ANALYSIS OF THE EFFECT OF WORKING PRESSURE VARIATIONS ON ENGINE SPEED (RPM) IN A RECIPROCATING COMPRESSOR TEST DEVICE

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Abstract. *Reciprocating compressors are one of the important devices in industrial applications that require high air pressure. Variations in working pressure applied to the system are believed to affect dynamic performance, especially engine rotation speed (RPM). This study aims to analyze the effect of variations in working pressure on RPM in a reciprocating compressor test device. The methods used include experimental testing with three speed levels (Speed 1–3) over a certain time interval, as well as theoretical analysis using the polytropic equation and calculation of volumetric efficiency ηv The results show that an increase in working pressure is positively correlated with an increase in RPM. At Speed 3, the maximum pressure reaches 3.8 bar with an RPM of 8034. This study indicates that operating speed regulation has a significant role in optimizing compressor performance.*

Keywords: *Polytropic Process, Reciprocating Compressor, Rotational Speed, Volumetric Efficiency, Working Pressure.*

1. INTRODUCTION

Reciprocating compressors are a type of compressor widely used in various industrial sectors, such as refrigeration systems, manufacturing, and power generation. These compressors operate on the principle of reciprocating piston motion to compress gas fluids, producing pressurized air according to application requirements. Reciprocating compressor performance is heavily influenced by two main parameters: working pressure and engine speed (RPM). Engine speed is a key indicator in determining system efficiency, operational stability, and compressed air production capacity.(Sadiana et al., 2022).

During operation, variations in working pressure resulting from changes in load or system conditions will affect the mechanical characteristics of a reciprocating compressor. Increasing working pressure tends to increase the load on the system, potentially reducing the engine rotational speed (RPM). Conversely, decreasing working pressure can cause RPM to increase, which under certain conditions can trigger vibration or accelerated wear on mechanical components. The relationship between working pressure and RPM needs to be systematically studied to understand the dynamic characteristics of reciprocating compressor operation, especially on test devices used for laboratory simulations and small-scale compressor testing.(Cappenberg & Ramadan, 2018).

Several previous studies have highlighted the performance of reciprocating compressors in terms of energy efficiency and output capacity optimization.(Leni & Kesuma, 2023', nd)However, studies specifically analyzing the effect of variations in working pressure on engine rotational speed are still relatively limited. Yet, a thorough understanding of this relationship is crucial for supporting the design of effective control systems and preventing mechanical problems due to load fluctuations.(Rahmat et al., 2023).

This study aims to analyze the effect of variations in working pressure on changes in engine rotational speed (RPM) in a reciprocating compressor test device. The study was conducted by testing the compressor at several working pressure levels and measuring the RPM response to these conditions. The results of this study are expected to contribute as experimental data to support the development of more efficient and reliable compressor systems. Furthermore, these findings can also serve as a reference for industry in determining optimal working pressure settings to maintain system performance within safe and stable limits.(Dwinanto et al., 2022).

2. LITERATURE REVIEW

A reciprocating compressor is a type of positive displacement compressor widely used in various applications, from the manufacturing and automotive industries to engineering laboratories. The working principle of this compressor is based on the reciprocating movement of a piston within a cylinder, which allows for the sequential intake, compression, and exhaust of air. This piston movement is driven by a crankshaft, which converts mechanical energy from the drive motor into air pressure energy.(Syamsuri, 2023).

The operating characteristics of a reciprocating compressor are greatly influenced by the operating pressure and engine speed (RPM). Higher operating pressures can increase the potential energy of the compressed air, but can also increase the piston workload and decrease the engine RPM. Thermodynamically, the compression process can be explained by Boyle's Law and Charles's Law, which relate changes in gas pressure, volume, and temperature. This process is generally described as a polytropic process, with a polytropic index (η) in the range of 1.2–1.4.(Arsyah et al., 2024).

The performance of a reciprocating compressor can be evaluated by its volumetric efficiency, which is the ratio of the actual volume of air entering the cylinder to the theoretical volume of the cylinder. This efficiency depends on the cylinder size, piston stroke length, and cylinder diameter and can be analyzed from a pressure–volume (P–V) diagram that depicts the changes in energy and work done by the system during the working cycle.(Hapsari et al., 2023).

Beyond the technical aspects, a comprehensive understanding of how reciprocating compressors work is also closely linked to the needs of mechanical engineering students. Test equipment or learning media based on reciprocating compressors can provide realistic visualizations of working phenomena that are difficult to explain using theoretical methods alone, particularly those related to the suction, compression, and exhaust processes. These learning tools also enable the measurement and evaluation of operating parameters such as pressure, volume, and RPM, as well as providing students with practical experience in operating and analyzing pneumatic systems.(Nugroho et al., 2022).

