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THE DEVELOPMENT OF CALCULATION TECHNIQUES FOR HFC BLEND – OIL BEHAVIOUR

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ABSTRACT

Industry in the developed world has come to depend heavily on HFC refrigerants, all blends except for R134a. This dependency will increase when the last of the HCFCs, R22, becomes unavailable in the near future. Furthermore, the pressure for increased efficiency combined with reduced running costs and environmental impact is relentless, particularly since the Kyoto Protocol which has had the effect of exposing the HFC to competition from the "natural" refrigerants. The authors responded by searching for better blends by the use of calorimetric testing and mathematical modelling. This paper reports progress and illustrates features of the technique in the evaluation of a binary blend/POE oil combination suitable for centrifugal compressors.

INTRODUCTION

The intention of those who framed the Kyoto Protocol was the achievement of a reduction in man-made global warming. The net result is a threat to the availability of hydrofluorocarbon (HFC) refrigerants, which have high direct global warming indices, all blends apart from R134a. Work since Kyoto on alternatives, the "natural refrigerants", i.e. ammonia, carbon dioxide, air, water, and hydrocarbons, has shown that for some applications the "total equivalent warming index" (TEWI), which takes into account direct effects and indirect effects due to the release of carbon dioxide caused by plant energy consumption, is increased by the use of natural refrigerants due to their inferior thermodynamic performance (Keogh 2002). There are signs that this view is gaining increasing acceptance, very importantly among legislators across a range of countries.

The authors believe that the HFCs will remain in use for a significant period of time and retain a significant share of the refrigeration market. This belief has led to a program of research having the following objectives:

1. the discovery and evaluation of new HFC blends, lower in TEWI than current technology.
2. the provision of information and calculation methods for realistic HFC blend – oil combinations of value to plant designers.

A particular obstacle to HFC blend – oil research is the lack of thermophysical measured data. The authors discuss a method of dealing with this problem with regard to a particular blend which has been proposed for a plant having a centrifugal compressor. The work reported here forms a part of a larger program.

A TECHNIQUE FOR BLEND DEVELOPMENT

The discovery of new HFC blends requires specialized facilities, in particular for the convenient and accurate assessment of trial blends. If calculations are too inaccurate (due usually to the lack of basic thermophysical data rather than the lack of an adequate conceptual model), then performance testing of trial blends is unavoidable. Unfortunately testing is time consuming and expensive. The time for one measurement for example, following a change in the blend composition is determined largely by the time to re-establish steady state conditions in the test equipment. Even in a small calorimeter like that used by the authors having a 3 kW maximum refrigerating effect, one to two hours is required followed by a further one hour of steady state running during which the measurements are made.

The authors took the view that an approach which coordinates the use of relatively simple calculations dependent on available thermophysical data (Yan 2002) with a limited range of measurements, would yield useful results in a shorter timescale. This paper discusses this approach in relation to the evaluation of a binary blend (Pearson 1999) thought suitable for use in centrifugal compressors.

