Lecture 11: ME 8493 Thermal Engineering-I

Topic to be covered	Classification, Working of single stage compressor, Work done without clearance volume

Learning Outcomes

LO	At the end of the lecture students will be able to	CO	BL
LO1	Explain working of reciprocating compressor	CO2	L3
LO2	Estimates the work done on compressor without clearance volume		
Bloom's Level: 1-Remembers, 2-Understand, 3-Apply, 4-Analyse, 5-Evaluate, 6-Create			

Air compressor

Air compressor is a machine takes in atmospheric air, compresses and delivers high pressure air. The compressor is driven by an electrical motor or internal combustion engine. The schematic diagram of compressor is shown in figure.

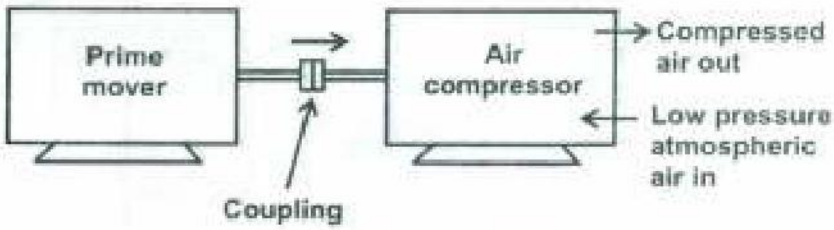


Fig. 6.1: Air compressor

Use of compressed air

- For operating small pneumatic hand tools
- Operating drills and hammers in road building
- To fill automobile tyres
- For operating brakes in buses and trucks
- Melting furnace
- For operation of lifts and pneumatic conveyers
- For starting internal combustion engine
- Paint spraying and tunnelling

Classification of air compressor

- According to working: Reciprocating and rotary compressor
- According to action: Single acting and double acting compressor
- According to number of stages: Single stage and multi stage compressors

Working principles of single stage reciprocating compressor

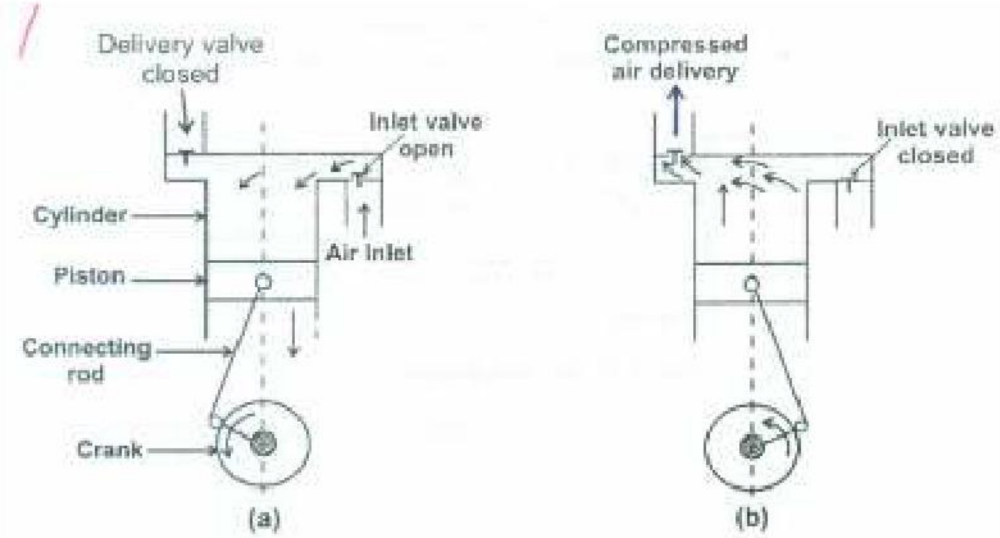
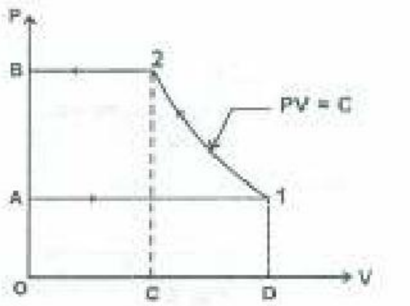


Fig. 6.2: Single stage Reciprocating compressor

Work done without clearance volume

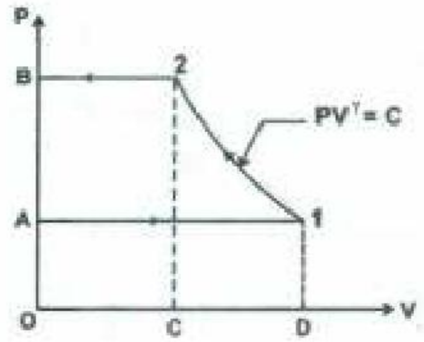
1. **Isothermal Compression**



Work done during isothermal compression
W = area A12B
 = area OB2C + area C21D – area OA1D

$$W = P_2V_2 + P_1V_1 \ln\left(\frac{P_2}{P_1}\right) - P_1V_1 = P_1V_1 \ln\left(\frac{P_2}{P_1}\right) = mRT_1 \ln\left(\frac{P_2}{P_1}\right)$$

