INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL
NPTEL ONLINE CERTIFICATION COURSE

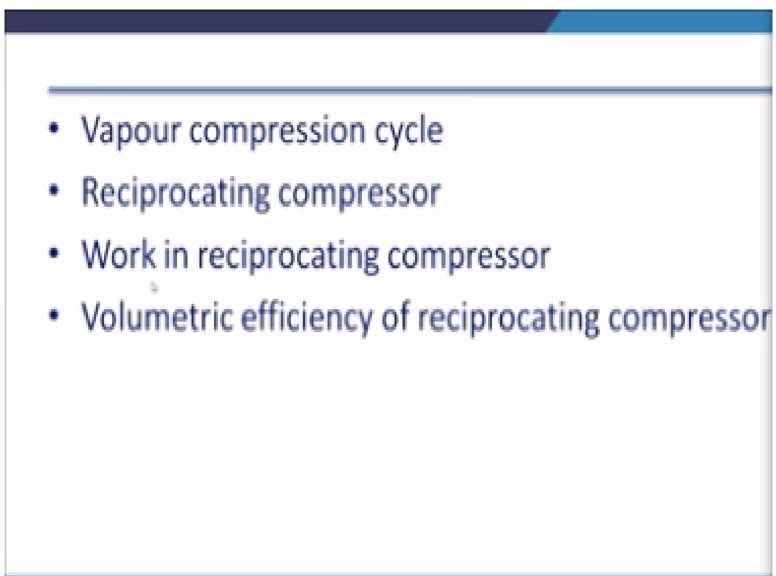
Refrigeration and Air-conditioning

Lecture-07
Vapour Compression Cycle-1

with
Prof. Ravi Kumar
Department of Mechanical and Industrial Engineering
Indian Initiation of technology, Rookee

Hello I welcome you all in this course on refrigeration and air conditioning. And today we will discuss the vapor compression cycle.

(Refer Slide Time: 00:37)



In this lecture we will cover the reciprocating compressor, work in reciprocating compressor, volumetric efficiency of reciprocating compressor in addition to the analysis on vapour compression cycle. In vapour compression cycle of refrigeration instead of using ideal gas equations we will be using charts and tables in order to find the properties of vapour at different states.

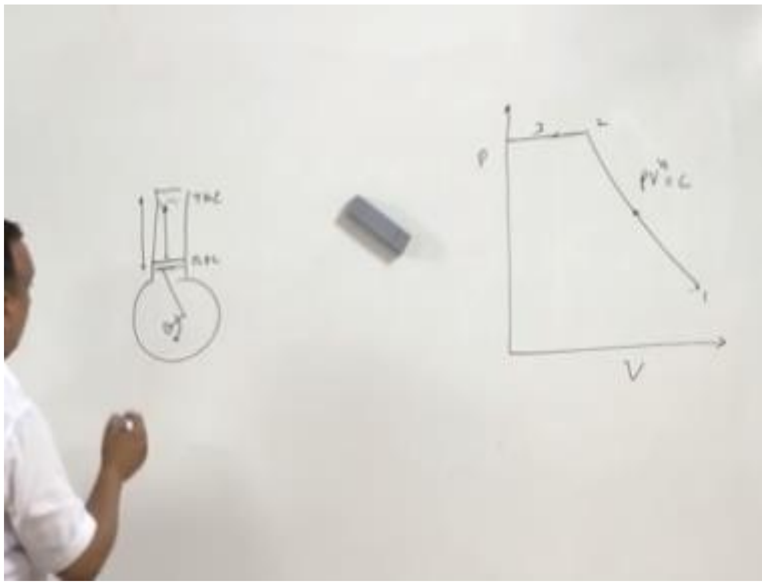
(Refer Slide Time: 00:59)

In vapour compression cycle if you look at the Carnot cycle on temperature entropy diagram in vapour compression cycle the heat addition and heat rejection that is start 1, 2, 3, 4 heat addition and heat rejection this is QL and this is QH. It takes place during boiling and condensation of refrigerant. So process two to three is nothing but the condensation of refrigerant and process four to one is nothing but boiling of refrigerant at respective temperature t1 and t2.

