Alkanes: CH_4, C_2H_6, C_3H_8

Physical and thermodynamic properties are presented in concise graphs, which are based on data that include the latest results from investigators worldwide.

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Methane, ethane and propane are of primary importance to the chemical process industries: *methane* for the large-scale production of chloromethanes (such as carbon tetrachloride and chloroform), alcohols, aldehydes, acids, ammonia and carbon black; *ethane* for the manufacture of chlorinated solvents, fluorochloroethanes, and such important monomers as ethylene and vinyl chloride; and *propane* as a raw material, and as a refrigerant and a low-temperature extraction solvent (for example, separation of asphalt components in crude oils).

Of course, all three are also important as fuel.

Critical Properties—Table 11—1

Experimental critical constants for methane, ethane and propane deviate 0.3%, 0.9% and 1.9%, or less, respectively, for critical temperature, pressure and volume [*9, 10, 14, 246, 417, 453, 454, 455, 457, 460, 464*].

Vapor Pressure—Fig. 11—1

Vapor-pressure data for each alkane cover the entire liquid range. The data from different sources agree well, with deviations in most cases being less than 1.5%.

Heat of Vaporization—Fig. 11—2

Data for heat of vaporization have been extended with Watson's correlation (Eq. 1—1) to full liquid-phase coverage. Correlation results agree excellently with experimental data.

See Part 1 of this series, *Chem. Eng.*, June 10, 1974, for equations starting with a boldfaced numeral "1"; Part 2 for those with "2"; etc. Part 2 appeared July 8; Part 3, Aug. 19; Part 4, Sept. 30; Part 5, Oct. 28; Part 6, Nov. 25; Part 7, Dec. 23, 1974; Part 8, Jan. 20, 1975; Part 9, Feb. 17; and Part 10, Mar. 31.

Heat Capacity—Fig. 11—3, 11—4

Extensive heat-capacity data at atmospheric pressure are available for the ideal gas. The agreement among the various sources is good, with average deviations of 0.9%, 2.8%, and 1.4%, respectively, for methane, ethane, and propane.

Heat-capacity data at constant pressure for the saturated liquid were extended with the density extrapolation relation (Eq. 1—3, $n = 1$). The extrapolation values agree well with published data. Average deviations are 5% and 3.2% for ethane and propane.

Density—Fig. 11—5

Data for methane, ethane and propane are available for the entire liquid phase. The results of API Project 44 [417, 453] and National Bureau of Standards investigations [454] were selected. Deviations in most cases are less than 2%.

Surface Tension—Fig. 11—6

Recent tabulations by Jasper [*79*] and API Project 44 investigations [*417*] were selected for the experimental data. Surface tension over the full liquid range was then determined by extending the data with the Othmer relationship (Eq. 1—4). The straight line obtained for each alkane deviates less than 2%.

Viscosity—Fig. 11—7, 11—8

The available viscosity data for each alkane have been extended by means of the Flynn and Thodos correlation

(*Text continues on p. 97*)

How To Use the Graphs

Each graph is outfitted with a key that lists references and explains just what part of the curve is determined experimentally, and what part is estimated from theoretical correlations.

The shaded squares denote the following:

