Welding Processes
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Heat Transfer inside the Arc

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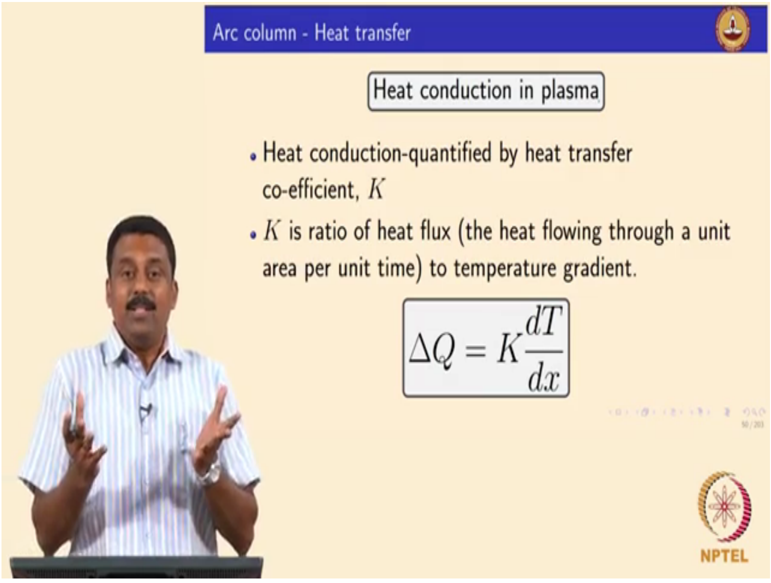

So once you know the heat obviously you also know how you transfer from one place to another place. Isn't it? So that means that the heat is generated at an arc. And that heat will be transferred by maximum three ways, that is what nature says. Isn't it? Why conduction convection, radiation. In normal conductor how the heat is transferred? You have one rod okay, you apply some heat in this end. Then heat is transferred right? Assuming that there is no radiation heat transfer or convective radi heat transfer, so mainly by a few conduction, so how does the heat transfer from this to this place takes place?

Student: Vibration

Professor: Vibration, so what happens during vibration?

Professor: So when they vibrate, they collide during this process heat is transferred from one place to another place. So that is a classical heat transferred by conduction okay and we can estimate the heat transferred by calculating the temperature difference between these two end. Isn't it? So the change in the heat delta Q from this end to this end is nothing but if you measure the temperature and the length, then you can calculate how much heat is transferred from this end to this end, isn't it? It is a classical conduction heat transfer equation, is not it? So if you know the temperature gradient of a unique length can also be calculate how much heat is transferred from this end to other end. In other words, the amount of heat transfer in conduction is directly proportional to, proportional to? Temperature gradient, is not it?

And the proportionality constant is K, K is? What is that K? It is a heat transfer coefficient where as in arc lot of other things can also happen. So the K is the heat transfer coefficient, right?

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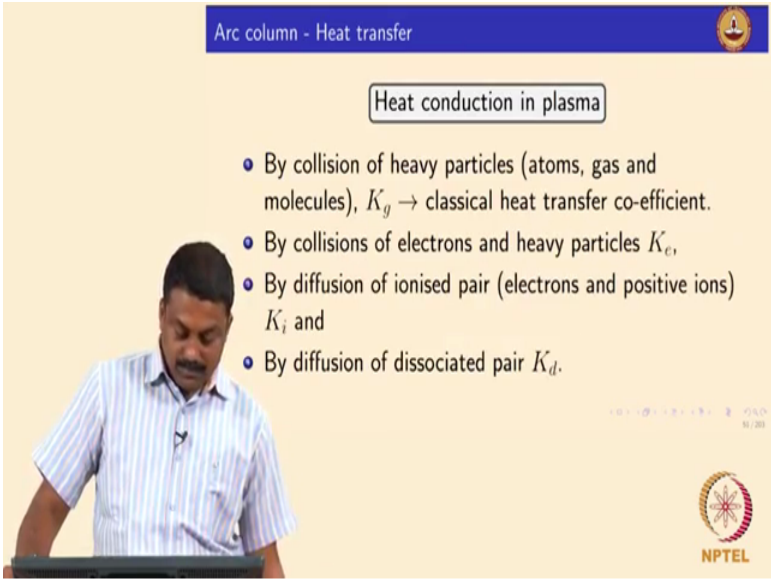

Can happen by four ways again the first one is classical way by collision of heavy particles by collision of atoms gas molecules okay that means that if a one particle which is hard is collided with the other one obviously heat is transferred from one place to another. So that is the classical heat transfer coefficient case it happens in conductors for example in copper rod, okay.

