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EXPERIMENTAL COMPARISON OF THE PERFORMANCE OF REFRIGERANTS R134a AND R32/134a IN DRY EXPANSION AND LIQUID RECIRCULATION REFRIGERATING SYSTEMS

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ABSTRACT

The ability of zeotropic mixtures with a temperature glide to operate in liquid recirculation systems is investigated in this paper, and the preliminary results of an experimental comparison between the performance of R134a and of zeotropic mixture R32/R134a, (25/75 by mass) are presented. The performance of R134a operating in dry expansion mode are also presented as baseline data.

INTRODUCTION

Conventional refrigerating systems operate in the so called "dry expansion" configuration: the same refrigerant flow rate is encountered throughout the system and a superheated vapor exits the evaporator, under the control of the expansion valve. In liquid recirculation systems a liquid/vapor separator supplies saturated liquid to the evaporator and saturated vapor to the compressor; the low pressure side of the system and the high pressure side work with different refrigerant flow rates. The evaporator is overfed with respect to the compressor and the condenser: as a consequence the refrigerant flowing through the evaporator does not evaporate completely and, at the outlet of that heat exchanger, the vapor quality is always less than one. The ratio between the refrigerant flow rate in the low pressure side (evaporator) and the flow rate in the high pressure side (compressor and condenser) is called "recirculation ratio".

When operated with pure refrigerants, liquid recirculation systems take advantage of a better utilization of the evaporator surfaces, so that the heat exchange coefficients are higher. Furthermore, the compressor is fed with saturated vapor, allowing for lower discharge temperatures, whilst the presence of the liquid/vapor separator prevents the compressor from receiving liquid in the vapor [1].

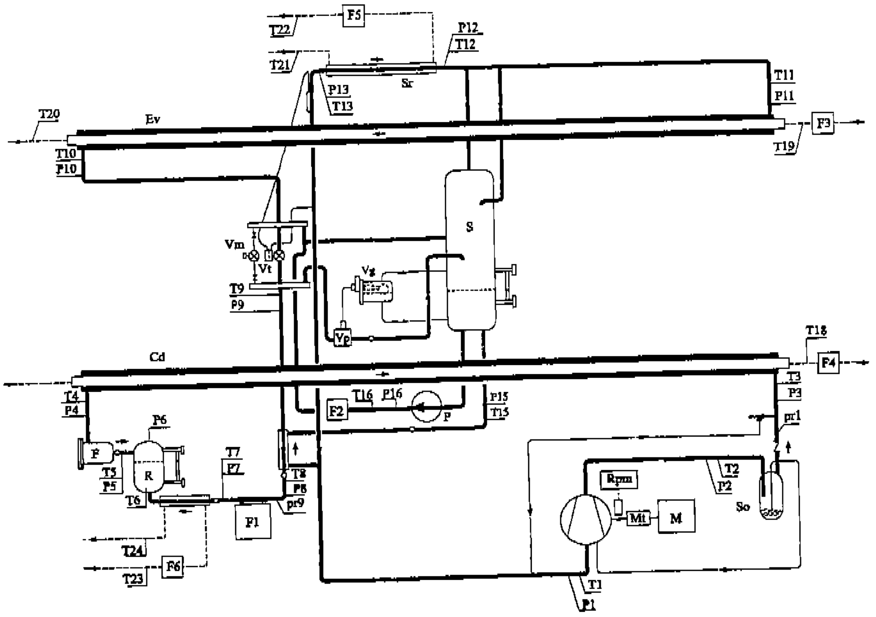
If the same systems operate with a zeotropic mixture as working fluid, the vapour and the liquid inside the liquid/vapor separator will have different compositions. Therefore the mixture flowing in the high pressure side and the mixture flowing in the low pressure side have different compositions. In addition, the liquid at the inlet of the evaporator is richer of the less volatile components of the mixture, while the vapor at the inlet of the compressor is enriched with the more volatile components of the mixture. This change in composition has been claimed responsible for the reduction in any of the advantages of using a refrigerant with a temperature glide during the phase changes [2], [3], [4]. Also there is an implication in the design of such systems in that there are unknown circulating compositions and therefore the properties of any such fluids are unknown.

The purpose of this research is to study and compare the behavior of two different refrigerants, one characterized by a temperature glide during the phase changes and the other showing constant temperature (at constant pressure), when they operate in dry expansion and liquid recirculation systems. A customized test facility has been built to evaluate the relative performances of R134a and of the mixture R32/R134a (in the composition 25/75 by mass). The comparison is based on the evaluation of four parameters: the compressor discharge temperature, the pressure ratio across the compressor, the coefficient of performance and the refrigerating capacity.

