Practical Considerations Regarding R-404A and POE Lubricant Used in Transport Refrigeration Systems

S. L. Kwon
Thermo King Corporation

PRACTICAL CONSIDERATIONS REGARDING R-404A AND POE LUBRICANT USED IN TRANSPORT REFRIGERATION SYSTEMS

Sung Lim Kwon
Thermo King Corporation
314 West 90th Street
Minneapolis, MN 55420

ABSTRACT

In developed countries, Chlorofluorocarbon (CFC) refrigerants have been phased out. Hydrochlorofluorocarbon (HCFC) refrigerants are now subject to regulation and are scheduled to be phased out in the 21st century. Today many chemical manufacturing companies offer a comprehensive range of both pure (single chemical) HFC refrigerants and HFC blends to replace CFC and HCFC refrigerants. This paper reviews the performance results of R-404A with polyol-ester (POE) lubricant in transport refrigeration systems and the component modifications required to accommodate R-404A and POE compressor oil. The laboratory test results of composition shifting during system operation in both ternary and quaternary blends of R-404A in the liquid and vapor states are presented and discussed. Laboratory test results of the effects of R-404A liquid and vapor charging methods on system performance are also reviewed.

INTRODUCTION

CFC refrigerants R-12 and R-502, and HCFC refrigerant R-22 provided good performance in both medium and low temperature applications in commercial and transport refrigeration applications for the last sixty years. Therefore the physical, chemical and thermodynamic properties of these refrigerants had a major impact on the design of the compressors and refrigeration system components developed for transport refrigeration. When the search for alternative refrigerants began, refrigerants with similar thermophysical and performance characteristics were required for use in new unit applications as well as in existing equipment.

HFC refrigerant R-134a was determined to be the most suitable replacement for R-12, because it has similar thermodynamic properties that were ideal for use in medium and high temperature applications. However, because the performance of R-134a decreases significantly at low evaporator temperatures, another chlorine-free alternative refrigerant needed to be found to replace R-502 and R-22 in low temperature applications.

Through careful examination of HFC compounds R-32, R-125 and R-143a, four HFC refrigerant blends (R-404A, R-407A, R-407B and R-507) emerged as leading replacement candidates. Close evaluation of the physical, chemical and thermodynamic characteristics of these blends indicated that most of them have properties similar to R-502. Through a comparative evaluation of the operational characteristics and system performance of these HFC blends, we found R-404A to be the best replacement for R-502 in medium and low temperature applications on transport refrigeration systems. Today, R-404A is recognized and approved as a replacement refrigerant for R-502 in new unit applications. Furthermore, the application of R-404A has expanded beyond low and medium temperature applications to air conditioning applications (in certain areas).

UNIQUE REQUIREMENTS FOR TRANSPORT REFRIGERATION

Ambient and Operating Temperatures

Transport refrigeration units operate over broader temperature ranges than other refrigeration units, especially stationary unit applications (i.e. supermarket). While stationary equipment is typically installed to meet a particular load and ambient temperature requirement, transport refrigeration equipment must be capable of operating over a wide range of ambient temperatures that range from -40°F to 130°F (-40°C to 54°C), even while protecting product at widely different temperatures that range from -30°F to 70°F (-34°C to 21°C).

Under harsh, high ambient temperature operating conditions, it is especially important that the refrigerant vapor discharge temperatures and pressures remain within safe operating limits. This is necessary to protect the refrigerants, lubricants and components in the refrigeration system. Because of these harsh operating conditions and stringent safety requirements, the number of replacement alternatives for CFC refrigerant R-502 have been particularly limited in the transport refrigeration industry.

Operating Environment

A transport refrigeration unit is a mobile system. The size and weight of a transport refrigeration unit is important because applications require maximum cooling and heating capacity to optimize equipment efficiency. Also, operating conditions are extremely harsh. Transport refrigeration systems also have to be able to withstand the vibration and shock from rough roads, and continuous vibration at changing frequencies generated by unit components including the engine and compressor. However, despite careful attention to the design and assembly of durable equipment, the possibility that a refrigeration system joint or seal may fail and cause a refrigerant leak exists. Therefore it is important that a replacement refrigerant absolutely minimize any threat of harm to the environment or people if a leak occurs.

