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The Effect of the Volume of Air Intake on the Indicated Power of a Single-acting Reciprocating Compressor

Ekong. Godwin I.[1], Ibibom, Emmanuel N.[1], Bassey, Isaiah U.[1]

[1]Department of Mechanical Engineering, Akwa Ibom State University (AKSU), Nigeria

Email: goddy3e@yahoo.com

Abstract:

This research was aimed at analysing the effect of the volume of the air intake on the Indicated power of a single-acting reciprocating compressor. In order to achieve this, an in-house single–acting reciprocating compressor, whose prime mover rating is a 1.5 hp electric motor running at the speed of 2100 r.p.m, with a volume of 2.0 m^3/min of air, an intake pressure of 1.0 bars and a discharge pressure of 5.0 bars was used. Thermodynamic concepts were employed to analyse the consequence of the volume of air intake per minute on the mass of air delivered, the delivery temperature at the end of compression, the indicated work, and hence, the overall influence on the indicated power. The results show that, as the volume of air increases, there is a corresponding increase in the mass of air delivered by the compressor, leading to an increase in the indicated work, hence an increase in the indicated power. With a volume air intake of 2.0 m^3/min, the mass of air delivered was 2.37 kg/min, a delivery temperature of 526.52K, and an indicated work of 337.02 kJ/min with an indicated power of 5.62 kW. Further analyses were carried out to obtain values that would represent the relationship between the various parameters and each of their reactions to the overall consequence on the indicated power for four different volumes of air intake.

Keywords: Single-acting, reciprocating, compressor, compression air, thermodynamics.

1. INTRODUCTION

There are various types of compressors for different applications and one of the most common types is the reciprocating compressor which is widely used in for different applications. A conventional reciprocating compressor uses pistons driven by a crankshaft to deliver fluid at high pressure. In order to improve the performance of reciprocating compressors, several new designs have been recommended involving the modification in the driving mechanism and cylinder characteristics.

To improve the power of the reciprocating compressor, priority should be given to the improvement of the volume of the air intake by accurately optimising the air compressor controls to for optimum result. Air compression finds applications in various areas such as oil refineries, gas pipelines, chemical plants, natural gas processing plants, and refrigeration plants. Other areas are homes for cleaning, workshops for inflating tyres, industries for sealing, and laboratories for research are of great importance. This paper focuses on the reciprocating compressor where the air that is compressed in the cylinder is on one side of the piston only, and this is known as a single-acting reciprocating compressor. The problems intended to analysed is the effect of the volume of air have on the power produce by single-acting reciprocating compressor for its operation.

2. LITERATURE REVIEW

Compression is accomplished by the reciprocating movement of a piston within a cylinder. This motion allows the cylinder to be filled with air and then compresses the air and delivers it at high-pressure to perform the required work. This section presents reviews of the previous work relating to the reciprocating compressor and other reciprocating systems which has been extensively discussed by several scholars such as CM (1) that applied numerical soft wares CATIA and ADAMS to identify the unbalanced forces of the reciprocating compressor by analysing the forces and vibration acting on its components, Bc Volfa (2) undertook a one-dimensional study of reciprocating compressor valve dynamics using a mathematical model, to qualitatively evaluate the individual aspects of valve dynamics as well as their interaction. According to the work by Sultan (3) the performance of the reciprocating compressors can be improved by incorporating a modified geared four-bar slider-crank mechanism which will produce a favourable stroke characteristics, this has a positive impact on the thermodynamic performance improvement, crankshaft torque reduction, and flywheel size. Ercan (4) undertook a novel study by using the MinFaS-Tar mechanism and concluded that the energy consumption and the power requirements of the driving motors of MinFaS-TaR-based compressors may be reduced significantly when compared to the slider crank-based compressors and should be noted that, the shaking forces and moments transmitted to the chassis are identically zero in a MinFaS-TaR based compressor. According to Schander Pott [5], a design of the internal components of a single-acting reciprocating piston compressor was carried out in order to dimension the components and investigate the load case using a dynamic mathematical mode, hence the impact the balancing of the compressor, and MacLaren, and Tramschek [6] stated in their work the prediction of valve behaviour with the pulsating flow in reciprocating compressors that, the automatic valves, used almost universally in compressors for reasons of simplicity and low cost, constitute a greater limitation on the throughput of the working fluid than do the mechanically operated valves of an engine, in the work.