Baseline testing results with R134a are presented in this paper, but only preliminary results with R32/134a mixture are reported. Experimental work is still in progress and involves gaschromatographic analyses of mixture composition within the liquid/vapor separator.

TEST FACILITY

The experimental facility is a vapor compression refrigerating machine utilizing a two-cylinder reciprocating compressor driven by a variable speed electric motor. A schematic flow diagram of the facility, with the location of measurement sensors, is shown in Fig. 1.



nomenclature	
Cd	condenser
Ev	evaporator
F	filter
F#	flowmeter
M	electric motor
Mt	torque sensor
pr#	sampling point
P#	pressure sensor
rpm	speed sensor
R	liquid receiver
S	vapor/liquid separator
Sc	subcooler
So	oil separator
Sr	superheater
T#	thermocouple
Vg	float valve
Vm	manual expansion valve
Vp	pilot operated valve
Vt	thermostatic expansion valve

Fig. 1 schematic view of the experimental test bed

The condenser and the evaporator are counterflow heat exchangers, the refrigerant flowing through the surrounding annuli. The suction line to the compressor is provided with a refrigerant tube-in-tube superheater which prevents liquid refrigerant from flowing through the compressor. Additional liquid subcooling is obtained before the refrigerant enters the expansion device by a brazed plate heat exchanger, in which the working fluid transfers heat to a water circuit.

Heat to the evaporator is provided by a water/ethylene-glycol mixture circuit; heat produced in the condenser is transferred to a water circuit. The temperatures of the cold and the hot tanks are controlled by two motorized three-port valves, which regulate the flows of the water and the water/ethylene-glycol mixture in separate plate heat exchangers, while the flow rate of the heat source and the heat sink are controlled by proportioning valves on the pumps.

The test facility can be operated either in a dry expansion mode or a liquid recirculation mode, depending on the expansion device and associated circuitry chosen. In the dry expansion mode, the system uses either a manual expansion valve or a thermostatic expansion valve, while in the liquid recirculation mode, the expansion is performed by a low pressure side float valve which maintains a constant level on the liquid/vapor separator vessel.

Type T thermocouples measure the temperature of water and water/ethylene-glycol mixture entering and leaving the various heat exchanger sections and the temperature of the refrigerant flowing through the various parts of the plant. The cold junctions are maintained at 0°C in an ice-water bath and each thermocouple is mounted on the surface of the copper tubes and are insulated from any ambient effects. Refrigerant pressures are measured using twelve absolute pressure strain-gauge transducers based on a Wheatstone bridge arrangement. Since the compressor is an open arrangement, the speed of the compressor is measured by a toothed wheel arrangement. The toothed wheel, with 60 teeth, is magnetically coupled to an electronic analog voltage transmitter. Compressor torque is measured by a strain-gauge apparatus, placed between the variable-speed drive and the compressor. The instrument is connected to the motor and compressor by two flexible couplings which allow an imperfect arbor alignment. A Coriolis-effect mass flowmeter, located downstream of the condenser, is used to measure the refrigerant mass flow-rate. A turbine flowmeter measures the volumetric flow rate of the refrigerant in the low pressure side of the circuit, and it is located downstream of the hermetic pump, while three electromagnetic flowmeters measure the volumetric flow-rate of the water and the water-glycol mixture which flow through the condenser, the evaporator, and the superheater.

The data acquisition system used is connected to a PC which collects measured data, manipulated by programs running in Labview software environment. The data are then processed in real time in order to calculate both the thermophysical properties of the refrigerant and the refrigerating system performance. The evaluation of the thermophysical properties of refrigerant has been performed with REFPROP [5] which has been interfaced with Labview.

As performance parameters are usually not directly measured but calculated from measured quantities, a thorough investigation has been carried out, as proposed in [6], to evaluate how the measurement uncertainties propagate into the performance parameters. The calculated uncertainties are reported as error bars within the graphs showing our experimental results.

DRY EXPANSION AND LIQUID RECIRCULATION PERFORMANCE COMPARISON FOR R134a

The dry expansion configuration is the most conventional and therefore the results obtained with this type of configuration are used as baseline data. The refrigerant leaves the evaporator as saturated vapor or as slightly superheated vapor, and the superheat is controlled to the desired level by means of the superheater heat exchanger.

