

**DIPOLE MOMENT, EXPANSIVITY AND
COMPRESSIBILITY COEFFICIENTS OF HFC 125
DERIVED FROM
DIELECTRIC CONSTANT MEASUREMENTS¹**

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ABSTRACT

The hydrofluorocarbons (HFC's) including pure and mixture refrigerants of HFC-32, HFC-125, HFC-134a and HFC-143a are the most promising environmentally-safe compounds for replacing ozone depleting HCFC-22 and R-502 in air-conditioning systems and large-scale commercial refrigeration units.

The dielectric constant of the alternative refrigerants is important for the study the electric properties of these polar fluids. It also gives insight to develop the molecular theory of liquids, and, at the same time, it is an important parameter for the design of the machinery used in the air-conditioning and refrigeration industry. This paper reports measurement of the static dielectric constant of HFC-125, in the liquid phase, performed by using the direct capacitance method at 10 kHz and for temperatures from 214 to 304 K and pressures up to 16 MPa. The repeatability of the measurements was found to be less than $\pm 0.7 \times 10^{-4}$ and the uncertainty is estimated to be better than $\pm 0.72 \times 10^{-3}$. We provide a complete set of tables of experimental data as a function of temperature, pressure and density, which cover the dielectric property needs for most engineering applications. The data obtained was used to establish dielectric equations of state as a function of density and temperature and as a function of pressure and temperature.

Moreover, in order to study the dependence of the dielectric constant on temperature, pressure and density, we have applied the molecular theories of polar liquids, such as the equation of Vedam et al. [2,3], adapted by Diguet [4] and the Kirkwood modification of the Onsager equation [5,6]. The apparent dipole moment obtained was $\mu^* = 2.482$ Debye.

From the dielectric equation of state it was possible to make estimation of the isobaric thermal expansion coefficient and of the isothermal compressibility of HFC-125, in the range studied.

KEY WORDS: dielectric constant, dipole moment, HFC-125, Kirkwood equation, isobaric thermal expansion coefficient, isothermal compressibility, Vedam equation.

1. INTRODUCTION

One of the most urgent issues to be solved in the refrigerant industries is to identify the optimum alternative refrigerant to replace the conventional R-502 (an azeotrope of HCFC-22 and CFC-115), which is being dominantly used in low-temperature refrigeration system. A binary mixture of HFC-125 and HFC-143a (R507) and a ternary mixture of HFC-125/134a/143a (R-404A) are considered as the most promising candidates to replace R-22 and R-502. Pentafluoroethane (R-125) was tested by the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) and considered as a non-toxic, a non-genotoxic and non-mutagenic compound.

The dielectric constant of HFC-125 was measured as a continuation of our research program for the determination of the dielectric properties of some environmentally acceptable refrigerants and their mixtures. We have previously reported dielectric constant data and the subsequent dipole moment in the liquid state for several pure fluids, such as, HCFC-141b, HCFC-123, HCFC-142b, HFC-134a [7,8], HFC-32 [9], HFC-152a [17], and for some refrigerant mixtures, namely R-410A¹ [10], R-404A², R-407C³ and R-507⁴ [11]. In this work we present accurate experimental results of dielectric constant of HFC-125 as a function of temperature and pressure in the liquid phase, providing an information for industrial needs. Using a direct capacitance method, measurements were carried out at 10 kHz, from 214 to 304 K and pressures from 2 to 16 MPa.

The isobaric thermal expansion coefficient and of the isothermal compressibility, α_p and k_T , were calculated from the dielectric equations of state developed.

¹ A HFC-based nearly azeotropic mixture, composed by HFC-32/HFC-125.

² A ternary zeotropic blend composed by HFC-125/143a/134a.

³ Also a zero ozone depletion blend composed by HFC-32/125/134a.

⁴ The azeotrope of HFC-125 and HFC-143a.

2. EXPERIMENTAL

The experimental technique performs absolute measurements of dielectric constant, based on a direct capacitance method. The sample handling and the apparatus performance have been described in detail by Gurova et al. [12], while a description of the cell has been presented by Mardolcar et al. [13]. Vacuum capacitance was measured prior to filling the cell with the sample. An impedance analyser (Shlumberger, model 1260) was used, with an accuracy of 5×10^{-4} pF. The technique employed a four terminal connection to the cell in order to compensate for parasitic impedances. The mean value of a 10-dimensional sample taken at a 10 kHz frequency provides the experimental value of dielectric constant, which proved to be properly suited to the working accuracy. All the measuring process involving instrumentation is now fully automated and operated from a computer graphics user interface, which also provides storage and descriptive statistics to the data.

The temperature of the cell was measured with a calibrated (at 4 points) platinum resistance thermometer (100Ω at $0 \text{ }^\circ\text{C}$), located near the sample. The resistance of the Pt-100 thermometer was determined with a four-wire measurement, with a 5 1/2 digital multimeter (Keithley, model 199 DMM). This instrument was also calibrated with three standard resistors. The sensor was calibrated at four points.

