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RELIABILITY OF HEAT PUMPS CONTAINING R-410A REFRIGERANT

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ABSTRACT

As a result of the Montreal Protocol in 1987 and subsequent approval of the U.S. Clean Air Acts, air conditioning manufacturers in the United States may not produce new products containing Hydrochlorofluorocarbons or HCFC after 2010 because of their potential destruction of stratospheric ozone. Residential and commercial rooftop units usually contain hydrochlorofluorocarbon -22, (also referred to as HCFC-22 or R-22). R-22 has been used successfully as a refrigerant in HVAC equipment for over 40 years. High volume production through these years has helped manufacturers to produce reliable products. R-410A, a hydrofluorocarbon (HFC) mixture, is a leading candidate to replace R-22 in residential and light commercial air-conditioners and heat pumps. Most manufacturers do not have enough experience using R-410A to confidently design and build reliable R-410A units.

The HVAC industry joined together in 1992 by forming AREP, Alternate Refrigerant Evaluation Program, to share pre-competitive data on alternate refrigerants. One major manufacturer announced a formation of black smudge on internal surfaces of field trial units using HFCs. Several causes were suggested but none were published. Reports of capillary tube plugging were rampant. Moisture in the Polyol Ester (POE) oils used with HFC refrigerants will break down to acid and alcohol when exposed to heat.

Manufacturers have many tools to establish reliability with a product prior to mass production. Units and compressors can be run on life tests. Prototype test units can be built in the factory and then installed in the field by service technicians. Examples and results from each of these techniques are described within the paper.

INTRODUCTION

Air-conditioner and heat pump manufacturers must mass-produce reliable products to achieve a profit. The level of reliability with R-22 has come with over 40 years of continuous improvement. Switching to another refrigerant such as R-410A negates much of the learned information that makes the current product so reliable. Some manufacturers offer up to 10-year warranties on the products they produce. Customers have grown to expect air-conditioners to last for 15 years or longer. Unreliable mass produced products will alienate customers and cost the manufacturer high warranty repair expense.

R-410A is a leading candidate to replace R-22 in unitary air-conditioning equipment. R-410A does not contain chlorine, which destroys ozone in the stratosphere. Because R-22 will not be phased out of new equipment until 2010 there will a period of time where both R-22 and R10A products will be available. R-410A products will have to compete head to head against R-22 products.

Once manufacturers decide which refrigerant they wish to use, the challenge of designing and building a reliable cost equivalent system begins. Reliability testing can be extensive and expensive. Long lead times are required to understand system weaknesses before production. By explaining the reliability testing that goes into new product development and the known problems with HFC refrigerants and POE oils the customer will be able to make an informed decision about the refrigerant to choose in an air-conditioner.

RELIABILITY ISSUES

The reliability of many air-conditioner system components will not be affected by the refrigerant such as the fan systems, sheet metal

and electrical controls, which do not contact the refrigerant. Hermetic motors, seals, elastomers, compressors, thermal expansion devices, distributors, capillary tubes, short tube orifices, line valves, service valves, switch over valves, check valves, filters / driers, accumulators, heat transfer surfaces and connecting tubing could cause a refrigerant related failure.

One major OEM found black smudge on the the internal coating of heat pumps used with R407C and a POE oil.[1] Unofficial reports blamed the compressor oil additives or residual mineral oil in the system when the systems were installed. Capillary tube plugging in room air-conditioners were reported to AREP[2]. A mini-split air-conditioner was converted from R-22 and mineral oil to use R407C and POE for 20 units. The rotary compressors had excessive wear. The POE decomposed and the iron concentration in the lubricant clogged the capillary tubes. The primary clogging contaminant was Iron soap formed by decomposition of the POE oil. In a field trial with R-410A heat pumps described later in this paper manufacturing process chemicals contribute to the plugging/sticking of thermal expansion valves.

Cost Consequence

OEMs must control in-warranty charges to operate profitably. Estimated warranty repair costs are charged to the total cost of each manufactured unit. Every service technician working on a warranty repair is someone who is not out selling units. The replacement market is a large part of total air-conditioner sales and each service technician is a dealers and OEMs first opportunity to sell a replacement unit.

