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Development of a New Air Compressor System for Ship Operations

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Abstract: An optimal operation of compressors used onboard vessels for various purposes is very important. In this study, the drawbacks of conventional air compressors are addressed. Interruption of the operations by unpredictable electrical power blackout and corrosion are the key drawbacks. The corrosion occurs due to a manual drain, which depletes the life of the air tank, thereby causing damages to the compressors. To address this challenge, the need for modification of conventional air compressors is imperative. Hence, this study entails the design and fabrication of an air compressor system with rechargeable characteristics, well equipped with an automatic drain sensor and pressure switch, to obtain optimal system efficiency and reliability. From the obtained results of the test and performance of the compressor, it is obvious that it is efficient and reliable for onboard ship operations.

Keywords: Air compressor, Design, Fabrication, Ship operations, Rechargeable

1. Introduction

Compression technology has made a significant impact in industries [1]. Air compressors are used in various marine vessels to provide compressed and pressurized air for many applications, such as starting the main engine, auxiliary engine, emergency generator, and emergency fire pump [2]. Various compressors design and experiments have been conducted in different publications [3-7]. Air compressors such as main air compressors, emergency air compressors, and topping up air compressors are used onboard vessels. The mechanism of the air compressor is used to force air into a storage tank, which causes a gradual pressure increase in the tank [8-9].

The underlying engineering science supporting the design practices of compressors is demonstrated in various research [10-11]. Shuts off of air compressor occurs whenever the pressure of tank reaches its upper limit. The compressed air is stored in an air tank for utilization. Whenever the air is released from the tank, it releases kinetic energy that can be used for pneumatic device activation, transfer of air, and cleaning operations. The tank depressurizes when the air is released from them. Once tank pressure reaches its lower limit, the air compressor turns on again and re-pressurizes it.

Xu and Muller [1] studied the volute flow mechanisms in a compressor to provide comprehensive design guidance. They demonstrated how the viscous Navier-Stokes equations simulate the flow inside the vane-less diffuser and volute of air compressor to improve efficiency and operating range. The numerical calculation obtained from the study is in line with the experimental data [1]. In Shin *et al.* [8], a rotary-type compressor with a novel structure design is proposed to improve the cooling capacity and mechanical efficiency. The novel structure used the inner space of the roller as an additional working volume to compress more refrigerant under the same main dimensions of the compressor. Thus the cooling capacity is improved by 31.28–37.99% compared to the conventional rolling piston-type rotary compressor [8]. In Langa *et al.* [12], the impact of Profiled End Wall (PEW) on the performance and working range of centrifugal compressors is demonstrated. PEW is an effective method used to reduce secondary flows and associated losses to improved efficiency. The numerical simulations conducted for different PEW treatments are recorded and benchmarked against experimental data from the exemplar open test case called 'Radiver.' The results produced from the research illustrated that the compressor operating range is significantly extended to 39%, with no significant decrease in efficiency or pressure ratio. Conventional air compressors tend not to meet today's demand for onboard services because of operational failure caused by unpredictable electrical power blackout and corrosion. One of the corrosion causes is the manual drain, which depletes the tank's life. To improve the efficiency and reliability of compressors onboard vessel, a compressor with unique characteristics such as the ability to recharge, possess automatic drain with less human intervention, more ease of operation and transportation, and operating silently with high thermal efficiency be developed.

In view of this, the research aims to design and fabricate a rechargeable and automatic drain air compressor system. The design and fabrication exercise accommodated a hermetic compressor. The hermetic compressor will make it noiseless and reduce the condensate level accumulated in the air receiver tank to an acceptable level. An automatic condensate drain sensor or solenoid valve, an inverter, battery charger, pressure switch, pressure relief valve, pressure regulator, hermetic compressor, control panel, pressure gauge, air gun or quick connect, dampers, moisture absorber, and a mobile body frame will be used to design and fabricate the air compressor. The research structure is outlined as material and methods in Section 2, results and discussion in Section 2, and conclusion in Section 4.

