Technology of Surface Coating
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Lecture-32
Production of High Vacuum

In surface coating technology we already know that this vacuum system is one of the very important peripheral support and it maintains a certain level of pressure within the system, it depends upon a particular coating process and among one finally say for example CVD we have different degree of vacuum which will be essential to maintain a steady state in the process and to finally achieve a quality coating. Similarly, PVD is also a process where also we need to maintain a certain degree of vacuum that means the process pressure within the chamber but more importantly evacuation of the system before initiation of this process that is also very important.

So from that point of view we have 2 classes of equipments vacuum equipment namely the pumps and as we have already mentioned the basic purpose of this pump is to reduce the number of gas molecules within the reaction chamber within this coating chamber so that the process can be initiated. And in this we have 2 types of pumping system and today we shall discuss this production of high vacuum how we can produce high vacuum inside the system and that for that we have to really look into what are the types of pumps.

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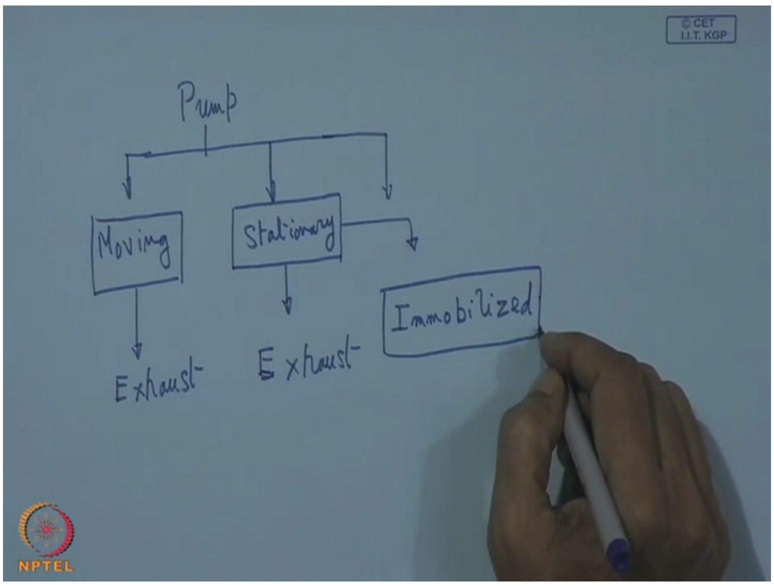

Now here what we can see that a pump for the high vacuum it can be just a moving, it can be even stationery that means there is no moving part. And then it can have further classification that means it is mostly mechanically working and here it is stationery so there is no rotor as such, no rotor or impaler, however in this moving one we have to finally find out whether the waste is thrown outside that means whether it needs one exhaust. So in the stationery pump also we have one such variety when we need also this exhaust that means that is delivered outside however, in this stationery group we have another one where this residual gas molecules which were very much in the present in the pump those are not shown outside and then what is done then?

It actually in this case what we call it is actually immobilised so this gas molecules are really immobilised within the chamber itself and there are certain parts or certain surfaces on which this whole thing will be absorbed or trapped so this is also another way of doing that thing so here we should look into and we shall see how all these pumps are working and all these are definitely working based on certain principles so let us look one by one what are those pumps.

The pumps for high vacuum that we what we are going to discuss today so this is actually a Vapour ejector pump. In fact, what we can write here this is actually a Vapour pump, vapour pump means we take the help of some vapour of some elements, it can be vapour of Mercury or it can be vapour of some oil and that is used and that entrance the gas molecules and it is along with that this oil vapour which attains certain velocity and since it it entrance that gas molecules so that gas molecules is thrown outside and this way we have 2 types of vapour pump, one we call Vapour ejector pump ejector pump and another is diffusion pump.

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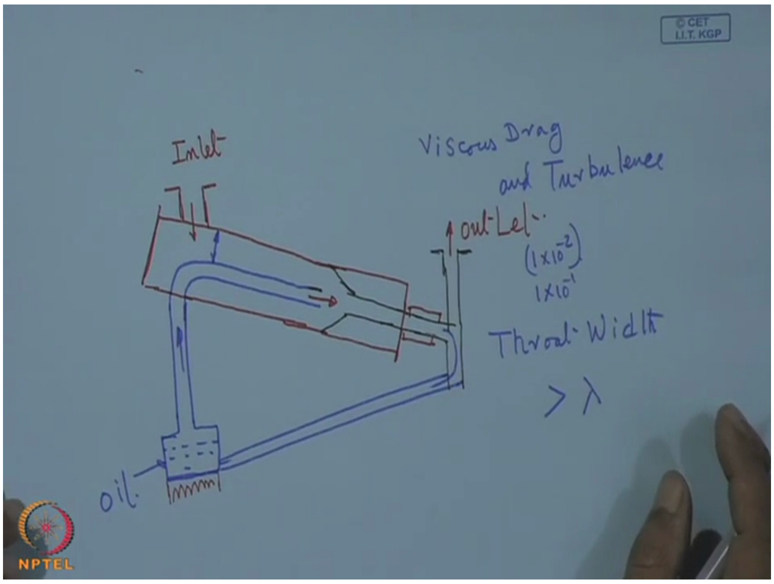