In these type of machines the compression process is very important and in this type of compression we cannot use this formula right. So and most of the vapour compression refrigeration system reciprocating compressors are used. So the analysis of reciprocating compressor with reference to the vapour compression systems become important a reciprocating compressor works on slider-crank mechanism.

A slider-crank mechanism is a four-link mechanism persisting of a piston is leading link connected to a rotating link which is known as crank and there is a connecting rod. This rotational motion of crank is converted to the reciprocating mission of the piston.

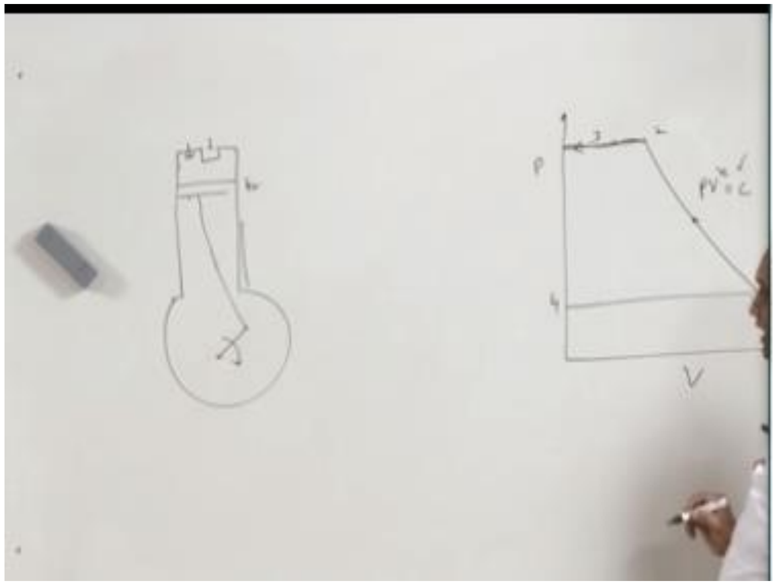
(Refer Slide Time: 02:39)



Most of the applications in vapour compression system it is a vertical type of system. So there is a crank case and a cylinder and piston is fitted inside the cylinder. So when the crank rotates with a certain rpm to inflow motion of the piston takes place their two positions that is top dead center and bottom dead center where the direction of the movement of the piston, the change in the direction of the movement of the piston takes place and this length is known as stroke of the compressor.

Now if we draw this on PV diagram starting from state 1 when the piston is at bottom dead center compression takes place, and this compression process is a polytrophic compression process state 1, state 2 and state 3. Now in this process part of the process is isentropic sorry not isentropic polytrophic PV^N is equal to constant and part of the process is constant pressure process.

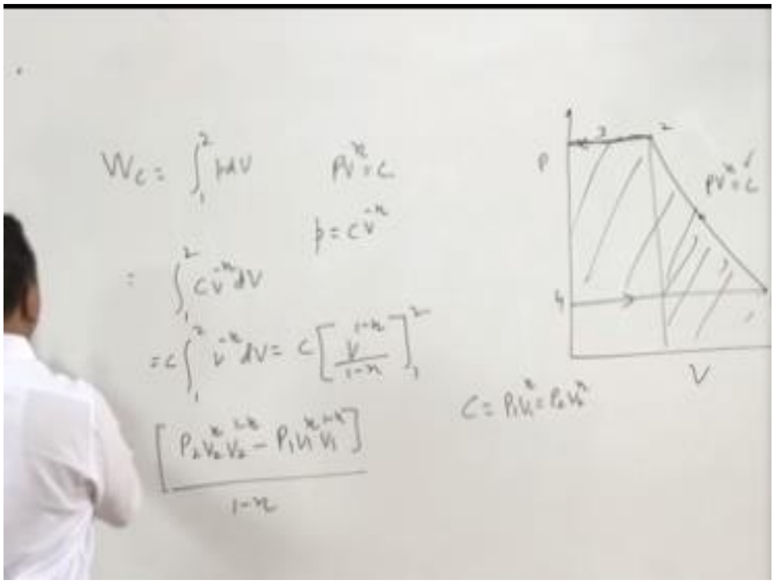
(Refer Slide Time: 04:01)