The measurement and control of fluid using other fluid machinery such as in a gas turbine is presented in Ekong *et al* (7) and (8). Ekong *et al* (9) undertook the performance analysis of a single-acting reciprocating compressor using thermodynamic concepts, while the performance analysis of a single-acting reciprocating mechanism was studied by Ekong and Ekanem (10) and Ekong *et al* (11). Ekong (12) present the effect of the design parameters on mass flow measurement and control in an orifice plate flow rig and Ekong (13) performed the parametric effect on the discharge of Venturimeter flow rig showing that as the difference in head increases, the is a corresponding increase in the discharge through the Venturimeter and according to Ekong [21], by increasing the value of the pressure head, there was a corresponding increase in discharge, hence confirming the effectiveness of the Bernoulli's principles and continuity equation in the analysis of flow discharge through Venturimeter.

3. MATERIALS AND METHODS

Reciprocating compressors operate on the principle of compression.The compression process in this study is polytropic and the thermodynamics principles are applied in the analysis. The thermodynamics properties include the volume, pressures and temperatures. In this study, the effect of the volume of air on the indicated power of the reciprocating compressor is determined. The working fluid is assumed as a perfect gas and the equation of state is applied. The following expressions were applied with their usual notation, nomenclatures, and meaning.

$$PV = mRT \quad (1)$$

$$PV^n = C, \quad (2)$$

$$hence, PV^{1.35} = C \quad (3)$$

$$Mass\ of\ air, m = \frac{P_1V_1}{RT_1} \quad (4)$$

$$Delivery\ temperature, T_2 = T_1\ [(\frac{P_2}{P_1})^{\frac{n}{n-1}} - 1] \quad (5)$$

$$Indicated\ work, IW = \frac{n}{n-1} mR(T_2 - T_1) \quad (6)$$

$$Indicated\ power, IP = \frac{IW}{60} \quad (7)$$

Creativity techniques such as forty inventive principles, lateral thinking, and brainstorming were applied in the conceptual stage for the design and in the selection of materials for manufacturing of the in-house reciprocating compressor shown in Figure 1 used for this study based on quality, availability, and cost; the application of these creativity techniques in problem-solving is presented in Ekong *et al* [14] the application of Creativity Tools to Gas Turbine Engine Compressor Clearance Control, Ekong [15] the application of Creative techniques in Effective Management of a Power Generation Plant, Ekong [16] the application of Ideal Final Result in the design of a Pneumatic Foot Pump for rural areas, Ekong [17] the application of 40 inventive principles in tip clearance control concepts in Gas Turbine H.P compressor, Ekong [18] the Improvement of Government Parastatals using Creativity tools, Ekong [19] the application of Ideal Final Results in the Establishment and Management of a Cold storage facility for rural areas and Ekong *et al* [20] the development of concepts for the control of tip clearance in Gas turbine HP compressors using TRIZ.

Figure 1: In-house Reciprocating Compressor

4. RESULTS AND DISCUSSION

This section presents the results and discussion of this work. The influence of the volume of air on the mass of air delivered, the delivery temperature at the end of compression, the indicated work, and hence, the overall influence on the indicated power is evaluated with the application of thermodynamics concepts. In this analysis, Clearance in the cylinder is neglected and the compression process is polytropic, with a polytropic index (n) of 1.35.

4.1 Designed parameters of the compressor

The designed parameters of the reciprocating compressor used include the initial room temperature (T1) of 25^0C, the volume of air taken per minute of $2.0m^3/min$, Intake pressure of 1.0bar, Discharge pressure of 5.0 bars, Shaft power of 6.37kw and the speed of 2100 r.p.m.