So this vapour ejector pump that actually works in the principle of molecules drag and turbulence so it is actually the drag force which is arising out of this viscous viscous force and that is called viscous drag, so let us look have a look quickly uh this pump just looking at this line diagram so here we have this one chamber which is reservoir of the oil so this is reserve of the oil and that is the extension of this oil reservoir so this is actually the reservoir of the oil and then this tube is bent it is bent and then what we have in addition to this is one vessel, it goes inside and here what we have, a cone like thing, so this is actually going to outside and here we have this tube so here we have a connection like this so this is actually a connection so this is more or less the basic thing what we have shown with this light diagram let us also recognise the various parts.

So here what we see that is the opening that means that is the inlet, this is actually the inlet so this is inlet and this is actually the outlet and what we have here this we can join so this is actually the tube. So this oil vapour so just beneath it we have one heater so this oil vapour this is heated and then this is moving upward because of this vapour pressure and at this point what happens, if there is some gas molecules from the chamber vacuum chamber is on this side so that will be in contact with this oil vapour and since it is moving in this direction then that will this oil vapour will entrant this gas molecules and that will move in this direction.

And since we have one convergence this cone shape that means in this case the velocity will increase and as a result the overall thing will move in this direction and then by proper cooling so here we have water cooling in this here, so in this water cooling in this zone we can recycle this oil vapour which will come that means which will be flown back from through this line and it will be recycled. So it is actually creation of the oil vapour and this will be a entrance this gas molecules from that chamber and down back will be dragged and why this called, it is actually viscous drag and turbulence that means this mixing that means this gas molecules that is actually entering by this gas this oil vapour so this is actually the oil vapour this is oil so it is actually the viscous drag and the turbulence because of the simple reason, here we have one direction and that we call the throat width.

And in this case this throat width that is greater than Lambda what we call the main free path so in this case since it is greater than Lambda so in this case there will be collusion and between these molecules and as a result of that we have viscous drag and turbulence and as a result of that this will be delivered in this direction and that is going to be one outlet. One thing we have to be careful here that this outlet pressure is still not atmospheric and it is in the order of 10 to the power – 2 order or 10 to the power – 1 and in this case just it cannot walk so on this side we need one rotary vane pump which is used for evacuating the system is down to 10 to the power – 2.

So from 10 to the power – 2 the pressure will be raised to atmospheric pressure atmosphere, and with that heat can be thrown outside and the job will be done effectively and successfully. So this is actually vapour ejector pump, so here this ejection is done by this viscous drag and turbulence. Now comes diffusion pumps, in fact here what happens what we have said throat area that means just at the entry point that means near the inlet, near the inlet we have a throat area and that term that parameter that is called width of the throat and this width of the throat in this case width of the throat width of the throat in this case that is actually less than Lambda that means in this case we do not expect any collusion within the gas molecules because the main free path is larger than this one greater than this one so in this case it will be just like diffusion and it is almost resembling the diffusion process.

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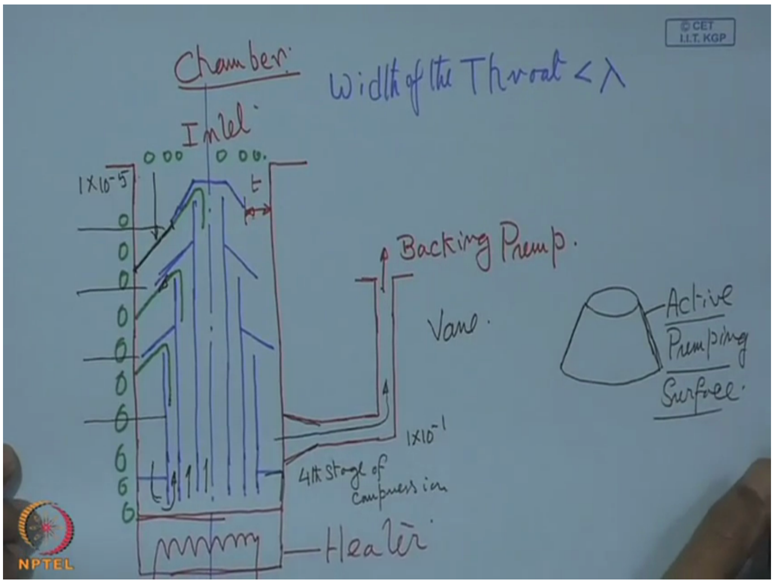