However, developing such learning tools faces various challenges, including budget constraints, design complexity, and the need for integration with existing curricula. Therefore, careful design is required, focusing on simplicity, ease of operation, and relevance to practical needs to support students' mastery of concepts and technical skills in mechanical engineering (Sulistya et al., 2019).

3. RESEARCH METHODS

This research is an experimental study with a quantitative approach aimed at analyzing the effect of working pressure variations on engine speed (RPM) values in a reciprocating compressor tester. Data collection was conducted directly in the Mechanical Engineering Laboratory, utilizing a tester equipped with pressure and RPM sensors for accurate measurements. The study was conducted from May to July 2025. The research implementation flow is explained more fully in Figure 1.

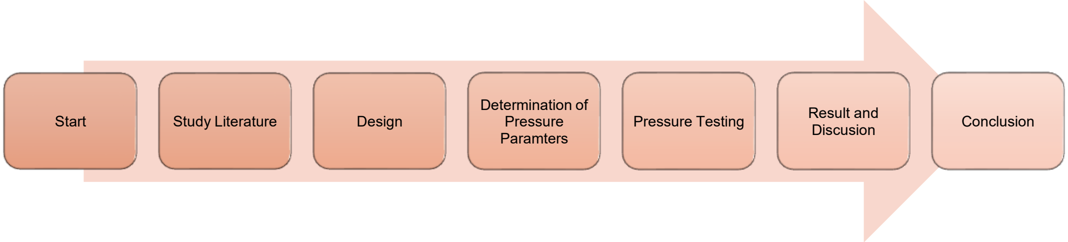

Figure 1. Flow chart

The method used consists of several stages as follows:

3.1 Literature Study

The initial stage of the research involved collecting and reviewing literature related to the working principles of reciprocating compressors and the application of the polytropic equation to the gas compression process. This study aimed to understand the working mechanism, the pattern of changes in working pressure values, and their relationship to engine speed (RPM) values, thus providing a theoretical basis for designing the testing method used.

3.2 Design of Reciprocating Compressor Test Equipment

After understanding the theoretical basis, a reciprocating compressor tester was designed to realistically represent the system's operation. This tool was designed with cylinder dimensions, piston stroke length, intake and exhaust valve mechanisms, and drive system in mind, allowing for controllable and recordable working pressure testing. This design (Figure 2) is also equipped with a pressure sensor and tachometer to accurately measure RPM.

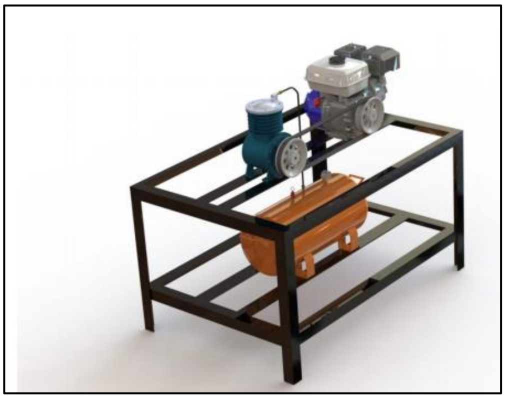

Figure 2. Design Reciprocating compressor test equipment

3.3 Determination of Working Pressure Variation

The working pressure value is varied from low to high to evaluate the effect of changes in working pressure on engine speed (RPM). This pressure variation is used as a control parameter to obtain a pattern of RPM changes at various compressor load levels.

3.4 Pressure Testing

The test equipment is operated according to the specified working pressure values. During the test, the working pressure and engine speed (RPM) are systematically measured and recorded using a pressure gauge and tachometer. The data obtained is used for analysis to understand the operating patterns of the reciprocating compressor system.

3.5 Results and Discussion

The working pressure and RPM data obtained from the test were processed and analyzed using a statistical approach and curve visualization. This analysis aims to identify patterns of RPM changes due to variations in working pressure, evaluate the effect of working pressure on volumetric efficiency and system power, and obtain a comprehensive overview of the performance of the reciprocating compressor.

3.6 Conclusions and Suggestions

The final stage of the research consists of drawing conclusions based on the patterns and values obtained from testing and data analysis. These conclusions are used to answer research questions related to the relationship between working pressure values and engine speed (RPM) and their implications for system performance and efficiency. Furthermore, recommendations are also made for the development of test equipment and further research, including improving sensor accuracy, implementing more precise working pressure control, and expanding the working pressure values to obtain a more comprehensive picture of system operation.

4. RESULTS AND DISCUSSION

4.1 Results

This study was conducted to evaluate the effect of working pressure on engine rotational speed. The designed test rig allows for observation of reciprocating compressor performance under laboratory conditions with controlled pressure parameters. Testing was conducted at three speed variations, each with three measurement time points, to monitor changes in RPM with increasing working pressure.

