Parameter Optimization of Hermetically Sealed Compressor for Optimum Lubrication

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Abstract— When load on compressor increases the compressor shaft rotates at high speed. In this case there is a lot of heat and friction between the moving parts of the compressor (piston, bearing, and crank). Therefore lubrication of these parts becomes crucial. In case of load elevation the need for lubrication also increases. Whereas when load on compressor decrease the lubrication required is also less. If the oil lubricated is in excess or deficient then the compressor action is not carried our properly. This calls for an optimal solution for a system that lubricated just the right amount of oil, which is neither excess nor insufficient. The Aim of this project is to create an experimental test to verify suitable lubrication design. This project helps explain the different parameter that affects the lubrication of oil. We are varying certain parameters such as (Motor speed, Pumping diameter, Drill offset and drill diameter) While keeping some parameters fix for avoiding complexities such as (shaft diameter, depth of oil level, temperature.

Index Terms— Centrifugal pumping system, DOE, Hermetically sealed compressor, optimal lubrication,

I. INTRODUCTION

The heart of any refrigeration system is the hermetically sealed compressor. It plays a crucial role in determining the efficiency of refrigeration. For the compressor to function properly to give maximum output at lower energy consumption its optimal lubrication is essential. In hermetically sealed compressor, in one side of the enclosed casing the various parts of the compressor like cylinder, piston, connecting rod and the crankshaft are located. If it is a multi cylinder compressor, there are more than two cylinders inside the casing. On the other side of the casing is the electric winding inside which the shaft of the motor rotates. This motor can be single speed or multi-speed motor. In hermetically sealed compressors the crankshaft of the reciprocating compressor and the rotating shaft of the motor are common. The rotating shaft of the motor extends beyond the motor and forms the crankshaft of the hermetically sealed reciprocating compressor.

It consists of oil sump located at the bottom, a shaft driven by motor. The shaft is dipped in the oil sump and a hole is drilled in the shaft which will acts as a tube for oil flow, the drilled hole is offset so that it when the shaft rotates it will create a centrifugal action and oil will start to flow upwards. The discharge of oil through the shaft depends mainly on the design of the shaft. Various factors like speed of motor, diameter of the shaft hole, pump diameter etc. will determine its effect on the quantity of oil required from the sump.

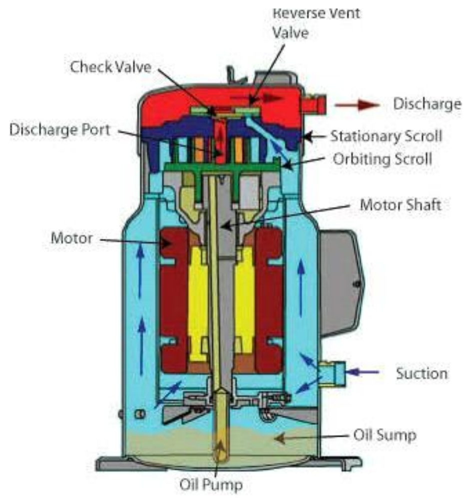

Fig. 1 Cross section of hermetically sealed compressor

II. LITERATURE REVIEW

Antonio J. Luckmann [1], in his “Numerical Investigation of Oil Flow in a Hermetic Reciprocating Compressor” investigated, initial condition of the problem, where the lubricant is stationary in the sump. As the pump-shaft starts moving and the oil flows into the pump, it starts its ascending motion in the inner part of the hollow shaft. After approximately 0.6 s, the lubricant reaches the inlet of the helix channel, where it starts feeding the radial bearings.

As the lubricant reaches the top end of the shaft (t~0.8 s), under the influence of its angular momentum the oil is directed to the walls of the upper reservoir. In the real situation, the fraction of the oil flow reaching the upper region of the compressor is responsible for lubricating the piston-cylinder gap. The contact between the oil and the piston is made when the latter is at the bottom dead centre and its lower portion becomes exposed to the internal environment (crankcase).

