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THE APPLICATION OF NON-AZEOTROPIC REFRIGERANT MIXTURES IN TWO TEMPERATURE REFRIGERATORS

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1. INTRODUCTION

The application of non-azeotropic refrigerant mixtures seems to be a possibility to improve the energetic performance of two-temperature refrigerators. The possible increase of the average evaporation temperature results in a decrease of exergy losses especially in the main compartment evaporator. A problem of interest is the suitable choice of the mixture components for this application. Up to now there is a lack of information concerning thermodynamic data(p,v,T,x) of refrigerant mixtures. Theoretical investigations led to two non-azeotropic refrigerant mixtures which are worthwhile to examine: R22/R114 and R13B1/R114. The potential of improvement had been shown by Lorenz and Meutzner /1/, who proposed a cycle with two internal heat exchangers with a decrease of an energy consumption of about 20% for a mixture of R22/R11 in comparison to the conventional cycle with R12. Stoecker /2/ published a simulation model of this cycle and carried out calculations for the mixture R12/R114. He assumed ideal behavior (laws of Raoult and Dalton) for the vapor-liquid-equilibria (VLE) calculations. The result was an improvement of COP of about 12% as compared to pure R12. Practical measurements did not confirm this results of the simulation /3/, when trying to keep the refrigeration capacity constant for all tests. With an increase of the concentration of the less volatile component the volumetric refrigeration capacity deteriorates. Therefore in the experiments an increase of the compressor speed was necessary, which caused problems for the compressor because of a decrease in volumetric and isentropic efficiency.

In this work the simulation model of Stoecker was improved by the application of an equation of state (Redlich-Kwong-Soave) for VLE- and thermodynamic data calculation. For the mixture R13B1/R114 no information about thermodynamic data was available. Therefore VLE-measurements had been carried out. As for the system R22/R114 the data of Hackstein /4/ were used to adapt the equation of state. Further, own R22/R114 measurements are carried out now. Besides computer simulations practical results will be dealt with in the paper.

2. VLE-MEASUREMENT AND CALCULATION FOR R13B1/R114

VLE- measurements were carried out for 5 isotherms in the temperature range of -30°C up to 50°C. The test facility has already been described in /5/. The results of the thermodynamic consistency tests indicate that the data of this work are consistent.

VLE- calculations were carried out by means of the Redlich-Kwong-Soave (RKS) equation of state. The equation as well as the applied mixture rules and VLE- calculations for the system R22/R114 were given in /6/. The constants for the RKS- equation are given in table 1.

Figure 1 illustrates the measured data and the calculated bubble point and dew point lines. The mixture rules include a binary interaction parameter k_{ij} which was adapted to measured data by minimization of measured and calculated pressures. For all five isotherms the optimum value was found to be $k_{ij}=0.011$. The figure shows a slight temperature

