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Performance investigation on double stage reciprocating air compressor

D.B. Jani[1], Chaudhari Raj[2], Bhoi Amit[3], Bhuriya Sandip[4], Bhuriya Jignesh[5], Bhatiya Murtza[6]
[1,2,3,4,5,6] *GEC, Dahod-389151, Gujarat Technological University, GTU, Gujarat, India*

Abstract- **The present article summarizes the performance of double acting reciprocating air compressor in laboratory set up. The purpose of the performance testing is to verify the theoretical calculations with the practical performance. A performance testing of the double acting reciprocating compressor is used to determine the working condition and analyzing the delivery and suction pressure which plays an important role in maintaining proper pressure heads in receiver. Using conventional performance testing methods, efficiency and working of the double acting reciprocating air compressors are improved. Various measuring instruments are used to measure air flow rate, suction and delivery pressure, power consumption etc. Reciprocating air compressors are mostly used where air flow is constant and high delivery pressures are required, so they are exposed to more risk of failure when changing the pressure by manually regulating a valve. The obtained result show that the effect of various parameters such as speed, flow rate, pressure etc. on reciprocating air compressor performance.**

Index terms- Delivery pressure, Performance testing, reciprocating air compressor, Suction pressure

1. INTRODUCTION

Compressor is a device used to increase the pressure of compressible fluid, either gas or vapor, by reducing specific volume of the fluid during passage of the fluid through compressor. The compressors used to compress the air are called air compressors. Compressors are invariably used for all applications which required pressurized air. One of basic aim of compressor usage is to compress the fluid and then deliver it to a higher pressure than its original pressure. The inlet and outlet pressure level are varying, from a deep vacuum to a high positive pressure, depends on required process necessity. This inlet and outlet pressure is compared corresponding with the type of compressor and its configuration. Reciprocating compressors generally have piston-cylinder arrangement where displacement of piston in cylinder causes rise in pressure. Reciprocating compressors are capable to give large pressure ratios but the mass handling capacity is limited or small. Reciprocating compressors may also be single acting compressor or double acting compressor. Single acting compressor has one delivery stroke per revolution while in double acting there are two delivery strokes per revolution of crank shaft.

The method of evaluating the cooling capacity of reciprocating compressor tanks is proposed by Grolier [1] carried out performance analysis of compressors by evaluating the volumetric efficiency and the estimated the suction gas temperature in the suction plenum of the cylinder-head of compressor. The determination of considered thermodynamic properties required in the calculation. This thermodynamic property is enthalpy difference between super-heat and sub-cooled points and suction gas density. The given paper proposes a method of evaluating the performance of reciprocating compressors. The simulation of the capacity and the compression work under various operating conditions can predict a good idea of the compressor performance.

Hou et al. [2] investigated energy efficiency and power factor were most essential performances for compressor unit driven by inverter-fed motors. The performances are simulated utilizing a parametric linear model under variable frequency and variable conditions. The results shows that, at given rated frequency, both the performances would fall down with lighter load, if frequency was reduced from rated, energy efficiency would fall even lower, though power factor rise up slightly.

A numerical and experimental investigation was proposed by Burgstaller et al. [3] to quantify the influence of main parameters of the suction valve on the overall performance of the compressor. The thermodynamic cycle calculation is performed by using software AVL BOOST & CFD. The calculation model shows the whole compressor domain between shell inlet and outlet.

According to Grisbrook [4] gap is provided between the recess and the space above the piston and cylinder head, increasing the initial pressure above the piston and causing greater pressure to be developed during the compression stroke. The result is an increase in the volumetric efficiency of the compressor.

According to Tsuji et al. [5] Calculations of the mechanical efficiency of a large reciprocating compressor are developed. The optimal combination parameters yielding the maximum mechanical efficiency could be determined, and then compared with the empirical combination used in the Mayekawa make compressor.

According to Zhang at al. [6] the mechanical efficiency was calculated for various combinations of piston diameter and stroke at operating speeds of 800, 1000 (rated) and 1200 rpm. The optimal combinations of the piston diameter and stroke were determined.

According to Wadbudhe et al. [7] the simulation model of variable speed air compressor provides a satisfactory performance study. The model can predict volumetric efficiency, free air delivered, indicated power, shaft power, cylinder air pressure, cylinder air temperature, resultant torque and mass of air drawn in or discharged out per cycle, by varying any operating parameters like, speed, discharge pressure, etc., and physical parameters like, clearance volume, crank radius, connecting rod length and cylinder diameter.

