

2010

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Allgood, Charles C. and Lawson, C. Curtis, "Performance of R-438A in R-22 Refrigeration and Air Conditioning Systems" (2010).
International Refrigeration and Air Conditioning Conference. Paper 1096.
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Performance of R-438A in R-22 Refrigeration and Air Conditioning Systems

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ABSTRACT

With the accelerated phase out of R-22 underway, equipment owners and service contractors must develop a plan for operating, retrofitting, or replacing their existing R-22 refrigeration and air conditioning systems. In many cases, retrofitting the existing R-22 equipment to an alternative refrigerant is a viable, cost effective option for the equipment owner. R-438A is a non-ozone depleting hydrofluorocarbon (HFC) refrigerant blend which can be used to retrofit existing hydrochlorofluorocarbon (HCFC) refrigerant R-22 refrigeration and air conditioning systems with direct expansion evaporators and positive displacement compressors. In most systems, the existing mineral oil (MO) or alkylbenzene (AB) lubricant can be used, reducing the cost and time required for the retrofit by eliminating the need to change to a polyolester (POE) lubricant.

This paper will review the performance characteristics and oil return properties of R-438A from both laboratory tests and actual R-22 system retrofits. Topics to be covered in this presentation include refrigerant physical and environmental properties, material compatibility information, oil return properties, and capacity, energy efficiency, and operating data from both compressor calorimeter tests and actual R-22 refrigeration and air conditioning system retrofits.

1. INTRODUCTION

With the accelerated phase out of R-22 underway, the servicing of the large installed base of R-22 refrigeration and air conditioning equipment is a growing concern for equipment owners and service contractors. In many cases, retrofitting the existing R-22 equipment to an alternative refrigerant is a viable, cost effective option versus continued operation of the equipment using R-22 or actual replacement of the existing equipment with new equipment specifically designed for an alternative refrigerant.

R-438A (ANSI/ASHRAE, 2009) is a non-ozone depleting zeotropic blend of HFC-32, HFC-125, HFC-134a, HC-600, and HC-601a (8.5/45.0/44.2/1.7/0.6 wt%, respectively) which has been formulated to provide a versatile , cost effective alternative refrigerant to replace R-22 in existing direct expansion (DX) refrigeration and air conditioning systems. This paper will review properties and performance characteristics of R-438A, and report on experimental results with R-438A in compressor calorimeter tests, system performance and oil return tests, and actual field retrofits of existing R-22 refrigeration and air conditioning equipment.

2. REFRIGERANT PROPERTIES AND PERFORMANCE

R-438A has an ASHRAE safety classification of A1 (nonflammable, low degree of toxicity) and similar pressure-temperature-enthalpy characteristics to R-22, making it suitable for use in existing R-22 equipment over a wide range of evaporator temperatures with no rerating or safety reclassification of the equipment. R-438A has a 100 year Global Warming Potential (GWP) of 2264 based on the weighted average GWPs of individual components from Assessment Report 4 (AR4) of the Intergovernmental Panel on Climate Change (IPCC) (Solomon *et.al*, 2007).

2.1 Material Compatibility

R-438A is compatible with mineral oil (MO), alkylbenzene (AB), and polyol ester (POE) lubricants, so in most cases no change of lubricant is required during a retrofit. Many of the same elastomers used for elastomeric seals and gaskets with R-22 are compatible with R-438A, but, as when exposed to other HFC refrigerants, many of the elastomers exhibit a lesser amount of swell when exposed to R-438A versus R-22. In a system retrofit, there is increased potential for leaks to occur at elastomeric seals which have previously been exposed to R-22 as a result of this lesser amount of swell. System components commonly affected are Schrader core seals, ball valves, solenoid valves, receiver gauges, and flange seals, particularly in the high side liquid portion of the system. It is recommended to change out elastomeric seals and gaskets during the retrofit, particularly critical seals which could result in a significant loss of refrigerant charge.

