Experiment 7

SINGLE STAGE AIR COMPRESSOR

1. OBJECTIVE

- To determine the compressor performance parameters and efficiencies.

2. INTRODUCTION & THEORETICAL BACKGROUND

Compressors use mechanical work to take gas at low pressure and raise it to a higher pressure. A reciprocating compressor consists of a piston and cylinder. The basic arrangement is shown in figure 1.

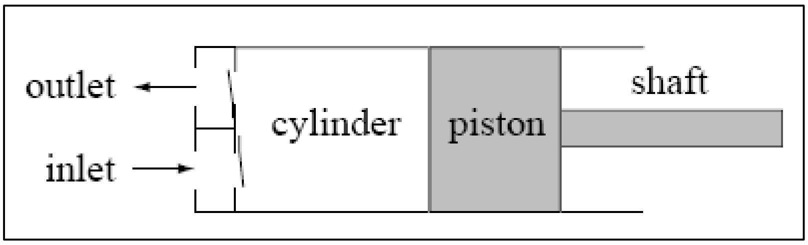


Fig. 1: Basic Reciprocating Compressor

Compressors are classified depending on the mechanical means used to produce compression of the fluid; the main types of compressors are: -

Positive Displacement Type

- Reciprocating Compressors

- Rotary Screw Compressors

Dynamic Type

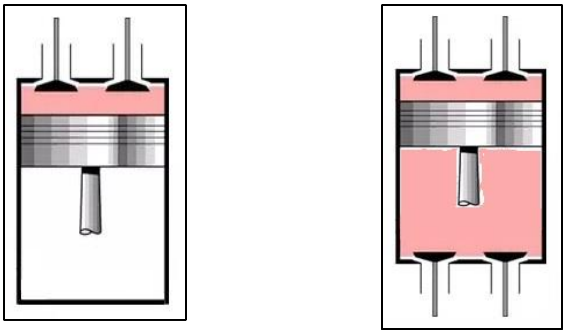
- Centrifugal Compressors

- Axial-flow Compressors
- Scroll Compressors

The main advantages of the reciprocating compressor are that it can achieve high pressure (but at comparatively low mass flow rates).

1- Single-acting vs. Double-acting Compressors

A single-acting compressor (Figure 2-A) has inlet and discharge valves on one side of the cylinder, and so only one side of the piston is active. A double-acting compressor (Figure 2-B) has inlet and discharge valves on both sides of the cylinder. This gives two compression cycles for every turn of the crankshaft. As the piston goes in a given direction, air is compressed on one side and the suction is created on the other one. During the return stroke, the same thing occurs with the sides reversed. (See Figure 2)

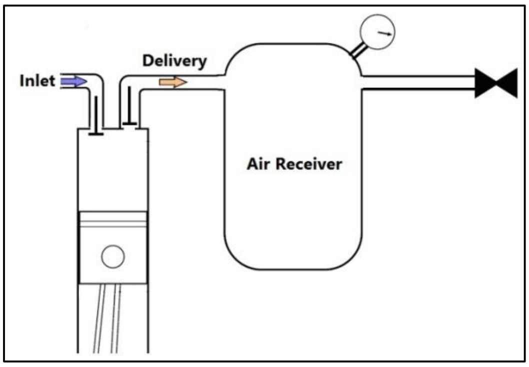


(A) (B)

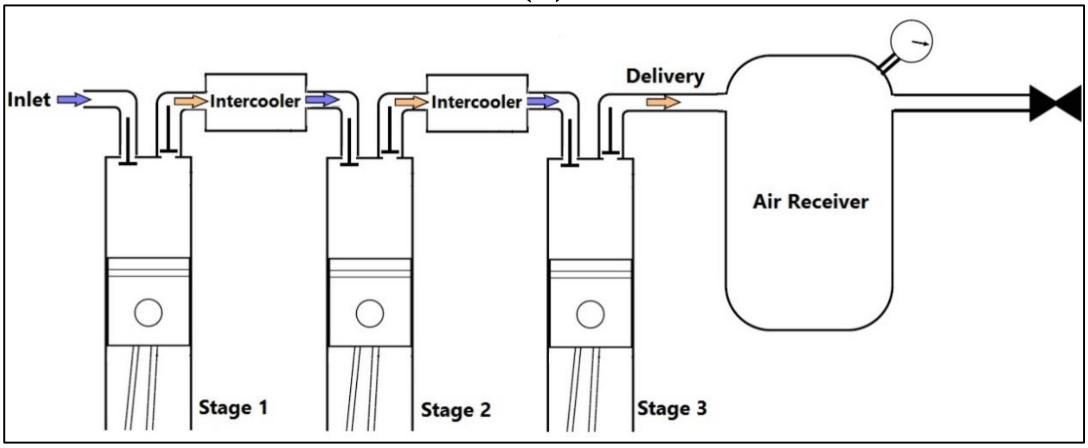
Fig. 2: Single-acting vs. Double-acting Compressors