The given study introduced the use of side inlet ports was proposed by Parker and Cawley [8] to improve volumetric efficiency. The author unexplored third use of the side inlet ports can be used for compressors in the high compression ratio range where additional lubrication of the piston ring as well as the suction and discharge valve is needed.

The present investigation has been carried out to study an approach for performance testing of double acting reciprocating air compressors by integrating sensors for measuring pressure variations and energy supply for running the compressors and analysis of the output. The present approach can be used for testing the reciprocating air compressors at industries or even at households and also similar equipment or product by determining the parameters and their values that affect the performance of the equipment. Reciprocating air compressors are widely used due to their ease of use and simple arrangement. In case of this double acting reciprocating air compressor, flow is constant but also varies with variation in pressure. Output flow will be decreased when system pressure will be increased.

II. EXPERIMENTAL SETUP

The apparatus consists of a double acting reciprocating air compressor is operated on closed circuit basis. An AC motor with 3 speeds is provided to regulate the rpm of the compressor. Suction and delivery pressure can be varied by the valves provided and Pressure & Vacuum Gauges can measure it. Flow of air is measured by using measuring tank and stopwatch as shown in Fig. 1.

Fig. 1. Experimental set-up of reciprocating air compressor

The following are the steps for the performance testing of a double acting reciprocating air compressor:

1. Clean the apparatus and make tank free from dust and foreign particles.
2. Close the drain valve provided below the receiver tank.
3. Open the suction valve provided in main suction line.
4. Ensure that power switch given on panel should be on.
5. Set the speed of compressor with control knob provided in electric panel board in front section of apparatus.

6. Operate the flow control valve to regulate the flow of air in the receiver by the compressor.
7. Record discharge pressure by means of pressure gauge, provided on discharge line.
8. Operate the control valve to regulate the suction of compressor.
9. Record the suction pressure by means of vacuum gauge, provided at suction line of the pump.
10. Also note energy input for this time from energy meter.
11. Note down the rpm of the compressor in revolution counter provided in the panel board.
12. Measure the flow of suction air by the compressor, using the stopwatch and measuring tank.
13. Repeat the same procedure for different pressure head.
14. Repeat the same procedure for the different rpm with help of rheostat provided in the panel board.
15. When the experimental measurements are over, properly open the control valve provided on discharge line.
16. Switch off the compressor first.
17. Switch of the main power line supply to panel board.

The following are the precautions taken while carrying out experiments on double acting reciprocating compressor.

1. Ensure all the connections of the thermocouples are proper and electrical wiring is in safe condition, since the system is working at high voltage.
2. Never fully close, the delivery line and by pass line valves simultaneously.
3. To prevent the clogging of moving parts, run compressor at least once in fortnight.
4. Always use clean air.
5. If the apparatus will now use for more than month, drain the apparatus completely.
6. Always keep apparatus free from dust.
7. If air suction is not carried out, the revolution of the AC motor may be reverse. Change the electric connection of motor to change the revolutions.
8. If the panel is not showing input, check the fuse and main supply electricity.
9. Do not run the compressor at fully speed for the longer period to avoid leakages of compressed air in discharge lines.

The following are the specifications of the double acting reciprocating air compressor:
The unit consists of a two stage reciprocating air compressor with second stage connected via a finned type air cooled intercooler to the first stage as well as after cooler has been made effective by providing a fan blade type of pulley. The compressor is driven by a 3 H.P. motor connected to compressor via the belt. Air receiver tank of approximately capacity of 500 liters made up of mild steel 5 mm thick sheet. Working pressure is 10 kg/cm2 approximately. Discharge capacity of compressor is 15 CFM. The control panel consists of digital temperature indicator with selector switch, energy meter, U-tube manometer connected to the orifice, pressure gauges for measuring suction and delivery pressure (after every stage) on/off starter and indicator lamp for the compressor. The air flow to the compressor is measured with help of an orifice meter of 10 mm internal diameter (as per IS) and U-tube manometer. Dampening of the air is achieved with help of air dampening tank. The receiver tank is hydraulically tested for leakage at the operating pressure and shall be provided with all accessories like as safety valve, pressure switch, pressure gauge, drain valve and wire breaded tubing network. Total 5 nos. of thermocouples are also provided to measure temperature of air into first stage, air out of the first stage, air in to the second stage, air out of the second stage and air to the air receiving tank respective.