TEST FACILITY, EQUIPMENT AND TEST PROCEDURES

Test cell and calorimeter requirements were established using test standards recognized world-wide for container, trailer and truck refrigeration certification, and for bus air conditioning performance verification. The test facility has the ability to test transport refrigeration units installed on the front wall of an individual calorimeter test box. Cooling capacity was determined by adding the total electrical heat input to the heat loss from calorimeter box. Figure 1 shows a typical test cell and calorimeter arrangement.

Refrigeration unit coil temperature measurements were made at several locations using thermocouples soldered directly to the outside of the copper tubing and covered with foam insulation. A computer controlled data logger recorded and automatically calculated an average temperature value. Thermocouple temperature measurement accuracy is with in ±0.025% of full scale. The only unit power source is the engine which is connected directly to the compressor. Because of this power supply arrangement, the energy efficiency of replacement refrigerant blends is based on total unit fuel consumption. Figure 2 shows a typical unit refrigeration system.

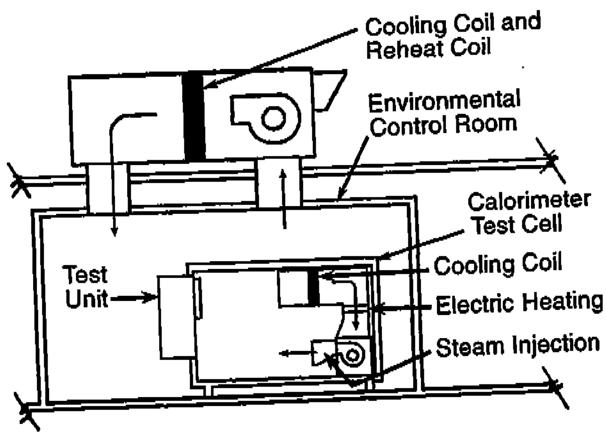

Figure 1. Typical Test Cell Section

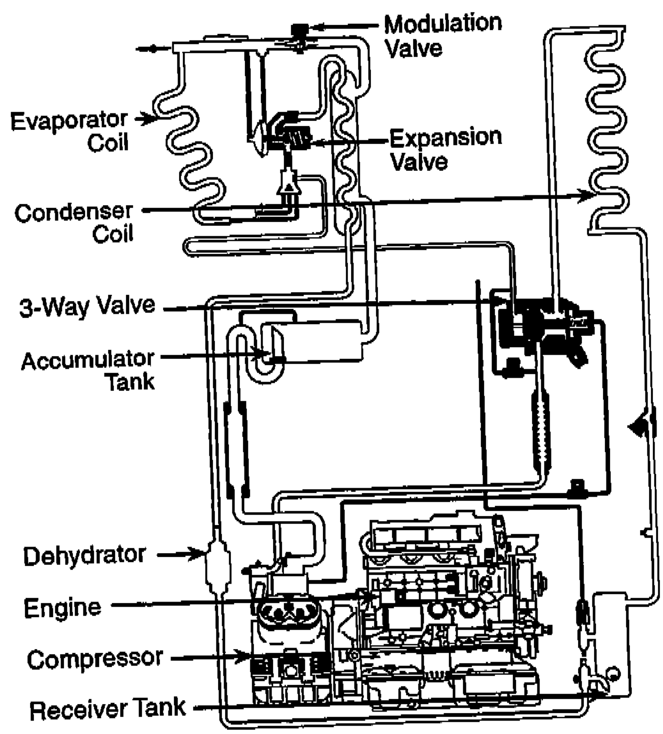

Figure 2. Typical Transport Refrigeration Unit

All tests were conducted in accordance with ARI Standard 1110-92 and applicable ASHRAE standards. Baseline tests were performed using R-404A. Lubricant oil samples were taken on a regular basis from the refrigeration system and analyzed to identify excessive contamination, wear or other long term compatibility problems between the refrigerant, lubricant and components in refrigeration system. Low box temperature tests were performed to check the defrosting process required to clear the evaporator coil of frost and ice. Liquid samples of the refrigerant blend were taken from the liquid line just after the receiver tank and vapor samples were taken from the header tube on the evaporator coil. Most samples were taken after one hour of continuous unit operation at the specified load temperature. Duplicate unit tests were conducted to ensure repeatability and to verify the accuracy and reliability of all test results. Care has been taken to ensure that the data presented here is fair and comparative to each other.

