STUDIES ON HARD CHROME PLATING IN RECIPROCATING AIR COMPRESSORS

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ABSTRACT

This present work is to investigate the effects of chrome plating in reciprocating air compressors that result in reduction of power consumption. Reciprocating air compressors are the most commonly used compressors for domestic and industrial purposes to give required air output in terms of free air delivery, delivery temperature and maximum working pressure. This study also develops a better understanding on the effect of honing in the cylinder which reduces the surface roughness in the cylinder liner and results in greater air output. Cylinders are made of graded cast iron. The cylinder liner was honed to a thickness of about 0.26 mm and hard chrome plated to the same thickness. The honing improves the volumetric efficiency and hard chrome plating reduces the power consumption. The adequacy of this model can be verified using thermal image analysis, which includes the various temperature distribution plots around the compressor components. Further delivery temperature, actual displacement and free air delivery pressure are the parameters that conclude the deviation in actual and experimental values. Power consumption and efficiency owe for the major expenditures and maintenance for Reciprocating air compressors. This paper suggests the need of hard chrome plating to a compressor cylinder that resulted in annual power savings of about 25%. The increase in volumetric efficiency was about 20 - 30% from the actual conditions.

INTRODUCTION

Air compressor is a device used to convert the electrical energy from a motor into potential energy in terms of pressurized air. The two major classification falls into positive displacement and dynamic displacement air compressors. Reciprocating air compressors are widely used in many engineering industries ranging from small scale domestic to large-scale industrial purposes such as irrigation purposes, instrumentation needs, air product industries and medical purposes. Only about 60–70% of prime mover energy utilized whereas balance power energy wasted as un-usable heat energy and in addition to this some part of the energy is lost due to friction, vibration and noise.

In order to avoid these losses, the research works focused on to reduce the losses and improving performance of the reciprocating air compressor with less power consumption. Raymond and Wood [1] suggested the process of applying chromium plating to aluminum made cylinders in IC engines. They found that low coefficient of friction, anti-galling properties and less wear life due to chrome plating. Siva et al. [2] proposed the method of applying hard chrome plating over piston surface in IC engines to increase the engine efficiency and boost the performance of engine. They concluded that the hard chromium plating reduces heat flux and temperature over the piston surface. Rishabh et al. [3] evaluated the performance of existing cast iron piston rings and hard chrome plated piston rings. The performances evaluated by Simple electron microscope. They reported that wear resistance increased with chromium ion coating irrespective of load. Bhaumik and Ashwin [4] conducted the thermal analysis of reciprocating air compressor piston. They measured the temperature distribution on the top surface of the piston and checked the damage or broken during operating conditions. The reported results found that the stresses developed were comparatively lesser than the design stress. The experimental study were done on 5 HP compressor of 1440 rpm, piston length 77.91 mm and diameter 100 mm. The average temperature below the piston found about 65ºC that the design safe to resist the specified temperature and pressure. Vijaykumar et al. [5] investigated on the reduction of the heating effect produced during compression. This investigation concerned with improving the efficiency of two-stage reciprocating air compressor by providing water coolant, radiator coolant and ethylene glycol. They proposed a way of water-cooling at 15ºC that resulted in 1-2% reduction in power required to drive the reciprocating compressor with respect to normal inter cooling. Jamadar and Patil [6] evaluated the performance analysis of a compressor cooling in vapor compression system. They developed a compressor-cooling coil. They concluded that the compressor operated with cooling coil possessed greater coefficient of performance (COP) than compressor without cooling coil. This was mainly due to the volumetric efficiency of the compressor increased and power consumption at constant load decreased.