A typical 2-ton compressor failure could lead to the following costs:

Trip Charge	$ 25
Diagnosis	$ 25
Recover R-410A	$ 50
Replace Compressor	$200
Compressor Cost	$350
Drier	$ 9
Refrigerant 6 lb.	$ 90
	$749

Lubrication

POE oils are more hygroscopic than mineral oils meaning they absorb more free water as well as moisture from the atmosphere. The detriment of POE oils absorbing water is that once the oil and water are exposed to heat similar to the heat found in compressors the oil and water break into acid and alcohol[3]. The oil hydrolize into Carbolic acid. The TAN measurement may show a high acid content but Carbolic acid will not severely react with the metals when in moderate strength.

POE oils are also better solvents than mineral oils used with HCFC refrigerants. The POE will collect much of the process fluids and metal filings and contaminants in the system and precipitate them out in expansion device or drop them in compressor sump. Deposition in the expansion device could cause plugging and force the compressor to pump refrigerant at higher pressures creating a less reliable system.

POE can be formulated in many combinations of branched, linear and mixed chains. Comparing HFCs and POE miscibility to HCFCs and mineral oil must be done on a case by case method. One study[4] did report acceptable miscibility with POE oils and R407c at the same flow rates as R-22 and mineral oil. Mineral oil is not miscible in HFC refrigerants and cannot be used in many applications.

R-410A Properties

R-410A saturation pressures are approximately 1.6 times those of R-22. The entire R-410A vapor compression cycle takes place at higher pressures as shown in Figure 1. The higher pressures require thicker walled heat transfer surfaces and thicker walled compressor shells for scrolls. The higher pressures create higher bearing loads on the compressor. Higher bearing loads contribute to bearing wear and ultimately higher failure rates. R-410A vapor densities are over 40% higher than R-22 vapor density. R-410A compressor displacement can be lower because of the higher vapor density, approximately 70% of the compressor displacement used in an R-22 compressor. The vapor higher densities translates to lower vapor velocities in suction lines. Adequate vapor velocities are needed to return oil to the compressor. The liquid density is lower and line sizes should be examined so the liquid doesn't add too much pressure drop. One OEM has

stated that current line sets between the indoor unit and the condenser are acceptable[5].

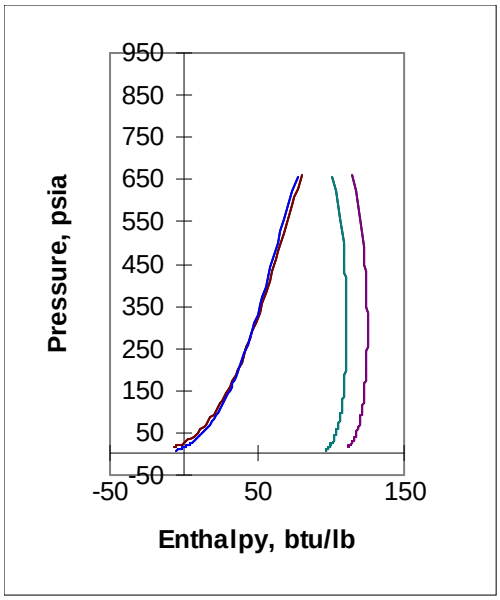


Figure 1 - Pressure Enthalpy chart for R-410A and R-22.

Contamination

Air Conditioning systems may be contaminated from internal and external sources. Manufacturing chemicals such as cutting oils, unclean parts and part wash cleaning fluids in sufficient quantities contaminate the system. A common contaminate to hermetic systems is air. A field practice of purging refrigerant through the line sets and indoor unit prior to opening line valves to the outdoor unit does not remove all the air from the system. Evacuating the line sets and indoor unit is a better technique which won't leak refrigerant to the atmosphere or leave air in the system. R-22 systems seem to be benign to very small quantities of air. R-410A refrigerants with POE oils may not be so tolerant.

When an outdoor unit must be replaced often the existing indoor units won't be replaced. The indoor units and line sets will contain mineral oil from the compressor that is being replaced. R-22 systems with mineral oil tolerate the additional mineral oil very well. R-410A outdoor units attached to a previously used R-22 indoor unit may not tolerate the residual mineral oil. Initially OEMs may require new indoor units to be installed with new outdoor units.

