THERMAL CONDUCTIVITY OF SATURATED R123 AND R134A
TRANSIENT HOT WIRE MEASUREMENTS -

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1. INTRODUCTION

Chemical stable chlorinated hydrocarbons destroy the protecting ozone layer in the upper parts of the atmosphere - this has been found about 15 years ago, and since that time it became more and more clear how serious the problem is. Traditional refrigerants, e.g. R11 (CCl_3F) and R12 (CCl_2F_2), have to be replaced in course of the next few years by substances which contain less or even no chlorine, for example by R123 ($C_2HCl_2F_3$) and R134a ($C_2H_2F_4$) respectively. Application of new substances as working fluids in refrigeration cycles and as blowing agents in foaming of polyurethane (PUR) requires detailed information about toxicological, chemical and thermophysical properties, like latent heat of vaporization, density, boiling curve, viscosity - and thermal conductivity.

2. EXPERIMENTS

2.1. Apparatus

The thermal conductivity has been measured by application of the transient hot wire method [1-6] in an apparatus described in [7]. The characteristics of this apparatus are compiled in table I.

TABLE I - Characteristics of the hot wire apparatus [7]

<u>Cell</u>	material:	steel	<u>Wire</u>	material:	platinum
	radius:	8 mm		radius:	0.0085 mm
	height:	230 mm		length:	154.1 ± 0.1 mm
				resistance:	92.28 ± 0.05 Ω

2.2. Evaluation

As described in [3] the governing equation is

$$\Delta T_{id} = \Delta T_w + \sum \delta T_i = \frac{q_l}{4\pi\lambda} \ln\left[\frac{4a\tau}{r^2 C}\right] \qquad (1)$$

with $\Delta T_w = T(\tau) - T_0$ being the temperature rise of the electrically heated wire from the initial temperature T_0 during the time τ, q_l being the heat flux per unit length of the wire, λ and a the thermal conductivity and diffusivity of the fluid, r the radius of the wire and C a constant, δT_i the various additive corrections. The correction terms δT_i in eq.(1) have been detailed in [3,8]. The first correction, δT_1, accounts for the finite heat capacity of the wire and has been given by Healy et al.[3]. The correction δT_2 arises from temperature dependence of the heat flux [3]. In the present measurements these correction have been applied. Further corrections, which arise, e.g., from the presence of an outer boundary to the fluid, from axial heat conduction near the supports, or from radiation, have been neglected in the present work due to their small amount.

The thermal conductivity can be calculated from

$$\lambda = \frac{q_l}{4\pi} / \frac{d(\Delta T_{id})}{d(\ln \tau)} \tag{2}$$

where $d(\Delta T_{id})/d(\ln \tau)$ is obtained from consecutively recorded temperatures after correcting if necessary. This temperature increase is linear as long as only heat conduction determines the heat dissipation from the wire during a certain time interval.

The transient temperature of the wire is transferred into a voltage change of a precision Wheatstone-bridge and recorded by a computerized data acquisition system. The pressure was measured by two pressure gauges in the ranges $p < 4$ bar (accuracy $\pm$ 0.05 bar) and $p > 4$ bar ($\pm$ 0.15 bar) respectively. The accuracy achieved for thermal conductivity was estimated to be within $\pm$ 2%.

2.3. Procedure

Prior to the experiments the apparatus was carefully cleaned, filled with an appropiate amount of fluid and finally closed hermetically.

For the liquid state experiments the test cell is brought to thermal equilibrium with the pressure well above saturation - the liquid is subcooled. At constant temperature the inner volume is now enlarged in small steps by means of a piston. The pressure decreases during this procedure until saturation state is obtained where pressure keeps constant at further expansion, due to beginning evaporation. A liquid level appears at the uppermost point of the test cell (far above the hot wire) where saturation state is found at the phase interface. Liquid below the level still remains subcooled to some very small extend which may be neglegted.

