

1996

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Roberts, N. A. and Pearson, S. F., "High Efficiency R22 Replacement" (1996). *International Refrigeration and Air Conditioning Conference*. Paper 456.
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High Efficiency R22 Replacement

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1. SUMMARY

There are no single component refrigerant replacements that have the complete range of advantageous properties of the ozone-depleting, CFC and HCFC refrigerants. Furthermore, it is unlikely that new materials having these properties will be discovered. Therefore, for many applications, it has become necessary to use blends, since these offer a means of attaining almost all of the previous advantages. This paper discusses the relevance and usefulness of blends to the present situation and specifically addresses replacement of the ozone depleting refrigerant R22 with a zero ODP alternative, compatible with polar and non-polar lubricants. The vapour pressure of the blend is given revealing that at elevated temperatures the condensing pressures of the blend are lower than for R22 at the same temperature. Results are shown from a series of calorimeter tests, confirming the refrigerating performance of the blend is similar to that of R22 and the efficiency is higher than when R22 is used. The blend is non toxic and non-flammable.

2. INTRODUCTION

The second set of phase-out regulations set by the signatories to the Montreal Protocol came into effect at the end of 1995 banning of production of chlorofluorocarbons (CFCs) in "developed countries". This has brought the spotlight onto the next category of ozone depleting chemicals to which the phase-out legislation applies i.e. the hydrochlorofluorocarbons (HCFCs) which to the refrigeration industry mainly concerns dichlorodifluoromethane (R22).

At present the Montreal Protocol specifies that production of HCFCs in developed countries will be banned from the year 2030 but there is intense pressure to bring this date forward and some authorities, most notably the European Union (EU), have passed their own legislation to phase-out production as early as the year 2015 with end use controls limiting usage well before this date .

The search for alternative refrigerants began by looking for single compounds or azeotropes with suitable properties to replace the CFCs and HCFCs but it was realised very quickly that, with the exception of 1,1,1,2-tetrafluoroethane (R134a) to replace dichlorodifluoromethane (R12), this was not achievable.

The effort was then focused on mixing compounds which possessed some of the desired properties to produce a blend without the deficiencies of the individual components. The first blends produced were aimed at replacing the CFC R12 and the CFC containing azeotropic blend R502. These blends initially utilised HCFCs, which still allowed the use of traditional mineral and alkyl benzene lubricants, later zero ozone depleting potential (O.D.P.) blends were formulated to replace R12, R502 and R22 using hydrofluorocarbons (HFCs) but these usually required synthetic lubricants such as the polyol ester oils.

This paper describes the results from a study to formulate a non-flammable zero O.D.P. blend to replace R22 and can utilise both the non-polar traditional lubricants and the new polar oils.

3. CHOICE OF BLEND COMPONENTS

The number of compounds available for use to formulate a blend with similar levels of flammability, toxicity and oil compatibility as R22 is limited (table 1.). Of the available HFCs two have been used for many years in CFC containing blends (i.e. R23 used in R503 and R152a used in R500) but the others were new to the industry and the necessary toxicology data has only recently been published from the PAFT (Program for Alternative Fluorocarbon Toxicity testing) program⁽¹⁾. Although hydrocarbons are highly flammable they may be considered as potential blend components since their inclusion in minor quantities does not compromise the non-flammability of the blend, but can have a major influence on the performance and compatibility of the blend with non-polar oils.

Table 1. Possible blend components.

Refrigerant Number	Chemical Name	Normal Boiling Point / °C (°F)	Safety Group
23	Trifluoromethane	-82 (-116)	A1
32	Difluoromethane	-52 (-62)	A2
125	Pentafluoroethane	-49 (-56)	A1
134a	1,1,1,2-Tetrafluoroethane	-26 (-15)	A1
143a	1,1,1-Trifluoroethane	-47 (-53)	A2
152a	1,1-Difluoroethane	-25 (-13)	A2
290	Propane	-42 (-44)	A3
1270	Propylene	-48 (-54)	A3
600	Butane	0 (31)	A3
600a	2-Methyl propane (Isobutane)	-12 (11)	A3

In selecting compounds to produce a blend to replace R22 as a refrigerant there are a number of considerations. Namely the blend should have equivalent toxicology and flammability, similar physical properties and similar operating performance.

