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Experimental Investigation of Effect of Orifice Diameter on Volumetric Efficiency of Two-Stage Reciprocating Air Compressor

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Abstract: *The volumetric efficiency is an important parameter commonly adopted to quantify the performance of air compressors. The present work is concerned with the design of an optimum air intake system for a single acting two stage reciprocating air compressor. The intake air system comprised of different diameter of orifice which affect the quantity, pressure of air to the compressor. The study approaches the effect of change in the intake orifice opening, affects the volumetric efficiency of air compressor. In this we used the standard procedure to find the efficiency, and it shows us the as orifice diameter increases the volumetric efficiency changes with increasing order to some extent.*

Keywords: Volumetric efficiency, orifice meter

I. INTRODUCTION

The air compressor is a machine which uses a drive motor to power the device, which sucks in successive volumes of air from the atmosphere, compresses (squeezes) each volume of air in the limited space to increase the pressure, resulting in asmaller amount, and then transfers the air high pressure in the receiver tank.

Performance of reciprocating compressor is improved by multi-staging. Here number of staging represents number of cylinder. Two stage reciprocating air compressor consist of two cylinders. One is called low-pressure cylinder and another is called high-pressure cylinder. When piston in a low-pressure cylinder is at its outer dead center (ODC) the weight of air inside a cylinder is zero (neglecting clearance volume), as piston moves towards inner dead center (IDC) pressure falls below atmospheric pressure & suction valves open due to a pressure difference.

Air compressors have many uses, including: supplying high-pressure clean air to fill gas cylinders, supplying moderate-pressure clean air to a submerged surfacesupplied diver, supplying moderate-pressure clean air for driving some office and school building pneumatic HVAC control system valves, supplying a large amount of moderate-pressure air to power pneumatic tools, such as jackhammers, filling high pressure air tanks (HPA), for filling tires, and to produce large volumes of moderate- pressure air for large-scale industrial processes (such as oxidation for petroleum coking or cement plant bag house purge systems).

1.1 Principle of Orifice meter:

When a liquid/gas, whose flow-rate is to be determined, is passed through an Orifice Meter, there is a drop in the pressure between the Inlet section and Outlet Section of Orifice Meter. This drop in pressure can be measured using a differential pressure measuring instrument.

An orifice meter is basically a type of flow meter which is used to measure the rate of flow of fluids (mainly Liquids or Gases), using the differential pressure measurement principle.

The orifice meter or plate can be defined as the device in Fluid Mechanics and machinery which is used for measuring the flowing fluid rate or in other terms the average velocity. The orifice meter or plate works on the principle of Bernoulli's theorem and that is the sum of all the energy at a point is equal to the sum of all the energy at another point in same flow channel.

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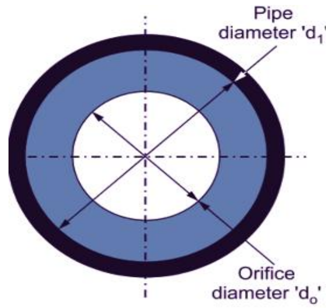

Fig.1 Orifice Meter/Plate

1.2 Working Principle of Orifice meter:

There is basically an orifice plate installed in the orifice meter which provides obstruction to the fluid flow. Here, the streamline contracts because of the area contraction due to orifice which is placed between the pipe by the flange. There is a vena -contracta considered as a minimum area -cross-section.

Differential pressure is developed across the Orifice Plate which is directly proportional to the flow-rate of the liquid or gas.

1.3 Operation of Orifice meter:

The fluid flows inside the Inlet section of the Orifice meter having a pressure P_1. As the fluid proceeds further into the converging section, its pressure reduces gradually and it finally reaches a value of P_2 at the end of the converging section and enters the cylindrical section. The differential pressure sensor connected between the Inlet and the cylindrical throat section of the Orifice meter displays the difference in pressure (P_1-P_2). This difference in pressure is in directly proportion to the flow rate of the liquid flowing through the orifice meter. Further, the fluid passed through the diverging recovery cone section and the velocity reduces thereby it regains its pressures. Designing a lesser angle of the diverging recovery section helps more in regaining the kinetic energy of the liquid.

