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K. K. Fung
Tyler Refrigeration

S. G. Sundaresan
Copeland Corporation

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STUDY OF OIL RETURN CHARACTERISTICS IN A DISPLAY CASE REFRIGERATION SYSTEM. COMPARISON OF DIFFERENT LUBRICANTS FOR A HFC-BLEND REFRIGERANT

Kwok K. Fung
Tyler Refrigeration
Niles, Michigan
USA

and

Sonny G. Sundaresan
Copeland Corporation
Sidney, OH 45365
USA

ABSTRACT

Refrigerant R502 has been successfully used with naphthenic mineral oil in commercial refrigeration systems. Oil return from the evaporator to the compressor crankcase is a critical requirement affected by the refrigerant-lubricant properties (such as viscosity, miscibility and solubility), gas velocity and piping geometries. Oil return characteristics of refrigerant blend R404A with two lubricants, a naphthenic mineral oil, and a polyolester were evaluated in a low temperature display case refrigeration system. The results support the contention that polyolester lubricants exhibit superior oil return characteristics in relationship to mineral oils.

INTRODUCTION

For proper performance and durability of refrigeration systems, the lubricant and system accessories such as oil separators have been selected to keep the lubricant in the crankcase of the compressor. The relationship of performance to refrigerant and oil type has been discussed by Downing(1988). Naphthenic mineral oil and alkyl benzene lubricants have excellent track records with refrigerants such as R-12, R-22 and R-502 (ASHRAE 1990). HFC refrigerants such as R134a, R404A and R507 are being applied with polyolester lubricants in refrigeration systems and expected benefits are equivalent or better performance and durability (Sundaresan 1992a, 1992b, 1992c & 1993).

Oil return from the evaporators for the new HFC blend refrigerant, R404A, in an actual low temperature display case refrigeration system was studied with naphthenic mineral oil and polyolester lubricant. The refrigerant R502 and naphthenic mineral oil combination was studied as a reference baseline. The HFC blend refrigerant, R404A, was tested with two different lubricants, naphthenic mineral oil and polyolester. The study was conducted in a low temperature display case refrigeration system using a semi-hermetic discus compressor. For one particular refrigerant/lubricant combination (R404A/mineral oil) the effect on the following variables were studied: number of defrosts per day, refrigerant charge, condensing temperature, evaporative temperature, and case load. This paper also includes comparative results on the evaporative heat transfer characteristics of the three refrigerant-lubricant combinations.

EXPERIMENTAL SET UP

The test apparatus is a commercial refrigeration system (see figure 1) which consists of a single supermarket display case coupled to a condensing unit consisting of a reciprocating compressor, water cooled condenser, liquid line filter drier and 100 feet of suction (includes 10 feet of riser) and liquid lines in between. Refrigerant flow direction is indicated by the arrows.

The display case is a 12 feet low temperature multi-shelf case with doors. Heaters are mounted inside for case load adjustment. The evaporator has 4 circuits and 32 smooth copper tubes with plate fins at 2 fins per inch, and the finned section is 131 inches long. Refrigerant enters the evaporator through the posterior tubes and exits through the anterior tubes. Expansion valve regulates the refrigerant flow, creates refrigerant pressure drop and adjusts for refrigerant superheat at evaporator outlet. A fan system circulates air in the display case to maintain display volume temperature and exchange heat with the refrigerant at the evaporator in a cross flow manner. Electric Heater is mounted at the evaporator for defrost purpose.

The condenser is a shell and tube type heat exchanger with water flowing through the tube side and gas refrigerant condensing on the shell side. Refrigerant enters the condenser from the top and exits through an outlet at the bottom. Sight tube is mounted at the compressor crankcase for oil level readings. A mass flow meter on the liquid line measures the refrigarant flow rate. Sight glasses are mounted on the condenser outlet, flow meter inlet and suction line riser for visual inspection purpose. Evaporator pressure regulator (EPR) on the suction line regulates the evaporator pressure and temperature. Defrost clock is used to set defrost time, duration and frequency for the system.