The experimental runs have been performed maintaining constant the temperature of the hot source and varying the temperature of the cold tank, i.e. the situation where the heat sink has a fixed temperature, and the heat source, the ambient to cool, can vary its temperature depending on the specific plant demands.

The tested parameters are the pressure ratio across the compressor, the discharge temperature, the refrigerating capacity and the Coefficient Of Performance (COP). The refrigerating capacity includes the heat exchanged in the superheater.

The COP has been calculated dividing the refrigerating capacity by the power absorbed by the compressor, since in this way is it possible to take into account also the thermal and mechanical losses at the compressor, e.g. the heat which is dispersed into the surroundings and the internal friction.

The tests were performed at 3 different hot tank temperature, namely 35°C, 45°C and 50°C; for each of them the cold tank temperature was set at three values successively: 4°C, 8°C, 12°C. The compressor speed was maintained at 800 rpm, and the superheat level at the compressor inlet was set at 9°C. During the liquid recirculation configuration tests a recirculation ratio of 2 was used.

The results for the test in dry expansion configuration are presented in Fig. 2, where the variations of the refrigerating capacity and COP at different cold tank and hot tank temperatures are shown. As expected, both the refrigerating capacity and the coefficient of performance are decreasing when the hot tank temperature is increasing, and are increasing when the cold tank temperature is increasing.

The same results for the liquid recirculation configuration are displayed in Fig. 3. The refrigerating capacity and the COP have the same trend as in the dry expansion tests.

The beneficial characteristic of the liquid recirculation system are not evident from the analysis of Fig. 2 and 3. However, they can be underlined when the two cycles are compared on a pressure-enthalpy chart. The cycles are almost the same, except for the evaporation process: the liquid recirculation system has a higher evaporation temperature, which means a smaller power is required from the compressor. This is a consequence of the better heat exchange process that is the characteristic of this configuration, since the heat tranferred is the same, but the potential for this process, i.e. the temperature difference between the refrigerant and the heat transfer fluid, is lower. The presence of an additional heat exchange device downstream the condenser (the subcooler), whose effect is to diminish the vapor quality at the expansion device outlet, improves the performance of the dry expansion configuration. Therefore, the difference in performance between the two configuration is less evident.

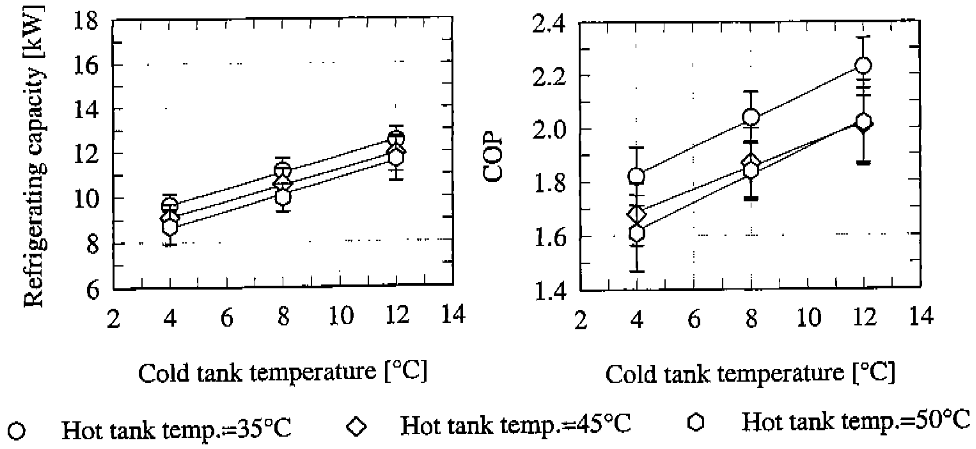


Fig. 2 Experimental results for R134a operating in dry expansion configuration (heat exchanged at superheater is included)