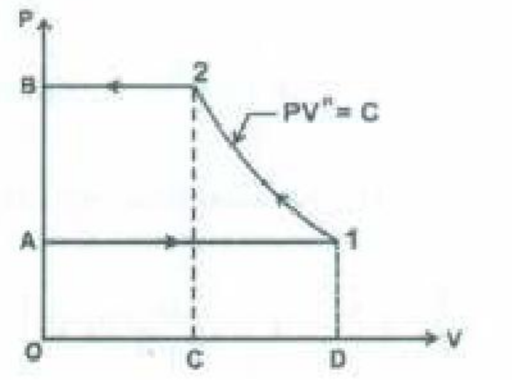
2. **Adiabatic compression**



Work done during isothermal compression
W = area A12B
 = area OB2C + area C21D – area OA1D

$$W = P_1V_1 + \frac{P_1V_1 - P_2V_2}{\gamma - 1} - P_2V_2 = \frac{\gamma}{\gamma - 1} P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

3. Polytropic compression



Work done during isothermal compression
W = area A12B
= area OB2C + area C21D – area OA1D

$$W = P_1V_1 + \frac{P_1V_1 - P_2V_2}{n-1} - P_2V_2 = \frac{n}{n-1}P_1V_1\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

Learning Outcome Assessment Questions

1. The work input to air compressor is minimum if the compression follows the law
   a. $PV^{1.25}$=Constant
   b. PV=Constant
   c. PV^{γ}=Constant
   d. $PV^{1.3}$=Constant
2. Isothermal compression in a reciprocating compressor is possible when the compressor is running at
   a. Very low speed
   b. Very high speed
   c. Low pressure during suction and high speed during delivery
   d. Any speed
3. Work input to the reciprocating air compressor with 'n' as index of compression
   a. Increases with increase in value of n
   b. Decreases with increase in value of n
   c. Remains constant with n
   d. None of the above
4. Classify the air compressor (AU-May 2013)
5. Give the classification of compressor based on movement of piston (AU-Nov 2013)
6. Mention important applications of compressed air (AU-Nov 2013)
7. Explain the working of a single stage single acting reciprocating compressor with a neat sketch and PV diagram. (AU-May 2010)

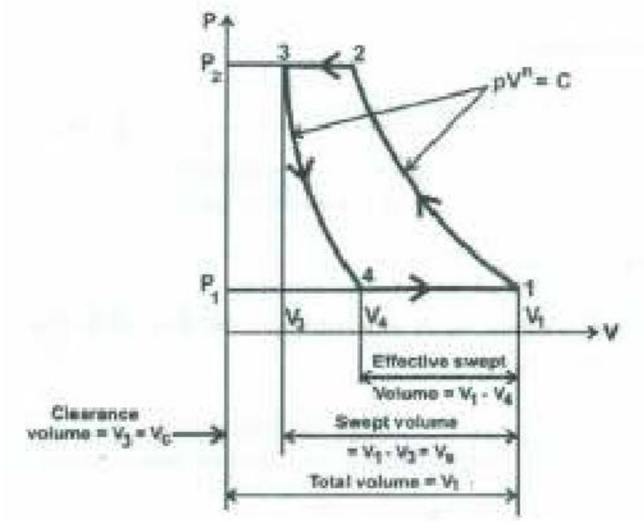
Lecture 12: ME 8493 Thermal Engineering-I

Topic to be covered	Work done with clearance volume, Efficiency of compressor-volumetric efficiency

Learning Outcomes

LO	At the end of the lecture students will be able to	CO	BL
LO1	Estimate the work done with clearance volume	CO2	L2
LO2	Explain various efficiencies	CO2	L2
LO3	Derive the volumetric efficiency	CO2	L2
Bloom's Level: 1-Remembers, 2-Understand, 3-Apply, 4-Analyse, 5-Evaluate, 6-Create			

Work done with clearance volume



Work done = area 12341

$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] - \frac{n}{n-1} P_4 V_4 \left[\left(\frac{P_3}{P_4} \right)^{\frac{n-1}{n}} - 1 \right]$$

From the PV diagram $P_1=P_4$ and $P_3=P_2$

$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] - \frac{n}{n-1} P_1 V_4 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$W = \frac{n}{n-1} P_1 (V_1 - V_4) \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$W = \frac{n}{n-1} mRT_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