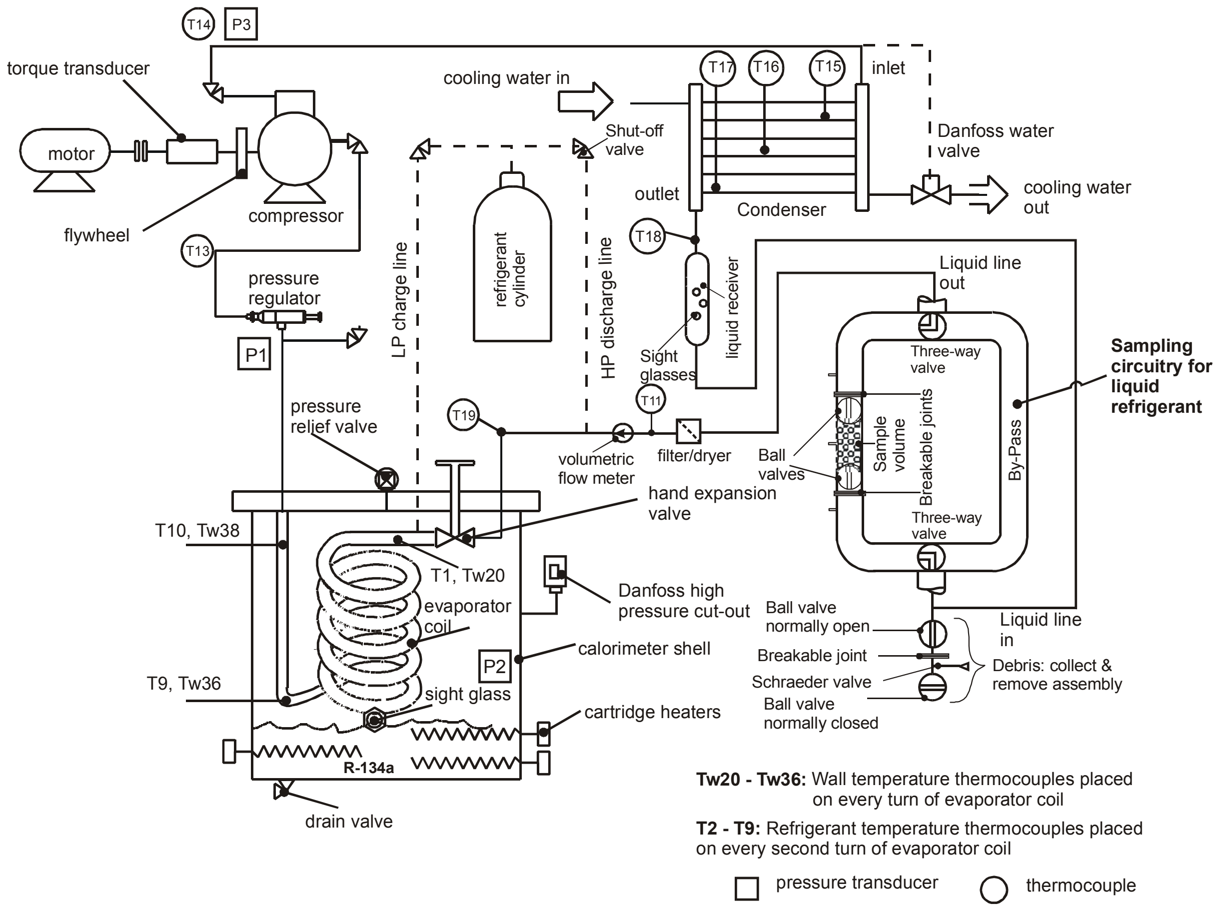

Figure 1: Schematic of test rig

TEST REFRIGERANTS AND TEST CONDITIONS

The test refrigerant is a blend of R134a and R227ea in the proportion 68:32%. It has a pressure-temperature relationship which is similar to that of R12 and a molecular weight of about 117 (close to that of R12 which is 121). It has been shown by Pearson (1999) to be a good candidate as a replacement for R12 in centrifugal systems. For the purposes of checking calculation trends it is compared here with another R134a/R227ea blend, richer in R134a (78:22%) and R134a on its own, as a comparitor fluid.

The properties of the test fluids are listed in Table 1. The 68:32% test blend is a near azeotrope with a glide of only 0.4K at an evaporating temperature of -10^{o}C. In all tests the oil was Castrol Icematic SW46, a polyolester oil.

Tests cover evaporating temperatures from -30°C to 10°C, all at a constant condensing temperature of 40°C. The calorimeter vessel temperature was varied from -20°C ~ 25°C to give a 10K temperature difference between the vessel and the refrigerant inside the coil for R134a and a 15K temperature difference for the blends. Oil concentration was measured for R134a but not for the blends due to insufficient time.

Table 1 Basic properties of the refrigerant/refrigerant blends tested

	R134a	R227ea	R134a/R227ea (68:32 wt%)	R134a/R227ea (78:22 wt%)
Molecular Weight	102.03	170.04	117	112
Normal Boiling Point (°C)	-26.07	-16.35	-25.06	-25.47
Critical Temperature (°C)	101.15	101.9	110.6	110.7
Critical Pressure (bar)	40.67	29.5	44.12	45.36

REFRIGERANT BEHAVIOUR DURING EVAPORATION

The temperatures of the refrigerant and the outside wall of the evaporator tube in the calorimeter were measured during steady state operation and are shown in figure 2 for the blends of R134a/R227ea (68:32 wt%) and R134a/R227ea (78:22 wt%) at an evaporating temperature of 5°C. Belief in the repeatability of the calorimeter measurements, already demonstrated (Fleming 2000), is reinforced by these measurements. The two blends show very similar heat transfer behaviour, which is due to their similar properties (Table 1) and pressure-temperature relationship (Figure 3).

