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THE COEFFICIENT OF THERMAL
EXPANSION OF FLUORINERT FC-86

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May 1982

Lawrence
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Abstract	1
Introduction	1
I. Coefficient of Thermal Expansion of FC-86	2
A. Test Description	2
B. Results	2
B-1 CTE Measurement of FC-86 (As received)	2
B-2 CTE Measurement of FC-86 (Degassed)	2
II Cavitational Pressure Measurements	3
A. Test Description	3
B. Results	3
III. Discussion and Conclusions	3
Appendix	4
Experimental Detail	15
I General Discussion	15
II Calibration of the CTE Tube	15
III Loading the CTE Tube with FC-86 (As received)	16
IV Loading the CTE Tube with FC-86 (degassed), FC-86 (2.4% air)	17
V CTE Measurements	17
VI Cavitational Pressure Measurements	18
VII Limitations of the Experimental Method	18
Equipment Used	19
I Bath	19
II Pressure Measurement Equipment	19
Acknowledgements	20

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THE COEFFICIENT OF THERMAL EXPANSION OF FLUORINERT FC-86

ABSTRACT

The cubical coefficient of thermal expansion (CTE) of Fluorinert Fluid, FC-86 was measured before and after degassing.

The CTE for the FC-86 before degassing is:

$$\beta = 9.282 \times 10^{-6}T + 1.6115 \times 10^{-3}$$

(T = -30 to + 75°C)

The CTE for the FC-86 (degassed) is:

$$\beta = 6.133 \times 10^{-6}T + 1.7643 \times 10^{-3}$$

(T = -30 to + 75°C)

Measurements were also made of the pressures required to prevent cavitation in the degassed FC-86 and in FC-86 containing 2.4 volume percent of air. At 71.0°C the cavitation pressure of degassed FC-86 is 1285 torr and at 73.8°C the cavitation pressure of the FC-86 containing 2.4 volume percent of air is 1229 torr.

INTRODUCTION

Fluorinert* Fluid FC-86 is a fully fluorinated hexane manufactured by the Minnesota, Mining and Manufacturing Company (3M). It is a colorless, odorless liquid at ambient temperatures. It has a low viscosity over a wide temperature range. It is an inert and non-toxic material which can be readily handled in laboratory and factory applications.

FC-86, because of the favorable properties listed above, is being employed by LLNL.

*Fluorinert is registered as a trade name by the Minnesota Mining & Mfg. Co.

We were asked to measure the coefficient of thermal expansion of FC-86 before and after degassing. We were also asked to determine the pressures required to prevent cavitation of FC-86 at several of the higher temperatures.

I. Coefficient of Thermal Expansion of FC-86

A. Test Description

Details of the experimental method and the apparatus used are given in the Appendix.

B. Results

B-1. CTE Measurement of FC-86 (As Received)

The FC-86 (as received) before degassing contained 34 volume percent of air. This material will be designated throughout the test as "FC-86 (as received)." Data points taken for this material at about ten degree (celsius) intervals are plotted in Fig. 1 of the Appendix according to $V_2 = V_1 [1 + \beta (T_2 - T_1)]^1$. A linear regression fit was made on the data points resulting in the following equation:

$$\begin{aligned}\beta &= 9.282 \times 10^{-6} T + 1.6115 \times 10^{-3} \\ (T &= -30 \text{ to } +75^\circ\text{C}) \\ (r &= 0.982)\end{aligned}$$

A table of the data points is given in the Appendix, Table 1 CTE of FC-86 (as received).

B-2. CTE Measurements of FC-86 (Degassed)

The FC-86 (as received) was degassed and, after degassing, was found to contain 0.06 volume percent of air. Data points were taken on this material and are plotted in Fig. 2 of the appendix. A linear regression fit was made on the data points resulting in the following equation:

$$\begin{aligned}\beta &= 6.133 \times 10^{-6} T + 1.7643 \times 10^{-3} \\ (T &= -30 \text{ to } +75^\circ\text{C}) \\ (r &= 0.831)\end{aligned}$$

A table of the data points is given in the Appendix, Table 2 CTE of FC-86 (degassed).