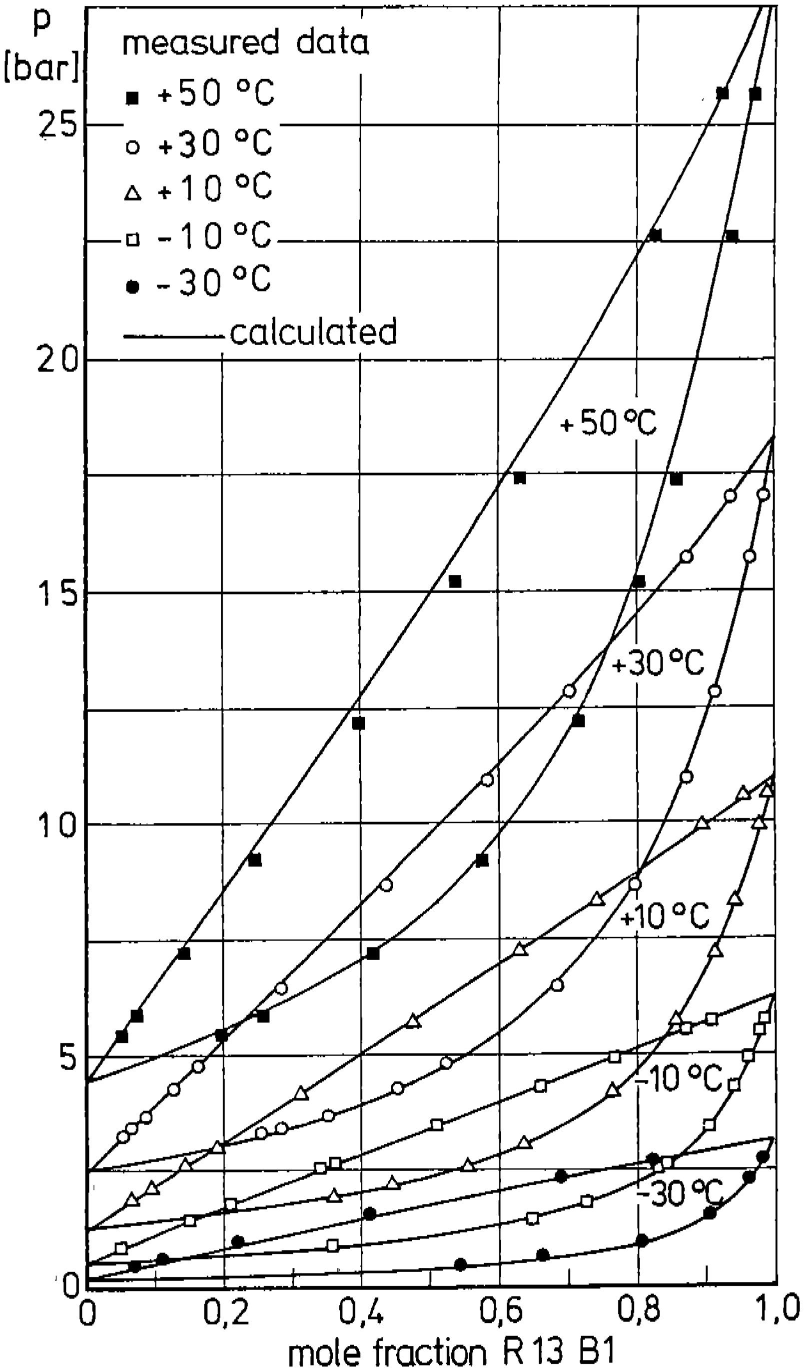

Figure 1 : pressure - mole fraction diagram for the system R13B1/R114

dependency of the interaction parameter. The average error between experimental and calculated bubble point pressures is 1.45%.

Table 1 : parameters for the RKS-equation of state

	T_c (K)	p_c (Mpa)	m (-)	n (-)
R13B1	340.15	3.98	0.6209	0.1684
R114	418.85	3.26	0.6420	0.2577

3. SIMULATIONS AND PRACTICAL TEST RESULTS

Figure 2 shows a scheme of the examined refrigeration cycle. The cycle includes two evaporators and two internal heat exchangers, as proposed by Lorenz and Meutzner /1/.

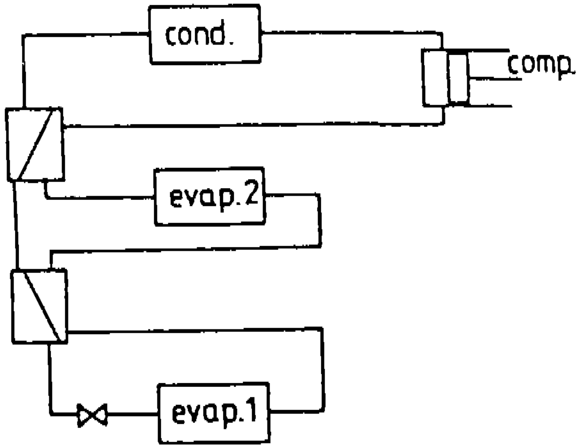

Figure 2 : schematic diagram of the test facility

The following conditions were kept constant for simulations and measurements:

condenser:	t_{win}= 32°C	t_{wout}= 40°C
1.evaporator:	t_{gin}=-18°C	t_{gout}=-23°C
2.evaporator:	t_{gin}= 5°C	t_{gout}= 0°C

A few other simplifying assumptions were made for the calculations:

compressor	: isentropic efficiency	0.7	(-)
condenser	: U-value	600	(W/m^2K)
	area	0.5	(m^2)
1.evaporator	: UA-value	120	(W/K)
	capacity	500	(W)
2.evaporator	: U-value	600	(W/m^2K)
	capacity	350	(W)
internal heat exchanger	: UA-value	3	(W/K)

It was supposed that saturated liquid leaves the condenser and superheated vapor (5K) leaves the second evaporator.