2- Single stage vs. Multi stage Compressors

In a single stage compressor (Figure 3-A), the air is drawn into a cylinder and compressed to a certain pressure and then sent to the storage tank. In Multi stage compressor (Figure 3-B) and to avoid unacceptable reductions in compressor capacity (RPM and volumetric efficiency) and to minimize power input with high compression ratios, the first step is the same except that the air is not directed to the storage tank, the air is sent via an intercooler tube and compressed a second time and finally it is sent to the storage tank. (See Figure 3)



(A)



(B)

Fig. 3: Single Stage vs. Multi Stage Compressors

1- Basic theory of air compressor

When the piston moves from BDC to TDC air gets compressed, as a result, pressure increases and therefore volume decreases. The work done to compress the air converted to heat energy in the air so that, the air temperature is increased.

Isothermal Compression

During compression, if all the heat generated is taken by cylinder wall then it is called **Isothermal compression**. Here, further temperature rise is avoided and the compression is taking place at constant temperature. The relationship between the pressure and volume would follow Boyles law (PV= C).

Adiabatic Compression

During compression, if there is no heat transfer from the compressed air, then all the work done during compression would appear as stored heat energy. This is known as the **Adiabatic compression** and the relationship between pressure and volume would be **$PV^k = C$, (k** = 1.4 for air).

Polytropic Compression

The actual compression process in an air compression is between the isothermal and the adiabatic and is referred to as **Polytropic compression**. And the relationship between pressure and volume is $PV^n = C$, where n is a value of about 1.25-1.35. (See Figure 4)

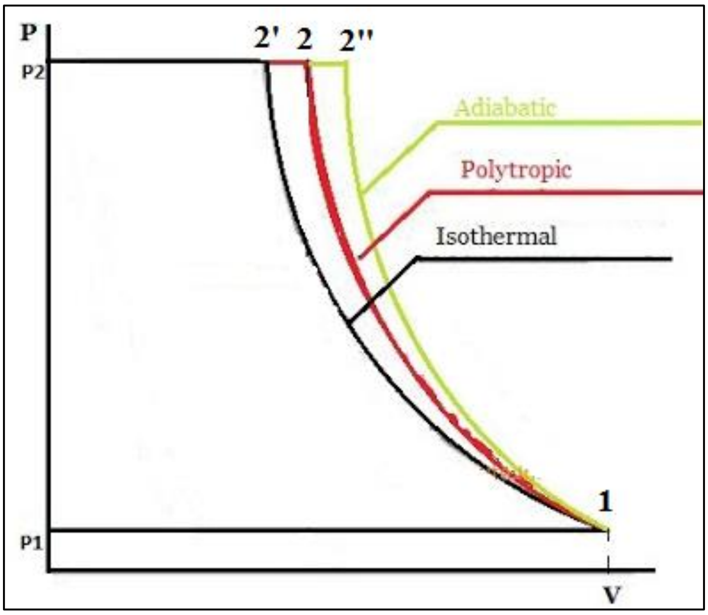


Fig. 4: Compression Types

2- PV Diagram with Explanation

@ Point (3): The piston is at TDC & the cylinder volume is smallest, (Clearance Volume - V_C), with a pressure P_2, and temperature T_2.

(3 → 4): Expansion: The piston is start moving down from TDC, (Air is expand polytropcally ($PV^n = C$), pressure & temperature of air decreases, and volume increases, with suction valve still closed.

@ Point (4): The suction valve open and air starts to enter the cylinder.

(4 → 1): Intake (Suction): Air is drawn into the cylinder from the atmosphere at constant pressure P_1.

@ Point (1): The piston is at BDC & the cylinder volume is greatest, (Swept Volume –Vs), with a pressure P_1, and temperature T_1.

(1 → 2): Compression: The piston is start moving up from BDC (Air is compressed polytropcally ($PV^n = C$), pressure & temperature of air increases, and volume decreases, with the delivery valve still closed.