2. Material and Methods

The various air compressor components such as air storage tank or air receiver, a hermetic compressor, a solenoid valve, a 12volts DC battery, a pressure control unit, control panel, inverter, battery charger, air gun and hose, cooling fan, air filter, dryer, a non-return valve or check valve, damper, body frame, battery terminals, tires, and foam or moisture absorber are used in the design and fabrication. The usability of various systems has been detailed in various literature [13-20]. The component specification and rating are described as follows: The air tank's capacity: The air tank's volume is 0.0160 m^3, which is equivalent to 16litres. Material of the air tank or air receiver: The material used for producing the air tank is Alloy steel. The properties are of great permeability and durability, high tensile, and yield strength. The color is blue. The maximum pressure capacity of the tank is 250Psi (17.24bar). The maximum safe operating pressure is 145Psi (10bar). The length of the air tank is 380mm (0.38m), the diameter is 232mm (0.232m), and the radius is 116mm (0.116m).

- Compressor ratings: The compressor brand is Samsung. The type of material used is steel, and the motor type is RSIR with a frequency of 50Hz. The power is 225watt with a voltage rating of 220/240volts.
- Battery ratings: The battery rating is 24 volts and 18 amperes for voltage and current, respectively. The inverter has a similar rating as the battery.

Storage capacity of the air tank analysis

The storage capacity of the air tank is calculated using Equation 1.

$$V = \pi r^2 l \quad (1)$$

where the radius, $r = \frac{d}{2} = \frac{0.232}{2} = 0.116m$

Length, = 0.38m; Therefore,

$$V = \pi \times 0.116^2 \times 0.38(m^3)$$
$$V = 0.0160m^3 \approx 16\text{litres}$$

2.1 Free Air Delivery Analysis

The capacity of the Free Air Delivery (FAD) can be calculated using Equation (2).

$$FAD = Q = \frac{P_2 - P_1}{P_o} \times \frac{V}{t}\left(m^3/\min\right) \quad (2)$$

Where P_2 in the bar is the final pressure after filling.

P_1 in the bar is the initial pressure after bleeding.

P_0 is the atmospheric pressure which is equal to 1.0135bar.

V is the storage volume in m^3 which includes the receiver and delivery pipes.

t is the time it takes to build up pressure to P_2. Its unit is minutes.

From the International Standard Organization (ISO), free air delivery can be calculated in standard cubic feet per minute (SCFM) at conditions between 1 to 7bars. Therefore,

P_2 = 7bar, P_1 = 1bar, P_0 = 1.0135 bar

Standard FAD = $\frac{7-1}{1.0135} \times \frac{0.016}{4.4} = 0.0215m^3/\min$

Also, SCFM = 0.0215×35.31=0.76 (CFM)

Calculating the actual FAD from the experiment at values of the following:

P_2 = 10bar, P_1 = 4bar, t = 4.30minutes

Actual FAD = $\frac{10-4}{1.0135} \times \frac{0.0160}{4.30} = 0.0220m^3$ / min.

Therefore, ACFM = 0.0220 × 35.31 = 0.78CFM.

Volumetric efficiency of the compressor

The volumetric efficiency of the compressor is the ratio of actual capacity to piston or compressor displacement. Mathematically, it is expressed as:

$$\eta_V = \frac{FAD}{D_P} \times 100\% \quad (3)$$

Piston displacement denoted as D_P is the swept volume of the piston per unit time. It is expressed in cfm.

$$D_P = \frac{\pi d^2}{4} \times 1 \times n \times N \quad (4)$$

Where the $b$ore diameter, d=25mm, stroke = 24mm, $n$umber of cylinders, n=1, and several $r$evolution = 3000rpm.

$$D_P = \frac{\pi \times 0.025^2}{4} \times 1 \times 0.024 \times 3000 = 0.0353m^3/\min$$

Substitution of D_P in Equation (3) gives:

$$\eta_V = \frac{0.022}{0.0353} \times 100\% = 62.30\%$$

2.2 Battery Charging Time Analysis

The calculation of the time it takes the 18 amp battery to charge and drain is expressed below. The charging current is 10 Ampere. Then, the charging time for the 18 Amps battery is given as shown in Equation (5):

$\frac{18}{10} = 1.8hrs$ (This is an Ideal case)

It is practically noted that 40% of losses occur in the case of battery charging. Then,

$$18 \times \left(40/100\right) = 7.2amps$$

Charging time of battery

$$= \frac{\text{Ah (Amp Hour)}}{\text{Charging current}} \quad (5)$$

$= \dfrac{50.4}{10} = 5.04hrs$ (in real case)

Therefore, an 18 Amp battery would take 5.04 hours to be fully charged.