TEST PROCEDURE

The system was charged with 27 pounds of refrigerant blend R404A and 95 cu. in. of polyolester lubricant (POE, 22cSt). Test was then conducted at 85 F condensing temperature, -35 F evaporative temperature, 8189 BTUH (2.4 KW) heater load and 4 defrosts per day.

R404A refrigerant was then removed and R502 was charged into the system, and the oil there was replaced with naphthenic mineral oil (32cSt), with a system total of 146 cu. in. of oil (designed to maintain the same oil level during defrost at the same test conditions) and 27.5 pounds of R502. Tests were carried out at 85 F condensing temperature, -35 F evaporative temperature, 2.4 KW heater load, and both 4 and 1 defrost per day.

R502 refrigerant was then removed and 27 pounds of R404A were charged into the system, and tests were performed at the same conditions as the refrigerant R502. Nine pounds of R404A refrigerant were then removed from the system for reduced charge simulation, and tests were repeated. Additional tests were made at the following conditions:

Additional test(no.)	Condensing Temp (F)	Evaporative Temp (F)	Defrost per day	Additional Heater Load(KW)
1	85	-35	4	1.8
2	100	-35	4	1.8
3	100	-25	4	1.8

RESULTS AND DISCUSSION

Compressor Crankcase Oil Level - Figure 2 shows a plot of typical oil level in the compressor crankcase versus time. With different refrigerant and lubricant, the value of oil level in the compressor may vary, but the general shape remains similar. Compressor crankcase oil level is at its lowest level just before defrost begins, it rises during defrost and then drops quickly after defrost is terminated. The oil level then rises quickly at first and then slowly to a peak, after which the oil level drops continuously until the next defrost begins.

During defrost, compressor and refrigerant flow are stopped and no oil is returned to the compressor through the suction line, compressor oil level changed due to oil drip down from lubricated parts. At end of defrost, oil level drops quickly because oil is being pumped to rewet compressor parts that required lubrication. The ensuing rise in oil level is due to higher rate of oil return during the pull down period of the refrigeration cycle. At which time both the refrigerant flow rate and the temperature of the evaporator and suction line are higher. Higher refrigerant flow rate provides more kinetic energy to move the oil while higher evaporator and suction line temperature result in higher oil temperature and lower viscosity and it flows more easily. After steady state is reached, refrigerant flow rate and temperature of evaporator and suction line drops back to normal level, resulting in slower oil return and decline of oil level until the next defrost.

Oil Return To Compressor - Table 1 shows that R404A/POE oil has the best oil return to the compressor (highest compressor crankcase oil level) when compared to R502/mineral oil and R404A/mineral oil at the same operating conditions. Compressor crankcase oil level before defrost is the best indicator for oil return characteristics comparison as it is the point of lowest oil reserve available for lubrication throughout the refrigeration cycle. The system using mineral oil had lower oil level than when using POE oil as lubricant, along with the fact that more mineral oil charge (146 cu. in.) is required in the system than POE oil (95 cu. in.) shows that mineral oil system had a lot more oil in the rest of the system than the POE oil system and oil is not returning as well.

The effects of temperature alone on viscosity is shown in Table 2. The effect of temperature on refrigerant gas solubility in the oil for three pairs of refrigerant-lubricant combinations is provided at constant pressure (20 psia) in Figure 3 and the effect on kinematic viscosity at constant pressure (20 psia) is provided in Figure 4. In the evaporator and the suction line, the pressure was close to constant and the data in Figures 3 and 4 provides the following explanation: R404A/POE results in a lower viscosity (improved fluidity) of the oil in comparison with R502/mineral oil and R404A/mineral oil. This resulted in better oil return from the evaporator under equivalent conditions of refrigerant gas velocity and piping geometry. The molecular weight difference between the mineral oil (~320) and the POE (~560) accounts for the difference in solubility and the viscosity index difference between the mineral oil (0 to 20) and the POE (~130) accounts for the difference in viscosity at low evaporator temperature.

