

PREDICTING THE THERMODYNAMIC PROPERTIES
OF FREONS BY USING RESTRICTED DATA

A.E.HANAFY *

Mech.Power Eng.Dep.,Faculty of Eng.&Tech.
Menoufia University,Shebin El-Kom ,EGYPT .

ABSTRACT

New and simple methods are presented for predicting the thermodynamic properties of freons . These methods had been tested by using the data of the refrigerants R123b , R134a ,R32 and many others and gave good accuracy specially in the range [$0.9 < T / T_b < 1.25$] which is the range of refrigeration and air conditioning applications . Also the accuracy of the presented methods is very good in comparison with other methods

KEYWORDS

Refrigerants- Thermodynamic properties- Prediction .

INTRODUCTION

Montreal Protocol [1] calls to restrict the production of certain fully halogenated chlorofluorocarbon (CFC) refrigerants . Several programs are underway for evaluating the alternative refrigerants , that closely match the existing original refrigerants . Alternatives may be a pure component, a binary mixture or even triple azeotropic mixture .

*Lecturer

Manuscript received from Dr: A. E. Hanafy at: 18/ 8/ 1997,
Accepted at: 14/ 10/ 1997, pp. 71-92,
Engineering research bulletin, Vol. 20, No. 3, 1997,
Menoufiya University, Faculty of Engineering,
Shebin El-Kom, Egypt, ISSN. 1110-1180.

In [15] it is mentioned that alternatives for R22 are R134a , a ternary azeotropic mixture R407C (23%R32 , 25%R125 , 52% R134a by weight) , and R410B (35%R32 , 55%R125 by weight) . It is very important to use theoretical work to decrease the area of searching before role of experimental work .

An equation of state [5] for the Lennard -Jones fluid (LJF) had been derived in the form of modified Benedict-Webb-Rubin equation (MBWR), has 33 constants, and valid for $0 \leq \rho \leq 1.2$, and $0.5 \leq T \leq 6.0$. Nicolas equation of state for the Lennard Jones Fluid has the form :

$$P = \rho \cdot T + \sum_{l=2}^9 B_{l(T)} \cdot \rho^l + \sum_{J=1}^6 C_{J(T)} \cdot \rho^{(2J+1)} \cdot e^{-\gamma \rho^2} \quad (1)$$

where

$$\rho : \text{density} = \rho \cdot \frac{M}{Na \cdot S} \quad , \text{ Kg/m}^3 \quad (2)$$

$$P : \text{pressure} = P \cdot \frac{R \cdot E}{Na \cdot S} \quad , \text{ kPa} \quad (3)$$

$$T : \text{the reduced temperature} = T / E \quad (4)$$

The objective function is a function of vector \bar{X} containing the individual parameters of the refrigerant . This function is optimized and at its minimum condition (i.e. the minimum deviation between experimental properties and the calculated ones) , the values of vector \bar{X} are found . The form of the objective function is very important and affects the accuracy of representing the experimental data .

Mazur et al [6] suggested two methods which had been tested beyond the range of experimental data and also for the liquid region . First method based on minimizing the difference between the experimental values of pressures and the calculated ones at the same isothermal line . This method has very poor accuracy in representing saturation properties . The second method based on minimizing the differences between the experimental values of saturated pressure and densities and the calculated ones . The data of critical point of a refrigerant may be used to find

the individual parameters of an equation of state . The calculated quantities by this method would have large relative error specially away of the critical point . In all previous methods the conditions of phase equilibrium are not fulfilled , need large number of data and their accuracy in calculating the properties beyond the used data is poor .

In [7] a method based on the minimum deviation between the experimental saturation properties and the calculated ones by using the equation of state at certain temperature and also fulfills the phase equilibrium conditions of the equation of state was used . The suggested method achieves the minimum deviation between the model saturation line and that of the refrigerant away of the critical zone . This method is based on knowing the saturated properties (pressure , specific volume of both liquid and vapor), so, it needs less number of data . Its accuracy in representing saturation properties is good, fulfills the conditions of phase equilibrium , its accuracy in calculating the properties beyond the used data is good . On the other hand , it is not simple , the solution is not easy and needs long time . All previous methods cannot be used for predicting the unknown thermodynamic properties by knowing two saturated properties only .

The main purpose of this work is to realize methods for predicting the thermodynamic properties of not well studied freons according to the type of information available .

CALCULATING THE SATURATION LINE PARAMETERS OF LJF

The conditions of equilibrium are

$$T_l = T_v , P_l = P_v , \mu_l = \mu_v . \quad (5)$$

For pure components the chemical potential equals the Gibbs function G. . For finding the saturation parameters at a temperature T , the used objective function is :

$$F(Y) = (A1 - A2)^2 + (A2 - A3)^2 + (A3 - A1)^2 \quad (6)$$

Where :

$$A1 = P_l * (1/\rho_v - 1/\rho_l) \&$$

$$A2 = P_v * (1/\rho_v - 1/\rho_l) \& \quad A3 = \int_v^l P \, d v \quad , \quad (7)$$

$$Y(1) = \rho_l \quad \& \quad Y(2) = \rho_v \quad (8)$$

THE SUGGESTED OBJECTIVE FUNCTIONS

According to the type of the available information ,the objective function is suggested as follows :

1- THE THREE SATURATED PROPERTIES ARE AVAILABLE

In present work a simpler form of objective function is used and the vector \bar{X} has two components only(E & S) . The used objective function has the form :-

$$F_{(\bar{X})} = \left[(1 - P^*/P_s)^2 + (1 - \rho_v^*/\rho_v)^2 + (1 - \rho_l^*/\rho_l)^2 + (1 - G_v/G)^2 + (1 - G_l/G)^2 + (1 - G_l/G_v)^2 \right] \quad (9)$$

The suggested method is a more reliable one . It minimizes the deviation between the saturation properties of the refrigerant and that of the equation of state and also fulfills the conditions of phase equilibrium conditions as in Eq. 5 .

2- TWO SATURATION PROPERTIES ARE AVAILABLE :

a- PRESSURE AND DENSITY OF THE SATURATED LIQUID

The objective function has the form :

$$F_{(\bar{X})} = \left[(1 - P^*/P_s)^2 + (1 - \rho_l^*/\rho_l)^2 + (1 - G_l/G)^2 \right] \quad (10)$$

b- PRESSURE AND DENSITY OF THE SATURATED VAPOUR

The objective function has the form :

$$F_{(\bar{X})} = \left[(1 - P^*/P_s)^2 + (1 - \rho_v^*/\rho_v)^2 + (1 - G_v/G)^2 \right] \quad (11)$$

c- SATURATED DENSITIES OF BOTH LIQUID AND VAPOUR

The objective function has the form :

$$F\left(\frac{x}{x}\right) = \left[\left(1 - \frac{\rho_v^*}{\rho_v}\right)^2 + \left(1 - \frac{\rho_l^*}{\rho_l}\right)^2 + \left(1 - \frac{G_v}{G}\right)^2 + \left(1 - \frac{G_l}{G}\right)^2 + \left(1 - \frac{G_v}{G_v}\right)^2 \right] \quad (12)$$

where

G - Gibb's function deduced from LJE saturation line

$$= \frac{P}{\rho} + \int_0^{\rho} (P - \rho.T) \frac{d\rho}{\rho^2} + T \cdot \ln \rho$$