2.3 Battery Draining Time Analysis

The backup time of a battery depends essentially on power consumption, battery voltage, and battery capacity. Most batteries have a nominal voltage of 12volts and may require a back–up for effectiveness. Mathematically, it is given by the expression in Equation (6):

Back up time

$$= \frac{\text{Power consumption (watt)} \times \text{Battery backup (hours)}}{\text{Voltage of the battery}} \quad (6)$$

In this research, the power consumption is 225 W. The power of the battery = 18 Amp × 24 = 432 W

Therefore, Back-up time = $\dfrac{432}{225} = 1.92 \approx 2hrs$

This means that the battery will take 2 hours to drain.

2.4 Design and Assembly Drawing of the Automated Compressor

The various design views of the automated compressor are shown in Figures 1-4 as model design overall dimensions, exploded view of the system showing more of the electrical parts, exploded view of the compressing unit of the system. And complete design model of the rechargeable compressor and automatic drain system, respectively. Figure 5 shows the prototype of the locally fabricated Rechargeable and automatic drain air compressor system

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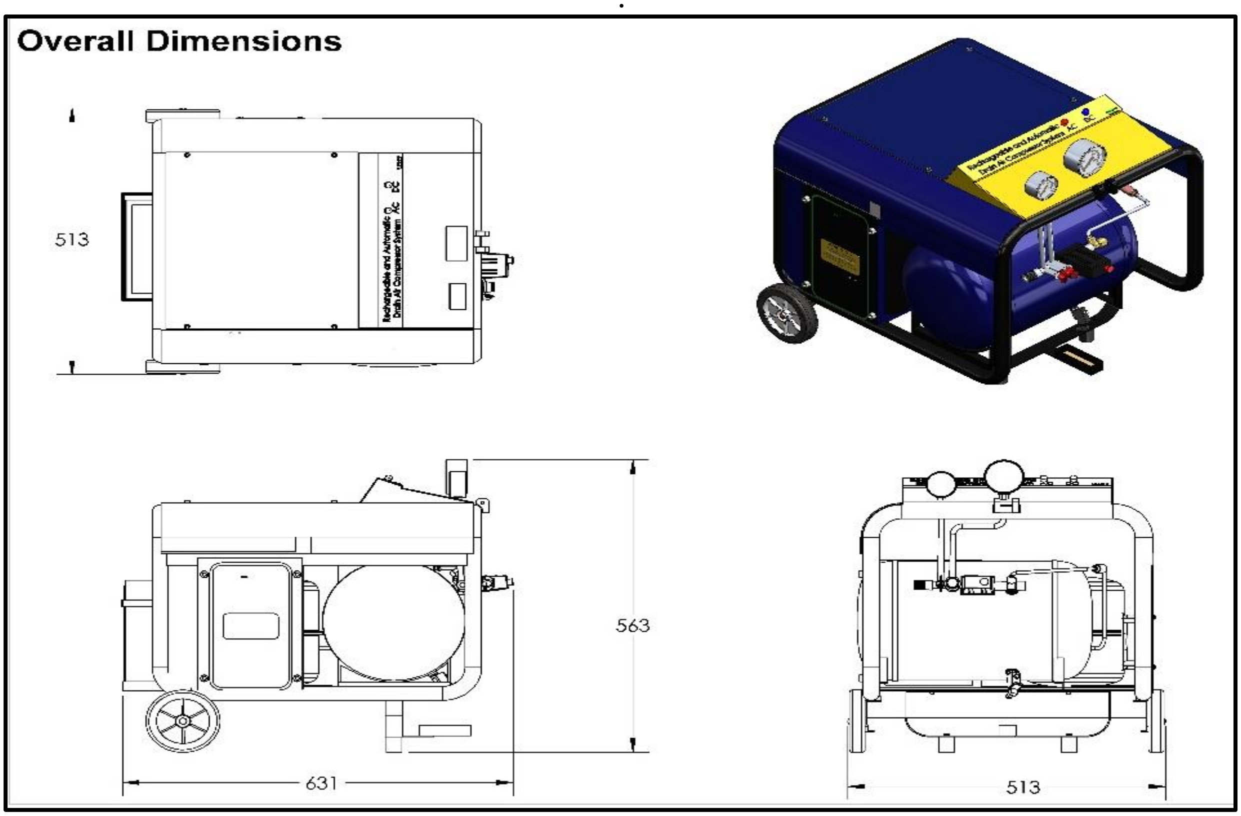
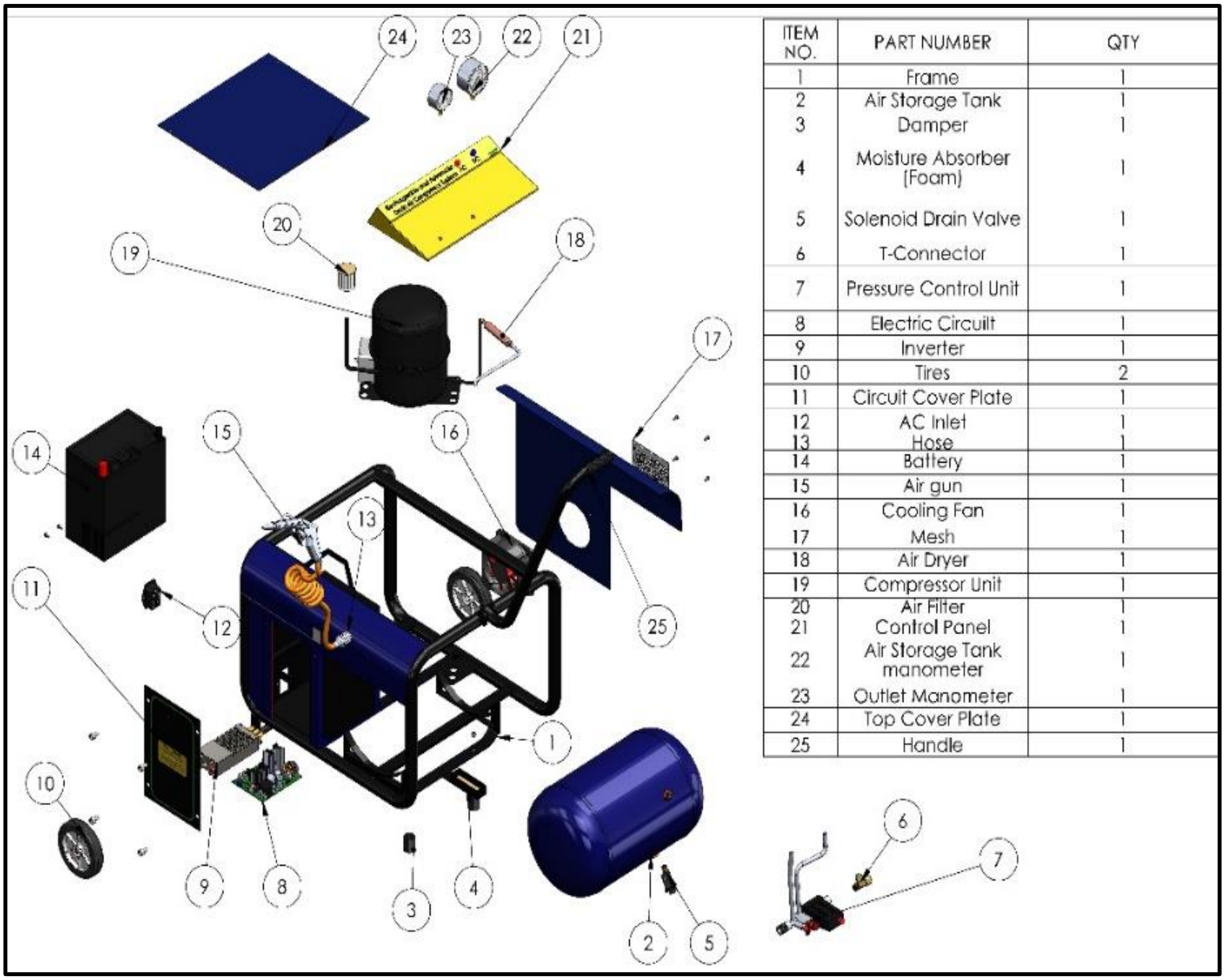
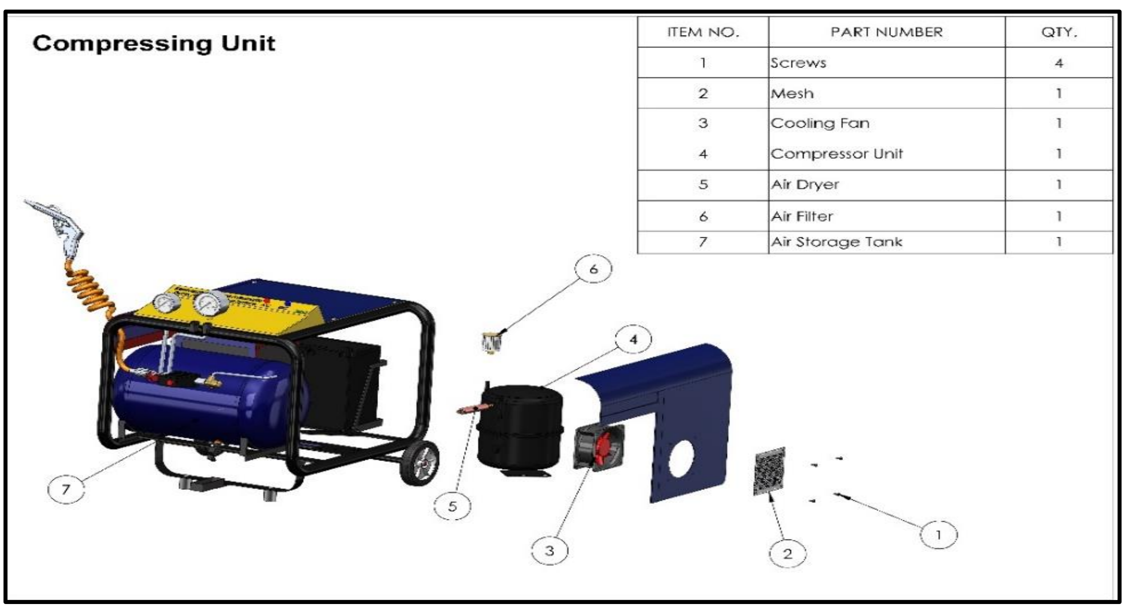


