1990

Refrigerants Thermodynamic Properties Evaluation and Exergetic Analysis of Vapor Compression Systems

F. de Rossi
DETEC - University di Napoli

R. Mastruillo
DETEC - University di Napoli

P. Mazzei
University di Salerno

REFRIGERANTS THERMODYNAMIC PROPERTIES EVALUATION AND EXERGETIC ANALYSIS OF VAPOR COMPRESSION SYSTEMS

Filippo de Rossi, Assistant Professor, IIR Member
Rita Mastrullo, Associated Professor
DETEC - Univ. di Napoli - Piazzale Tecchio 80, 80125 Napoli - ITALY

Pietro Mazzei, Full Professor, Ashrae Member
Ist. Ing. Meccanica - Univ. di Salerno - 84081 Baronissi (SA) - ITALY

INTRODUCTION

Nowadays, the CFC issue is a "hot" topic for the air conditioning and refrigeration researchers and manifacturers. Studies on plants operating with "ozone safe" substances constitute an important contribution to find a satisfactory solution to the problem [1,2].

A working fluid must be safe to the environment and to the operators. At the same time, it must present suitable values of thermodynamic parameters, such as pressure ratio, condensing pressure, isoentropic exponent, latent enthalpy. Even, it must have no chemical reaction in touch with metals, polymers and lubricating oils too; finally, it must have a good stability at high temperature, non flammability, availibility and low cost.

Referring to a thermodynamic point of view, a code for automatic calculation of working fluids properties is a very useful tool. In fact, a complete comparison between usual and "ozone friend" fluids, must be accomplished by evaluating the plant performance parameters with different working fluids.

In this paper a code (MS-DOS, BASIC language) for both the thermodynamic properties evaluation and the simplified simulation of several plant schemes, is presented. The program can be run with about twenty working fluids, comprehending both substances now most used in vapor compression systems and some of the most promising ones relating to the alteration of the climate and the depletion of the ozone layer.

Some demonstrative charts are presented to show the usefulness of the code in carrying out a comparison between the R12, which is believed unsafe for the environment, and the R134a, its more probable substitute. Furthermore, usual thermodynamic diagrams can be plotted by interfacing the code with a graphical package; in this paper the R134a exergy-enthalpy chart is presented.

PROGRAM STRUCTURE

The software package presented can be runned along two different paths:

i) following the "properties evaluation" way, the main thermodynamic properties of twenty working fluids can be evaluated interactively, given any two independent ones;

ii) in the "schemes analysis" way a thermodynamic analysis can be accomplished on a vapor compression plant scheme for refrigerating and/or heating purposes to select among nine different ones.

Properties evaluation

At the present time, by running the first way, the following working fluids can be studied: R503 [3], R23 [4], R13 [3], R13B1 [3], R115 [4], R502 [3], R22 [3], R500 [4], R134a [5,6,7], R12 [3], R152a [4], RC318 [8], R124a [5], R717 [3], R142b [4], R114 [3], R21 [5], R11 [3], R113 [3], R114B2 [9]. This set comprehends both substances now used in vapor compression systems and most promising alternatives from an environment safety point of view.

The algorythm for the thermodynamic properties evaluation is based on the "integration" approach; in other words, the specific enthalpy, internal energy and entropy variations are determined from p-v-t data together with specific heat data. A detailed description of this procedure is available in [10]. The equations employed are:

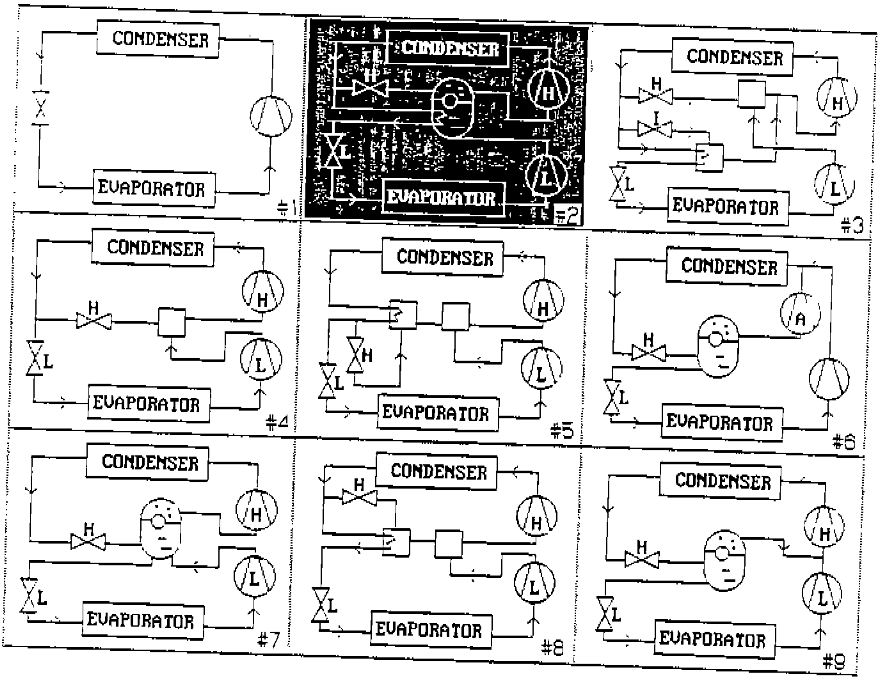

Fig. 1 Plant schemes.