The pressure vessel is immersed in a cylindrical copper vessel cooled by a serpentine connected to a commercial cryostat (Julabo, model FPW90-SC), filled with ethanol and operative in the temperature range from 183 to 373 K, with an accuracy of 0.1K.

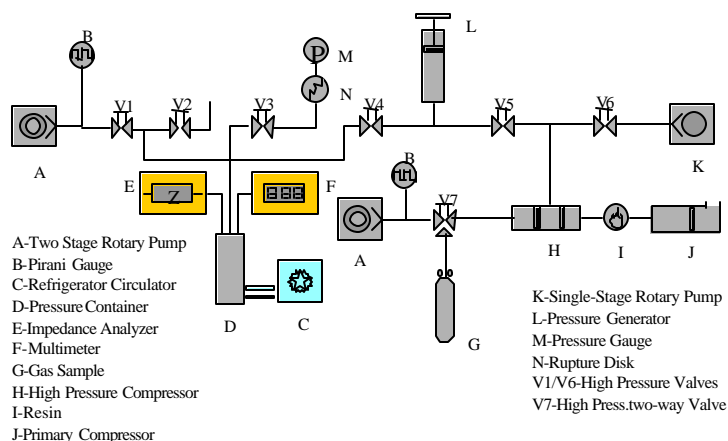
The vacuum system consisted of a 2-stage rotary pump and was used to obtain the measurements of the capacitance of the empty cell and to clean all the system before filling in the cell with the samples. Vacuum points were stable in the order of 10^{-4} pF over the duration of this study.

For the measurements of capacitance under pressure, a high-pressure line was built, composed by a HIP manual liquid-pressure generator and an air-operated, diaphragm-type compressor (Newport Scientific). The pressure was measured with a pressure transducer from Setra Systems with an uncertainty of 0.01 MPa. The sample used has been obtained from Elf-Atochem, France, with an estimated purity of 99.5%. Its state of purity and physical properties can be seen in Table 1.

Table 1. Physical properties and purity of HFC-125

Chemical name	Pentafluoroethane
ASHRAE Nomenclature	R-125
Molecular formula	CHF_2CF_3
Relative Molar Mass (g/mol)	120.02
Boiling point @ 1atm ($^{\circ}\text{C}$)	- 48.6
Estimated water content (ppm)	< 10
Purity (%)	> 99.5

A schematic diagram of the apparatus set-up for the measurements of the dielectric constant in the liquid phase is presented in figure 1.

**Fig.1. Schematic diagram of the experimental apparatus.**

The refrigerant was measured without further purification. The measurements were performed at an average of 10 isotherms separated by ≈ 10 K, in steps of 1 MPa, from 2 to 16 MPa. The values of the density of R-125 were calculated using a 32-term modified Benedict-Webb-Rubin (MBWR) equation of state, proposed by Outcalt and McLinden [14], which represents available experimental data from 174 to 448K and pressures to 68 MPa with a maximum deviation of ± 0.2 %, in the region corresponding to the present measurements.

The uncertainty of the experimental measurements of the dielectric constant with the present apparatus was found in previous papers to be better than 0.16 % [1, 7, 8, 17],

for a confidence interval of 95%⁵, reflecting the uncertainty in the temperature, pressure and capacitance measurements (in the fluid and in vacuum). For the dielectric constant measurements with HFC 125 the value of the uncertainty is estimated to be $\pm 0.72 \times 10^{-3}$.

3. RESULTS AND DISCUSSION

The following relation gives the dielectric constant of the fluid:

$$\mathbf{e} = \frac{C(p,T)}{C_0(T)} \quad (1)$$

where $C(p,T)$ is the geometric capacitance at pressure p and temperature T and $C_0(T)$ is the capacitance under vacuum at a temperature T . Table 2 presents the data obtained as a function of pressure and density for each isotherm, for the refrigerant studied.

