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# OIL DROPLET GENERATION AND CONTROL IN ROLLING PISTON TYPE COMPRESSORS

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## ABSTRACT

This paper addresses the generation and control of oil droplets in rolling piston type refrigerant compressors at speeds greater than 5000 RPM. This work is part of the development of a variable speed compressor which addresses the problem of critically low oil sump levels that can occur at these extreme speeds. This paper identifies the dominant mechanism of oil droplet generation based on experimental and analytical results.

## NOMENCLATURE

$\beta$	Internal oil groove angle
$d$	Diameter of radial oil hole
$f$	Frequency of shaft
$f_c$	Friction factor of radial oil hole
$f_f$	Friction factor of oil groove
$l$	Length of radial oil passage
$\dot{m}$	Mass flow rate of oil
$\mu_{\text{gas}}$	Dynamic viscosity
$\nu$	Kinematic viscosity
$\rho_{\text{oil}}$	Density of oil
$r_d$	Radius of droplet
$r$	Radius oil groove cross section
$R_i$	Inner radius of oil hole
$R_o$	Outer radius of oil hole
$v$	Gas velocity
$g$	Gravitational acceleration

## INTRODUCTION

The problem of oil migration became evident in the development of Carrier's variable speed compressors at speeds above 5000 RPM. The issue became evident primarily in heating conditions in field trial split system units as a result of bearing failures. These conditions were duplicated in the laboratory in the variable speed condensing unit with a sight glass on the compressor to determine the conditions of the oil. The results of this testing revealed significant loss of oil at speeds above 5000 RPM. This oil loss causes bearings to be prone to damage in the event of flooding. Solving this problem would allow the use of multi-evaporator in units without oil separators and oil dilution during flooding conditions would be reduced.

In an attempt to determine the dominant oil migration drivers in the compressor, oil circulation sources, paths and collectors were mapped in order to account for the equilibrium level. Oil sources are from oil discharge from the bearing oil groove, from the center hole in the shaft, from the agitation of the oil at the vane slot relief hole, from the windage of the refrigerant over the sump and from the oil circulation discharged from the pump assembly into the shell of the compressor. There are paths through the shaft and into the shell and both above and below the motor. Direct paths into the refrigerant gas are from the vane agitation, from the windage over the sump and from the gas and oil discharge from the muffler discharge. Primary collector surfaces are the motor windings, stator slots and shell interior surfaces. This is illustrated in Figure 1.

### **Objective of study**

The study was directed to identify and eliminate the dominant oil circulation mechanisms and was done with a sight glass at the compressor sump in a variable speed compressor. The compressor was modified to reduce the oil circulation sources and paths to determine if potential improvements could be made. The speed of the compressor was increased slowly to determine the oil pump-out speed at various conditions. Figure 2. defines the oil pump out speed with respect to saturated discharge temperature and saturated suction temperature.

### **Investigation**

By increasing the flow area through the motor to reduce the gas velocity below the average terminal velocity of the droplets, the oil migration through the motor was predicted to decrease. This effect is similar to the Millikan oil drop experiment where the flow resistance on the small oil drops is due to viscous force, because the Reynolds number is very small. In this case Stoke's equation may be applied to determine the terminal velocity of a particle of a given diameter. If the gas velocity is greater than the terminal velocity of a given droplet size, then the droplet will migrate to the top of the compressor shell. Thus, the weight of the oil drop must be greater than the viscous force on the oil drop to return to the lower shell.

$$\frac{4}{3} \pi r_d^3 \rho_{oil} g > 6 \pi \mu_{gas} r_d v$$

Experimental results did not agree exactly with the predicted results as the flow area through the stator was increased to very large flow areas through the stator. Also only small improvements could be obtained by these flow area changes.

By increasing the refrigerant discharge gas temperature at a given condition by increasing the suction superheat, the gas viscosity increases and the oil pump-out speeds observed decreases as predicted by stokes equation.

Motor bearing oil discharge from the oil groove was determined to be a significant oil source that is discharged from the motor end bearing hub into the shell directly below the rotor. The oil flow rate significantly increases with speed based on the following equations. Figure 3 and 4 clarify the nomenclature. These equations are base on the assumption that no other pressures are acting on the control volume.

The dynamic driven flow rate though a radial hole in the shaft is,

$$\dot{m} = f_c \rho \pi^2 f^2 (R_o^2 - R_i^2) d^4 / (64 l v)$$

And the viscous driven flow through an internal oil groove in the journal is,

$$\dot{m} = (2/3) \pi \rho f_f f R_o r^2 \cos\beta$$

The flow rate above 5000 rpm is dominated by dynamic pumping though the oil holes and is discharged out of the upper and lower bearing oil grooves. The flow through the upper bearing groove is approximately half the total flow rate generated by the lubrication system with in the bearings and shaft at high speed. This oil discharge is of concern in the

compressor because it becomes entrained into the main stream of refrigerant gas by the motor as it is discharged directly below the rotor.