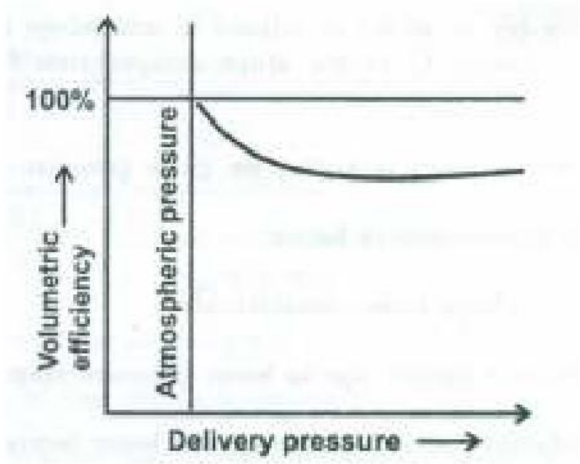
Efficiency of compressor

1. Isothermal efficiency $\eta_{isothermal} = \frac{\text{Isothermal Work done}}{\text{Actual work done}}$
2. Adiabatic efficiency $\eta_{adiabatic} = \frac{\text{Adiabatic Work done}}{\text{Actual work done}}$
3. Volumetric efficiency

$$\eta_{vol} = \frac{\text{Free air delivered}}{\text{Swept volume of compressor}} = \frac{V_1 - V_4}{V_1 - V_3} = 1 + k - k\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}$$

Where $k = \frac{\text{Clearance volume}}{\text{Swept volume}} = \frac{Vc}{Vs} = \frac{V_3}{V_1 - V_3}$

The volumetric efficiency decreases with increase in pressure ratio or delivery pressure



4. Mechanical Efficiency $\eta_{mech} = \frac{\text{Power used for compression of air}}{\text{Power given to compressor from the prime mover}}$

Learning Outcome Assessment Questions

1. When the clearance volume increases, the work of compression per kg of air
   a. Increases
   b. Decreases
   c. First increases and then decreases
   d. Remains constant
2. For constant suction pressure, when the delivery pressure increases the volumetric efficiency
   a. Increases
   b. Decreases
   c. Remains constant
   d. Not affected
3. In a reciprocating air compressor the clearance ratio is

$a. \frac{\text{Total volume of cylinder}}{\text{Clearance volume}}$ $b \frac{\text{Swept volume of cylinder}}{\text{Clearance volume}}$

$c \frac{\text{Clearance volume}}{\text{Swept volume of cylinder}}$ $d \frac{\text{Clearance volume}}{\text{Total volume of cylinder}}$

4. The suction and delivery valves in reciprocating compressor opened and closed by
    a. Valve actuating mechanism
    b. Temperature difference across the valve
    c. Pressure difference across the valve
    d. Governing mechanism
5. In a reciprocating compressor P_2=delivery pressure, P_1=suction pressure , k=clearance ratio and n=index of compression and expansion, the volumetric efficiency is given by
    a. $1-k+k(P_2/P_1)^{1/n}$
    b. $1+k-k(P_2/P_1)$
    c. $1+k-k(P_2/P_1)^{1/n}$
    d. $1+k+k(P_2/P_1)^{1/n}$
6. Define volumetric efficiency of compressor. (AU-May 2006)
7. What is the need for clearance volume in reciprocating air compressor (AU-Nov 2012)
8. What is the effect of clearance volume on the power required and work done in a reciprocating air compressor? (AU-May 2009)
9. State the conditions which lower the volumetric efficiency of air compressor. (AU-Nov 2012)
10. What is meant by isothermal efficiency of a compressor? (AU-May 2010)
11. Define isentropic efficiency of reciprocating compressor? (AU-Nov 2014)
12. What are the differences between isothermal and isentropic efficiencies of air compressor? (AU-Nov 2009)
13. What is FAD in connection with reciprocating compressor? (AU-Nov 2009)
14. Derive an expression for volumetric efficiency of an air compressor (AU-May 2014)
15. How the volumetric efficiency of the reciprocating air compressor is affected by the following parameters (i) the speed of the compressor (ii) the delivery pressure (iii) throttling across the valves. (AU-Nov 2009)

Lecture 13: ME 8493 Thermal Engineering-I

Topic to be covered	Multistage compression with intercooling

Learning Outcomes

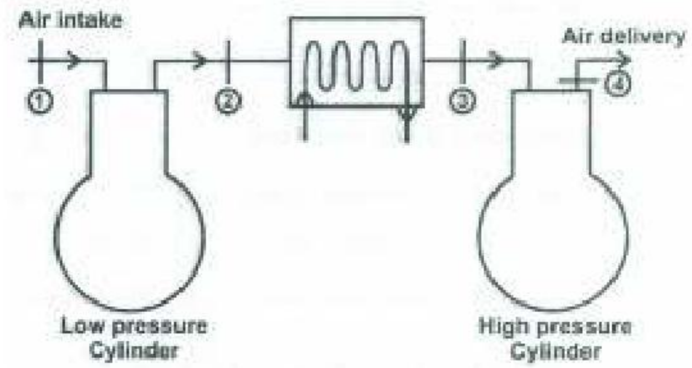
LO	At the end of the lecture students will be able to	CO	BL
LO1	Explain working two stage compressor	CO2	L2
LO2	Derive the work done equation for two stage compressor	CO2	L2
Bloom's Level: L1-Remember, L2-Understand, L3-Apply, L4-Analyse, L5-Evaluate, L6-Create			