Measurements of vapour thermal conductivity are taken in a similar way but now at a stepwise increased pressure, ranging from superheated vapour to nearly saturation state. This is done by a stepwise reduction of the inner volume. The pressure rises until saturation state is approached where the pressure keeps constant due to beginning condensation. A liquid level appears at the lowest point of the test cell (far below the hot wire). This is the exact point of saturation state, but as pressure variations inside the vapour space are extremely small, saturation state may be assumed at any place inside. Measurements of vapour thermal conductivity next to saturation proved to be not feasible, no linear relationship according to eq.(2) could be obtained. This strange behaviour is thought to be due to onset of condensation at the wire itself prior to the measurement. Therefore the thermal conductivity of saturated vapour has to be evaluated in any case by extrapolation from superheated vapour data. This will be shown below.

3. RESULTS

3.1. Saturated liquid

Thermal conductivities measured for saturated liquid R123 and R134a (purities 99.5% and 99.8% respectively) are listed in table II and plotted vs. temperature in fig.1 and 2. Additionally, respective curves are given for the R11 and R12 (as recommended by ASHRAE [9]).

Fig.1 includes some results of preliminary experiments with R11 which show good agreement with recommended values [9] (within $\pm$ 2 %) and with numerous data points which have been measured by various authors (as reported in [10]). The thermal conductivity of liquid R123 proves to be smaller than that of R11 at the same temperature by about $\Delta\lambda$ = 0.01 W/(K m) which corresponds to 10 - 15 %. The data points for R123 have been correlated (within $\pm$ 1.5 %) by eq.(3) for $-20^\circ C \leq \vartheta \leq 80^\circ C$:

$$\lambda' = 0.08389 - 2.6611\ 10^{-4}\ \vartheta \tag{3}$$

with ϑ being the temperature in [°C] and λ' the thermal conductivity of saturated liquid in [W/(K m)].

TABLE II - Thermal conductivity of liquid R123 and R134a measured in saturation state

saturated liquid R123						saturated liquid R134a					
ϑ (^oC)	p_s (bar)	λ' W/(K m)	ϑ (^oC)	p_s (bar)	λ' W/(K m)	ϑ (^oC)	p_s (bar)	λ' W/(K m)	ϑ (^oC)	p_s (bar)	λ' W/(K m)
-18.6	0.15	0.0884	21.6	0.8	0.0784	-11.3	1.9	0.0977	30.8	7.7	0.0792
-15.7	0.18	0.0878	30.6	1.1	0.0755	- 9.8	2.0	0.0975	41.0	10.2	0.0750
-12.0	0.21	0.0874	41.2	1.6	0.0731	- 4.5	2.4	0.0943	51.1	13.3	0.0709
-10.4	0.22	0.0864	50.7	2.2	0.0700	- 2.2	2.6	0.0919	61.0	16.7	0.0669
- 4.9	0.29	0.0848	61.0	2.9	0.0672	0.7	2.9	0.0914	71.0	21.2	0.0620
1.2	0.37	0.0837	70.5	3.8	0.0650	10.7	4.2	0.0873	81.1	26.3	0.0581
10.8	0.55	0.0820	81.0	4.9	0.0626	20.5	5.7	0.0826			
19.9	0.78	0.0790									