Figure 1: Model design overall dimensions



ITEM NO.	PART NUMBER	QTY
1	Frame	1
2	Air Storage Tank	1
3	Damper	1
4	Moisture Absorber (Foam)	1
5	Solenoid Drain Valve	1
6	T-Connector	1
7	Pressure Control Unit	1
8	Electric Circuilt	1
9	Inverter	1
10	Tires	2
11	Circuit Cover Plate	1
12	AC Inlet	1
13	Hose	1
14	Battery	1
15	Air gun	1
16	Cooling Fan	1
17	Mesh	1
18	Air Dryer	1
19	Compressor Unit	1
20	Air Filter	1
21	Control Panel	1
22	Air Storage Tank manometer	1
23	Outlet Manometer	1
24	Top Cover Plate	1
25	Handle	1

Figure 2: The exploded view of the system showing more of the electrical parts



ITEM NO.	PART NUMBER	QTY.
1	Screws	4
2	Mesh	1
3	Cooling Fan	1
4	Compressor Unit	1
5	Air Dryer	1
6	Air Filter	1
7	Air Storage Tank	1

Figure 3: Exploded view of the compressing unit of the system.

Figure 4: The Complete design model of the rechargeable compressor and automatic drain system

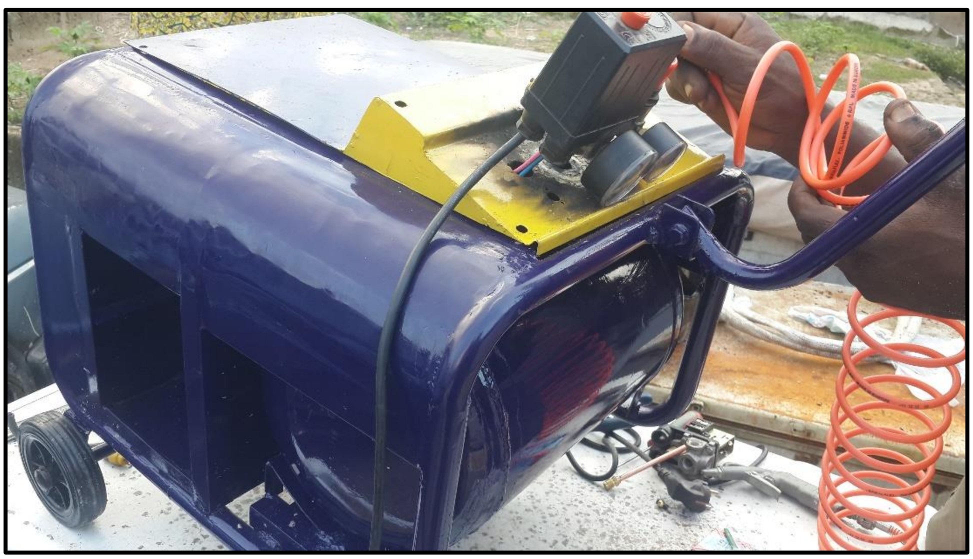


Figure 7: Picture of the Locally Fabricated Prototype

3. Results and Discussion

The volume of the air tank is 0.0160m^3, which is equivalent to 16litres. In calculating the quantity of compressed air stored in the air tank, 28.33litres of free air at 7.58bar was reduced to 1/10 original volume. Therefore, for a 16 litres tank pressurized to 7.58bar, the tank would store about 4.623 × 10 = 42.3 gallons (160litres) of air. For the Compressor, the value of the airflow rate at standard condition (SCFM) is 0.0215m^3/min (0.76CFM), and that of the airflow rate at any reference point (ACFM) is 0.0220 m^3/min (0.78CFM). These results imply that the actual quantity of compressed air delivered to the discharge system at rated speed and underrated conditions between 4 to 10bar. At 4.30 minutes is 0.78 cubic feet of air per minute (22litres of air per minute) of the work cycle. Various rated conditions for calculating the Actual

FAD at P_0=1.035 bar, P_1= 4*b*ar, gave the results as shown in Table 1. From the illustration in Figures 6 and 7, it is clear that the FAD is dependent on the operating pressure. This can be seen as the FAD increases with an increase in operating pressure. The rating of FAD is usually associated with pressure. It is also a function of time. As the time increases with an increase in operating pressure, the FAD increases. In Figure 7, the actual FAD is 0.0220 m^3/min at 10.0 bar. According to the Compressed Air and Gas Institute (CAGI) ratings of air compressors, the rechargeable and automatic drain air compressor system is perfect for light pneumatic duties. The complete results of the calculations are expressed in Table 2.

Table 1: Relationship between operating pressure and ACFM at various time intervals

P_2 (bar)	Volume (m^3)	Time (minutes)	FAD (m^3/min)
10.0	0.0160	4.30	0.0220
9.0	0.0160	4.17	0.0189
8.0	0.0160	4.13	0.0152
7.0	0.0160	3.98	0.0118
6.0	0.0160	3.80	0.0082