G_l - Gibb's function of the saturated liquid of freon in reduced coordinates .

$$= \frac{P^*}{\rho_l^*} + \int_0^{\rho_l^*} (P - \rho.T) \frac{d\rho}{\rho^2} + T \cdot \ln \rho_l^*$$

G_v - Gibb's function of the saturated vapor of freon in reduced coordinates .

$$= \frac{P^*}{\rho_v^*} + \int_0^{\rho_v^*} (P - \rho.T) \frac{d\rho}{\rho^2} + T \cdot \ln \rho_v^*$$

CALCULATION OF THERMAL PROPERTIES :

Latent heat of vaporization of a pure freon can be calculated by the Clapeyron equation :

$$H_{lat} = \frac{J^* (V_v - V_l) * R}{N_a * S} \left(\left(1 - T^* \frac{dE}{dT}\right) * \frac{dP_s}{dT} + P_s * \frac{dE}{dT} - \frac{P_s * E}{S} * \frac{dS}{dT} \right) \text{ kJ/kg} \quad (13)$$

Latent heat of vaporization per unit volume of saturated vapour of a freon can be calculated by the equation :

$$Q_v \approx H_{lat} / V_v \quad \text{kJ/m}^3 \quad (14)$$

Referring to point 0 in appendix A , the following equations can be used ,

For the internal energy

$$\int_{u_0}^u d u = \frac{R}{M} \left\{ u \left(E - \frac{\partial E}{\partial T} * T \right) - \frac{P}{\rho} * \frac{E}{S} * \frac{\partial S}{\partial T} * T \right\}_{\rho_0, T_0}^{\rho, T} + u^0 \quad (15)$$

For the enthalpy

$$\int_{H_0}^H d H = u + \left\{ \frac{P}{\rho} \right\}_{P_0, D_0}^{P, D} + H_{ref} \quad \text{kJ/kg} \quad (16)$$

$$H = u + \left\{ \frac{P}{\rho} \right\}_{P_0, D_0}^{P, D} + H_0 + H_{ref} \quad \text{kJ/kg} \quad (17)$$

For the entropy kJ/kg/K

$$s = \frac{R}{M} \left\{ s - u \frac{\partial E}{\partial T} - \frac{P E}{\rho S} \frac{\partial S}{\partial T} \right\}_{\rho_0, T_0}^{\rho, T} + s^0 + s_0 + s_{ref} \quad (18)$$

For the ideal internal energy and entropy

$$u^0 = \int_{T_{ref}}^T C_{v_0} d T \quad , \quad s^0 = \int_{T_{ref}}^T \frac{C_{v_0}}{T} d T \quad (19)$$

The reliability of calculating a property is expressed by the relative error , defined by :

$$\text{Relative error} = \frac{\text{Calculated value} - \text{Tabulated value}}{\text{Tabulated value}}$$

METHOD OF OPTIMIZATION

The method of Powell [8] was used . This method depends upon fixing all vector components except one

direction and searching the minimum in this direction by any other uni-search method (Goggin method), then the obtained minimum value is fixed and the process is repeated for another direction .

RESULTS AND DISCUSSION

The objective function eq.(6) is used for obtaining the saturated vapour and liquid reduced densities and the saturated pressure at certain reduced temperature. The obtained results are correlated by the following equations :

$$\rho_l - \text{The saturation reduced liquid density} \\ = - .283956 / \mathcal{T} + 1.91127 - 2.40997 * \mathcal{T} + 1.79650 * \mathcal{T}^2$$

$$\text{where } \mathcal{T} = (1.35 - T)^{0.93} \quad (20)$$

$$\ln \rho_v - \text{The saturation reduced vapor density} \\ = - 3.5787667 + 7.63761 * \ln(T) - 7.20913/T \\ + 23.5681 - 24.5264 * T - 8.14644 * T^2 \quad (21)$$

$$\ln P_s - \text{The saturated reduced pressure} \\ = -3.84089375 + 7.94861 * \ln(T) - 5.79951/T \\ + 16.8657 - 14.8416 * T + 3.83065 * T^2 \quad (22)$$

$$G - \text{The saturated reduced Gibbs function} \\ = 2.31139 * \log T - 2.86425 \quad (23)$$

$$\frac{dP_s}{dT} - \text{The reduced pressure derivative is} \\ = (7.94861/T + 5.79951/T^2 - 14.8416 + 7.66130 * T) * P_s$$

The obtained results for Lennard-Jones potential parameters by different methods for many freons (R11, R12, R13, R14, R21, R21, R22, R23, R32, R40, R50, R113, R114, R115, R123b, R134a, R142b, R152a, R170, R216, R218, R245, R290, R3110) had been correlated as :

$$E_s = E_{s0} + E_{s1} * (\mathcal{T} / T_b - 1.0) + E_{s2} * (\mathcal{T} / T_b - 1.0)^2 \\ E = E_0 + E_1 * (\mathcal{T} / T_b - 1.0) \quad (24)$$

Table 1. $E = E_0 + E_1 * (\mathcal{J} / T_b - 1.0)$, $ES = ES_0 + ES_1 (\mathcal{J} / T_b - 1) + ES_2 (\mathcal{J} / T_b - 1)^2$

Objective function	E_0	E_1	ES_0	ES_1	ES_2
R123b (9)	.399246E+03	-.105559E+03	.565890E+05	-.174665E+05	.285874E+05
R123b (10)	.399183E+03	-.104678E+03	.569424E+05	-.159812E+05	.172499E+05
R123b (11)	.399241E+03	-.105678E+03	.569768E+05	-.226349E+05	.340759E+05
R123b (12)	.399356E+03	-.105921E+03	.569526E+05	-.178746E+05	.230622E+05
R134a (9)	.334302E+03	-.950368E+02	.339360E+05	-.135957E+05	.227333E+05
R134a (10)	.334159E+03	-.919924E+02	.341029E+05	-.124389E+05	.172376E+05
R134a (11)	.334302E+03	-.950057E+02	.341306E+05	-.970986E+04	.616048E+03
R134a (12)	.334265E+03	-.953911E+02	.341512E+05	-.134761E+05	.180663E+05
R152a (9)	.343171E+03	-.859845E+02	.309163E+05	-.102839E+05	.167462E+05
R152a (10)	.342733E+03	-.802926E+02	.309943E+05	-.864596E+04	.123526E+05
R152a (11)	.343166E+03	-.860533E+02	.304340E+05	-.177622E+04	.841976E+04
R152a (12)	.342636E+03	-.857722E+02	.310743E+05	-.107863E+05	.150132E+05
R32 (9)	.315455E+03	-.733123E+02	.188526E+05	-.344175E+04	.362989E+04
R32 (10)	.315304E+03	-.683729E+02	.189322E+05	-.277581E+04	.221004E+04
R32 (11)	.315470E+03	-.736519E+02	.190252E+05	-.250110E+04	.000000E+00
R32 (12)	.315584E+03	-.764429E+02	.189680E+05	-.302227E+04	.000000E+00

and their derivatives w.r.t. temperature are :

$$\frac{dS}{dT} = ES \left(-\frac{1}{E} \frac{dE}{dT} \right) + \left(ES_2 + 2ES_1 \left(\frac{T}{T_b} - 1 \right) \right) \frac{1}{T_b * E}$$

$$\frac{dE}{dT} = E_1 / T_b \quad (25)$$

For the purposes of comparison, the obtained coefficients of eq.(24) obtained by different methods (objective functions 9, 10, 11 & 12) for the freons (R123b, R134a, R32 & R152a) are listed in Table 1 .