4.1.1 Mass of the air delivered per minute,

Referring to the concept presented as Equation 4, $m = \frac{P_1V_1}{RT_1}$

$$Then, \qquad m = \frac{1.0 \times 10^5 \times 2}{287 \times 298} = 2.37\ kg/min$$

And the delivery temperature is given as;

$$Delivery\ temperature, T_2 = T_1\ [(\frac{P_2}{P_1})^{\frac{n}{n-1}} - 1]$$

$$Delivery\ temperature, T_2 = 298[(\frac{5}{1})^{\frac{1.35}{1.35-1}} - 1] = 426.52K$$

4.4.4 Indicated Power of a Single-acting Reciprocating Compressor

In this study, the indicated power was analysed taking into consideration the volume of air intake per minute, the intake and delivery temperatures, the intake and delivery pressures and the mass of air delivered and the indicated work done by the single-acting reciprocating compressor.

The indicated work is given in Equation 6 as,

$$Indicated\ work, IW = \frac{n}{n-1} mR(T_2 - T_1)$$

$$hence, Indicated\ work, IW = \frac{1.35}{1.35-1} * 2.37 * 0.287(526.52 - 298) = 337.02\ kJ/min$$

Therefore, from the Indicated power concept given in Equation 7,

$$Indicated\ power,\ IP = \frac{IW}{60},$$

$$Indicated\ power, IP = \frac{IW}{60} = \frac{337.02}{60} = 5.62kW$$

4.3 The effect of the Volume of air intake on the Indicated Power of a Single-acting Reciprocating Compressor

The effect of the volume of the air intake on the indicated power of a single-acting reciprocating compressor with shaft power of 6.37kW running at the speed of 2100 r.p.m was investigated and analysed. Analyses were carried out to obtain values that represent the relationship between the variable such as the volume of air intake, mass of air, delivery temperature, indicated work, and their reactions to the indicated power for four different volumes of air intake. The results are presented in Tables 1, 2, 3, and 4 and are graphically interpreted in Figures 2, 3, 4, and 5. The analyses indicate that as the volume of air intake increases, there is a corresponding increase in the mass of air and temperature delivered, leading to an increase in the indicated work, hence an increase in the indicated power of the compressor.

Table: 1: Show the relationship between volumes of air and the mass of air delivered by the reciprocating compressor

S/N	Volume of air, m^3/min	Mass of air delivered, kg/min
1	2	2.37
2	3	3.55
3	4	4.74
4	5	5.92
5	6	7.11

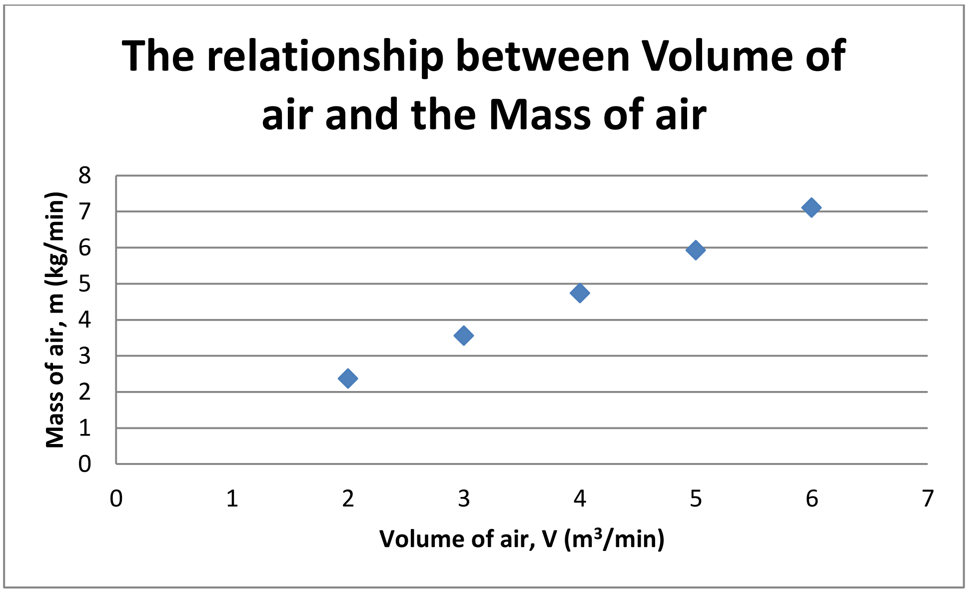

Figure 2: The relationship between the volumes of air and the mass of air delivered by the compressor.

From Table 1, it is observed that as the volume of air increases, there is an increase in the mass of air delivered by the compressor. These analyses are illustrated graphically in Figure 2.