So but in arc we also have the ions, the electrons the also we also continuously ionizing the gas. And they are also dissociating the if we have the diatomic gas of molecular gas so in all four ways what is listed here the heat can be conducted in an arc the first case is classical heat transfer coefficient by collision of heavy particles atoms and gas. In second case when the electrons collide with the heavy particles isn't it?

That is also possible hot electron it go somewhere and then collide obviously it transfer heat from this point to this point isn't it? So that is we can take as KE. The first term the classical heat transfer is KG if we assure and two other phenomena is also possible because of ionization imagine there is an argon item here in the inside the arc it ionizes okay and the ionized argon item argon plus goes over here it is attracted by an electron and electron diffuse again back to this argon plus it becomes argon items.

And that is the exothermic process because electron gain is exothermic process isn't it ionization is endothermic similarly here the argon plus is in different temperature if it goes over there it also carries heat with it whether its a positive heat or negative heat doesn't matter heat is transferred plus you also have a deionization isn't it?

That can also happen so ionization the ionized gas item can also be the ionized and (())(5:47) is passes the heat is transferred whether it is negative heat or positive heat doesn't matter but there is a heat transfer isn't it? So that is also possible in one way of transferring heat from one place to other place whether you are making the other place hotter or this place becomes colder doesn't matter any way the heat is transferred in this case here when you are doing ionization heat is observed isn't it?

In a way this observed heat released elsewhere, isn't it? So you are an ionization process that endothermic the ionization is a energy is observed in this point that means that you are packing an energy in this point sending it back to other point in this point that energy is released something like we have lunch box you pack it and eat it there to gain energy okay.

So the ionization energy which is conceived for ionization is released elsewhere by de ionization it is a heat transfer isn't it? So that can also happen similarly the same thing can also happen for disassociation you have a nitrogen N2 becomes 2Ns they can also go and combine become strength to again same as ionization and deionization you can also have dissociation and de dissociation isn't it?

So these all four heat transfer by conduction is possible in arc. And this extremely important especially if you are using a diatomic gas and this can be very significant okay because you always continuously dissociating and de dissociating and that can influence the arc temperature along the radius of an arc. Along the length of arc.

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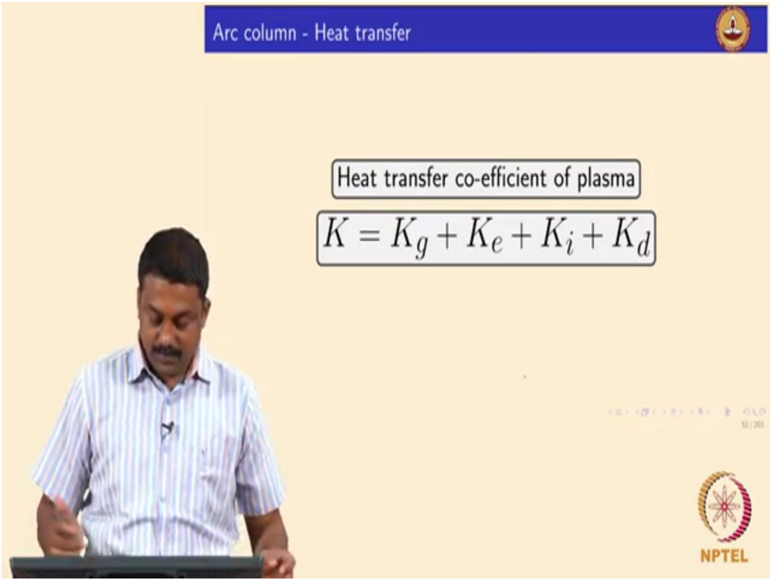

Okay so the total K of an arc is nothing but KG but it is a classical heat transfer coefficient by the collision of heavy particles atoms and molecules and then the collision of electrons and (())(8:19) heavy particles the electrons carry huge amount of heat they also have a much higher drift velocity and they determine the electric current in an arc we just saw. Isn't it?

And then the diffusion of ionised path and ionized gas item combines with electron becomes a neutral gas item doing this process it liberates so what are it consumed during the ionization process okay the same thing can also happen with a dissociation and de dissociation so by conduction in arc heat is transferred by all this four mechanisms in a classical solid conductor these go away yeah why?