Installing R-410A systems in a dirty environment may introduce dirt into the line sets before the outdoor unit is hooked up. No systems tolerate the addition of abrasives such as dirt very well. R-410A systems may be particularly sensitive.

As long as there are two refrigerants used in unitary HVAC then there exists the possibility of introducing R-22 into an R-410A system. R-22 in an R-410A system will affect the system pressures, efficiency and may well affect the reliability.

Chemical Compatibility

HFC refrigerants are generally more stable than HCFC refrigerants. POE oils are generally less stable than mineral oils. The more stable a substance the less likely it will react with other substances. The POE oil may react with elastomers such as those found in switchover valves, line valves, schraeder valve cores, compressor windings. The reaction may create a reliability problem by destroying the elastomer or degrading the oil lubrication properties.

Process fluids used in the manufacture of compressors, coils and other components may remain on the parts at the time of final assembly. The process chemical may degrade the POE oil or may precipitate on the flow control device.

LAB TESTING

A sophisticated lab testing program will uncover many reliability issues. The Trane Company uses a two-prong attack by testing compressors and systems independently. The purpose of reliability testing in the lab is to reduce cost by diagnosing design flaws. Systems and compressors can be tested under closely controlled specific conditions known to cause stress in the compressors or systems. When a prototype fails in the lab the cost change the design is minimal compared to the cost to address the flaw in the field and then to also have to change the design once it has been placed into production

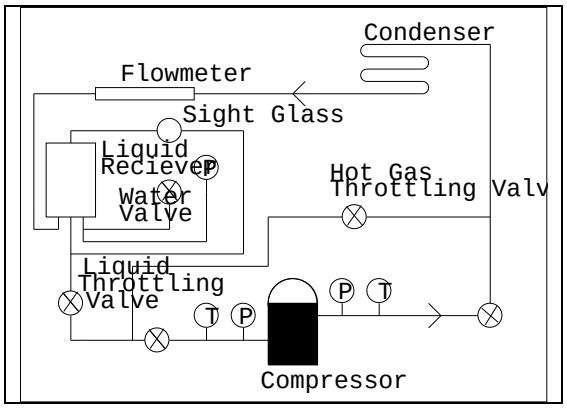
If 1000 flawed thermal expansion valves were put into units and subsequently had to be repaired under warranty the cost would be

Trip Charge	$ 25
Problem Diagnosis	$ 25
Refrigerant Recovery	$ 50
Replace TXV	$ 50
TXV Cost	$ 50
	$200
	x 1000
	$200,000

Without a sophisticated test program such a failure could easily be introduced - with a comprehensive test program - such instances can almost certainly be minimized. This example does not show the cost associated with selling 1000 flawed units to customers, these customers most certainly would think twice about buying from the same company.

Compressor Testing

Compressors are the most complicated component of air-conditioner systems. If the compressor fails the system will fail. Many tests can be run on a compressor in a life test stands or compressor calorimeter without requiring a complete system to be built around it. Compressor life test stands and calorimeters are similar in design and are depicted in Figure 1. In both cases the compressor is instrumented to measure suction and discharge temperature and pressure, power consumption, and compressor sump and dome temperatures.



Compressor calorimeters are generally used to test the performance of a compressor and determine how much mass flow the compressor will generate while requiring a measured amount of power. Both test apparatus control the compressor suction pressure, suction temperature and discharge pressure. The suction quality can be controlled also to simulate a flooded evaporator condition. Compressor life test stands are used to stress the compressor repeatedly over extended periods of time. Examples could include testing high, low, flooded start, heat pump, low charge, overcharge, etc.

System Testing

Flaws can exists in the system aside from the compressor as well as system design can effect the compressor reliability. Two types of system testing are used to establish unit reliability. Extreme long term environmental testing or accelerated life testing and condition specific testing to evaluate compressor oil levels at low flow conditions low ambient heating conditions or determine the compressor temperature during cooling conditions at high ambient temperatures.