The test facility was built up with respect to figure 2. Refrigerant temperatures and pressures were measured at the inlet and outlet of each heat exchanger. Temperatures of water and glycol were measured with thermocouples by a data aquisition and personal computer system . The compressor was of an open-type, two cylinder, model ., with a volumetric flowrate of 3.6 to 13 m^3/h. The compressor was belt-driven from a variable speed dynamometer equipped with a spring scale for measuring the force of the torque arm. To predict the refrigeration loads it was necessary to measure the glycol flowrates by a weighing method.

A series of tests were conducted with the reference refrigerant R12. The refigeration load for the low temperature evaporator was found to be twice that of the high temperature evaporator. Because the density of superheated vapor and the latent heat of vaporization differ from R12, the speed of the compressor had to be changed for each different concentration of the mixtures to maintain constant capacity. The following concentrations were tested: 40/60, 50/50, 60/40 and 80/20 mass percent R22/R114; 50/50, 60/40, 70/30 and 80/20 mass percent R13B1/R114. The first tests with the mixtures showed that it is not possible to maintain exactly the 2:1 ratio of distribution of the refrigeration loads. Therefore compressor speed, expansion valve setting, and electrical heater power input to the glycol loops were adjusted to obtain a constant sum of refrigeration loads and to obtain the desired glycol temperatures. Figure 3 shows the percentage improvements of measured and calculated COP's referring to the COP of R12.

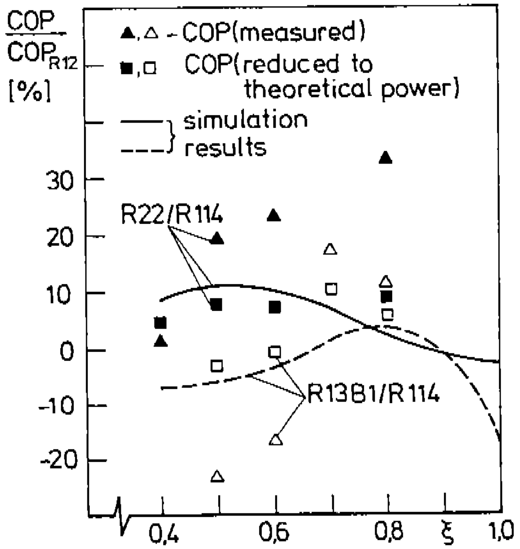

Figure 3: measured and calculated COP's

The isentropic efficiency of the compressor depends on the compressor speed and the pressure ratio. To exclude speed influences an alternate estimation of compressor power was conducted. The actual refrigerant flowrate (predicted by heat output of condenser divided by enthalpy difference of refrigerant) was multiplied by the calculated isentropic increase in enthalpy. For these computations the RKS-equation of state was used. The simulation results show a maximum in COP for 50 percent R22 and 80 percent R13B1 with an improvement of 11% and 5% respectively. The COP's referring to isentropic compressor power show a similar behavior except the 70 percent R13B1 point and the 80 percent R22 point. The deviation between calculation and measurement was mainly caused by pressure drops on the low pressure side which the simulation model does not take into account. The application of R22/R114 seems to be preferable if the measured COP's are considered with a maximum improvement of about 34%.

Figure 4 illustrates the graph of pressure ratios, pressure differences, and rotational speed.

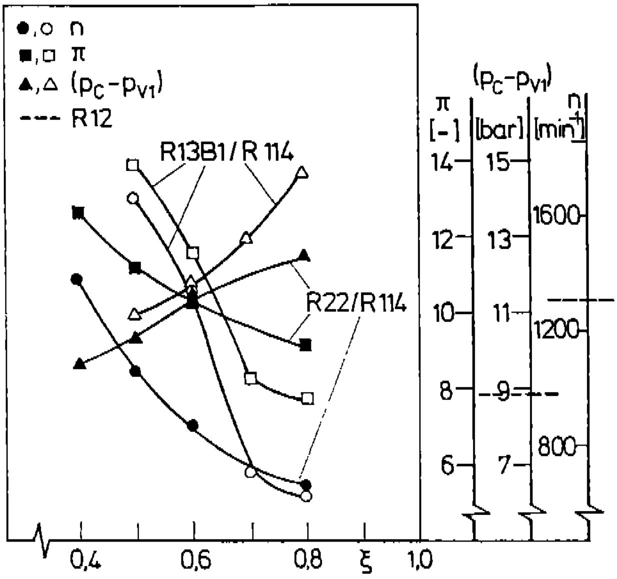

Figure 4 : pressure ratio, pressure difference and rotational speed

With increasing concentrations of the more volatile components the pressure ratio decreases to more favorable values as compared to R12. As the refrigeration capacity was kept constant the compressor speed is a criterion for volumetric refrigeration capacity. The abrupt increase of rotational speed for R13B1/R114 is somewhat surprising.