2.2 Refrigerant Performance – Laboratory Tests

R-438A provides similar cooling performance and energy efficiency to R-22, while operating at a lower compressor discharge temperature and similar evaporator and condenser pressures. Table 1 provides a comparison of key performance characteristics for R-438A relative to R-22 based on results from actual compressor calorimeter tests run at low, medium, and high evaporator temperatures. Specific test conditions are shown below the table.

Table 1

Performance Criteria	R-438A Performance Relative to R-22		
	LT	MT	HT
Cooling Capacity (%)	-6	-8	-7
Estimated EER (%)	+7	-1	-2
Suction P (kPa)	-14	-21	-21
Discharge P (kPa)	+21	+21	+34
Discharge T (°C)	-12	-23	-17
Temperature Glide (°C)	+3.6	+3.3	+3.9

LT: Low Temperature: -31.7°C avg evaporator, 40.6°C avg condenser, 18.3°C return gas, 5.6° liquid subcooling from avg condenser T

MT: Medium Temperature: -6.7°C avg evaporator, 40.6°C avg condenser, 18.3°C return gas, 5.6°C liquid subcooling from avg condenser T

HT: High Temperature: 7.2°C avg evaporator, 46.1°C avg condenser, 18.3°C return gas, 8.3°C liquid subcooling from avg condenser T

R-22 assumes liquid injection with discharge temperature of 135°C

As can be seen, cooling capacities are within 5-10% of R-22 across the range of evaporator temperature, and Energy Efficiency Ratio (EER) is similar to that of R-22. Discharge pressure is only slightly higher and suction pressure is only slightly lower than R-22, so in most cases, existing system pressure settings can be used. While the existing Thermal Expansion Valve (TEV) sizing and power head can be used with R-438A, the slightly lower suction pressure and the small amount of temperature glide of R-438A may require minor adjustments to the Thermal Expansion Valve (TEV) to obtain the desired amount of superheat from the evaporator. For low temperature operation, the lower discharge temperature of R-438A will require less liquid injection than with R-22; at lower condenser temperatures, no liquid injection will be needed.

Figures 1 and 2 summarize the results of compressor calorimeter tests conducted at low, medium, and high temperature conditions. Compressor calorimeter tests were run according to AHRI-540 Standard (ANSI/AHRI, 2004), where superheat line superheat is included in the capacity and EER calculations. Figure 1 summarizes the capacity results from the compressor calorimeter tests with R-438A and R-22, with R-438A results reported relative to R-22 results. Relative compressor capacity results include the suction line superheat in the compressor capacity. Relative evaporator capacity results have been adjusted to include only 5.6°C of available superheat in the capacity. Similar to other HFC refrigerants, like R-407C or R-404A, the lower amount of superheat included in the evaporator capacity results in a slightly lower relative evaporator capacity for R-438A versus the relative compressor capacity. As expected, the difference decreases as the evaporator temperature increases, with the greatest difference at the low temperature condition (~5%) and essentially no difference at the high temperature condition. Figure 2 summarizes the EER results from the compressor calorimeter tests with R-438A and R-22, and again, R-438A results are reported relative to R-22 results. Once again, the lower amount of suction line superheat included in the evaporator EER results in a slightly lower relative evaporator EER for R-438A versus the relative compressor EER, with the differences similar to the capacity results at low temperature, medium temperature, and high temperature conditions.

