Purdue University
Purdue e-Pubs

International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

1994

Adiabatic Capillary Tube Expansion Devices Working with CFC-12, HCFC-22 and HFC-134a

F. Escanes
Universitat Politecnica de Catalunya

C. D. Perez-Segarra
Universitat Politecnica de Catalunya

A. Oliva
Universitat Politecnica de Catalunya

ADIABATIC CAPILLARY TUBE EXPANSION DEVICES WORKING WITH CFC-12, HCFC-22 AND HFC-134a

F. Escanes, C. D. Pérez-Segarra, A. Oliva

Laboratori de Termotècnia i Energètica
Dept. Màquines i Motors Tèrmics, Universitat Politècnica de Catalunya

Colom 9, 08222 Terrassa, Barcelona (Spain)
FAX: +34-3-739.81.01; Tel: +34-3-739.81.92

ABSTRACT

The objective of this work is to present a collection of charts for a preliminary selection of capillary tube expansion devices in refrigerating units working with CFC-12, HCFC-22 and HFC-134a. The charts have been elaborated from the results offered by a numerical simulation of the steady adiabatic flow through capillary tube expansion devices. The numerical sumulation developed integrates the one-dimensional governing equations of the fluid flow (continuity, momentum and energy), using a step by step numerical scheme. For a given set of input data (working fluid, length and inside diameter and roughness of the capillary tube, condensing and evaporating pressure, and subcooling), the modelization offers the following results: flow condition (critical or non-critical), mass flow rate, refrigerating power (for a given superheating), and flow variables along the capillary tube (temperature, pressure, mass vapor fraction, void fraction, velocity, etc). The model was carefully checked and validated by comparison with experimental data reported by Bolstand and Jordan, Whitesel, and Mikol, using both CFC-12 and HCFC-22; good agreement was observed between numerical and experimental data.

NOMENCLATURE

D	inside diameter
h	specific enthalpy
L	length
$\dot{m}$	mass flow rate
p	pressure
P	perimeter
RSC	refrigerating system capacity
s	specific entropy
S	cross-section
T	temperature
v	velocity
x_g	vapor quality

Greek symbols:

Δh	refrigeration per unit mass
Δh_{fg}	latent heat
Δs_{fg}	latent entropy
Δz	control volume length
ρ	density
τ_w	shear stress
ζ	inside roughness

Subscript:

g	gas
i	inlet
l	liquid
o	outlet
tp	two-phase
c	condensing
e	evaporating
sc	subcooling (capillary tube inlet)
sh	superheating (compressor suction)

INTRODUCTION

The capillary tube expansion devices are widely used in refrigeration equipment, especially in small units such as household refrigerators and freezers, dehumidifiers, room air conditioners, etc, which are normally associated with the use of hermetic compressors and halocarbon refrigerants. Accurate predictions of the behaviour of these units require the development of general and systematic methods to simulate the different elements of the units, and in a particular case, capillary tube expansion devices.

The calculation of pressure, temperature, velocity fields, heat fluxes, etc, in capillary tubes like any thermal system, would require the solution of the governing equations (mass, momentum and energy) in the analyzed domain. Considering two-phase flow, both analytical and numerical treatments of the multi-dimensional flow, offers very restricted possibilities of solution. However, an important variety of technical situations can be analyzed assuming one-dimensional flow, which can be treated on the basis of a control volume formulation of the conservation equations, as for example, all those situations involving two-phase flow through tubes (double tube and shell and tubes condensers and evaporators, capillary tubes, etc). The one-dimensional analysis requires the knowledge of the shear stress, heat flux and two-phase flow structure, generally obtained from empirical information.

The numerical solution has been done by the discretization of the mass, energy and momentum equations considering one-dimensional flow. The creation entropy principle is also considered to detect the limitation of the physical process produced under critical flow conditions. The software developed evaluates the mass flow rate that corresponds to the given boundary conditions, independently of whether the flow is critic or non-critic. The distribution of the flow variables along the capillary tube (temperature, pressure, velocity, etc.) is also obtained. The characteristic parameters that define a concrete situation are:

- Geometry: inside diameter and roughness, length.
- Inlet and discharge pressure.
- Inlet temperature (case of single-phase liquid flow entering the capillary tube) or vapor fraction (case of two-phase flow entering it).
- Thermophysical properties of the fluid.

In this paper, a description of the mathematical formulation and numerical solution of the two-phase flow through capillary tubes is presented. Finally, based on the software developed, a collection of charts for the preliminary selection of capillary tubes are presented, together with some aspects of their construction and use.

