Determination of the Performance, Leak Scenario, Flammability and Oil Return Characteristics of a Novel R22 Replacement

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DETERMINATION OF THE PERFORMANCE, LEAK SCENARIO, FLAMMABILITY AND OIL RETURN CHARACTERISTICS OF A NOVEL R22 REPLACEMENT.

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1. ABSTRACT

Across the world the agreed phase out schedules for the HCFC R22 have led to the development of non-flammable zero ozone depletion potential (ODP) replacements. Most of these have included R32 as one of the blend components and require fully synthetic lubricants such as ester based oils, but there is one non-flammable replacement that has been developed which does not utilise R32 and can be used with traditional lubricants in the majority of applications. This paper discusses the development of the blend comparing the performance characteristics under laboratory conditions. Several leak scenarios are investigated to ascertain the theoretical worst case scenario and considers the implications on flammability. Finally the oil transport properties are investigated in order to assess the suitability of using the blend with traditional oils.

2. INTRODUCTION

Since the discovery of stratospheric ozone depletion due to chlorine containing molecules, and the subsequent phase out of chlorofluorocarbons (CFCs) in 1995 the focus over recent years has centred on the hydrochlorofluorocarbon (HCFC) chlorodifluoromethane (R22). Although the latest revision of the Montreal Protocol does allow the use of R22 for more than 20 years, individual countries or groups of countries (e.g. European Union) are introducing more stringent legislation requiring total phase out in less than 20 years and in some cases banning the use in new equipment as early as the year 2000. To address this need a number of alternatives have been proposed or developed ranging from hydrocarbons to ammonia.

There is no doubt that hydrocarbons and ammonia will play a role in replacing R22 but it is likely that the bulk of equipment/applications currently utilising the non flammable non toxic R22 will move to a zero ozone depleting (ODP) non-flammable non toxic alternative. Currently there are two blends with ASHRAE designations which are being proposed as potential alternatives, namely R407C, a blend of difluoromethane (R32), pentafluoroethane (R125) and tetrafluoroethane (R134a), and R410A, a blend of R32 and R125.

R407C has physical properties similar to R22 and therefore can be used in equipment of a similar design, but R407C is used in conjunction with the new fully synthetic lubricants such as polyol esters (POE). R407C also shows a pronounced temperature glide in practice which can lead to operational difficulties e.g. in water chillers where the nominal evaporator temperature of

R22 would be ~1°C, with R407C, if the dew point condition is taken then the evaporating temperature could range from a minimum of -4°C up to 1°C across the evaporator with the risk of ice formation in the evaporator.

R410A also requires the use of fully synthetic lubricants and has physical properties which are very different to that of R22, e.g. saturated vapour pressure for R410A at 40°C is almost 60% higher than R22, and therefore the equipment has to be designed specifically for use with the blend. A number of advantages have been identified when using R410A such as the unexpectedly high heat transfer coefficient and the fact that smaller compressors and pipes are required. However the critical temperature of the blend is relatively low (72°C) which does raise questions as to the performance under extreme ambient conditions or heat pump applications where condensing temperatures of 60°C or higher may be achieved.

Clearly the alternatives mentioned above are potential replacements but they both require equipment changes to be made and raise the potential of new practical problems as outlined previously. The purpose of this study was therefore to investigate a novel blend of R125, R134a and a butane (R600) which is intended to give a performance comparable to R22 and use traditional mineral oil or alkyl benzene lubricants. This paper details independent calorimeter measurements, theoretical leak scenarios, flammability of the blend and worst case scenarios and the oil return characteristics compared to R22.