Reliability of the obtained correlations in calculating the saturation properties of all the studied freons(24 freons) is demonstrated in figures 1 to 3 . The number of data points are 363 . The relative error in the calculated liquid density is less than 1% . The relative error in calculating the density of saturated vapor and also the saturated pressure is $\pm 2\%$.This accuracy is very good for a two-parameter model equation of state .

The reliability of predicting the density of saturated vapour by eq.(10), the saturated liquid density by eq.(11)& the saturated pressure by eq.(12) for different freons is shown in figs.4 , 5 & 6 respectively . Comparison between the reliability of different methods for predicting the latent heat of evaporation by eq. (13) and the latent heat of evaporation per unit volume by eq.(14) for (R134a , R123b & R32)is shown in figs. 7 to 12 respectively

In all cases the relative error is $\pm 2\%$, while for $Q_v \pm 3\%$, in the range $[0.9 < T / T_b < 1.25]$ which is the range of refrigeration and air conditioning applications .

It is worth to compare the accuracy of the presented methods by the other methods as in [16] where the authors selected well proven equations of state as Lee and Kesler (LKP) , Peng and Robinson (PR). The results of their check were in most cases $\pm 5\%$ for calculating the saturated vapour pressure and densities ,which means that the suggested methods are better .

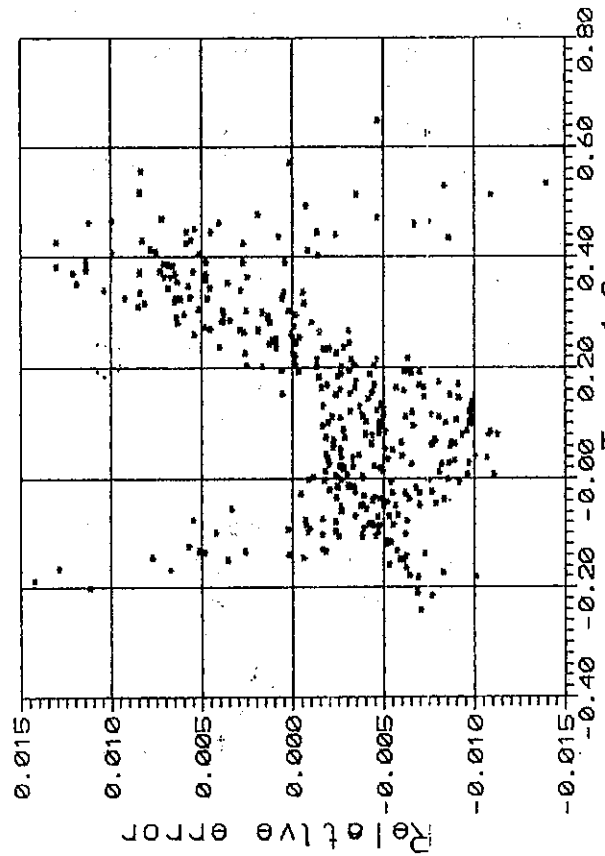


Fig. 1 The relative error of calculating saturated liquid density of freons by eq.(9).

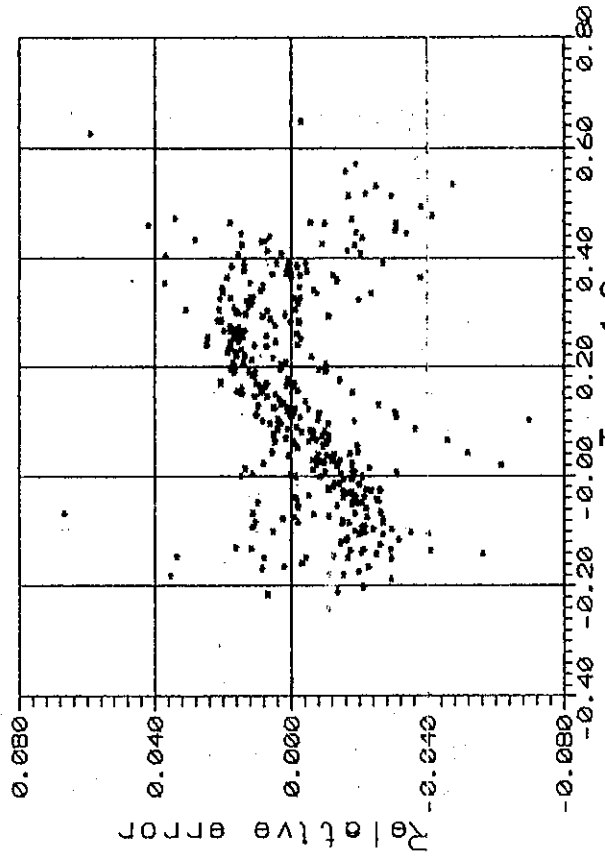


Fig. 2 The relative error of calculating saturated vapour density of freons by eq.(9).

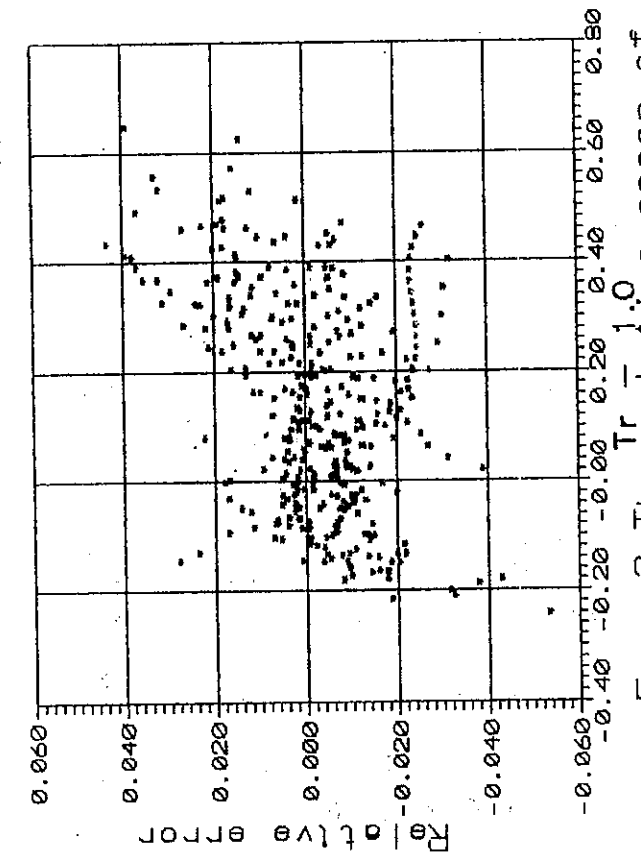


Fig. 3 The relative error of calculating saturated vapour pressure of freons by eq. 9 .

