Measurement of sonic velocity in liquid Refrigerant 12

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The sonic velocity in subcooled liquid Refrigerant 12 (CCl_2F_2) was measured at 26.7°C using an apparatus designed to investigate transients associated with pipe blowdown. The mean value for sonic velocity obtained from 65 measurements was 502 m/s. Sonic velocity obtained from other references are compared to the present measurements using the law of corresponding states.

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Measurements of sonic velocities in many common liquids and gases have been made. In some cases it is possible to predict sound velocities from thermodynamic data using the definition of isentropic sound speed;

$$c=\left[\left(\frac{\partial P}{\partial \rho}\right)_s\right]^{1/2}. \qquad (1)$$

The appropriate thermodynamic data for Refrigerant 12 (CCl_2F_2) in the compressed liquid region is not available, and experimental sound velocity data is rather limited. Poole and Aziz[1] utilized a pulse superposition technique to measure the sound velocity in saturated liquid R-12 in the temperature range −156 to −75.2 °C while Kokernak and Feldman[2] measured the sound speed in saturated liquid R-12 at 6.1 °C. In the present study, the sonic velocity in subcooled liquid R-12 was measured at 26.7 °C using an apparatus designed to investigate transients associated with a pipe blowdown.

The experimental apparatus consisted of stainless tubes, 5.33 cm i.d. and either 61 or 122 cm in length, on which four piezoelectric pressure transducers were mounted at various axial locations in order to measure transient pressures inside the tube (Fig. 1).

After evacuation and purging of residual air, the tube was filled with liquid R-12 under pressure. Pressure waves were generated during rapid depressurization initiated at one end of the tube by piercing a cellulose triacetate membrane. The sonic velocity was determined by measuring the time required for the initial decompression wave to pass the transducer locations.

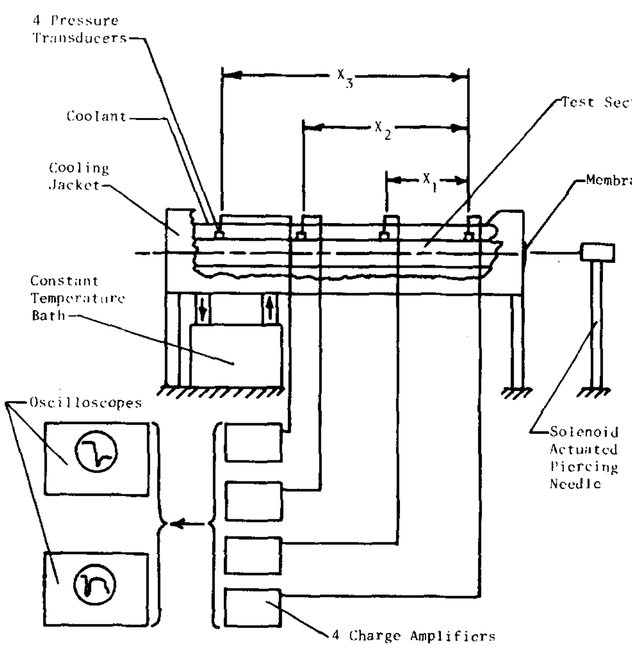

FIG. 1. Schematic of experimental apparatus.

A thermostated cooling jacket was used to maintain the test-section temperature initially uniform at 26.7 ±0.6 °C as monitored by nine thermocouples attached to the tube wall at various axial and circumferential locations. Initial R-12 pressures ranged from 0.703 to 0.928 MPa and blowdown was always to atmospheric pressure (0.101 MPa).

Signals from the pressure transducers were amplified and displayed on a Tektronix 565 dual-beam oscilloscope. By chopping each beam, it was possible to display all four pressure signals on the same time base. The time base was calibrated using sine waves of known frequency, and a camera provided a permanent record. The oscilloscope, in single sweep mode, was triggered by the initial decompression wave as it reached the first piezoelectric pressure transducer. The resonant frequency of the pressure transducers is quoted by the manufacturer as being greater than 500 000 Hz.