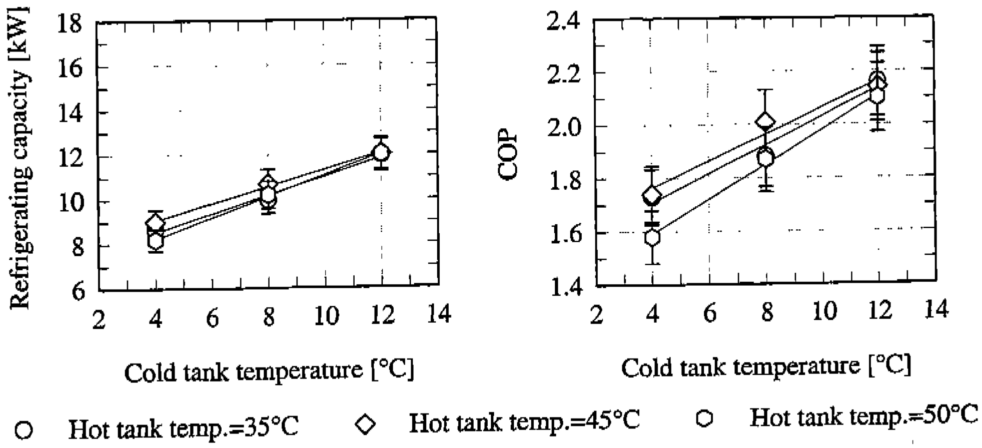


Fig. 3 Experimental results for R134a operating in liquid recirculation configuration (heat exchanged at superheater is included)

Figure 4 shows the comparison between the experimental results for the two configurations on the tests at 45°C hot tank temperature: discharge temperature, pressure ratio, refrigerating capacity and COP are the compared parameters. Here the refrigerationg capacity does not include the heat which is absorbed by the superheater, so to focus on the difference of the heat transfer processes in the evaporator in the two different configuration. It can be noticed that the refrigerating capacity and the COP have, as expected, higher values for the liquid recirculation system, due to a better heat exchange.

LIQUID RECIRCULATION RESULTS FOR R32/134a AND COMPARISON WITH R134a

Tests for the mixture R32/134a (25/75 by mass) where run at the same conditions presented in the previous paragraph for R134a, but at lower (27, 32 and 35°C) hot tank temperatures in order not to exceed allowable pressures. The refrigerant charge was the same as in R134a tests. Figure 5 shows, in the usual pattern, the results for the refrigerating capacity and for the COP at different hot and cold tank temperatures.

In comparison with R134a, the tested mixture presents a sensible increase in the values of the refrigerating capacity but similar values of the COP. The compared values of refrigerating capacity and COP at 32°C hot tank temperature and for different values of cold tank temperature are presented in Fig. 6. The fact that the COP is almost the same, while the refrigerating capacity varies, is due to the fact that the mixture has better thermodynamic properties, but needs higher power from the compressor.

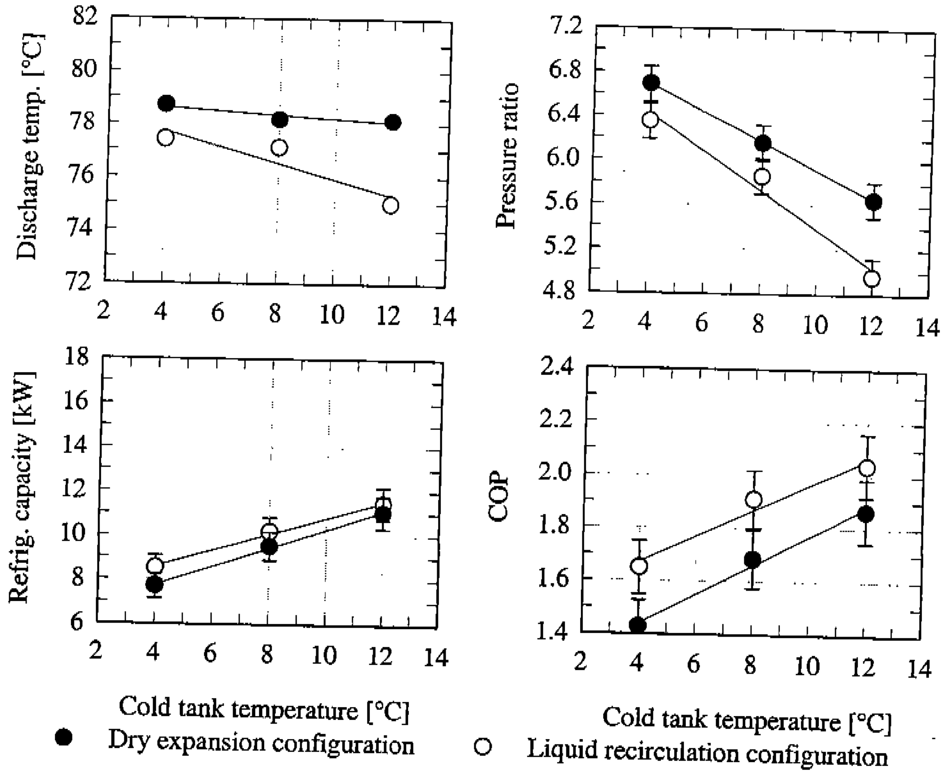


Fig. 4 Comparison between performance of R134a in dry expansion and liquid recirculation configuration (heat exchanged at superheater <u>is not</u> included) (results obtained at 45°C Hot tank temperature)

