2000

# Performance of R-407C with Miscible and Immiscible Lubricants in Unitary Systems

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## PERFORMANCE OF R-407C WITH MISCIBLE AND IMMISCIBLE LUBRICANTS IN UNITARY SYSTEMS

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### ABSTRACT

There is some interest in using conventional lubricants such as mineral oil and alkylbenzene with hydrofluorocarbons. This is due to some concern with use and handling of polyol esters because of their hygroscopicity and higher cost. Experiments were conducted in a 12.3 kW (3.5 T) split system heat pump to determine the oil return characteristics of R-22/mineral oil as well as that of R-407C with three different lubricants (polyol ester, mineral oil and alkylbenzene). Tests were conducted in both heating and cooling modes. The liquid level in the compressor was monitored with a video camera and recorded. The system capacity and the compressor power consumption were also measured.

Test results indicated that the liquid level in the compressor with immiscible lubricants was slightly lower (about 5 mm or 0.2") than that with miscible lubricants. However, the oil level with immiscible lubricants held steady and within acceptable levels indicating more oil in circulation in the system. The differences in both capacity and COP when R-407C was used with any of the three lubricants, were small with the R-407C/AB combination being slightly higher than other cases. Based on these tests, it appears that R-407C could be used in many cases with immiscible lubricants without significant differences in either oil return to the compressor or system performance.

### NOMENCLATURE

| | |
|---|---|
| AB | Alkylbenzene |
| COP | Coefficient of Performance |
| HFC | hydrofluorocarbon |
| MO | Mineral Oil |
| POE | Polyol Ester |

### INTRODUCTION

Use of R-22 in new equipment will be banned in 2010 in the USA and has already been banned in some European countries. R-407C and R-410A have emerged as the leading replacement candidates. R-407C is a ternary mixture of R-134a, R-125 and R-32 and has a vapor pressure that is only slightly higher than that of R-22. Its volumetric capacities and Coefficients of Performance (COPs) in both heating and cooling modes are close to that of R-22. Comparison of the performance of R-407C and other alternatives to R-22 has been extensively studied [1 - 8]. Because of these reasons, it has become the major 'retrofit' refrigerant for R-22. It can also be used in new equipment with minimal modifications to the R-22 design.

The lubricant that is currently used with R-22 is either Mineral Oil (MO) or Alkylbenzene (AB). The retrofit procedure to R-407C, recommended by manufacturers, requires a lubricant change to Polyol Ester (POE) since the solubility and miscibility of R-407C in either MO or AB are much lower than in POE. Miscibility is a measure of the extent to which the liquid refrigerant dissolves in the lubricant while solubility is a measure of the ability of the refrigerant vapor to dissolve in the lubricant. By conventional wisdom and practice, miscibility and solubility are necessary to ensure that the lubricant is returned to the compressor. By using a lubricant that is miscible with liquid refrigerant, separation and retention of the lubricant in the evaporator can be prevented. A refrigerant that is miscible with the lubricant is typically also very soluble in the lubricant. Solubility helps in reducing the viscosity of the lubricant in the evaporator and in the compressor suction line facilitating easy transport by the refrigerant vapor. However, there is some interest in using the conventional lubricants (such as MO or AB) with R-407C. This is because of some concerns in use and handling of POEs since they are much more hygroscopic than MO or AB. POEs are also more expensive than MO or AB. Previous studies have identified both promise and issues in using immiscible lubricants with HFCs. Sunami et al. [9], concluded that for use with high-side rotary compressors, low viscosity AB lubricants had a much stronger oil film than HFC/POE combinations leading to a better long-term durability of the compressors. Sundaresan et al. [10, 11] presented results from a study comparing the oil return characteristics of R-22 and its substitutes both with miscible and immiscible lubricants in a split air conditioner. They concluded that when MO was used with R-407C or R-410A, the oil return was unreliable. Gopalnarayanan [12] presented results from use of R-407C with AB in a close-coupled system that uses a rotary compressor and concludes that the performance and oil return characteristics of the immiscible pair were similar to that of R-22/AB and R-407C/POE.