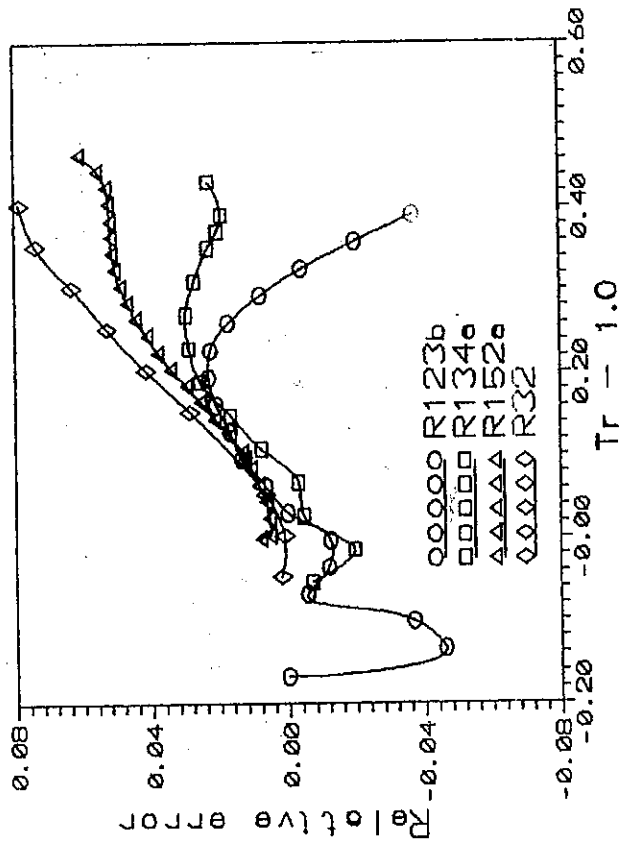


Fig. 4 Prediction of saturated vapour density for different freons

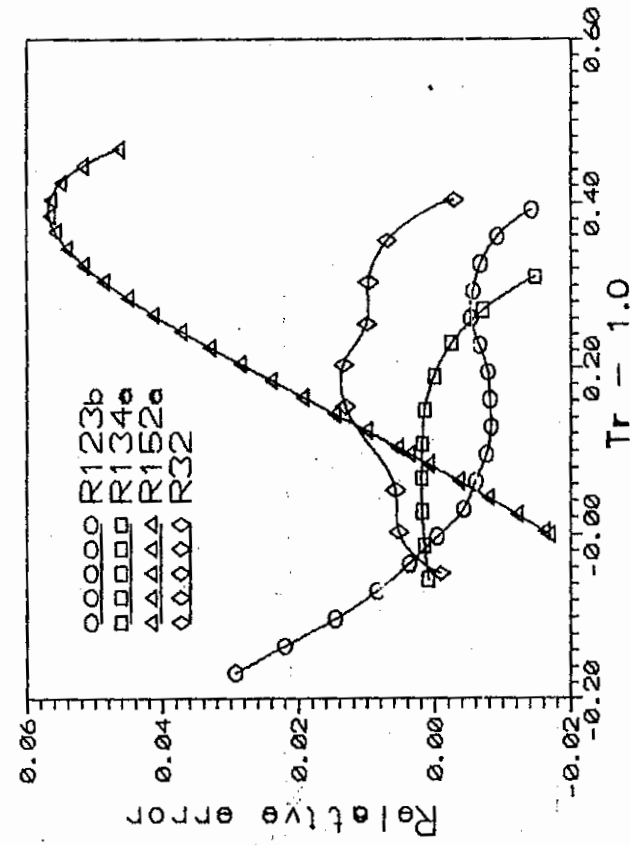


Fig. 5 Prediction of saturated liquid density for different freons

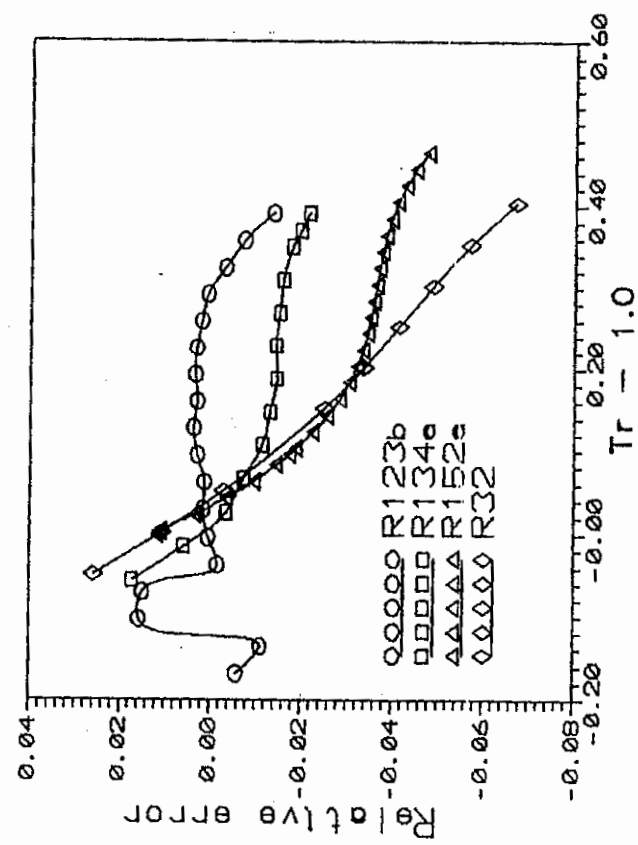


Fig. 6 Prediction of saturated pressure for different freons

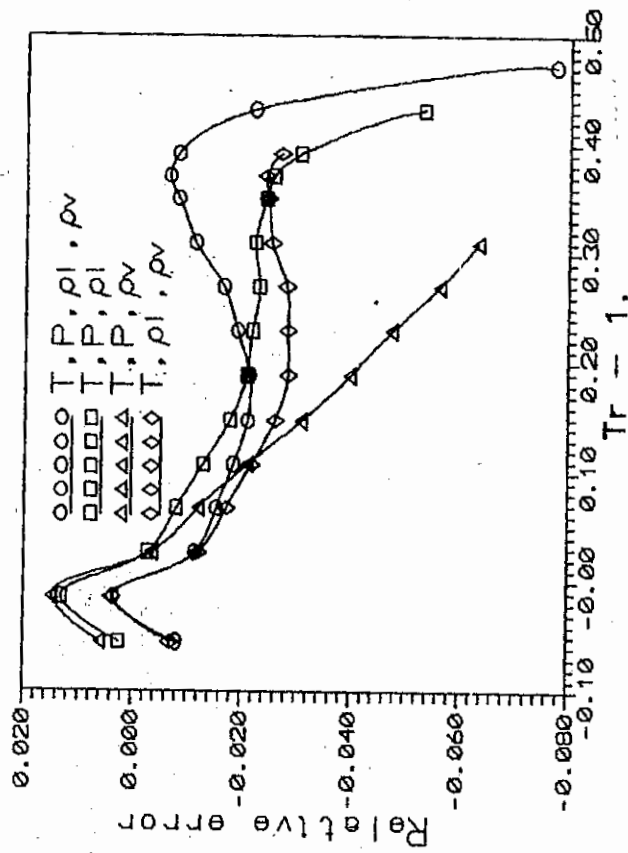


Fig. 7 Comparison between the accuracy of different methods for predicting latent heat of R134a