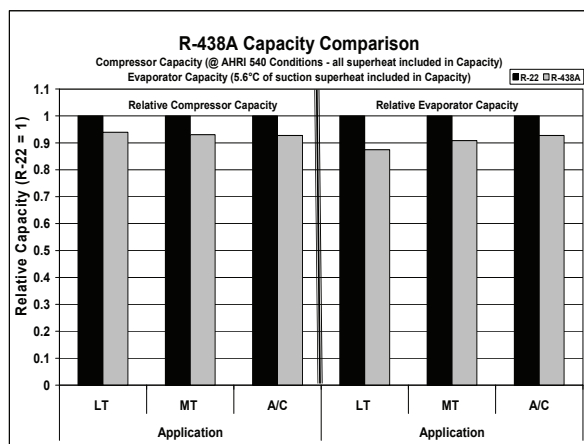


Figure 1

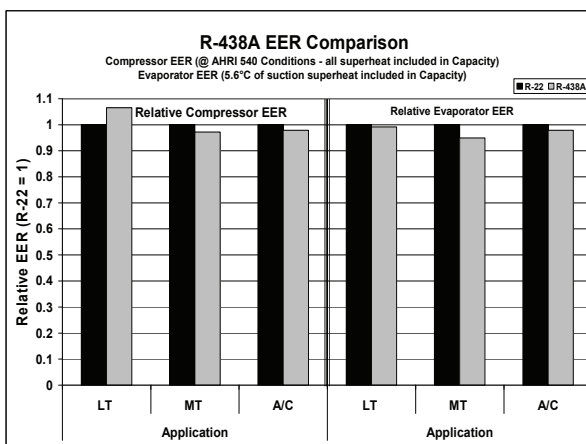


Figure 2

2.3 Refrigerant Performance – Field Retrofits

Numerous successful retrofits of existing R-22 DX refrigeration and air conditioning systems have been performed using R-438A as the retrofit refrigerant. As expected, results have been similar to results from laboratory tests. Field experience has shown that R-438A provides comparable cooling and similar energy efficiency to R-22 in a variety of equipment, including supermarket rack systems, condenser units, and air conditioning systems.

Suction and discharge pressures and compressor discharge temperatures in field retrofits have been similar to those measured in laboratory tests. In most systems, no system pressure or temperature set point changes are needed. A small number of superheat adjustments using the existing TEVs have been required to maintain the desired amount of superheat exiting the evaporator.

Field experience has reinforced the recommendation to replace critical elastomeric seals and gaskets as part of the retrofit procedure. In general, the older the system, the higher the probability that leaks will be observed after the retrofit if elastomeric seals and gaskets are not replaced. Elastomeric materials become more brittle over time, and can become deformed or damaged after exposure to several pressure cycles as systems have been serviced over the lifetime of the equipment. Replacement of elastomeric seals and gaskets during the retrofit, particularly on the high side liquid portion of the system, is a recommended practice to minimize the potential for refrigerant leaks following the retrofit.

System energy consumption versus ambient temperature is shown in Figures 3, 4, and 5 for a variety of systems typical of those which have been retrofitted to R-438A, with similar energy consumption before and after the retrofit.