Wai and Htay [7] did a research in design and analysis of piston for two-stage reciprocating air compressor. The maximum final discharge depends on the bore and stroke of the cylinder. Saidur et al. [8] proposed the various techniques of energy saving such as use of efficient nozzle, reducing pressure drop and recovering waste heat from the cylinder. The researchers also established mathematical formulations for different energy saving options. Suprasanna and Subba [9] experimentally investigated to increase the efficiency of air compressor by changing coolant in the inter-cooler. The selection of coolant depended upon the properties such as miscibility, self-ignition temperature, boiling point and exploding range. They concluded that the combination of radiant coolant intercooling and mixture of ethylene glycol with water resulted in better volumetric efficiency. Kalpeshkumar et al. [10] reviewed on surface treatment on piston ring cylinder liner. Hard chrome plated piston rings improved the service life of the rings that provides wear resistance and low coefficient of friction. Coating thickness played a vital role in tribological behavior of the components. Vishal et al. [11] tested the performance and analysis of single stage reciprocating air compressor. They concluded the performances of two different compressors with a compressor test rig. The difference in efficiencies of the compressors found that due to difference in their construction, capacities and specifications. Isothermal efficiency of the compressors decreased with increasing discharge pressure. Vishnu and Deepika [12] modified the air compressor system to study and improve the performance analysis. Placement of pre-filter significantly improved the efficiency of the compressor. Amit and Sanjeev [13] worked on optimization of air compressor motor speed for reducing power consumption. The motor speed optimized by microcontroller and variable speed drive unit. 900X transducer used to control output pressure that gives signal to microcontroller for speed reduction.

From the reported papers, a postulate to apply the hard chrome plating to the reciprocating air compressor implied. The idea of applying hard chrome plating to the cylinder liner instead of applying over piston rings proposed in this study. Since, it reduces the temperature distribution inside the cylinder considerably. This leads to longer life of the components and maximize air delivery at a reduced delivery air temperature. The power consumption before and after hard chrome plating is to be calculated. The various temperature distributions of the outer cylinder surfaces have been monitored using thermal imager. The experimentation is to be repeated in different pressure ranges to find the difference between specific power consumption before and after the alterations.

EXPERIMENTATION

All the components including air filter, piston rings, piston, needle bearings cleaned and assembled. Bore length of the compressor cylinder is 65 mm and Stroke length of the piston is 35 mm. Temperature gauge that fitted at the delivery line used to calculate the temperature of the compressed air coming out of the cylinder. Pressure gauge mounted at the tank used to measure the air pressure that been built inside the tank. The experimental arrangement is illustrated by the following figure:

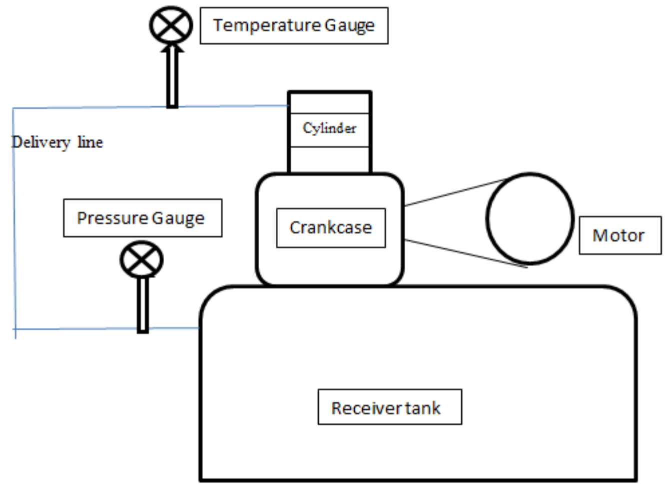

Figure 1. SCHEMATIC REPRESENTATION OF EXPERIMENTAL SETUP

Figure 2 illustrates that the ELGI compressor 1 HP [model-LG100P] considered for experimentation [14]. A voltmeter wired to the single phase LG100P motor used to measure the voltage. A digital ammeter with clamp accessory used to measure the current quickly. Stopwatch used to note down the time intervals. This forms the complete experimental setup. Motor connections checked and compressor properly connected to pressure switch for auto tripping at required pressure level. Piston rings are made of graded cast iron and piston by aluminum.

Figure 2. EXPERIMENTAL ARRANGEMENT OF LG100P COMPRESSOR

The technical specifications of the compressor used in this study given in Table 1.

