THERMODYNAMIC PROPERTIES OF OCTOFLUOROCYCLOBUTANE (FREON C-318)

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The specific heat C'_s of octofluorocyclobutane has been measured between −36° and +44° C using the apparatus of [1]. A table of thermodynamic properties of liquid Freon C-318 and its saturated vapor has been prepared based on the thermal parameters in [2] and experimental values of the specific heat.

Basic physical properties of octofluorocyclobutane [2]. Molecular weight is 200.04; normal boiling point $t_s = -6.42$° C; gas constant R = 41.5645 J/kg · C; melting point $t_m = -40.2$° C; $v_m = 0.00057$ m^3/kg; critical point $t_{cr} = 115.39$° C; $p_{cr} = 28.05 \cdot 10^5$ n/m^2; $v_{cr} = 0.001583$ m^3/kg.

Table 1

Experimental Values of the Specific Heat C'_s of Octofluorocyclobutane C_4F_8 (Freon C-318)

t, °C	C'_s, kJ/kg · C	t, °C	C'_s kJ/kg · C
−36.0	0.8964	0.8	0.9734
−30.0	0.8969	3.7	0.9870
−28.6	0.9043	12.0	1.0082
−24.4	0.9085	19.0	1.0318
−23.5	0.9087	28.0	1.0676
−19.1	0.9240	40.0	1.1137
−16.1	0.9265	43.0	1.1249
−13.4	0.9362	43.8	1.1233
−7.4	0.9433		

Due to its properties (exceptional chemical and thermal stability, inertness to metals and mineral oils, nontoxicity and nonflammability, low critical pressure and temperature, etc.) octofluorocyclobutane appears to be quite a promising working medium.

Octofluorocyclobutane can be widely applied as a carrier of heat and cold in freon turbines, in geothermal heat-pump and refrigeration installations, as well as in turbocompressors for air-conditioning. In refrigeration equipment octofluorocyclobutane (designated Freon C-318) can advantageously replace such freons as F21, F114, and F142.

The present article describes the results of measurements of octofluorocyclobutane specific heat, on the basis of which an equation is formulated giving the temperature relation of enthalpy and entropy of the liquid.

The calorific values were calculated by utilizing the experimental data on thermal properties in [2] and the specific heat of octofluorocyclobutane. Also a table of the thermodynamic properties of the saturated vapor was compiled.

Determination of the specific heat C'_s for Freon C-318. The specific heat of octofluorocyclobutane in the temperature range from 17° to 270° K was measured by Furukawa in [3]. Data on specific heat at higher temperatures is lacking in the literature.

The thermal capacity of 99.8% octofluorocyclobutane was determined in a vacuum adiabatic calorimeter by the method described in [1]. During the experiments the valve between the thin capillary of the calorimeter and the charging line was closed. The air was removed from the calorimeter and the liquid before charging the calorimeter. In the closed calorimeter the liquid was at equilibrium with the vapor, and the heat input was expended not only in warming up the liquid but also in changing the vapor temperature and vaporizing part of the liquid. In the experiments the calorimeter was filled with liquid up to approximately 97% of capacity.

With this charging of the calorimeter the reverse is true, i.e., vapor condensation and generation of heat take place. Calculations show that the correction for condensation (evaporation), change in volume of vapor and liquid, does not exceed 0.15%, i.e., almost all of the heat supplied is spent on heating up the liquid. Therefore, the experiments in fact define the specific heat C'_s (more precisely, the specific heat of the two-phase system).

For Freon C-318 in the temperature range from −40° to 60° C we can take $C'_s = C'_p$, since in the equation

$$C'_p = C'_s + T\left(\frac{\partial v'}{dT}\right)_p \frac{dp_s}{\partial T}$$

the expression $T\left(\frac{\partial v'}{\partial T}\right)_p \frac{dp}{dT}$ with a maximum error (at t = 60° C) of 1.6% may be disregarded. In order to obtain reliable data, a number of experiments were performed within the range of temperatures under investigation. In this case a good duplication of experimental data was observed.