Table 2. Experimental values of the Dielectric Constant of HFC-125⁶

p (MPa)	r (kg m ⁻³)	\mathbf{e}	p (MPa)	r (kg m ⁻³)	\mathbf{e}	p (MPa)	r (kg m ⁻³)	\mathbf{e}
$T_n = 303.74$ K			$T_n = 273.19$ K			$T_n = 243.31$ K		
16.00	1298.24	5.14852	16.00	1405.28	6.26914	16.00	1502.49	7.63996
14.99	1291.85	5.11837	15.00	1401.02	6.24447	15.00	1499.48	7.61840
14.00	1285.30	5.08702	14.00	1396.63	6.21937	14.00	1496.39	7.59681
13.00	1278.39	5.05436	13.00	1392.13	6.19277	13.00	1493.24	7.57477
11.99	1271.08	5.02044	12.00	1387.47	6.16666	12.00	1490.05	7.55295
11.00	1263.55	4.98402	11.00	1382.66	6.13874	11.00	1486.79	7.53001
10.00	1255.47	4.94645	10.00	1377.71	6.11013	10.00	1483.46	7.50717
9.00	1246.91	4.90617	9.00	1372.58	6.08062	9.00	1480.08	7.48382
7.99	1237.75	4.86352	8.00	1367.24	6.04995	8.00	1476.62	7.46020
7.00	1228.03	4.81868	7.00	1361.72	6.01879	7.00	1473.06	7.43593
6.00	1217.47	4.77033	6.00	1355.98	5.98646	6.00	1469.45	7.41098
5.00	1205.91	4.71625	5.00	1349.98	5.95193	5.00	1465.74	7.38610
4.01	1193.26	4.66147	4.00	1343.69	5.91568	4.00	1461.93	7.35937
3.00	1178.91	4.59737	3.00	1337.08	5.87978	3.00	1458.01	7.33261
2.01	1162.67	4.52497	2.00	1330.19	5.84240	2.00	1454.02	7.30559

⁵ Here we use the ISO definition of uncertainty, with $k=2$ (95% confidence). Using the common calculation for accuracy, the values reported must be divided by 2.

⁶ T_n is a nominal temperature. All experimental points measured at a given temperature T , close to T_n ,

where adjusted to this temperature, by using $\mathbf{e}(T_n, p) = \mathbf{e}(T, p) + \left(\frac{\partial \mathbf{e}}{\partial T} \right)_p (T_n - T)$.

$T_n = 294.08$ K			$T_n = 263.32$ K			$T_n = 233.19$ K		
16.00	1333.08	5.48165	16.00	1438.08	6.68550	16.00	1534.25	8.19469
15.00	1327.53	5.45345	15.00	1434.29	6.66185	15.00	1531.54	8.17440
14.00	1321.77	5.42441	14.00	1430.39	6.63776	14.00	1528.79	8.15388
13.00	1315.77	5.39408	13.00	1426.41	6.61299	13.00	1525.99	8.13338
12.00	1309.51	5.36303	12.00	1422.32	6.58781	12.00	1523.14	8.11288
11.00	1302.99	5.33044	11.00	1418.12	6.56213	11.00	1520.24	8.09128
10.00	1296.17	5.29617	10.00	1413.78	6.53548	10.00	1517.29	8.06963
9.00	1288.98	5.26028	9.00	1409.34	6.50866	9.00	1514.30	8.04760
8.00	1281.36	5.22241	7.99	1404.73	6.48060	8.00	1511.21	8.02494
7.00	1273.35	5.18247	7.00	1400.01	6.45191	7.00	1508.12	8.00224
6.00	1264.86	5.14094	6.00	1395.15	6.42282	6.00	1504.97	7.97943
5.00	1255.71	5.09609	5.00	1390.11	6.39290	5.00	1501.75	7.95558
4.00	1245.88	5.04838	4.00	1384.87	6.36180	4.00	1498.47	7.93196
3.00	1235.13	4.99649	3.00	1379.42	6.32898	3.00	1495.12	7.90791
2.00	1223.34	4.94095	2.00	1373.77	6.29534	2.00	1491.68	7.88279

Table 2. Experimental values of the Dielectric Constant of HFC-125 (contn'd)

p (MPa)	r (kg m ⁻³)	e	p (MPa)	r (kg m ⁻³)	e	p (MPa)	r (kg m ⁻³)	e
$T_n = 283.21$ K			$T_n = 253.29$ K			$T_n = 223.20$ K		
16.00	1371.13	5.87740	16.00	1470.69	7.14283	16.00	1565.11	8.80421
15.00	1366.32	5.85120	15.00	1467.33	7.12118	15.00	1562.67	8.78479
14.00	1361.32	5.82372	14.00	1463.87	7.09862	14.00	1560.19	8.76537
13.00	1356.16	5.79544	13.00	1460.34	7.07545	13.00	1557.65	8.74478
12.00	1350.82	5.76684	12.00	1456.73	7.05170	12.00	1555.08	8.72433
11.00	1345.28	5.73689	11.00	1453.04	7.02735	11.00	1552.49	8.70343
10.00	1339.53	5.70600	10.00	1449.25	7.00258	10.00	1549.87	8.68295
9.00	1333.53	5.67351	9.00	1445.37	6.97736	9.00	1547.24	8.66253
8.00	1327.27	5.64054	8.00	1441.40	6.95149	8.00	1544.55	8.64173
7.00	1320.73	5.60552	7.00	1437.32	6.92499	7.00	1541.81	8.62041
6.00	1313.84	5.56917	6.00	1433.13	6.89847	6.00	1539.04	8.59877
5.00	1305.86	5.53081	5.00	1428.82	6.87060	5.00	1536.20	8.57692
4.00	1298.92	5.49199	4.00	1424.39	6.84253	4.01	1533.36	8.55498
3.00	1290.73	5.44786	3.00	1419.79	6.81299	3.01	1530.44	8.53212
2.00	1281.98	5.40315	2.00	1415.05	6.78240	2.00	1527.43	8.50964
$T_n = 214.32$ K			$T_n = 214.32$ K			$T_n = 214.32$ K		
p (MPa)	r (kg m ⁻³)	e	p (MPa)	r (kg m ⁻³)	e	p (MPa)	r (kg m ⁻³)	e
16.00	1592.05	9.40676	16.00	1592.05	9.40676	16.00	1592.05	9.40676
15.00	1589.84	9.38960	15.00	1589.84	9.38960	15.00	1589.84	9.38960
14.00	1587.61	9.37041	14.00	1587.61	9.37041	14.00	1587.61	9.37041
13.00	1585.33	9.35174	13.00	1585.33	9.35174	13.00	1585.33	9.35174
12.00	1583.02	9.33209	12.00	1583.02	9.33209	12.00	1583.02	9.33209
11.00	1580.68	9.31215	11.00	1580.68	9.31215	11.00	1580.68	9.31215
10.00	1578.31	9.29232	10.00	1578.31	9.29232	10.00	1578.31	9.29232