That means what we can see just by looking at this construction of the diffusion pump so it is actually the oil vapour creation of the oil vapour then this oil vapour will be deflected through a nozzle through a slit thereby attending a supersonic speed and with this supersonic speed it is going to entrant that gas molecule which comes by chance in front of the throat which we like to which we can see just now and by that process it will move with a very high velocity in the downstream direction and then just pushing this thing in the delivery side that brings on the exhaust side, so let us look how does it work.

It is basically a concentric tube that is in the construction of this pump, so this is one tube over which we have what we call one umbrella and then further to this what we have, we have here another umbrella and then we have another concentric tube, so this is the second stage we can also have the third and in this case we have another concentric tube, so this is more or less the construction and you have 1, 2 and 3 concentric tubes and these are called this is one chimney then you have one second one and that is the third one and here we see the 3 umbrellas. And what we can show further to this here this is the outermost surface that means the shell so that is the casing and just beneath this we have one heater so this area actually filled with oil this is the oil reserve.

Now what we can see here, so what we call throat so let us put this way so that is the plunge and on this side we have the Chambers for this side we have the Chamber that to be evacuated so this is actually the inlet side inlet, and what is called throat area actually this is the throat area so this is called the throat area so width of the throat means this gap, so what is what we can see here that stream of vapour that will move in this move upward but it will be deflected and here we have cooling coils cooling coil and what we have further to this here we have one opening here this is the opening and that is going to the exhaust, it is not exactly exhaust it will be connected to the backing pump, this is the backing pump it will be connected.

So let us look how does it work so it will be deflected and here we have the stream, similarly we have another stream emerging out through this second stage, we have also another stream flux that is also moving this way and here we have the gas molecules which are on this side on the chamber side so what we can see here that this part this particular portion this portion from this to this it is actually the vapour but if we magnify this thing it will look like a cone it is a truncated cone that means virtually it is going to be truncated cone having this shape and in this truncated cone that means this vapour stream is diverted it is deflected and now it is falling just almost like making one truncated cone. So for this part this surface this conical surface which is part of the cone that is actually the active pumping surface.

This is actually the active pumping surface on which will this particle is going to impinge. Now when it does not impinge with strikes it is already imprint and at the same time this string is going to strike or heat this cold wall of this chamber so first is impingement of this gas particles from this chamber this is impingement number 1 then it is entrant now it is moving and at the same time it is going to heat the straightforward cold wall and it is cooled by chilled water and they are this oil gets condensed and this condensation is continued throughout this down this height down this length of this outermost shell and what is what happens then the oil which gets condensed that is flown back to this surface that means this is oil reserve, it flows back and then the process repeats itself.

So that means there will be continuous evaporation vapour production of vapour of the oil through these 3 tubes, this is the cone these are the 2 annular tubes and at the same time there will be deflection of this vapour where it attains supersonic speed. So here it is moving with a supersonic speed and that is the impingement of the air air molecules or the gas molecule then the whole thing moves with this high velocity and in the process it strikes the wall and this gets condensed and what happens, this gas molecules which is separated that is accumulate here and then this is actually the opening and through this opening it is going in this side and here we can expect a pressure of 10 to the power – 5 with ordinary diffusion pump at this throat area very close to that inlet and the pressure very close to 1 into 10 to the power – 1 at this stage.

So what we can say here that this is actually the first stage compression here so this is the first page compression, this is the second stage compression and this is going to be the third stage compression and as a result of this what we see here that this will be a choke so here we also have the fourth stage of compression. So pressure will be raised from 1 into 10 to the power – 5 to the power – 1 but since it is already bought into this oil vapour and it is almost resembling a diffusion process and from this we need to have a backing pump say for example Vane pump and this vane pump will be connected here so that will be a backing line which have been already discussed in some of the previous lectures so that will be the total system consisting of the diffusion pump and the mechanical pump and that actually constitutes the backing line.