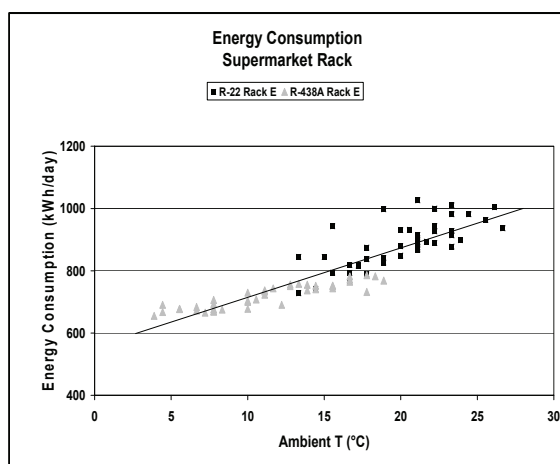


Figure 3

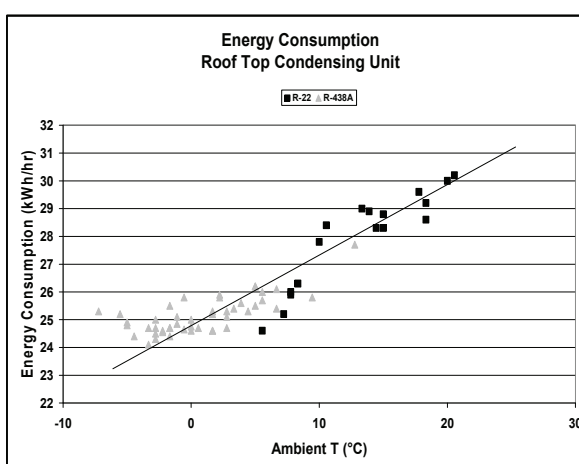


Figure 4

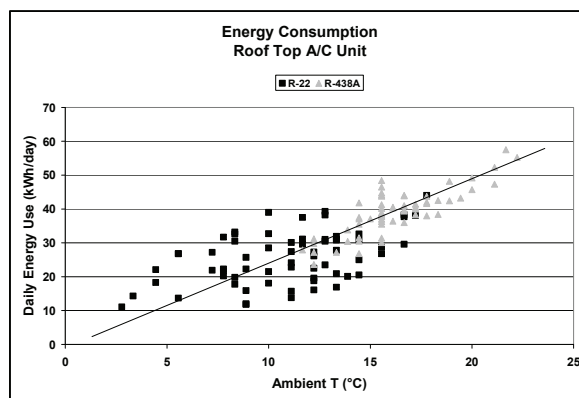


Figure 5

Most systems retrofitted with R-438A have operated normally using the existing MO or AB lubricant in the system. In systems with a liquid receiver and no oil separator or in systems where oil logging has been an occasional issue when operating with R-22, addition of a small amount of POE (10-20%) is usually sufficient to ensure adequate oil return after a retrofit to R-438A.

3. Oil Management Considerations during R22 Retrofits

One of the most important aspects in retrofitting refrigerant or air conditioning equipment designed for R-22/mineral oil (MO) to an alternative refrigerant, is managing oil issues such as compatibility, viscosity, solubility, miscibility, transport etc. Traditionally, conversion from a (H)CFC refrigerant gas to an HFC refrigerant has been accompanied by a change from mineral oil (MO) or alkylbenzene (AB) to a polyol ester (POE) oil. Industry standards call for less than 5% residual mineral oil to remain after conversion to POE; a time and labor intensive process requiring multiple system flushes to achieve. In addition to well known POE issues such as cost and moisture uptake, the increased solvency power of POE relative to MO has often resulted in scouring of deposits from throughout the system, freeing up debris and sludge which cause operational issues by plugging valves and filters. R-438A, with its unique formulation, has enabled many R-22 systems to be converted without the need to change out the mineral oil. However, there are a few potential oil return issues that bear further study which are reported below.

3.1 Solvency of POE lubricants

The solvency issue described above is illustrated in Figure 6, a plot of the Aniline Point value for MO/POE lubricant mixtures. Lower Aniline Points indicate stronger solvency power, and as evident in the graph, POE is a substantially better solvent than mineral oil. In the case of oil mixtures, up to about 20% POE has only a modest impact on overall solvency but at higher percentages of POE (~40% or higher) the solvency properties and risk of system clean out/plugging is increased, consistent with field experience. Thus the use of mineral oil compatible refrigerants, like R-438A, that eliminate/minimize POE in the system during retrofits would be beneficial.