In this paper the results form a test program to determine both the oil return characteristics as well as the performance of a split system heat pump with both miscible and immiscible lubricants are presented.

## Experimental set up

The evaluation was carried out in a commercially available 12.3 kW (3.5 RT), 12 SEER heat pump that used a reciprocating compressor, spine-finned tube heat exchanger on the outdoor unit, fin-and-tube heat exchanger on the indoor and Thermostatic Expansion Valves (TXVs) for both cooling and heating. In the indoor unit, the refrigerant had a parallel cross flow to the air flow in the cooling mode and counter cross flow to the air flow in heating mode. In the outdoor unit, the refrigerant had a cross flow to the air flow. The compressor was fitted with a 25.4 mm (1") diameter sight glass. The original lubricant for the system was MO with a viscosity grade of 32 cSt (150 SUS). The amount of lubricant charge was 1500 mL (0.4 gal). The sight glass was located such that the oil level was at about the center line of the sight glass. The liquid level and the characteristics of the liquid inside the compressor were observed through a video camera and recorded.

The tests were carried out according to the conditions specified in ANSI/ASHRAE Standard 116 [13], in a psychometric test facility at the four different test conditions listed in Table 1.

Table 1: Test Conditions

| Test | Indoor temperatures | | Outdoor temperatures | |
|---|---|---|---|---|
| | Dry bulb, °C (°F) | Wet bulb, °C (°F) | Dry bulb, °C (°F) | Wet bulb, °C (°F) |
| Cooling B | 26.7 (80) | 19.4 (67) | 27.8 (82) | 18.3 (65) |
| Cyclic cooling | 26.7 (80) | <13.9 (<57) | 27.8 (82) | 18.3 (65) |
| Heating 47 | 21.1 (70) | <15.6 (<60) | 8.3 (47) | 6.1 (43) |
| Heating 17 | 21.1 (70) | <15.6 (<60) | -8.3 (17) | -9.4 (15) |

The facility was capable of maintaining temperatures to ±0.11°C (± 0.2°F) and a temperature uniformity in the chamber of ±0.28°C (±0.5°F). The test unit was extensively instrumented and the instruments periodically calibrated. Accuracy of all temperature measurements was ±0.05°C (±0.1°F) and of the dew point measurements was ±0.11°C (±0.2°F). The accuracy of air flow measurement was ±0.14%. The mass flow rate of the refrigerant was measured using a Coriolis type mass flow meter with an accuracy of ±0.1% and the power consumption with a power meter having an accuracy of ±0.2% of full scale (± 8 W). The system capacity was measured both on the air side as well as the refrigerant side with agreement between them typically being less than 2%. The refrigerant charge was individually optimized for both R-22 and R-407C and was found to be 5000g (11.02 lbs) for R-22 and 4700g (10.36 lbs) for R-407C.

## RESULTS AND DISCUSSION

### Oil level

Figures 1 a-d show the oil level in the compressor as a function of time for the various refrigerant/lubricant combination for the four different test conditions. The oil level was considered to be satisfactory as long as it did not fall below the sight glass level. From these plots, it can be seen that the oil level stayed at the satisfactory level for all the four refrigerant-lubricant combinations. The oil level for the immiscible pair was slightly lower in both cooling and heating conditions than for the miscible pair. However, the differences between the oil levels were less than 5 mm (0.2") at any given time. This corresponds to about 1% of the total volume of the lubricant in the system. The oil returned to its original level in the compressor after the system was shut down. This suggests that with immiscible lubricants, more lubricant was in circulation while the system was running.

Observation as seen through sight glass:

(1) Steady state cooling conditions (Cooling B):

(i) R-22/MO (miscible):
The oil was clear before the compressor start up and the level was at about the center line of the sight glass. At start up of the compressor, there was a churning action and the liquid was whitish in color due to the presence many small vapor bubbles. At about 90 s after start, the sight glass became completely frothy. At about 10 minutes from start up, the liquid was completely clear with very few bubbles. There was a 5mm (0.2") thick layer of froth on top of the clear interface. The oil level dropped steadily reaching a constant value after about 15 minutes.