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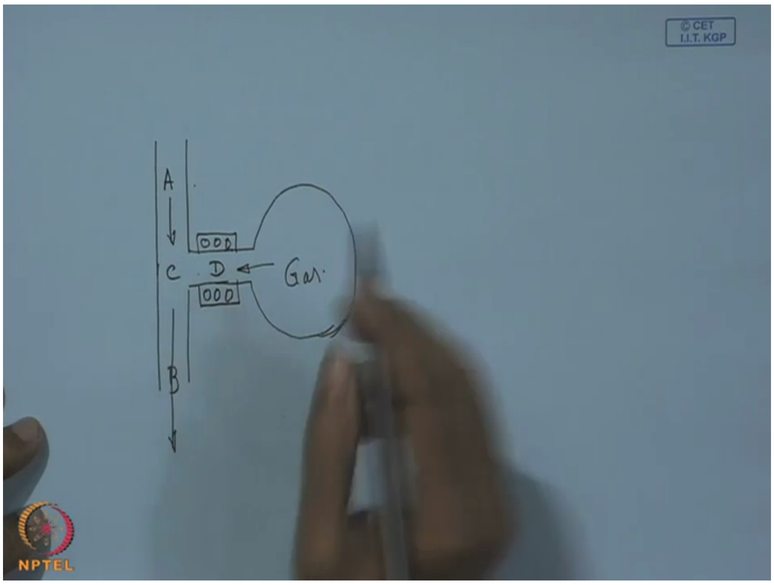

So this way the diffusion pump or actually this diffusion pump this can be explained by one principle. Suppose if we have a tube and here we have a right angle connection and then what we have here a vessel which is filled with some gas so this is actually gas filled and here say this is point A, B, this is C and this is D, this part we have a (())(24:53) so it is actually mercury vapour which is flowing in this direction, this is mercury vapour. If we cool this area cool this area then what is going to happen, all on a sudden there will be condensation of the gas and there will be a fall of pressure so this will move in this direction and in this process it will be entrant by this mercury vapour, so mercury vapour will entrant that one and as a result of that it will flow with the mercury vapour and there will be a continues flow of gas and this process is very similar to a diffusion process.

So this principle what we understand here just by condensing the vapour and then just dragging it that is exactly what we have applied or based on which principle this diffusion pump works. Now come turbo molecular pump, so what we have seen diffusion pump actually this diffusion pump it is non-rotating part, no part no component of this system is moving one so it is a stationary one but it is it actually throws this residual gas to the outside and then that is why we need a vacuum pump.

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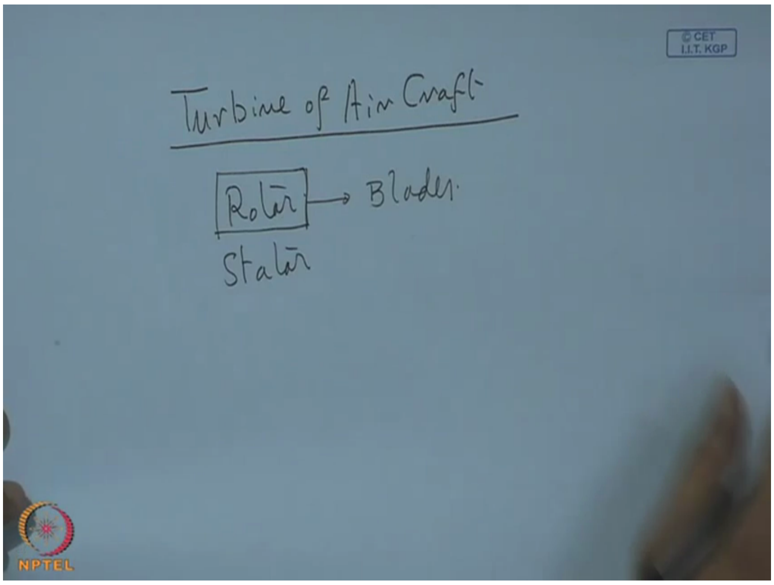

So it is not adsorbing the system or the residual gas is not immobilised but this turbo molecular pump that is rotating one and in this case what happens in fact the principle is something like this that means suppose there is a surface which is moving at a very high velocity and if one gas molecules strikes that one then a directional velocity will be parted on that so this is actually the principle of turbo molecular pump that means the gas molecules is imparted with a high directional momentum when it strikes or encounters actually a moving surface. In fact, this turbo molecular pump it is just like the turbine of aircraft. So it has sets of Rotors and stator and this rotor that is actually consist of Blades just like the turbine, so this rotor that is a disc it consists a number of Blades. Similarly in the stator we have also the corresponding number of slits so this way it works.