9.00	1575.92	9.27243
8.00	1573.53	9.25279
7.00	1571.10	9.23317
6.00	1568.64	9.21291
5.00	1566.12	9.19204
4.01	1563.58	9.17107
3.00	1560.97	9.15001
2.00	1558.52	9.12981

The experimental data of the dielectric constant were fitted by an iterative \mathbf{c}^2 method (each iteration implemented by a Levenberg-Marquart procedure) to a function in density and temperature, of the following form (T in K and \mathbf{r} in kg m^{-3}):

$$\mathbf{e}(\mathbf{r}, T) = a_0 + \frac{a_1}{T} + a_2 \mathbf{r} + \frac{a_3 \mathbf{r}}{T} \quad (2)$$

with a standard deviation of 0.08%.

For industrial needs the data were also fitted to a function in pressure and temperature according to the equation (p in MPa and T in K):

$$\mathbf{e}(p, T) = b_0 + \frac{b_1}{T} + b_2 p + \frac{b_3 p}{T} \quad (3)$$

with a standard deviation of 0.21%. The coefficients of eq.2 and eq.3 with their uncertainty are given in Table 3.

Table 3. Coefficients of the dielectric equations of state (eq.2 and eq.3)

a_0	a_1 / K	$10^{-3} a_2 / \text{kg}^{-1} \text{ m}^3$	$a_3 / \text{K m}^3 \text{ kg}^{-1}$
5.141 ± 0.086	-1866 ± 29	-3.3867 ± 0.0521	2.471 ± 0.017
b_0	b_1 / K	$10^{-2} b_2 / \text{MPa}^{-1}$	$b_3 / \text{K MPa}^{-1}$
-6.364 ± 0.031	3314 ± 7.8	8.908 ± 0.309	-15.426 ± 0.784

An analysis of the experimental data of dielectric constant as a function of density is also presented in this paper. The Vedam formalism was applied based on the work of Vedam et al. [3] and Diguët [4]. According to this theory, the variation of the dielectric

constant with pressure is a function of the deformation of the volume, showing a non-linear behaviour in the case of the liquids. This nonlinearity can be reduced when the variation of \mathbf{e} , \mathbf{D} , is analysed as a function of the Eulerian deformation, \mathbf{S} , also named Eulerian strain. It is possible to verify that \mathbf{S} provides a linear relation for \mathbf{D} independently of the type of molecules that compose the fluid. We have used the relation between $\mathbf{e}^{1/2}$ and the Eulerian strain, \mathbf{S} which is defined, according to the Vedam relation, as:

$$\Delta = \mathbf{e}^{1/2}(\mathbf{r}) - \mathbf{e}^{1/2}(\mathbf{r}_0) = A\Sigma + B \quad (4)$$

$$\Sigma = \frac{1}{2} \left[\left(1 - \frac{\mathbf{r}}{\mathbf{r}_0} \right)^{2/3} \right] \quad (5)$$

Here \mathbf{r}_0 is the reference density, taken in this case as the saturation value for each isotherm. The saturation density data of R125 was calculated using the equations of state provided by Outcalt and McLinden [14].

The calculations made, show that the function Δ indeed represents a linear variation with the Eulerian Strain Σ , as can be seen in figure 2.