KG but in arc unfortunately (())(8:19) account for all this four so you look at heat how heat is conducted in an arc so you need to calculate all this 3, 4 and this four reaction would determine the temperature distribution if you neglect radiation, convection heat transfer so this four would determine the arc temperature. Okay

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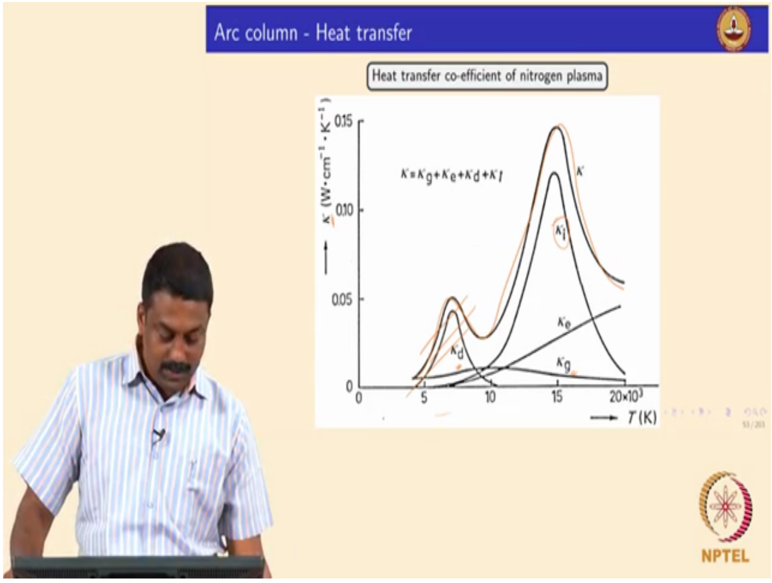

How? Like this so this is the total a coefficient heat transfer coefficient by conduction so KD what is the term dissociation de dissociation that can be significant lower temperatures okay and high temperature yeah deionization okay KE is collision of electron with heavy particles and then KG is the classical heat transfer okay by the collision of atoms and molecules if we sum it up this how the distribution looks like.

If we use more atomic gas then this shoulder goes away isn't it? So if you mix your arching gas with diatomic gas it will considerably change the temperature distribution of an arc okay so if you use diatomic gas 100 percent diatomic gas the heat distribution by conduction in arc it will be entirely different than if we use more atomic gas right its clear good so this works I mean in real case as well.

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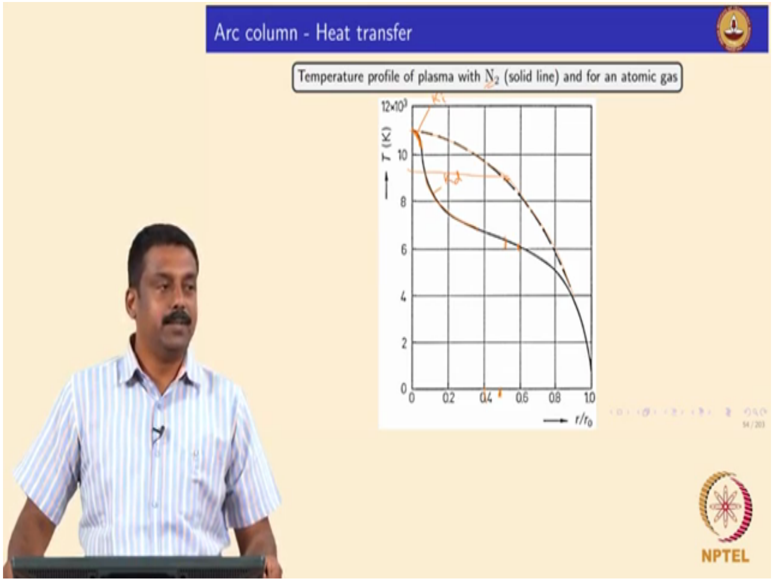

For example this is a temperature profile of an arc neglecting radiating radiation convective heat transfer so we have calculated temperature profile of a plasma with diatomic nitrogen and a mono atomic nitrogen gas. And what we see over here it is RBR zero R zero is the radius of an arc at any given location if it is centre that means it will become zero right or becomes U.

At the centre you have very centre of the arc if you look at the temperature distribution this solid line is for diatomic gas you see the two shoulders there is one change in slope and another change in slope and this is corresponding to KI and this is KD. KS what is KI? De ionization okay and this is KD which is?

Student: disassociation

Professor: disassociation. And if you use a more atomic nitrogen obviously the KD completely goes away isn't it? And the temperature dis distribution is more or less a parabolic. Right is it clear? So obviously from this graph you can clearly say that is using a more atomic nitrogen if you use that (())(12:59) nitrogen the arc temperature will be much lower at a given location so for example at the centre of the arc.

Okay or half way from the centre the temperature of more atomic nitrogen will be somewhere around 9000. Whereas in an diatomic gas it will be much lower. Yes about 6000 kelvin so we often see mixing of diatomic gas is a sealing arcing gas to control the heat in the arc. Okay similarly if you use diatomic gas heat is also effecting the transfer it is not only concentrated at middle isn't it because the de dissociation can affectively transfer the heat from the centre to elsewhere that what is shows here.