III. DATA REDUCTION

The theoretical required per unit time W

$$W = Pi * V1 \ln\left(\frac{P2}{Pi}\right) \quad (1)$$

The air flow rate at suction in m^3/s

$$V1 = Cd * Ao * \rho_{air}\sqrt{2 * g * h * (}\rho_{air} - \rho_w)/\rho_w \quad (2)$$

Volumetric efficiency is given by

$$\eta = 1 - \zeta\left[\left(\frac{P2^{1/exp}}{Pi}\right) - 1\right] * 100 \quad (3)$$

IV. RESULTS AND DISCUSSIONS

The following are the observations obtained for the motor speed 2680 rpm in Table 1. It is seen that a high delivery air temperature increases oil carryover and thereby further increase in the delivery air temperature due to the formation of carbon deposits on the piston and the cylinder head. Carbon deposits on the cylinder head reduce the heat dissipation capacity of the fins on the inner cavity of the cylinder head. Cylinder head design has a vital influence on the delivery air temperature.

Table -1. Observation table

Temperature (°C)		Pressure (bar)		Time(Sec)
T_{inlet}	T_{outlet}	P_{inlet}	P_{outlet}	t
26	39	1.013	4	6.68
26	43	1.013	6	5.88
26	51	1.013	8	5.60
26	55	1.013	10	5.35

The obtained results show that the isothermal efficiency of the compressors decreases with increase in the discharge pressure. As the discharge pressure increases the pressure ration goes on increasing which ultimately results decrease in Isothermal efficiency as shown in Fig. 2 and Fig. 3.

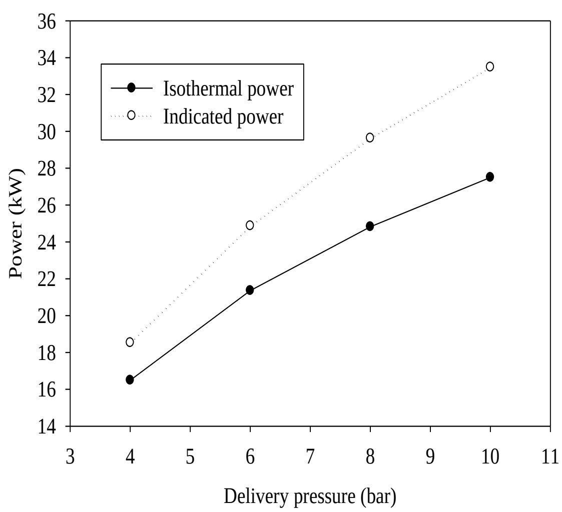

Fig. 2. Effect of variation in delivery pressure on isothermal and indicated power

The calculation of isothermal power does not include power needed to overcome friction and generally gives an efficiency that is lower than adiabatic efficiency. The reported value of efficiency is normally the isothermal efficiency. This is an important consideration when selecting compressors based on reported values of efficiency.

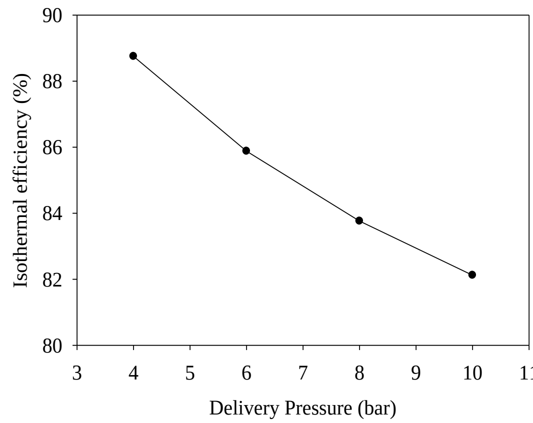

Fig. 3. Effect of variation in delivery pressure over isothermal efficiency

V. CONCLUSIONS

The performance of the double acting reciprocating compressor has been found by measuring the operational parameters during operation. The reciprocating compressor produces a fixed discharge volume of compressed air at a high compression pressure. Efficiency of the compressor is directly related to the energy consumption. The volumetric efficiency of double acting reciprocating air compressor is found as 86%. This reciprocating compressor can provide compressed air at constant flow rates over a wide range of pressure. It is expected that the convenience, efficiency and advantages offered by double acting reciprocating compressor will make it commercial for its use. There is likely to be a significant increase in the application due to its energy efficiency.

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