¹E. Hausman and E. Slack, "Physics," page 238, section 140, Expansion of Fluids.

II. Cavitation Pressure Measurements

A. Test Description

Details of the experimental method are given in the Appendix.

B. Results

Cavitation pressures were measured on FC-86 (degassed), and FC-86 containing 2.4 volume percent of air. The cavitation pressures are plotted on Fig. 3 of the Appendix along with the vapor pressure of the FC-72(86)² fluid. The data points are listed in Table 3 of the Appendix, Table 4 is a listing of the vapor pressure of FC-72(86).

III. Discussion and Conclusions

Statistical Analysis of the two sets of CTE data indicate that the CTE of FC-86 (degassed) is different from that of the CTE of the FC-86 (as received). However, this difference is small and it is felt that in the projected use of FC-86 it would be negligible.

To prevent cavitation of the FC-86 (degassed) or the FC-86 (2.4%V air), it would be necessary to apply about 200 torr pressure in excess of the vapor pressure of FC-86 at the higher temperatures and to apply about 100 torr pressure excess pressure at the lower temperatures.

²FC-86 is a refined FC-72. Both materials have the same vapor pressure. This vapor pressure data was supplied by the 3M Company.

APPENDIX

Table 1. Coefficient of Thermal Expansion of FC-86 (as received).

Table 2. Coefficient of Thermal Expansion of FC-86 (degassed).

Table 3. Cavitation Pressures of FC-86

- A. FC-86 (degassed)
- B. FC-86 (2.4%V air)

Table 4 Vapor Pressure of FC-72(86)

Figure 1. C.T.E. of FC-86 (as received)

Figure 2. C.T.E. of degassed FC-86

Figure 3. Pressures required to prevent cavitation of FC-86

Figure 4. C.T.E. Tube

Figure 5. C.T.E. Tube Loaded

Figure 6. Experimental System

Experimental Detail

- I. General Discussion
- II. Calibration of C.T.E. Tube
- III. Loading the C.T.E. Tube with FC-86 (as received)
- IV. Loading the C.T.E. Tube with FC-86 (degassed), FC-86 (2.4%V air)
- V. CTE Measurements
- VI. Cavitation Pressure Measurements
- VII. Limitation of the Experimental Method

Equipment Used

- I. Bath
- II. Pressure measurement Equipment

Table 1. Coefficient of Thermal Expansion of FC-86 (as received)

$$V_2 = V_1 \left[1 + \beta (T_2 - T_1) \right]$$

Temp ^{°C}	β	Temp ^{°C}	β
+ 8.8	0.00180	+19.2	0.00183
+19.6	0.00176	+31.4	0.00187
+31.0	0.00184	+49.6	0.00204
+41.0	0.00194	+61.2	0.00220
+51.4	0.00210	+72.0	0.00227
+63.0	0.00220	+40.0	0.00193
+72.8	0.00232		
-29.2	0.00125	-19.8	0.00143
-31.0	0.00126	-10.0	0.00158
-18.4	0.00145	- 0.4	0.00163
- 7.8	0.00166	+ 9.6	0.00178
- 0.2	0.00151		
+9.8	0.00172		
+21.2	0.00179		
+30.6	0.00194		

β = coefficient of thermal expansion

V_2 = final volume, cm³

V_1 = initial volume, cm³

T_2 = final temperature, °C

T_1 = initial temperature, °C

Table 2. Coefficient of Thermal Expansion of FC-86 (as Degassed)

$$V_2 = V_1 \left[1 + \beta (T_2 - T_1) \right]$$

Temp°C	β	Temp°C	β
-23.2	0.00157	+19.2	0.00185
-14.2	0.00179	+30.0	0.00205
- 3.6	0.00166	+39.5	0.00181
+ 3.0	0.00187	+50.2	0.00203
+11.8	0.00183	+61.4	0.00230
+21.8	0.00165	+72.8	0.00231
-19.4	0.00175		
- 9.0	0.00168		
+11.8	0.00160		
+23.4	0.00199		
+35.4	0.00186		
+44.0	0.00205		
+54.2	0.00221		