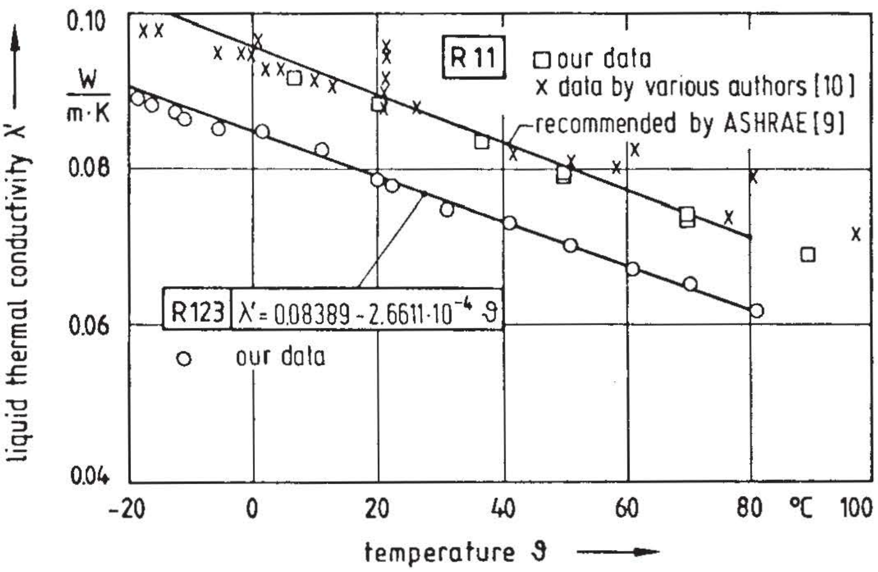

Fig.1 - Thermal conductivity of R123 (and R11) in state of saturated liquid

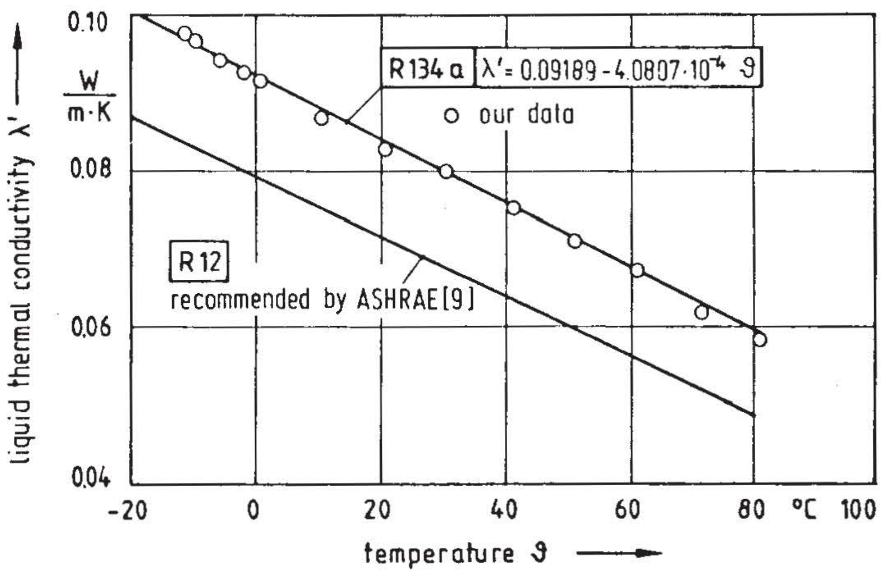

Fig.2 - Thermal conductivity of R134a (and R12) in state of saturated liquid

TABLE III - Thermal conductivity of vaporized R123 and R134a

vaporized R123					vaporized R134a				
ϑ (°C)	p (bar)	λ W/(K m)	p_s (bar)	λ'' W/(K m)	ϑ (°C)	p (bar)	λ W/(K m)	p_s (bar)	λ'' W/(K m)
31.9	1.0	0.0105	1.2	0.0106	0.6	3.0	0.0123	3.0	0.0125
41.5	1.3	0.0112	1.6	0.0113	21.0	5.7	0.0140	5.9	0.0140
51.0	1.8	0.0120	2.2	0.0119	42.0	9.5	0.0162	10.7	0.0164
61.3	2.5	0.0126	3.0	0.0126	60.8	15.0	0.0184	17.1	0.0192
71.1	3.4	0.0133	3.9	0.0133	81.0	22.0	0.0214	26.9	0.0230
91.2	5.0	0.0148	6.4	0.0147					

Fig.2 shows our results for saturated liquid R134a which exhibit an increase of about $\Delta\lambda$ = 0.012 W/(K m) in comparison to respective R12 data [9] at the same temperature. This corresponds to 10 - 20 %. The thermal conductivities measured for saturated liquid R134a are correlated within ± 1.5 % by:

$$\lambda' = 0.09189 - 4.0807\ 10^{-4}\ \vartheta \tag{4}$$

3.2. Saturated vapour

Table III shows vapour thermal conductivities for both substances, R123 and R134a. For any temperature two conductivities are given, one (λ) which has been measured as close to saturation line as possible, and another one (λ'') which is obtained by extrapolation for saturation state. This is indicated in fig.3 where thermal conductivity is plotted for superheated vapour vs. pressure. Measurements with vaporized R123 have been carried out at 6 different temperatures. Isotherms are indicated as straight parallel equidistant lines. They represent the data points within ± 2 %. At constant temperature, λ slightly increases when the pressure is raised. Thermal conductivities λ'' in state of saturation are determined by an extrapolation along the isotherms until saturation pressure is reached. The respective points are interconnenced in fig.3 by a dashed line. Fig.4 shows the effect of temperature on λ'' which has been correlated by a linear relationship within 31°C ≤ ϑ ≤ 92°C:

$$\lambda'' = 0.00844 + 6.8440\ 10^{-5}\ \vartheta \tag{5}$$

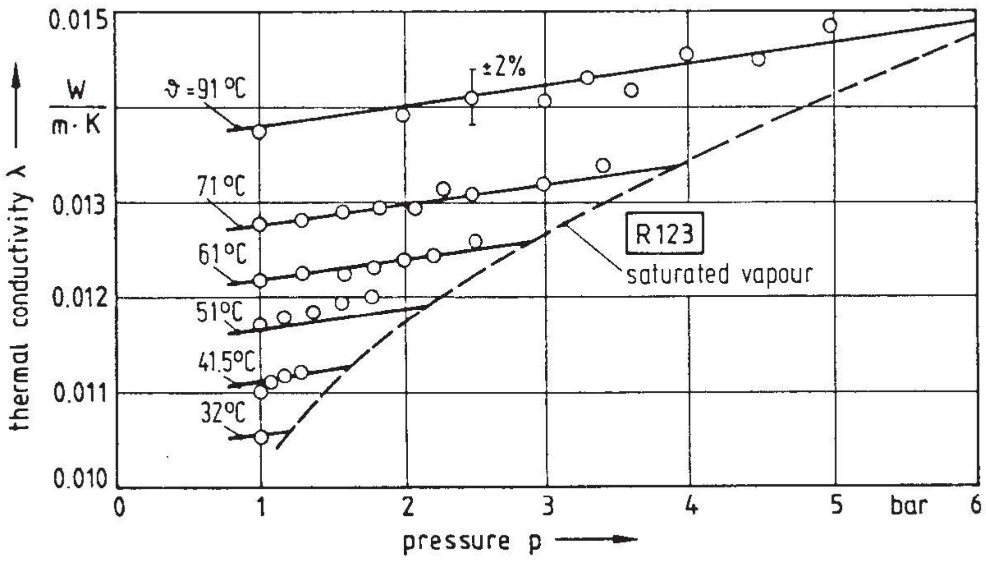

Fig.3 - Thermal conductivity of R123 in state of superheated vapour

A comparison with recommended data for R11 [9] shows a pronounced increase of the thermal conductivity from R11 to R123 which amounts to about 30 - 40%. This effect is extremely unfavourable, if R123 instead of R11 is used in PUR foams for isolation purposes.

Finally fig.5 shows the thermal conductivity for vaporized R134a which has been obtained in the same way as for R123. Saturation data are based on measurements along 5 isotherms as indicated in table III. They have been correlated by

$$\lambda'' = 0.01250 + 5.2422\ 10^{-5}\ \vartheta + 9.5655\ 10^{-7}\ \vartheta^2 \tag{6}$$

This curve is plotted together with the linear curve for R12 (taken from ASHRAE [9]). There is an increase from R12 to R134a which amounts to about $\Delta\lambda$ = 0.004 W/(K m) corresponding to 40 - 50 %.