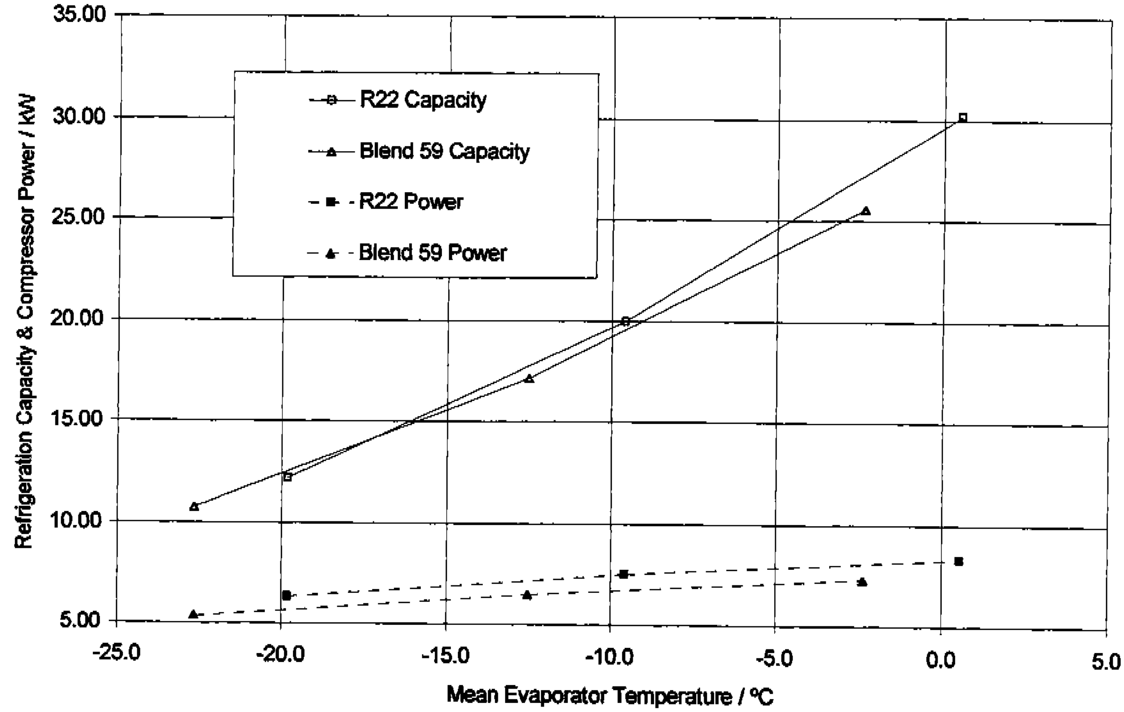
3. PERFORMANCE TESTING

The performance testing was performed on a blend of composition 46.5% w/w R125, 50.0% w/w R134a and 3.5% w/w R600 (blend 59). The testing was performed at ILK (Institut für Luft und Kältetechnik, Dresden, Germany) on a rig comprising a semihermetic Bitzer compressor (type 4T-12.2) with B5.2 mineral oil, shell and tube condenser and a shell and tube brine fed evaporator fitted with heaters to balance against the refrigerant cooling capacity. Both R22 and blend 59 were tested at the following conditions;

Condensing Temperature = 40°C   Evaporating Temperatures   -20°C, -10°C and 0°C

The refrigeration capacity and compressor power results are shown below in figure 1 and it can clearly be seen that the refrigeration capacity of blend 59 is comparable to that of R22 with a significant decrease in the compressor power requirement. This leads to an increase of coefficient of performance (COP) between 12.5% at -20°C to 4.5% at 0°C. This large increase in COP has the beneficial effect of dramatically reducing the power consumption over the lifetime of the equipment and therefore the environmental impact, with regards to global warming, is also reduced.

Figure 1. Performance of Blend 59 Compared to R22



4. LEAK SCENARIOS AND FLAMMABILITY

In order to comply with ASHRAE Standard 34 it is necessary to demonstrate that a blend is non-flammable not only as formulated but also from a theoretical leak scenario. The leak scenarios are performed at two fill ratios (15% v/v and 90% v/v) and at three temperatures (boiling point + 10K, 23°C and 54.4°C). The composition from either vapour or liquid phase found to have the highest concentration of the flammable component is then tested for flammable limits. The flammability test method used in this study was ASTM E 681-85 and the flammability tests were performed at 60°C for the worst case leak and 100°C for the as formulated composition.

The leak scenario was performed by charging a cylinder with the required amount of the blend, placing the cylinder in a temperature controlled bath and then isothermally removing quantities from the vapour phases. The composition of the vapour phase and liquid phase was then determined and the process repeated until the pressure in the cylinder was equal to atmospheric pressure. The conditions for the worst case scenario was at -31.8°C (boiling point +10K) with a 90% fill ratio as shown in figure 2 below. The composition with the highest concentration of the most flammable component was found to occur after 72% had leaked giving a vapour phase of composition 59.9% w/w R125, 35.8% w/w R134a and 4.3% R600. This composition along with the as formulated composition was then tested for flammable limits as detailed above and the results are shown in table 1.