Table 3. Cavitation Pressures of FC-86

A. Degassed FC-86

Temp ^o C	Cavitation Pressures (torr)
+71.0	1285
+62.3	953
+51.2	652
+40.0	426

B. FC-86, 2.4% V air

Temp ^o C	Cavitation Pressures (torr)
+73.8	1229
+60.0	772
+50.0	548
+40.0	365

Table 4. Vapor Pressure of FC-72 (86)

The vapor pressures listed here were calculated from the vapor pressure curve supplied by the manufacturer of the fluid.

$$\log_{10} P(\text{torr}) = 7.6042 - \frac{1562}{T + 273}$$

Temp °C	Vapor Pressure (torr)
-55	2.75
-50	3.98
-45	5.67
-40	7.95
-35	11.0
-30	15.0
-25	20.2
-20	26.9
-15	35.5
-10	46.2
- 5	59.7
0	76.3
+ 5	96.7
+10	121
+15	152
+20	188
+25	230
+30	281
+35	341
+40	410
+45	492
+50	587
+55	695
+60	819
+65	961
+70	1123
+75	1305
+80	1511

FIG. 1. CTE of FC-86 (as received)

FIG. 2. CTE of degassed FC-86

FIG. 3. Pressure required to prevent cavitation of FC-86

FIG. 4. C.T.E. Tube

FIG. 5. C.T.E. Tube loaded

FIG. 6. Experimental system

EXPERIMENTAL DETAIL

I. General Discussion

Figure 4 shows the CTE tube that we used in the measurement of the cubical thermal expansion of FC-86. Figure 5 illustrates the CTE tube when it is loaded with mercury and FC-86 liquid. Figure 6 shows the overall experimental system. The mercury acts like a liquid piston and nitrogen pressure can be applied to the top of the mercury column to prevent cavitation during the various measurements being taken. The movement of the mercury column was measured with a cathetometer which can be read to 0.5 mm and estimated to the nearest 0.02 mm.

II. Calibration of the CTE Tube

During construction of the CTE apparatus, the left leg of the tube was left unattached so that the tube could be calibrated. A calibration mark was scribed close to the Kovar seal on the left leg. Mercury was carefully added to the inverted left leg so that it filled the void from the valve to the scribe mark. The left leg was then tilted to transfer the mercury from the leg to a tared beaker and weighed. The calibration volume was calculated from the density of mercury and an accurate measurement of ambient temperature. The volume measured was 1.978 cm³.

A piece of precision bore tubing, scrap from the construction of the left leg, was cut in several 5 cm pieces. The internal diameter (I.D.) of the pieces were measured and the average of several measurements is 0.953 cm. From the I.D. of the precision bore tubing the volume calibration was calculated to be 0.713 cm³/cm run of the tube.

At any temperature the volume of FC-86 liquid can be determined as follows:

$$\text{Volume (cm}^3\text{*)} = (\text{Ro}-\text{Rm})(0.713 \frac{\text{cm}^3}{\text{cm}}) + 1.978 \text{ cm}^3.$$

Ro = cathetometer reading of the calibration mark, cm

Rm = cathetometer reading of the mercury
meniscus at the FC-86/mercury interface after
temperature equilibration, cm

III. Loading the CTE Tube with FC-86 (as received)

A vessel of mercury was attached to the left stopcock of the reservoir. The other two stopcocks were left open to the air. Mercury was added until the levels in both arms of the tube were approximately at the calibration mark. A vessel of FC-86 open to air was attached to the glass joint above the metal valve. The valve was opened and fluid was allowed to flow through the valve and fill the void between the mercury meniscus and the FC-86 supply vessel. A vacuum was carefully applied to the reservoir and about 20 cm of FC-86 was pulled into the left leg. The metal valve was closed and the reservoir was opened to the atmosphere. The loaded tube Fig. 5, was now ready to mount into the bath. The air dissolved in the saturated FC-86 had been previously measured on a gas manifold employing vacuum analytical techniques and found to be 34.4 percent volume.