Table 1. TECHNICAL SPECIFICATIONS OF COMPRESSOR LG100P

Parameters	Description	Units
Compressor Manufacturer	ELGI [LG100P]	
Speed	1300	RPM
Tank capacity	45	Liters
Working pressure	7	ATU
Displacement volume	150	Liters/minute
Motor manufacturer	Texmo motors	
Type	AC single phase	
Motor power	1	HP
Speed	1400	RPM
Voltage	240	V
Current	6.4	A

PERFORMANCE ANALYSIS

The following parameters analyzed in the reciprocating air compressor. These parameters used to study the difference in performance of LG100P air compressor before and after applying the hard chrome plating.

The power required by the compressor calculated by the following formula [16]

$$Power = V \times I \times P.F \times \sqrt{1} \quad (kW) \tag{1}$$

where, V-Voltage (V), I-Current (A), and P.F- Power Factor.

The volumetric displacement of the compressor calculated as follows:

$$Volumetric\ displacment\ (Actual) = \frac{(P_N \times 45 + 45) \times 60}{Time\ taken\ to\ reach\ P_N}\left(\frac{kg}{cm^2}\right) \tag{2}$$

Isothermal power and efficiency of the compressor calculated by using the following formulae [17]:

$$Isothermal\ efficiency\ (\%) = \frac{P_{iso}}{P_{input}} \tag{3}$$

$$P_{iso} = \frac{P_i \times FAD \times r_{cp}}{9.7} \tag{4}$$

where, Pi - Inlet Pressure (kg/cm^2), FAD - Free Air Delivery (kg/cm^2), r_{cp} - Compression ratio = P_2 / P_i, P_2 = Delivery Pressure (kg/cm^2)

The power consumed by the compressor per unit hour written as [18]:

$$SPC = \frac{P_{input}}{FAD}\left(\frac{kW}{kgcm^{-2}}\right) \tag{5}$$

The quantity of compressed air converted back to the inlet conditions known as free air delivery. Here free air delivery measured in terms of pressure developed in the gauge by allowing the compressed air to pass through the delivery pipeline (3.5 mm) to the open atmosphere.

HARD CHROME PLATING CHARACTERISTICS

Hard chrome plating is an electroplating COLD process method under a working temperature of about 50-60ºC in which chromium deposited from a hexavalent chromic acid solution. Deposits can be applied with a range of 0.25 to 1000 microns where small layered thickness materials used for wear resistance and large layered thickness materials used predominantly for salvage or repair of worn of wrongly machined components. Hard chrome used for its better wear and corrosion resistance in addition to its low friction characteristics. The coefficient of friction of hard chrome 0.21 against steel makes it ideally suited for sacrificial layer in machinery components that acts as a temperature barrier and temporary wear layer without affecting the base material. The Table 2 [15] gives the properties of hard chrome.

The following Table 3 [19] compares that the loss of heat energy inside the cylinder minimized when hard chrome plating applied over cast iron due to thermal conductivity of hard chrome is high and thermal expansion coefficient of hard chrome is low when compared to cast iron at the same density.

Table 2. PROPERTIES OF HARD CHROME PLATING

Properties	Hard chrome plating
Vickers micro hardness (kg/mm^2)	800-1000
As sprayed surface finish, R_a(µm)	40-50
Ground finish, R_a (µm)	16-32
Service temperature, (˚C)	425
Melting point, (˚C)	1875 – 1920
Coefficient of sliding friction	Cr-steel 0.12 to 0.16, sliding, well lubricated
Maximum coefficient of adhesion	Structured chrome against steel up to 0.7
Thermal conductivity at 18˚C, (W/m. K)	69.069

Table 3. PROPERTIES: CAST IRON AND HARD CHROME

Properties	Cast iron	Hard chromium
Specific gravity (g/cm^3)	7.3	7.0

Thermal conductivity (J/m s K)	46	69.069
Coefficient of thermal expansion (K^{-1})	12 x 10^{-6}	6.6 x 10^{-6}
Melting point (˚C)	1180	1900
Hardness (HB)	180–302	750–1050
Tensile strength (MPa)	276	390
Modulus of elasticity (GPa)	124	144

BEFORE HARD CHROME PLATING

The experimental setup kept ready. Initially, the control gate valve fitted at the tank fully opened and the compressor started. This used to measure the free air delivery (FAD).