(ii) R-407C/POE (miscible):
Very similar to R-22/MO except that the liquid was much more frothy in the first 8 minutes after start-up. The steady state liquid level inside the compressor was slightly higher than that of R-22/MO. The oil level reached a constant value after about 30 minutes from start up.

(iii) R-407C/MO (immiscible):
In the first 30 s, after start up, globules of liquid refrigerant, about 2.5 mm (0.1") in diameter, appeared. Within the first minute, the globules became much smaller and at about 2 minutes there did not seem to be any liquid refrigerant globules present. In the first 5 minutes, the liquid was still whitish with small vapor bubbles present. Throughout the duration of the test, there was a 10 mm (0.4") thick layer of froth on top of the clear liquid level. The froth was thicker than the miscible pair possibly due to the fact that the surface tension of the oil was not reduced by the refrigerant (being less soluble). The liquid level dropped initially and rose steadily during the first 30 minutes from start up and remained steady there after.

(iv) R-407C/AB (immiscible):
Very similar to R-407C/MO

(2) Cyclic cooling conditions:
For all the four refrigerant/lubricant combinations, the conditions as seen through the sight glass were similar to that of the respective steady state cooling conditions. At shut down of the compressor during an off cycle, the liquid level briefly dropped and then rose steadily to the original level. The conditions at the restart were very similar to that of the original start up except that a clear liquid level appeared much sooner

during the restarts.

(3) Medium temperature heating conditions (Heating 47):

For all the four refrigerant lubricant combinations, the conditions as seen through the sight glass were similar to that of the respective steady state cooling conditions.

(4) Low temperature heating conditions:

During the low temperature tests, the test unit underwent defrost cycle once in about every 30 minutes. During that time, the liquid level tended to rise during the reverse operation. This was possibly due to the flushing action of the warmer refrigerant in removing the lubricant in the evaporator (outdoor unit). Once the reversing valve returned to heating mode, the liquid level dropped off initially before rising to a steady level.

During the initial start up, with the use of both the miscible and immiscible lubricants, the liquid level tended to stay clear for a longer duration than for the medium temperature conditions. The liquid turned whitish with bubbles only after about 6 minutes from the compressor start up (as opposed to the first minute in the case of the medium temperature heating test). The delay was the time required for the lubricant to warm up before out gassing the refrigerant.

## System performance

Figures 2 a-d summarize the salient performance data for the different fluid combinations. Comparing R-22/MO with R-407C/POE, R-407C/MO and R-407C/AB, the differences in the capacity and COP are less than 5%, some portion of which could have come from the measurement inaccuracies. Nevertheless, in general, the compressor power consumption for R-407C/AB was typically lower than that of either R-407C/POE or R-407C/MO. Similarly, the cooling and heating capacities for R-407C/AB was typically higher than that of either R-407C/POE or R-407C/MO. The combined effect led to a slightly higher COP for R-407C/AB than other refrigerant/lubricant pairs.

Comparing the compressor suction and discharge parameters (Figure 3 a-d), the discharge temperature for R-407C with any of the lubricants was much lower than that of R-22 with the discharge pressure being higher. There was not any noticeable trend in the differences in temperatures and pressures between the various lubricants when used with R-407C.

## CONCLUSIONS

Experiments were conducted in a split system heat pump to determine the oil return characteristics of R-22/mineral oil as well as R-407C with three different lubricants (polyol ester, mineral oil and alkylbenzene) in both heating and cooling modes. Test results indicated that the liquid level in the compressor with immiscible lubricants was slightly lower (about 5 mm, 0.2") than that with miscible lubricants. However, the oil level with immiscible lubricants held steady and within acceptable levels indicating more oil in circulation in the system. The differences in both capacity and COP when R-407C was used with any of the three lubricants, were small with the R-407C/AB combination being slightly higher than other cases.