Multi stage compression

Compressing the air in more than one stage (cylinder) is called as multi stage compression. The multi stage compression is used when the pressure ratio is higher say 8 to 10. The two stage compressor is shown in figure. The advantages of multi stage compressor are:

1. The work done per kg of air is reduced in multistage compression with inter cooling as compared to single stage compression for the same delivery pressure
2. The volumetric efficiency is higher for given pressure ratio
3. The mechanical balancing is better
4. It reduces the leakage losses considerably
5. The construction is lighter due to lower pressure stages
6. It provides effective lubrication because of lower temperature range

Two stage air compressor



Work done in two stage compression with perfect intercooling is

$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] + \frac{n}{n-1} P_3 V_3 \left[\left(\frac{P_4}{P_3} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$W = \frac{n}{n-1} mRT_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] + \frac{n}{n-1} mRT_3 \left[\left(\frac{P_4}{P_3} \right)^{\frac{n-1}{n}} - 1 \right]$$

For perfect intercooling $T_1 = T_3$

$$W = \frac{n}{n-1} mRT_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} + \left(\frac{P_4}{P_2} \right)^{\frac{n-1}{n}} - 2 \right]$$

Now, Suction pressure P_1, intermediate pressure P_2 and delivery pressure P_3, then

$$W = \frac{n}{n-1} mRT_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 2 \right]$$

$$W = \frac{n}{n-1} P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 2 \right]$$

For minimum work done $dW/dP_2 = 0$, performing the differentiation $P_2 = (P_1P_3)^{1/2}$ Therefore the work done is

$$W = \frac{2n}{n-1} P_1V_1 \left[\left(\frac{P_3}{P_1}\right)^{\frac{n-1}{2n}} - 1 \right]$$

For N number of stages, the stage pressure ratio is $\frac{P_2}{P_1} = \frac{P_3}{P_2} = ... = \frac{P_{N+1}}{P_N}$. Then, the work done for N number of stages

$$W = \frac{Nn}{n-1} P_1V_1 \left[\left(\frac{P_{N-1}}{P_1}\right)^{\frac{n-1}{Nn}} - 1 \right]$$

Learning Outcome Assessment Questions

1. Consider a two stage reciprocating air compressor with perfect intercooler operating at the best intermediate pressure. The air enters the low pressure cylinder at 1 bar, 27°C and leaves the high pressure cylinder at 9 bar. Assume the index of compression and expansion in each stage is 1.4 and that for air R=287 J/kg K, the work done in high pressure cylinder is
   a. 111 kJ
   b. 222 kJ
   c. 37 kJ
   d. 74 kJ
2. Clearance volume of a reciprocating compressor is 100 ml and the volume of the cylinder at bottom dead centre is 1 litre. The clearance ratio of the compressor is
   a. 1/11
   b. 1/10
   c. 1/9
   d. 1/12
3. Which of the following statements does NOT apply to volumetric efficiency of a reciprocating air compressor
   a. It decreases with increase in inlet temperature
   b. It increases with decrease in pressure ratio
   c. It increases with decrease in clearance ratio
   d. It decreases with increase in clearance to stroke ratio

4. A single acting two stage compressor with complete inter cooling delivers air at 16 bar. Assuming an intake state of 1 bar and 15°C, the pressure ratio per stage is
   a. 1
   b. 8
   c. 4
   d. 2
5. What are the advantages of multi stage compression? (AU-May 2006)
6. Draw the PV diagram of two stage compressor (AU-May 2014)
7. Define the term inter cooling. (AU-Nov 2009)
8. What do you mean by perfect intercooling? (AU-Nov 2012)
9. What is the effect of intercooling in multi stage compressor? (AU-Nov 2009)
10. How does the inter cooling reduces the work input of compressor? (AU-May 2010)
11. Give the expression for work done for a two stage reciprocating compressor with inter cooler (AU-May 2013)
12. How does the valve operation of a compressor differ from the valve operation of IC engine (AU-May 2010)
13. Explain the construction and working principles of multi stage compressor and discuss the perfect and im-perfect intercooling with neat sketch (AU-Nov 2013)
14. Derive the expression for minimum work required for a two stage reciprocating air compressor. (AU-May 2009)

Lecture 1: ME 8493 Thermal Engineering-I

Topic to be covered	Working principles and comparison of Rotary compressor with reciprocating compressor

Learning Outcomes

LO	At the end of the lecture students will be able to	CO	BL
LO1	Explain the working of various rotary compressor	CO2	L2
LO2	Compare the reciprocating and rotary compressor	CO2	L2
Bloom's Level: 1-Remember, 2-Understand, 3-Apply, 4-Analyse, 5-Evaluate, 6-Create			

Rotary compressor

Rotary compressors are the machines which develop pressure by the rotary action of the rotor or impeller. The rotary compressors are used where large quantity of air is required at relatively low pressure. The various types of rotary compressors are (i) Root blower, (ii) Vane blower (iii) Centrifugal compressor and (iv) Axial compressor.