The various steps involved in this study as follows:

The components of the compressor thoroughly cleaned and assembled. Initially five set of readings taken at the interval of 10 min in free load condition (delivery line left open to atmosphere). Another set of readings taken by closing the gate valve fully at an interval of 1 kg/cm^2 and time for the tank to fill 1 kg/cm^2 noted down respectively. The experiment is repeated for pressure ranging from 1 to 7 kg/cm^2 and corresponding time required to fill the tank noted respectively. All the parameters of compressor such as free air delivery, Isothermal efficiency and specific power consumption calculated by using the experimental values. The actual volumetric displacement compared with the theoretical volumetric displacement by using the formula.

Table 4. DATA BEFORE HARD CHROME PLATING

Inlet tem (˚C)	Outlet tem (˚C)	Current (A)	Voltage (V)	Pressure (kg/cm^2)	Time taken to fill tank (s)	Free air Delivery (kg/cm^2)
31	-	4.5	240	0	-	-
31	88	4.42	236	1	66	0.5
31	102	4.56	232	2	114	0.6
31	100	4.5	233	3	168	0.8
32	96	4.7	236	4	212	0.7
32	95	4.6	240	5	256	0.7
32	86	4.6	238	6	304	0.65
32	86	4.6	236	7	344	0.7

AFTER HARD CHROME PLATING

The steps involved for hard chrome plating the liner of the cylinder as follows:

The components of the compressor dismantled. Cylinder honed and hard chrome plated. The compressor made to run without delivery valve and cylinder head for 24 hours as ideal running. Free load condition readings are noted. Followed by another seven set of readings been taken.

Table 5. DATA AFTER HARD CHROME PLATING

Inlet tem (˚C)	Outlet tem (˚C)	Current (A)	Voltage (V)	Pressure (kg/cm^2)	Time taken to fill tank (s)	Free air delivery (kg/cm^2)
37	-	3.5	240	-	-	-
37	76	3.81	236	1	47	0.9
37	84	3.80	232	2	75	0.95
37	82	3.78	233	3	98	1.1
38	80	3.76	236	4	122	1.2
38	78	3.75	240	5	145	1.25
38	78	3.73	238	6	168	1.4
38	78	3.70	236	7	191	1.4

The cylinder (of model LG100P) honed to thickness of 0.26 mm with tolerance limit of 0.0025mm. The chrome-plated cylinder displayed in Figure 3.

Figure 3. HARD CHROME PLATED CYLINDER

Because for every 25 mm diameter of cylinder bore 0.1 mm sidewall honed. Rag cleaned and oil sprayed over it. The honed cylinder is then hard chrome plated for the same thickness of 0.26 mm in order to maintain the clearance specification. The cylinder sprayed with zinc sulfide to cover the uncoated areas. Then the cylinder dipped in the molten chrome to be plated. After few hours, the plated cylinder is puffed to the specified tolerances. The below mentioned figure illustrates the hard chrome plated Cylinder.

RESULTS AND DISCUSSION

The air inlet temperature at the suction increased while conducting the experiment after hard chrome plating but the delivery air temperature reduced. The pressure loss in pipeline neglected both cases. The pressure loss across the delivery pipeline lowered by placing a pipe with an equivalent nominal pipe diameter with material such as copper or galvanized iron pipes. Since, the outlet pressure and temperature is low and so high tensile rubber hose used in the experiment.

Table 6. CALCULATED VALUES FOR COMPARISON

Parameters (unit)	Before Plating	After plating
Actual volumetric displacement (l/min)	63.28	111.72
Volumetric efficiency (%)	42	74
Free air delivery (kg/cm^2)	0.7	1.1
Isothermal power (kW)	0.4386	0.6892
Isothermal efficiency (%)	40.42	79.22
Power (kW)	1.085	0.87
Specific power consumption (kW/kgcm^{-2})	1.55	0.7909

From the performance analysis, the parameters calculated before and after plating tabulated in Table 6 to compare the values from experiments. It is observed from Table 6 that Specific power consumption decreased by 48% and volumetric efficiency increased by 76%. Free air delivery of the compressor also significantly increased by 57% after hard chrome plating.