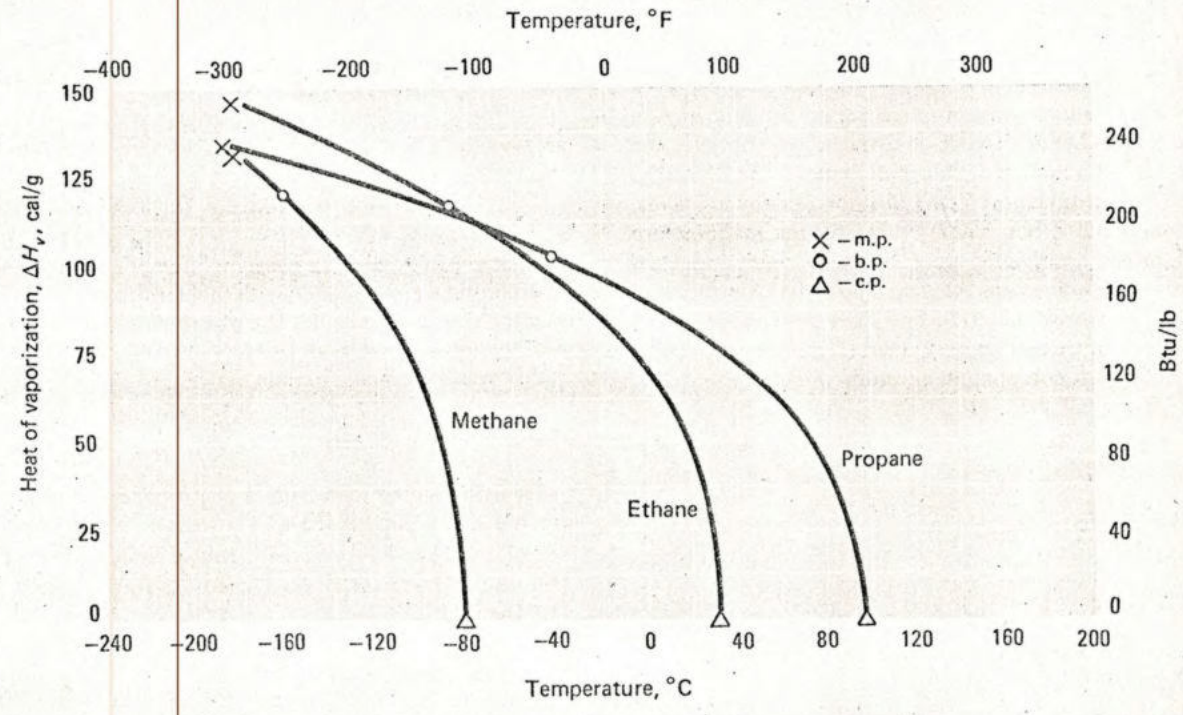
- ■ Data in this region are experimentally known.
- ◪ Experimental and correlated data used.
- □ All data in this region are correlated.

The "regions" referred to are the temperature ranges between the melting, boiling and critical points (m.p., b.p. and c.p., respectively), or in some cases, the specific temperatures noted in the key.

Physical Properties of the Alkanes
Table 11–1

Identification	Methane CH_4	Ethane C_2H_6	Propane C_3H_8
State (std. conditions)	Gas*	Gas*	Gas*
Molecular weight, M	16.043	30.07	44.096
Boiling point, T_b, °C	−161.5	− 88.2	− 42.1
Melting point, T_m, °C	−182.6	−183.2	−187.7
Critical temp., T_c, °C	− 82.6	32.3	96.7
Critical pressure, P_c, atm	45.4	48.3	41.9
Critical volume, V_c, $cm^3/g\text{-}mol$	98.5	146.3	203.0
Critical compressibility factor, Z_c	0.286	0.282	0.280

*Colorless.



Heat of Vaporization – Fig. 11–1

Fig. 11–1	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Methane	■	■	3,10,47,246,417,419,454
Ethane	◪	■	3,10,246,417,419,453
Propane	◪	■	3,10,246,417,419,463

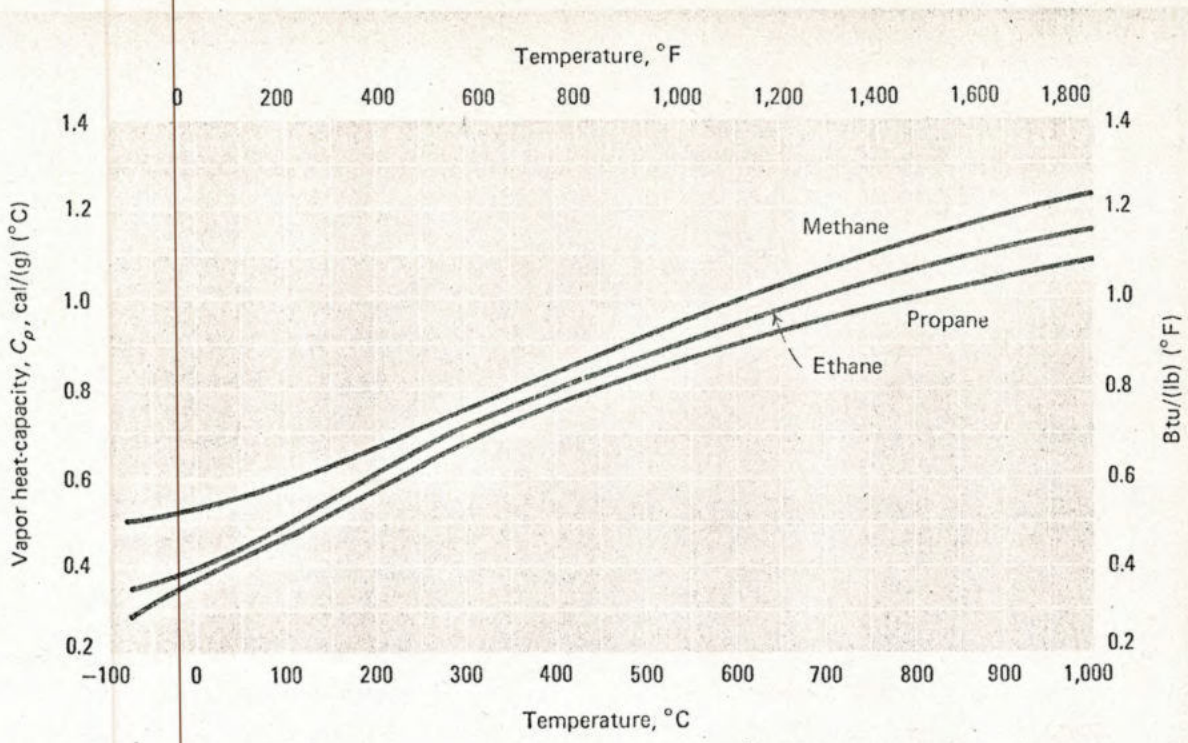
■ Laboratory data ◪ Laboratory plus correlations □ All correlated data