The toxicology of all the compounds listed in table 1 are equivalent to that of R22 and therefore any could be used. However this is not the case from the flammability view point. The HFCs R32, R143a and R152a are rated as being flammable and of course the hydrocarbons are highly flammable. This obviously limits the proportions of these compounds, but does not exclude their use to formulate a non-flammable blend.

The components of the blend need to be chosen very carefully to give similar properties to that of R22. Properties such as vapour pressure, bubble point, oil compatibility, temperature glide and flammability need to be as close as possible to the refrigerant being replaced if the same design of equipment is to be used.

The vapour pressure and bubble point are the easiest properties to reproduce. Just mixing high pressure components with low pressure components, e.g. R125 and R134a, can give a blend with the correct bubble point vapour pressure curve however the temperature glide would probably be large and obviously compatibility with traditional lubricants would not be obtained.

To obtain compatibility with traditional oils at least one of the blend components is required to have a high solubility in the oil and therefore have the capability of significantly increasing the overall oil solubility of the entire blend. Of the compounds available only the hydrocarbons have sufficient solubility with non-polar lubricants to achieve this, but the quantities need to be carefully balanced to prevent the blend becoming flammable.

Temperature glide is one of the most difficult properties to control and predict. The obvious choice of components that would give a low temperature glide, not forgetting the vapour pressure requirement, might lead to the selection of those compounds with the smallest difference between boiling points.

Table 2 shows a number of combinations incorporating a hydrocarbon as a minor component and the blend R407C.

Table 2. Component boiling point range compared to blend temperature glide.

Composition	Boiling Point Range / K	Temperature Glide at -40°C/ K
R125/R290/R134a	22.4	14.1
R125/R1270/R134a	22.4	10.9
R32/R125/R134a (R407C)	25.6	7.2
R125/R134a/R600a	36.9	5.4
R32/R125/R134a/R600a	40.1	9.3

It can clearly be seen that limiting the difference in boiling points of the individual components is not a reliable means of achieving a low temperature glide. Indeed the combinations with the smallest boiling point range provide the blends with the largest temperature glide and conversely a combination with one of the largest ranges produces a blend with the smallest temperature glide.

These apparent anomalies can normally be explained by the presence of azeotropic compositions within the blend, for example R134a and R600a form a high pressure azeotrope⁽²⁾ with a vapour pressure greater than that of R134a alone. The presence of azeotropic behaviour within a blend not only has an effect on the temperature glide of the blend, but can also be beneficial to the thermodynamic properties of the blend.

The operating performance of the blend should obviously be comparable to that of R22. This is very strongly linked to the physical properties of the components once more, where latent heat of evaporation and critical temperature are important factors. It is possible to estimate the thermodynamic behaviour of the blend but this should always be determined practically in a calorimeter since, as mentioned above, azeotropic effects within the blend can have a significant influence on the overall performance.

4. PERFORMANCE TESTING

4.1 Experimental Equipment

The apparatus for comparing performance of refrigerants under controlled conditions consists of an electrically heated secondary fluid calorimeter, which has been described elsewhere⁽³⁾. The fluid contained in the shell of the calorimeter is R134a. The refrigerant under examination circulates within a coil suspended within the calorimeter.

The refrigerating circuit includes a small, open-type compressor driven through a torque meter, a tube-in-tube water cooled condenser with pressure operated water valve and a pulse type expansion valve operated from a modulating electronic level controller.

The calorimeter is operated at ambient temperature to minimise uncontrolled leakage of heat and the refrigerant at exit from the calorimeter is superheated to ambient temperature. The large superheats so produced are not typical of practical operation of real refrigerating systems but they allow very accurate comparisons to be made between the performance of different refrigerants.

4.1 Experimental Results

From the above discussion concerning choice of components it was found that a blend of R125/R134a/R600a was the most interesting combination. Initially different quantities of R125 were investigated ranging between 43% and 56% with the R600a content being kept constant at 4% to avoid

entering the flammable region. All combinations produced a favourable pressure temperature relationship (figure 1.).