Isn't it? Not only reduces the temperature of an arc it also effectively condense the heat from one place to other place so that means that if you want to reduce the penetration and if you want to make the well bid wider obviously you can use diatomic gas isn't it? Because heat is distributed much widely whereas UV is non atomic organs helium he have a deeper penetration but an arrow will pull.

Yes its clear we will see in the case studies how this affects is going to affect the real life so now you need to understand that if you use diatomic gas the heat conduction will be much more efficient than using a more atomic gas because of the de dissociation can affectively transfer the heat from centre to elsewhere and doing this process okay so the temperature decreases okay because the de dissociation also effectively observed the heat yes its clear? Example good.

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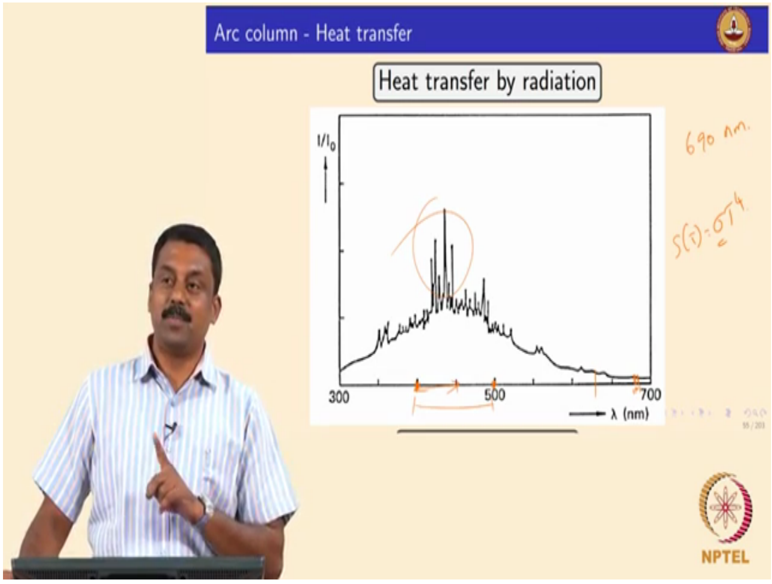

So the second heat transfer which is also very significant in terms of arc heat transfer by radiation let me see an arc what is the colour. Colour of an arc don't stare an arc when (()) (15:39) isn't it? So look at these these (())(15:42) so this is the spectrum of an arc. You see the peaks where are they appearing between.

Student: 400 and 500

Professor: 400 to

Student: 500

Professor: 500 so what is the range? 400 to 500

Student: is increasing

Professor: the entire range is up to this is visible right? So it's a blue range isn't it? So that is a Louis spectrum so maximum intensity please liberate it in the wave lengths of above 400 to 500 nano meters okay let us say same all your shirt colours the black is observed black body its lower rate radiation is (())(16:32) now it is coming out yellow isn it? Why this shirt is yellow?

Student: (())(16:39)

Professor: the intensity the maximum in the yellow range isn't it? So you have two colour T shirt okay so I have two the peaks at two different wave lengths that is why your T shirt looks two colours okay the same way the arc as well so arc we assume that at temperature is because so high it is a continuous radiations like an like a black body.

Okay its not a line spectrum you can be line spectrum only at very low temperature because of the temperature so you talking about is 20,000 kelvin so we can safely assume that it is continuous spectrum okay so with the peaks between 200 to 500. So that is how when you recording the arc we always use band pass filters you know what are the band pass filters?

No so if you record with the camera normal camera arc you would not see anything because it is this wavelength is so spread you will just see only one glare okay suppose if I want to study how the electrode is melting I don't want to see the arc isn't it I want to see the electrode part so what we do I will use a band pass filter so band pass filters they filter all the wave length except one tiny range.

Okay suppose if I use 690 nano meters band pass filters okay this band pass filter it allows only the wavelength with coming from 690 nano meter that means that I would mask the entire arc so I can look at the only the well pool for example. Isn't it? Otherwise the arc is so bright I would not see anything isn't it?

Or if you want to see only arc I do not want to see anything else I can choose a band pass filter between say 400 to 450 that means that the lights coming from this region would only reach by camera. Okay so I can look at only arc nothing else isn't it? So the colour of the arc is bluish white because it has all the wavelength there for white with some peaks in bluish range you see the peaks in blue range that is why we see arc that is a bluish white.