DISCUSSION OF PRACTICAL CONSIDERATIONS

Comprehensive evaluations and testing focused intensely on compressors and components as well as the complete refrigeration system. In particular, the compatibility of the alternative refrigerant, lubricant and system components was carefully examined during each phase of the test program to identify suitable replacement refrigerants. These evaluations contributed to the successful modification of the compressor and other components to solve problems encountered during the evaluation of HFC alternative refrigerants with new POE lubricants. The impact of composition shifting during both the liquid and vapor states was also carefully examined to determine the impact on individual components as well as total system performance.

POE Lubricant

Finding a suitable lubricant for use with HFC refrigerants was important to maintaining transport refrigeration system compressor performance and reliability. After POE lubricants were found to provide good protection against internal compressor wear (particularly piston and piston ring wear) on low temperature cooling applications, additional work was required to modify seals and other internal components to prevent refrigerant and oil leakage. Also, a special external oil filter was required to prevent the buildup of sludge and black metal soap caused by the reaction of POE oil with copper and minute amorphous particles formed from trace amounts of processing fluids and drawings oils used in the manufacture of compressor components. With the completion of several compressor modifications and the addition an external oil filter, HFC blends achieved performance reliability comparable to R-502.

Refrigerant

Additional modifications to the compressor and system components were required because of the increased compression ratio and higher system operating pressures of the R-404A. Operating pressures throughout the refrigeration system increased approximately 5 to 20 psi (0.35 to 1.38 bar) with R-404A compared to R-502. These higher system pressures can require a proportional increase in the pressure control settings.

R-404A is a multi-component refrigerant containing R-125, R-143a and R-134a. Because of concern about the tendency for shifting in the composition blend of R-404A, the impact of composition shifting on the performance, safety, service and operability was carefully evaluated. However, many laboratory and field evaluations of R-404A indicate that the extent of composition shifting (or fractionation of each component in R-404A) that could occur theoretically does not actually take place. Rigorous laboratory analysis shows that the variation in the composition of each R-404A blend sample was negligible. Also, the test data show that the impact of composition shifting on system discharge temperature, discharge pressure, cooling capacity, and energy efficiency is negligible.

TEST RESULTS

R-404A and HFC Ternary Blends

The composition of R-404A in the refrigeration system was changed by withdrawing a carefully measured amount of R-404A from the system in the liquid phase. The exact same amount of R-507 was then added to the system to obtain the desired composition. A complete refrigeration system performance test was then conducted using the new composition blend. This procedure was repeated for each R-134a ratio of refrigerant composition tested from 4% to 0%.