Measured pressure drops are shown in figure 4 for a range of evaporating temperatures. It is interesting to note that the blends give similar results at evaporating temperatures lower than -5°C. When the evaporating temperature increases, the 68:32 blend has a higher pressure drop than the 78:22 blend. Compared with R134a both blends have a slightly higher pressure drop at the same working condition, which may result from the mixing resistance between the two components of the blend during the evaporation process.

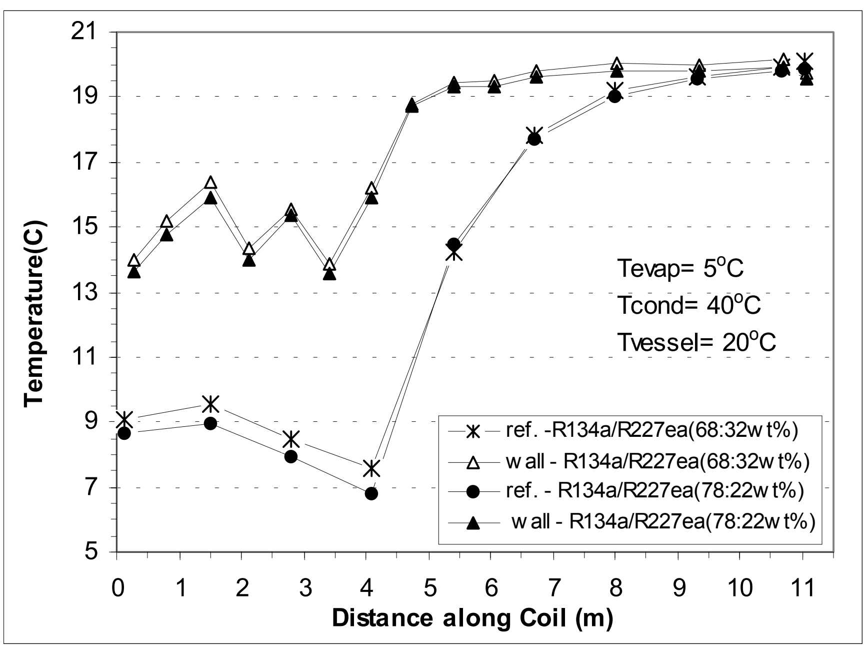

Figure 2: Temperature profile compared for R134a/R227ea (68:32wt%) and R134a/R227ea (78:22wt%)

