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CFC-FREE REPLACEMENTS FOR R-503

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ABSTRACT

R-503 is an azeotropic mixture of CFC-13 and HFC-23. It is widely used in low temperature cascade refrigeration systems. Due to the ozone depletion effects of the CFCs including CFC-13, R-503 production has been banned. An environmentally acceptable nonflammable replacement for R-503 is needed with refrigeration properties similar to R-503.

We describe azeotropic mixtures containing HFC-23 as possible replacements for R-503. We have identified the azeotropic composition and have measured the basic properties needed for the performance evaluation of these mixtures as refrigerants. These properties are compared with those of R-503. We also compare the environmental properties of these refrigerants.

We provide the preliminary equations-of-state for the two mixtures reported here. The equations are used to compute refrigeration properties of these fluids in a typical cascade cycle operating at low temperature.

INTRODUCTION

The phase out of R-503, an azeotrope of 60 wt% R-13 and 40 wt% R-23 was completed at the end of 1995. This refrigerant has traditionally been used in specialized low temperature cascade systems, with evaporator temperatures usually between -100 and -130°F. Till recently only HFC-23 was considered as a replacement but its discharge temperature, especially during pull down conditions is unacceptably high. More recently R-508 series of refrigerants have been proposed in this application. These are mixtures of HFC-23 and FC-116 and are stated to be azeotropic in nature. We have carried out thermodynamic measurements on one of these refrigerants (R-508B) and on another proposed mixture, a ternary azeotropic mixture of HFC-23, FC-116 and R-744 (carbon dioxide). We report on these measurements, provide Matin-Hou equation-of-state coefficients and compare performance characteristics of the two mixtures in typical R-503 cascade applications.

THERMODYNAMIC PROPERTIES

The samples of R-508B (46 wt% HFC-23, 54 wt% FC-116) and that of the ternary azeotrope (42 wt% HFC-23, 43 wt% FC-116 and 15 wt% carbon dioxide) were prepared by gravimetric additions of at least 99.8% pure components and were degassed by freeze-and-thaw techniques thoroughly. The vapor pressure measurements were done using a pressure transducer accurate to ±0.5 psia in a bath thermostatically controlled to ±0.1°C. The critical temperature was measured in a sealed glass tube visually by noticing the appearance and disappearance of the maniscus and the critical opalascence. The liquid density was measured using the calibrated glass bead method. The experimental details may be found elsewhere in our earlier publications on measurements on HFC-32/HFC-125 and HFC-125/HFC-143a systems[1],[2].

The data was then fitted into the Martin-Hou equation of state, the most common e.o.s. used in the refrigeration industry. The thermodynamic constants, the coefficients for vapor pressure equation, the liquid density equation and the constants of the e.o.s. are all listed in the tables at the end of the paper in I-P units. These data are availble from the authors upon request in SI units also.

CASCADE PERFORMANCE MODELING

The performance of R-508B and the ternary mixture as refrigerants in the low stage of a cascade cycle were assessed using a computer model based on the Martin-Hou equation-of-state developed and reported above. This model allows analysis of a theoretical vapor compression cycle consisting of constant pressure evaporation, compression using variable efficiency compressor, constant pressure condensation and adiabatic expansion. The following table compares the result of this performance modelling for CFC-13, R-503, HFC-23, R-508B and the ternary mixture. The data for CFC-13, R-503 and HFC-23 came from the ASHRAE Thermodynamic Properties of Refrigerants book.

R-13/503 Alternatives Thermodynamic Cycle Calculations

Condition: -100°F Evaporating; -30°F Condensing
150°F Superheat (10°F Useful); 10°F Subcooling; 60% Compr. Eff.

	R-13	R-503	R-23	R-508B	23/116/CO2
Suction Press. (psia)	22.3	31.6	23.7	30.4	31.5
Discharge Press. (psia)	106.3	147.5	125.9	147.2	158.2
Compression Ratio	4.77	4.67	5.31	4.84	5.02
Discharge Temp. (°F)	223	242	288	212	239
Relative Capacity (%)	100%	138%	118%	132%	144%
Relative Mass Flow Rate	100%	119%	71%	125%	108%
Relative COP	100%	97%	99%	97%	98%
Freezing Point	<-200°F	<-200°F	<-200°F	<-200°F	-140°F

This analysis indicates that the ternary azeotropic mixture may offer improved capacity and slightly higher efficiency (COP) while matching other performance characteristics of R-503. However, the discharge temperature and compression ratio of the ternary blend are somewhat higher than R-508B and the freezing point is also slightly higher.