Okay that is same goes with all your shirts for eyes see the colours whatever wave length is coming from your shirts. Okay so by assuming continuous radiation not line spectrum if he is continuous radiation its a black body right then we can use one equation to calculate the heat transfer what equation? Heat transfer by radiation.

Student: hmm (())(20:11)

Professor: Yeah Stephen boltsman equation okay what is Stephen Boltzmann equation?

Student: (())(20:20)

Professor: so this sigma Stephen Boltzmann constant soon be confused with the other Boltzmann so this is different okay so this is Stephen Boltzmann constant okay.

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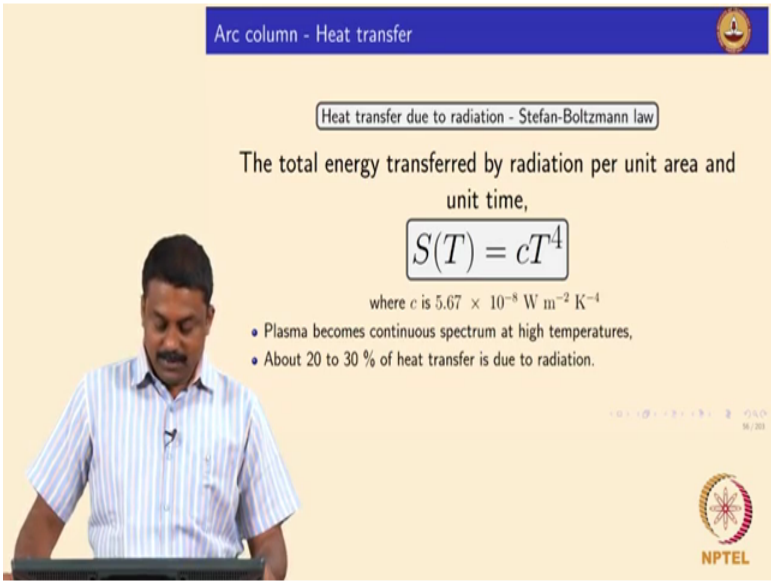

So here so if you assume the arc is a continuous spectrum there is a black body so once you assume that obviously at high temperature DD is a continuous spectrum if temperature is low then only you get line spectrum then this equation is not valid okay so plasma becomes continuous spectrum at high temperatures.

So this is a black body radiation the assumption here is it will be continuous spectrum which in a way we can assume at high temperature so once you know that you can calculate again heat transfer by radiation it is significant compare to conduction about 20-30 percent is by radiation okay so when you are welding you just take your hand close to the arc okay you feel heat right that being radiation okay.

So if power goes to IIT Guwahati you do for intra (())(21:42) you do camp fire right you will do you will not transfer heat by conduction isn't it? So you make yourself warm by radiation in camp fire isn't it? May be conductive flow as well because they are also con breaks the next heat transfer majority is by radiation heat transfer right its clear?

So we calculate the heat transfer of the radiation by the Stephen Boltzmann law so Boltzmann also did lot of work isn't it? Poor guy I don't know why he committed suicide I am really feeling for him.

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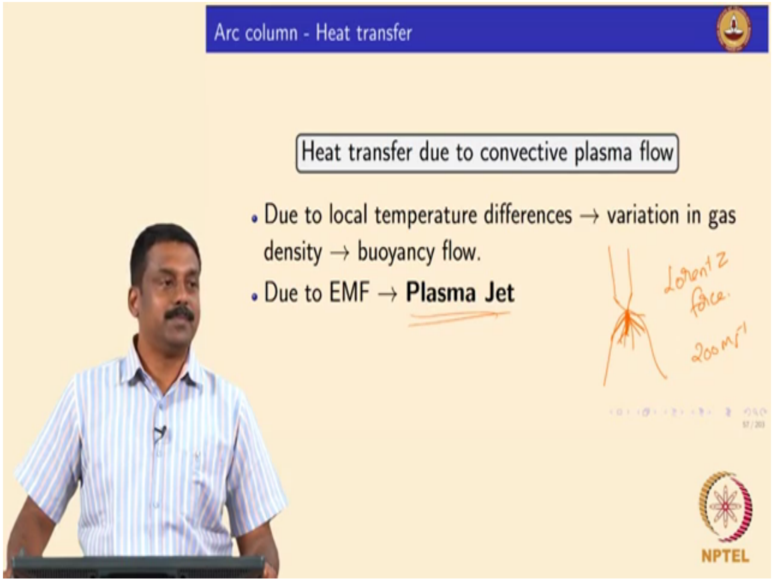

So then heat the third heat transfer mechanism is convective flow. And this is also significant how the heat is transferred from one place to other place in arc okay there are two ways the heat is transferred becomes convective heat transfer. So one is very simple buoyancy law what is buoyancy flow again? Because of because of density difference gas is at high temperature will be less tense than the gases at low temperature and that will lead to a buoyancy flow isn't it?