Since evaporator and suction line temperatures are relatively lower, mineral oil would be more viscous than POE oil and tend to move slower under the same conditions, forming a thicker film and adding up to larger quantity outside of the compressor and larger oil requirement for the system. Table 1 shows oil level for R404A/mineral oil (column 3) was very low and is not acceptable as it is close to the level where insufficient oil feed to the oil pump may in turn result in insufficient pressure to lubricate the moving parts and an oil trip out could occur. An oil trip out would shut down the compressor to avoid damage due to insufficient lubrication, and the system would lose refrigeration. R502/mineral oil system (column 2) operates, however, at an acceptable oil return characteristic.

<u>Effect Of Defrost Frequency</u> - Table 3 shows that higher frequency of defrost enhances oil return to the compressor as indicated by test results comparing tests with 4 defrosts per day versus 1 defrost per day. Columns 1 and 2 show R404A/mineral oil using refrigerant charge of 27 pounds; columns 3 and 4 show R404A/mineral oil with refrigerant charge of 18 pounds; and column 5 and 6 show R502/mineral oil at the same operating conditions. Oil level is higher for tests with 4 defrosts than that with only 1 defrost per day. The higher frequency of defrost resulted in more pull down period after defrost termination when more oil is returned from the rest of the system to the compressor. Also, since pull down period remains the same, fewer defrost per day means longer period of steady state before defrost, at which time the rate of oil return to the compressor is less than oil outflow rate from the compressor and would result in lowering of compressor crankcase oil level. However, higher number of defrost is not desirable due to its adverse effect on display product temperature and system energy efficiency.

<u>Effect of Refrigerant Charge</u> - Table 4 shows that for R404A/mineral oil, system with a marginal refrigerant charge (18 lb.) had better oil return characteristic than with regular charge (27 lb.) at the same operating conditions. For both 4 defrosts and 1 defrost per day, compressor crankcase oil level is higher for the marginally charged system (column 2 & 4) than the regularly charged system (column 1 & 3).

This is because the condenser acts as a reservoir that holds liquid refrigerant before it moves on to the rest of the system via a outlet located at the bottom of the condenser. With regular refrigerant charge, there was more than enough refrigerant in the system to fill the lines and evaporator, so any excess refrigerant remains in the condenser and forms a pool of liquid after condensation. It is likely that higher amount of refrigerant charge would retain more oil at equivalent solubility. Further work is needed to document and explain oil return from condenser under various dynamic conditions.

Effect Of Case Loading - Table 5 shows that higher display case load requirement at the same operating conditions results in a better oil return characteristic. R404A/mineral oil with 2.4 KW additional heater load inside the display volume had better compressor crankcase oil level than when only 1.8 KW additional heater load was used. This is because higher case loading requires higher refrigerant flow rate and thus more kinetic energy available to move the oil through the system and return to the compressor.

Effect of Condensing Temperature - Table 6 shows that higher condensing temperature results in poorer oil return characteristic. By comparing test results for condensing temperature of 100 F to that of 85 F, it can be seen that at the higher condensing temperature, the compressor crankcase oil level was significantly lower than that at 85 F. This is because at the higher condensing temperature, the oil temperature at the compressor is also higher and the oil becomes less viscous, thus the compressor oil outflow rate is higher than that at the lower condensing temperature.

Effect of Evaporative Temperature - Table 7 shows that increasing evaporator temperature improves oil return characteristics. For R404A/ mineral oil, at -25 F evaporative temperature, test data indicate that the compressor crankcase oil level were almost double that at -35 F evaporative temperature. This is the result of lower oil viscosity at higher evaporator and suction line temperature, it flows more easily and returns to the compressor better.