Fig. 11–2	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Methane	■	■	10,13,246,415,417,419,464
Ethane	■	■	10,13,246,415,417,419,446,452,453
Propane	■	■	10,13,246,415,417,419,446

■ Laboratory data ◪ Laboratory plus correlations □ All correlated data

Vapor Pressure – Fig. 11–2 →


Temperature, °F
−300
−200
−100
0
100
200
−300
−200
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Vapor pressure, P_v, mm Hg
Methane
Ethane
Propane
× — m.p.
○ — b.p.
△ — c.p.
Ethane
Propane
Vapor pressure, P_v, mm Hg
−200
−120
−40
40
−200
−120
Temperature, °C



Vapor Heat Capacity — Fig. 11–3

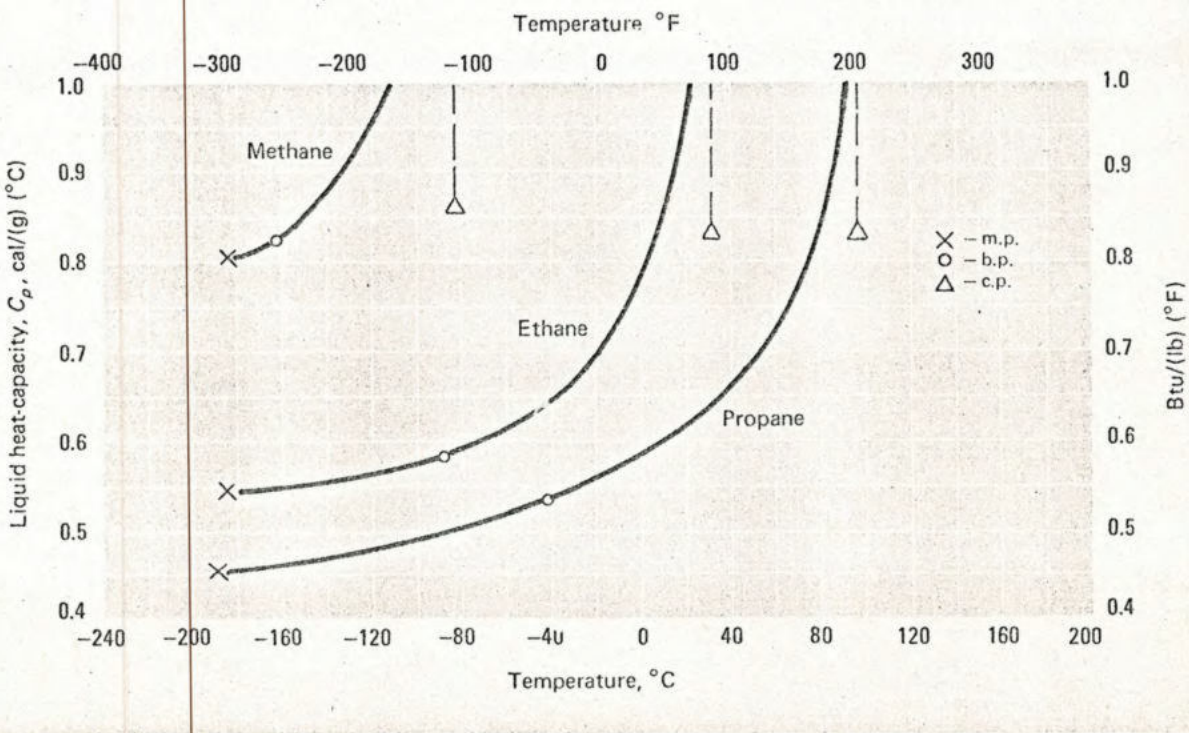
Fig. 11–3	Temperatuer Range, °C		References
	0–500	500–1,000	
Methane	◪	◪	15,19,417,461,464
Ethane	◪	◪	15,19,417,447,461
Propane	◪	◪	15,19,417,447,461