What happens I will draw a larger diagram, what happens when the piston moves in upward direction the system behaves as a go system it has two walls this compressor has two walls initially both the walls are closed. So when compression takes place it follows the polytrophic equation up to state 2, the moment the pressure 2 is attained exit walls opens, when the exit wall opens the vapor inside the cylinder is removed at constant pressure.

So the system becomes an open system the total work in the system is the area of this diagram 1, 2, 3 and 4, if you want to take area of this diagram.

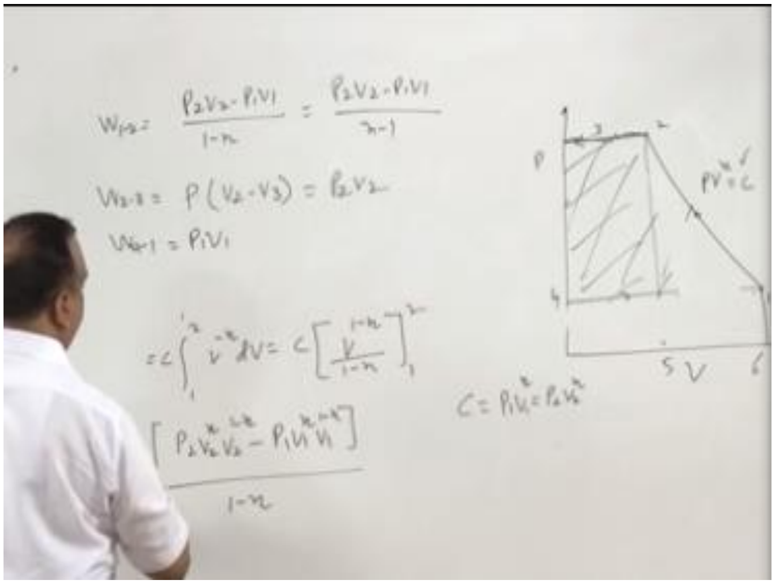
(Refer Slide Time: 05:10)



So what then during this process 1, 2, 3, 4 is the area of this diagram on PV and the work done can be calculated as the work done during process 1 to 2 + work done during process 3 to 2 to 3 – work done during process or area under 4 1. So area under 1 2 is nothing but 1 to 2 PDV where PV^N is equal to constant, because during process 1 to 2 the system behaves as a closed system. So P is equal to CV^{-N} putting this value here we will be getting CV^{-N} DV.

Now again 1 to 2 CV^{-N}-NDV=C[V^{1-n}/1-N] from 1 to 2. Now C can, C is also equal to $P1V1^N$ is equal to $P2V2^N$ now if we are taking $P1V1^N$ here and $P2V2^N$ here and C goes inside then it becomes $P2V2^N V2^{1-n}$-$P1V1^N$ and $V1^{1-N}$/1-N.