Based on these results, it can be concluded that R-407C may be used in many cases where the miscibility with the oil is poor. It is necessary, however, to determine what the limiting cases are. In these experiments, for example, the indoor and outdoor units were located at the same elevation. The oil return in the cooling mode when the indoor unit is typically located below the outdoor unit could be different and will have to be evaluated.

## ACKNOWLEDGMENT

The authors would like to thank Elf Atochem N. A. Inc. for providing permission to publish this paper and would also like to acknowledge the contribution of Mr. M. Hoffman in conducting the tests.

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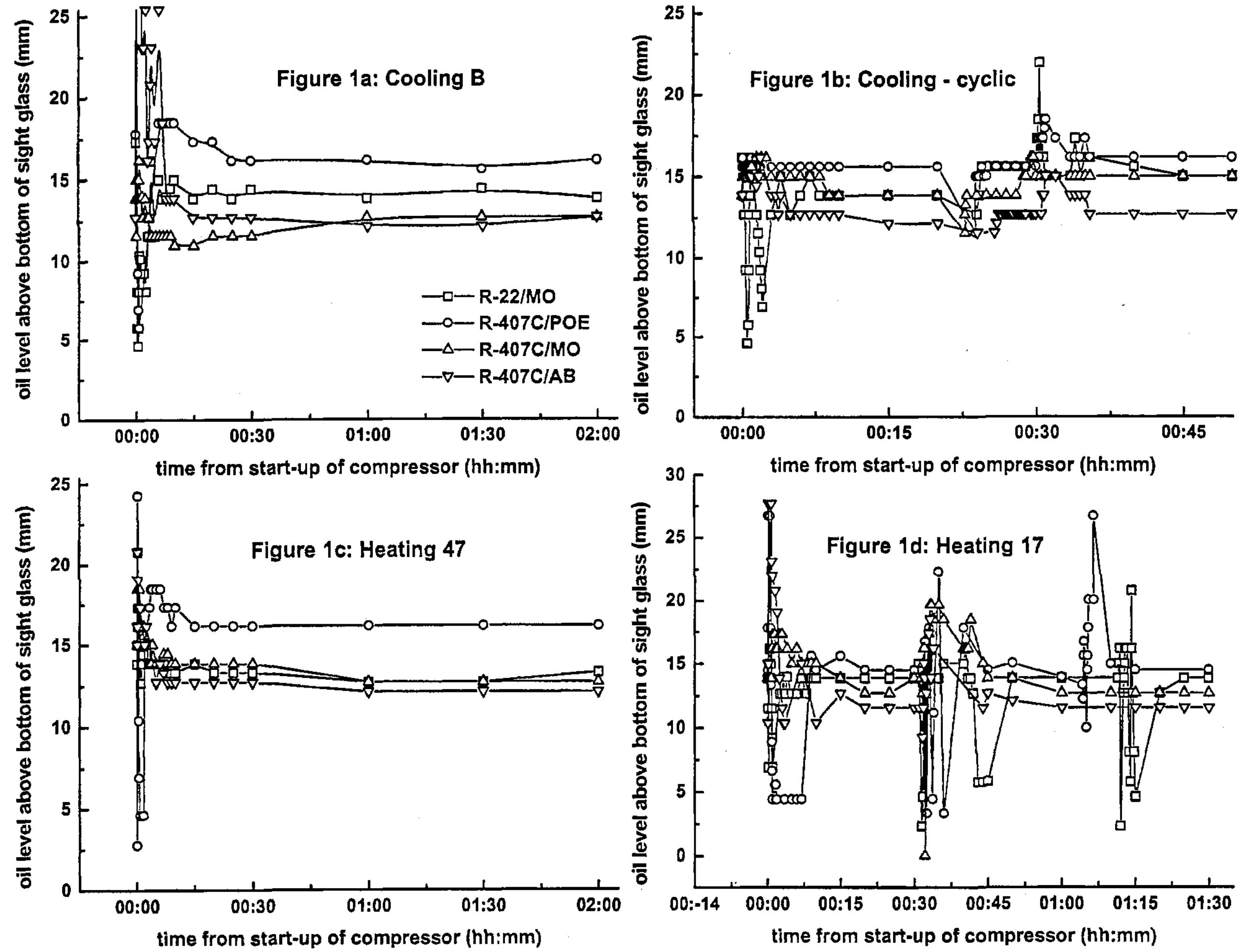