Root Blower

A root blower consists of two rotors with lobes rotating in an air tight casing. The casing has inlet and outlet PORTS ON OPPOSITE SIDES. Root blower has two or three lobes as shown in figure. The lobes are so designed that they provide an air tight joint at point of their contact. One of the rotors is rotated by external means. The other is gear is driven by the first one. When the rotators rotate, the air at atmosphere pressure is trapped in the pockets formed between rotors and casing. The rotary motions of the lobes deliver the entrapped air into the receiver. Thus more and more air is delivered in to the receiver. This increases the pressure of air in the receiver. Finally the air is used at required pressure from the receiver.

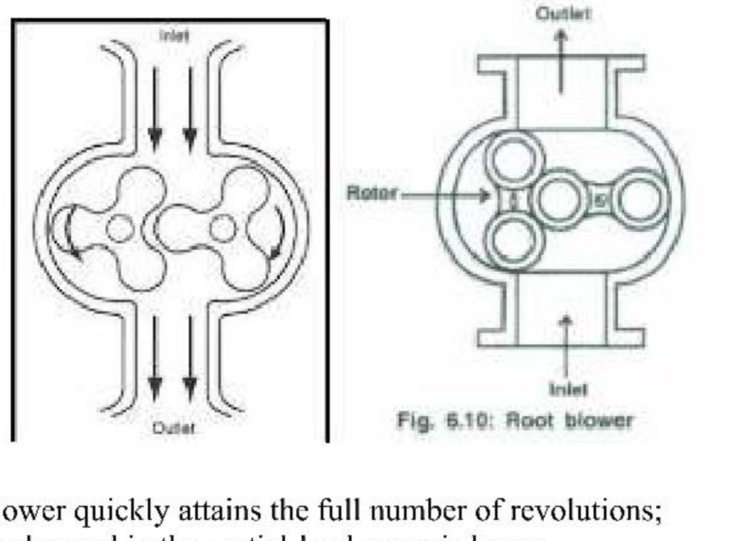


Fig. 6.10: Root blower

Advantages

- A roots-blower quickly attains the full number of revolutions;
- The power demand in the partial-load range is lower.

Disadvantages

- Wear on the conveyor pipe and breakage of the conveying material will be greater
- Noisy operation so dampers are required
- Sensitive to foreign materials so air cleaning is essential
- After a long period of time, capacity loss occurs

Vane Blower

As shown in figure the vane blower consists of a rotor mounted eccentrically in the body. It is a positive displacement machine. The rotor consists of slots in which the vanes are fitted with non-metallic materials usually fibre or carbon. The numbers of vanes are 4 to 8. The vanes are always in contact with the body due to the spring pressure. When the rotor is rotating the space between the rotor and body is decreasing from inlet to outlet. The air is compressed due to the decrease in the volume between the inlet and outlet and the high pressure air is delivered.