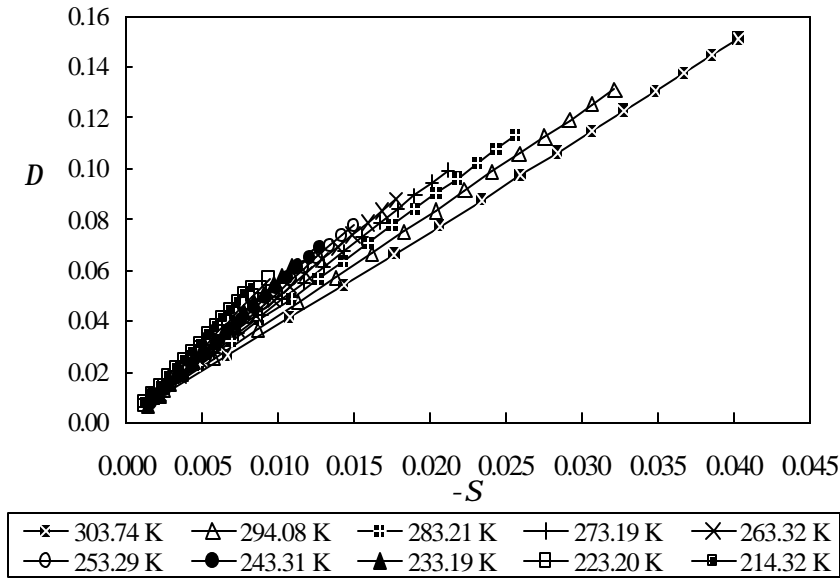


Fig.2. Variation of D with the Eulerian Strain, S (eq.4).

Table 4 presents the values of the coefficients A and B of the Vedam equation for each isotherm. The intercept values are closer to zero for all isotherms, $B \cong 0$. The slope of the linear variation of D with S is negative for all temperatures, decreasing linearly with the increase with temperature, as expected from the theory.

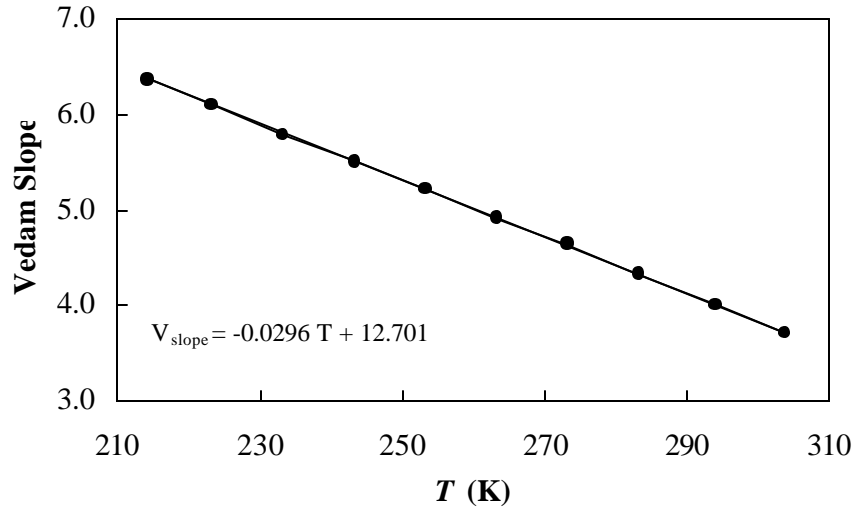


Fig.3. Graphical representation of the Vedam slope.

Assuming that $B=0$ (eq.4) it is possible to use the Vedam relation to estimate the dielectric constant values. In the present work, as reported before [1,10,11,15], we have estimated the new value of A' , by fitting the experimental results as a function of Σ and forcing the constant B to be equal to zero. In this case the Vedam equation takes the following form:

$$D = A' S \tag{6}$$

The new values of the slope A' according to eq.6 are presented also in Table 4.

Table 4. Values of the constants A and B of the Vedam equation (eq.4) and values of the constant A' in eq.6

T (K)	r_{sat} (kgm^{-3})	$e(r_{sat})$	A	B	A'
214.32	1553.2	9.080	-6.3685	0.00088	-6.5186
223.20	1521.7	8.473	-6.1038	-0.00142	-5.8903
233.19	1485.2	7.846	-5.7912	-0.00184	-5.5538
243.31	1446.7	7.263	-5.5071	-0.00151	-5.3404
253.29	1406.9	6.733	-5.2290	-0.00071	-5.1622
263.32	1364.7	6.238	-4.9207	0.00037	-4.9502
273.19	1320.5	5.781	-4.6442	0.00091	-4.7040
283.21	1272.0	5.342	-4.3302	0.00176	-4.4249
294.08	1214.0	4.884	-4.0091	0.00200	-4.0941
303.74	1155.7	4.484	-3.7114	0.00125	-3.7535

We can estimate the variation of the dielectric constant with density for each isotherm. Figure 4 presents the deviations between the estimated values and the experimental data of dielectric constant, calculated according to this method. As can be seen they are random and smaller than 0.25%.