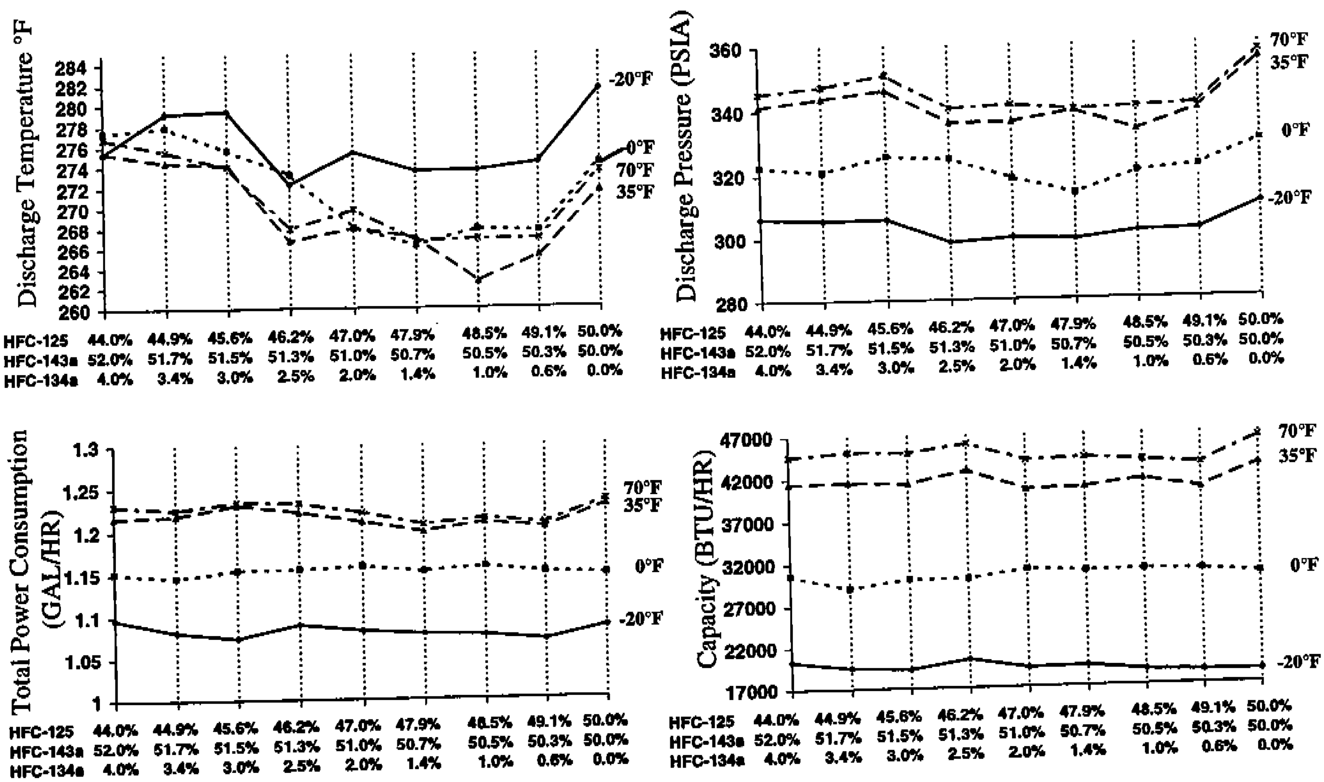

Figure 3: Summary of Unit Test Data for HFC Ternary Blend
Box Temperature Plotted Versus Ratio of Refrigerant Composition in Blend
(Effects of Changing the Ratio of Composition)
Operation: High Speed at Ambient Temperature of 100°F (37.8°C)

Figure 3 summarizes the unit performance test results for the effect of changing the composition of HFC refrigerants in the ternary blend by increasing R-125 content from 44% to 50%, and decreasing R-134a content from 4% to 0%. Test results show that the shifting of R-134a content did not have any meaningful impact (effect) on system performance.

R-404A and HFC Quaternary Blends

The composition of R-404A in the refrigeration system was changed by withdrawing a carefully measured amount of R-404A from the system in the liquid phase. The exact same amount of R-407B (10% R-32, 70% R-125 and 20% R-134a) was then added to the system to obtain the desired composition. Consequently, the quaternary blend was composed of R-125, R-143a, R-134a and R-32. A complete refrigeration system performance test was then conducted using the new composition blend.

Figures 4 and 5 summarize the unit performance test results for the effect of changing the composition of HFC refrigerants in the quaternary blend by limited amounts. The R-125 content was increased from 44% to 70% while the R-143a content was reduced from 52% to 0% and the R-32 content was increased from 0% to 10%. The total content of R-143a and R-32 in the system kept the refrigerant charge within flammability limits. The test results show that the shifting of R-125, R-143a, R-134a, and R-32 content a limited amount in the Quaternary blend did not have any meaningful impact on the system performance.

Charging Composition of Refrigerant Blends

The air conditioning and refrigeration industry has traditionally use two methods of charging a system with refrigerant: vapor phase charging and liquid phase charging. However, as many new blends of alternative refrigerants were introduced, many chemical manufactures recommended that the refrigerant blends be transferred to a system in the liquid phase whenever possible to minimize composition shifting in the product. After selecting alternative blend R-404A to replace R-502, Thermo King extensively evaluated both charging methods. Laboratory tests conducted