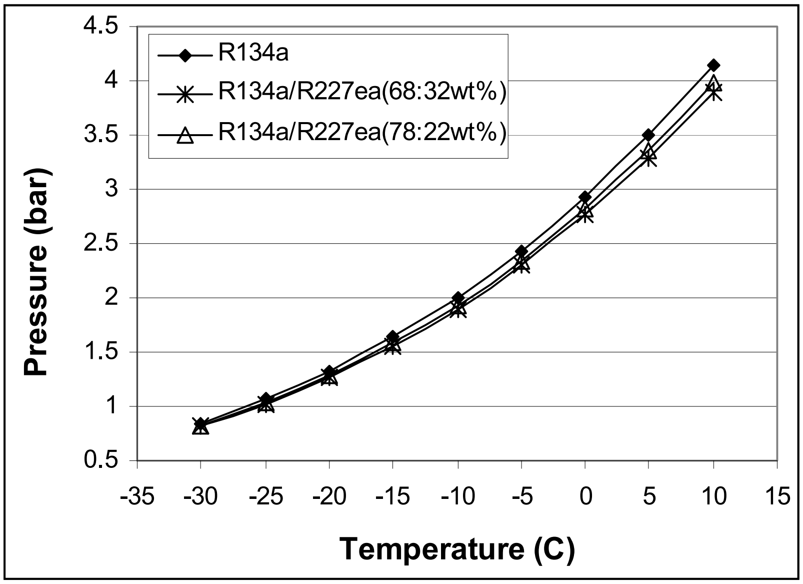

Figure 3: Pressure-temperature relationships from REFPROP for zero oil presence

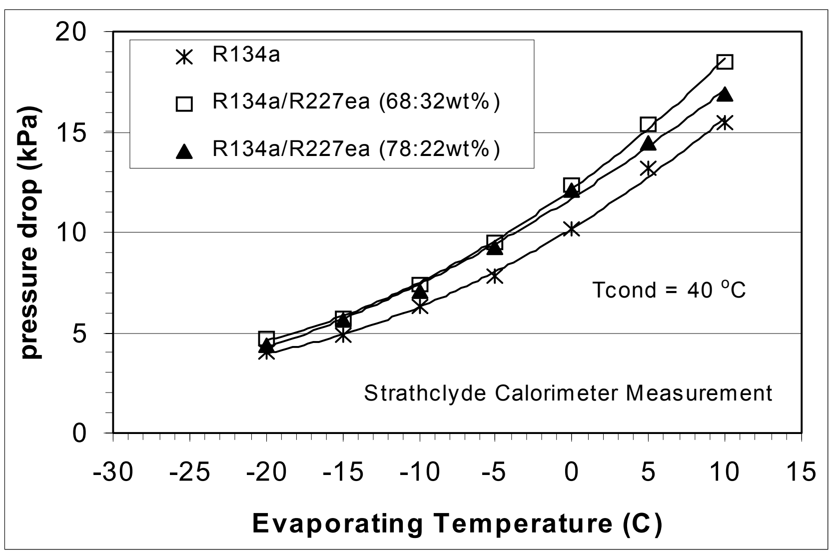

Figure 4: Measured evaporator pressure drop

The friction pressure drop in the evaporator obtained by subtracting a calculated value of the acceleration pressure drop from the measured total pressure drop was used to determine the two-phase friction factor as given by Equation (1). Friction factors determined thus for all three test refrigerants were plotted against Reynolds number as shown in figure 5.

Equation (2) was obtained by fitting a curve to the data for both blends and R134a combined which gives an indication of the error incurred by making use of an equation derived for one refrigerant to do calculations for another. The same equation fits the R134a results on their own. Hence calculations of pressure drop are likely to be accurate for R134a and but poorer for the 68:32 blend with the 78:22 blend being in between, as expected.

$$\frac{(\Delta P)_{fr}}{l} = \frac{2f\,G^2}{\bar{\rho}d} \tag{1}$$

$$f = 0.24\,\mathrm{Re}_{L,m}^{-0.21} \tag{2}$$

where $(\Delta P)_{fr}$ is the friction pressure drop during the evaporation, l is the evaporator tube length, G is the mass flux, d is the evaporator tube diameter, $\bar{\rho}$ is the mean density of the two-phase flow, f is the two-phase friction factor, and $\mathrm{Re}_{L,m}$ is the Reynolds number calculated with use of the properties of the liquid refrigerant-oil mixture.