*The CTE of the glass manometer was ignored in this experiment.

IV. Loading the CTE Tube with FC-86 (degassed), FC-86 (2.4% air)

FC-86 was degassed on a vacuum manifold employing a double flash distillation. The residual air left in the degassed material was measured by vacuum analytical techniques. The air left in the FC-86 after degassing was 0.06 volume percent. The degassed FC-86 was transferred to a sealed glass vessel.

The CTE tube was evacuated through both legs and mercury was admitted through the left stopcock of the reservoir in a fine trickle while pumping on both legs during the loading. The FC-86 supply vessel was fastened to the glass joint above the metal valve. Air was evacuated from the connecting volume. FC-86 was allowed to fill the void between the supply vessel and the mercury meniscus when the metal valve was opened. Hot air from a heat-gun was applied to the FC-86 supply vessel to cause a slight increase of vapor pressure to drive the FC-86 about 20 cm into the left leg of the CTE Tube. The metal valve was closed and the reservoir was opened to atmospheric pressure. The loaded tube with the degassed material was now ready to be mounted into the bath.

V. CTE Measurements

After loading the CTE tube with FC-86 the apparatus was connected to the experimental system as shown in Fig. 6. Nitrogen pressure was applied to the mercury through the reservoir. A pressure greater than the vapor pressure of FC-86 was applied at each temperature to insure that cavitation would not occur during the measurements. A cathetometer was used to determine the reading in centimeters of the calibration mark and subsequently the reading in centimeters to of the mercury meniscus at the FC-86/mercury interface. The volume of FC-86 at each temperature, about ten degrees apart, is calculated from these readings employing the method described in Section II, Calibration of the CTE tube. The range of temperatures covered was -30 to + 75°C.

The CTE, coefficient of thermal expansion (β), was then calculated from the equation and the measurements taken above.

VI. Cavitation Pressure Measurements

The same experimental setup as employed in the CTE measurements was used for this set of measurement. The tube loaded with FC-86 and mercury was installed into the bath.

The bath was held constant at a given temperature within the range of interest. The meniscus at the interface was measured with the cathotometer until thermal equilibrium was reached. The mercury head above the FC-86 was measured with a centimeter scale. The pressure was slowly reduced until the first downward movement of the mercury was noted.

At this point the pressure of the N_2 above the reservoir was read. The pressure required to prevent cavitation is the sum of the pressure applied plus the pressure equivalent of the mercury head above the FC-86. The cavitation pressure were determined for several of the higher temperatures considered in this study.

VII Limitations of the Experimental Method

In employing the techniques as described we should point out that there are three limitations, these are:

The system is glass and the pressure used is therefore limited to about two atmospheres for safety.

The fluid being tested must be non-reactive with mercury.

The freezing point of mercury (-38.8°C) limits the lower temperature to about -32° to -30°C .

EQUIPMENT USED

I. Bath

The bath in the CTE measurements of FC-86 was assembled with the following components.

- A) An unsilvered dewar flask, 5" I.D. x 26" length.
- B) A heat-exchanger copper coil connected to a liquid nitrogen supply.
- C) A 500 watt Calrod heater.
- D) A Fenwall thermoregulator using a glass-sheathed iron-constantan thermocouple. Model 550, Type J.
- E) Temperature Reading Device
A glass-sheathed, iron-constantan thermocouple using an ice-bath reference junction coupled to a Data-Precision Multi-Meter, range 100 millivolts.
- F) Bath Stirrer
Stirring was accomplished using a nitrogen gas bubbling jet at the bottom of the dewar flask. Adequate movement of bath fluids was achieved during measurements. From +20 to +75°C water was used as the bath fluid. At sub-ambient temperatures, -40 to +20°C, isopropanol (IPA) was used.

II. Pressure Measurement Equipment

Pressure during the experiments was monitored with a MKS Baratron pressure transducer, model 170 M and a 10,000 torr head. The mercury head on the FC-86 was measured with a centimeter scale.

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