Did a difference in temperatures the gas will be in different density at various location obviously gas would flow from one place to other place buoyancy because of the density defines or that is set in negligible compare to the other major force in arc that is known as plasma jet.

Okay so plasma jet can be created with very very velocities okay the principle is very simple for example so this is your electrode okay obviously at this point the centre of the arc this is one arc you have accumulation charges isn't it cathode fall zone or anode fall zone okay so we can deny the entire transfer of the current into very small particles very smalls particles obviously is an electrons or ions isn't it?

These are charge carriers so these charge carriers they have (())(24:20) property for example if they come together obviously they will repel okay so the force is inversely proportional to the distance isn't it? If they are very very close they create enormous amount of force to repel so obviously if you have accumulation of charges in one point obviously in arc you always have accumulation at the centre of the arc at the tip of the electron for example so then you create a force what you call as Lawrence force.

So Lawrence force is nothing but when the charge carriers when they come close they repel much faster as a force created in the fundamental the electric charge carriers when they attracted to each other obviously they will be repelled much much faster so the force at which it repels its inversely proportional to the distance so if you have accumulation of charge carriers there will be repelled with enormous velocities isn't it.

So that for he is not as a Lawrence force. And Lawrence force is in arc is very significant okay so if they are accumulating they are repelled isn't it? And this repletion creates a jet and that is known as a plasma jet. In this jet can go as fast as 200 meters per second, 200 meters per second so the flow inside the arc plasma can go as high as 200 meter per second okay at the centre of the arc column because of the accumulation of enormous amount of charge okay creates a Lawrence force leading to a jet formation.

So obviously once you have jet you will transfer heat isn't it? So you also have heat transfer by the flow which is convective flow heat transfer. Yes guys its clear? So if you look at

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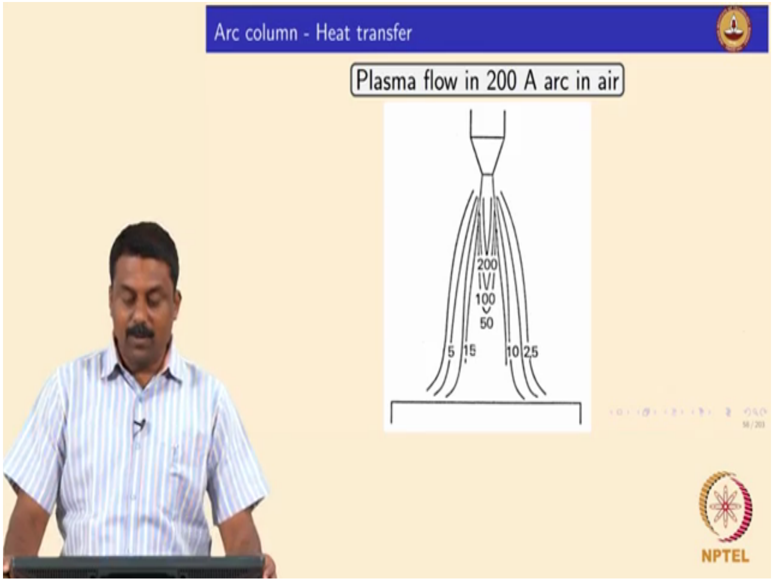

Plasma flow it is just a simple toned amperes arc in an arc. So the centre so this is your electrode the flow close to the electrode can go as high as 200 meter per second. And if you go far away in the arc envelope the envelope side you don't have the accumulation isn't it? Of the charges, charge recommendation always happens either at cathode or anode.

And here you have accumulation is spread okay because obviously it is a base material either anode or cathode it would not be accumulative at one point it will be spread right but here at the tip is very tiny area right so there is enormous amount of accumulation of the charge carriers and once it accumulates they repel between each other creating a jet force and this jet force can also transfer heat .

And that is one way of convective heat transfer so now we have three types of conduction, convection and then radiation. Conduction again in four types heat transfer by classical heat transfer, by the collision of atoms on molecules and then that is KG and KI the collision of electrons with heavy items, heavy molecules that is KE and then KI deionization and then KD de dissociation that is the conduction heat transfer.

Now the heat is transferred in an arc and then radiation heat transfer it is Stephen Boltzmann law by radiation and then convective heat transfer two types by buoyancy, buoyancy flow right and then plasma jet formation due to the Lawrence force creation okay the charge carriers repel when they are placed together creating a jet force okay so now we generated heat and we transfer the heat now we can weld isn't it?