Table: 2: Show the relationship between the mass of air and the indicated work by the reciprocating compressor

S/N	Mass of air delivered, kg/min	Indicated work, kJ/min
1	2.37	337.02
2	3.55	505.53
3	4.74	674.05
4	5.92	842.56
5	7.11	1011.07

In Table 2, it is observed that as the mass of air delivered increases, there is an increase in the indicated work by the compressor. These analyses are illustrated graphically in Figure 3.

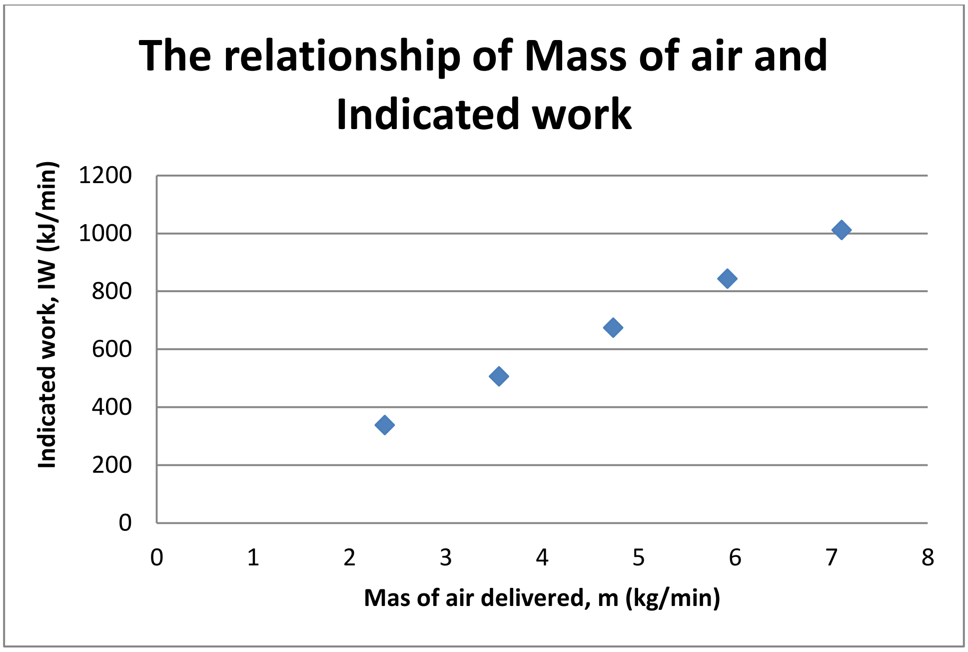

Figure 3: the relationship between the mass of air and the indicated work by the reciprocating compressor

Table 3 indicates that as the indicated work increases, there is an increase in the indicated power of the compressor. These analyses are illustrated graphically in Figure 4.

Table: 3: Show the relationship between the indicated work and the indicated power of the reciprocating compressor

S/N	Indicated work, kJ/min	Indicated power, kW
1	337.02	5.62
2	505.53	8.43
3	674.05	11.23
4	842.56	14.04
5	1011.07	16.85