- vapor equation of state, which gives pressure as a function of temperature and specific volume;
- vapor pressure equation, giving the saturation pressure of the fluid as a function of temperature;
- liquid density as a function of temperature;
- costant volume specific heat capacity of the vapor at zero pressure as a function of temperature.

<u>Schemes analysis</u>

The "schemes" way allows to carry out an energetic, entropic and exergetic analysis referring to a plant scheme to be selected among nine different ones, according to the particular application. This set of schemes, showed in fig. 1, comprehends from the simple standard reversed Rankine cycle, up to more complex ones like two-stage compression, separation by flash tank, intermediate heat exchange. Cycle components are modeled in a simplified way, nevertheless design variables, such as subcooling and superheating degrees, pressure drops, heat exchangers logarithmic mean temperature difference and compressor isoentropic efficiency, are taken into account to point out some of the important aspects of actual applications. For a selected matching scheme-working fluid and for a fixed set of data input, the program provides a table showing the main thermodynamic properties for the cycle key-points. Afterwards, both first and second law analysis are performed and a balance table is displayed. For each component the mass flow, the energy flow and the generated entropy are exhibited; the overall values together with the coefficient of performance are also presented in a separate frame. Exergetic balances are carried out too; in detail, for each component, exergy destruction, exergetic efficiency and efficiency defect are evaluated and displayed. In the same screen overall exergy destruction and exergetic efficiency are presented. A comparison between two different schemes can point out the improvements coming from the use of devices such as subcooler, flash tank and so on. Moreover, each scheme can be tested with any available working fluid to evaluate the plant performance dependence on fluids characteristics.

SOME DEMONSTRATIVE APPLICATIONS

The program facilities have been employed to accomplish some sample comparisons between the "ozone killer" R12 and its alternative R134a. As generally believed [1,2], the R12 has a very high POD (Potential Ozone Depletion) and should be, gradually, pushed out from the market together with the other CFCs R11, R113, R114 and R115. Therefore, it is necessary to find quickly an alternative working fluid exhibiting a very low or, better, zero POD. At the present time, this searching has pointed out the R134a as the better R12 substitute, but its commercial production marks time since safety tests are still in progress. Of course, a fluid, to be qualified as a good substitute, must exhibit a satisfying thermodynamic behaviour too; an appropriate software can be an useful tool in verifying it.

In fig. 2 some diagrams, among other ones obtainable running the "properties evaluation" path of the program, are presented: they show the saturated specific volume and the the saturated vapor pression, the

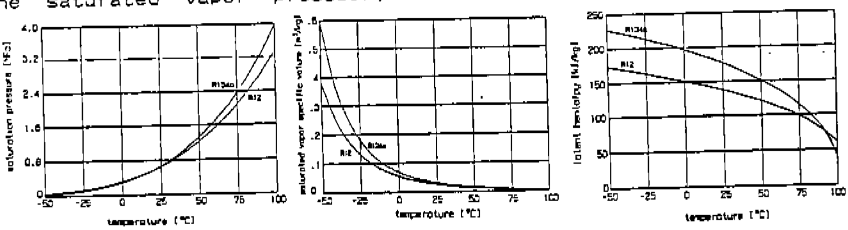

Fig. 2 Saturated vapor pression, saturated specific volume and latent enthalpy vs. temperature.

latent enthalpy as functions of the temperature. They show that the properties values are close, according to results already acknowledged.

The great deal of numerical results, provided in a very short time and with a good reliability, can be organized in form of tables and charts [11]. In fig. 3 the exergy-enthalpy chart of R134a, based on [6], is showed. By means of this diagram a visual aid for the exergetic analysis is provided.

