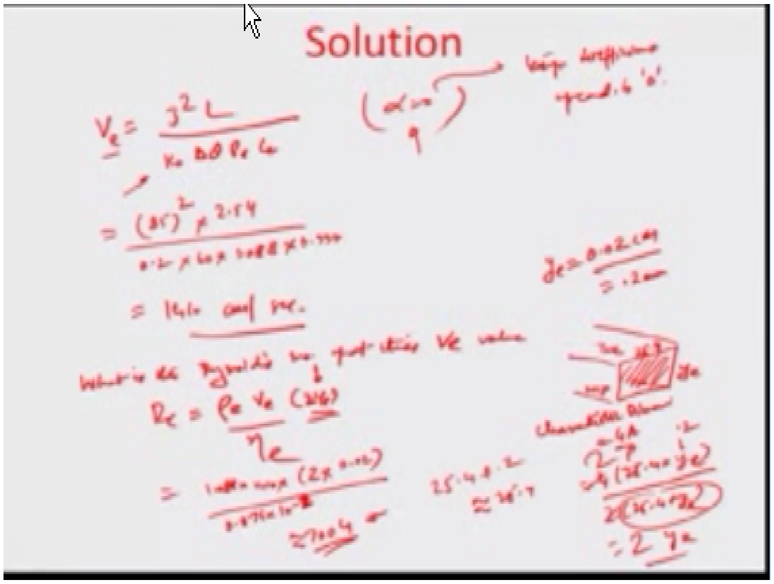

Solution

$$V_e = \frac{J^2 L}{k_0 \Delta\theta \rho_e C_e}$$

$$= \frac{(85)^2 \times 2.54}{0.2 \times 60 \times 1.088 \times 0.997}$$

= 1410 cm/sec.

$$R_e = \frac{\rho_e V_e (2h)}{\eta_e}$$

≈ 7004

I looking at J^2 else times of $k_0 \Delta\theta$ ρe C we are assuming that in this particular case for simplistic sake the temperature coefficient of conductivity 0 although we really in actual case is not the scenario that is going to be a finite value of alpha and conductivity is really going to change with respect to temperature but just for simplicity in this particular problem we assuming α to be 0 here so in this case if we provide all the values which have been given to us and calculated in the last step.

The value of J for example which is 85 A/cm^2 times of the value of L which is actually again if we look back the area of the face is about twenty five point fo25.4 millimeters or 2.54 centimeters divided by the conductivity of the electrolyte which is 0.2 Ω inverse centimeter inverse times Δθ which is 60 allowable temperature rise times of density of the electrolyte which is 1.088 g/cm^3 times of the specific heat capacity Ce of the electrolyte which is 0.997okay.

So that is how the specific heat capacity of a electrolyte is recorded as so we are left with now the value of Ve electrolyte velocity which is actually equal to about fourteen hundred and ten centimeter per second so let us now look at what would be the Reynolds number so what is the

Reynolds number at this velocity at this V value so the Reynolds number re is again given by ρ of electrolyte times of velocity of the electrolyte the viscosity of the electrolyte times of the characteristic dimension which is twice the equilibrium gap in this particular case you have to understand.

We are talking about a gap which is again you know why for example here and 25.4 and this is what is going to continue so on one side is a tool another side is the work piece okay and we want to find out what is the Reynolds number in this cross section right here so we already have Reynolds number as four times area by parameter so in this particular case four times 25.4 times of y divided by the parameter which is actually twice 25.4+y.

So obviously at equilibrium the y becomes ye so I can replace everything by ye and why we was found out in the last step 0.02 centimeters about 0.2mm okay so in this particular case if I put a 0.2 mm here so obviously you know you can approximate this as twice ye because this kind of 25.4 plus OH point two more or less similar to 25.4 and so you are left with only 2e ye so the Reynolds number here is having a characteristic dimension given by four area above perimeter as twice ye.