The specific heat C'_s of Freon C-318 was determined in the temperature range from −36° to 44° C. The experimental values of the specific heat are given in Table 1. The scatter of the experimental points amounted to 0.8%. The mathematical processing of the experiments established that the over-all relative error does not exceed 0.8%. Based on the experimental data in the temperature range from −40° to +60° C the equation of the specific heat relative to temperature is defined as

$$C'_s = 0.9726 + 2.848 \cdot 10^{-3} t + 1.620 \cdot 10^{-5} t^2, \quad (1)$$

Table 2

Thermodynamic Properties of Liquid Freon C-318 (Octofluorocyclobutane C_4F_8) and its Saturated Vapor

Temperature, t, °C	Absolute pressure $P \cdot 10^{-5}$, N/m^2	Specific volume		Enthalpy		Heat of vaporization r, kJ/kg	Entropy	
		liquid v', m^3/kg	vapor v'', m^3/kg	liquid i', kJ/kg	vapor i'', kJ/kg		liquid s', kJ/kg · C	gas s'', kJ/kg · C
—40·2	0.2107	0.5704	0.4488	462.95	581.27	118.32	0.8531	1.3609
—40	0.2130	0.5706	0.4444	463.08	581.36	118.28	0.8538	1.3611
—38	0.2366	0.5727	0.4026	464.81	582.83	118.02	0.8613	1.3631
—36	0.2625	0.5749	0.3654	466.56	584.29	117.73	0.8688	1.3651
—34	0.2907	0.5771	0.3321	468.36	585.76	117.40	0.8763	1.3671
—32	0.3214	0.5793	0.3023	470.14	587.24	117.10	0.8838	1.3693
—30	0.3546	0.5815	0.2756	471.94	588.72	116.78	0.8913	1.3714
—28	0.3908	0.5838	0.2515	473.75	590.18	116.43	0.8987	1.3734
—26	0.4299	0.5861	0.2301	475.60	591.66	116.06	0.9060	1.3756
—24	0.4722	0.5884	0.2106	477.40	593.12	115.72	0.9134	1.3778
—22	0.5179	0.5908	0.1931	479.22	594.57	115.35	0.9207	1.3800
—20	0.5672	0.5932	0.1772	481.08	596.01	114.93	0.9280	1.3821
—18	0.6203	0.5956	0.1629	482.89	597.44	114.55	0.9353	1.3842
—16	0.6774	0.5980	0.1499	484.78	598.91	114.13	0.9426	1.3864
—14	0.7388	0.6005	0.1381	486.66	600.37	113.71	0.9498	1.3886
—12	0.8047	0.6030	0.1273	488.56	601.81	113.25	0.9570	1.3908
—10	0.8753	0.6055	0.1175	490.44	603.23	112.79	0.9642	1.3929
— 8	0.9510	0.6081	0.1087	492.34	604.67	112.33	0.9714	1.3950
— 6	1.0318	0.6108	0.1004	494.26	606.13	111.87	0.9786	1.3972
— 4	1.1182	0.6134	0.0937[4]	496.20	607.57	111.37	0.9857	1.3994
— 2	1.2103	0.6161	0.08635	498.12	608.99	110.87	0.9928	1.4016
0	1.3086	0.6189	0.08010	500.06	610.42	110.36	1.0000	1.4039
+ 2	1.4132	0.6217	0.07444	502.00	611.82	109.82	1.0071	1.4062
4	1.5245	0.6246	0.06921	503.98	613.25	109.27	1.0142	1.4085
6	1.6428	0.6274	0.06341	505.98	614.71	108.73	1.0213	1.4108
8	1.7684	0.6304	0.05999	507.95	616.14	108.19	1.0284	1.4132
10	1.9016	0.6334	0.05592	509.96	617.56	107.60	1.0355	1.4155
12	2.0428	0.6364	0.05218	511.99	619.00	107.01	1.0426	1.4179
14	2.1922	0.6395	0.04872	514.03	620.42	106.39	1.0497	1.4202
16	2.3503	0.6427	0.04552	516.05	621.85	105.80	1.0567	1.4226
18	2.5174	0.6459	0.04257	518.13	623.30	105.17	1.0638	1.4250
20	2.6947	0.6492	0.03983	520.22	624.72	104.50	1.0708	1.4274
22	2.8799	0.6526	0.03730	522.29	626.16	103.87	1.0779	1.4298
24	3.0761	0.6560	0.03495	524.41	627.61	103.20	1.0849	1.4322
26	3.2828	0.6595	0.03278	526.51	629.04	102.53	1.0920	1.4347
28	3.5004	0.6631	0.03075	528.66	630.48	101.82	1.0991	1.4372
30	3.7181	0.6668	0.02837	530.78	631.93	101.15	1.1062	1.4398
32	3.9540	0.6706	0.02725	532.96	633.40	100.44	1.1132	1.4423
34	4.2014	0.6744	0.02564	535.16	634.85	99.69	1.1203	1.4449
36	4.4605	0.6784	0.02414	537.35	636.32	98.97	1.1275	1.4476
38	4.7425	0.6825	0.02369	539.59	637.81	98.22	1.1346	1.4503
40	5.0152	0.6867	0.02144	541.81	639.28	97.47	1.1417	1.4529
42	5.3116	0.6909	0.02023	544.07	640.74	96.67	1.1488	1.4555
44	5.6211	0.6954	0.01909	546.34	642.22	95.88	1.1559	1.4582
46	5.9440	0.6999	0.01802	548.64	643.72	95.08	1.1630	1.4609
48	6.2809	0.7046	0.01703	550.95	645.24	94.29	1.1701	1.4637
50	6.6318	0.7094	0.01609	553.28	646.73	93.45	1.1773	1.4665
52	6.9873	0.7144	0.01521	555.61	648.22	92.61	1.1844	1.4692
54	7.3778	0.7195	0.01439	557.97	649.74	91.77	1.1915	1.4720
56	7.7735	0.7250	0.01362	560.38	651.25	90.89	1.1987	1.4748
58	8.1849	0.7305	0.01289	562.76	652.78	90.02	1.2059	1.4777
60	8.6122	0.7361	0.01221	565.18	654.32	89.14	1.2131	1.4807