Of great interest is also the comparison between the two refrigerants when working in dry expansion mode and the comparative analysis of performance in both configurations: in other words it is necessary to evaluate if, during dry expansion operations, the mixture related improvements are of the same magnitude or higher than those experienced during liquid recirculation operations. These results are not yet available: work on this subject is still under way, coupled with a systematic analysis of mixture composition in different vapor/liquid separator locations.

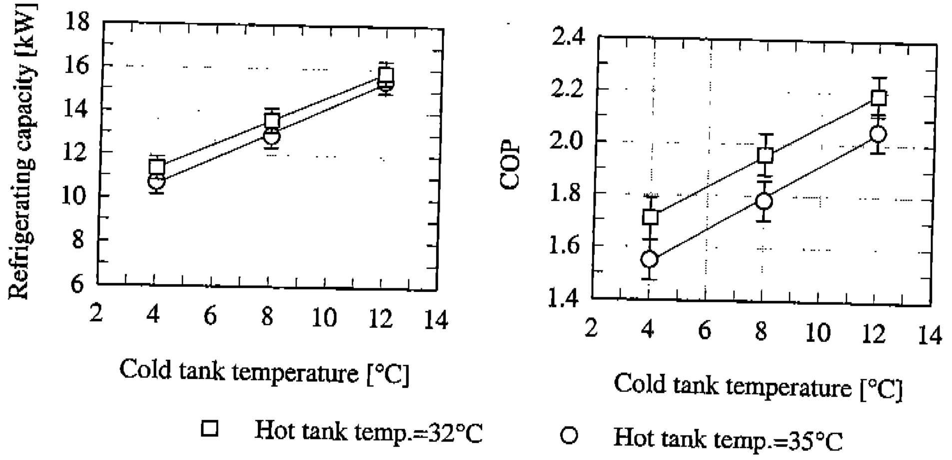


Fig.5 Experimental results for R32/134a (25/75 by mass) operating in liquid recirculation configuration (heat exchanged at superheater <u>is</u> included)

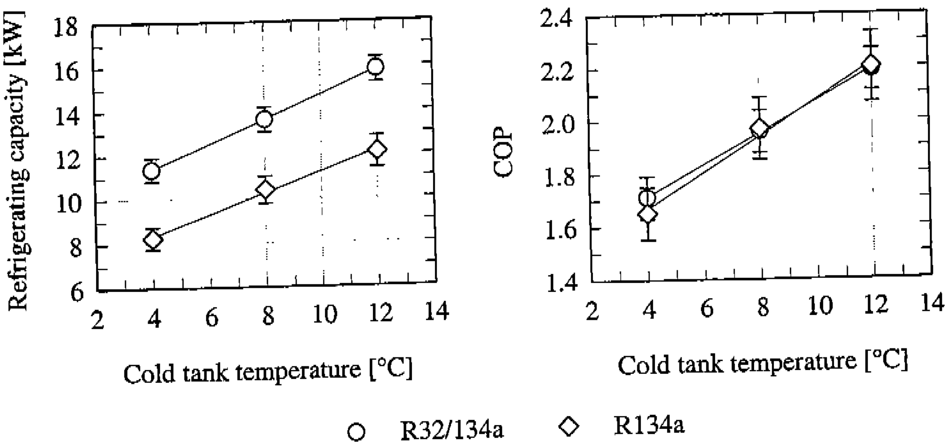


Fig. 6 Comparison of experimental results for R134a and R32/134a (25/75 by mass) in liquid recirculation configuration (heat exchanged at superheater is included) (results obtained at 32°C Hot tank temperature)

CONCLUSIONS

The results of an experimental investigation carried out with a purpose-built test bed on the behavior of pure and mixed refrigerants operating in liquid recirculation systems is presented in this paper. Results for pure refrigerant R134a have been obtained either with the dry expansion configuration and with the liquid recirculation configuration. They have been presented as baseline data. Preliminary results for the performance of mixture R32/134a (25/75 by mass) in liquid recirculation configuration are also presented and compared with R134a. More experimental work is under way in order to better understand the behavior of azeotropic mixtures, such as R32/134a, in dry expansion and liquid recirculation systems.

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