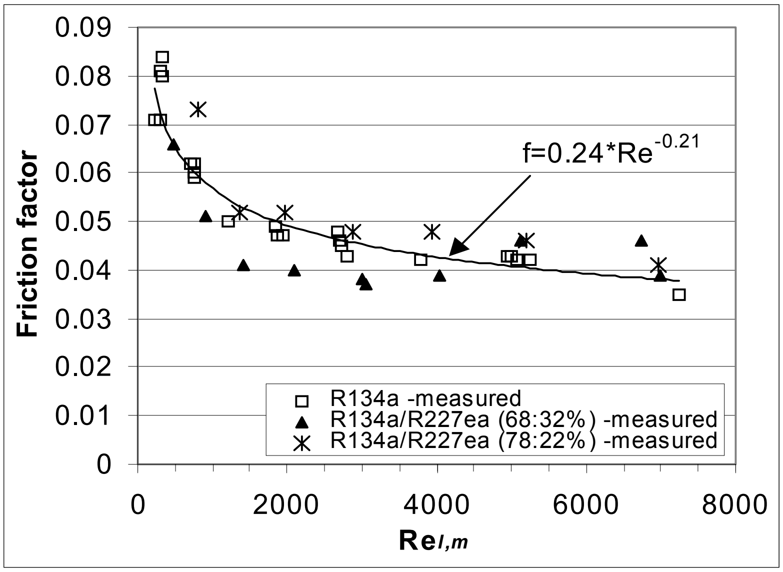

Figure 5: Friction factor

CYCLE PERFORMANCE

The cycle performance of R134a and both blends were evaluated in terms of refrigerating capacity, compressor power and COP. Figures 6 and 7 compare the results for the blends. They have nearly identical refrigerating capacity, with the 78:22 blend slightly superior to the 68:32 blend. At all test conditions the overall performance of the 78:22 blend is slightly better than that of the 68:32 blend when comparing their compressor power and COP, which reflects the good performance of R134a. As a consequence, both blends are inferior in efficiency though not greatly, to R134a. For example, at an evaporating temperature of 0°C, R134a can achieve 1.9kW refrigerating capacity, while to 68:32 blend can only achieve 1.7kW, 9.5% less than that of R134a. At the same condition the COP of R134 is 3.41, while the COP of the 68:32 blend is only 2.89. However, it should be born in mind that the 68:32 blend was created for a centrifugal compressor. Testing it in a calorimeter with a positive displacement compressor could give an unrealistically low impression of its thermodynamic efficiency. In fact Pearson (1999) has shown that in a centrifugal plant its efficiency is competitive.