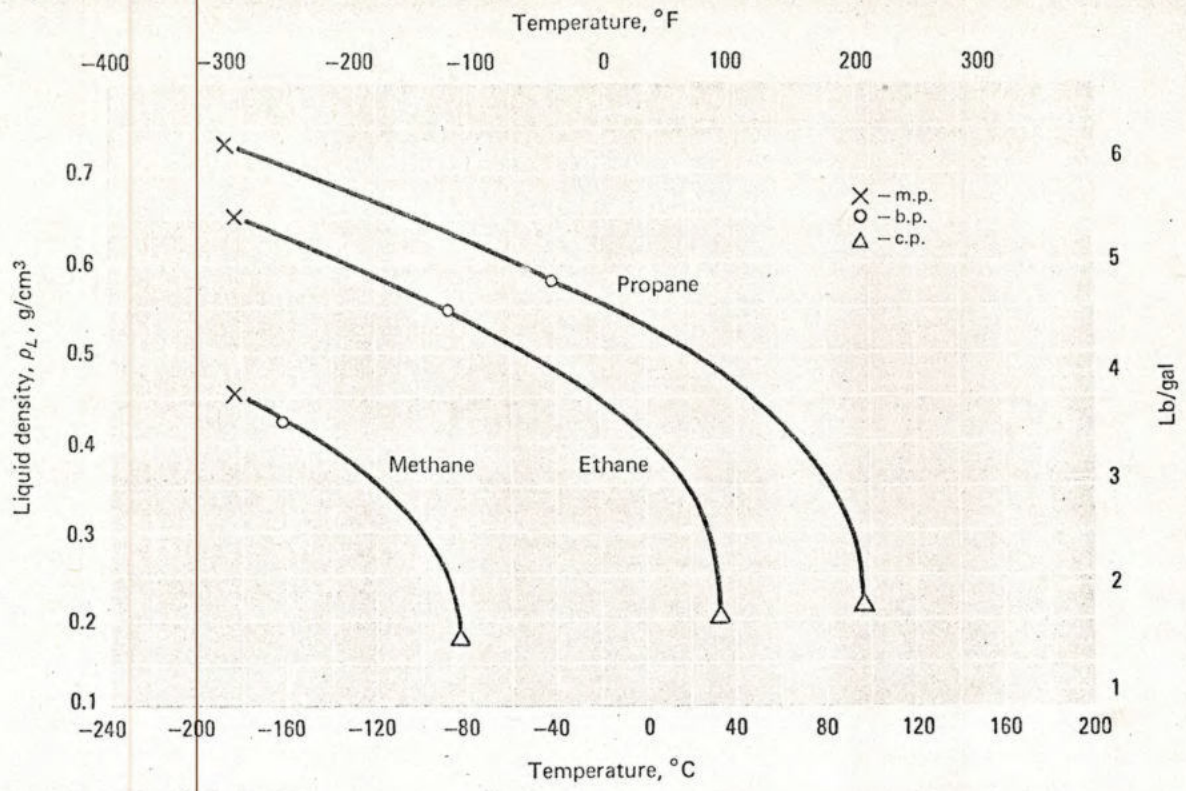
■ Laboratory data ◪ Laboratory plus correlations □ All correlated data

Fig. 11–4	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Methane	◪	◪	10,19,47,415,425,464
Ethane	■	◪	10,19,246,415,425,453
Propane	◪	◪	10,19,246,415,425,463

