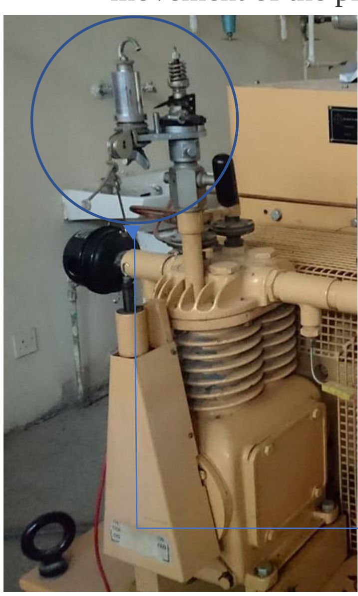
Objective

- To study the performance of a single stage reciprocating air compressor.

Experimental Setup

The experimental setup is shown in figure (1,a). The Single stage air compressor unit consists mainly of five components: an electric motor, a compressor, an air receiver, a control panel and a cooling unit, which uses water to cool the system, since the compression process generates heat. The compressor, which is driven by the electric motor, consists of single stage, single acting, reciprocating twin cylinders. The compressor and the electric motor are connected by a built drive. A dynamometer, that consists of a spring balance and arm torque, is used to measure the torque produced by the electric motor.
The air compressed by the compressor is stored in the air receiver. The pressure of the air in the receiver is measured by a pressure gauge. Furthermore, the mass flow rate of the air can be calculated with the aid of the orifice plate and the manometer reading.
Regarding the control panel, three screens are seen at its front face. The first screen is an ammeter, which displays the value of the current supplied to the electric motor. The second one is a tachometer, which displays the rotational speed of the electric motor. The last one is a temperature indicator, which displays the temperature of the air at specific states designated by the numbers 1-6, depending on the position of the selector switch. In addition, there is also a control knob to control the motor speed, and a push-pull button to start and to stop the unit.

The indicator diagram of the compressor (or the pressure-volume diagram) is generated by an indicator instrument(figure(1,b)). The air pressure in the cylinder deflects the piston and pushes against a spring. A pen, which is connected to that spring, records the deflection on a piece of paper, which is wrapped around a rotating drum. It is obvious that there will be a linear relationship between the pressure of the air and the deflection of the spring caused by the movement of the piston.



Figure(1,a): Single stage air compressor unit

Figure(1,b): Indicator instrument

Start-Up & Experimental Procedure:

1. Pull the push-pull button to operate the unit.
2. Rotate the control knob to adjust the motor speed.
3. Once steady state is reached record the following data : motor speed , motor voltage, motor current, dynamometer force, manometer reading, compressor inlet temperature, compressor outlet temperature, air receiver temperature, air nozzle temperature and air receiver gauge pressure.
4. Obtain a piece of treated paper and wrap it around the small drum of the indicator instrument.
5. Point the pen towards the piece of paper and allow the drum to rotate.
6. Use a planimeter to measure the area of the indicator diagram.

Given Data

- Atmospheric pressure P_{atm} = 90 kPa
- Atmospheric temperature T_{atm} = 19 ^{o}C

Technical Data

Table(1): Technical data

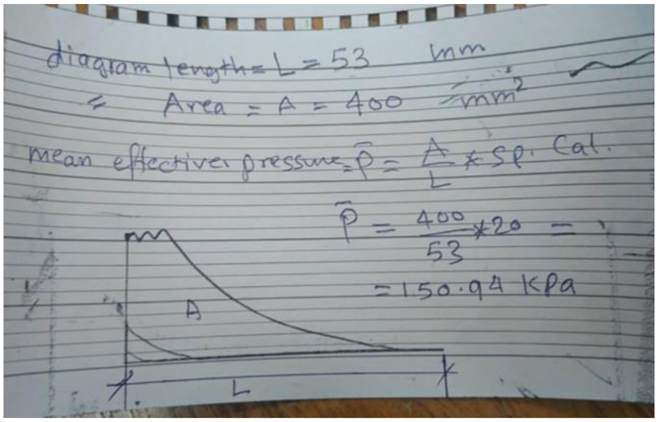
NO.	Item	Value	Unit
1	Numbers of cylinders, n_c	2	
2	Bore, b	66.7	mm
3	Stroke, S	63.5	mm
4	Diameter of the orifice, d	11	mm
5	Spring Calibration, SPC	20	kPa/mm
6	Torque arm radius, T_{arm}	220	mm
7	Speed ratio, motor/compressor	3:1	