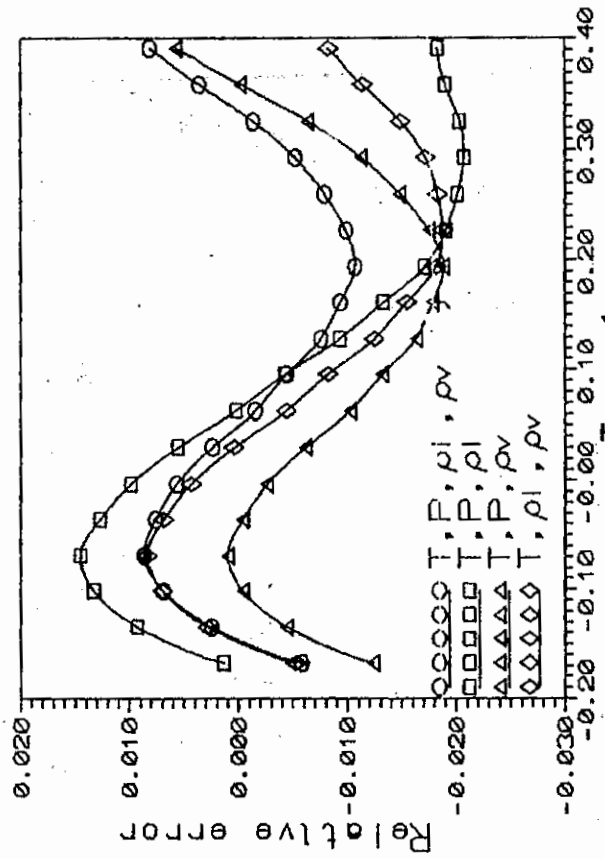


Fig. 8 Comparison between the accuracy of different methods for predicting latent heat of R123b

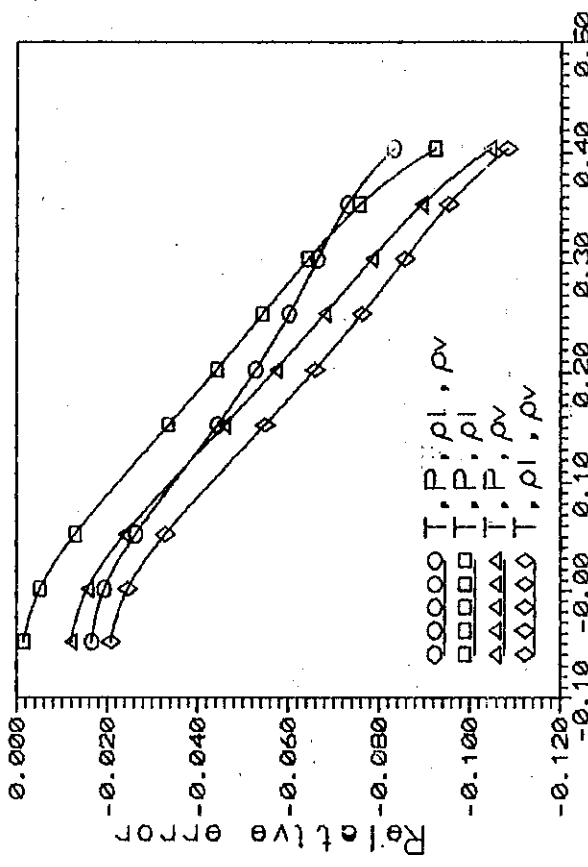


Fig.9 Comparison between the accuracy of different methods for predicting latent heat of R32

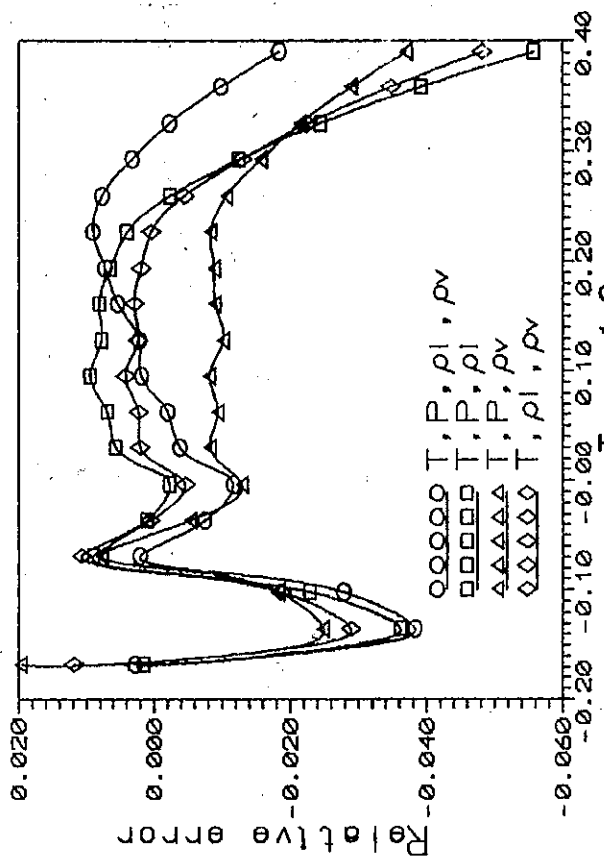


Fig.10 Comparison between the accuracy of different methods for predicting heat of evaporation per unit volume of vapour R123