■ Laboratory data ◪ Laboratory plus correlations □ All correlated data

Liquid Heat Capacity — Fig. 11–4





Liquid Density — Fig. 11–5

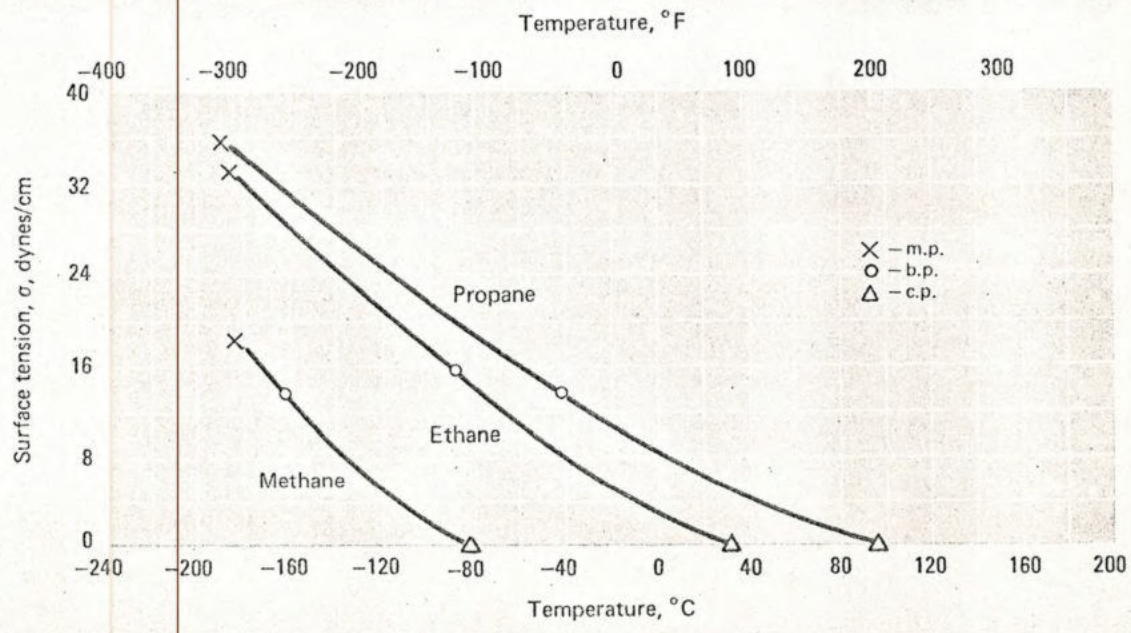
Fig. 11–5	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Methane	■	■	10,47,246,417,454,455,464
Ethane	■	■	10,246,417,448,453
Propane	■	■	10,246,417

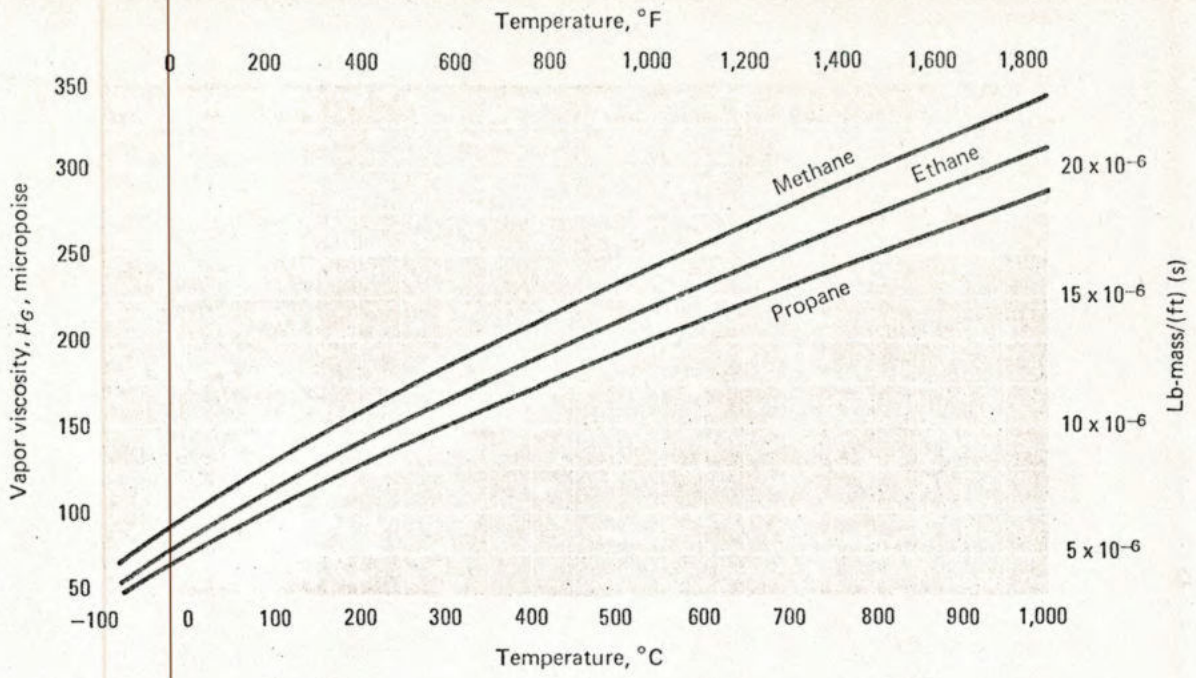
■ Laboratory data ▨ Laboratory plus correlations □ All correlated data