or

$$C'_s = 1.410 - 6.05 \cdot 10^{-3} T + 1.620 \cdot 10^{-5} T^2, \qquad (2)$$

where C'_s is expressed in kJ/kg · C. The constant coefficients in (1) and (2) are determined on the basis of the experimental data.

The results of the experiments were used to compile Table 2.

Determination of enthalpy and entropy. The enthalpy i' and entropy s' of the liquid are calculated from the known thermodynamic differential equations. Here the starting point of the reading was arbitrarily taken as the state of the boiling liquid at 0° C. In this state we assumed $i_0 = 500$ kJ/kg and $s_0 = 1.0000$ kJ/kg · C.

By integrating the differential equations

$$C'_s = \frac{di'}{dT} - v' \frac{dp}{dT} \text{ and } ds' = C'_s \frac{dT}{T}$$

and substituting the specific heat values from (1) and (2), we obtain expressions for the enthalpy i' and entropy s' of the saturated liquid:

$$i' = i_0 + \int_0^t C'_s dt + \int_{p_0}^p v' dp,$$

$$s' = s_0 + \int_{273.15}^T C'_s \frac{dT}{T},$$

or

$$i' = 500 + 0.9726t + 1.424 \cdot 10^{-3} t^2 + 5.40 \cdot 10^{-6} t^3 + \int_{p_0}^p v' dp, \qquad (3)$$

$$s' = 2.0449 + 3.2475 \lg(T/273.15) - 6.05 \cdot 10^{-3} T + 8.143 \cdot 10^{-8} T^2. \qquad (4)$$

The enthalpy i" and entropy s" of the dry saturated vapor are determined from the following formulas:

$$i'' = i' + r, \qquad (5)$$

$$s'' = s' + r/T. \qquad (6)$$

In all the equations i', i" and r are expressed in kJ/kg, while s' and s" are expressed in kJ/kg · C.

The following equation

$$r = 65.881 + 0.586T - 1.55 \cdot 10^{-3} T^2 \qquad (7)$$

for calculating the heat of vaporization was obtained on the basis of the data computed from the Clapeyron-Clausius equation, which contains the experimental values of v', v", and dp/dT obtained by Bambach [2].

The thermodynamic properties of the saturated vapor were calculated from the equations for p-t, v', v" [2] and r (7). The values of i', i", s' and s" were calculated from Eqs. (3), (4), (5), and (6). The resulting data are given in Table 2.

NOTATION

C'_s—specific heat of liquid along the saturation line; i_0 and s_0—enthalpy and entropy of liquid at 0° C; v', i', and s'—respectively, the specific volume, enthalpy, and entropy of liquid along the saturation line; v", i", and s"—respectively, the specific volume, enthalpy, and entropy of the dry saturated vapor; r—heat of vaporization; p_0—absolute pressure at 0° C.

REFERENCES

1. E. T. Vas'kov, Inzhenerno-fizicheskii zhurnal, no. 6, 1964.

2. G. Bambach, Kältetechnik, Bd. 8, 1956.

3. G. T. Furukawa, R. E. McCoskey, and M. Z. Reily, J. Research N BS, 52, no. 1, 1964.

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