1. Speed 1

In the Speed 1 test, the relationship between time, engine rotation speed (RPM), and working pressure was obtained as presented in Table 1.

Table 1. Speed 1

Time	Rotation (RPM)	Pressure (bar)	Pressure (psi)
1 minute	3961	2.0	29
1.5 minutes	4832	2.5	36
2 minutes	4846	2.7	39

(Source: Authors, 2025)

Based on the data in Table 1, an increase in engine rotational speed (RPM) is seen as the test time and working pressure increase. In the first minute, the engine rotational speed was recorded at 3961 rpm at a working pressure of 2.0 bar (29 psi). After 1.5 minutes, the RPM increased to 4832 rpm when the pressure increased to 2.5 bar (36 psi). In the second minute, the RPM increased again slightly to 4846 rpm along with an increase in pressure to 2.7 bar (39 psi).

This trend indicates that increasing working pressure in the reciprocating compressor system causes the engine's rotational speed to increase until it reaches a near-steady state. The largest RPM spike occurs between the first minute and 1.5 minutes, with a difference of 871 rpm. However, in the 1.5- to 2-minute interval, the RPM increase is relatively small (only 14 rpm) despite the increase in pressure. This indicates that the system is entering a steady state phase, where additional pressure no longer significantly affects the engine's rotational speed.

2. Speed 2

In the Speed 2 test, the relationship between time, engine rotation speed (RPM), and working pressure is shown in Table 2.

Table 2. Speed 2

Time	RPM	Pressure (bar)	Pressure (psi)
1 minute	6973	2.5	36
1.5 minutes	7007.7	2.8	40.5
2 minutes	7312	3.0	43.5

(Source: Authors, 2025)

The test results on Speed 2 showed a consistent correlation between test time, engine rotational speed (RPM), and working pressure. In the first minute, the engine rotational speed was recorded at 6973 rpm at a working pressure of 2.5 bar (36 psi). After 1.5 minutes, the RPM increased marginally to 7007.7 rpm as the pressure increased to 2.8 bar (40.5 psi). In the second minute, the RPM increased more significantly to 7312 rpm when the working pressure reached 3.0 bar (43.5 psi).

The observed pattern shows that the increase in working pressure is directly proportional to the increase in RPM, although at varying rates. The increase in RPM in the initial interval (0–1.5 minutes) is relatively small (+34.7 rpm), while in the subsequent interval (1.5–2 minutes) there is a larger increase (+304.3 rpm). This phenomenon indicates a transition phase in the compressor's mechanical system, where in the initial stage the engine speed tends to be stable because the load has not yet reached its optimum point. As pressure increases, the compressor's working resistance increases, so the system requires adjustments to the motor speed to maintain the compressed air supply, which results in a more significant increase in RPM in the subsequent phase.

3. Speed 3

The test results at Speed 3 show the relationship between time, engine rotation speed (RPM), and working pressure as presented in Table 3.

Table 3. Speed 3

Time	RPM	Pressure (bar)	Pressure (psi)
1 minute	7522	3.1	47
1.5 minutes	7716	3.4	50
2 minutes	8034	3.8	54

(Source: Authors, 2025)

The test results at Speed 3 showed a positive relationship between test time, engine rotation speed (RPM), and working pressure. In the first minute, the engine rotation speed was recorded at 7522 rpm at a working pressure of 3.1 bar (47 psi). After 1.5 minutes, the RPM increased to 7716 rpm along with an increase in pressure to 3.4 bar (50 psi). In the second minute, the RPM increased again more significantly to 8034 rpm when the working pressure reached 3.8 bar (54 psi).

This trend indicates that at higher working pressure levels, the engine rotation speed shows a more pronounced increase. The increase in RPM in the initial interval (0–1.5 minutes) was recorded at 194 rpm, while in the subsequent interval (1.5–2 minutes) the increase was greater at 318 rpm. This pattern indicates that the system is under full load conditions, where each increase in pressure requires greater power adjustments by the drive motor to maintain a stable compressed air supply. This is consistent with the working characteristics of reciprocating compressors, which at high pressures require greater torque, thus affecting the dynamics of engine rotation.

4.2 Discussion

The test results show a strong correlation between test time, engine rotational speed (RPM), and working pressure at each speed level (Speed 1–3). In general, RPM increases with time, as shown in Figure 2. In the Speed 1 test, the engine rotational speed increases from 3961 rpm in the first minute to 4846 rpm in the second minute. A similar trend is also observed in Speed 2 and Speed 3, with increases from 6973 rpm to 7312 rpm, and from 7522 rpm to 8034 rpm, respectively. This increase in RPM reflects the transient phase in the system, where the drive motor adapts to the dynamic load due to the increase in working pressure until it reaches a steady-state condition. This phenomenon is consistent with the working principle of a reciprocating compressor, which requires time to achieve operational stability after load initiation.