Fig. 11–6	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Methane	▨	▨	10,47,79,417
Ethane	▨	□	10,79,417
Propane	▨	▨	10,79,417

■ Laboratory data ▨ Laboratory plus correlations □ All correlated data

Surface Tension — Fig. 11–6





Vapor Viscosity – Fig. 11–7

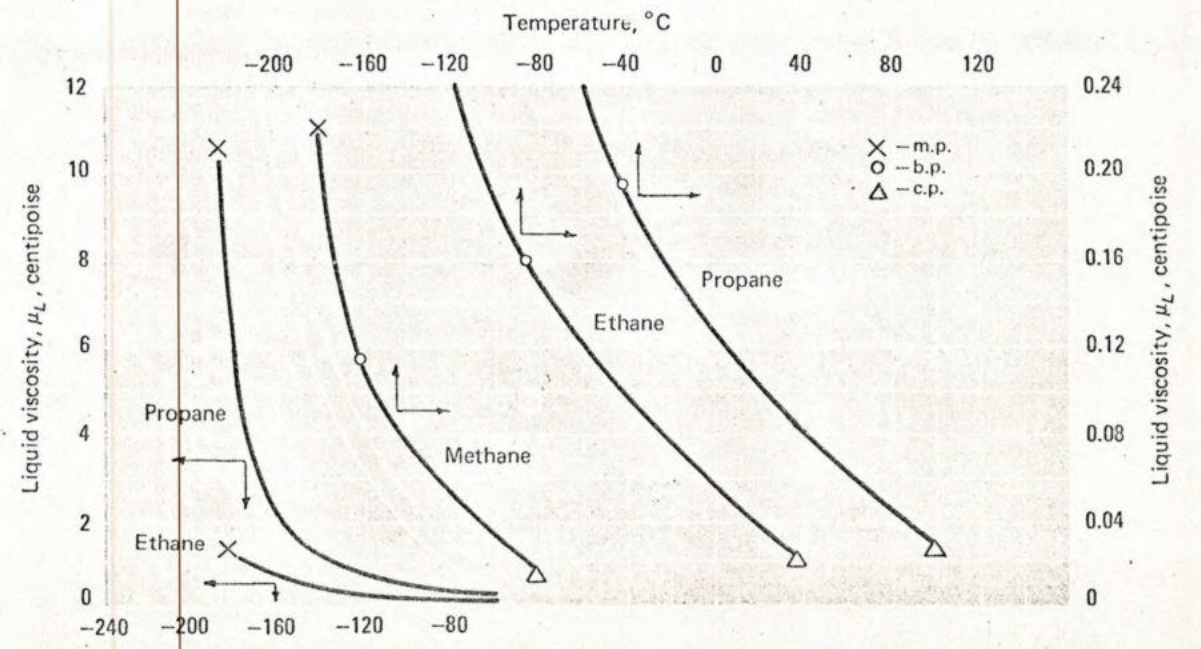
Fig. 11–7	Temperature Range, °C		References
	0–500	500–1,000	
Methane	■	◪	10,47,246,294,427,442,456,464
Ethane	■	◪	10,246,427,442,444
Propane	◪	□	10,246,427,442