Observed Data

Table(2): Observed data

NO.	Measured Parameter	Run 1	Unit
1	Motor Speed, N_1	603	rpm
2	Motor Voltage, V	220	V
3	Motor Current, I	12	A
4	Dynamometer Force, F	21.5	N
5	Manometer reading, H_m	6	mm H_2O
6	Compressor Air Inlet Temperature, T_1	23	^{o}C
7	Compressor Air Outlet Temperature, T_2	67	^{o}C
8	Air Receiver Temperature, T_5	22	^{o}C
9	Air Nozzle Temperature, T_6	19	^{o}C
10	Air Receiver Gauge Pressure, P_2	370	kPa
11	Diagram Area , A	400	mm^2
12	Diagram Length, L	53	mm

Figure(2) shows the indicator diagram obtained from the experiment



Figure(2): Indicator diagram of the compressor

Sample Calculations

Step(1): Find the mass flow rate of the air

$$\dot{m}_a = 0.002012 \times d^2 \times \sqrt{H_m \times \frac{P_{atm}}{T_1}} \quad [1]$$

$$= 0.002012 \times 1.1^2 \times \sqrt{0.6 \times \frac{90}{296}} = 1.0398 \times 10^{-3}\ kg/s$$

Step(2): Find the rate of the work done on the air $\dot{W}_{isoth}$

$$\dot{W}_{isoth} = \dot{m}_a \times R_a \times T_1 \times \ln\left(\frac{P_2}{P_1}\right) \quad [1]$$

But P_2 must be converted from gauge pressure to absolute pressure

$$P_{2\,abs} = P_{2\,gauge} + P_{atm} \quad [1]$$

$$= 370 + 90 = 460\ kPa\_abs$$

$$\dot{W}_{isoth} = 1.0398 \times 10^{-3} \times 287 \times 296 \times \ln\left(\frac{460}{90}\right) = 144.108\ Watt$$

Step(3): Find the mean effective pressure $\bar{P}_m$

$$\bar{P}_m = \frac{diagram\ area}{diagram\ length} \times spring\ calibration \quad [1]$$

$$= \frac{400}{53} \times 20 = 150.94\ kPa$$

Step(4): Find the indicated power developed inside the compressor $\dot{W}_{ind}$

$$\dot{W}_{ind} = \left(\frac{\pi}{4} \times d^2 \times s\right) \times n_c \times \bar{P}_m \times \frac{N_1}{3 \times 60} \qquad [1]$$

$$= \left(\frac{\pi}{4} \times \left(\frac{66.7}{1000}\right)^2 \times \frac{63.5}{1000}\right) \times 2 \times 150.94 \times 10^3 \times \frac{603}{3 \times 60} = 224.385\ Watt$$

Step(5): Find the power supplied to the electric motor $\dot{W}_E$

$$\dot{W}_E = V \times I \qquad [1]$$

$$= 220 \times 12 = 2640\ Watt$$

Step(6): Find the power delivered by the motor $\dot{W}_{m\ out}$

$\dot{W}_{m\ out} = \frac{F \times N_1}{K}$; where k is a constant (k=43.41) [1]

$$= \frac{21.5 \times 603}{43.41} = 298.652\ Watt$$

Step(7): Find the power supplied to the compressor $\dot{W}_{in\ c}$

The efficiency of the belt drive = 98%

Thus , the input power to the compressor

$$\dot{W}_{in\ c} = 0.98 \times \dot{W}_m = 0.98 \times 298.652 = 292.679\ Watt$$

Step(8): Find the isothermal efficiency of the compressor η_{isoth}

$$\eta_{isoth} = \frac{\dot{W}_{isoth}}{\dot{W}_{ind}}\ [1] = \frac{144.108}{224.385} \times 100\% = 64.22\%$$

Step(9): Find the mechanical efficiency of the compressor η_{mech}

$$\eta_{mech} = \frac{\dot{W}_{isoth}}{\dot{W}_{in\ c}}\ [1] = \frac{144.108}{292.679} \times 100\% = 49.24\%$$

Step(10): Find the volumetric efficiency of the compressor η_{vol}

$$\eta_{vol} = \frac{\dot{m}_a}{\rho_a \times \forall_1 \times n_c \times \frac{N_1}{3 \times 60}} \qquad [1]$$

$$\rho_a = \frac{P_{atm}}{R \times T_1} = \frac{90}{0.287 \times 296} = 1.05942\ kg/m^3$$

$$\forall_1 = \frac{\pi}{4} \times d^2 \times s = \frac{\pi}{4} \times \left(\frac{66.7}{1000}\right)^2 \times \frac{63.5}{1000} = 2.21878 \times 10^{-4}\ m^3$$

$$\eta_{vol} = \frac{1.0398 \times 10^{-3}}{1.05942 \times 2.21878 \times 10^{-4} \times 2 \times \frac{603}{3 \times 60}} \times 100\% = 66.02\%$$