Experimental oil flow results were determined by routing oil from the bearing discharge to a small 0.060 inch inside diameter pipe that discharged across the view of the sight glass. Based on the trajectory and the diameter of the discharge flow, the flow rate was roughly estimated. The discharge stream was discharged below a plate in order isolate it from the motor windage. This allows the oil discharge stream to enter into a gas environment without significant disturbance on the trajectory of the oil discharge stream. Figure 5 illustrates this sight glass experiment. The results indicated that the flow through the motor end bearing is very significant at speeds above 5000 rpm. However, the oil pump-out was still evident at speeds above 6500 rpm. This indicated that there was still a dominant oil circulation mechanism in the compressor. It became evident that oil droplets were being generated below the flange of the motor end bearing and below the separator plate.

Another interesting observation was that the oil level would always reduce to a level exactly at the bottom of the cylinder when the oil pump-out speed was obtained and oil level equalized. Figure 6 illustrates this part of the compressor design. During the oil pump-out process the compressor noise at the vane location was evident until the oil level dropped below the vane relief hole. Secondly, at speeds greater than the oil pump-out speeds, the oil level would remain at this same level corresponding to the bottom of the cylinder. The general observation was, that as the compressor speed was increased slowly at these high speeds, the oil level would remain at a full sump level until the oil pump-out speed was obtained and then the oil level would reduce to this discrete point just below the cylinder.

## **CONCLUSION**

The dominant source of oil migration at speeds above 5000 rpm was found to be from the vane motion in the vane relief hole. Above the critical oil pump-out speed the vane motion in the vane relief hole behaves as a crude positive displacement pump with liquid at the suction and gas at the discharge. This behavior causes oil spray to be discharged from the top of the vane hole and ingested in the mainstream gas flow through the motor and out of the shell.

## **ACKNOWLEDGMENTS**

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Fig.1 Oil migration sources, paths and collectors

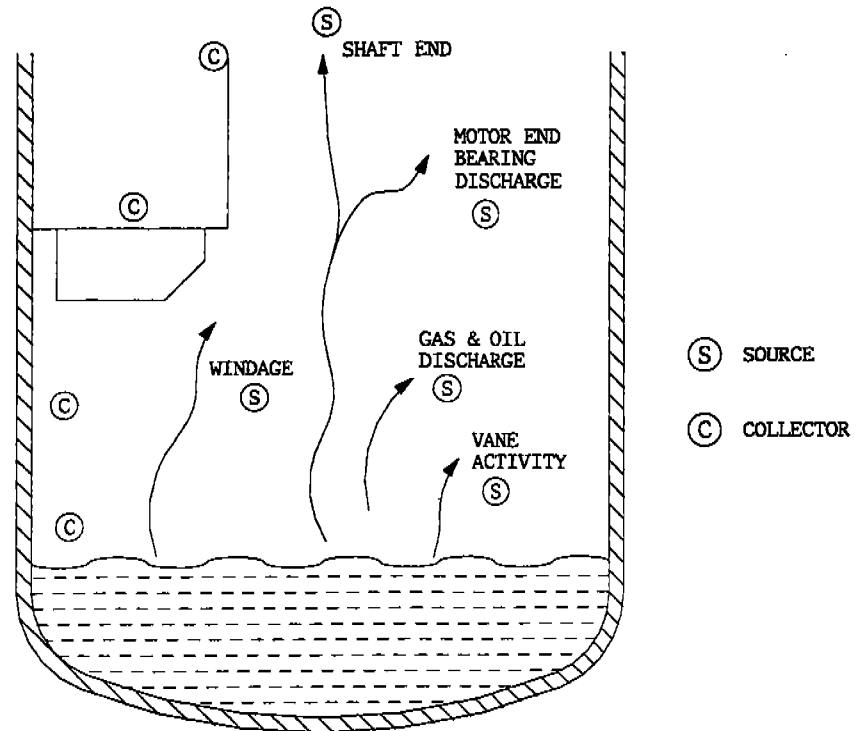


Fig.2 Oil pump-out in rotary compressor. Contours are pump-out speeds in Hz.