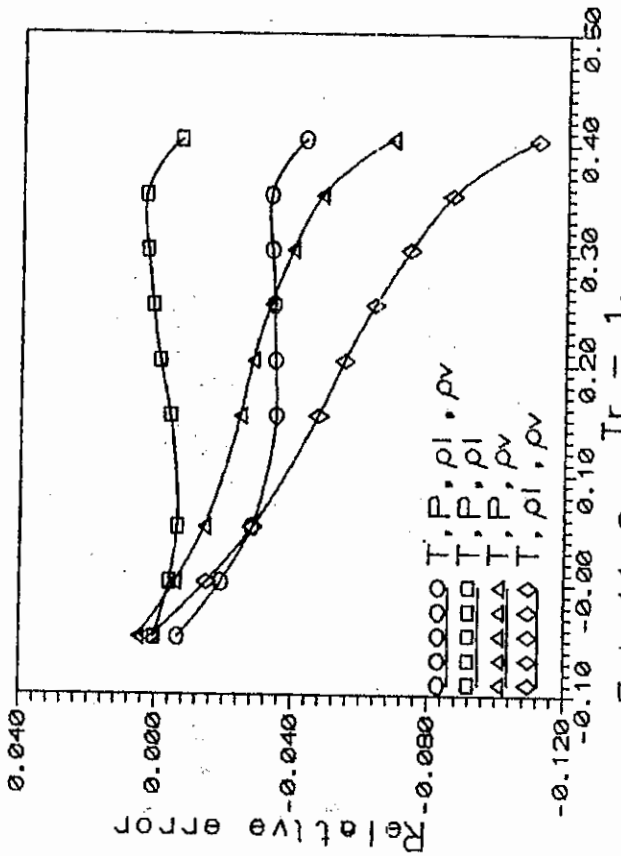


Fig. 11 Comparison between the accuracy of different methods for predicting evaporation heat per unit volume of R32

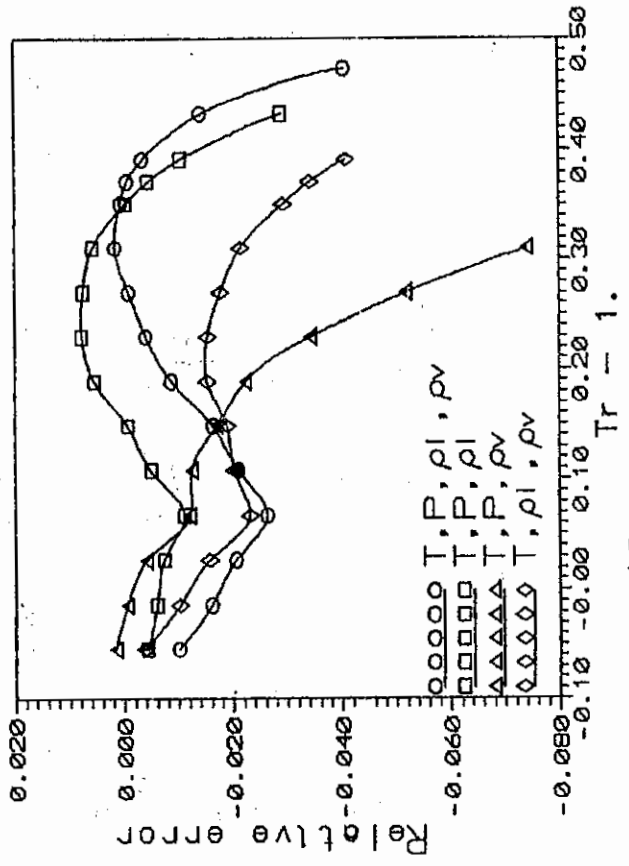


Fig. 12 Comparison between the accuracy of different methods for predicting heat of evaporation per unit volume of vapour R134a

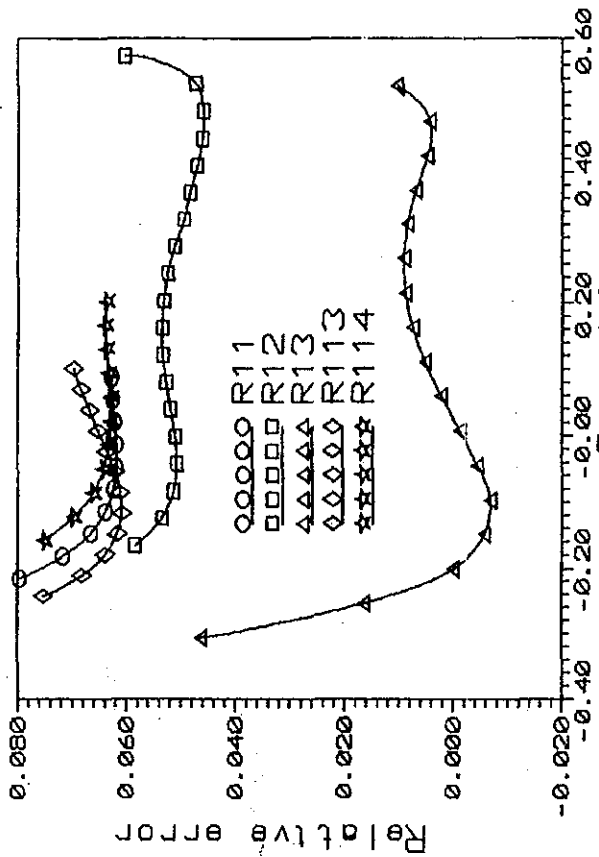


Fig. 13 The reliability of predicting the saturated liquid enthalpy of different freons .

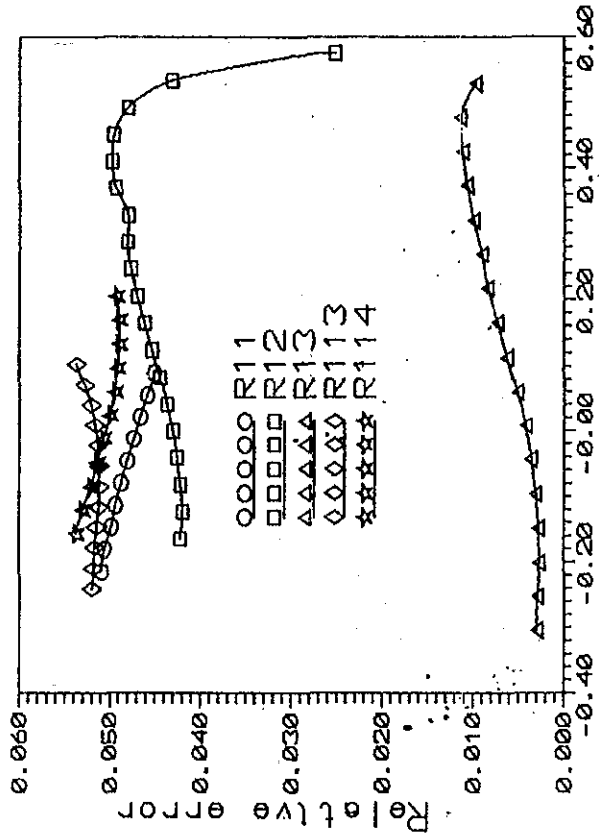


Fig. 14 The reliability of predicting the saturated vapour enthalpy of different freons .

The reliability of predicting the enthalpy of the saturated liquid and saturated vapour for different freons is demonstrated in figs. 13, 14. The relative error is + 5% for the vapour enthalpy while for liquid is less than 8% .