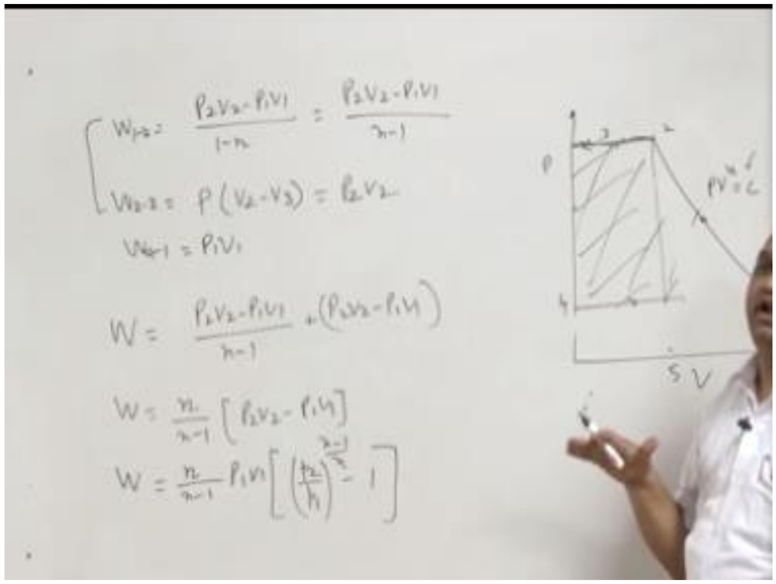
(Refer Slide Time: 07:01)



And that turns out to be work under during one to two that turns out to be P2V2 - P1V1/1-N because here in this process work is consumed by the system we will take negative of this and the final expression will be and this expression is for the work under this curve. Let us say 5 and 6, so work under 1, 2, 5, 6 this is the work done during compression from state 1 to state 2 for state 2 to state 3 is going to be P2V2 - V3 because V3 is 0 we can always write P2V2.

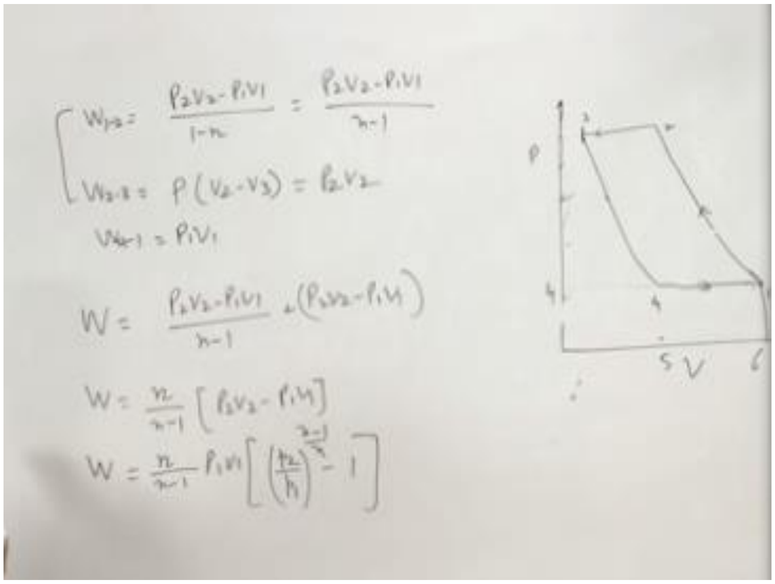
Now we have area under this also now total area minus this area will give the work done during compression and this area is again P1V1.

(Refer Slide Time: 08:21)



Now if we add all these 1 and 2 and subtract this 1 we will be getting an expression for work for the compressor that is P2V2 - P1V1/N-1+ P2V2 - P1V1 and the final expression is going to be n/n-1 P2V2 - P1V1. We can further simplify it by taking it in terms of pressure ratio then it is going to be equal to P1V1 $P2/P1^{n-1/n-1}$. This is the work of compression for this process but in actual practice what happens because at this state the piston will be striking the head of the cylinder volume is 0.