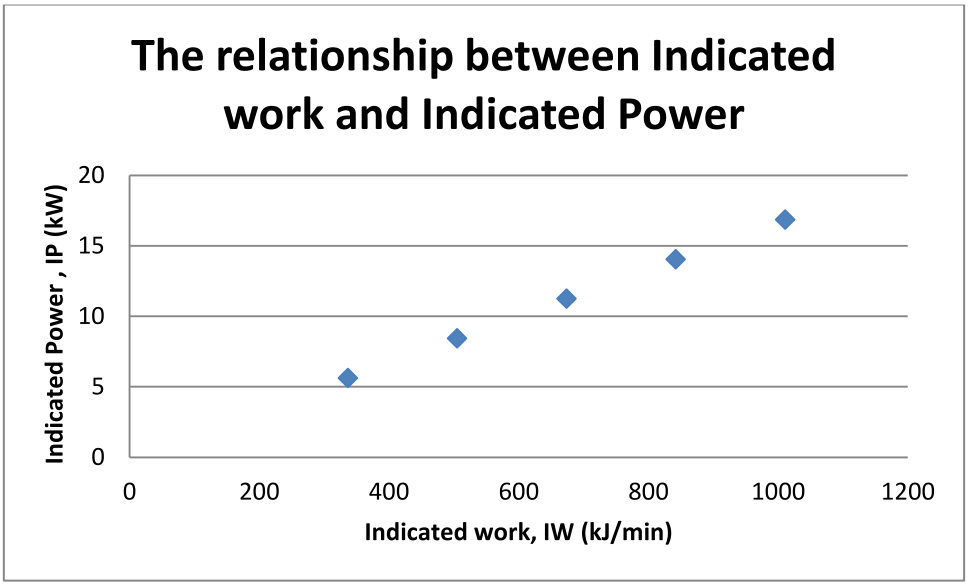

Figure 4: The relationship between the indicated work and the indicated power of the reciprocating compressor

In view of the relationship between parameters, it can then be concluded as presented in Table 4 that as the volume of air increases, there is an increase in the indicated power by the compressor. These analyses are illustrated graphically in Figure 5.

Table: 4: Show the relationship between volumes of air and the indicated power of the reciprocating compressor

S/N	Volume of air, m^3/min	Indicated power, kW
1	2	5.62
2	3	8.43
3	4	11.23
4	5	14.04
5	6	16.85

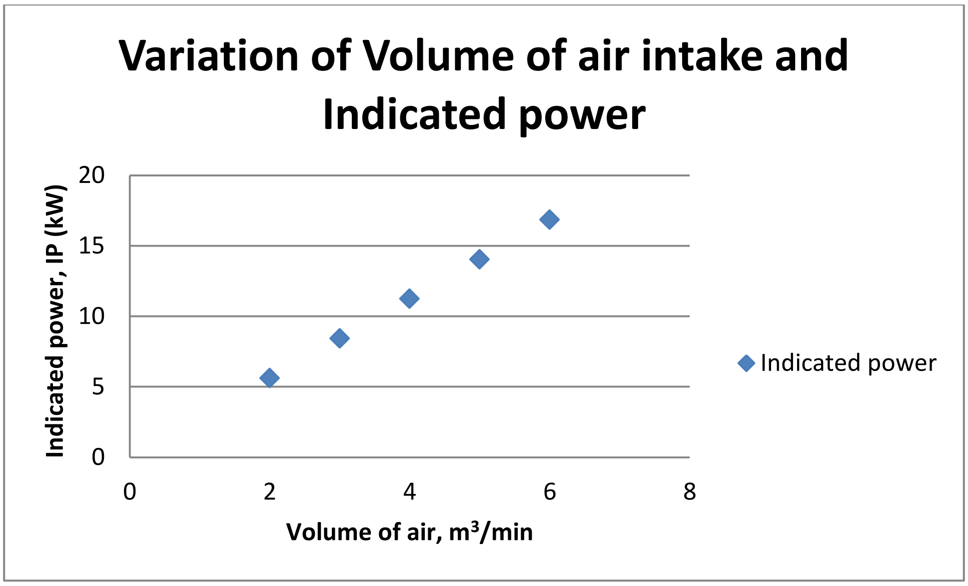

Figure 5: The relationship between volumes of air and the indicated power of the reciprocating compressor

From Figure 5, it can be confirmed that the indicated power of the reciprocating compressor depends largely on the volume of air intake into the compressor.

5. CONCLUSION

In this work, the effect of the volume of air intake on indicated power of the single-acting reciprocating compressor was investigated. The test carried out revealed that as the air intake increases, there is an increase in the mass delivered, leading to an increase in the indicated work, hence, an increase in the indicated power of the reciprocating compressor. Thermodynamic principles were employed for the analysis of the volume of air intake per minute, indicated work, and the indicated power analysed. At the compressor-designed shaft power of 6.7kW with a volume air intake of 2.0 m^3/min, the analysis revealed that the mass of air delivered was 2.37 kg/min, a delivery temperature of 526.52K, leading to an indicated work of 337.02 kJ/min with an indicated power of 5.62 kW. This in-house device can be employed for domestic purposes, such as cleaning, operation of tools in the workshop, operating drills and hammers in road work, excavating, inflating of tyres, and spray painting among others.

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