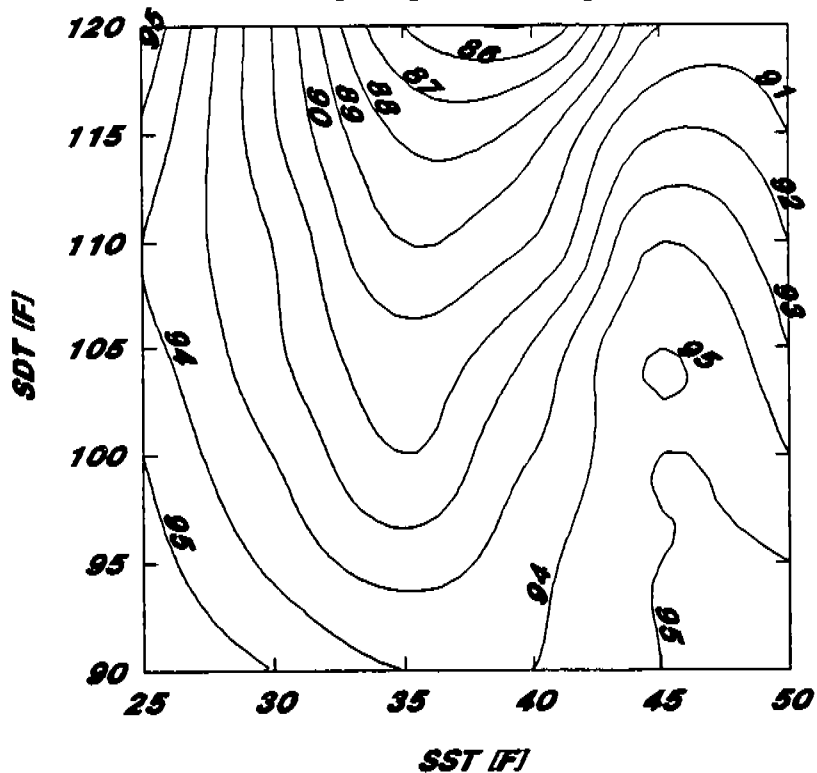


Fig.3 Radial hole passage dimensions

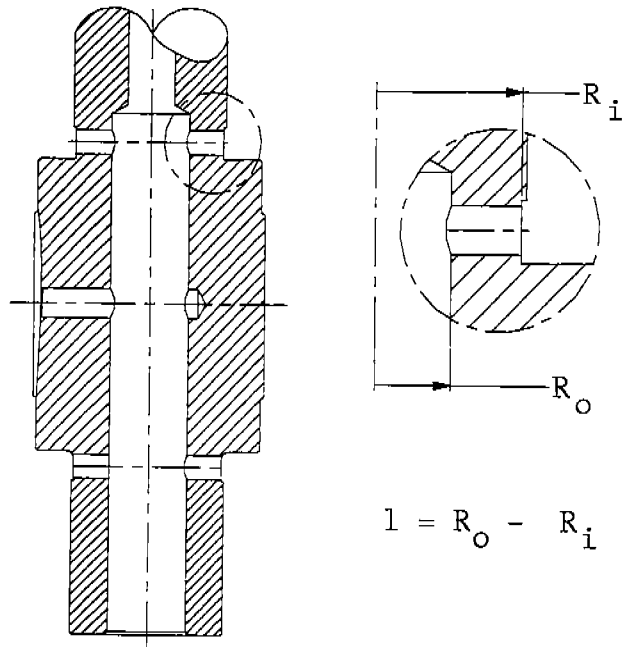


Fig.4 Oil groove in motor end bearing

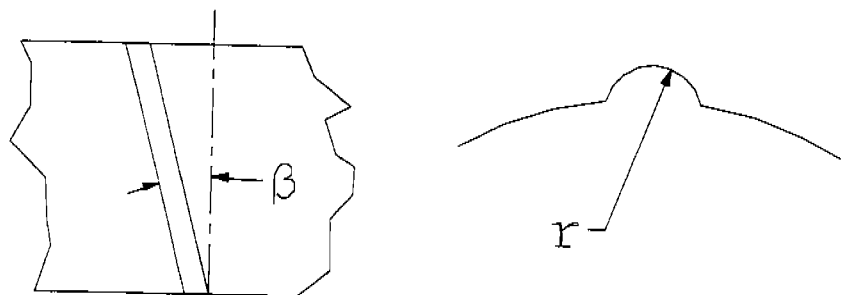


Fig.5 Sight glass view of sump

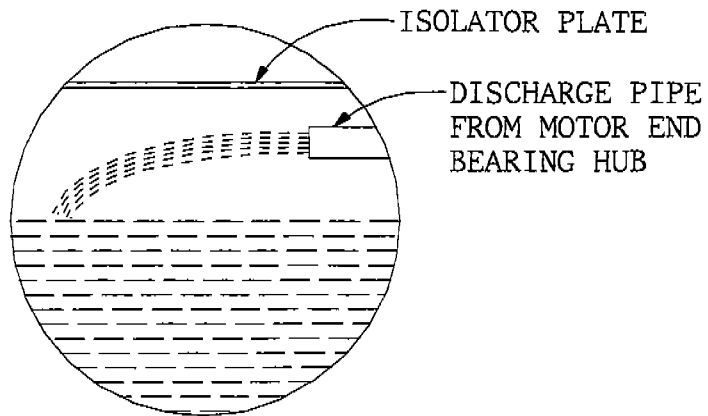


Fig.6 Vane slot oil agitation