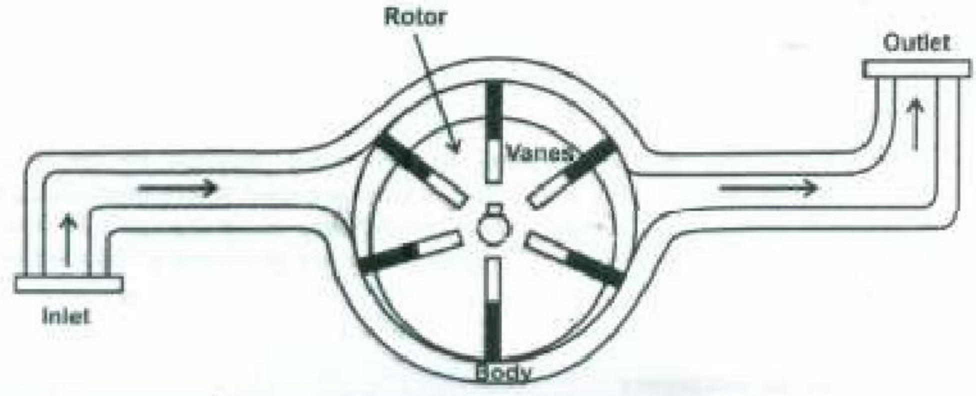


Fig. 6.11: Vane blower

Centrifugal compressor

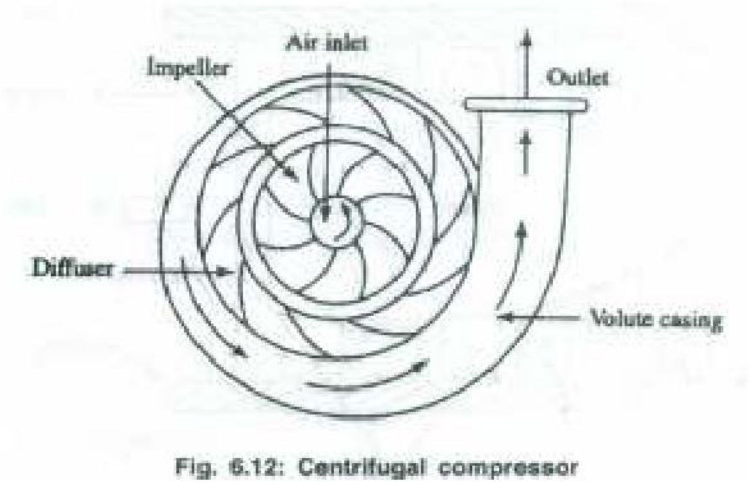


Fig. 6.12: Centrifugal compressor

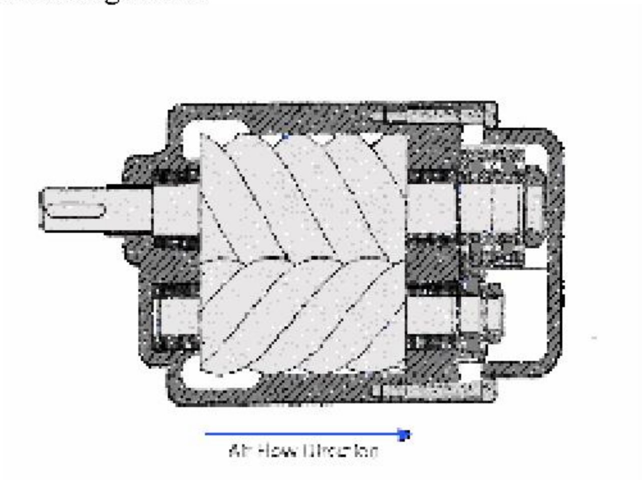
A centrifugal compressor is a type of dynamic compressor, or turbo-compressor, with a radial design. The centrifugal compressor consists of impeller, diffuser, and volute casing. Air is drawn into the center of a rotating impeller and is pushed away from the center by centrifugal force. This radial movement of air results in a pressure rise and the generation of kinetic energy. Before the air is led to delivery pipe, the kinetic energy is also converted into pressure by passing through a diffuser and volute casing. Each stage takes up a part of the overall pressure rise of the compressor unit. Depending on the pressure required for the application, a number of stages can be arranged in a series to achieve a higher pressure. This type of multi-stage application is often used in the oil and gas and process industries.

Screw Compressor

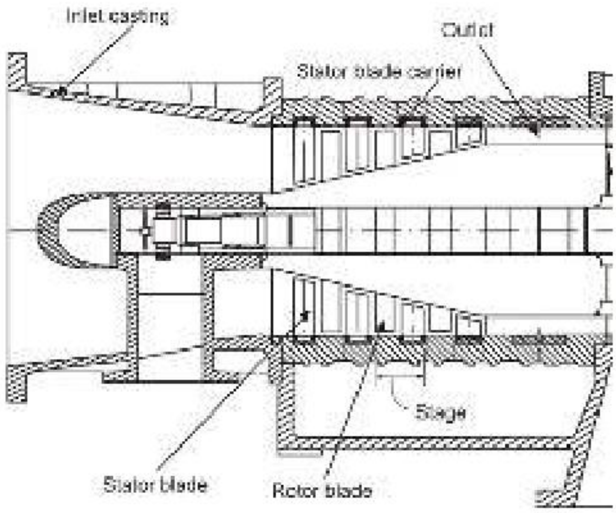
A screw compressor is a type of rotary compressor which compresses air due to screw action. The main advantage of using this compressor is that it can supply compresses air continuously with minimum fluctuation in delivery pressure. It is usually applied for low pressure applications up to 8 bars. A screw compressor comprises of two screws like rotating elements, a casing, an air filter, rubber seals, suction valve and delivery valve mainly.

In a screw compressor one of the shafts is driving shaft and the other is driven shaft. The driving shaft is connected to the driven shaft via timing gears which help to match speeds of both the shafts. The driving shaft is powered by an electric motor generally. The two shafts are enclosed in an air tight casing.

Firstly the suction valve is opened to allow air suction. Then the motor is turned on which drives the shaft. The driven shaft, thus, also starts rotating counter to the driving shaft because of timing gears. The air enters the gap between the two screws cut over the shafts. As the two screws turn in opposite direction the air gets trapped in the groove between the two screws. The gap between the two screws decreases gradually from suction end to delivery end, which leads to compression of air. Also due screw action the air moves from the suction end to the delivery end. When the compressed air reaches the delivery end, it passes through the delivery valve to the storage tank.



Axial Compressor



The axial flow compressor consists of number of sets of stator and rotor blades. A set of stator and rotor blades is known as a stage of a compressor. The number of stages in the compressor depends on the pressure rise required across the compressor. The stator blades also known as fixed blades are attached with the casing of the compressor. The function of the stator blades is to decrease the kinetic energy of air leaving the rotor blade and to increase the pressure. The rotary blades also known as moving blades are mounted on the rotor of the compressor. The rotor is driven by the prime mover. The energy transfer takes place from the rotor blades to air to increase its pressure and velocity. The velocity then converted into pressure by the stator blades. The flow direction is axial in the compressor.