Step(10): Find the motor efficiency η_{motor}

$\eta_{motor} = \frac{\dot{W}_{m\,out}}{\dot{W}_E}$ [1] $= \frac{298.652}{2640} \times 100\% = 11.31\%$

Step(11): Find the overall efficiency $\eta_{overall}$

$\eta_{overall} = \frac{\dot{W}_{isoth}}{\dot{W}_E}$ [1] $= \frac{144.108}{2640} \times 100\% = 5.45\%$

Uncertainty Analysis

- For a calculated quantity x that is dependent on another quantities $x_1, x_2, x_3, \dots, x_n$

$$x = f(x_1, x_2, x_3, \dots, x_n)$$

The uncertainty of x (w_x) is given by :

$$w_x = \pm\sqrt{\left(\frac{\partial x}{\partial x_1} \times w_{x1}\right)^2 + \left(\frac{\partial x}{\partial x_2} \times w_{x2}\right)^2 + \left(\frac{\partial x}{\partial x_3} \times w_{x3}\right)^2 + \dots + \left(\frac{\partial x}{\partial x_n} \times w_{xn}\right)^2}$$ [2]

- In this experiment, the calculated $\dot{W}_{m\,out}$ value is dependent on F and N_1 i.e
- $\dot{W}_{m\,out} = f\ (F, N_1)$

The uncertainty of $\dot{W}_{m\,out}$ is given by

$$w_{\dot{W}_{m\,out}} = \pm\sqrt{\left(\frac{\partial \dot{W}_{m\,out}}{\partial F} \times w_F\right)^2 + \left(\frac{\partial \dot{W}_{m\,out}}{\partial N_1} \times w_{N_1}\right)^2}$$

- The uncertainty of an observed quantity measured using a device , is the value of one-half the smallest division of the device. [2] The uncertainty of V, I are as follows :
  $w_{N_1} = \pm 0.5\, rev \quad w_F = \pm 0.25\, N$

- The following quantity is found by differentiating $\dot{W}_{m\,out} = \frac{F \times N_1}{K}$ partially

$$\frac{\partial \dot{W}_{m\,out}}{\partial F} = \frac{N_1}{K} \qquad \frac{\partial \dot{W}_{m\,out}}{\partial N_1} = \frac{F}{K}$$

$$w_{\dot{W}_{m\,out}} = \pm\sqrt{\left(\frac{603}{43.41} \times 0.25\right)^2 + \left(\frac{21.5}{43.41} \times 0.5\right)^2}$$

$= \pm 3.482$ Watt $= \pm 1.166$ %

Results & Discussion

An air compressor is a mechanical device that increases the pressure of air by reducing its volume. Since the objective of this experiment is to study the performance of a single stage air compressor, several conclusions can be drawn from the results obtained from calculations. Firstly, the volumetric efficiency of the compressor is η_{vol} = 66.02%. This value means, that only 0.6602 of the volume of the cylinder was filled with air during the air suction process. Secondly, the mechanical efficiency of the compressor is η_{mech} = 49.24%. This value means that 0.4924 of the power supplied to the compressor is used to compress the air and increase its pressure. Heat and frictional losses dissipates the rest of the power supplied to the compressor. Thirdly, the isothermal efficiency of the compressor η_{isoth} = 64.22%. This value represents the ratio of the work required to compress a gas isothermally to the work actually done by the compressor. This means that the compression process is not absolutely an isothermal process . Furthermore, the motor efficiency η_{motor} = 11.31% . This means that 88.69% o f the power supplied to the motor was dissipated due to frictional and heat losses. Finally, the overall efficiency $\eta_{overall}$ indicates that only 5.45% of the power supplied to the unit was used to compress the air and increase its pressure.

Sources of Error

Errors in this experiment are caused by several factors such as: human error in recording the experimental data of the motor current, motor voltage, pressure gauge and the dynamometer force, since these data are not recorded digitally like the rotational speed of the motor and the values of temperature. In addition, computational errors are also considered as a source of error.

Summery & Conclusions

Overall, the experiment shows that compressors are devices that increase the pressure of a gas by reducing its volume. Frictional and heat losses dissipate most of the power supplied to the compressor, which causes a reduction in the mechanical, isothermal and overall efficiencies of the compressor.

References

[1] Çengel, Y. A., & Boles, M. A. (2015). Thermodynamics: an engineering approach (8th ed.). New York: McGraw-Hill Education.

[2] Holman J. P. (2012). Experimental Methods for Engineers (8th ed.). New York: McGraw-Hill Education.