CONCLUSION

The importance of the suggested new methods is concluded in predicting the thermodynamic properties of not well studied freons according to the type of information available . These methods had been tested by using the data of the refrigerants R123b , R134a ,R32 and others and gave relative error $\pm 2\%$ or less specially in the range $[0.9 < T/T_b < 1.25]$ which is the range of refrigeration and air conditioning applications . Also the accuracy of the presented methods is very good in comparison with other methods

REFERENCES

- 1 - Montreal Protocol on substances that Deplete the Ozone Layer, United Nations Environment Program, Final Act , September (1987) .
- 2 - MICHAEL M. ABBOTT (1979). Cubic equations of state - an interpretive review , American Chemical Society , pp 47-70 .
- 3 - HANDERSON , D.(1979). Advances in chemistry ,V.128 ,American Chemical Society ,Washington, pp 1-30,
- 4 - MORRISON,G.,MCLINDEN ,M.(1985),Two refrigerant mixtures and the hard sphere fluid , ASHRAE Transactions, vol.91 ,part 2B, ,HI-85-18 NO. 3 ,pp . 929 - 943] .
- 5 - NICOLAS,J.J. ,GUBBINS,K.E., STREET,W.B. and TILDESLEY,D.J. (1979). Equation of state for Lennard-Jones fluid ,Molecular Physics, vol.37, No.5 ,1429-1454.
- 6 - MAZUR,V.A., BOSHKOV,L.Z. , HANAFY,A.E. (1986). ,Modeling properties of working fluids in solar cooling systems , Khaladilnaia Tekhnika e Tekhnologia ,vol 42 ,pp 33- 39 .(in Russian).
- 7 - HANAFY,A.E. (1987). ,Modeling thermodynamical properties of pure and binary mixture for refrigerating and heat pump cycles. Kandidat

- Tekhnicheskikh Naouk . . . OTIKhP . . . ODESSA (in Russian).
- 8 - DAVID M. HIMMELBLAU (1972)., Applied nonlinear programming , McGraw-Hill Book Company .
 - 9 - YORENEVA , V.N. and LEBEDEVA , P.D. (1975) Thermo-Technology Handbook .vol. 1 ,Energia , Moscow (in Russian).
 - 10- WILLIAM C. REYNOLDS (1979)., Thermodynamic properties in SI , Stanford University ,Stanford ,CA 94305 .
 - 11- TOMANOVSKAIA ,V.F. ,KOLOTOVA B.B.,(1970) ,Freons: properties and use.,Khimia ,Moscow (in russian).
 - 12- GRIGORIEVA , V.A. and ZORINA V.M. (1980), Heat energy and thermal technology handbook ,Energia ,Moscow (in russian).
 - 13- MCLINDEN M.O. , MORRISON G. (1989) , Measurement and formulation of the thermodynamic properties of refrigerants R 134a and R123 ., ASHRAE Transactions,vol.95 ,Part2 ,3282 (RP-588) pag. 263.
 - 14- KAMEI A.,PIAO C.C.,SATO H. and WATANABE K. , (1990) Thermodynamic charts and cycle performance of FC-134a and FC-152a .,ASHRAE transactions , vol. 96, part 1 , (3318) pag. 141.
 - 15- DONALD B. ,and others ,(1995)HCFC-22 Alternatives for air conditioners and heat pumps . ASHRAE Transactions :Symposia ,CU-95-12-2, page 1065 - 1071
 - 16- DORING R. , and KNAPP H., (1981) Calculation of thermodynamic properties with generalized equations of state for mixed refrigerant cycles . International Journal of refrigeration ,Vol.4 , No. 2 March 1981 .

NOMENCLATURE

B(T),C(T): functions of reduced temperature in eq.(1)
 dQ : change of heat entering the system , kJ/kg
 dU : change of intenal energy of a system , kJ/kg
 ρ : density , kg/m³
 E :the Lennard-Jones energy parameter = ϵ_0 / k , K
 ES:the Lennard-Jones energy volume parameter = E*S
 F :helmholz function kJ/kg
 G :Gibb's function deduced from LJF saturation line

H_{lat} : Latent heat of evaporation, kJ/kg
 H : enthalpy, kJ/kg
 k : Boltzmann constant = $1.38064E-26$ kJ/K/molecule
 M : molecular weight
 N_a : Avogadro's number = $6.022169E+26$, Kmol^{-1}
 P : the reduced pressure
 \mathcal{P} : pressure, kPa
 QV : heat of evaporation per unit volume, kJ/m³
 R : gas constant = $N_a * k = 8.31441$ kJ/K/Kmol
 r : the distance from molecule center.
 S : the Lennard - Jones volume parameter = σ^3 , \AA^3
 \mathcal{S} : entropy, kJ/kg/K
 T : the reduced temperature = \mathcal{T} / E
 T_b : refrigerant boiling temp. at normal pressure, K.
 \mathcal{T} : temperature, K
 \mathcal{U} : internal energy, kJ/kg
 V : specific volume of the system, m³/kg
 γ : constant in eq.(1)
 ϵ_0 : the minimum energy of interaction, kJ
 μ : chemical potential, kJ/kmole
 ρ : the reduced density
 σ : distance at which Lennard-Jones potential = 0, \AA
 Φ : Lennard - Jones potential = $4\epsilon_0 \left[\left(\frac{\sigma}{r} \right)^{12} - \left(\frac{\sigma}{r} \right)^6 \right]$

Subscripts

- l saturated liquid freon in reduced coordinates .
- v saturated vapour freon in reduced coordinates .
- * deduced from experimental (tabulated) quantities

APPENDIX A

THERMODYNAMIC RELATIONSHIPS IN TERMS OF LJF PARAMETERS

Helmholtz function $F = \mathcal{U} - \mathcal{T} * \mathcal{S}$
 $dF = d\mathcal{U} - \mathcal{T} d\mathcal{S} - \mathcal{S} d\mathcal{T} = d\mathcal{U} - (d\mathcal{U} + \mathcal{P} dV) - \mathcal{S} d\mathcal{T}$
 $= - \mathcal{P} dV - \mathcal{S} d\mathcal{T}$
 $-\left. \frac{\partial \mathcal{P}}{\partial \mathcal{T}} \right|_V = -\left. \frac{\partial \mathcal{S}}{\partial V} \right|_{\mathcal{T}}$
 $dQ = \mathcal{T} d\mathcal{S} = \mathcal{T} \left[\left. \frac{\partial \mathcal{S}}{\partial V} \right|_{\mathcal{T}} dV + \left. \frac{\partial \mathcal{S}}{\partial \mathcal{T}} \right|_V d\mathcal{T} \right]$

For the isothermal process :

$$dQ = T \left. \frac{\partial \mathcal{F}}{\partial V} \right|_T dV = dU + \mathcal{P} dV$$

and

$$\begin{aligned} dU &= T \left. \frac{\partial \mathcal{F}}{\partial V} \right|_T dV - \mathcal{P} dV = T \left. \frac{\partial \mathcal{P}}{\partial T} \right|_V dV - \mathcal{P} dV \\ &= \left(\left. \frac{\partial \mathcal{P}}{\partial T} \right|_V - \mathcal{P} \right) dV \end{aligned}$$

Nicolas equation of state has the form :

$$P = \rho \cdot T + \sum_{i=2}^{\sigma} B_{i(T)} \cdot \rho^i + \sum_{J=1}^{\sigma} C_{J(T)} \cdot \rho^{(2J+1)} \cdot e^{-\gamma \rho^2}$$