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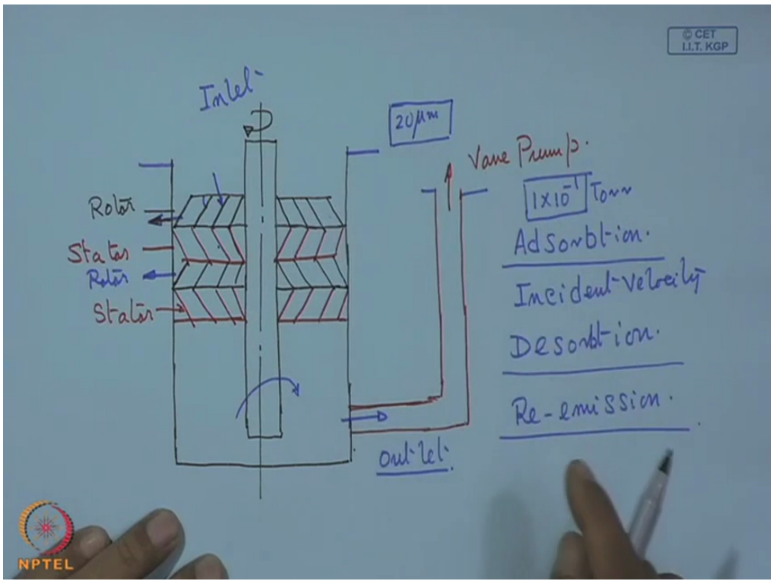

Now let us look into the busy construction of this pump, so here what we have? So there is a shaft and it is moving this way at a very high speed, it can be 50,000, 60,000, it can be even 100,000. Now what we can see here, on this we can have just like these blades so similarly what we can show in the slide this one so this is one set similarly, this is actually the rotor now just adjacent to this we have the stator, so this is one stage we can draw another stage also like this and another set of stator. So the whole thing so that means this is actually rotating so if we consider the velocity linear velocity, it will be directed in this direction so this is also another rotor so let us put this thing so it is moving in this direction this is also moving in this direction so this is also rotor and this is the stator.

And what we have further to this so we can have I have shown just 2 stages, we can have 5-6 stages and this way the thing will go and here what we have, we have one outlet from this turbine pump in this direction and that is going to be that is actually just like the backing line of the diffusion pump so that can go to the vane pump so it is just like a vacuum support. So what we see here in this case the gas molecules so this is just like the opening so this is the inlet and that is the outlet so the gas molecules these are actually when it heats this surface, it attains a directional velocity and momentum and here what we can see that these are not parallel to the axis but they are inclined.

So that means there are slots so these are the radial slots which are cut on this disc and these radial slots which are having certain angles so this is an angle so it is an oblige manner it is cut and in the process what happens if the gas particles encounter here so it will be heated by this surface, as a result of that it is going to be adsorbed on this surface so it is actually absorption that means it is approaching and it is absorbing at the type of adsorbtion on this blade so these are the Blades so it is absorption and it is actually arriving with certain incident velocity.

And then it will also desorbs with after some residents time desorption so adsorbtion and desorbtion that will also take place so from that point what is going to happen it will have a normal velocity and with this normal velocity it will move in this direction that means the direction is such that this particular material will move in this it is inclined in such a manner that this gas molecule when they are readmitted so disorbtion and this is called re-emission and during re-emission what is going to happen that during the re-emission this particle will be directed towards this surface mostly because of this particular orientation so that means here in the design what is very important that as this material heats the surface of the blade then it receives directional velocity end momentum and this directional velocity favours its further movement to the stator in this direction.

So this orientation of this blade that favours the directional momentum and velocity towards this stator and this rotor is also moving so compared to this stator and it has also certain relative velocity though it is stationary, but if we consider this speed of this compared to this it also has the pivotal one relative velocity. So in this way there will be effect in series so the thing will move, after striking its surface it will move to that and then it will be redirected and finally it will come out from this surface and where we have no further rotor so from this surface it will be pushed through this line.

And because of this very high velocity it will have movement and in this case there will be a vane pump which will do the remaining part of the operation that means if it leaves at a pressure of 10 to the power – 1 which is Torr which is below atmosphere then it will also from this pressure residual pressure it will raise the pressure up to the atmosphere so that the remaining gas molecules which are actually evacuated from this vacuum chamber that will be actually pushed through this tube and through the vane pump it will be thrown to the atmosphere. So the basic principle is like this, here the high velocity of this rotor that is utilised to give a directional velocity and momentum to the gas molecule which is going to strike this surface and these surfaces are designed in such a manner that means at should not be any backward flow and flow will be always from inlet to this discharge spout.