@ Point (2): Air is completely compressed with pressure = P_2, volume = Vc, and temperature = T_2, the delivery valve open and air starts to leave the cylinder.

(2 → 3): Delivery: Compressed air is delivered out of the cylinder to the receiver at constant pressure P_2. (See Figure 5)

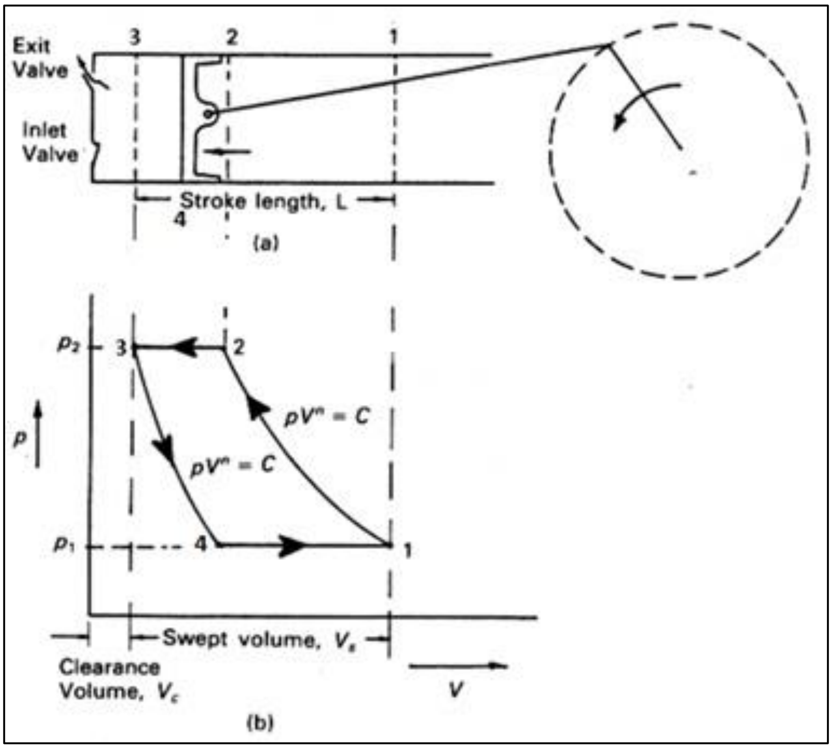


Fig. 5: PV Diagram with Explanation

3. APPARATUS

It is a single stage double cylinder compressor, with a provision for indicator diagrams. The compressor is driven by an electric motor / dynamometer. The speed is recorded by signals from a magnetic transducer whose output is fed to a digital tachometer which shows the RPM time and total revolutions. The compressed air-is stored in a receiver and a throttling valve permits the air pressure to be controlled. (See Figure 6 & 7)