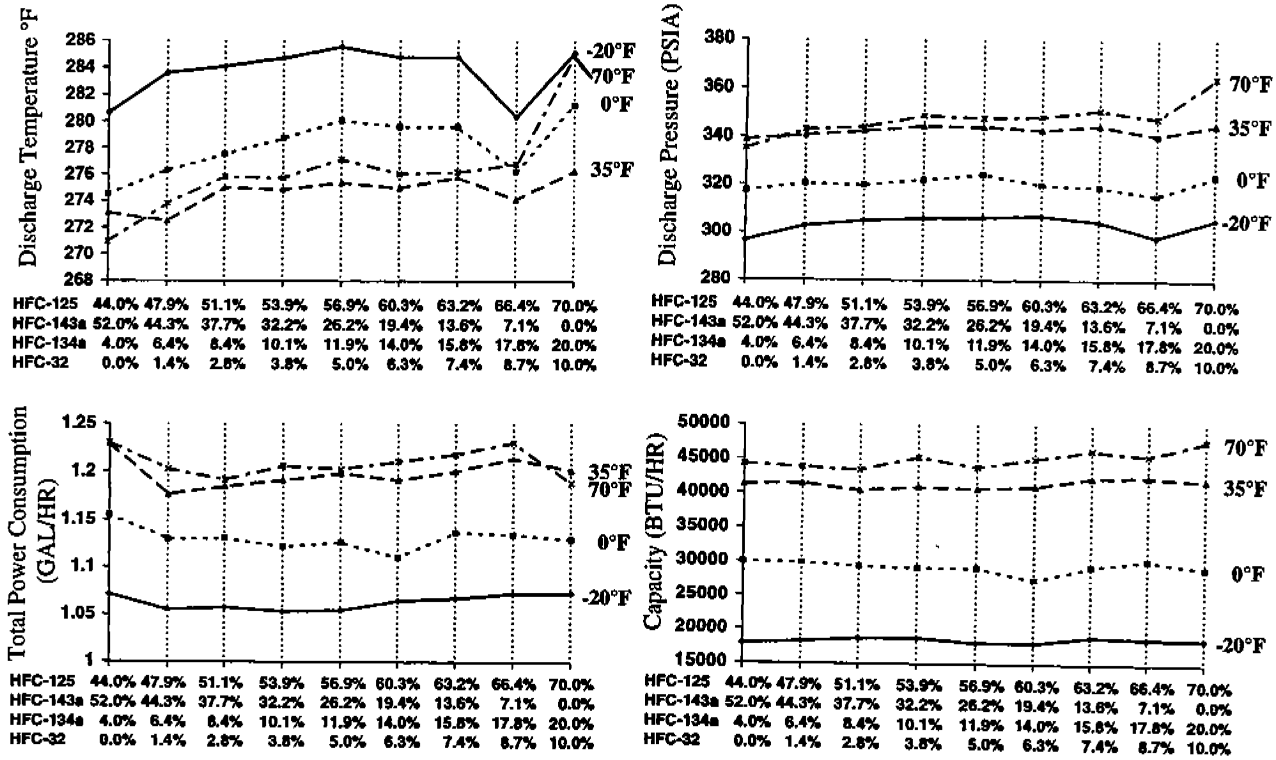

Figure 4: Summary of Unit Test Data for HFC Quaternary Blend
Box Temperature Plotted Versus Ratio of Refrigerant Composition in Blend
(Effects of Changing the Ratio of Composition)
Operation: High Speed at Ambient Temperature of 100°F (37.8°C)