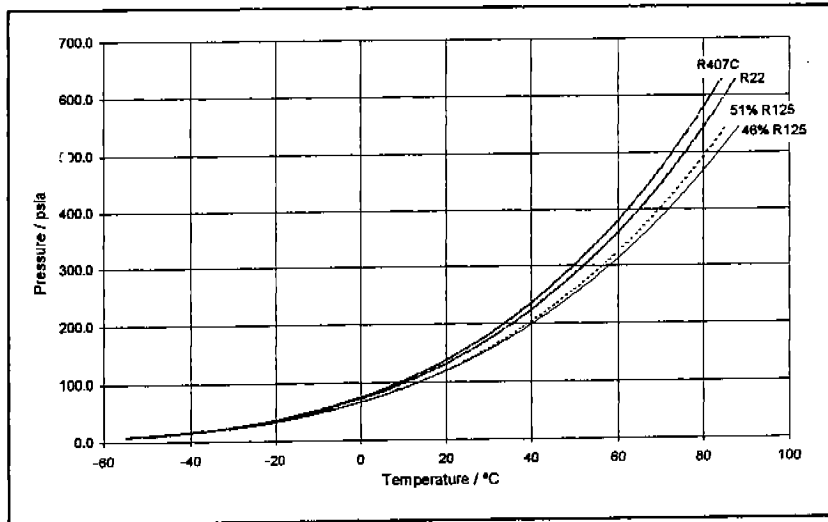


Figure 1. Vapour Pressure Comparison

It was expected that by increasing the R125 content of the blend that there would be an increase in refrigeration effect, but by increasing the R125 content the critical temperature of the blend would be lowered (table 3.) which could have a detrimental effect in high ambient temperature conditions.

Table 3. Change of blend critical temperature with increase in R125 content.

% R125 Content	Critical Temperature / °C
43	90.9
46	89.9
48	89.3
51	88.3
56	86.7

Each of the blends were tested in the calorimeter and it was found that there was a gradual increase in refrigeration effect with increase of R125 but this started to decrease once the R125 content passed 51%. Taking into account the critical temperatures of the blends and the coefficients of performance obtained from the calorimeter tests it was decided to study further the blend containing 46% R125 which was known as Isceon 59.

Figure 2A shows the refrigeration effect of Isceon 59 compared to R22 and R407C with a condensing temperature of 40°C. The results show that all the refrigerants have a very similar refrigerant effect with R22 having a slightly higher value at low temperatures and R407C having the highest value at high temperatures. Figure 2B shows the C.O.P. obtained for the three refrigerants under the same conditions. At evaporator temperatures above -20°C Isceon 59 has a slightly higher value than the other two refrigerants.

Figures 3A and 3B show refrigerating effect and C.O.P. for the three refrigerants at a condenser temperature of 55°C. Fig 3A again shows that the cooling capacities are very similar with R22 having the highest refrigeration effect at low temperatures and R407C at high temperatures. Fig 3B continues to demonstrate that the Isceon 59 formulation has a significantly higher C.O.P. than R22 or R407C under these demanding but not uncommon conditions.

Fig. 2A Refrigeration effect comparison of Isceon 59, R22 and R407C condensing at 40°C.