Figure 4 shows the comparison of FAD before and after the plating. It reveals that FAD is increased after honing and chrome plating. Surface roughness inside the cylinder causes backflow of air back into the cylinder and crank which results in reduction of air outlet. Honing completely eradicates these roughness and hence the compressed air is completely passed out through the delivery pipe. This is the main reason for increase in free air delivery pressure as the maximum air output is increased.

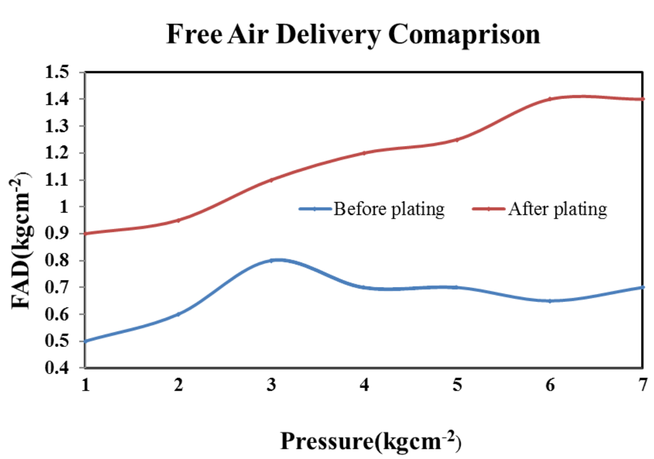

Figure 4. FREE AIR DELIVERY COMPARISON BEFORE AND AFTER PLATING

Free air delivery (kg/cm^2) varies in vertical axis and Pressure (kg/cm^2) developed inside the tank varies in horizontal axis.

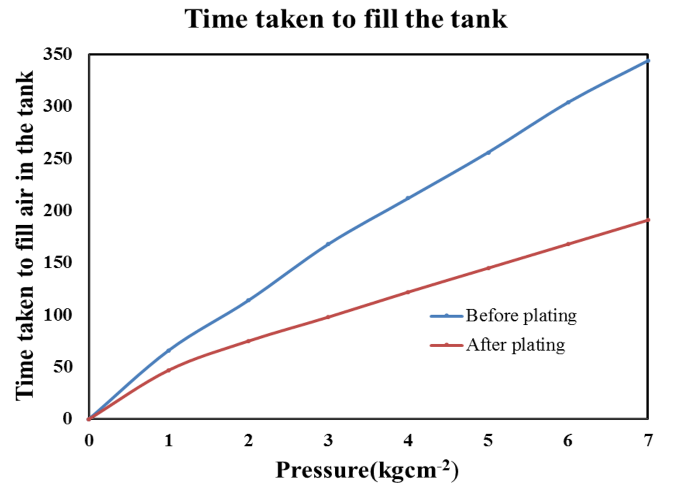

Figure 5. TIME TAKEN TO FILL AIR IN THE TANK BEFORE AND AFTER PLATING

Time taken to fill compressed air in the reservoir tank (s) plotted vertically and pressure (kg/cm^2) developed due to the filled air inside the tank plotted horizontally.

Figure 5 illustrates the comparison of time taken to fill air in the tank before and after plating cylinder. This concludes that the volumetric efficiency of the compressor increased after the honing and hard chrome plating.

The current consumed by the motor at free load conditions before and after plating is represented by the following graph. The heat loss in the cylinder reduced since coefficient of thermal expansion of hard chrome is less and thermal conductivity of hard chrome is high when compared to cast iron that shown in Figure 5.3. From the figure 5.3 it is evidently concluded that the hard chrome plating coated to the cylinder liner has reduced the work load of the motor. Without coating it is seen that the current consumption oscillates and varies a lot where after the coating found to be linear throughout the operation.