And if I calculate that with respect to the velocity we just formulated here so we have the value of equilibrium gap two times of 0.02 centimeters times the density of the electrolyte which was provided as 1.088 g/cm^3 times of the velocity which the current case can be estimated to be 14 10 centimeter per second divided by the viscosity of the electrolyte given as 0.876 times of 10^{-5} kg per centimeter second.

Actually we have to convert into gram per centimeter second so -2 grams per centimeter second so that is how you arrived at the Reynolds number here so this number comes out to be in a calculation equal to seven thousand four so it is pretty turbulent regime in which the Reynolds number is present.

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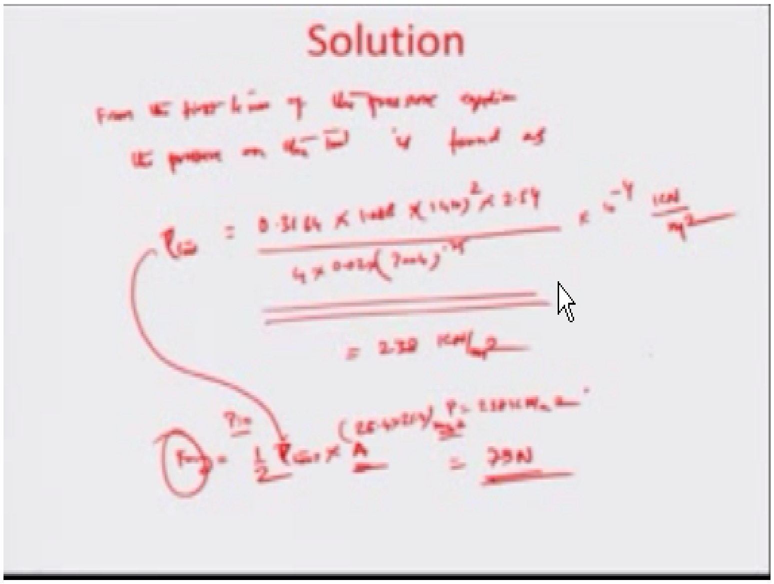

Solution

so from the first term of the equation of pressure of the pressure equation the pressure equation I have intentionally not derived because this is a very common formulation found in any fluid mechanics textbook and so our purpose here was really to device the flow design and so therefore it was not felt necessary that we should go to do all the divisions about how these viscous drag the viscous force of friction can be estimated on the surface.

So from the first term of the pressure equation the pressure on the tool is found as ρ tool equal to 0.3 164 times of the density value which is 1.088 g/cm^3 times of the electrolyte density of the electrolyte times of the square of the velocity in this case it is 1400 x10 cm^2 14x10 cm^2 times the total length which in our case is 20.44 millimeters or 2.54 centimeters and this again four times of the equilibrium gap.

Which is there and you can record that is 0.02 times of the value of the Reynolds number to the power of 0.25 so Reynolds number has been calculated to be 7000 for the power 0.25 and this is basically the pressure the total pressure on the tool assuming that the other inertial component is insignificant in comparison to this surface pressure and this again if you want to convert into kilo N/m^2 you have to multiply it by 10^{-4}.

So that many kilo N/m^2 is the kind of pressure that we are assuming here so in this case it is about 238 kilo N/m^2 and the force acting on the tool face if we assume that there is a leaner linear pressure drop when the electrolyte has just entered the pressure applied by the applied is obviously 0 and the other side it is a full-blown 238 kilo N/m^2 so you know the overall average force that the electrolyte would apply is given by half times of this density or this this sorry the pressure maximum pressure that the electrolyte has applied at the end of the length L times of the total face area which is 25.4x 25.4 millimeter^2 okay.

So convert this into meter square and then the total force comes out to be 79 Newton is so that is how the average force that is there on the electrodes happens to be so in fact we can also calculate what is the average force per unit area and we can also ensure that that average force per unit area does not go down the yield strength of the material to in order to prevent any warping or any damage due to the velocity.

So that is how you can design the velocity of the electrolyte flow in a ECM system so in the interest of time I would like to close on this particular module but in the next module we will try to look at some more interesting problems related to defect sit seems up till then good bye thank you.

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