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TRIALS WITH ZEOTROPIC REFRIGERANTS AS REPLACEMENTS FOR R-22 IN AN INSTRUMENTED GLYCOL/WATER CHILLER.

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ABSTRACT

A large number of measurements taken from an instrumented glycol/water process chiller are summarized for R-22 and a number of zeotropic refrigerant blends. The range of materials used in the study includes 2 zeotropic binary blends of R-32/R-134a, 30/70wt/wt and 25/75wt/wt, and 2 zeotropic ternary blends of R-32/R-125/R-134a, 30/10/60wt/wt and 23/25/52wt/wt. The information covers the evaporator temperature range -20C to +5C and condenser range 27C to 41C. Results include COP, capacity and discharge temperature for the chiller running on R-22/mineral oil and HFC refrigerant blend/polyolester lubricant combinations. Over the temperature range of test, the HFC blends show comparable COP and capacity to R-22 while exhibiting lower discharge temperatures.

INTRODUCTION

The Montreal Protocol was revised and considerably strengthened at a meeting of the United Nations Environment Program on November 25, 1992. The Protocol accelerated the phaseout dates for the production of CFCs to January 1, 1996 from January 1, 2000. The European Community (EC) will phaseout CFCs one year earlier. In addition, for the first time, HCFCs, such as R-22, are also regulated with a complete phaseout by the year 2030. It is not unrealistic to expect that the Montreal Protocol will also accelerate the HCFC-phaseout schedule.

With the ever increasing pressure to move the HCFC phase-out schedule forward, comes an urgency to find suitable replacements. The wide spread application of R-22 poses a challenge to both meet the environmental regulations while still fulfilling the technical requirements of industry. The objective of this paper is to evaluate the performance of four possible zeotropic, HFC alternatives to R-22 in a glycol/water process chiller.

EQUIPMENT

Zeotropic refrigerant compositions from three constituent materials, R-32, R-125 and R-134a were chosen for evaluation against R-22 due to their thermodynamic similarity to R-22.

The following blends were used for this evaluation:

- R-32/R-134a (30/70 wt/wt): referenced as "30/70" in the text,
- R-32/R-134a (25/75 wt/wt): referenced as "25/75" in the text,
- R-32/R-125/R-134a (30/10/60 wt/wt): referenced as "30/10/60" in the text,
- R-32/R-125/R-134a (23/25/52 wt/wt): referenced as "23/25/52" in the text.

The lubricant originally used in the compressor with R-22 was an ISO 32 mineral oil. This was later retrofitted to an 32cSt polyolester based lubricant (POE). All performance measurements with the HFC refrigerants were taken with the POE lubricant. The compressor employed in the chiller is a Bitzer Type 4P (open) running at 970 RPM. The swept volume of the compressor is 47 m^3/hr at 1440 RPM. The evaporator is a two pass Hall Thermoking 'hairpin' type shell and tube evaporator with the refrigerant on the tube-side. The condenser is a Bitzer shell and tube type K 651 H with refrigerant on the shell-side and water on the tube-side. The accumulator was a type AC/R S7613.

TREATMENT OF RESULTS

Approximately 450 data points were generated for R-22 and the four HFC refrigerants under examination. Not all of the data could be used in the analysis due to the wide range of operating conditions evaluated for each refrigerant. In order to make as much use of the raw information as possible, and achieve a comparable measure between the blends and R-22, many of the data points were recalculated to standard conditions of evaporator and condenser temperature. Superheat and subcooling are expressed relative to the appropriate mid point temperatures of the condenser and evaporator. Temperatures quoted for the condenser correspond to the mid point for each refrigerant, (arithmetic mean between dew and bubble point). Evaporator temperatures are the arithmetic mean of the evaporator inlet temperature and the dew point at the corresponding evaporator pressure.

EXPRESSION OF RESULTS

COP and capacity were selected to compare the performance of the blends against R-22. For COP, the situation most applicable to the units service conditions (process cooling) is a fixed evaporator temperature with variable condenser temperatures (ambient conditions). Performance of the blends against R-22 is also important for fixed condenser, variable evaporator, since this takes account of different process cooling application requirements. Both situations have been examined in this study.