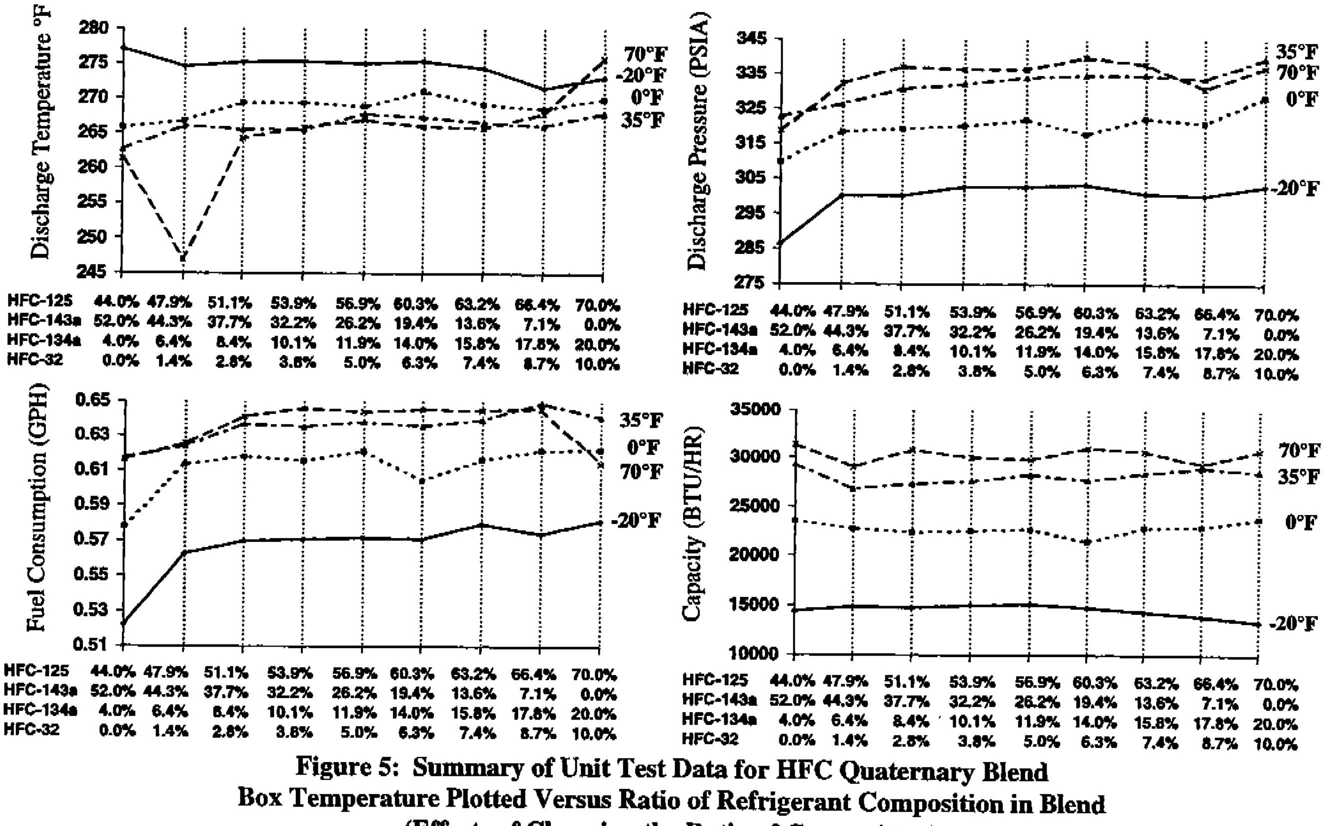

Figure 5: Summary of Unit Test Data for HFC Quaternary Blend
Box Temperature Plotted Versus Ratio of Refrigerant Composition in Blend
(Effects of Changing the Ratio of Composition)
Operation: Low Speed at Ambient Temperature of 100°F (37.8°C)