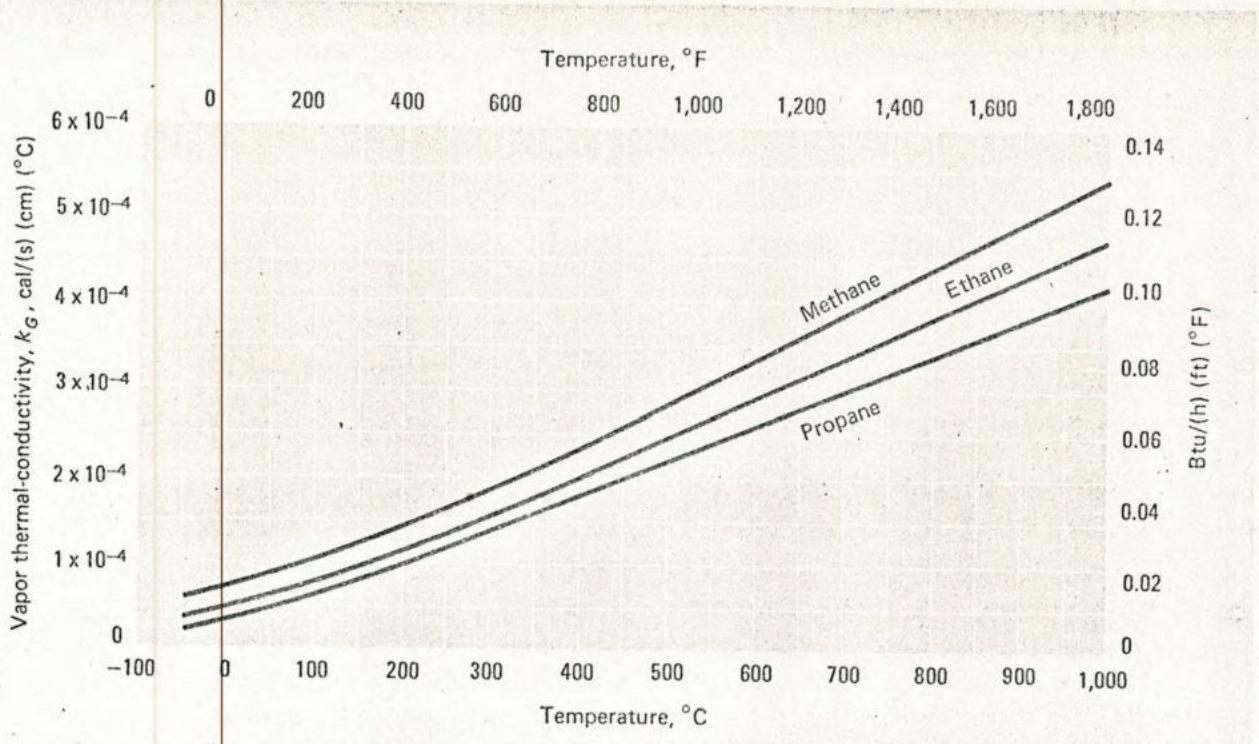
■ Laboratory data ◪ Laboratory plus correlations □ All correlated data

Fig. 11–8	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Methane	■	■	3,47,246,417,464,465,466
Ethane	◪	■	3,246,417,444,465
Propane	■	■	3,246,465,466

■ Laboratory data ◪ Laboratory plus correlations □ All correlated data

Liquid Viscosity – Fig. 11–8





Vapor Thermal Conductivity — Fig. 11–9

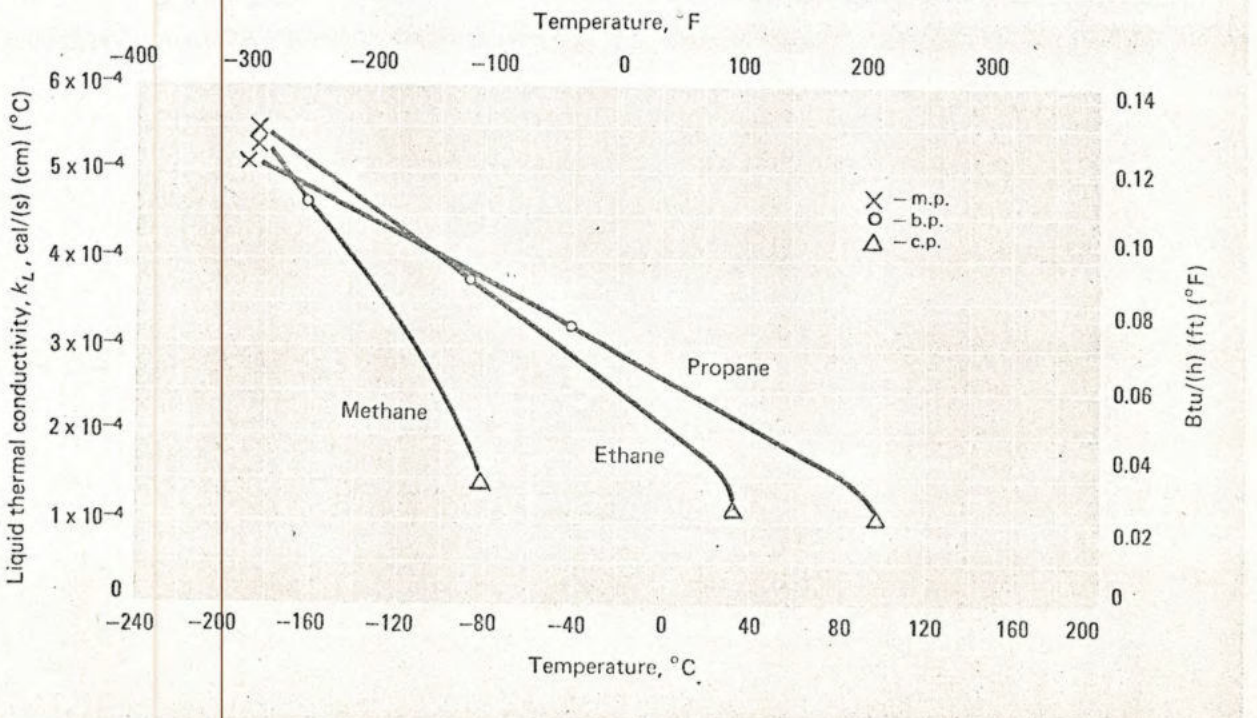
Fig. 11–9	Temperature Range, °C		References
	0–500	500–1,000	
Methane	■	◪	19,47,84,246,443,458,462,464
Ethane	■	◪	19,84,246,443,444,458
Propane	■	◪	19,84,246,443,450