MATHEMATICAL FORMULATION AND NUMERICAL SOLUTION

The integration of the steady, adiabatic, one-dimensional, two-phase flow governing equations over a control volume (taken longitudinally in the flow direction, between two cross-sections) gives the following equations:

- Continuity: $$\dot{m}_i = \dot{m}_o = \dot{m} \qquad (1)$$
- Momentum: $$(p_i - p_o)\, S - \tau_w\, P\, \Delta z = \dot{m}\, (v_o - v_i) \qquad (2)$$
- Energy: $$h_{l,o} + x_{g,o}\, \Delta h_{fg,o} + v_o^2/2 = h_{l,i} + x_{g,i}\, \Delta h_{fg,i} + v_i^2/2 \qquad (3)$$
- Second thermodynamic principle: $$s_{created} = (s_{l,o} + x_{g,o}\, \Delta s_{fg,o}) - (s_{l,i} + x_{g,i}\, \Delta s_{fg,i}) \geq 0 \qquad (4)$$

This formulation assumes the homogeneous flow model [1], so the fluid velocity is evaluated from the mass flow rate as: $v=(\dot{m}/S)(\rho_g^{-1}+\rho_l^{-1})$. The shear stress τ_w, is evaluated from the two-phase friction factor f_{tp} as: $\tau_w=(f_{tp}/4)(\dot{m}^2/2\rho S^2)$. This formulation leaves the single-phase liquid flow as a particular case.

The domain is divided into control volumes. Due to the high gradients produced towards the exit of the capillary tube, a non-uniform grid that concentrates the control volumes progressively in the flow direction has been implemented. For each control volume, the values of the flow variables at the outlet section and the created entropy are obtained by the solution of the equations (1) to (4), from the known values at the inlet section. The solution procedure is carried out in this manner, moving forward step by step in the flow direction.

The critical mass flow rate, i.e. the mass flow rate that offers critical conditions at the outlet section of the capillary tube, is iteratively estimated by means of a numerical Newton-Raphson algorithm. After the calculation of the critical conditions, the critical and discharge pressures are compared. If the critical pressure is greater than or equal to than the discharge pressure, the flow is critic and the algorithm stops. In the opposite case, the flow is not critic: the mass flow rate that offers an outlet pressure equal to the discharge pressure is evaluated by means of another Newton-Raphson algorithm.

The single-phase friction factor has been evaluated from the expression proposed by Churchill, cited in [2]. In order to evaluate the two phase friction factor the expression for single phase flow has been used, calculating the two-phase Reynolds number on the basis of the two-phase viscosity defined by McAdams, cited in [1].

The software developed has been carefully checked and it has been validated using experimental data reported by Bolstand and Jordan [3], Whitesel [4] and Mikol [5], for CFC-12 and HCFC-22. A complete description of the numerical simulation can be found in ref. [6].

RESULTS

A collection of charts are presented for a preliminary selection of capillary tube expansion devices. They correspond to CFC-12, HCFC-22 and HFC-134a as working fluids, for the four different refrigerating cycles shown in table 1.

Cycle	T_c (C)	T_{sc} (C)	T_e (C)	T_{sh} (C)
A	55	55	-25	32
B	55	32	-23.3	32
C	55	55	5	32
D	55	46	7.2	35

Table 1 Refrigerating cycles considered

In order to offer a quick preliminary selection tool, for each considered cycle and fluid, the refrigerating system capacity RSC appears as a function of the length L, with the inside diameter as a parameter. The mass flow rate can be evaluated by dividing the refrigerating system capacity by the refrigeration per unit mass, defined as $\Delta h=h_{sh}-h_{sc}$, shown in the tables. The charts can be used in those situations where heat exchanger between the capillary tube and the suction line is used; in these cases, some precautions have to be taken into account: the subcooling temperature is the one obtained at the outlet section of the heat exchanger; although the mass flow rate evaluated in the above mentioned form is correct, the refrigerating system capacity has to be modified to accounting for the heat exchanging.

A total of twelve charts are presented (three fluids for four refrigerating cycles), each one contains nine curves, corresponding to nine inside diameters D, ranging from 0.6 to 1.0 mm. with a 0.05 mm. step. The length of the capillary tubes L ranges from 0.3 to 5 m. An inside roughness of $\zeta/D=3.8\cdot10^{-4}$ has been used in all cases.