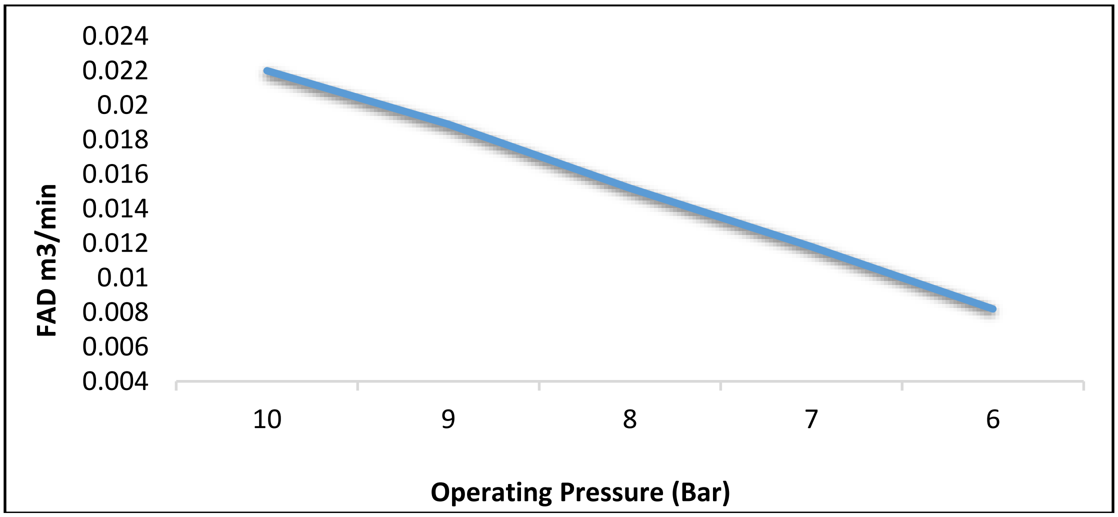


Figure 6: The graph of air delivery against operating pressures airflow diagram

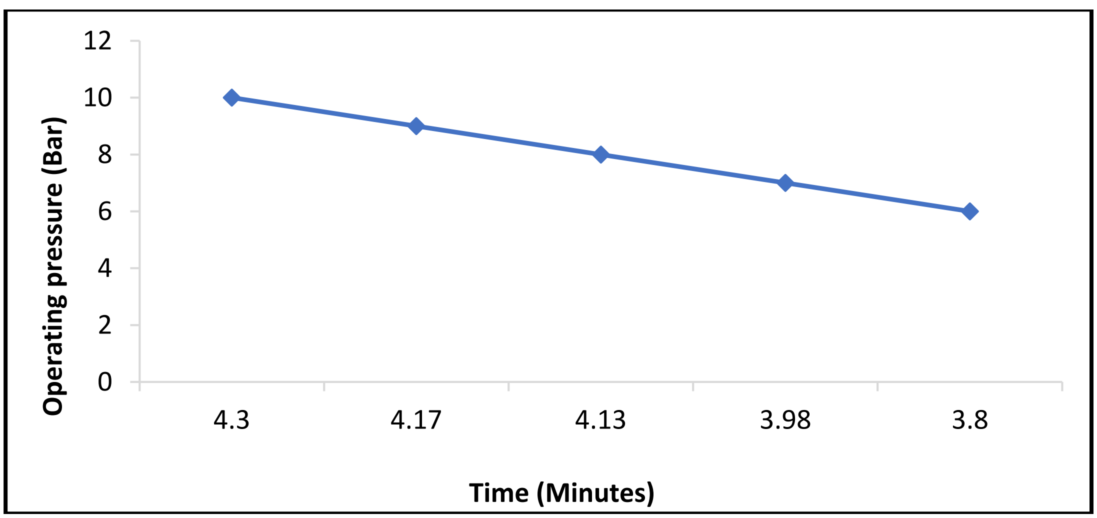


Figure 7: The graph of operating pressures against time

Table 2: The results of the calculations

PARAMETERS	VALUES
The capacity of Tank (V)	0.0160 m^3 (16litres)
Maximum Safe Operating Pressure (P_2)	145 Psi (10 Bar)
Power	225 Watt
SCFM	0.76 CFM
ACFM	0.78 CFM
Standard FAD	0.0215 m^3/min
Actual FAD	0.0220 m^3/min
Volumetric Efficiency	63.2%
Piston Displacement	0.0353 m^3/min
Battery Charging time	5.04 Hours
Battery Drain time	2 Hours

4. Conclusion

The research aims to design and fabricate a rechargeable and automatic drain air compressor system for shipboard services. The 16litres capacity system was designed to safely and reliably compress air at a maximum operating pressure of 10bar. The material selection, design considerations, calculations, drawings, and assembly were made before the project was fabricated. The materials used were selected to meet standard requirements. The air storage tank volume was determined using the basic parameters. Tank Length of 0.38m and a diameter of 0.232m were used. The other parameters required were determined and are stated in Table 2. The fabrication was done using locally available materials. The test results show that the performance of the fabricated air compressor system was found to be satisfactory, and the output of the compressor is up to the expected level.

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