(Refer Slide Time: 09:23)

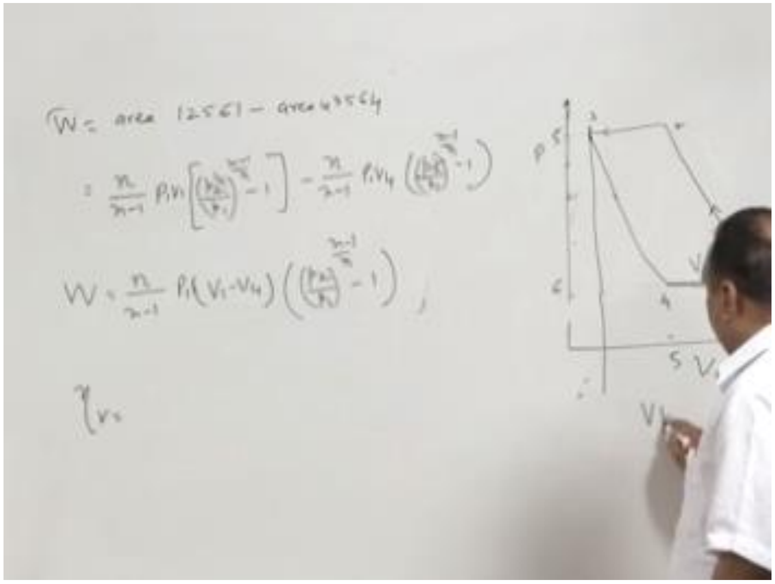


So piston will be striking the head of the cylinder therefore in order to avoid any damage to the head some clearance is provided, and this volume is known as clearance volume. So after the compression process remains same from state 1 to state 2, but instead of reaching up to here the stroke terminates at state 3 and some clearances provided between the piston head and the cylinder head.

Here we have compressed gas which could not go out of the compressor so the expansion of this gas takes place state four is attained, and after attaining a state 4 the intake of or the suction of vapor takes place. So this is actual cycle where initially the compression takes place at the bottom dead center then after state 2 the exit of vapor starts from the compressor it terminates at the state 3, at state 3 we have compressed vapor this compressed vapor expands the system behaves as a closed system up to state 4 when the state 4 is attained the suction of the inlet valve of the compressor opens and suction of vapor takes place.

So in order to find work done during this process, now we have already calculated work done in this process. So if we take work done in this process - work done in this process will give the work assumed by the compressor.

(Refer Slide Time: 11:12)

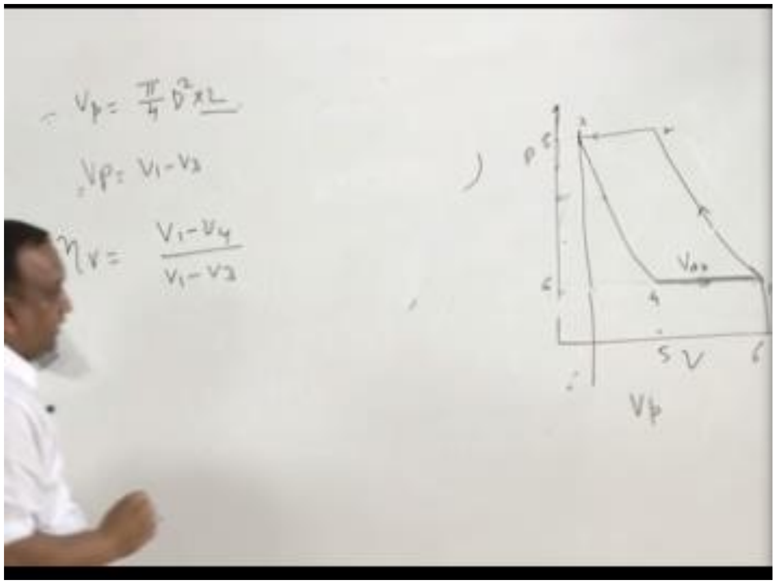


So net work done 4 this is let us take 5 and 6. So network that will be area 1, 2, 5, 6, 1 - area 4, 3, 5, 6, 4 area 1, 2, 5, 6, 1 we have already derived and similar fashion we can find the area for this as n/n-1 P1V4 P2 sorry $P2/P1^{n-1/n-1}$. And that work consumed by compressor during compression of vapor is going to be n/n-1 P1V1 - V4 P2/P1 n-1/n-1. So instead of having V1 in previous expression now we have V1 - V4.