Heat Transfer Characteristics - The comparison of heat transfer characteristics among the data points can be made by comparing the coil to air temperature differential (TD) at each data point. Coil to air TD is the temperature difference between air temperature exiting the coil and the evaporator temperature. At the same operating condition, lower coil to air TD means better heat transfer characteristics at the evaporator. From Table 8, R404A/POE (column 1) had the best coil to air TD (lowest at 21.72 F) among the data points when compared to R404A/mineral oil (column 3 & 5) or R502/mineral oil (column 6). For evaporator applications, small amount of oil would enhance the heat transfer characteristic, however, further increase of oil amount in the evaporator would reduce its heat transfer capability. From Table 8, when comparing column 1 with column 3 and 5, column 1 had the best oil return characteristic, thus oil is returning to the compressor instead of logging elsewhere in the system. While tests shown in column 3 & 5, with larger amount of oil in the system to start out with, along with the lower compressor crankcase oil level, this results in larger amount of oil in the rest of the system including the evaporator. And it is the presence of this oil that is reducing the evaporator's heat transfer effectiveness and increases the corresponding coil to air TD.

CONCLUSIONS

1. For the specific system studied, the refrigerant lubricant combination of R404A and POE exhibit significantly better oil return characteristics in comparison with R502/mineral oil and R404A/mineral oil.

2. The coil to air temperature differentials indicate that the evaporator heat transfer for the same system, R404A/POE is better than R502/mineral oil and R404A/mineral oil.

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FIGURE 1: SCHEMATIC FOR SYSTEM OIL RETURN TEST

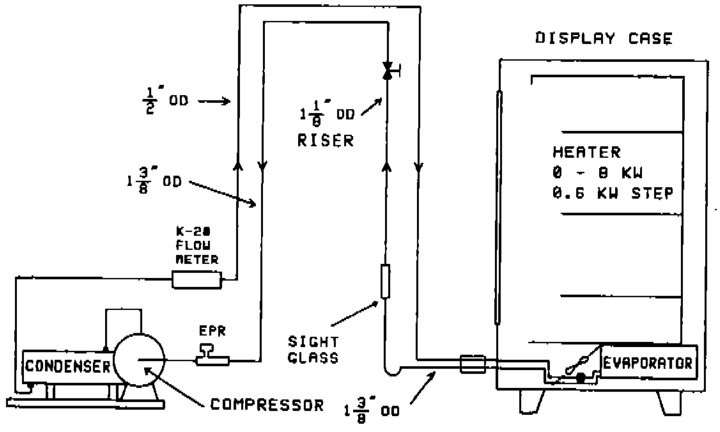

FIGURE 2: TYPICAL OIL LEVEL IN COMPRESSOR CRANKCASE VERSUS TIME

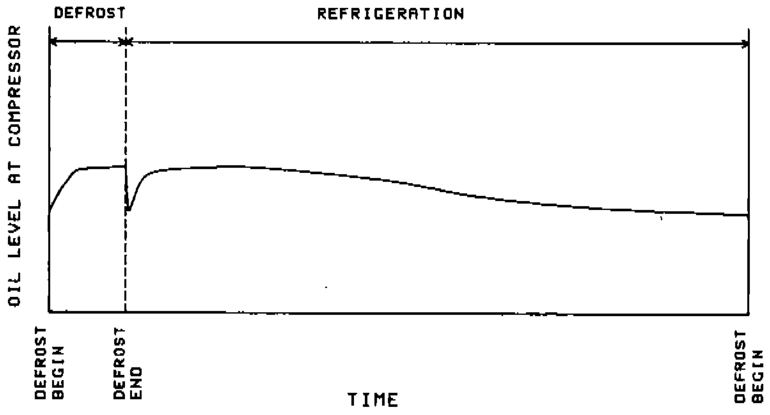

TABLE 1: Compressor Crankcase Oil Level Comparison

REFRIGERANT TYPE			R404A	R502	R404A	R404A
OIL TYPE			POE	MINERAL OIL	MINERAL OIL	MINERAL OIL
TEST CONDITION	CONDENSING TEMPERATURE (F)		85	85	85	85
	EVAPORATOR TEMPERATURE (F)		-35	-35	-35	-35
	ADDED CASE HEATER LOAD (KW)		2.4	2.4	2.4	2.4
	REFRIGERANT CHARGE (LB)		27	27.5	27	18
	NUMBER OF DEFROST PER DAY		4	4	4	4
TEST RESULT	COM-PRESSOR CRANK-CASE OIL HEIGHT (1/16")	BEFORE DEFROST	30	26.5	12	16
		DURING DEFROST	33	33	16	20
		AFTER DEFROST	31	31	14	17

Figure 3. Solubility versus Temperature at constant pressure (20 psia). R502/MO data from Downing (1988). R404A/POE data and R404A/MO data estimated from ideal solution theory.