Figure 2. Theoretical worst case leak scenario for blend 59

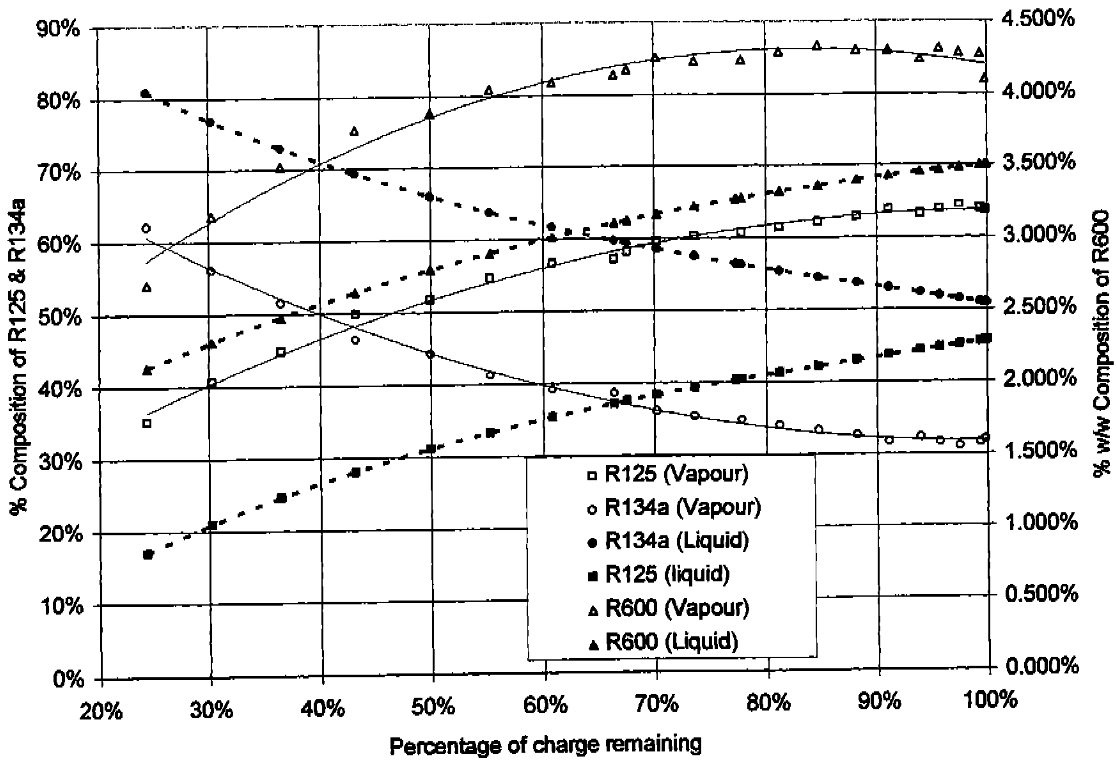


Table 1. Flammability results for Blend 59

	Flammability Result @		
Composition	25°C	60°C	100°C
46.5% R125 / 50.0% R134a / 3.5% R600	Non-Flammable	Non-Flammable	Non-Flammable
59.9% R125 / 35.8% R134a / 4.3% R600	Non-Flammable	Non-Flammable	Not Tested

5. OIL RETURN CHARACTERISTICS

The development of non-flammable zero ODP HFC refrigerants has been accompanied by a parallel development of lubricants suitable for use with these compounds since the solubility of these fluids in traditional oils is very low. The lubricants developed were initially based on blends of poly alkylene glycols (PAG) but these demonstrated a very high affinity to atmospheric moisture and it was discovered that there were potential chemical stability problems, particularly in the presence of chlorinous residues left in equipment previously utilising CFCs. This prompted the development of refrigeration grade polyol ester (POE) based lubricants which are chemically stable but are also significantly hygroscopic, although to a lesser extent compared to the PAG oils. Both the PAG and POE lubricants require careful handling due to their hygroscopic nature but are fully miscible with HFC refrigerants such as R134a over a wide temperature range, and this is often assumed to be a critical requirement in order to obtain satisfactory oil return characteristics. In fact total miscibility is not a prerequisite for oil transport[1,2,3] which is a complex process and a function of various parameters:

1) Degree of solubility (Often grossly simplified to miscibility),
2) Velocity of refrigerant through the pipes,
3) Viscosity of the oil / refrigerant mixture,
4) Refrigerant density,
5) Operating temperatures,
6) System layout.