This is the actual suction volume and it is often referred as VAS actual suction volume because in this process only suction of vapor takes place this process only expansion of high pressure vapor takes place and there is no suction of vapor. So if you are shifting point to this direction less and less vapor will get sent into the compressor. Now after this the volumetric efficiency of the compressor is important.

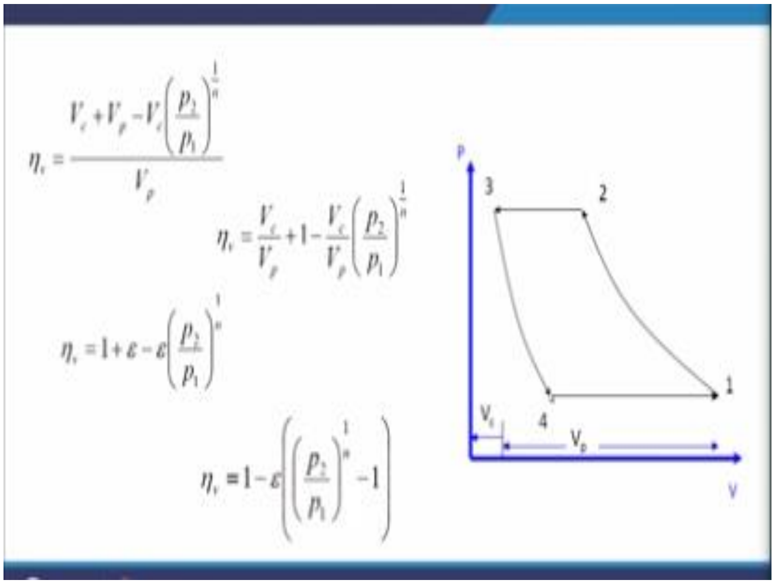
Now volumetric efficiency of the compressor is the ratio of actual mass of the vapor swept divided by mass of the vapor corresponding to the swept volume of the compressor. So mass of the vapor corresponding to the swift volume of the compressor that is VP.

(Refer Slide Time: 13:42)



So now we have two volumes one is swept volume of the compressor VP that is equal to Л/4D^{2}xL, D is the diameter of the cylinder and L is the stroke of the compressor. Now this VP is equal to here it is V1 - V3. So mass of vapor equivalent to this volume, so mass of the vapor equivalent to actually swift volume divided by the mass of vapor equivalent to the swift volume is volumetric efficiency. So volumetric efficiency is going to be equal to V1 -V3 divided by sorry V1 - V4/V1 - V3. Now here V1, V1 is this is clearance volume VC.

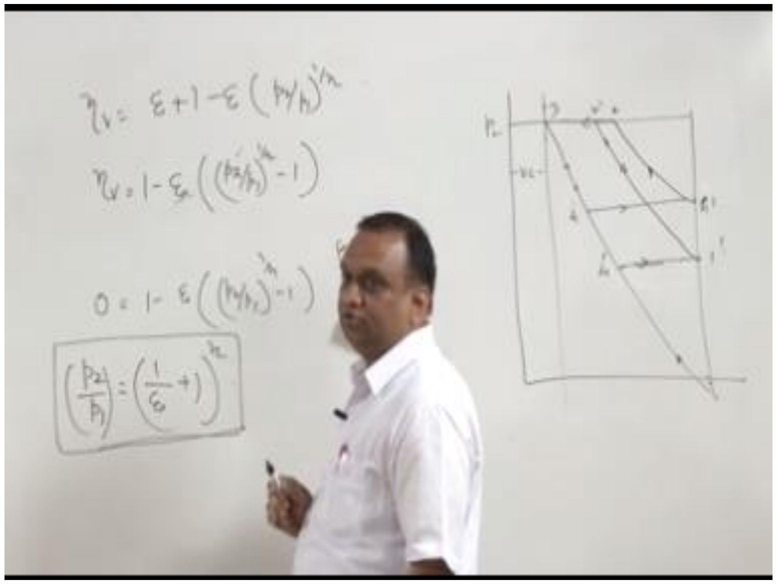
(Refer Slide Time: 14:53)