RESULTS

Figure 1 shows comparative performance between R-22/mineral oil and R-22/POE. The figure shows that replacement of the mineral oil with an appropriate ester-based lubricant has no detrimental effect on the performance of the refrigeration system.

Figures 2 compare the performance of R-22 with the three refrigerants at constant evaporator temperature (-10C) and variable condenser temperature. The characteristic curve of COP against condenser condition (constant evaporator), represents the variation in performance with ambient conditions for a particular set-temperature process cooling. Typical scatter for most of the data points is approximately +/-4%. This resolution is on the same order as the resolution in cooling capacity measurement from which the COP figures were derived. The 'best-fit' correlations illustrate both the relative performance with R-22 and the insensitivity of performance to HFC blend composition.

Figure 3 compare R-22 and the two ternary blends "30/10/60" and "23/25/52" under constant condenser temperature conditions (+30C) over a range of evaporator temperatures. COP values for the ternary refrigerants are comparable with those for R-22.

Figure 4 compares the refrigeration effect (capacity) for R-22 and the two ternary blends. The results indicate that under these test conditions, the capacity of the blends is comparable to R-22.

Figure 5 shows the compressor discharge temperature in relation to inlet temperature, ie delta T, for R-22 and three of the zeotropic refrigerants. At the same pressure ratio the discharge temperature is approximately 10C less for the blends than for R-22.

DISCUSSION

Evaporator Design - Effect on COP

If all of the data points acquired during this testing were used to assess the performance of the zeotropic blends, the graph of COP versus condenser temperature (for a constant evaporator temperature) would show a high degree of scatter. For example, at the same condenser temperature some of the COP measurements showed differences amounting to 20%. This can be seen most easily in Figure 2 for the binary refrigerant "30/70" at the 37C condensing temperature region.

The major influence on COP is the refrigeration effect (as measured) from a heat balance on the glycol/water at inlet and exit of the evaporator. At any particular set of conditions variations in the refrigeration effect contribute directly to the scatter above. Analysis of individual values highlighted that on some test runs the refrigerant temperature at the inlet of the compressor was below that at the exit of the evaporator. This suggested additional evaporation outside the heat exchanger. In addition, subsequent examination of the chart recorder trace also indicated an onset of instability at low superheat (below 10C approximately). In effect, refrigerant leaving the evaporator at superheat values lower than 10 C contained sufficient entrained liquid droplets which would later evaporate between the evaporator exit and the compressor suction causing a reduction in refrigeration effect.

An attempt to separate the 'liquid carryover' data points from the 'complete evaporation data points is shown in Figure 6. It is interesting to note that the evaporator used in these tests allows the refrigerant to pass only twice through the unit (a single U-tube). It is believed that such a heat exchanger design is inappropriate for the application and that a different heat exchanger with a greater degree of engagement between liquid and vapor would yield better results for both the pure and zeotropic refrigerants.

For completeness, not all liquid carryover data has been excluded from the analysis. It is proposed that the +/-4% scatter band in much of the remaining data is a combination of both the precision of the measurement instruments and incomplete evaporation.

Cooling effect was determined from a heat balance on the water/glycol passing through the evaporator. Typical temperature drops through the evaporator were 3C with the resolution on temperature measurement of 0.1C (3%). Motor power was determined principally from measured motor amps and line voltage, expressed as power, typically 6KW to 7KW with resolution 0.1KW ie 1.5%.

Capacity

Figure 4 shows the refrigeration effect for both ternary blends and R-22. This figure indicates that R-22 and the HFC blends have comparable capacity at the conditions specified.