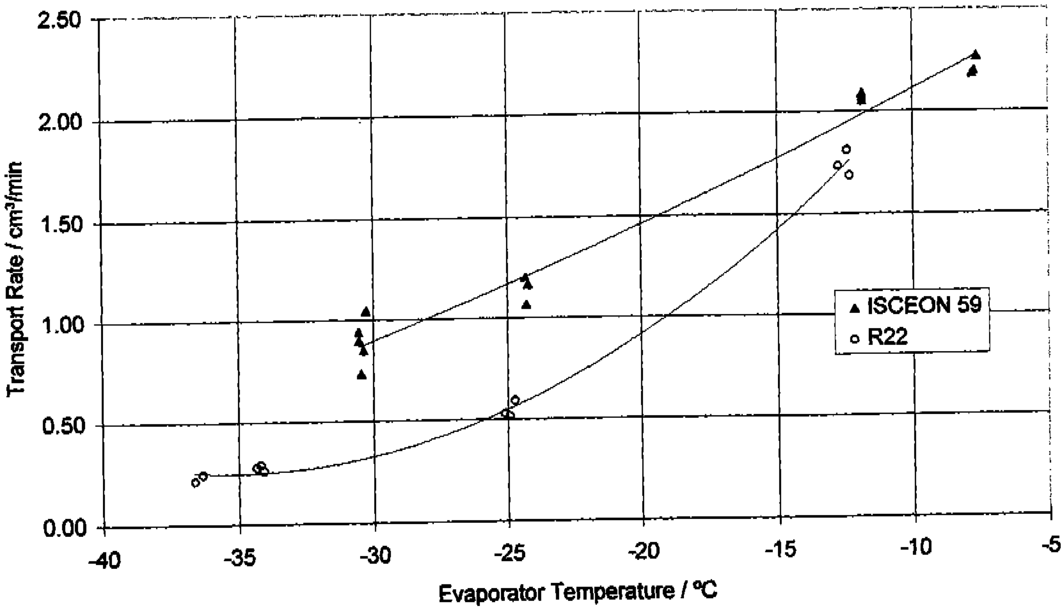
This is by no means a new concept since it is well known that refrigerants such as R22 or R502 are not fully miscible with mineral oils[2,4] but have a partial solubility, yet have been successfully used in the industry for many years.

It is well known that hydrocarbons have a very high solubility in mineral oils but they are also totally miscible with fluorocarbon refrigerant fluids. This results in a mutual solubility effect when the refrigerant blend is mixed with mineral oil, i.e. significant amounts of the fluorocarbon refrigerants also dissolve in the mineral oil, which is sufficient to provide the necessary properties to enable oil transport.

Previous studies[1,5] have concentrated on monitoring compressor oil levels to assess oil return in a system but in this study it was decided to monitor the rate of oil transport through the suction line.

The equipment used consisted of Danfoss SC12BXT2 air cooled condensing unit with the original mineral oil lubricant and a sight glass fitted to the compressor shell to enable the oil level to be checked. An automatic expansion valve was used leading to an evaporator placed in a temperature controlled bath to control the suction gas superheat. The suction line immediately after the evaporator was heavily insulated and a heat exchanger was used to maintain a constant temperature in the suction line up to the point where the oil flow was measured. Also prior to the point of measurement the suction line rose vertically for ~1 meter. The rate of oil flow was determined by closing valve V1 and measuring the time taken for the oil level to rise between two marked points on the transparent perfluoroalkoxy (PFA) tubing. A further section of the PFA tubing was placed in the suction line after the measurement point to act as a visual check that the oil was not by-passing the collection tube. The tests were performed over the temperature range -36°C to -8°C and the results (figure 3 below).show that blend 59 can transport traditional lubricants at a faster rate than R22, particularly at low temperatures. This good result for the ability to transport traditional oils within a refrigeration system was achieved despite the relatively low solubility of the refrigerant in the oil (~8% w/w at -30°C). However this relatively low solubility also means that blend 59 may only be used in direct expansion systems. Systems utilising a flooded evaporator design would require the high degree of solubility offered by the fully synthetic oils such as POE.

Figure 3. Comparison of rate of oil transport for R22 and Blend 59 against evaporator temperature.



6. CONCLUSIONS

The results from this study show that the refrigerating capacity of the blend 59 is comparable to that of R22 with a superior COP. The leak scenarios performed have given compositions which have been found to be non-flammable. Finally the oil return characteristics have been found to be superior to that of R22. Therefore the blend 59 of composition 46.5% w/w R125, 50.0% w/w R134a and 3.5% w/w R600 is a realistic alternative to replace R22 without the need to use fully synthetic lubricants in direct expansion systems.

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