So V1 is clearance volume plus VP and V4, V4 we can take as clearance volume multiplied by P2 by $P1^{1/n}$ this is this expansion process. The index of compression is from state 1 to state 2 is n and we have assumed that index of expansion is also n, however it may be different also. So this is V1 - V4 expression for V1 - V4 and expression for V1 - V3 is VP only. Now if you simplify this we will be getting VC/VP + 1- VC/VP $P2/P1^{n}$.

Now VC/VP is clearance ratio of the compressor. So volumetric efficiency is equal to clearance ratio η+1 - η $P2/P1^{1/n}$ and further we can write volumetric efficiency is equal to 1 - $P2/P1^{1/n}$-1 sorry, 1- η.

(Refer Slide Time: 16:36)



If you look at this expression if the pressure ratio is high if the pressure ratio is high it is going to affect the volumetric efficiency and volumetric efficiency will reduce. If you increase the clearance ratio if we increase the clearance ratio or clearance for say VP the volumetric efficiency of the compressor will reduce. But in any case in a refrigeration system approximately 5% of clearance ratio is maintained. It can go up to 7% but minimum of 5% of clearance ratio is maintained.

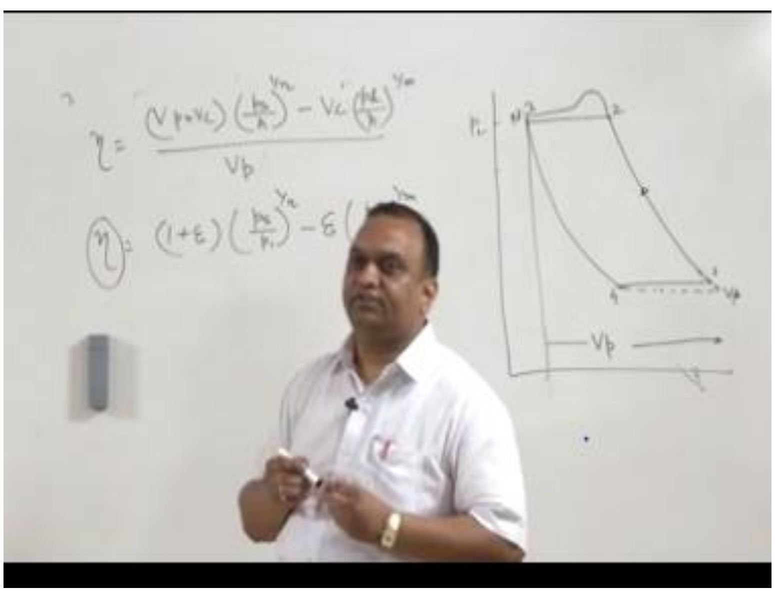
Regarding P2 and P1 there may be a situation when volumetric efficiency is zero. Now if the volumetric efficiency is zero in that case the value of clearance ratio is going to be this is the value of clearance ratio this is the value of pressure ratio not clearance ratio of pressure ratio for a given clearance ratio. It means for a given compressor because clearance volume is constant so there is a constant clearance volume right, maximum pressure is constant discharge pressure is constant P2 is constant VC is constant.

If we keep on reducing the P1 if we keep on reducing the P1 let us see at what stage we will be getting the volumetric efficiency is zero. So starting from P1 here the vapour is compressed from 1 to 2 then constant pressure discharge and then expansion takes place. So we can locate the point 1, 2, 3, 4 here. Now we reduce P1, P1 to let us say somewhere here. Now in this case what is going to happen we will be the point 2 will be shifted as 2’ point 3 is fixed because clearance volume is fixed.