CONCLUDING REMARKS

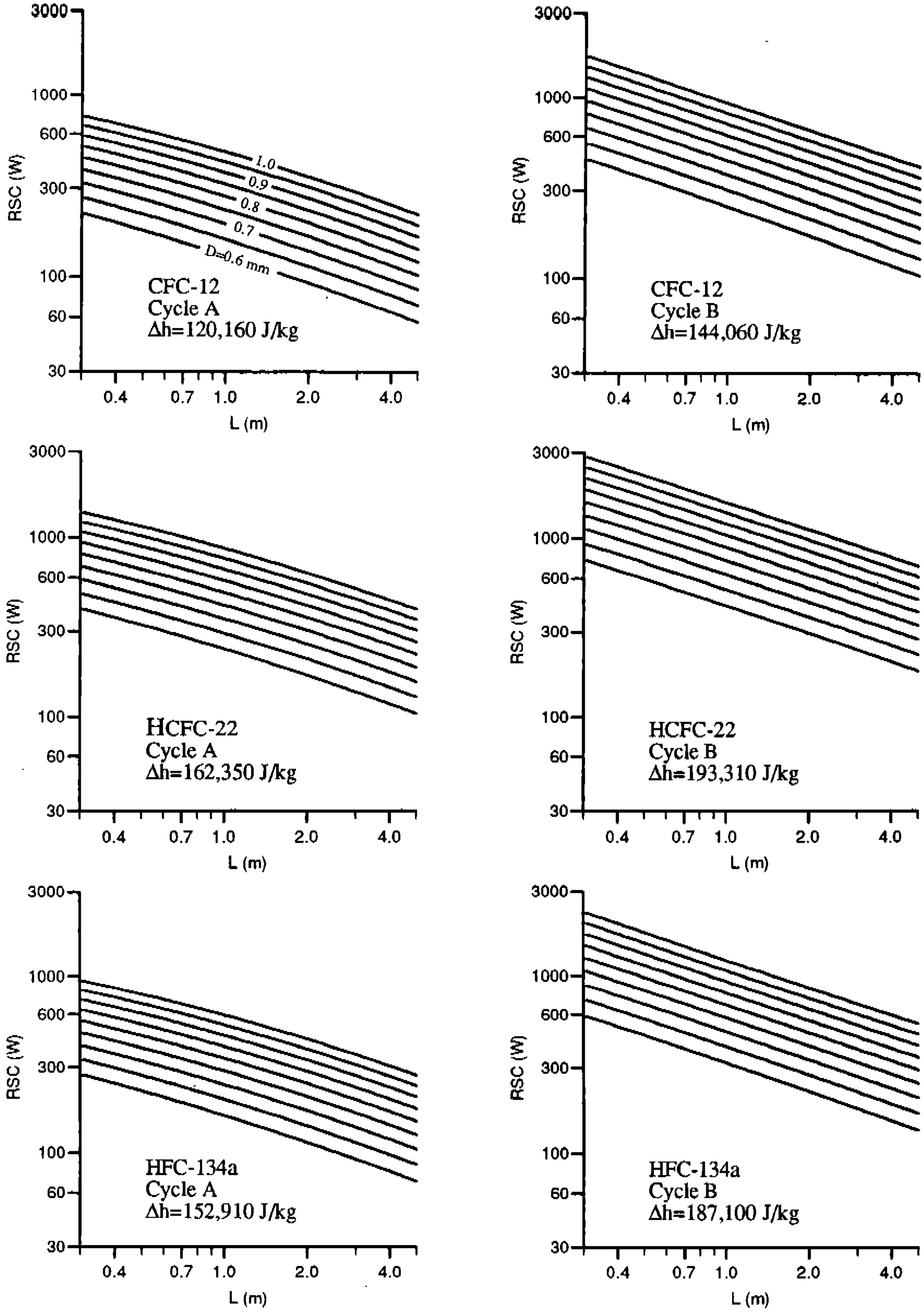
A collection of charts to make a preliminary selection of adiabatic capillary tube expansion devices is presented. The charts have been elaborated from a numerical simulation based on a one-dimensional integration of the governing equations, either with critical or non-critical flow. The charts can be useful in evaluating the behaviour of capillary tubes working with three different fluids (CFC-12, HCFC-22 and HFC-134a) and within four different refrigerating cycles. Taking into account some precautions, they can serve in those situations involving heat exchange between the capillary tube and the compressor suction line.

ACKNOWLEDGEMENTS

This study has been supported by the company Unidad Hermética S.A. (group Electrolux Compressors), by the Comisión Interministerial de Ciencia y Tecnología, Spain (Ref. no. PTR-90060), by the Dirección General de Investigación Científica y Técnica, Spain (ref. no. PB90-0606), and by the Direcció General d'Universitats, Catalonia, Spain (Program AD1). The authors thank J. M. Serra, J. Pons, A. Castillo, of Unidad Hermética S.A. for the technical support given.