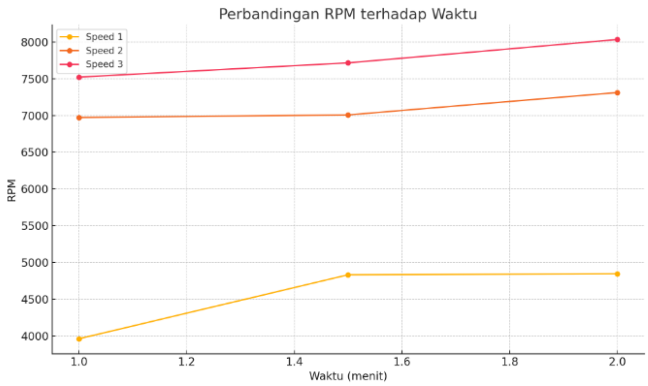

Figure 2. RPM to Time Comparison

In addition to the rotational speed, the working pressure produced by the system also shows a progressive increase pattern over time as seen in **Figure 3.** At Speed 1, the pressure increases from 2.0 bar (29 psi) to 2.7 bar (39 psi) in a two-minute period. A similar increase occurs at Speed 2, with an increase from 2.5 bar (36 psi) to 3.0 bar (43.5 psi), and at Speed 3 from 3.1 bar (47 psi) to 3.8 bar (54 psi). This trend indicates a continuous increase in the compressed air flow rate, caused by the compressor's volumetric efficiency increasing as the system stabilizes.

Figure 3. Pressure (Bar) vs. Time Comparison

Furthermore, analysis of the effect of speed variations shows that increasing the speed level from Speed 1 to Speed 3 results in a significant difference in system performance. The initial RPM increases sharply from 3961 rpm (Speed 1) to 6973 rpm (Speed 2) and reaches 7522 rpm (Speed 3). The maximum pressure achieved also increases, respectively 2.7 bar (39 psi), 3.0 bar (43.5 psi), and 3.8 bar (54 psi). These results show that increasing the compressor's operating speed directly contributes to the compression capacity and compressed air flow rate, which is in accordance with the characteristics of reciprocating compressors that work more optimally at high speeds to produce greater pressure.

Furthermore, performance comparisons over time also show increased system efficiency at higher speed levels. For example, in the second minute, Speed 1 produced 4,846 rpm with a working pressure of 2.7 bar, while Speed 3 achieved 8,034 rpm with a working pressure of 3.8 bar. This indicates that the system is not only responsive to speed changes but also more efficient in generating pressure at high speeds. This performance improvement can be attributed to the greater power supplied by the drive motor, allowing the compressor to effectively overcome higher system resistance.

4.3 Validation of Results

The results of this study show that increasing the engine rotational speed (RPM) of a reciprocating compressor directly impacts operating pressure and volumetric efficiency. This finding aligns with several recent studies.

Negrão et al. (2022) in their study on the effect of rotor speed on volumetric and isentropic performance in compressors found that volumetric efficiency increases with increasing speed up to a certain limit. This increase occurs according to the polytropic model and rotor speed correction applied to the system. The results of this study support the findings in this study, where at the highest speed level (Speed 3), working pressure and volumetric efficiency experienced a significant increase in the same time period, indicating more optimal system performance at high speeds.

Zheng et al. (2024) also reported similar findings through experimental studies and mathematical modeling on rotary compressors. They showed that the volumetric efficiency increased from 84% to 105% when the rotation frequency was increased from 80 Hz to 180 Hz. This increase was attributed to the formation of a supercharging effect at high speeds. The same phenomenon was seen in this study, where Speed 3 with an RPM of around 8000 produced a working pressure of around 3.8 bar, much higher than Speed 1 and Speed 2. This indicates that the reciprocating compressor system is able to utilize increased speed to increase pressure and volumetric efficiency.

Furthermore, a review study on positive-displacement compressor performance (2022) stated that increasing the pressure-compression ratio can cause volumetric drawbacks such as leakage and temperature increases, but system efficiency can still be improved if the polytropic process settings and mechanical controls are optimally implemented. This pattern is consistent with the test results in this study, where Speed 3 showed the most significant increase in pressure and RPM, indicating that the system successfully minimized internal resistance and utilized the workload volumetrically.

CONCLUSION

This study has analyzed the effect of variations in working pressure on the engine rotational speed (RPM) in a reciprocating compressor test device. The results show that the increase in working pressure is directly proportional to the increase in RPM at each speed level. At Speed 1 to Speed 3, the working pressure increases from 2.7 bar to 3.8 bar, while the RPM increases from 4846 rpm to 8034 rpm in the same test period. Analysis using the polytropic equation and volumetric efficiency ηv indicates that the system achieves optimum performance at high speeds. This confirms that operating speed regulation is a key factor in optimizing compressor performance.

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