Accelerated life testing of systems must be carried out in samples of significant size to find design flaws. Often 6 - 24 identical systems will be tested simultaneously. Such a test used by the Trane company lasts 16 weeks and consists of periods of high ambient temperature cooling conditions exceeding 130oF, low temperature heating conditions with ambient temperatures below 30oF with significant snow. R-410A heat pumps will reach discharge pressure levels above 800 psig at ambient temperatures above 130F. Other mechanical failures are introduced such as outdoor and indoor fan failure modes, to determine if a minor failure such as a fan motor failure will cause a major repair such as a compressor failure. Electrical components are stressed by using high and low voltages and voltage spikes and outages.

Accelerated life testing of systems is further expanded by introducing field circumstances. Overcharging and undercharging are the two most common field errors. Both cause the system to operate in a sub-optimal level. A compressor can be forced to burnout in a system and a new compressor installed as it would be in the field and the test begins to establish replacement compressor failure rates. The POE oils may perform differently once

impure oil is introduced into the system. Systems can be run at extremely low charges symbolic of a leak in the system. Contaminants such as water were added to units to determine if the driers were acceptable to remove the moisture. These are test routinely used with R-22 and were applied to R-410A. R-410A heat pumps haven't shown sensitivity to mild overcharging, undercharging or with the addition of oil from a burned out compressor. The addition of water doesn't effect the R-410A heat pump as long as there is sufficient drier capacity to absorb the water.

Specific testing to measure the oil return to the compressor is done with extremely low temperature ambient and compressors with sight tubes. The line sets are also lengthened and raised to further restrict oil return to the compressor.

FIELD TESTING

No amount of lab testing can take the place of building units in the manufacturing environment, boxing them up, shipping them to dealers and installing them in homes and businesses. The Trane Company has installed over 45 R-410A heat pumps into residences all across the country. These 45 units were installed in the last half of 1995 and the first half of 1996. 40 of these units were built in the Tyler, Texas manufacturing facility on a temporarily converted R-22 line. More field installations are planned at the time of the writing of this paper. Installations

Field Service Technicians

Lab testing allows the engineer to concentrate on the hardware and field testing allows the engineer to focus on the field technician.

The homeowner or final customer is concerned about cost, comfort, and reliability. The objective is to provide an R-410A product competitive with an R-22 product on those three items. The field trial brings out undiscovered issues on comfort and reliability. The customers have been well pleased with both comfort and reliability of R-410A heat pumps except for one correctable issue. 7 of the 40 field trial indoor thermal expansion devices plugged on startup. Later analysis revealed a process chemical caused stuck to the thermal expansion device and collected metal fillings and other manufacturing debris in the orifice of the thermal expansion device. The orifice is the first cold spot in the system and particles or chemicals immiscible in the oil will precipitate out. Identification and elimination of the offending process chemical fixed the problem.

Four units were undercharged and operated in an inefficient manner through most of 1996. The homeowners didn't notice a lack of comfort but one homeowner complained that his unit ran all the time. One of the first units installed had an adjustable indoor unit expansion device and low charge. The homeowner complained of lack of capacity and long run times. Once these issues were fixed the homeowner was well pleased with the comfort provided by the R-410A system.

Field Service Technicians have quite a surprise in store when they check line pressures on an R-410A unit. Typical summer discharge pressures run 265 psig for high efficiency R-22 units and the same R-410A unit discharge pressures are 392 psig. Temperatures, subcooling and superheat settings are similar for R-22 and R-410A systems. The overall pressure is much higher for R-410A and this requires special gauge sets with higher pressure gauges and hoses.

R-410A systems must be marked significantly different from R-22 systems to keep refrigerant contamination to a minimum. Service technicians will be accustomed to working with R-22 and will automatically expect a unit to contain R-22 unless it plainly marked.

Service training is imperative since POE oils are hygroscopic. Once a field failure occurs, field service technicians must keep the replacement compressor sealed until ready for use. The open compressor will absorb moisture from the atmosphere. This moisture if not absorbed by a good filter drier will react with the POE oil and form acid and alcohol. Using proper field techniques, pulling appropriate vacuum levels prior to charging have a greater potential to induce failure in the system. Keeping the system clean and dry are two of the most important steps in building and installing R-410A heat pumps.

SUMMARY

R-410A is a leading candidate to replace R-22 in unitary heat pumps. Reliability can be evaluated by testing systems and compressors in the lab and in the field.

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