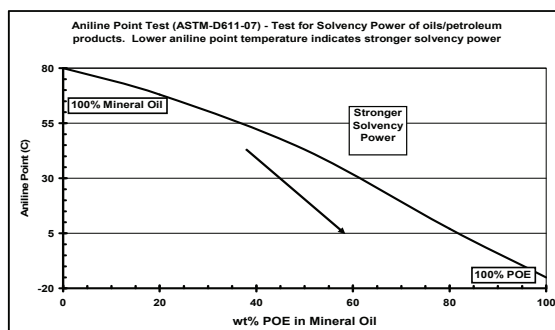


Figure 6-Plot of Aniline Point Value for Lubricant Mixtures

3.2 Oil Return – Low Pressure Side (Cold Evaporators)

On the low pressure side of a refrigeration system, the major oil management concern is the high viscosity of the lubricant at low evaporator temperatures; making return of oil back to the compressor difficult. Miscible oil – refrigerant pairs like R-22/MO or HFC/POE typically have adequate solubility to keep viscosity low, enabling good oil return. However, non-miscible pairs such as HFC/MO have only limited solubility, and may not be able lower the oil viscosity adequately, hence the traditional need to switch to POE. R-438A offers another option that has been successfully demonstrated previously; the addition of a small amount of hydrocarbon to a HFC refrigerant blend. The HC provides solubility in the MO to lower the oil's viscosity and provide good oil return. Figure 7 is a plot of oil viscosity for HFC mixtures with, and without, a small % of HC. As seen in the figure, even the small percentage of HC in R-438A can significantly reduce oil viscosity, particularly at low temperatures where oil concerns are greatest.

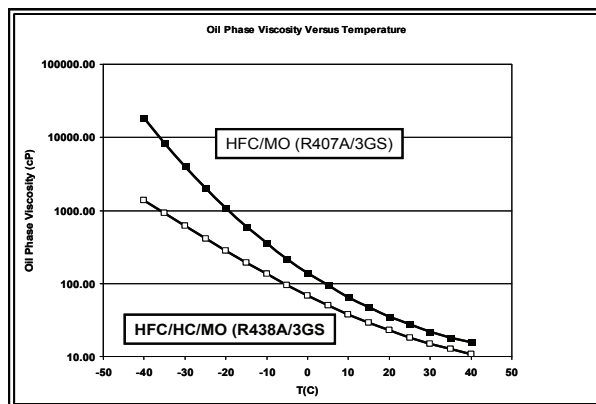


Figure 7-Oil Viscosity vs. Temperature for HFC and HFC/HC Refrigerant Mixtures

3.3 Oil Trapping in System Components – Liquid Receivers

In systems with oil separators, the majority of any oil discharged from the compressors is quickly captured and returned to the crankcase. However, in systems with that do not have oil separators, but do have liquid receivers designed to store refrigerant, there is a potential concern of oil trapping in the receiver vessel, if the oil circulation rate (OCR) exceeds the solubility limit of oil in liquid refrigerant as illustrated in Figure 8. For HFC/MO the solubility limit, is ~0.5 wt % even with the addition of hydrocarbon.

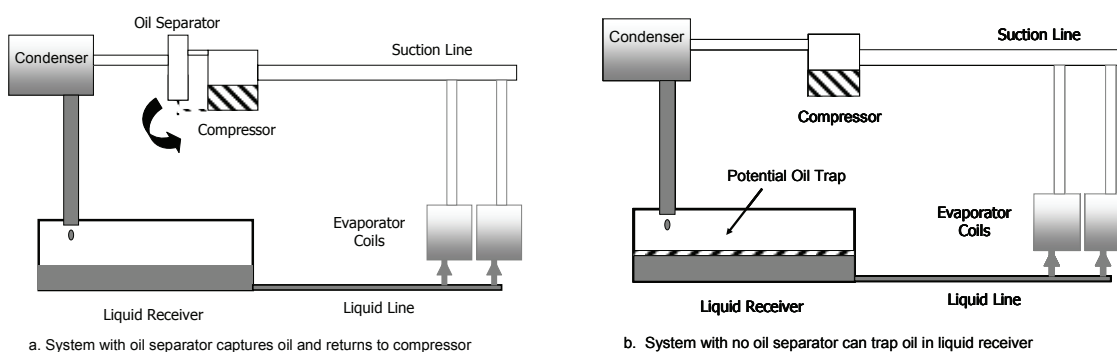


Figure 8-Diagram of Oil Return for a typical refrigeration system with (a) and without (b) an oil separator.