Even more, a lot of other important informations about the expected behaviour of a substance can be obtained from the "schemes" way of the program. The refrigerants R12 and R134a have been tested for the schemes #1, #2, #3, #6, #7 of fig. 1, with the following input data:

- heat sink temperature (environment temperature) 25 °C
- heat source temperature -25 °C
- condensing temperature difference 5 °C
- evaporating temperature difference 5 °C
- pressure drops 0 bar
- superheating degree at evaporator outlet 2 °C
- superheating degree at high compressor inlet (#3) 2 °C
- subcooling degree at condenser outlet 0 °C
- terminal temperature difference of subcooler (#7) 5 °C
- low compressor isoentropic efficiency 70 %
- high compressor isoentropic efficiency 70 %
- single stage compressor isoentropic efficiency (#1) 60 %

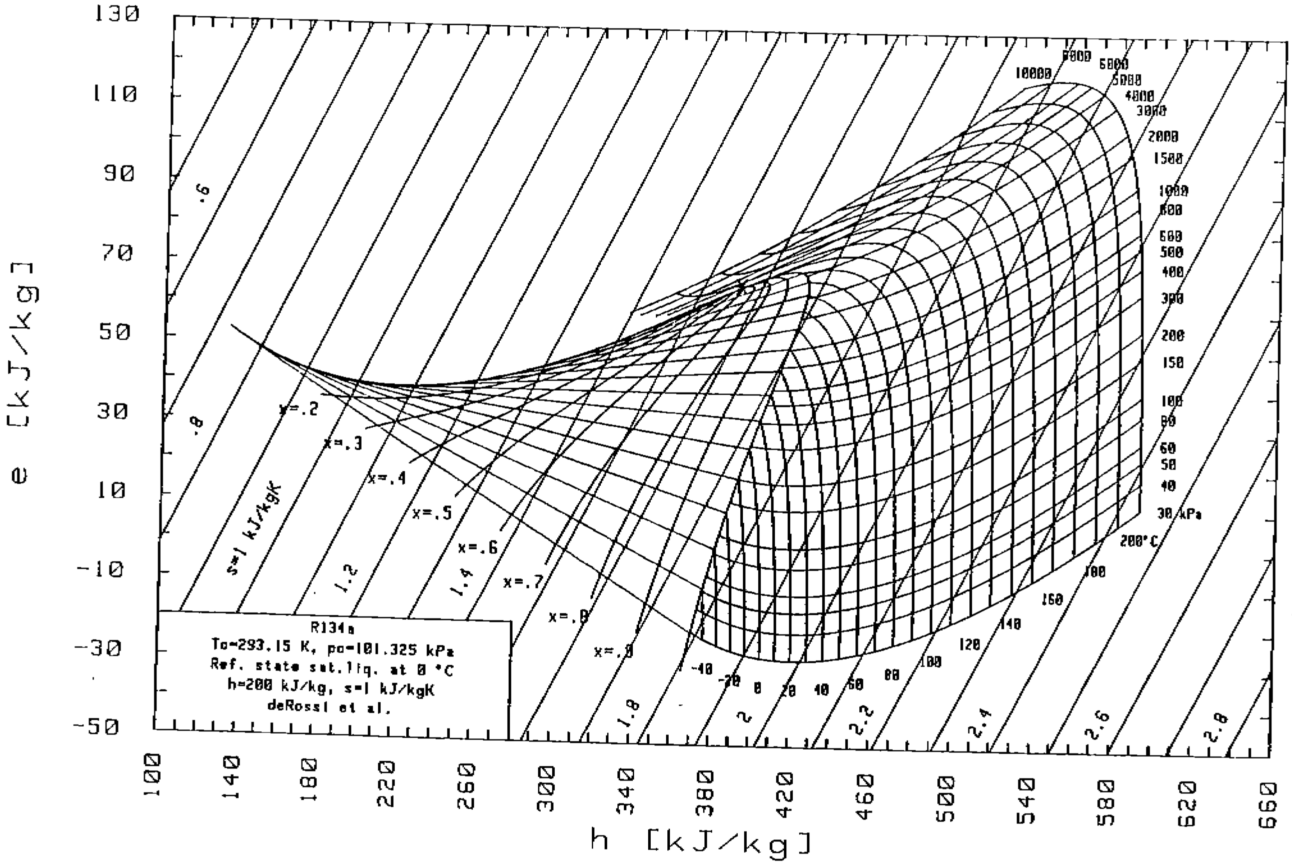

Fig. 3 R134a Exergy-enthalpy chart.