Right so when look at the various welding processes and we will then look at railing process then and there we will discuss about the physics what are we learnt so far okay so how the heat is generated or heat is transferred how efficient is the process okay and if it is one gas how if you how the efficiency can change or heat generation can change again.

So we will move then we look at each process we will use this basic to understand the physics of the process right its clear good.

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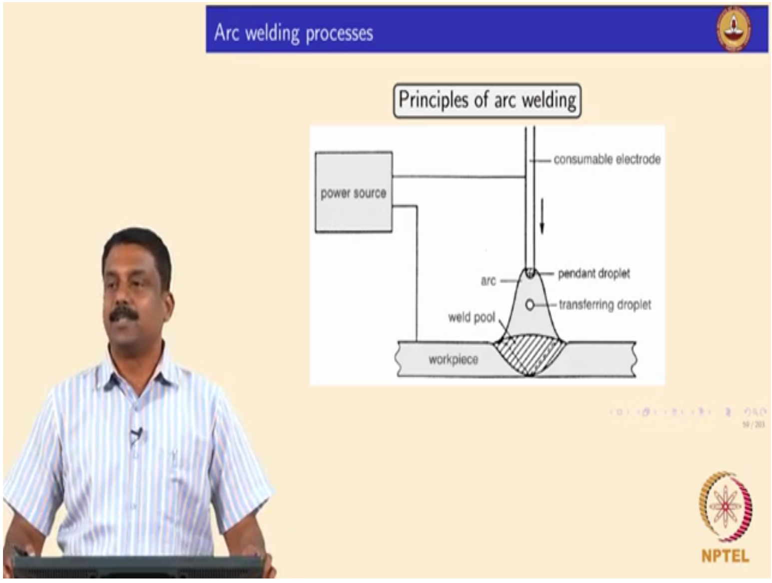

So I mo showing you very simple schematic of a typical weld setup so now we are moving and to the actual welding setups welding processes so what we see over here so obviously need to give e isn't it? And then we need to generate electrons so further you need a cathode and then you need an anode to receive whatever it generates isn't it?

The way its process you also need to have a gas which can be ionized so that you can strike an arc and once you struck an arc the process itself the ionization would determine the heat generation by the term JE isn't it? And then from JE you generate heat when heat is transferred by conduction, convection, radiation so this is the physics of physics of the welding arc welding right.

So once you understand these concepts now you can create your own process methodologies because the fundamentals are the same only thing is how you change these process variations for example here I plotted in a schematic so in an consumer welding process so you have a power source so that so generate E okay and then you need to have a cathode can be (()) (31:29) this or it can also be minus depending on your polarity okay.

So you need to have a gas for arcing and then once you have arcing obviously either you can melt the consumable you can deposit right so in the arc heat is transferred to the cathode and anode by conduction, convection, radiation inside the arc also heat is transferred by this way and you generate heat so by controlling E we can also control JE and then NE can be controlled by the nature of the gas you used. Isn't it?

That determines your ionization energy okay so once you know all this things now you can understand the beauty of this process okay it's a simple welding that you can see on a road side but if you look at the physics behind this process it is an as good as a rocket science isn't it? So once you understand all these fundamentals you can enjoy the beauty of the process isn't it so we look at one by one the first process.

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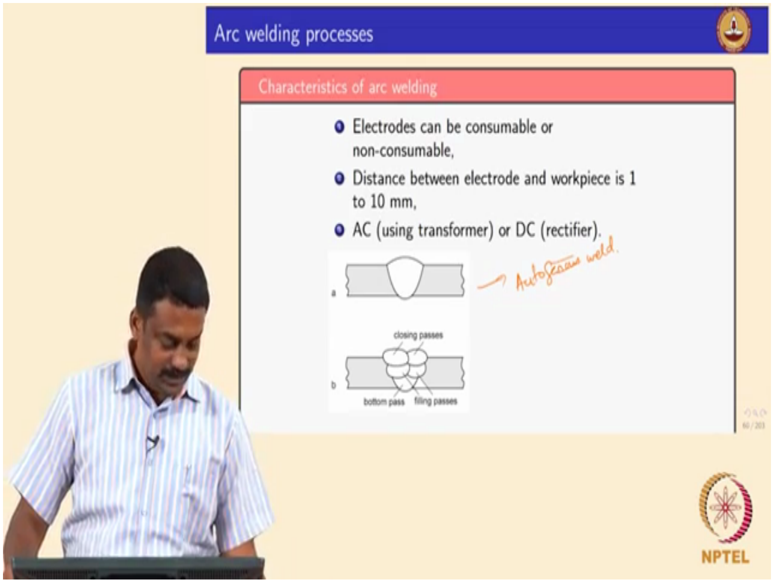

In a typical characteristics welding you can either make the electrode consumable or non consumable okay so generally the distance between the tip of the electrode to work piece not more than 10 mm otherwise your arc stability decreases significantly because then the conduction, convection, radiation it becomes extremely unpredictable okay because the current density is distributed much over distances okay.