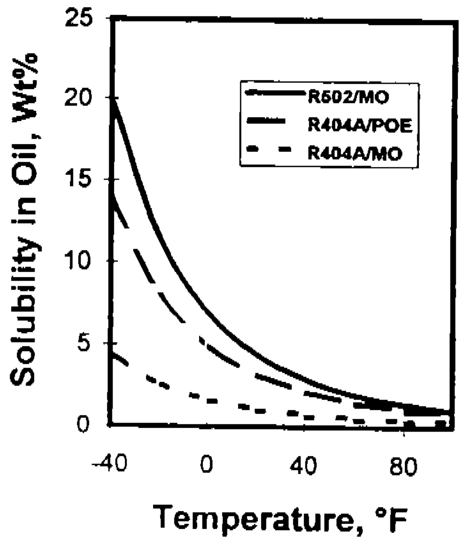

Figure 4. Viscosity versus Temperature at constant pressure (20 psia). R502/MO data from Downing (1988). R404A/POE data from J. Shim (1994). R404A/MO data estimated from ideal solution theory.

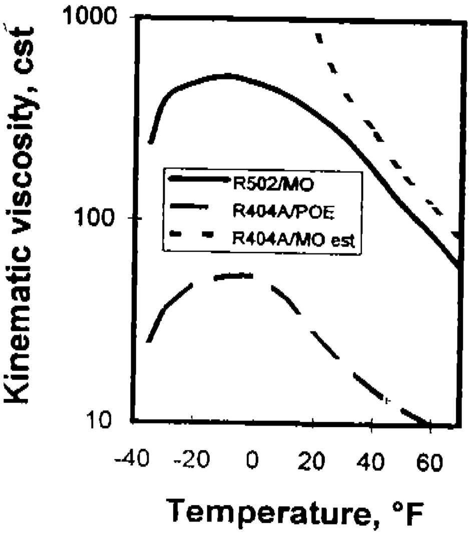

TABLE 2 Lubricant Viscosity

Temperature		Viscosity, cSt	
F	C	Mineral Oil	POE
0	-17.8	3200	800
100	37.8	33	26
212	100	3.0	5.0

TABLE 3:
Effect of Defrost Frequency on Oil Return to Compressor

REFRIGERANT TYPE			R404A	R404A	R404A	R404A	R502	R502
OIL TYPE			MINERAL OIL	MINERAL OIL	MINERAL OIL	MINERAL OIL	MINERAL OIL	MINERAL OIL
TEST CONDITION	CONDENSING TEMPERATURE (F)		85	85	85	85	85	85
	EVAPORATOR TEMPERATURE (F)		-35	-35	-35	-35	-35	-35
	ADDED CASE HEATER LOAD (KW)		2.4	2.4	2.4	2.4	2.4	2.4
	REFRIGERANT CHARGE (LB)		27	27	18	18	27.5	27.5
	NUMBER OF DEFROST PER DAY		4	1	4	1	4	1
TEST RESULT	COM-PRESSOR CRANK-CASE OIL HEIGHT (1/16")	BEFORE DEFROST	12	8	16	10	26.5	26
		DURING DEFROST	16	12	20	14.5	33	32
		AFTER DEFROST	14	13	17	15.5	31	31

TABLE 4 :
Effect of Refrigerant Charge on Oil Return to Compressor

REFRIGERANT TYPE			R404A	R404A	R404A	R404A
OIL TYPE			MINERAL OIL	MINERAL OIL	MINERAL OIL	MINERAL OIL
TEST CONDITION	CONDENSING TEMPERATURE (F)		85	85	85	85
	EVAPORATOR TEMPERATURE (F)		-35	-35	-35	-35
	ADDED CASE HEATER LOAD (KW)		2.4	2.4	2.4	2.4
	REFRIGERANT CHARGE (LB)		27	18	27	18
	NUMBER OF DEFROST PER DAY		4	4	1	1
TEST RESULT	COM-PRESSOR CRANK-CASE OIL HEIGHT (1/16")	BEFORE DEFROST	12	16	8	10
		DURING DEFROST	16	20	12	14.5
		AFTER DEFROST	14	17	13	15.5