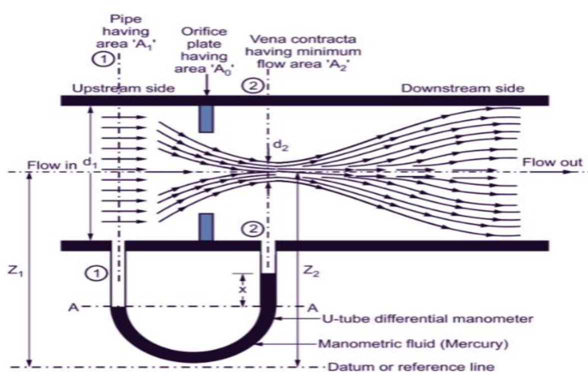

Fig. 2 Operation of Orifice meter

1.4 Applications of Orifice meter:

- Natural Gas
- Water Treatment Plants
- Oil Filtration Plants
- Petrochemicals and Refineries

1.5 Advantages of Orifice meter:

- The Orifice meter is very cheap as compared to other types of flow meters.
- Less space is required to Install and hence ideal for space-constrained applications

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- The operational response can be designed with perfection.
- Installation direction possibilities: Vertical / Horizontal / Inclined.

1.6 Limitations of Orifice meter:

- Easily gets clogged due to impurities in gas or in unclear liquids.
- The minimum pressure that can be achieved for reading the flow is sometimes difficult to achieve due to limitations in the vena-contracta length for an Orifice Plate.
- Unlike Venturi meter, downstream pressure cannot be recovered in Orifice Meters. Overall head loss is around 40% to 90% of the differential pressure.
- Flow straighteners are required at the inlet and the outlet to attain streamline flow thereby increasing the cost and space for installation.
- Orifice Plate can get easily corroded with time thereby entails an error.
- The discharge Co-efficient obtained is low.

II. OBJECTIVE

- To find volumetric efficiency of two stage reciprocating air compressor.
- To determine effect of orifice diameter on volumetric efficiency of air compressor.
- To study the performance of air compressor under change in orifice diameter.
- To study the effect of orifice diameter on change in pressure difference.

III. EXPERIMENTAL PROCEDURE

3.1 Precautions to be followed:

- Avoid improper handling of two stage air compressor.
- Maintain the proper level of lubricating oil up to red mark
- Checking for oil and air leaks.

3.2 Procedure:

- Fill the manometer with water up to half level.
- Keep delivery valve and manometer cock on suction line in closed position.
- Start the compressor and open the manometer cock. Then, let the air pressure build-up in the tank. .
- Maintain pressure of air inside the tank constant, by adjusting delivery valve. Note this delivery pressure reading by pressure gauge mounted on tank.
- With this constant delivery pressure, measure motor speed using tachometer and note it down.
- With the same delivery pressure, note down water manometer reading, intake pressure, intermediate pressure, delivery pressure, intake temperature, temperatures before and after intercooler and delivery temperature.

Fig.3 Typical experimental set up of two stage Reciprocating air compressor testrig.

3.3 Resources Used:

Sr. No.	Name of Resource	Suggested Broad Specification		Quantity
1	Two stage single acting reciprocating air compressor	Pressure Gauge	0 - 300Kg/cm^2	2
			0 - 400Kg/cm^2	1
		Water Manometer	0 - 300 mm	1
		Air box	--	1
		Orifice plate	12,16,20,24,28mm	555
		Air receiver tank	--	11
		Thermometer/Thermocouple	K type(Chromel and Alumel conductor)	4
		Digital Temperature indicator	Digital	`1
		Tachometer	NA	NA
		Low Pressure cylinder Dia.	0.085mm	1
		High Pressure cylinder Dia,	0.090mm	1
		Coefficient of discharge(C_d)	0.065	1
2	Motor	Speed		1440rpm

3.4 Observations and Calculations:

3.4.1 Observations:

Case: I Tank Pressure =4 kg/cm^2

Sr. No	Particular	Orifice Diameter in Meter				
		0.012	**0.016**	**0.020**	**0.024**	**0.028**
1	Intake pressure(P_1) in bar	1.01325	1.01325	1.01325	1.01325	1.01325
2	Inlet Temperature (T1) in ^OK	307	307	307	307	307
3	Manometer Reading Left side h_1 in m	0.090	0.080	0.067	0.062	0.052
4	Manometer Reading Right side h_2 in m	0.010	0.025	0.040	0.043	0.047

Calculations for Volumetric Efficiency:

Compressor Speed

As belt drive is used, $D_1 \text{ x } N_1 = D_2 \text{ x } N_2$

Compressor Speed, $N_2 = \frac{D_1 \text{x} N_1}{D_2} = 900\ rpm$

Density of air

Using characteristic gas equation,

$P_1 \text{ x } V_1 = m_a \text{ x } R_a \text{ x } T_1$

Where, m_a = mass of air

R_a = Characteristic gas constant = 287 J/kg

$m_a = \frac{P_1 V_1}{(R_a T_1)}$

Now, density of air = $\rho_a = \frac{m_a}{V_1} = \frac{P_1}{(R_a \text{x} T_1)}$ where P_1 is in N/m^2.

$= \frac{P_1}{[R_a \text{x}(t_1+273)]} = \frac{1.01325 \text{ x} 10^5}{28\ 7\text{x}\,(27+273)}$

ρ_a=1.15 kg/m^3

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Water Manometric head

$h_w = h_1 - h_2 = 90 - 10$

$h_w = 80$ mm of water

$h_w = 0.080$ m of water

Air ahead causing the flow of air

$h_a = \frac{h_w x \rho_w}{\rho_a}$ Where, ρ_w = Density of water = 1000 kg/m^3

Therefore, $h_a = \frac{0.08\ 0x\ 1000}{1.15}$

$h_a = 69.565$ m of air

Actual volume of free air delivered

Area of Orifice, $a = (\pi/4)\ d^2 = (\pi/4)x(0.012)^2$

$a = 1.131\ x\ 10^{-4}\ m^2$

Actual volume of free air delivered, $\boldsymbol{V_a = C_d x\ a\ x \sqrt{2gh_a}}$

$$V_a = 0.65\ x\ 1.131\ x\ 10^{-4}\sqrt{2\ x\ 9.81\ x\ 69.565}$$

$V_a = 2.715x10^{-3}\ m^3/s$

Mass of air supplied $m_a = \rho_a\ xV_a\ = 1.15\ x\ 2.715\ x\ 10^{-3}$

$m_a = 3.122x\ 10^{-3}$ kg/s.

Theoretical volume of air delivered

Volume of low pressure cylinder = $V_{LP} = (\pi/4)\ D_{LP}^2\ x\ L1\ m^3$ / cycle

$= (\pi/4)x(0.085)^2\ x\ (0.064)$

$V_{LP} = 3.63*10^{-4}\ m^3$/cycle

Theoretical volume of air delivered at intake condition,

$$\boldsymbol{V_{th} = \frac{V_{LP} x\ N_2}{60} m^3/s}$$

$$V_{th} = \frac{3.63\ x\ 10^{-4} x\ 900}{60}$$

$V_{th} = 5.44*10^{-3}\ m^3/s$.

Volumetric efficiency

Volumetric efficiency=(Actual volume of free air delivered) / (Theoretical volume of air Delivered)

$$\eta_{vol} = \left(\frac{V_a}{V_{th}}\right) x100$$

$$\eta_{vol} = \left(\frac{2.715x\ 10^{-3}}{5.44\ x\ 10^{-3}}\right) x100$$

$$\eta_{vol} = 46.16\%$$

Case: II Tank Pressure = 6 kg/cm^2

Sr. No	Particular	Orifice Diameter in Meter				
		0.012	**0.016**	**0.020**	**0.024**	**0.028**
1	Intake pressure(P_1) in bar	1.01325	1.01325	1.01325	1.01325	1.01325
2	Inlet Temperature (T1) in ^{O}K	307	307	307	307	307
3	Manometer Reading Left side h_1 in m	0.95	0.075	0.067	0.064	0.061
4	Manometer Reading Right side h_2 in m	0.012	0.037	0.042	0.046	0.051