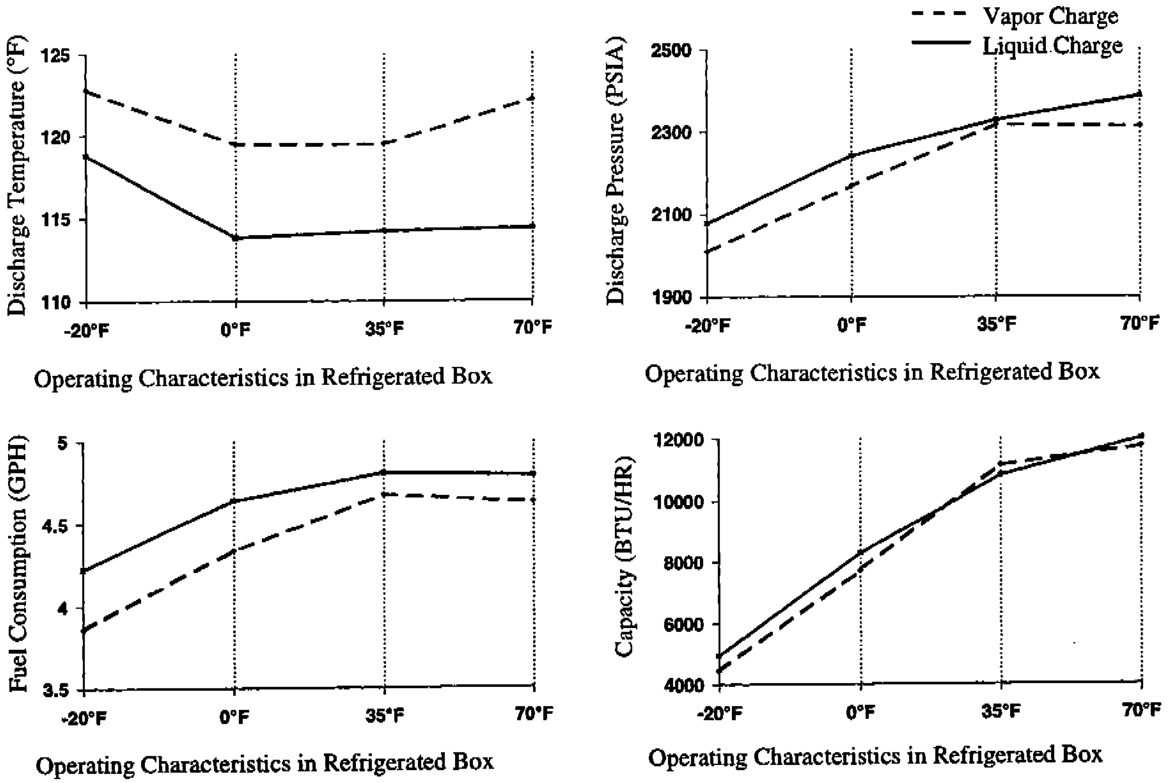

**Figure 6: Summary of Unit Performance Test:
Comparison of HFC Blend R-404A Vapor Charge and Liquid Charge
Operating Mode: High Speed at Ambient Temperature of 100°F (37.8°C)**