In systems with high OCR ($>0.5\%$), no oil separator, and liquid receiver present, potential oil trapping in the receiver can be prevented by simple addition of small amount of POE oil to the system. As shown in Figure 9, POE greatly increases the overall solubility of the mixed lubricant in refrigerant, allowing oil to travel out of the receiver and return to the compressor via the liquid lines, evaporator and suction lines. The use of only 10-20% POE is adequate to prevent oil trapping but avoids the need for multiple flushes associated with a complete oil change and also limits the solvency problems associated with POE discussed previously.

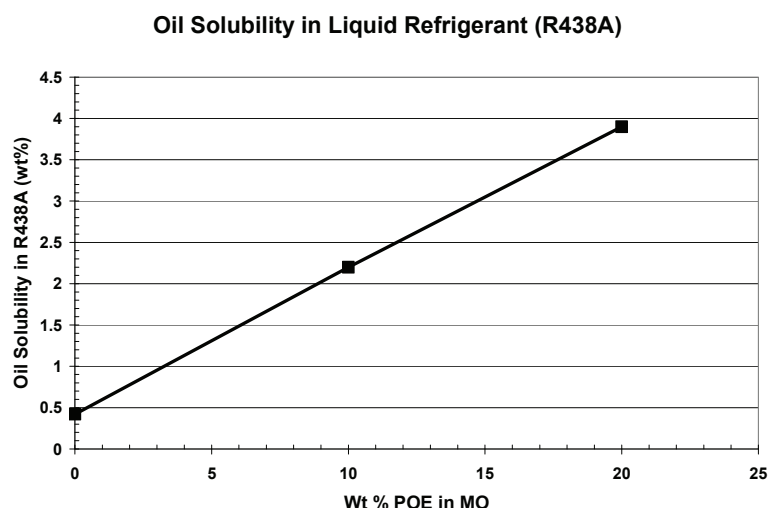


Figure 9-Oil Solubility in Liquid Refrigerant (R438A) for Mineral Oil w/ POE

An experiment to demonstrate this solution was performed on a commercial condensing unit and frozen food case where the compressor was modified with an oil level tube for measuring compressor sump oil level. The oil level for R-438A/MO with 20% POE is plotted in Figure 10, and in this system with no oil separator but with a liquid receiver that could potentially trap oil, the addition of the POE adequately enabled oil return as evidenced by stable oil level in the compressor sump over several weeks of continuous low temperature operation.

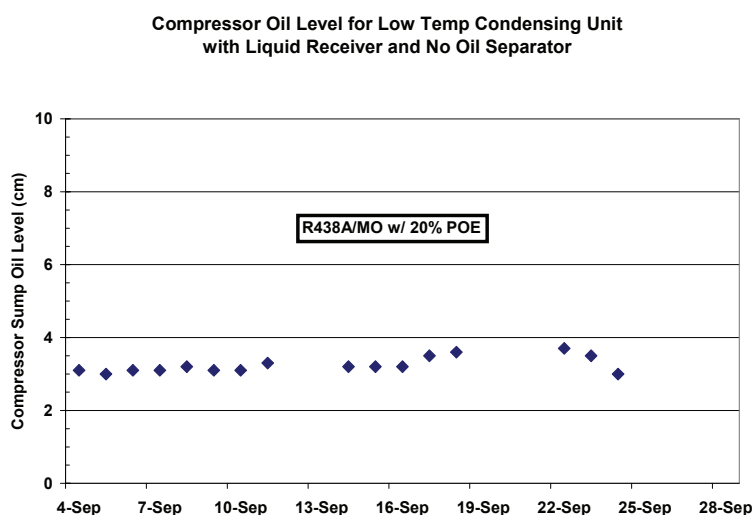


Figure 10-Compressor oil level in low temp condensing unit with no oil separator and liquid receiver
R-438A/MO + 20% POE