The time t_i required for the initial decompression wave to pass the three transducer locations X_1, X_2, and X_3 was measured directly from the photographic record. The maximum uncertainty for any time measurement was estimated to be ±1.5%. Most of this uncertainty can be attributed to the difficulty in determining the precise point on the photograph where the local decompression began. The maximum uncertainty in determining the effective pressure sensing positions X_1, X_2, and X_3 was ±3.5%, due to the width of the pressure transducer. Using the method outlined by Kline and McClintock[4] these uncertainties can be combined to give a total maximum uncertainty of ±3.8% for the sound velocity measurements.

A total of 65 measurements were made using the relation

$$c=X_i/t_i, \quad i=1,2,3. \qquad (2)$$

The sonic velocity measurements exhibited an approximately normal distribution about a mean value of 502 m/s with a standard deviation of 17 m/s. Varying the initial pressure between 0.703 and 0.938 MPa produced no observable effects, and the sonic velocity obtained from these measurements can be regarded as the value for saturated liquid R-12 at 26.7 °C, for which the saturation pressure is 0.6817 MPa.

TABLE I. Comparison of experimental and computed sonic velocity.

Substance	Temperature (°C)	Source	Experimental value (m/s)	Calculated value (m/s)	% deviation from calculated velocity
N_2 gas	26.7	Present work	352	353[a]	−0.28
Air	26.7	Present work	344	347[a]	−0.86
R-12	26.7	Present work	502	491[b]	+2.2
R-12	−75.2	Ref. 1	921	921[b]	0
R-12	−149.0	Ref. 1	1269	1340[b]	−5.3
R-12	6.1	Ref. 2	500	575[b]	−13.0

[a]Calculated from Eq. (3).

[b]Calculated from Eq. (4).

The accuracy of the experimental apparatus was checked by repeating the above procedure at 26.7 °C and 0.517 MPa using nitrogen and air as test gases. These sound speed measurements were compared to values obtained from the equation for isentropic sound speed in an ideal gas;

$$c=(\gamma RT)^{1/2}, \tag{3}$$

where γ is the ratio of specific heats and R is the ideal gas constant. The results are shown in Table I, where the measured values are within 1% of the calculated ones.

To provide a basis for the comparison of various liquids, Eq. (4) has been recommended for computing the sonic velocity in liquids which behave according to the law of corresponding states (Ref. 1–3);

$$c=\left(\frac{\phi\rho}{M}\right)^3, \tag{4}$$

ρ is the density, M is molecular weight, and ϕ is a coefficient which is a function of the molecular structure of the liquid. Sakiades and Coates[3] obtained measurements for 135 pure organic liquids and found Eq. (4) to be valid with an average error ±2.6%. Unfortunately, an uncertainty exists in the value of ϕ for fluorocarbons. For comparison purposes, here ϕ was calculated from the sound speed data of Poole and Aziz[1] for R-12 at −75.2 °C, and this value used at the conditions of the present measurements. This procedure should be reasonable if the assumption is valid that ϕ depends only on the molecular structure and not on temperature. At −75.2 °C Poole and Aziz observed a sonic velocity of 921 m/s. From Eq. (4) then, $\phi=7.313\times10^{-4}$ $\mathrm{m^{10/3}\,mol^{-1}\,s^{-1/3}}$. Using this value, the sonic velocity at 26.7 °C is predicted as 491 m/s, which is within 2.2% of the measured value. Comparison with other measured values result in larger discrepancies, as may be noted in Table I.

Sonic velocity predictions from Eq. (4) are sensitive to the value of ρ used. Calculated values for c in Table I were obtained using the saturated liquid density data from Ref. 5.

[1]G.R. Poole and R.A. Aziz, AIChE J. 18, 430 (1972).

[2]R.P. Kokernak and C.L. Feldman, ASHRAE J. 13, 59 (1971).

[3]B.C. Sakiadis and J. Coates, AIChE J. 1, 275 (1955).

[4]S.J. Kline and F.A. McClintock, Mech. Eng. 75, 3 (1953).

[5]R. Plank, *Handbuch der Kaltetechnik* (Springer-Verlag, Berlin, 1956), p. 336.