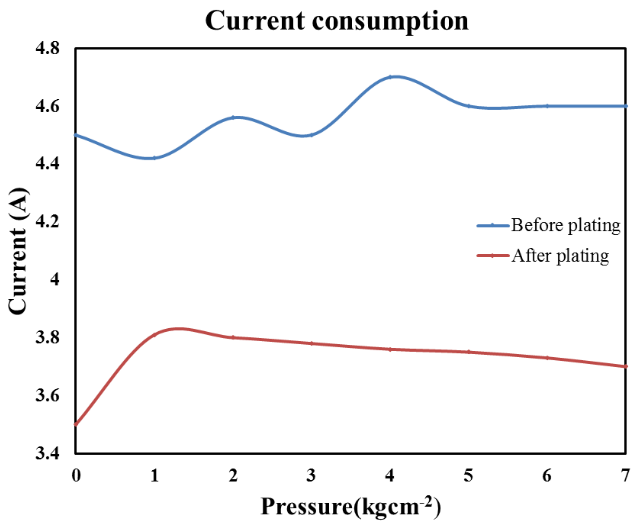

Figure 6. CURRENT VS PRESSURE BEFORE AND AFTER HARD CHROME PLATING

Current (A) consumed by the motor is shown in vertical axis against the pressure (kg/cm^2) developed inside the reservoir tank in horizontal axis.

An infrared camera (Fluke Thermal Imager) captures the temperature distribution across the fins on the cylinder outer casing. It detects and measures the infrared energy of the cylinder. Then the camera coverts it into an electronic image which apparently indicates the surface temperature of the cylinder.

Figures 7 and 8 illustrate the thermal image before plating side and top views of the compressor respectively. The thermal images show that delivery temperature is very high before hard chrome plating. There is a reduction about 10°C at the center of the cylinder after hard chrome plating. This is due to the fact that hard chromium has very low coefficient of friction when compared to cast iron. Reduction in the delivery temperature leads to lesser power consumption. Honing and hard chrome plating arrested the backflow of air back into the cylinder thus significantly reducing the energy required for re-compression.

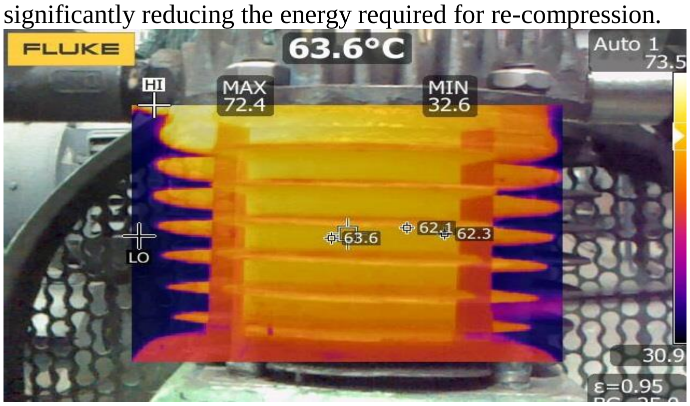

Figure 7. THERMAL IMAGE BEFORE PLATING (SIDE VIEW)

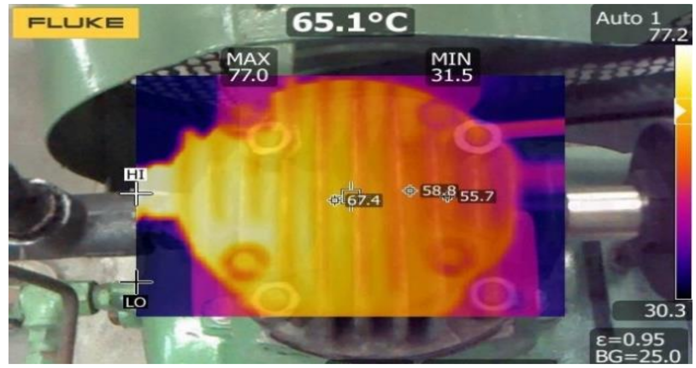

Figure 8. THERMAL IMAGE BEFORE PLATING (TOP VIEW)