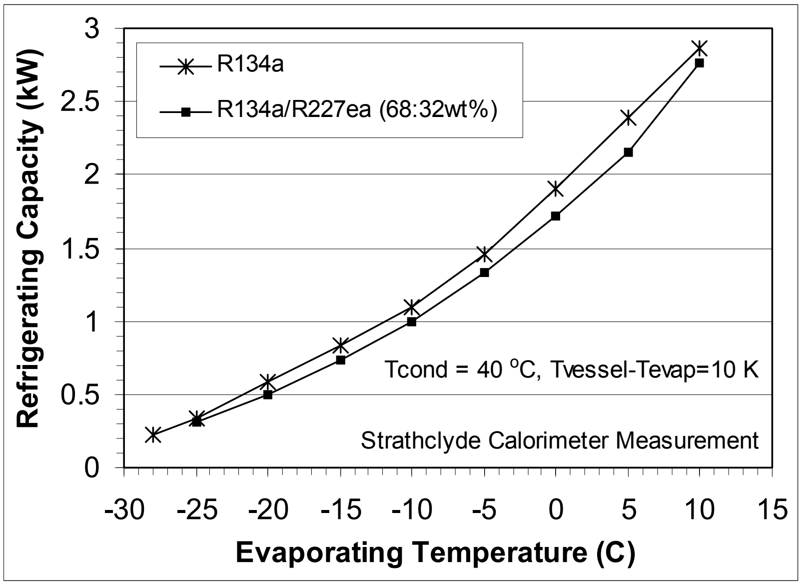

Figure 6: Refrigerating capacity of R134a/R227ea (68:32wt%) and R134a compared

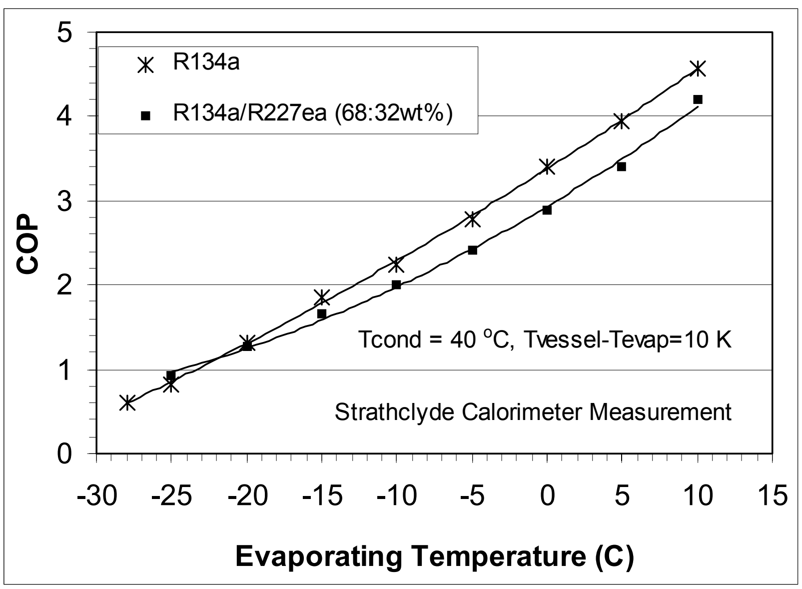

Figure 7: COP of R134a/R227ea (68:32wt%) and R134a compared

OIL CONCENTRATION AND ITS INFLUENCE ON PRESSURE DROP

The oil concentration in the liquid refrigerant (here it is defined as the mass ratio of the oil to the total refrigerant and oil sampled in the test) was determined by use of a test assembly (shown in figure 1), which is installed between the liquid refrigerant receiver and the expansion valve, where the refrigerant is slightly subcooled liquid. The measurements of oil concentration were conducted for R134a only. The mass flux measured in the liquid line before the expansion valve varied from about 20 to 105 kg/(m^2s). The measurements showed that the oil concentration increased with decreasing mass flux and evaporating temperature. Figure 8 is derived from these measurements. This phenomenon is believed to be the result of the flow regime associated with low mass flux and high fluid viscosity at low temperature. Low mass flux increases the likelihood of the flow becoming stratified, thus causing the refrigerant and oil to separate from each other, an effect enhanced by the low temperature which increases the difference between the viscosities.

The presence of oil has two consequences of importance: (1) For the evaporator; as the quantity of liquid refrigerant decreases due to loss by evaporation the mass ratio of oil to liquid refrigerant increases, which inhibits the evaporation of the last traces of liquid refrigerant. (2) For the compressor; due to the retention of oil in the evaporator a smaller quantity of oil is available in the compressor to perform its primary function.

Efforts have been made by the authors to determine a dimensionless correlation for use in an evaporator mathematical model (which requires the oil concentration at the entry of the evaporator) to reduce the number of measurements because relying solely on measurements is very time-consuming. Reynolds number was used in this study and fitted to the measured data shown in figure 8 by making use of the function:

$$Woil = a\,\mathrm{Re}^{b}$$

where *Woil* is the percentage oil concentration. For the R134a and POE SW46 mixture the constants are a = 299.6 and b = –1.256. The Reynolds number, Re, is calculated for the liquid refrigerant-oil mixture. The authors believe that the curve fit is generally satisfactory especially when the difficult nature of the oil mass ratio measurement is taken into consideration. The technique of calculating evaporator pressure drop for a blend taking into account the presence of oil is addressed elsewhere (Yan 2002) and is part of the broader program of work of which the work reported here is a part.

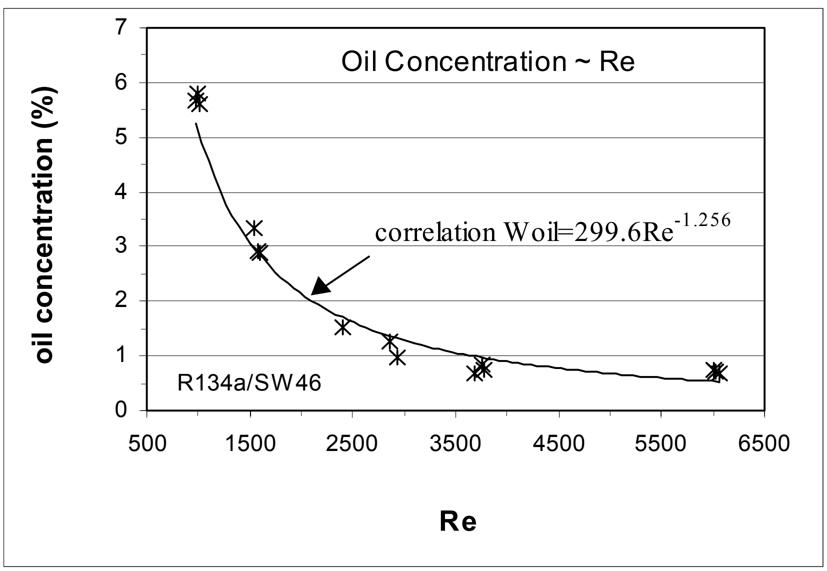

Figure 8: Oil concentration vs. Re (R134a/SW46)

CONCLUSION AND REMARKS

This paper discussed the necessity of continuing HFC research, which is against a background of opinions and possible legislation unfavourable to HFCs. Experimental work of the authors is discussed, which aims at evaluating HFC blend performance by use of an extensively instrumented secondary refrigerant calorimeter. Results are given for a binary blend R134a/R227ea in a mass fraction of 68:32% and compared with results for a 78:22% blend and R134a for a range of evaporating conditions. The experimental work is a part of a larger program of work of the authors on HFC research. Mathematical work, which aims at complementing the experimental work by means of predicting pressure-temperature relationships with particular regarding to the oil influence, evaporator pressure drop and heat transfer, and compressor performance, is in process and may be published at a later date.

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