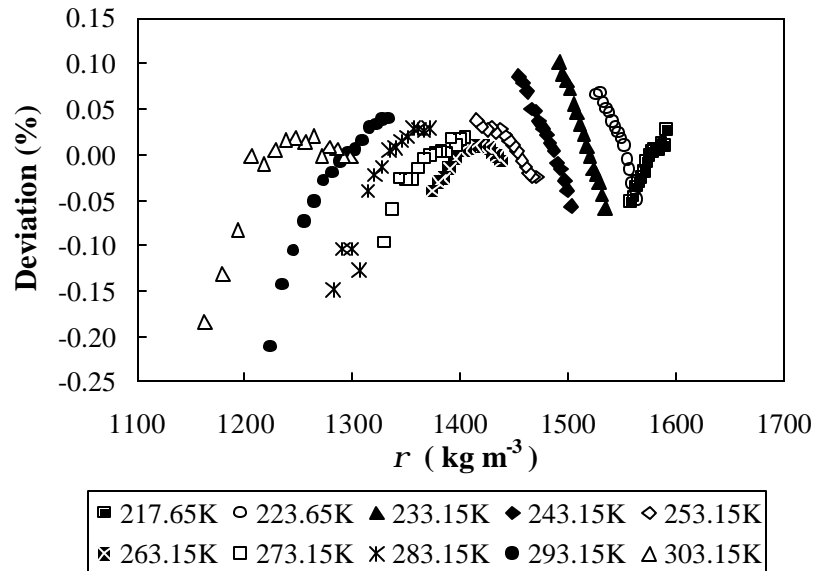


Fig.4. Deviations from the experimental data of the dielectric constant values $[(e_{VR} - e_{exp}) / e_{exp} * 100]$, according to the Vedam relation (eq.6).

The only molecular theory that can be applied to the present data, in the absence of data on the refractive index of the liquid, is the theory of molecular polarizability developed by Kirkwood [6] after the definition of Onsager's local field [5]. In this theory, an apparent dipole moment of the liquid \mathbf{m}^* is calculated from the following relation:

$$\frac{(\epsilon - 1)(2\epsilon + 1)}{9\epsilon} \left(\frac{M}{r} \right) = \frac{N_0}{3} \left[\mathbf{a} + \frac{(\mathbf{m}^*)^2}{3\epsilon_0 k_B T} \right] \quad (7)$$

where M is the relative molar mass of the fluid, N_0 is the Avogadro number, \mathbf{a} is the molecular polarizability of the molecule, ϵ_0 the electric permittivity in vacuum, T the absolute temperature, k_B the Boltzmann constant and r represent the values of density determined using the equation of state proposed by Outcalt and McLinden [14], evaluated at the experimental (T, p) points. The apparent dipole moment is $\mathbf{m}^* = g^{1/2} \mathbf{m}$ where \mathbf{m} is the dipole moment in the ideal gas state and g is the Kirkwood correlation parameter, that measures the restriction to rotation imposed by a cage of molecules surrounding a given one. The value of \mathbf{m}^* can be calculated by a linear regression of the left-hand side of eq.7 as a function of $1/T$. The experimental measurements were used to calculate the Kirkwood function, and Figure 5 shows its variation with $1/T$ for HFC-125, as well as the value of the apparent dipole moment obtained ($\mathbf{m}^* = 2.482 \text{ D}$).

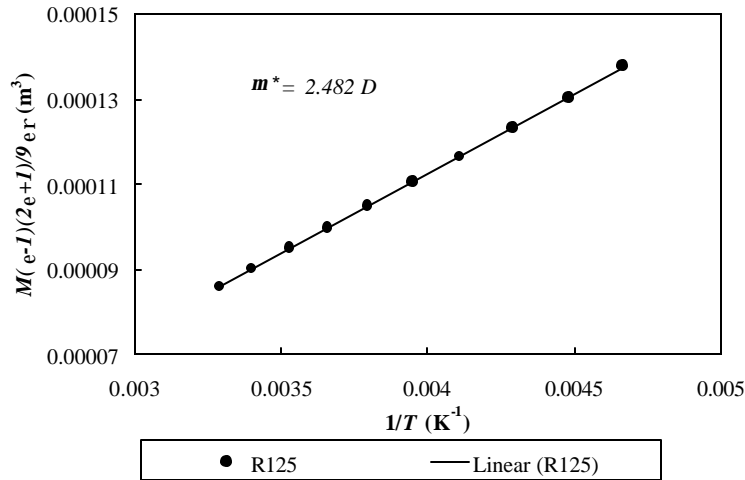


Fig.5. Kirkwood function vs. $1/T$ for HFC-125.

Using the value of the dipole moment of HFC-125 ($m=1.563$ D) in the gas phase [16], the value of the Kirkwood parameter g was found to be equal to 2.52. In figure 6 we can see the percentage deviations from the linear fit. The maximum deviation does not exceed 0.3%. The advantage of this model is the physical insight behind it.