Comparison between reciprocating and rotary compressors

Reciprocating air compressor	Rotary air compressor
Suitable for low discharge of air at high pressure	Suitable for handling large quantity of air at low pressure
Delivery pressure is high per stage	Delivery pressure is low per stage
The air supply is pulsating	The air supply is continuous
Operational speed is low	Operational speed is high
The balancing is a major problem	There is no balancing problem

Learning Outcome Assessment Questions

1. Which compressor is wrongly listed below
   a. Reciprocating compressor
   b. Vane type compressor
   c. Root type compressor
   d. Centrifugal compressor
2. In a centrifugal compressor the pressure developed depends on
   a. Impeller tip velocity
   b. Inlet temperature
   c. Type of impeller
   d. All the above
3. Compare the rotary and reciprocating compressor (AU-Nov 2010)
4. Give two examples of positive displacement rotary compressors (AU-May 2009)
5. State the principle of working of screw compressors (AU- May 2013)
6. Explain with neat sketch the construction and working of roots blower with two lobe and three lobe rotor and vane type compressor (AU-Nov 2012)
7. Explain with a neat sketch the working of a vane blower compressor and show its PV diagram (AU-May 2013)

Lecture 15: ME 8493 Thermal Engineering-I

Topic to be covered	Problems in air compressor

Learning Outcomes

LO	At the end of the lecture students will be able to	CO	BL
LO1	Solve problems in air compressor	CO2	L3
Bloom's Level: L1-Remember, L2-Understand, L3-Apply, L4-Analyse, L5-Evaluate, L6-Create			

Solve the following problems

1. A single stage reciprocating compressor takes in 1.4 kg of air per minute at 1 bar and 17 °C and delivers it at 6 bar. Assuming compression process follows the law $PV^{1.25} = C$. Calculate the work of compression (AU-May 2013)
2. A single stage single acting reciprocating air compressor has a bore of 0.2 m and a stroke of 0.3 m. It receives air at 1 bar and 293 K and delivers it at 5.5 bar. If the compression follows the law $PV^{1.3}$ = constant and clearance volume is 5% if the stroke volume, determine the mean effective pressure and the power required to drive the compressor, if it runs at 500 rpm. (AU-May 2009)
3. A reciprocating air compressor has cylinder with 24 cm bore and 36 cm stroke. Compressor admits air at 1 bar, 17 °C and compresses it up to 6 bar. Compressor runs at 120 rpm, considering compressor to be single acting and single stage determine mean effective pressure and power required to run compressor when it compresses following isothermal process and polytrophic process with index of 1.3. Also find the isothermal efficiency when compression is of polytrophic and adiabatic type. (AU-May 2009)
4. A single acting reciprocating compressor having L/D = 1.5 has a cylinder diameter 200 mm runs at 100 rpm. The compressor compresses air at 1 bar 300 K to a pressure of 8 bar according to the law $PV^{1.25}$ = constant. Find indicated power of the compressor, mass of air delivered, temperature of air delivered. Also calculate power required to drive the compressor if mechanical efficiency is 80% (AU-Nov 2009)
5. The following date relate to a performance test of a single acting 14 cm x 10 cm reciprocating compressor: Suction pressure = 1 bar, suction temperature = 20 °C, discharge pressure = 6 bar, discharge temperature = 180 °C, speed of the compressor = 1200 rpm, shaft power = 6.25 kW, mass of air delivered = 1.7 kg/min. Calculate (i) the actual volumetric efficiency (ii) the indicated power (iii) the isothermal efficiency (iv) the mechanical efficiency and (v) the overall efficiency. (AU-Nov 2009)
6. A single stage reciprocating compressor takes 2 m^3 of air per minute at 1.013 bar and 15 °C and delivers at 7 bar. Calculate the indicated power, and isothermal efficiency. Index of compression is 1.3. (AU-May 2010)
7. Estimate the volumetric efficiency and power consumption of a single stage single acting reciprocating compressor given the following data: cylinder diameter = 30 cm, stoke = 22 cm, clearance ratio = 0.03, deliver pressure = 8 bar, suction pressure = 1 bar, speed = 400 rpm, compression and expansion follows the law $PV^{1.3}$ = constant (AU-May 2010)
8. A single stage single acting air compressor delivers 0.6 kg of air per minute at 6 bar. The temperature and pressure at the end of suction stroke are 303 K and 1 bar. The bore and stroke of the compressor are 100 mm and 150 mm respectively. The clearance is 3% of the swept volume. Assuming the index of compression and expansion to be 1.3, find (i) volumetric efficiency of the compressor (ii) power required if the mechanical efficiency is 85% and speed of the compressor in rpm (AU-Nov 2012)