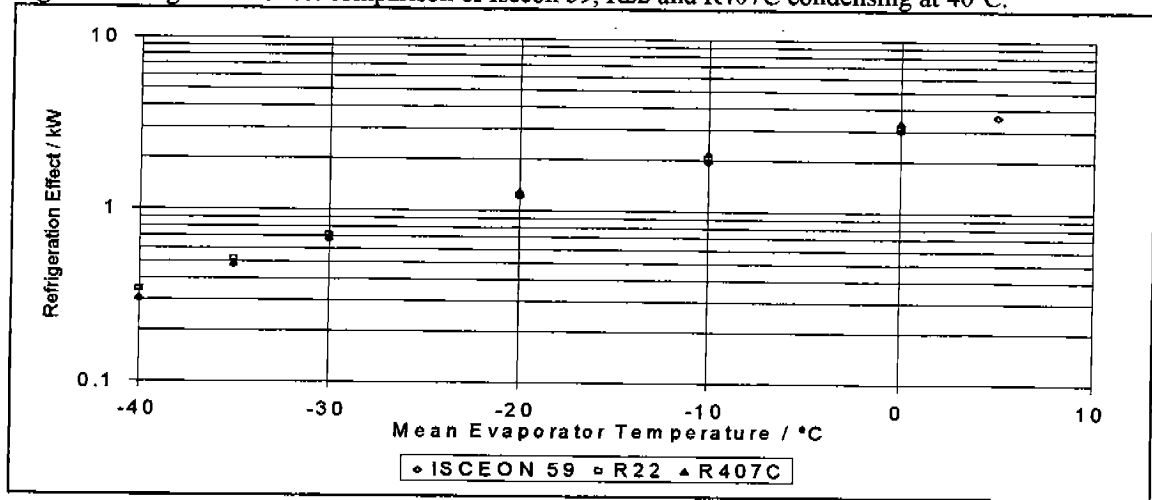


Fig. 2B C.O.P. comparison of Isceon 59, R22 and R407C condensing at 40°C

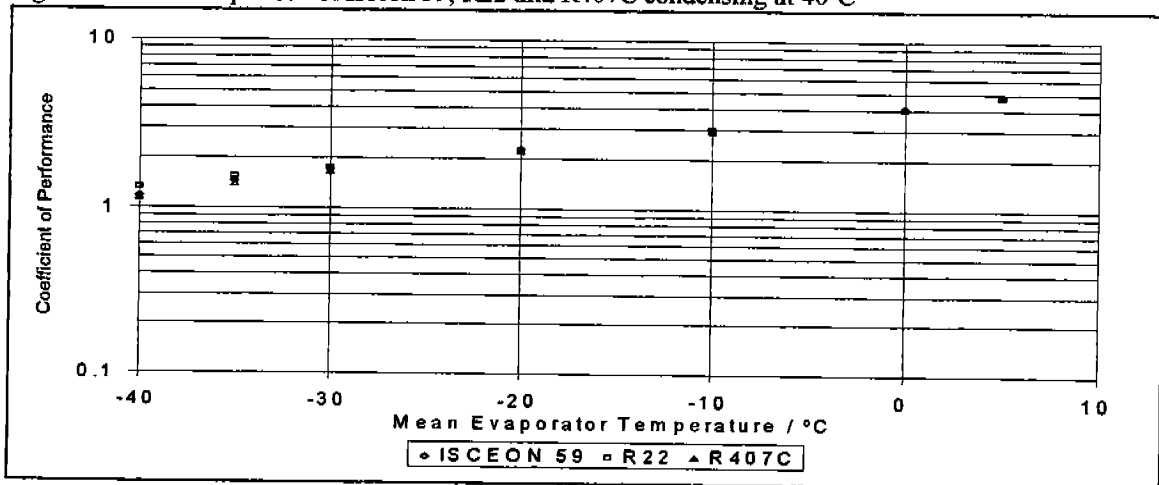


Fig. 3A Refrigeration effect comparison of Isceon 59, R22 and R407C condensing at 55°C