TABLE 5 :
Effect of Case Loading on Oil Return to Compress

REFRIGERANT TYPE			R404A	R404A
OIL TYPE			MINERAL OIL	MINERAL OIL
TEST CONDITION	CONDENSING TEMPERATURE (F)		85	85
	EVAPORATOR TEMPERATURE (F)		-35	-35
	ADDED CASE HEATER LOAD (KW)		1.8	2.4
	REFRIGERANT CHARGE (LB)		18	18
	NUMBER OF DEFROST PER DAY		4	4
TEST RESULT	COM-PRESSOR CRANK-CASE OIL HEIGHT (1/16")	BEFORE DEFROST	14	16
		DURING DEFROST	18	20
		AFTER DEFROST	15.5	17

TABLE 6 :
Effect of Condensing Temperature on Oil Retun to Compressor

REFRIGERANT TYPE			R404A	R404A
OIL TYPE			MINERAL OIL	MINERAL OIL
TEST CONDITION	CONDENSING TEMPERATURE (F)		100	85
	EVAPORATOR TEMPERATURE (F)		-35	-35
	ADDED CASE HEATER LOAD (KW)		1.8	1.8
	REFRIGERANT CHARGE (LB)		18	18
	NUMBER OF DEFROST PER DAY		4	4
TEST RESULT	COM-PRESSOR CRANK-CASE OIL HEIGHT (1/16")	BEFORE DEFROS	8	14
		DURING DEFROS	11.5	18
		AFTER DEFROS	12	15.5
	COIL TO AIR TD (F)			

TABLE 7 :
Effect of Evaporative Temperature on Oil Retun to Compressor

REFRIGERANT TYPE			R404A	R404A
OIL TYPE			MINERAL OIL	MINERAL OIL
TEST CONDITION	CONDENSING TEMPERATURE (F)		100	100
	EVAPORATOR TEMPERATURE (F)		-25	-35
	ADDED CASE HEATER LOAD (KW)		1.8	1.8
	REFRIGERANT CHARGE (LB)		18	18
	NUMBER OF DEFROST PER DAY		4	4
TEST RESULT	COM-PRESSOR CRANK-CASE OIL HEIGHT (1/16")	BEFORE DEFROS	15	8
		DURING DEFROS	19.5	11.5
		AFTER DEFROS	19.5	12
	COIL TO AIR TD (F)			

TABLE 8 :
Coil to Air Temperature Differential Comparison

REFRIGERANT TYPE			R404A	R404A	R404A	R404A	R404A	R502	R502
OIL TYPE			POE	MINERAL OIL	MINERAL OIL	MINERAL OIL	MINERAL OIL	MINERAL OIL	MINERAL OIL
TEST CONDITION	CONDENSING TEMPERATURE (F)		85	85	85	85	85	85	85
	EVAPORATOR TEMPERATURE (F)		-35	-35	-35	-35	-35	-35	-35
	ADDED CASE HEATER LOAD (KW)		2.4	2.4	2.4	2.4	2.4	2.4	2.4
	REFRIGERANT CHARGE (LB)		27	18	18	27	27	27.5	27.5
	NUMBER OF DEFROST PER DAY		4	1	4	1	4	4	1
TEST RESULT	COM-PRESSOR CRANK-CASE OIL HEIGHT (1/16")	BEFORE DEFROS	30	10	16	8	12	26.5	26
		DURING DEFROS	33	14.5	20	12	16	33	32
		AFTER DEFROS	31	15.5	17	13	14	31	31
	COIL TO AIR TD (F)		21.72	23.12	24.45	22.21	23.52	23.32	23.17