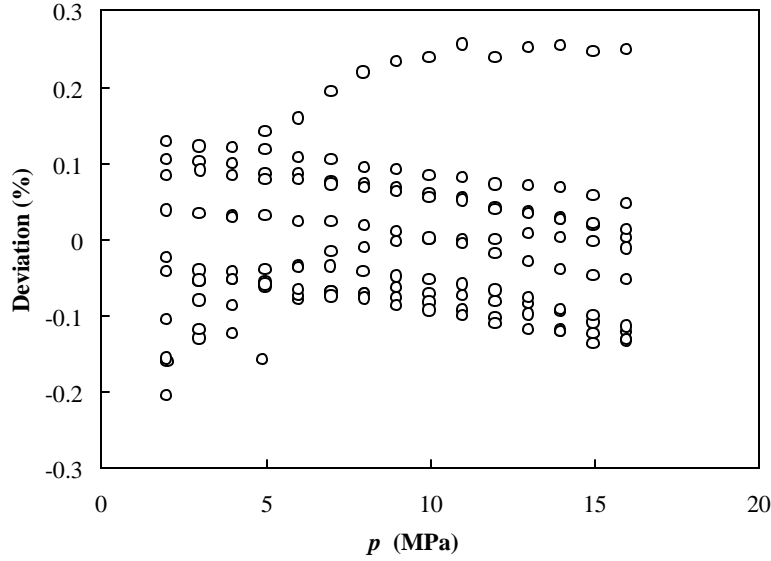


Fig.6. Deviations from the linear fit of the Kirkwood function for HFC-125.

The value of the dielectric equations of state developed (Eqs. 2 and 3) can be used to calculate the values of the isobaric thermal expansion coefficient (expansivity), \mathbf{a}_p , as well as the isothermal compressibility, k_T . The partial derivatives that have to be calculated to obtain these coefficients have very small values, and for these reasons the values of \mathbf{a}_p and k_T are also small [15]. This is an important characteristic of the liquids, since the region of application is far from the critical point. From the definition of \mathbf{a}_p and k_T , we can write

$$\mathbf{a}_p = -\frac{1}{r} \left(\frac{\partial r}{\partial T} \right)_p = \frac{1}{r} \frac{\left(\frac{\partial e}{\partial T} \right)_p}{\left(\frac{\partial e}{\partial r} \right)_p} \quad (8)$$

with

$$\left(\frac{\partial \mathbf{e}}{\partial \mathbf{r}}\right)_p = \left(\frac{\partial \mathbf{e}}{\partial T}\right)_r \left(-\frac{1}{r \mathbf{a}_p}\right) + \left(\frac{\partial \mathbf{e}}{\partial \mathbf{r}}\right)_T \quad (9)$$

$$k_T = \frac{1}{r} \left(\frac{\partial \mathbf{r}}{\partial p}\right)_T = \frac{1}{r} \frac{\left(\frac{\partial \mathbf{e}}{\partial p}\right)_r}{\left(\frac{\partial \mathbf{e}}{\partial \mathbf{r}}\right)_r} \quad (10)$$

The value of \mathbf{a}_p may then be calculated from equations (2), (3), (8) and (9), the value of k_T from equations (2), (3) and (10). Table 5 displays the values obtained.

Table 5. Coefficients of expansivity and compressibility for R125

p (MPa)	$10^5 \mathbf{a}_p$ (K ⁻¹)	$10^5 k_T$ (MPa ⁻¹)	p (MPa)	$10^5 \mathbf{a}_p$ (K ⁻¹)	$10^5 k_T$ (MPa ⁻¹)
$T_n = 214.32$ K			$T_n = 263.32$ K		
16.00	168	132	16.00	231	354
14.99	172	132	15.00	236	355
14.00	176	132	14.00	241	356
13.00	179	133	13.00	245	357
11.99	183	133	12.00	250	358
11.00	187	133	11.00	256	359
10.00	191	133	10.00	261	360
9.00	195	133	9.00	266	361
7.99	199	134	7.99	272	362
7.00	203	134	7.00	277	363
6.00	207	134	6.00	283	365
5.00	211	134	5.00	289	366
4.01	215	134	4.00	295	367
3.00	219	135	3.00	301	369
2.01	223	135	2.00	307	370
$T_n = 223.20$ K			$T_n = 273.19$ K		
16.00	178	166	16.00	246	410
15.00	182	166	15.00	251	412
14.00	186	167	14.00	257	413
13.00	190	167	13.00	262	414
12.00	194	167	12.00	268	416
11.00	198	167	11.00	273	417
10.00	202	168	10.00	279	418
9.00	206	168	9.00	285	420
8.00	210	168	8.00	291	422
7.00	214	169	7.00	297	423