C.M Punk and Kim Y in their “The Oil Pumping System of a Variable Speed Scroll Compressor"[2] stated that the oil flow rate significantly increases with a rise of compressor speed due to a higher oil flow rate from the swing pump and a greater centrifugal force on the oil gallery. This analytical method was proved to be very useful to determine the oil flow rate through the oil gallery and to design an optimized oil gallery for a variable speed scroll compressor. A proper lubrication in a scroll compressor is very important to achieve higher reliability and performance. A scroll compressor includes four major lubrication parts an orbiting scroll journal bearing, a main journal bearing, a main thrust bearing, and a lower journal bearing. A swing pump and oil gallery are core parts in the oil pumping system of a low-pressure type scroll compressor. The lubrication oil pumped from an oil reservoir by the swing pump is supplied to several lubrication parts through the oil gallery, which is located inside of a crankshaft. An analysis and optimum design of the oil supplying system is required to develop an energy efficient compressor with a higher reliability and durability.

Cui Michael in his "Investigation on the Oil Supply System of a Scroll Compressor"[3] investigated the startup process of the scroll compressor oil supply system is important for scroll compressor reliability and performance. Since the bearings are running dry when a scroll compressor starts, the bearing dry time is an important design parameter as well. Two operating parameters are studied using the numerical model developed. The first parameter is the oil depth inside the oil sump. When oil is pumped into the gallery and bearings, the oil sump depth changes gradually with time. This change of depth impacts the lubrication capacity of the oil system. Since the sump has an open surface, the surface shape is a function of time and waves from inside the compressor. These surface waves interact with oil flow inside the gallery and bearings. The second parameter is the fluid viscosity. The change in oil viscosity is caused by refrigerant absorbed in the oil and heat transfer between the motor and oil. A total of four cases are analyzed comparatively. The physical mechanisms controlling oil supply rate are defined. The oil supply rate and the dry periods of the bearings are obtained. The results can be used to design and optimize the oil supply system of scroll compressors.

The oil flow inside the oil pump and sump is a complex physical process. When a scroll compressor starts, oil remains inside the sump. The bearings and pump are dry. As the motor rotates, the centrifugal force gradually overcomes gravity and surface tension. The pressure generated by the centrifugal force inside the flow field drives the oil into the oil gallery. The shape of the oil surface is determined by the balance of gravity, centrifugal force, and surface tension as well as gas flow above the oil surface. The rising oil level eventually reaches the bearings and ports. When the oil pressure overcomes the resistance of the bearings and ports, the oil starts flowing into bearings and ports in the system. The oil supply rates to bearings are resulted from design features and working conditions of oil pump and bearings. The design objective of the oil supply system is to provide sufficient oil to the bearings and minimize the bearing dry period.

Prasad, B.G Shiva in his “Positive Displacement Compressor lubrication system”[4] gives empirical guidelines for optimum quantity of oil for various compressor cylinders operating in different gas streams, with different ring materials, under low-to-high pressures, and in a wide range of speeds. ‘‘Optimum’’ lubrication gives years of compressor life, while ‘‘starved’’ lubrication produces rapid wear and short life. ‘‘Over lubrication’’ gains little in operating life and requires more oil. It illustrates the compressor component life with various lubrication rates. There are various lube oil rate formulas or guidelines proposed by compressor manufacturers, oil suppliers and seal manufacturers. They provide an estimate for quantity of oil to lubricate gas transmission type compressor cylinders. These formulas are similar in that they are based on total swept surface area to be lubricated. No formula or graph can cover all possible conditions, pressures, speeds, gases, and ring materials. The oil usage for optimum lubrication is given in pints per day per cylinder for PTFE-equipped cylinders.

Antonio J. Luckmann and Marcus Vinicius C in their "Oil pumping in a reciprocating compressor”[5], Research stated that the immediate provision of lubricant oil to the radial and thrust bearings and to the piston–cylinder gap in reciprocating refrigeration compressors is a crucial reliability issue following compressor start-up. The aim of this paper is to present a hydrodynamic analysis of the lubricant oil pumping system of a reciprocating compressor using computational fluid dynamics. In the present system, oil is pumped from the sump through a reed-type centrifugal pump located at the bottom end of the shaft. The oil flows initially as a climbing film on the internal surface of the shaft before it is directed to the external surface where it flows along a helix channel carved on the shaft wall. The model was implemented on the commercial package Fluent using the volume of fluid (VOF) method to resolve the free-surface oil flow. Parameters regarding the oil behavior during start-up, such as the time required to reach steady-state operation and the associated oil mass flow rate are explored in the manuscript.

III. METHODOLOGY

Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. According to this, four parameters, Motor speed, Pumping diameter, Drill offset and drill diameter were taken into consideration as a input parameter and two parameters threshold time and volume of lubrication were taken as a output parameters.