# Figure 1: Liquid level in the compressor

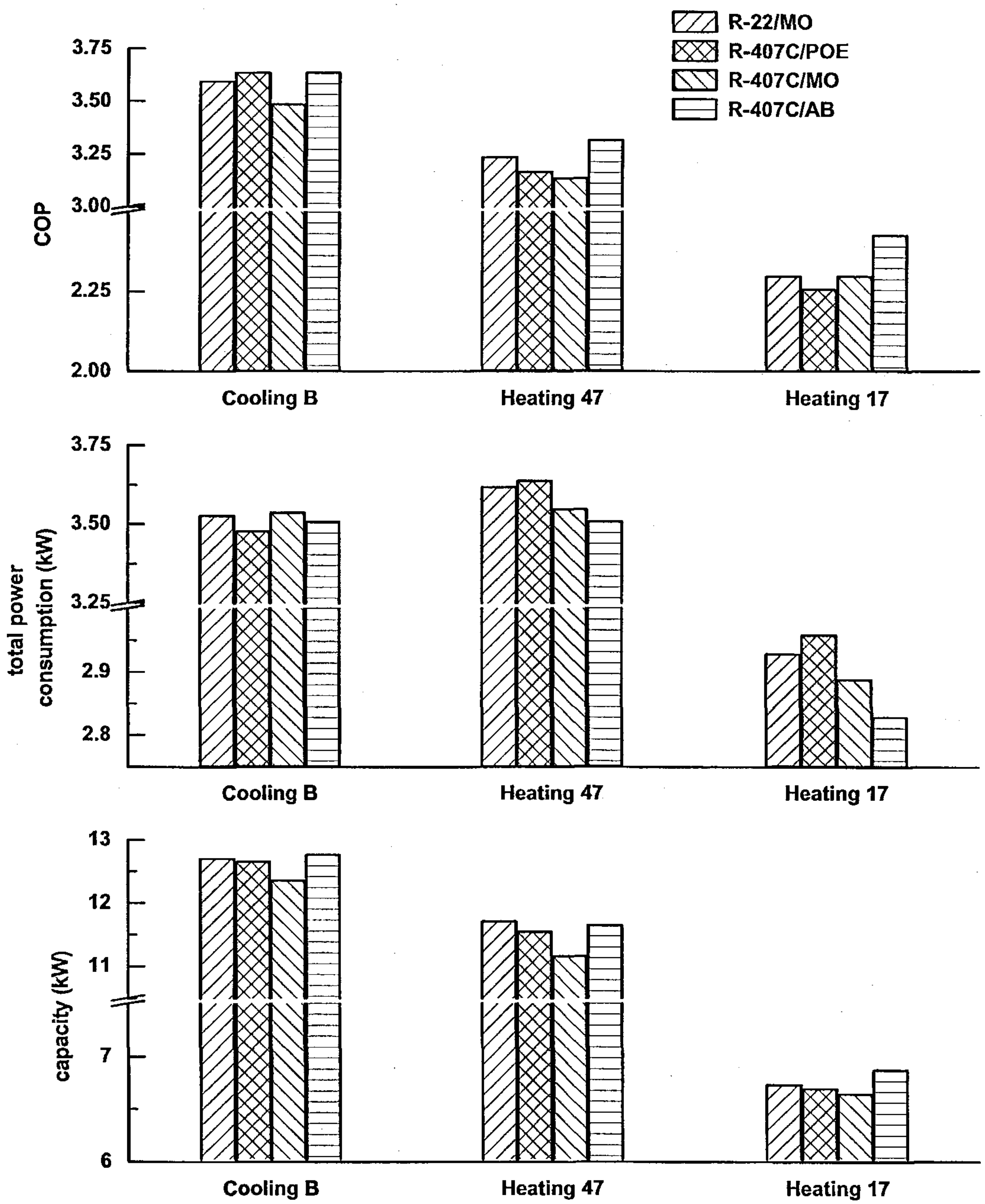


**Figure 2: System performance in