And in this case this angle that is one of the parameters of the design that should be taken into consideration and this way a high vacuum can be created and here one thing can be noted that earlier there was a requirement of giving just gap between the stator and rotor of just 20 microns and it was not an easy task in the very construction of this pump in the mechanical construction of this pump so it was not that very attractive equipment for or ultrahigh vacuum activity, but with some improvement and modification of this design thus requirement has been now much more liberalised and just a gap of as high as 1 millimetre now is allowed between the state and the rotor and that makes the task of fabrication of pump rather easy and with that what we can have?

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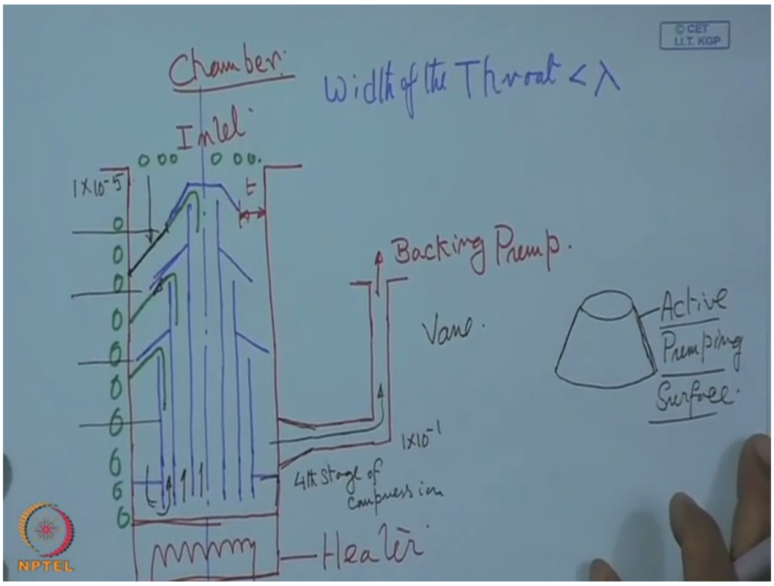

We can have further use much more use extensive use of this pump in all ultra high vacuum activity. One of the latest advantage of this pump with respect to the diffusion pump that we can have a quick look here. When we discussed this is a pump we have already always assumed that there is this deflection and that is actually in the downward direction, but for unfortunate eventualities if we do not have proper cooling and condensation if there be some back stripping of this vapour that can contaminate the chamber and the specimen but such thing we do not foresee in this case.

Here only the thing is that the rotational speed and this pump are actually put in the with a vertical axis because of the orientation of the chamber and in that case naturally alignment of any shaft with 2 end bearing support the vertical position and that is considering any mechanical assembly that is one of the greatest challenging task in the production and fabrication of this diffusion pump.

So this turbo molecular pump, it works at a very high velocity and with this high velocity we attain a very high momentum which is transferred to this. Actually it is no more a molecular drag, rather it is one should say that it is actually transfer of momentum in a particular direction when the material gas molecule actually impinged on this blade surface. So it is just like this momentum transfer that means this gas particle molecule this acquires a high magnitude direction momentum.

Now we can see this Cryo pump that means it is actually use of cryogenic medium. Now when we have seen sorption pump that means that we have already discussed sorption pump and here we also have seen that it is actually adsorbtion on the surface of molecule shield and which is super cooled by liquid nitrogen so that was the principle of this sorption pump and it it was mostly physical adsorbtion on the surface. So this was the molecule shape with surface was used for adsorbing the molecule and it is actually a not a high vacuum pump but it is roughing pump, it can be considered as one of the substitute for rotating vane pump.

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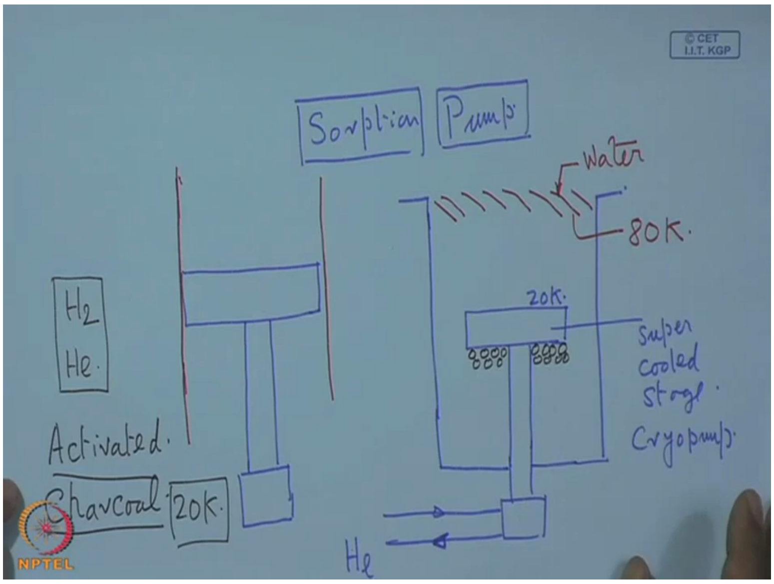