3.4 Oil Trapping in System Components – Suction Line Accumulator

The purpose of a suction line accumulator is to protect the compressor from liquid refrigerant flooding back from the evaporator and damaging the compressor. By providing a temporary volume to knock out and contain liquid refrigerant/oil and gradually meter them back to compressor, damaging slugs of liquid are avoided. Unlike receivers designed to operate continuously with liquid present, accumulators are typically needed during transient operation, i.e. starts/stops, defrosts, or during low temperature heating mode in heat pumps. Suction line accumulators often operate for extended periods with no liquid present.

While a similar situation as described for liquid receivers could, in theory, potentially trap oil, in practice the question is whether a stable two-phase mixture of oil/refrigerant could be sustained in an accumulator long enough to trap oil. A test was performed wherein a commercial heat pump operated in low temperature heating mode (21.1°C indoor/-8.3°C outdoor) was forced to flood back liquid into the accumulator, which had been modified for visual observation of liquid levels of refrigerant and/or oil. Compressor sump oil levels were also recorded. Low temperature heating mode was chosen since, during standard operation in cooling mode, the evaporator is typically operated with 5°-6°C of superheat and no liquid entered the accumulator.

Figure 11 is a plot of oil level in compressor sump during a low temp heat pump test with flooded evaporator and flood back to the accumulator. The amount of liquid in the accumulator varied through out the test period but never truly reached a steady state level. Visually the liquid in the accumulator was quite turbulent, with bubbles present and constant mixing which evidently prevented any sustainable two phase mixture from trapping oil as the compressor sump oil level remained stable, even with a flooded accumulator for the several hour duration of the run.

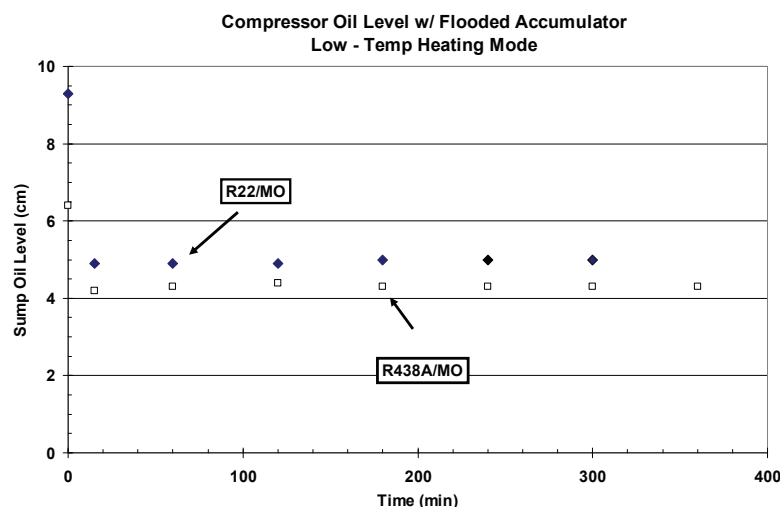


Figure 11-Compressor Oil Level during Low Temp Heating Mode Test with No superheat and Flooded Accumulator

4. CONCLUSIONS

R-438A is a reliable, versatile, and cost effective non-ozone depleting refrigerant which can be used to replace R-22 in existing direct expansion (DX) refrigeration and air conditioning systems. Field experience has shown that R-438A provides similar cooling performance and energy efficiency to R-22 in most systems, while operating at a lower compressor discharge temperature and similar evaporator and condenser pressures. It is compatible with MO, AB, and POE lubricants, and in most cases, no change of lubricant type is required during the retrofit.

5. ACKNOWLEDGEMENTS

The authors would like to thank our colleagues Ward D. Wells and Joshua Hughes for their contributions in designing and overseeing the calorimeter and system performance test work, and their Laboratory Technicians, James Hayes and Thomas Rigney for their assistance in running the tests.

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