Let : s : entropy in reduced co-ordinates

$$s = - \int_0^{\rho} \left. \frac{\partial (P - \rho \cdot T)}{\partial T} \right|_{\rho} \frac{d\rho}{\rho^2} - \ln \rho$$

u : internal energy in reduced coordinates

$$u = \int_0^{\rho} \left(P - T \cdot \left. \frac{\partial P}{\partial T} \right|_{\rho} \right) \frac{d\rho}{\rho^2}$$

Taking in mind that :

$$\frac{\partial T}{\partial \mathcal{F}} = \frac{1}{E} - \frac{T}{E^2} \cdot \frac{\partial E}{\partial \mathcal{F}}, \quad \left. \frac{\partial \rho}{\partial \mathcal{F}} \right|_V = \frac{\rho}{S} \cdot \frac{\partial S}{\partial \mathcal{F}}$$

$$\text{and : } \mathcal{P} = P \left(\frac{R \cdot E}{Na \cdot S} \right) \text{ kPa}$$

and differentiating w.r.t. temperature :

$$\begin{aligned} \left. \frac{\partial \mathcal{P}}{\partial \mathcal{F}} \right|_V &= \frac{R}{Na} \left[\left(\left. \frac{\partial P}{\partial T} \right|_{\rho} \cdot \frac{\partial T}{\partial \mathcal{F}} + \left. \frac{\partial P}{\partial \rho} \right|_T \cdot \left. \frac{\partial \rho}{\partial \mathcal{F}} \right|_V \right) \cdot \frac{E}{S} \right. \\ &\quad \left. + \left(\frac{P}{S} \cdot \frac{\partial E}{\partial \mathcal{F}} - \frac{P \cdot E}{S^2} \cdot \frac{\partial S}{\partial \mathcal{F}} \right) \right] \end{aligned}$$

Substituting and rearranging :

$$\begin{aligned} \left. \frac{\partial \mathcal{P}}{\partial \mathcal{F}} \right|_V &= \frac{R}{Na \cdot S} \left[\left(\left. \frac{\partial P}{\partial T} \right|_{\rho} \cdot (1 - T \cdot \frac{\partial E}{\partial \mathcal{F}}) \right) \right. \\ &\quad \left. + P \cdot \frac{\partial E}{\partial \mathcal{F}} + \left(\left. \frac{\partial P}{\partial \rho} \right|_T \cdot \rho - P \right) \cdot \frac{E}{S} \cdot \frac{\partial S}{\partial \mathcal{F}} \right] \end{aligned}$$

$$\left. \frac{\partial \Phi}{\partial \mathcal{J}} \right|_V = \frac{R}{Na \cdot S} \left[\left. \frac{\partial P}{\partial T} \right|_\rho + (P - T \cdot \left. \frac{\partial P}{\partial T} \right|_\rho) \cdot \frac{\partial E}{\partial \mathcal{J}} \right. \\ \left. + \left(\left. \frac{\partial P}{\partial \rho} \right|_T \cdot \rho - P \right) \cdot \frac{E}{S} \cdot \frac{\partial S}{\partial \mathcal{J}} \right]$$

Calculating :

$$\Phi - \mathcal{J} \left. \frac{\partial \Phi}{\partial \mathcal{J}} \right|_V = \frac{R \cdot E}{Na \cdot S} \left[(P - T) \left. \frac{\partial P}{\partial T} \right|_\rho - (P - T) \cdot \left. \frac{\partial P}{\partial T} \right|_\rho \right] \cdot \frac{\partial E}{\partial \mathcal{J}} \cdot T \\ - \left(\left. \frac{\partial P}{\partial \rho} \right|_T \cdot \rho - P \right) \cdot \frac{E}{S} \cdot \frac{\partial S}{\partial \mathcal{J}} \cdot T$$

The entropy :

$$\int_{\mathcal{J}^0}^{\mathcal{J}} d\mathcal{J} = \int \left. \frac{\partial \Phi}{\partial \mathcal{J}} \right|_V dV = \frac{-R}{Na \cdot S} \int_0^\rho \left\{ \left. \frac{\partial P}{\partial T} \right|_\rho + (P - T) \cdot \left. \frac{\partial P}{\partial T} \right|_\rho \right\} \cdot \frac{\partial E}{\partial \mathcal{J}} \\ + \left(\left. \frac{\partial P}{\partial \rho} \right|_T \cdot \rho - P \right) \cdot \frac{E}{S} \cdot \frac{\partial S}{\partial \mathcal{J}} \left. \right\} \frac{d\rho}{\rho^2} \cdot Na \cdot S \quad \text{kJ/kmole}$$

$$\mathcal{J} = \frac{R}{M} \left\{ s - u \frac{\partial E}{\partial \mathcal{J}} - \frac{P}{\rho} \frac{E}{S} \frac{\partial S}{\partial \mathcal{J}} \right\}_{0, T}^{\rho, T} + \mathcal{J}^0 \quad \text{kJ/kg}$$

$$\int_{u^0}^u du = - \int \left[\Phi - \mathcal{J} \left. \frac{\partial \Phi}{\partial \mathcal{J}} \right|_V \right] dV = R \int_0^\rho \left\{ (P - T) \left. \frac{\partial P}{\partial T} \right|_\rho \right\} \left(E - \frac{\partial E}{\partial \mathcal{J}} \cdot \mathcal{J} \right) \\ - \left(\left. \frac{\partial P}{\partial \rho} \right|_T \cdot \rho - P \right) \cdot \frac{E}{S} \cdot \frac{\partial S}{\partial \mathcal{J}} \cdot \mathcal{J} \left. \right\} \frac{d\rho}{\rho^2} \quad \text{kJ/kmole}$$

and

$$u = \frac{R}{M} \left\{ u \left(E - \frac{\partial E}{\partial \mathcal{J}} \cdot \mathcal{J} \right) - \frac{P}{\rho} \cdot \frac{E}{S} \cdot \frac{\partial S}{\partial \mathcal{J}} \cdot \mathcal{J} \right\} + u^0 \quad \text{kJ/kg}$$

عنوان البحث: توقع الخواص الترموديناميكية للفيونات باستخدام معلومات قليلة

المؤلف د. أحمد السيد حنفي

قسم هندسة القوى الميكانيكية , كلية الهندسة , جامعة المنزلة

الملخص

تم تقديم طرق جديدة و بسيطة لتوقع أو تخمين الخواص الترموديناميكية للفيونات باستخدام معلومات محدودة جدا و تبعا لتوعها . تم اختبار هذه الطرق على الفيونات , R132b , R32 , R134a و على أنواع أخرى كثيرة بلغت 22 نوعا و أظهر الاختبار جودة هذه الطرق و بصفة خاصة في المدى ($0.9 < T/T_b < 1.25$) وهو مدى التطبيق في مجالات التبريد و التكييف . و قد قورنت هذه الطرق المقدمة بطرق أخرى منشورة فكانت هي الأفضل .