But this Cryo pump that is actually a vacuum pump and here what we see that it is actually a liquid Helium is instrumental in getting this high vacuum. So this is actually one stage and here we have the provision so this is an this is a chamber we can have some gap okay let us have a quick, so this is actually a chamber so this is one stage, so this is so this is the pump this is cryo pump. Now this one is a super cooled stage and it is cooled by passing not liquid nitrogen but liquid helium, it is He and the temperature that is kept on the surface it is 20K Kelvin and here what we have some condensing arrays of metal plates condensing array and that is kept at about 80 K so these surfaces are used for condensing water that means trapping the moisture.

And this surface that is for trapping all sort of gases so here this will be absorbed on these surfaces except hydrogen and helium and for this what is used what is used? Activated charcoal that is used that can be also used and that can be kept at 20 K also 20 degree Kelvin and that will be most effective material for also trapping this hydrogen and helium. So this is one thing, we can also use and this is not only it is non-rotating and also you are what we have seen it is unlike that of paper ejector pump or diffusion pump. Here the material is absorbed and it is made totally immobilised and it has to stay here and later on this thing can be heated to move it out at that point the surface will be absorbed by this condensation of these gases at this point, so this is called what we call a Cryo pump.

Now this is called Gettering pump, Gettering pump in fact it means that a particular substance that capture or gets the gas molecules on its surface, so it is just the intention here how to get those gas molecules on the surface of a particular metal it is a strategic metal which can capture those things on its surface and we get all those material on its surface and that is why it is called a Gettering pump. In fact, in a Gettering pump the material which gets this gas molecules that is nothing but titanium so it is actually a titanium Gettering pump and we can also call it Titanium sublimation pump.

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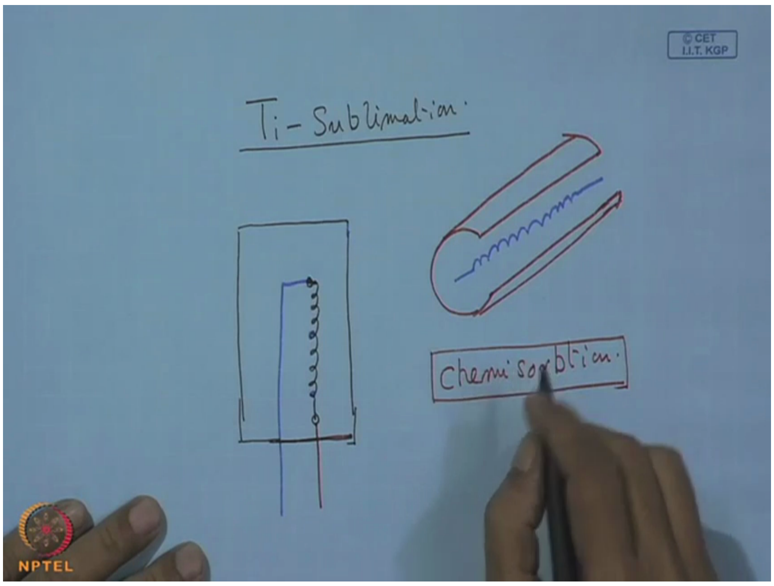

So what is done in this case it is also a non-rotating pump where these gas molecules are mobilised so they are not pushed anywhere outside the pump, so what we can see in this case so this is the chamber and what we have, we can have here say for example, one titanium foil or titanium coil so this can we can put this way so this is titanium so it has a lead wire which can go on the surface so we can close this sorry we can close this like the like this one and on this side we have a lead wire connection and the whole idea here that with this vacuum it has to sublimate that means it will be heated and the material from this titanium coil or titanium foil that will keep on evaporating that means we can also show this way say this is one titanium coil and it has just it is placed.