Fig. 6: Single Stage Air Compressor - General View

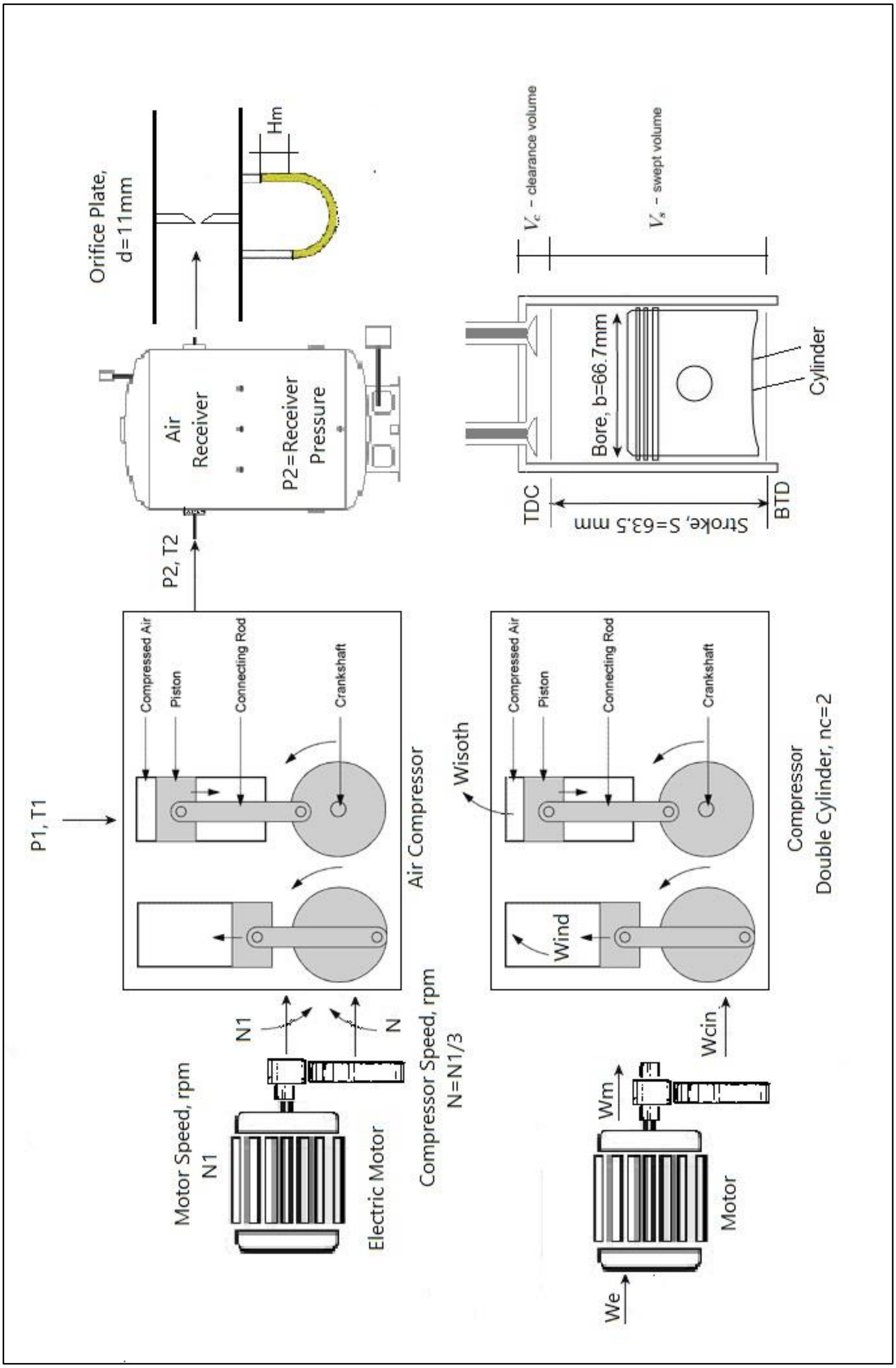


Fig. 7: Single Stage Air Compressor - Schematic Layout

4. PROCEDURE

1. Before starting, record the inlet air temperature and the barometer pressure.
2. Turn on the main switch
3. Revolve the speed wheel gradually to speed of about 530 rpm.
4. Wait receiver to approaches the desired pressure.
5. Open the throttling valve gradually; the manometer reading should indicate the pressure head.
6. By opening the throttling valve, check that manometer reading is not lower than 5 mm pressure head, for the condition of calculating air flow rate.
7. Set compressor speed and air receiver pressure to the desired values and run for 30 minutes to attain steady state which will be maintained by small adjustments of the throttling valve.
8. After changing any variable run the machine for 20 minutes before taking readings.
9. Take indicator diagram during each test.
10. Repeat for other values of compressor speed and air receiver pressure.
11. At the end of the test, revolve speed wheel gradually to return speed to the zero speed.

5. OBSERVATIONS

Table 1: TECHNICAL DATA

NO.	Item	Value	Unit
1	Number of Cylinders, n_C	2	
2	Bore, b	66.7	mm
3	Stroke, S	63.5	mm
4	Diameter of the Orifice, d	11	mm
5	Spring Calibration, SPC	20	kpa/mm
6	Torque Arm Radius, Tar	220	mm
7	Speed Ratio, motor/compressor,	3:1	

Table 2: DATA OBSERVED

NO.	Measured Parameter	Value	Unit
1	Barometric Pressure, P_1		kpa
2	Ambient Temperature,T1		℃
3	Motor Speed, N1		rpm
4	Motor Voltage, V		V
5	Motor Current, I		A
6	Dynamometer Force, F		N
7	Manometer Reading, H_m		mm H_2O
8	Compressor Air Inlet Temperature, T_1		℃
9	Compressor Air Outlet Temperature, T_2		℃
10	Air Receiver Temperature, T_5		℃
11	Air Nozzle Temperature, T_6		℃
12	Air Receiver Gauge Pressure, P_2		kpa
13	Diagram Area, A		mm^2
14	Diagram Length, L		mm