Case: III Tank Pressure = 8 kg/cm^2

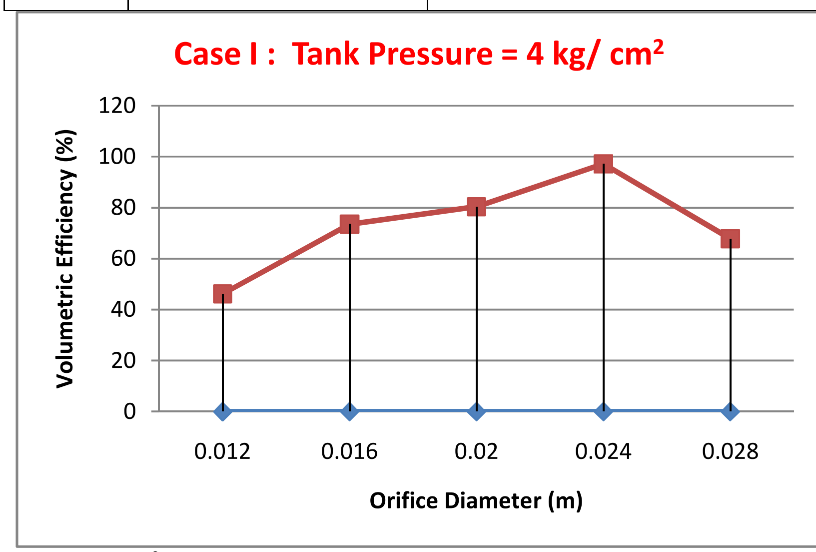
Sr. No	Particular	Orifice Diameter in Meter				
		0.012	**0.016**	**0.020**	**0.024**	**0.028**
1	Intake pressure(P_1) in bar	1.01325	1.01325	1.01325	1.01325	1.01325
2	Inlet Temperature (T1) in ^{O}K	307	307	307	307	307
3	Manometer Reading Left side h_1 in m	0.94	0.076	0.068	0.065	0.061
4	Manometer Reading Right side h_2 in m	0.010	0.036	0.043	0.045	0.052

IV. RESULT AND ITS GRAPHICAL REPRESENTATION

4.1 Result:

Case: I Tank Pressure= 4 kg/cm^2

Sr. No	Orifice Diameter in meter	Volumetric Efficiency in percentage
1	0.012	46.16
2	0.016	73.46
3	0.020	80.40
4	0.024	97.16
5	0.028	67.85



Case:II Tank Pressure = 6 kg/cm^2

Sr. No	Orifice Diameter in meter	Volumetric Efficiency in percentage
1	0.012	51.23
2	0.016	60.94
3	0.020	77.28
4	0.024	94.53
5	0.028	96.00