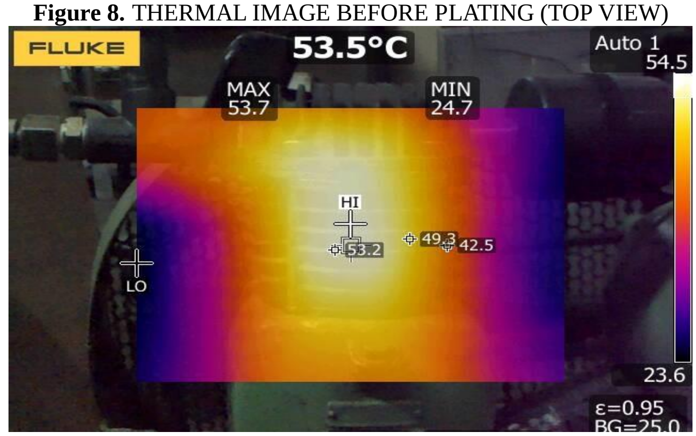

Figure 9. THERMAL IMAGE AFTER PLATING (SIDE VIEW)

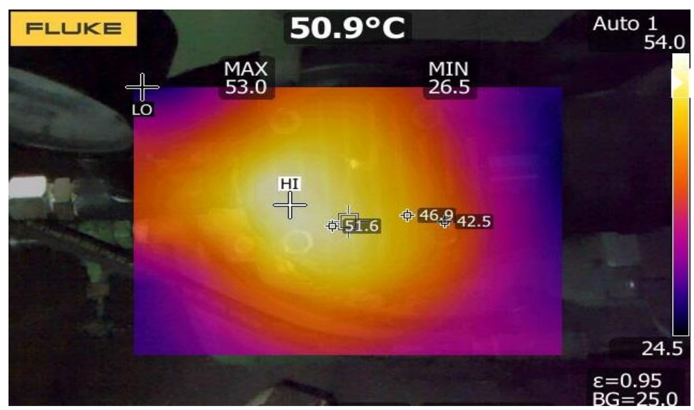

Figure 10. THERMAL IMAGE AFTER PLATING (TOP VIEW)

Similarly, the delivery head temperature at the surface of the cylinder reduced by 18.7°C. This observed from the Figures 9 and 10. This reduction in temperature is due to the low coefficient of friction behavior of hard chrome that applied to the cylinder liner. The wear resistance of the cylinder part also increased since hardness is high and thermal expansion coefficient is low of hard chrome when compared alloyed cast iron that usually used as the cylinder liner.

The uncertainties among the laboratories are based on allowed deviations of pressure, temperature, speed and voltage. The errors of the temperature and pressure gauge is mainly based on calibration. To evaluate the results, an arithmetic mean was calculated for each operating pressure in power consumption. Then the deviation between the arithmetic mean and the single measured values had been investigated. The maximum deviation for all values within 2 times standard deviation has been determined and found to be in the range ±1.2% for the power consumption. Since the temperature was calculated by Thermal fluke imager on the surface of the compressor components the uncertainty was nil in temperature distribution. The temperature gauge was calibrated perfectly and indicated zero tolerance error when checked for different temperatures.

CONCLUSION

The hard chrome plating reduces the friction between the piston rings and cylinder therefore leading to low frictional loss. It reduced the part operating temperature about 15°C to 30°C, which monitored by Fluke thermal imager. The hard chrome plating reduces the friction between the piston rings and cylinder thus leading to low frictional loss. Every 4°C decrease in outlet air temperature results in a lesser power energy consumption by 1 %. The hard chrome plating applied to the cylinder reduced the delivery air temperature by 16% and decreased the power consumption by 20%. Annual power saving for 1 HP compressor (Roughly 10 hours daily) costs Rs. 16,425 per year (approx.) where the cost of hard chrome plating for this compressor done within Rs. 2000 (approx.). From these observations, hard chrome plating can be applied to the higher HP compressors that results in increased air output with reduced delivery air temperature. In addition to this life of the piston, piston rings and cylinder increases as friction is reduced.

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