Compressor Discharge Temperature

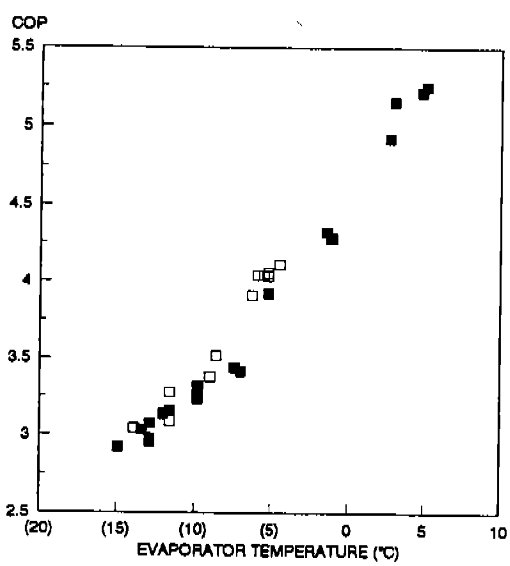
Results for discharge temperature variation with compressor inlet temperature were measured directly by thermocouples. The measurements were taken external to the cylinder head at entry and exit of the unit. Figure 5 illustrates that at a given pressure ratio the discharge temperature for the HFC refrigerants is lower than for R-22. Although the differences in temperature are appreciable, a more realistic comparison should take into account the differences in pressure ratio between the refrigerants.

SUMMARY OF RESULTS

Approximately 450 data points have been gathered from an instrumented glycol/water chiller system. Comparisons between R-22 and a number of HFC binary and ternary refrigerants have been made. Four refrigerant blends based on R-32, R-125 and R-134a have been examined over a wide range of conditions. These include constant evaporator temperature (variable ambient) and constant condenser (variable process cooling).

At the same test conditions the replacement refrigerants (HFC's) are comparable in COP and cooling capacity to R-22. The data further supports that compressor discharge temperature is lower for the HFC alternatives than for R-22. This is a particularly encouraging result since one of the drawbacks to the use of R-22 is its high discharge temperature under certain conditions. The binary refrigerants "30/70" and "25/75" compare well with the ternaries "30/10/60" and "23/25/52" in terms of COP, indicating that over the range of conditions tested, blend composition is not critical to performance in this particular application.

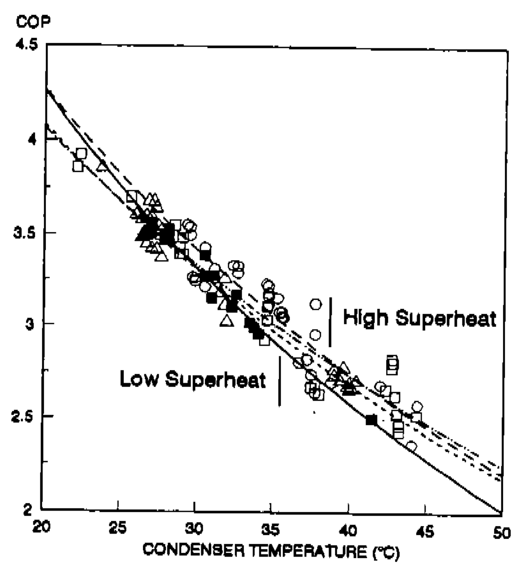
The results of this work demonstrate the technical viability of these HFC refrigerants as alternatives to R-22. This has led to various programs with these HFCs including field trials, retrofits and new installations using the ternary blends. Detailed evaluations of that work is beyond the scope of this document. In addition, further work is underway to extend the usage of zeotropic refrigerant to lower operating temperatures. Work is also planner for these refrigerants in flooded systems.



R22/ MIN. OIL   R22/ POE

15°F SUBCOOLING, 20°F SUPERHEAT
30°C CONDENSER TEMPERATURE

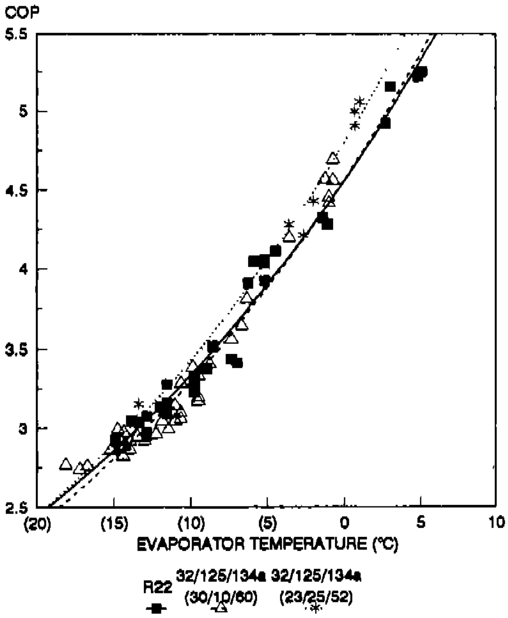
Figure 1



R22   32/125/134a (30/10/60)   32/134a (30/70)   32/134a (25/75)