Table 1: Factors and levels for experimentation

Factors / Levels	Motor Speed (RPM)	Pumping Diameter (mm)	Drill Diameter (mm)	Offset (mm)
1	**4000**	**10**	**4.5**	**2.5**
2	**5000**	**13.5**	**5.5**	**3.5**
3	**6000**	**15**		

IV. EXPERIMENTATION

The experimentation was carried out according to design of experiments as stated. About 36 runs were taken. And then interactive effects of each parameter is tabulated.

The setup was manufactured consisting of oil sump, high speed motor, oil collector along with shafts of different parameters as discussed.

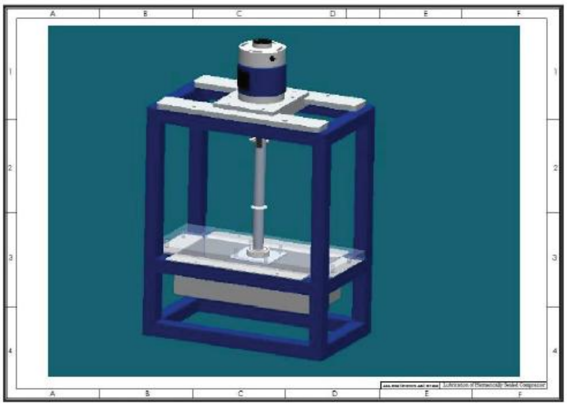

Fig 2. Experimental Setup

V. RESULTS AND DISCUSSION

Lubrication system for hermetic compressor wherein advantage is taken of the rotation of a shaft driven by the motor for lubricating parts of the compressor. The centrifugal force generated by the rotation of shaft acts as pumping device. With the lower end portion of the shaft constructed as a pump impeller to form a lubricant pumping means, when the motor is running, lubricant may be pumped upwardly through the system to lubricate between the parts of the compressor which are moving relative to each other.

Table2: Experimentation runs

Run No.	Motor Speed	Pump Dia	Hole Dia. (mm)	Offset (mm)	Time (sec)	Vol (mm^3)
1	4000	10	4.5	2.5	33	1
2	5000	10	4.5	2.5	17	1.5
3	6000	10	4.5	2.5	12	2
4	4000	13.5	405	205	28	2
5	5000	13.5	4.5	2.5	12	3
6	6000	13.5	4.5	2.5	12	3
7	4000	15	4.5	2.5	20	2.5
8	5000	15	4.5	2.5	10	3.5
9	6000	15	4.35	2.5	9	5
10	4000	10	5.5	2.5	30	1.5
11	5000	10	5.5	2.5	14	2
12	6000	10	5.5	2.5	9	2.7
13	4000	13.5	5.5	2.5	25	2.8
14	5000	13.5	5.5	2.5	10	4
15	6000	13.5	5.5	2.5	8	5
16	4000	15	5.5	2.5	17	3
17	5000	15	5.5	2.5	8	4.5
18	6000	15	5.5	2.5	6	5
19	4000	10	4.5	3.5	25	1.5
20	5000	10	4.5	3.5	12	2
21	6000	10	4.5	3.5	10	2.7
22	4000	13.5	4.5	3.5	23	3
23	5000	13.5	4.5	3.5	11	3.3
24	6000	13.5	4.5	3.5	9	4
25	4000	15	4.5	3.5	16	3
26	5000	15	4.5	3.5	8	4
27	6000	15	4.5	3.5	7	5.4
28	4000	10	5.5	3.5	24	1.8
29	5000	10	5.5	3.5	12	2.4
30	6000	10	5.5	3.5	8	3
31	4000	13.5	5.5	3.5	22	2.3
32	5000	13.5	5.5	3.5	8	4.3
33	6000	13.5	5.5	3.5	7	5.4
34	4000	15	5.5	3.5	14	3.2
35	5000	15	5.5	3.5	7	5
36	6000	15	5.5	3.5	6	6.5