And it has just one annular surface, it is just having one annular surface here so by heating this the entire surface will be covered by titanium and by this cover we get an enlarged surface coated with titanium and that surface will be used for getting those gas molecules which have to be removed from the evacuation vacuum chamber and in this case it is mostly chemisorbtion of those gas molecules because titanium is well-known as a reactive material so it is through this chemisorbtion we can get a reduction of pressure and this is normally done in any sputtering process just to evaporate if we have a titanium target just to evaporate sputter titanium and it can quote some of the surface and thereby we can get a relatively high vacuum which is just not possible without this sputtering of titanium. So this is actually this Gettering pump titanium sublimation pump.

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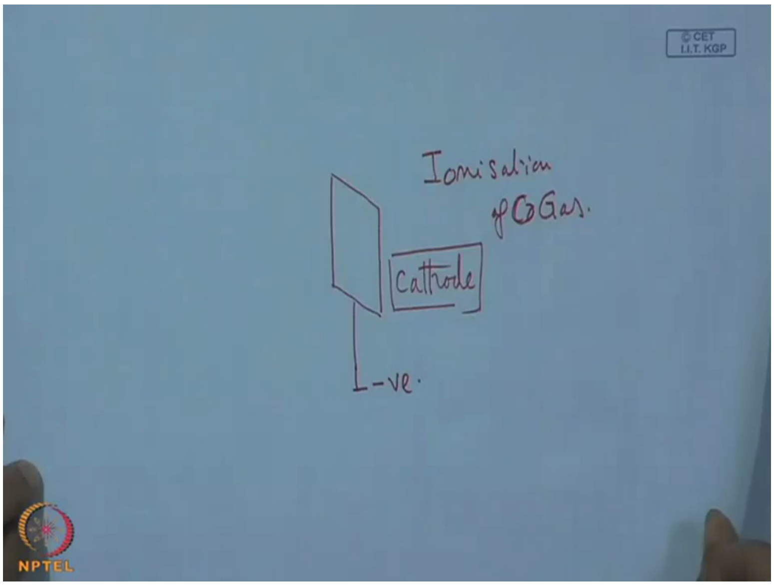

Now we get this Ion pump, now Ion pump is something here what we are going to do that the gas which is present inside the chamber that will be ionised and when it is ionised and if we can keep one cathode inside the chamber which is polarised with negative this negative potential so this is a cathode so that means first of all within the chamber we must have electron available which will be used to ionise the gas so it is actually ionisation of the gas followed by attracting these ions in a in a directional manner by putting one electric field. That means here these ions will be attracted electrically by this plate and by that there is movement of gas molecule gas particle not just as a neutral but just like an ion and this is actually in principle known as the ion pump or ion pumping so these are attracted by this cathode.

Now in this ion pump we can also have sputter ion pump or evaporation ion pump 2 types of pumps; either evapor it is called Evapor-ion pump or Sputter-ion pump. Now in both the cases what happens, in this case the material so for example titanium, titanium can be evaporated and this material the place where it is going to be evaporated that is actually polarised and that surface which is coated with titanium that which is coated with titanium, as a result of evaporation that will be colonised the negative bias that means that will be not used as cathode and then this ionised gas that will be attracted towards this surface so this is actually called evaporation ion pump.

That means titanium will be evaporated, gas will be ionised and this evaporated surface of titanium will be polarised with negative potential and this ionised gas will be attracted on this titanium coated surface which is now serving as a cathode. Now sputter ion pump here instead of evaporation we sputter the surface of interest by titanium and here the coating is done by sputtering and this particular gas which is reactive gas that can be absorbed on this surface which is actually sputter coated with titanium. So these are the pumps that means ion pump then sublimation pump and this cryo pump, these are the pumps which are used for evacuation and also for immobilising the gas particles which are present within the chamber.

Now with this we can summarise today's discussion that for high vacuum operation we have 2 types of pumps; one is rotating, another is non-rotating and in rotating we have turbo molecular pump where this gas particles acquire a directional momentum of a very high magnitude and through that it can attain sufficient velocity to be moved from the inlet towards the exhaust following various stages of rotor-stator state of the turbo molecular pump which is just like a turbine of an aircraft. Now here we have also diffusion pump which is also very commonly used, here actually the oil vapour entrance the gas molecules once it comes in close proximity and by this supersonic speed it drags it down the pump shell and thereby it releases and it gets the oil vapour gets condensed and then a 4 pump there which does the remaining part of the job that mean raises the pressure to atmosphere

We have further to these those pumps where those gas molecules are immobilised and these are non-rotating, in Cryo pump, it is adsorbtion of the gas molecules on a super cold surface and when it is sublimation pump or ion pump, either evaporation oil or sputter ion, in both the cases it is actually chemisorption of these gas molecules on the surface of titanium coated surface.