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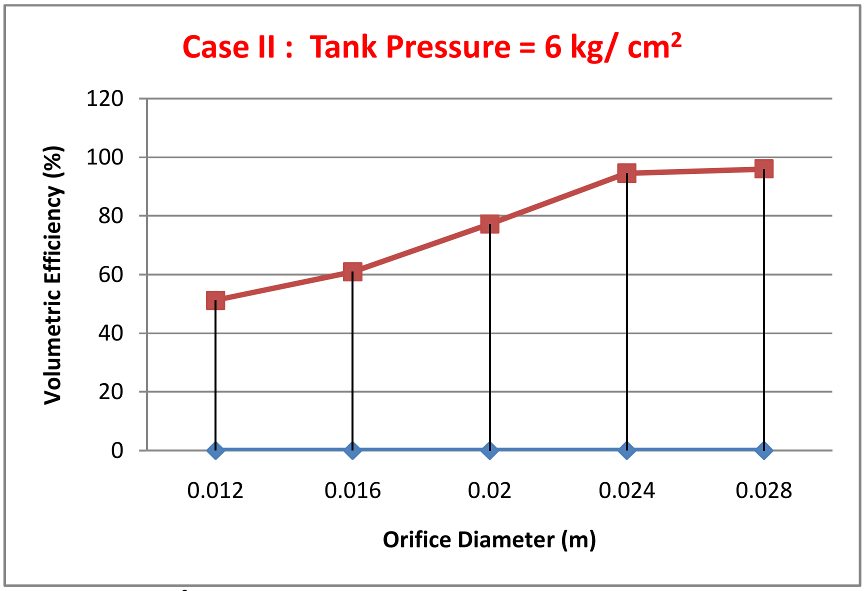
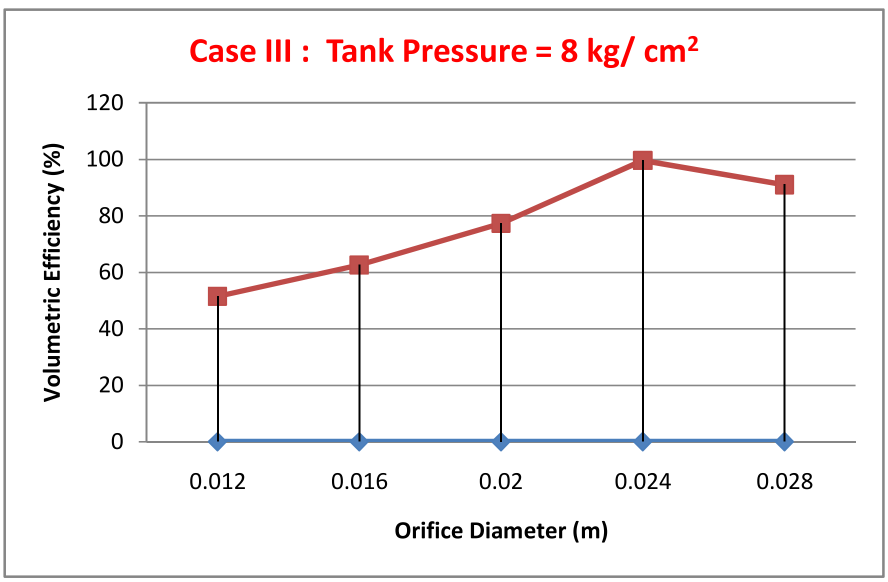
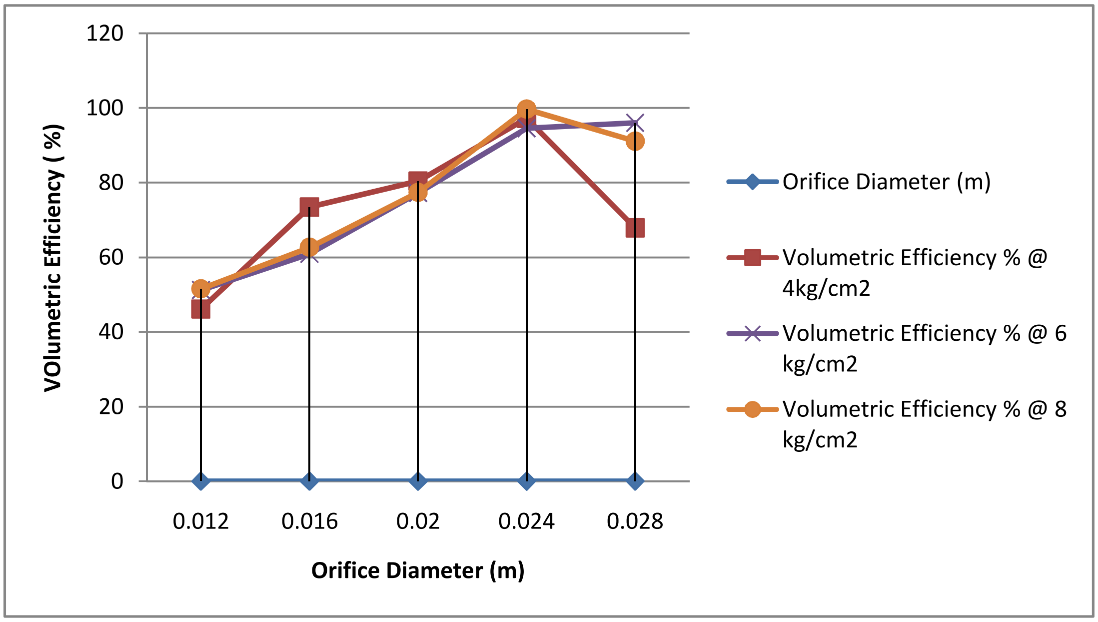


Case: III Tank Pressure = **8** kg/cm^2

Sr.No	Orifice Diameter in meter	Volumetric Efficiency in percentage
1	0.012	51.54
2	0.016	62.65
3	0.020	77.37
4	0.024	99.64
5	0.028	91.05



4.2 Graphical Representation:



Combined Graph of case – I , II & III
Orifice diameter Vs. Volumetric efficiency

V. CONCLUSION

From this Experimental investigation we concluded that with increase in diameter, the for constant tank pressure, volumetric efficiency of single acting two stage reciprocating air compressor increases, but after reaching its maximum value, it start decreasing further with increase in diameter.

VI. FUTURE SCOPE

This study does not indicate the effect of other parameters on volumetric efficiency of two stage reciprocation air compressor. However one can pay attention to different parameter which affects the volumetric efficiency in different areas.

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