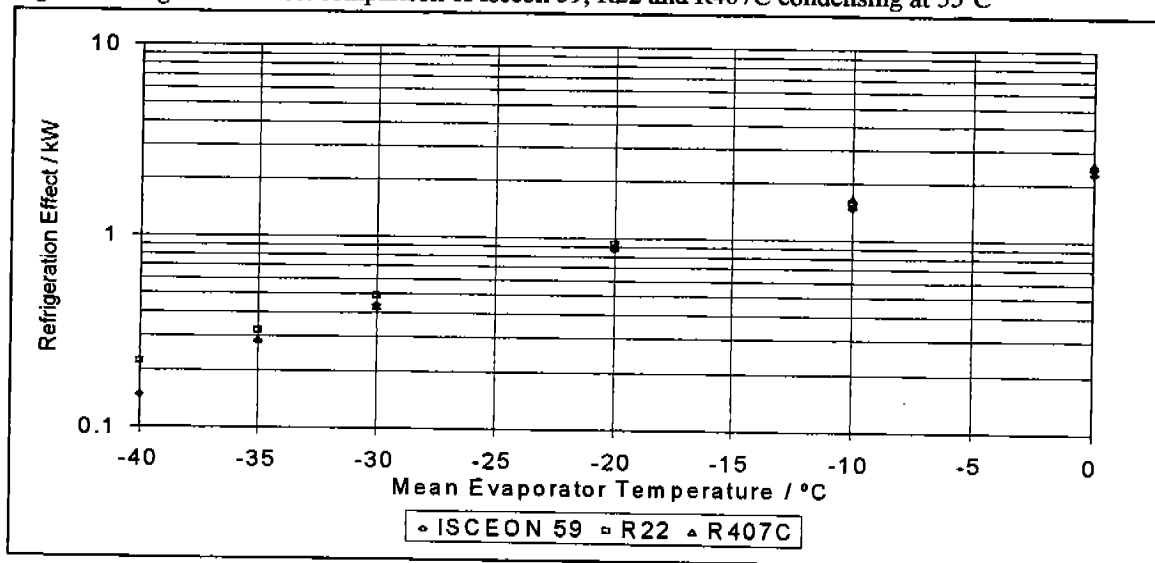
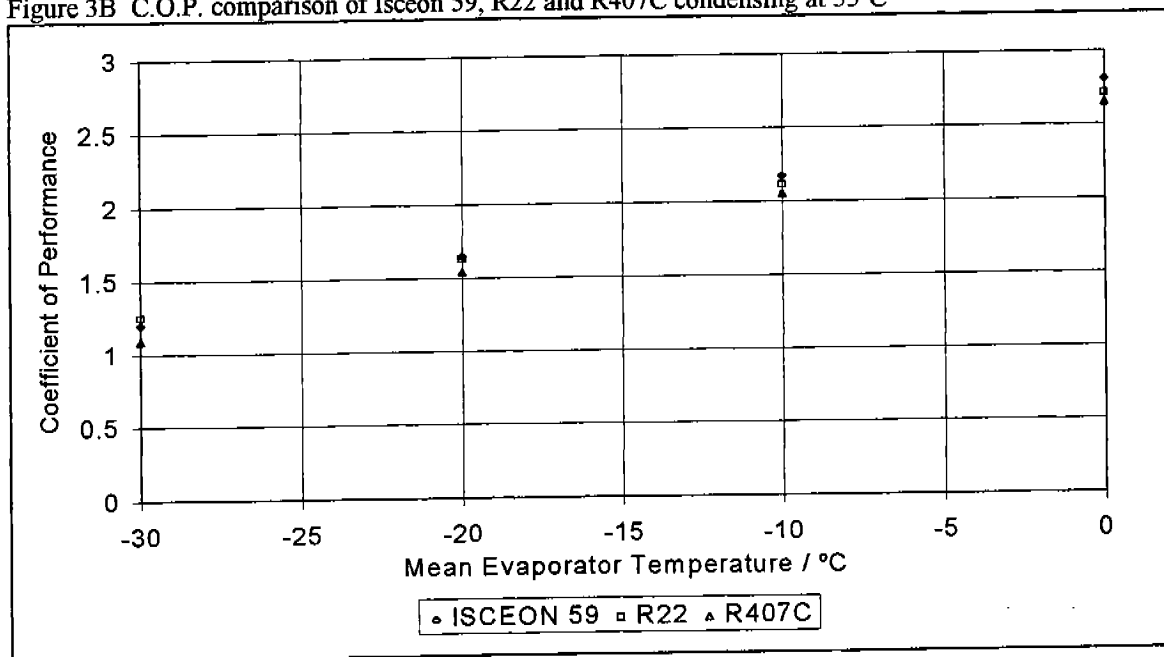


Figure 3B C.O.P. comparison of Isceon 59, R22 and R407C condensing at 55°C



5. CONCLUSIONS

The results from the calorimeter tests show that a blend of R125/R134a/R600a can be used to replace R22 without a significant change in refrigerating effect and an increased coefficient of performance. It has also been shown that using components with a wide range of boiling points need not result in the blend having a large temperature glide.

6. ACKNOWLEDGMENTS

The authors would like to thank the directors of Rhône-Poulenc Chemicals and Star Refrigeration for permission to publish this paper. They would also like to thank Miss Anne Norton, Mr Mike Turner and Mr Paul Shepherd who were instrumental in producing the results.

7. REFERENCES

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