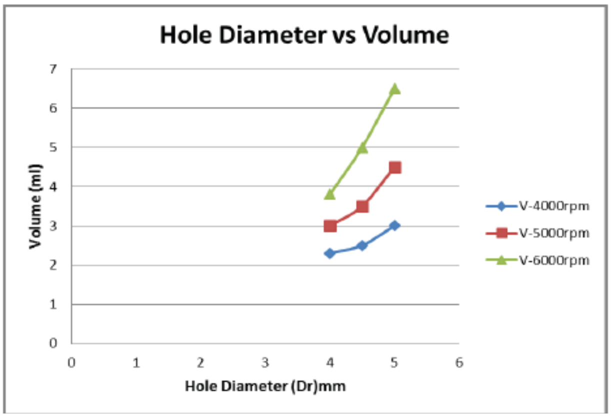

Fig.3 Hole Diameter vs. Volume

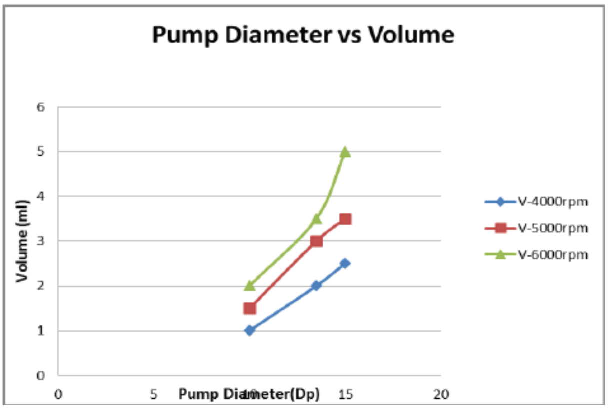

Figure 4 Pump Diameter vs. Volume

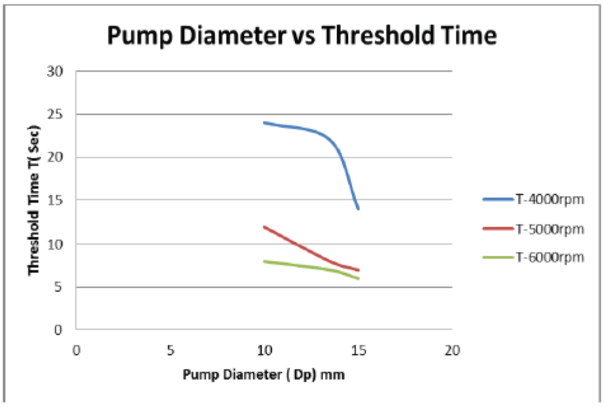

Figure 5 Pump Diameter vs. Threshold Time

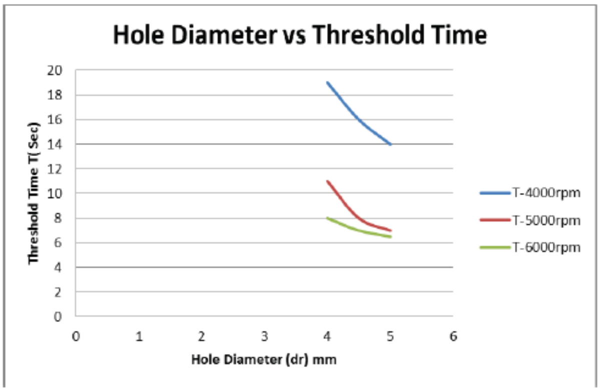

Figure 6 Hole Diameter vs. Threshold Time

After testing different parameters to calculate the amount of oil collected at the end of experiment, when lubricating a system, less supply of lubrication results in improper function of moving parts due to friction. Even excessive lubrication results in load on the oil pump and thereby not suitable. Hence adequate amount of fluid is essential and can be taken care of through this method. The flow of oil is more sensitive at higher speed and less sensitive at lower speed. As the design speed of shaft is near to 4000 rpm, the design of this oil pump is robust to accommodate small variations in the diameters during manufacturing of holes.

VI. CONCLUSION

The flow of oil fed to bearings is dependent of - Geometrical dimensions of oil pump (shaft hole diameter Dp and pump hole diameter Dh). Dp=15 and Dh=5mm are suitable for this design to have proper lubrication - Working Temperature of oil- as temp increases, viscosity drops and more oil is fed - Viscosity of oil- viscous oil is fed in less volume to bearing The time to pump oil at 4000 rpm is 14 seconds and this is high as it can lead to dry running during initial time period. But the time to pump oil at higher rpm is sufficient as bearings are designed to run dry momentarily for 5-7 seconds. This can be one a input for further study and investigation of field failure data for the subject compressor.

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