6. DATA ANALYSIS

1- Work Calculations

1 – Motor input – electrical power, (Watt)

$W_E = V \times I$	(1)

V = motor voltage, 220 Volt

I = motor current , in (Ampere)

2 – Motor output – Mechanical power, (Watt)

$W_m = \frac{F \times N1}{K}$	(2)

F = motor force, in (N)

N1 = motor speed, in (rpm)

K = constant = 43.41

3 – Compressor input power, in (Watt)

$W_{Cin} = 0.98 \times W_m$	(3)

Where 0.98 is the efficiency of the belt drive

The mean effective pressure developed inside the compressor, in Kpa

From indicated P – V diagram

$\bar{P}_m = \frac{diagram\ area}{diagram\ length} \times spring\ calibration = \frac{A(mm^2)}{L(mm)} \times 20kpa/mm$	(4)

Where the diagram area is obtained by using a blanimeter device

4 – Indicated power developed inside the compressor (*Watt*)

$W_{ind} = \left(\frac{\pi}{4} b^2 \times S\right) \times n_C \times \bar{P}_m \times \frac{N_1}{3} \times \frac{1}{60}$	(5)

$V_S = \left(\frac{\pi}{4} b^2 \times S\right) = Swept\ volume, in\ (m^3/rev)$

b = bore diameter, in (m)
S = stroke length, in (m)
n_C = number of cylinders

5 – The Isothermal power developed outside the compressor

$W_{isoth} = \dot{m}_a\, R\, T_1\, ln\left(\frac{P_2}{P_1}\right)$ (*Watt*)	(6)

$\dot{m}_a$ = mass flow rate of air in kg/s

R = Air gas constant = 287 J/kg. K

P_1 = Atmospheric Pressure , in kpa

P_2 = Receiver Pressure , in kpa, absolute value

T_1 = Air inlet temperature, in K

6- Mass flow of air measured with help of orifice plate in Kg/s

$\dot{m}_a = 0.002012\, d^2 \sqrt{\frac{H_m P_1}{T_1}}$	(7)

d = orifice diameter, in cm

H_m = Pressure difference a cross the orifice plate in cm H_2O (manometer reading)

P_1 = Atmospheric pressure, in kpa

T_1 = Atmospheric temperature, in K

N_1 = Motor speed, in (rpm)

2- Efficiency Calculations

1 – Motor Efficiency

$\eta_{motor} = \frac{W_m}{W_E}$	(8)

2 – Mechanical Efficiency

$\eta_{mech} = \frac{W_{isoth}}{W_{Cin}}$	(9)

3 – Isothermal Efficiency

$\eta_{iso} = \frac{W_{isoth}}{W_{ind}}$	(10)

4 – Volumetric Efficiency

$\eta_V = \frac{\dot{m}_a}{\rho_a \times V_s \times n_C \times \frac{N_1}{3} \times \frac{1}{60}}$	(11)

Where: ρ_a = *density of air, in* (kg/m^3), *and* $\rho_a = \frac{P_a}{R \times T_a}$

In this relation the pressure is in Pa, T_a *in K and* R = 287 J/kg. K

$V_s = \left(\frac{\pi}{4} b^2 \times S\right) =$ **swept volume, in** (m^3/rev)

5 – Overall Efficiency

$\eta_o = \frac{W_{isoth}}{W_E}$	(12)

7. RESULTS & DISCUSSION

Table 2: SUMMARY OF RESULTS

NO.	Performance	Value	Unit
Motor			
1	Motor input electrical power $- W_E$		kW
2	Motor output Mechanical power $- W_m$		kW
3	Motor Efficiency $- \eta_{motor}$		%
Compressor			
4	Compressor input power $- W_{Cin}$		kW
5	Indicated power developed inside the comp. $- W_{ind}$		kW
6	Isothermal power developed outside the comp. $- W_{isoth}$		kW
7	Mechanical Efficiency $- \eta_{mech}$		%
8	Isothermal Efficiency $- \eta_{iso}$		%
9	Volumetric Efficiency $- \eta_V$		%
Complete Cycle			
10	Overall Efficiency $- \eta_o$		%
Flow Rate			
11	Mass Flow Rate of Air $- \dot{m}_a$		kg/s

1. All the results were recorded and tabulated under the results table.
2. Discuss any discrepancy and the possible causes of errors of the experiment.
3. Write your own opinions about the results. What might be? Discuss about whether the results are acceptable or not?

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