COMPARATIVE ENVIRONMENTAL CHARACTERISTICS

The following table gives the GWP for R-508B and the ternary mixture calculated on the basis of the 1995 IPCC report.

Mixture	Composition wt%	GWP 100 yr horizon	GWP 500 yr horizon
R-508	46/54	10,350	12,070
23/116/CO2	42/43/15	8,870	10,140

This shows that, as expected, the ternary refrigerant has better environmental properties than R-508B. Differences in energy efficiency will also be an important contribution in comparing environmental impact, which can be determined from Total Equivalent Warming Index (TEWI) calculations when actual system performance data are developed in the future.

SUMMARY AND CONCLUSIONS

The commercial blend R-508B shows good promise as a R-503 replacement, but it has lower capacity. The ternary blend has better capacity and efficiency than R-508B, but also has higher compression ratio and discharge temperature. The latter is comparable to R-503. The ternary blend also has better environmental characteristics than R-508B. Thus it is difficult to recommend at this stage a single refrigerant for all purposes. Both the binary and the ternary azeotropes appear to present viable options to cascade refrigeration engineers, who are looking for R-503 alternates. The choice of which refrigerant to select as R-503 replacement will depend on the design requirements and application of the low temperature refrigeration system.

ACKNOWLEDGEMENTS

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REFERENCES

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[1] E.A.E. Lund, I.R. Shankland & R.R. Singh,, **R-32/R125 : an azeotropic refrigerant**, Proceedings of the International CFC-Halon Alternatives conference, October 1991

[2] E.A.E. Lund, I.R. Shankland & R.R. Singh,, **A R-502 replacement: R-143a/R125**, Proceedings of the International CFC-Halon Alternatives conference, October 1992

THERMODYNAMIC CONSTANTS

	R-508B	**23/116/CO2**
Tc (F)	56.66	60.44
Pc (psia)	571.02	660.45
ρc (lb./cu./ft.	36.81	35.38

VAPOR PRESSURE EQUATION

$$\log(Pvap / Pc) = -\phi(Tr) - (\alpha c - 7)\psi(Tr)$$

$$\phi(Tr) = 0.118\varphi(Tr) - 7\log(Tr)$$

$$\psi(Tr) = 0.0364\varphi(Tr) - \log(Tr)$$

$$\varphi(Tr) = 36 / Tr + 42\ln(Tr) - 35 - (Tr)\text{^}6$$

αc(508B)=7.05863572

αc(23/116/CO2)=7.13104470

LIQUID DENSITY EQUATION

$$\rho(lb\,/\,cu.\,ft.) = \rho c + \sum_{i=1}^{4} D_i(1-T_r)\hat{}\,(i/3)$$

	R-508B	23/116/CO2
D1	0.6362836E+2	0.6115604E+2
D2	0.2852898E+2	0.2742047E+2
D3	0.0000000E+0	0.0000000E+0
D4	0.5707277E+1	0.5485517E+1
ρc	0.3681318E+2	0.3538278E+2

MARTIN-HOU COEFFICIENTS

$$P = \frac{RT}{v-b} + \sum_{i=2}^{5} \frac{A_i + B_i T + C_i \exp(-KT_r)}{(v-b)\hat{}\,i}$$

P(psia), v(cu.ft./lb), T(R), T=T/Tc

R-508B

R=0.112514
b=0.539617257E-02
K=5.475

i	Ai	Bi	Ci
2	-0.311256224E+1	0.1958252971E-2	-0.6415806205E+2
3	0.1079066602E+0	-0.1281491673E-3	0.1618696600E+1
4	-0.2988350963E-3	0.0000000000E-0	0.0000000000E+0
5	-0.5376578439E-5	0.1526163943E-7	-0.1052440954E-3

23/116/CO2

R=0.134413
b=0.561432024E-02
K=5.475

i	Ai	Bi	Ci
2	-0.3899341462E+1	0.2438005508E-2	-0.8027673382E+2
3	0.1406393843E+0	-0.1658532745E-3	0.2107246197E+1
4	-0.6760763792E-3	0.0000000000E-0	0.0000000000E+0
5	-0.7593104535E-5	0.2138555944E-7	-0.1483099454E-3