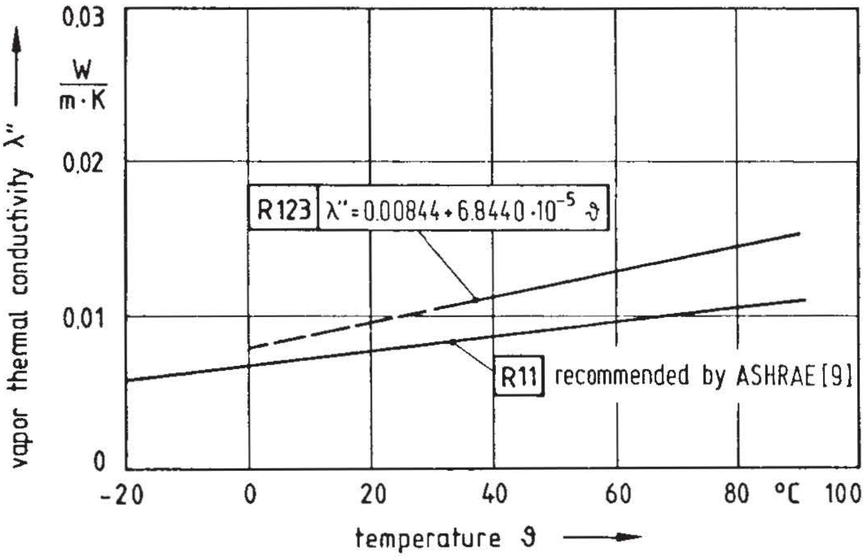

Fig.4 - Thermal conductivity of R123 (and R11) in state of saturated vapou

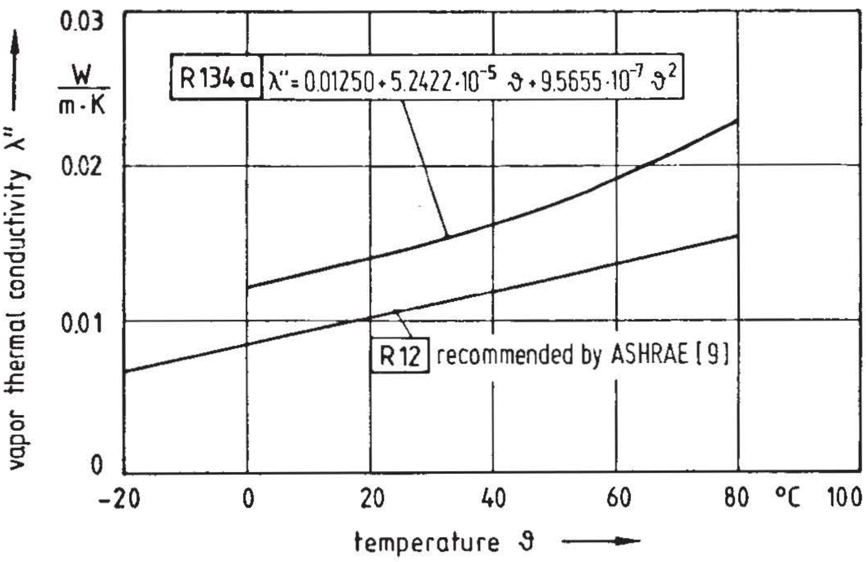

Fig.5 - Thermal conductivity of R134a (and R12) in state of saturated vapour

4. CONCLUSIONS

Liquid and vapour thermal conductivities of two 'new' refrigerants have been measured. Correlations (eq.(3)-(6)) are compiled for both R123 and 134a in saturation state based on a limited number of data points. The following conclusions may be drawn from the results:

- -- Vapour thermal conductivity increases by about 30 to 40 % from R11 to its feasible substitute R123 - an unfavourable effect which enlarges the thickness of thermal insolations made from PUR foams.
- -- Both liquid and vapour thermal conductivities increase from R12 to its substitute R134a - this is a favourable effect on heat transfer in refrigeration cycles (evaporation, condensation, heat transfer from superheated vapour).
- -- The correlations should be regarded as preliminary ones - more detailed measurements may bring slight changes.

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CONDUCTIVITE THERMIQUE DU R123 ET DU R134a.MESURES PAR LA METHODE DU FIL CHAUD EN REGIME TRANSITOIRE

RESUME : On présente la mesure de la conductivité thermique du R123 et du R134a, par la méthode du fil chaud en régime transitoire. Les données expérimentales s'étendent de la courbe de saturation aux domaines du gaz surchauffé et du liquide sous-refroidi. Des formules empiriques sont données pour la conductivité thermique du liquide saturé du R123 et du R134a (-20°C $\leq \theta \leq$ 80°C) et de la vapeur saturée (R123 : 30°C $\leq \theta \leq$ 90°C ; R134a : 0°C $\leq \theta \leq$ 80°C). Les conductivités thermiques du R123 et R134a à l'état vapeur sont supérieures à celles du R11 et du R12 de 30 et 50 % respectivement ; les conductivités thermiques du liquide diffèrent d'environ 20 % en plus pour le R134a par rapport au R12, et en moins pour le R123 par rapport au R11.