9. A single acting reciprocating air compressor has a piston diameter of 200 mm and stroke 300 mm and runs at 350 rpm. Air is drawn at 1.1 bar pressure and is delivered at 8 bar pressure. The law of compression is $PV^{1.25}$ = constant and clearance volume is 6% of the stroke volume. Determine the mean effective pressure and the power required to drive the compressor (AU-May 2013)
10. A single stage single acting reciprocating air compressor has a bore of 0.2 m and a stroke of 0.3 m. It receives air at 1 bar and 293 K and delivers it at 5.5 bar. If the compression follows the law $PV^{1.3}$ = constant and clearance volume is 5% of the stoke volume, determine the mean effective pressure and the power required to drive the compressor, if it runs at 500 rpm (AU-Nov 2013)
11. A single stage single acting reciprocating air compressor delivers 14 m^3 of free air per minute from 1 bar to 7 bar. The speed of the compressor is 310 rpm. Assuming polytrophic compression and expansion with n = 1.35 and clearance is 5% of the swept volume, find the diameter and stroke of the compressor. Take L = 1.5 D. Assume the temperature and pressure at suction is same as atmospheric air. (AU-May 2013)
12. A single stage double acting air compressor delivers 15 cu.m of air per minute measured at 1.013 bar and temperature 27 °C and delivers at 7 bar. The conditions at the end of the suction stroke are pressure 0.98 bar and temperature 40 °C. The clearance volume is 4% of the swept volume and the stroke/bore ratio is 1.3/1, compressor runs at 300 rpm. Calculate the volumetric efficiency, cylinder dimensions, indicated power and isothermal efficiency of the compressor. Take the index of compression and expansion as 1.3 and gas constant of air is 0.287 kJ/kg K. (AU-Nov 2010)
13. A single stage double acting air compressor delivers air at 7.5 bar. The pressure and temperature at the end of suction stoke are 1 bar and 27 °C. It delivers 2 m3 of free air per min when the compressor is running at 300 rpm. The clearance volume is 5% of the stroke volume. The pressure and temperature of the ambient air are 1.03 bar and 20 °C. The index of compression is 1.3 and index of expansion is 1.35. Calculate the volumetric efficiency and indicated power of the compressor (AU-May 2013)
14. Estimate the minimum work required to compress 1 kg of air from 1 bar 300 K to 16 bar in two stages if the law of compression is $PV^{1.25}$ = constant and the inter cooling is perfect. Take R = 287 J/kgK (AU-May 2009)
15. A two stage double acting air compressor operating at 200 rpm takes air in at 1.013 bar and 27 °C. The diameter and stroke of LP cylinder are 35 cm and 38 cm respectively. The stroke of HP cylinder is same as LP cylinder and clearance of both the cylinder is 4% of the stroke. The LP cylinder discharges air at a pressure of 4.052 bar. The passes through the intercooler so that it enters the HP cylinder at 27 °C and 3.85 bar. Finally the air is discharged from the compressor at 15.4 bar. The compression and re-expansion in both cylinders the same law $PV^{1.2}$ = constant. Determine the (i) brake power required to run the compressor if mechanical efficiency is 80% (ii) the diameter of HP cylinder (iii) heat rejected in inter cooler (AU-Nov 2010)
16. A single acting two stage reciprocating air compressor with complete inter cooling delivers 10.5 kg/min of air at 16 bar. The suction occurs at 1 bar and 300 K. the compression and expansion processes are reversible, polytrophic index n = 1.3. Calculate (i) the power required to drive the compressor (ii) the isothermal efficiency (iii) the free air delivered (iv) the heat transferred in intercooler. The compressor runs at 440 rpm. It the clearance ratio for IP and HP cylinders are 0.04 and 0.06 respectively, calculate the swept and clearance volumes for each cylinder (AU-Nov 2012)
17. A single acting two stage air compressor deals with 4 m3/min of air at 1.013 bar and 15 °C with a speed of 250 rpm. The deliver pressure is 80 bar. Assuming complete intercooling. Find the minimum power required by the compressor and the bore and

stroke of the compressor. Assume a piston speed of 3 m/s, mechanical efficiency is 75% and volumetric efficiency of 80% per stage. Assume the polytrophic index of compression in both the stages to be n = 1.25 and neglect clearance (AU-Nov 2012)

18. A two stage compressor with complete intercooling delivers 10 kg/min of air at a pressure of 16 bar. The suction occurs at 1 bar and 15 °C. The expansion and compression processes are reversible polytrophic with index n = 1.25. Calculate the power required and isothermal efficiency. (AU-May 2010)
19. A single stage, single acting air compressor 3 cm bore and 40 cm stroke runs at 200 rpm. The suction pressure is 1 bar at 15 °C and the delivery pressure 5 bar. Determine the indicated mean effective pressure and ideal power required to run it, when: (i) compression is isothermal (ii) compression follows the law $PV^{1.25}=C$ (iii) compression is reversible adiabatic. Determine the isothermal efficiency. Assure $\gamma=1.4$ and R=0.287 kJ/kgK. (AU-Nov 2017)
20. A single stage single acting compressor delivers 15 m^3 of free air per minute from 1 bar to 8 bar. The speed of compressor is 300 rpm. Assuming that compression and expansion follow the law $PV^{1.3}=C$ and clearance is 1/16 of swept volume, find IP, diameter and stroke of the compressor. Take L/D=1.5. the temperature and pressure of air at the suction are same as atmospheric air (AU-May 2018)