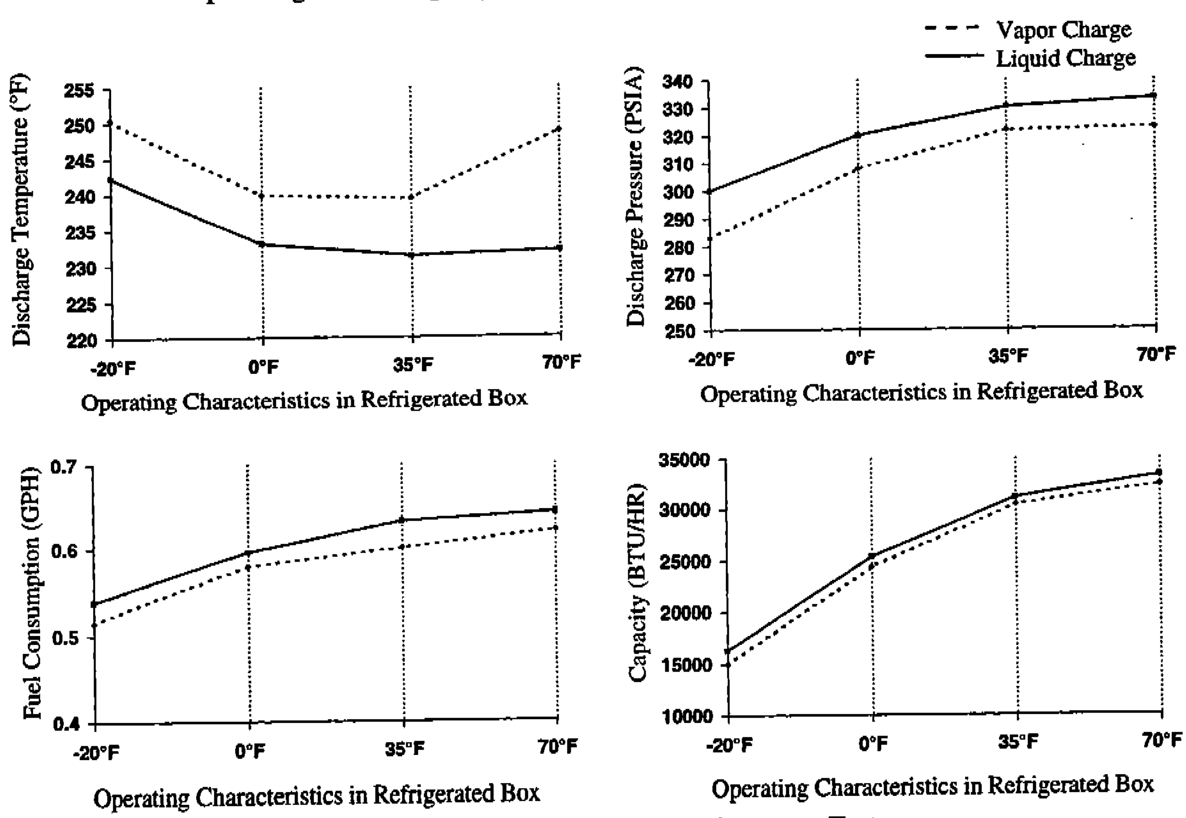

**Figure 7: Summary of Unit Performance Test:
Comparison of HFC Blend R-404A Vapor Charge and Liquid Charge
Operating Mode: Low Speed at Ambient Temperature of 100°F (37.8°C)**

over a wide range of operating conditions show that the vapor charge method is equally as effective as liquid charging for transport refrigeration applications of R-404A.

Figures 6 and 7 summarize the comparison data of system performance test results over a wide range of operating conditions between liquid phase and vapor phase charging of R-404A into the test unit. Test results show that the impact on system performance including discharge temperature, discharge pressure, energy efficiency and cooling capacity between liquid phase and vapor phase charging are generally minor.

CONCLUSIONS

Since introducing HFC blend R-404A into full production in January 1996, tens of thousand of new units are successfully operating throughout the world with components modified and developed for R-404A and POE lubricant. These operating units clearly demonstrate that the application of advanced technology and materials to new component designs can overcome many of the problems created by HFC blends and POE lubricant including high discharge pressure and material compatibility.

Finally, R-404A has a significantly lower compressor vapor discharge temperature that provides better overall refrigeration system performance at high ambient temperatures. Overall, tests show that the use of R-404A in new units with modified compressors and other system components produces better performance and reliability than conventional units obtained with CFC refrigerant R-502.

ACKNOWLEDGMENTS

The author wishes to acknowledge the valuable contributions made by the many individuals at Thermo King, including the Component Development team, Test Laboratory staff and Field Service personnel for their tremendous efforts. Special thanks also to Dr. Rajender K. Sadhir for performing the chemical analysis of all refrigerant blend samples and component materials.

REFERENCES

1. ARI-STD 1110-92. Mechanical Transport Refrigeration Units. ASHRAE Handbook. 1994. Refrigeration. 1-p Ed.
2. Barnett, J.R., Bruce Pylkas and William V. Richards. 1985. New Test Facility for Refrigerated Transport Vehicles. 11R Commissions D1, D2, & D3, Orlando, Florida (USA).
3. Bivens, D.B. 1994. Alternative Refrigerants for Today and Tomorrow. Shiflett, M.B. and A. Yokozeki. 1994. Compressor Calorimeter Experiments on R-502 and R-22 Alternative. Proceedings of 1994 International Refrigeration Conference at Purdue, July 19-22, 1994.
4. United States Department of Agriculture. The Commercial Storage of Fruits, Vegetables and Florist and Nursery Stocks. Agricultural Handbook Number 66.
5. United States Department of Agriculture. Protecting Perishable Foods. Agricultural Handbook Number 669.
6. Kwon, S.L., J.B. Berge and L.B. Naley, Evaluation of R-22 and R-502 Alternatives For Transport Refrigeration, Proceedings of The International Symposium on R-22 and R-502 Alternative Refrigerants, Kobe, Japan December 8-9, 1994
7. Kwon, S.L. "Practical Evaluation Results of Alternative Refrigerants and Their Application in Transport Refrigeration," International Conference on Ozone Protection Technologies, Washington D.C. October 21-23, 1996.
8. Kwon, S.L., J.B. Berge and L.B. Naley, Evaluation and Implementation of R-502 Alternatives For Transport Refrigeration Proceedings of the 1996 International Refrigeration Conference at Purdue, July 23-26, 1996.
9. 11R 1996 "New Developments in Refrigeration For Food Safety and Quality" International Institute of Refrigeration Paris.
10. 11R 1995 Guide to Refrigerated Transport International Institute of Refrigeration, Paris.
11. 11R 19th International Congress of Refrigeration 1995 Proceedings Volume I
12. Kwon S.L. "Implementation of Ozone Safe Alternative Refrigerant Mixtures in Transport Refrigeration Systems," Challenges and Opportunities International Conference on Ozone Protection Technologies, Baltimore, MD November 12-13, 1997.