6.00	218	169	6.00	304	425
5.00	222	169	5.00	310	427
4.01	227	170	4.00	317	429
3.01	231	170	3.00	324	431
2.00	235	170	2.00	332	433
$T_n = 233.19$ K			$T_n = 283.21$ K		
16.00	190	207	16.00	263	473
15.00	194	208	15.00	269	475
14.00	198	208	14.00	275	476
13.00	202	208	13.00	281	478
12.00	206	209	12.00	287	480
11.00	211	209	11.00	293	482
10.00	215	210	10.00	299	484
9.00	219	210	9.00	306	486
8.00	223	210	8.00	313	489
7.00	228	211	7.00	320	491
6.00	232	211	6.00	327	494
5.00	237	212	5.00	336	497
4.00	241	212	4.00	343	499
3.00	246	213	3.00	352	502
2.00	250	213	2.00	361	506
$T_n = 243.31$ K			$T_n = 294.08$ K		
16.00	203	253	16.00	284	548
15.00	207	253	15.00	290	550
14.00	211	254	14.00	296	553
13.00	216	254	13.00	303	555
12.00	220	255	12.00	310	558
11.00	225	255	11.00	317	561
10.00	229	256	10.00	324	563
9.00	234	256	9.00	332	567
8.00	238	257	8.00	340	570
7.00	243	258	7.00	349	574
6.00	248	258	6.00	358	577
5.00	252	259	5.00	367	582
4.00	257	260	4.00	378	586
3.00	262	260	3.00	389	591
2.00	267	261	2.00	401	597
$T_n = 253.29$ K			$T_n = 303.74$ K		
16.00	216	301	16.00	304	621
15.00	221	302	14.99	311	624
14.00	225	302	14.00	318	628
13.00	230	303	13.00	325	631
12.00	235	304	11.99	333	635
11.00	239	305	11.00	341	638
10.00	244	305	10.00	350	642
9.00	249	306	9.00	359	647
8.00	254	307	7.99	369	652

7.00	259	308	7.00	379	657
6.00	264	309	6.00	390	663
5.00	270	310	5.00	402	669
4.00	275	311	4.01	415	676
3.00	280	312	3.00	430	684
2.00	286	313	2.01	447	694

Although these results can not replace, in the future, direct measurements of these coefficients they represent a good estimate of these values and an additional benefit of the dielectric constant measurements in the liquid state, especially when there is no analytical equation of state available. The direct computation from the present MBWR EOS is possible, and expected to have an uncertainty of the same order of magnitude (2-3%).

Eqs. (8) and (10) are general and can be applied to any form of the dielectric equation of state.

4. CONCLUSIONS

This work contributes to increase our knowledge about the behaviour of polar fluids in the liquid state. It presents accurate dielectric constant measurements of one environmentally safe refrigerant, HFC-125, in the temperature range 214-304 K and pressure from 2 to 16 MPa. The experimental values were correlated as a function of density and temperature and as a function of pressure and temperature, generating two different dielectric equations of state for this fluid.

The Eulerian formalism developed was used to analyse the data, and as in previous studies, it can be concluded that it represents a powerful estimation method for the dependence of the dielectric constant with density.

The Kirkwood theory, which allows the evaluation of the value of the apparent dipole moment m^* , was also applied to calculate the Kirkwood correlation factor, g , found to be 2.52. When compared with the previous study of HCFC-123, HFC-152a, HFC-32, HCFC-141b, HCFC-142b and HFC-134a [17] it is possible to conclude that there is some restricted rotation of the molecule in the liquid state.

Using the derivatives of the dielectric equations of state $\epsilon = f(p, T)$ and $\epsilon = f(\rho, T)$, the isobaric thermal expansion coefficient and the isothermal compressibility have been obtained, with an estimated uncertainty of 2-3%.

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List of symbols

Greek symbols

\mathbf{a} - polarizability

\mathbf{a}_p – isobaric thermal expansion coefficient

\mathbf{c}^2 – iterative method

\mathbf{e} - dielectric constant (electric permittivity) of the liquid

\mathbf{e}_0 - dielectric constant (electric permittivity) in vacuum

\mathbf{r} - density

\mathbf{r}_0 - reference density

\mathbf{m} - dipole moment in the gaseous phase

\mathbf{m}^* - apparent dipole moment in the liquid phase

\mathbf{D} - defined by eq. (4)

\mathbf{S} - Eulerian strain

Roman symbols

a_i - coefficients of eq. (2)

b_i – coefficients of eq. (3)

g - Kirkwood factor

k_B – Boltzmann constant

p – pressure

A, B – coefficients of eq. (4)

A' – coefficient of eq. (6)

C – geometric capacitance of the cell filled with the liquid

C_0 - geometric capacitance of the cell in vacuum

N_0 – Avogadro number

T – absolute temperature