But during the expansion the point 4 will be shifted here. So this is going to be the modified cycle this is state 1 this is state 1’ so 1’ 2’ 3 4’ is going to be the modified cycle. Now we keep on reducing P1 if pressure ratio will come when we will be simply compressing the vapor and during expansion the expansion of the vapor will occupy the entire stroke of the compressor. So this is this situation.

So in order to have high value of volumetric efficiency because it is always desired, the pressure ratio should be as minimum as possible, this clearance ratio should be as well as possible but not lower than 5%. Normally in a single stage recording compressor for vapour compression system the pressure ratio is of the order of four to five.

(Refer Slide Time: 20:29)



Now this diagram I have drawn for this reciprocating compressor has not taken into account the pressure drops in the wall. The pressure drop in suction wall and this chart wall takes place because if the fluid has to flow suppose compressor has to suck air from outside the pressure inside the cylinder should be less than the atmospheric pressure. Otherwise air will not be sucked into the cylinder.

Because for the flow of the fluid there should be pressure drop in the direction of the fluid flow. So instead of having state one will have process something like this, so here we will have VP sorry VS suction. So instead of having state one we are going to have state 1' and a state 1' dash the volume is VS one to two process will remain same not two to three process compressor has to push vapour out of the cylinder.

Since vapour has to be pushed out of the cylinder the pressure inside the cylinder should be more than the pressure in the pipeline. So the pressure curve will be something like this and this is PD. So pressure will be slightly higher at the discharge. Now here in this case if I want to have volumetric efficiency the volumetric efficiency is going this is same VP, VP is up to here. So volumetric efficiency is V1 - V4/VP.

Now V1 so in order to find V1 first of all calculate VS, VS is equal to VP + VC suction volume. Now we assume inside the cylinder due to ramming action the VS is reduced to 1 and it is a polytrophic process. So V1 = VP + VC $PS/T1^{1/n}$. Similarly for the expansion process because expansion does not start from 3 but it starts a little higher than 3 and the V4 is therefore V4 is $PD/P1^{1/n}$xVC.

So expression for volumetric efficiency in this case is going to be equal to VP + VC x $PS/P1^{1/n}$-PD/P1-VC $PD/P1^{1/n}$ or it can be 1/M also, this index of expansion can be different from this. So divided by VP so for volumetric efficiency it is going to be 1 + ∑ $PS/P1^{1/n}$-∑ this is $PD/P1^{1/n}$ so this is the actual volume expression for the actual volumetric efficiency of a reciprocating compressor when we are taking into account the pressure drop across the walls.

Now after finding out the volumetric efficiency of this compressor because this expression is very helpful in analysis of vapour compression refrigeration system, because it vapour compression refrigeration system we always require while analyzing the vapour compression refrigeration system we always require the volumetric efficiency of reciprocating compressor. So here I end this lecture with this and in the next class we will start with the reverse Carnot cycle for vapour compression refrigeration system. Thank you.

Educational Technology Cell
Indian Institute of Technology Roorkee

Production for NPTEL
Ministry of Human Resource Development
Government of India

For Further Details Contact

Coordinator, Educational Technology Cell
Indian Institute of Technology Roorkee
Roorkee – 247667
E Mail: etcell@iitr.ernet.in, etcell.iitrke@gmail.com
Website: www.nptel.ac.in

Acknowledgement
Prof.Pradipt Banerji
Director, IIT Roorkee

Subject Expert & Script
Prof.Ravi Kumar
Dept of Mechanical and
Industrial Engineering
IIT Roorkee

Production Team
Neetesh Kumar

Jitender Kumar

Sourav

Camera

Sarath Koovery

Online Editing

Jithin.k

Video Editing

Pankaj Saini

Graphics

Binoy.V.P

NPTEL Coordinator

Prof.B.K.Gandhi

An Educational Technology Cell

IIT Roorkeee Production