heating and cooling modes**

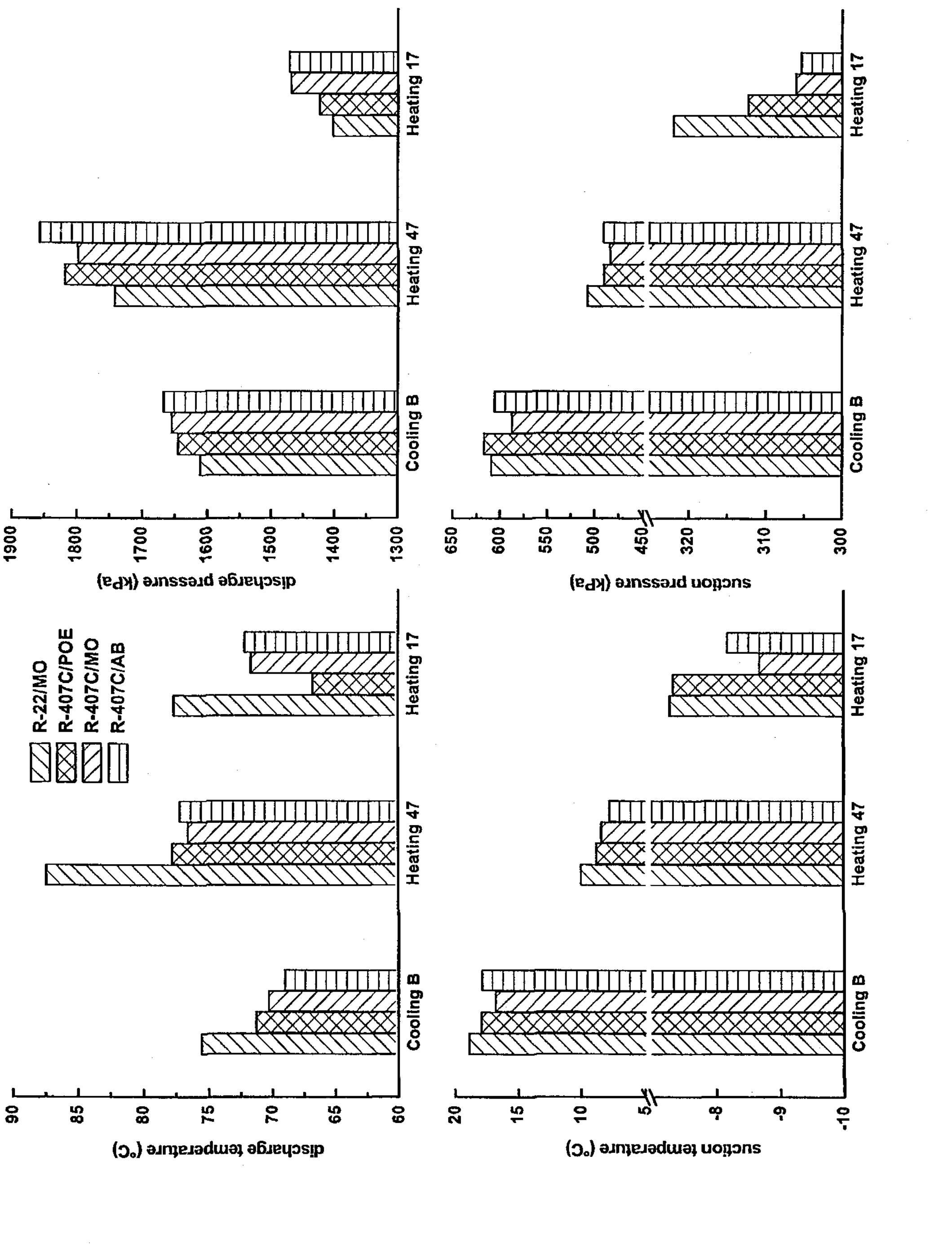


Figure 3: Compressor suction and discharge parameters