REFERENCES

1. G.F. Hewitt, 'Gas-Liquid flow', sec. 2.7.3, Heat Exchanger Design Handbook, ed. by E.U. Schlünder et al, Hemisphere Publishing Corporation, Washington, 1983.
2. S. Lin, C.C.K. Kwok, R.Y. Li, Z.H. Chen and Z.Y. Chen. 'Local Frictional Pressure Drop During Vaporization of R-12 Through Capillary Tubes' Int. J. Multiphase Flow vol. 17 No. 1, pp. 95-102, 1991.
3. M. Bolstand, and R.C. Jordan, 'Theory and Use of the Capillary Tube Expansion Device. Part II, Nonadiabatic Flow', Ref. Eng, pp. 557-583, June 1949.
4. H. A. Whitesel, 'Capillary Two-Phase Flow, Part II', Ref. Eng, pp. 35-40, September 1957.
5. E.P. Mikol, 'Adiabatic Single and Two-Phase Flow in small bore Tubes' ASHRAE J, pp. 75-86, November 1963.
6. F. Escanes, C.D. Pérez-Segarra, A. Oliva, 'Numerical Simulation of Capillary Tube Expansion Devices'. Submitted to the Int. J. of Refrigeration, 1993.



(Figure captation in the next page)

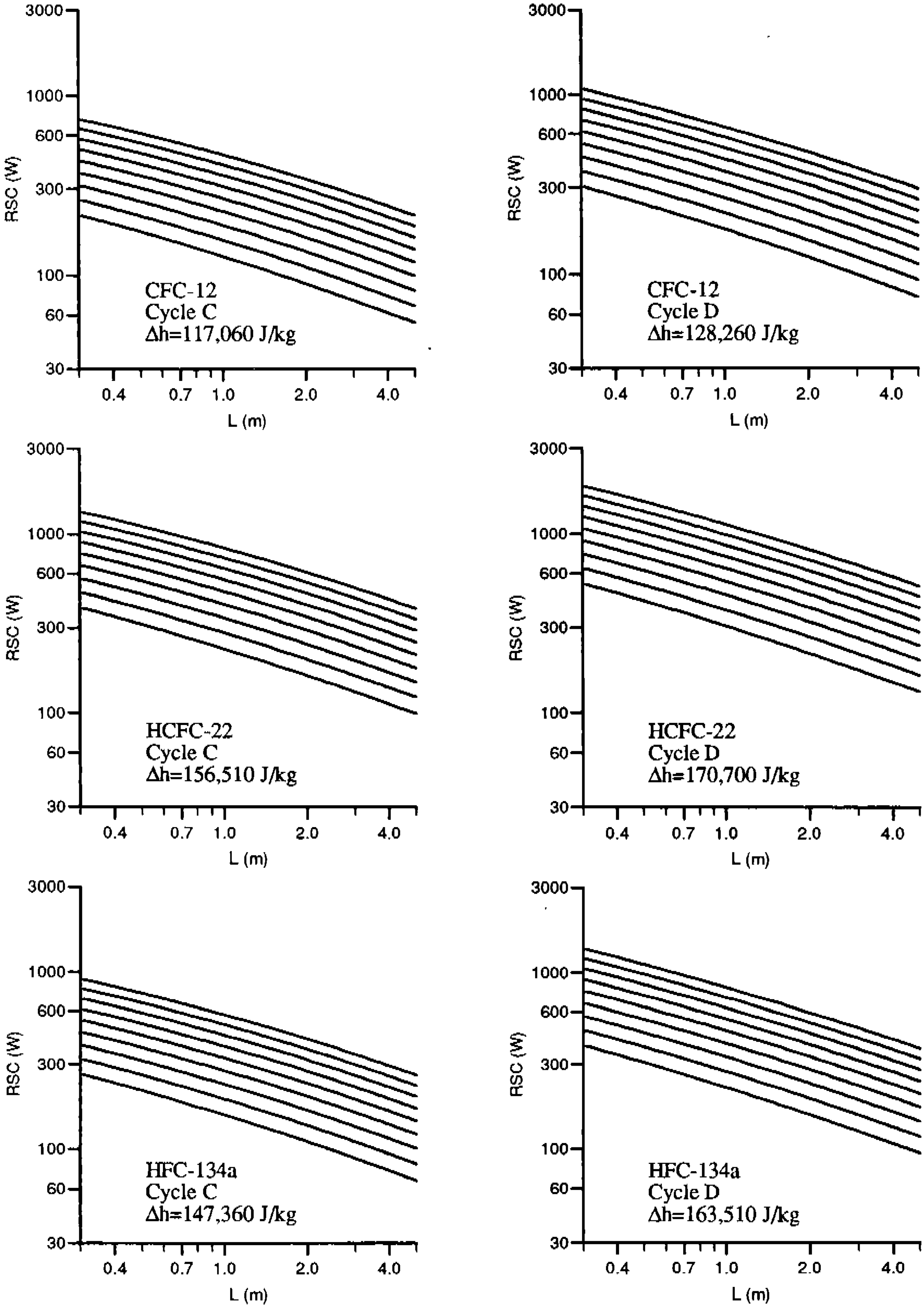


Fig. 1 Charts for a preliminary selection of capillary tube expansion devices