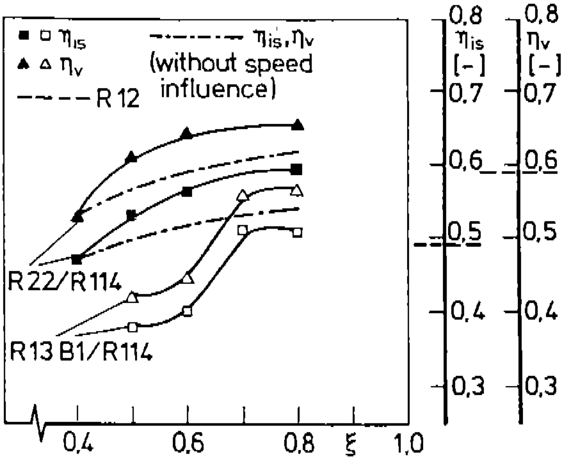

Figure 5: isentropic and volumetric efficiencies

The calculated volumetric refrigeration capacity shows the same behavior.

Using the RKS-equation of state it is possible to calculate volumetric and isentropic efficiency of the compressor. Figure 5 illustrates the graph.

Both efficiencies depend on pressure ratio and rotational speed. The speed reductions with regard to R12 are favorable for the mixtures. The influences of speed and pressure ratio as well as concentration on compressor efficiencies were examined in another research project for the same compressor and for mixtures of R22/R114 /7/. Therefore it was possible to exclude the influence of rotational speed on volumetric and isentropic efficiencies by an extrapolation. The results are shown by the dotted lines. For R22/R114 mixtures an improvement of isentropic efficiency could be stated for concentrations greater than 50 percent R22, and of volumetric efficiency for concentrations greater than 60 percent R22. In spite of speed and pressure ratio reduction the results for mixtures of R13B1/R114 are poorer. By the aid of the extrapolated graph for the isentropic efficiency it is possible to calculate the COP of a hypothetical compressor driven with constant speed. For a mixture of 50/50 mass percent R22/R114 an improvement of about 16% and for 80/20 mass percent of about 22% could be expected as compared to R12.

4. CONCLUSIONS

The application of non-azeotropic refrigerant mixtures in two temperature refrigerators offers advantages as compared to the standard refrigerant R12. Especially for mixtures of R22/R114 considerable improvements of COP could be expected. Measurements and calculations for R13B1/R114 show poorer results.

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SUMMARY

The application of non-azeotropic refrigerant mixtures seem to be a possible way to improve the energetic performance of two-temperature systems. The problem of interest is the suitable choice of the mixture components for this application. Theoretical investigation led to the conclusion that two mixtures, R22/R114 and R13B1/R114 deserve further investigation. The present paper: (1) discusses the VLE measurement and calculation for R13B1/R114. Measurements were carried out for 5 isotherms in the temperature range of -30 to 50°C. (2) theoretical calculation of improved performance using an improved Stoecker [14] model and (3) discusses the experimental set up, measurements, and results of a two temperature system.

The conclusions are non-azeotropic refrigerants offer advantages over standard refrigerants in a two temperature system and R22/R114 gives better improvement in COP than R13B1/R114.

RÉSUMÉ

L'utilsation de mélanges refrigérants non-azéotropiques pourrait
être un moyen d'améliorer le rendement en énergie des systèmes à deux
températures. Le problème reside dans le choix adéquat de la
composition du mélange utilisé. Les enquetês ont mené à la conclusion
que deux mélanges, le R22/R114 et le R13B1/R114, méritaient des
recherches plus poussées. Notre étude (1) s'interesse à la mesure et
au calcul VLE du R13B1/R114. On a mesuré la température decinq
isothermes entre -30 et 50°C (2) le calcul d'un meilleur rendement en
se servant d'un modèle Stocker [14] amélioré et (3) s'interesse à
l'installation expérimentale, aux mesures et aux résultats d'un
système à deux-températures.

On a conclu que les réfrigérants non-azéotropiques présentent
plus d'avantages que les réfrigérants habituels dans un système à deux
températures et on a aussi conclu que le R22/R114 a un rendement
meilleur que le R13B1/R114.