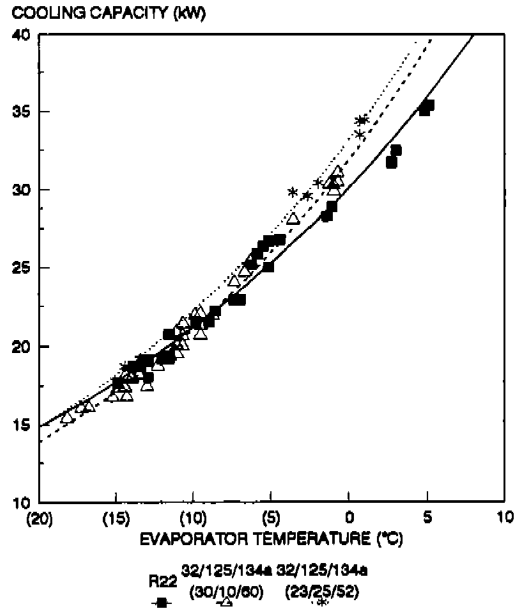
15°F SUBCOOLING, 20°F SUPERHEAT
-10°C EVAPORATOR TEMPERATURE

Figure 2



15°F SUBCOOLING, 20°F SUPERHEAT
30°C CONDENSER TEMPERATURE

Figure 3



15°F SUBCOOLING, 20°F SUPERHEAT
30°C CONDENSER TEMPERATURE

Figure 4

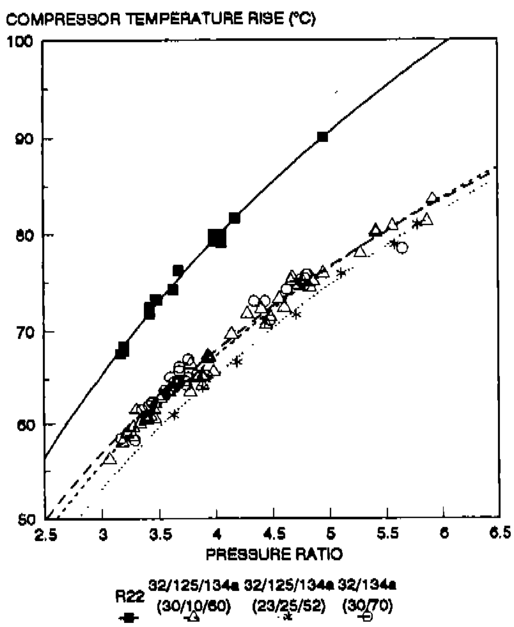
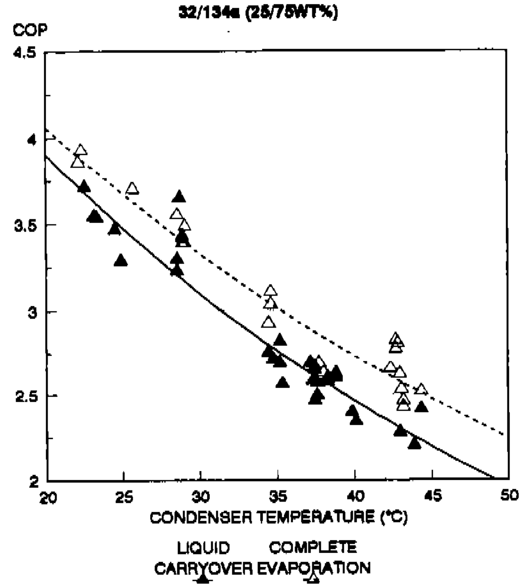


Figure 5

EFFECT OF INCOMPLETE EVAPORATION ON 32/134a (25/75WT%)



15°F SUBCOOLING, 20°F SUPERHEAT
-10°C EVAPORATOR TEMPERATURE

Figure 6