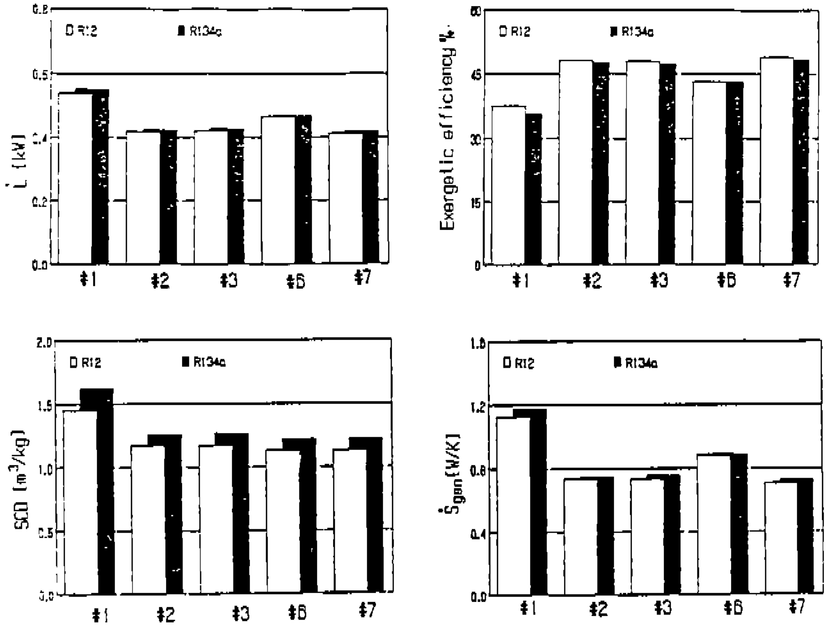

Fig. 4 Mechanical power requirement, overall exergetic efficiency, specific compressor displacement and global entropy generation in five different plant schemes.

The resulting mechanical power requirement, overall exergetic efficiency, specific compressor displacement and global entropy generation have been reported in fig. 4. One can note the very similar behaviour of both fluids.

CONCLUSIONS

In this paper, a software package for the thermodynamic properties computation and the vapor compression cycles analysis is presented. At the present time, the procedure can be runned with R503, R23, R13, R13B1, R115, R502, R22, R500, R134a, R12, R152a, RC318, R124a, R717, R142b, R114, R21, R11, R113, R114B2 but other substances can be easily added. Furthermore, more typical plant schemes are modeled in a simplified way, but actual design variables such as pressure drops, subcooling and superheating in the heat exchangers, as well as compressor isoentropic efficiency are accounted for all the same. Energy, entropy, and exergy balances for each device and for the plant are pointed out. The program is an useful tool in comparing both the thermodynamic properties and the plant performance factors of two or more different fluids. Nowadays this occurs more and more often owing to CFC replacement issue. In this paper, some comparison between the refrigerant R12 and its more probable substitute R134a are presented as a demonstrative application of the procedure. Particularly, the exergy-enthalpy chart of the R134a in SI units, and both R12 and R134a overall performances for five different plant schemes are provided.

REFERENCES

[1] Status of CFCs - Refrigeration systems and refrigerant properties. IIR Meeting of Comm. B1, B2, E1, E2, Purdue University (USA), 1988.

[2] CFCs: time of transition. ASHRAE, 1989

[3] R11, R12, R13, R13B1, R22, R113, R114, R502, R503, R717, Thermodynamic and physical properties, International Institute of Refrigeration, Paris.

[4] R.B.Stewart, R.T.Jacobsen, and S.G.Penoncello, Thermodynamic Properties of Refrigerants. ASHRAE, Atlanta , 1986.

[5] Arnaud D., Tanguy J.C., Proprietes thermophysiques des refrigerants R124a et R134a. Proc. of IIR Congress, Wien, 1987.

[6] Wilson D.P., Basu R.S., Thermodynamic Properties of a new Stratospherically Safe Working Fluid - Refrigerant 134a. ASHRAE Trans., V. 94, Pt 2, 1988.

[7] McLinden et al., Measurement and Formulation of the Thermodynamic Properties of Refrigerants 134a (1,1,1,2 - Tetrafluoroethane) and 123 (1,1 - Dichloro - 2,2,2 - Trifluoroethane). ASHRAE Trans., V. 95, Pt. 2, 1989.

[8] Dowing R. C., General equations and constants for thermodynamic equations. DuPont de Nemours & Co. Inc., "Freon" Products Division, Technical Bulletin X-88F, X-88B1.

[9] Doring R., Thermodynamische Eigenschaften des Kaltemittels R114B2. Die Kalte und Klimatechnik, n.9, 1977.

[10] Mastrullo R., Mazzei P., "Programma interattivo per il calcolo delle proprieta' di refrigeranti e l'analisi di cicli inversi" parte I e II, Il Freddo, anno 42, n. 1 e 2, gen.-feb., mar.-apr., 1988.

[11] de Rossi F., Mastrullo R., Mazzei P., Sibilio S., Exergy-Enthalpy Charts for eighteen Working Fluids. Proc. of XLIII Congr. ATI, Ancona (Italy), 1988.

ABSTRACT

A software packcage for both the thermodynamic properties computation and the analysis of usual vapor compression plant schemes is an useful tool for air conditioning and refrigeration researchers and manifacturers. At the present time, it could supply an important contribution to search for CFCs substitutes; in fact, comparisons between two or more working fluids could be accomplished more easily. A code carried out by the authors is presented by means of some demonstrative diagrams referring to a comparison between the "ozone killer" R12 and its substitute R134a. The R134a exergy-enthalpy chart is provided too.