So not more than 10 mm when you want to strike an arc. Okay so either you can use a DC the direct current then you need to check your polarity you want to make electrode positive or negative what you use if you want to use a consumable electrode. The electrons would reach?

Student: (())(33:51)

Professor: electrode yeah then what polarity then?

Student: (())(33:55)

Professor: yeah so electrode positive if you use DC okay or you can use AC alternating current as well. Again that is also not possible so now if you want to weld it now obviously you can also weld it without air consumable that is known as autogenous weld so welding without consumables.

Okay or you can also use again the consumable to fill the weld cavity so then in consumable welding process. Okay so you can use it the various number of passes okay if you appreciate the beauty of the physics then you can also talk about what the feel okay so the voltage so again that is how its important like voltage in a welding process at derived quantity isn't it so what we calculate here E that is the field strength.

So that is a current okay so voltage is derived quantity so when you want to control the process you only change current okay, so voltage is a by product so that is why when you are saying that I welded we never say I welded in so and so voltage we always say so and so current okay so the field strength determines your JE okay so it is always we say that so the welding is carried out in 200 amperes we never say 10 volts.

It is meaningless because voltage is a direct quantity we derive voltage from arc okay so the current is rate controlling so when you say that the current is important so 100 amperes I welded with 100 amperes around 20 amperes okay so voltage is relevant is irrelevant yes its clear so you always use some E the field strength to generate JE and that will determine your heat generation. Yes its clear? Good

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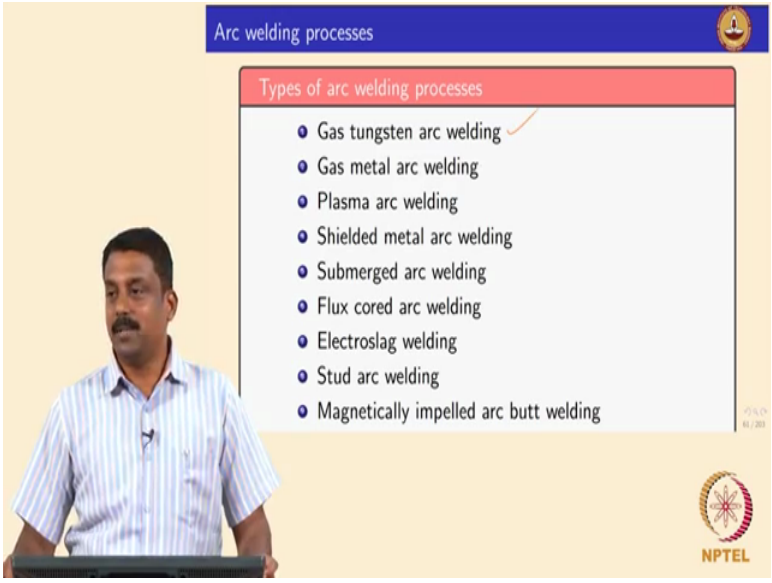

So we look at the types of welding processes and we will go one by one and arc using arc we can see the various types of processes and if you understand the physics you can also create a new process or invent a new process isn't it so now you have the physics or arc so basically you can modify the various parameters.

And you can also play around inventing a new process so there are types of arc welding process we look at in this selection gas tungsten arc welding, gas metal arc welding when arc be when does arc becomes plasma?

Student: (())(36:51)

Professor: Now it becomes electrically neutral okay so there is a type of welding process is a plasma welding it is not arc welding so we convert arc into plasma okay so the plasma arc welding and shielded metal arc welding, submerged arc welding, flux cored arc welding, electro slag welding, stud arc.

And a new process magnet, magnetically impelled arc butt welding we look at one by one so this we are going to install in in couple of months in our lab so these all welding process the majority of them that used in various engineering applications so if you are employed at a construction company okay you will be using one of welding processes okay or if you are employed many of the manufacturing metallurgical.

If you are metallurgy obviously you should know something about welding because that is the one of the major manufacturing process so you be handling at any point of your life any one of these welding processes so we look ahead again from the physics we understood how this process work okay so how heat is generated, how efficient this process, whether all the heat is generated in the arc is transferred okay if not why?

And can you quantify that okay so that is what we are going to study okay good you wind up here and then we will see in next class.