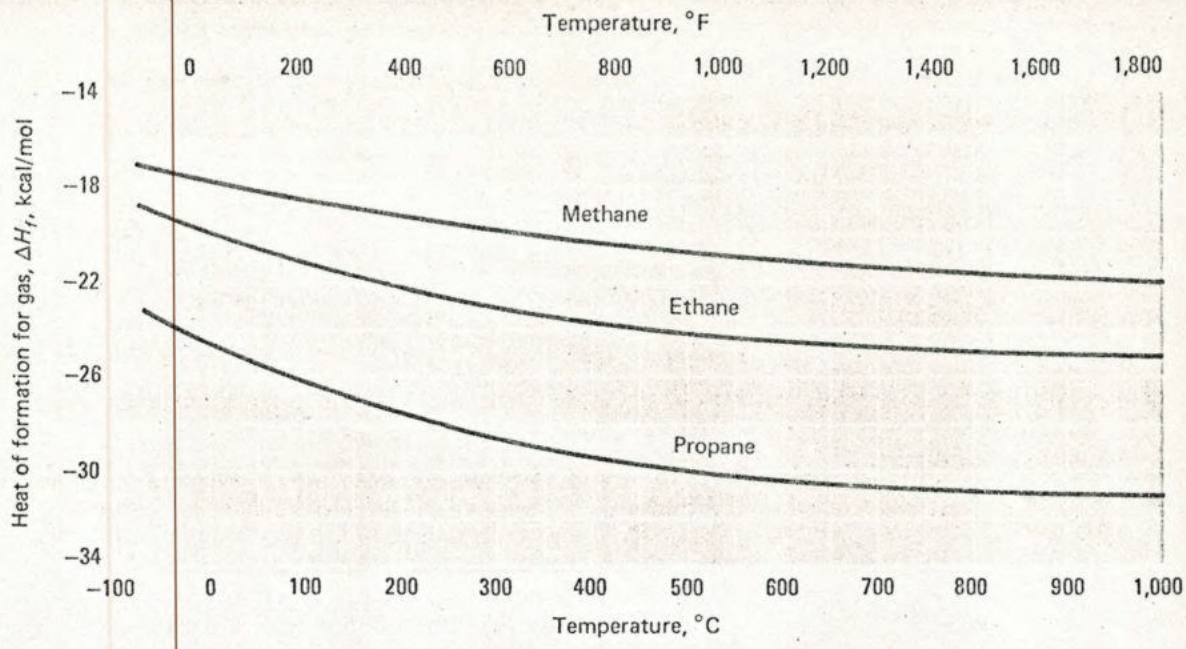
■ Laboratory data ◪ Laboratory plus correlations □ All correlated data

Fig. 11–10	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Methane	◪	◪	19,47,288,459,464
Ethane	◪	◪	288,444
Propane	◪	□	288,445

■ Laboratory data ◪ Laboratory plus correlations □ All correlated data

Liquid Thermal Conductivity — Fig. 11–10





Heat of Formation for Gas – Fig. 11–11

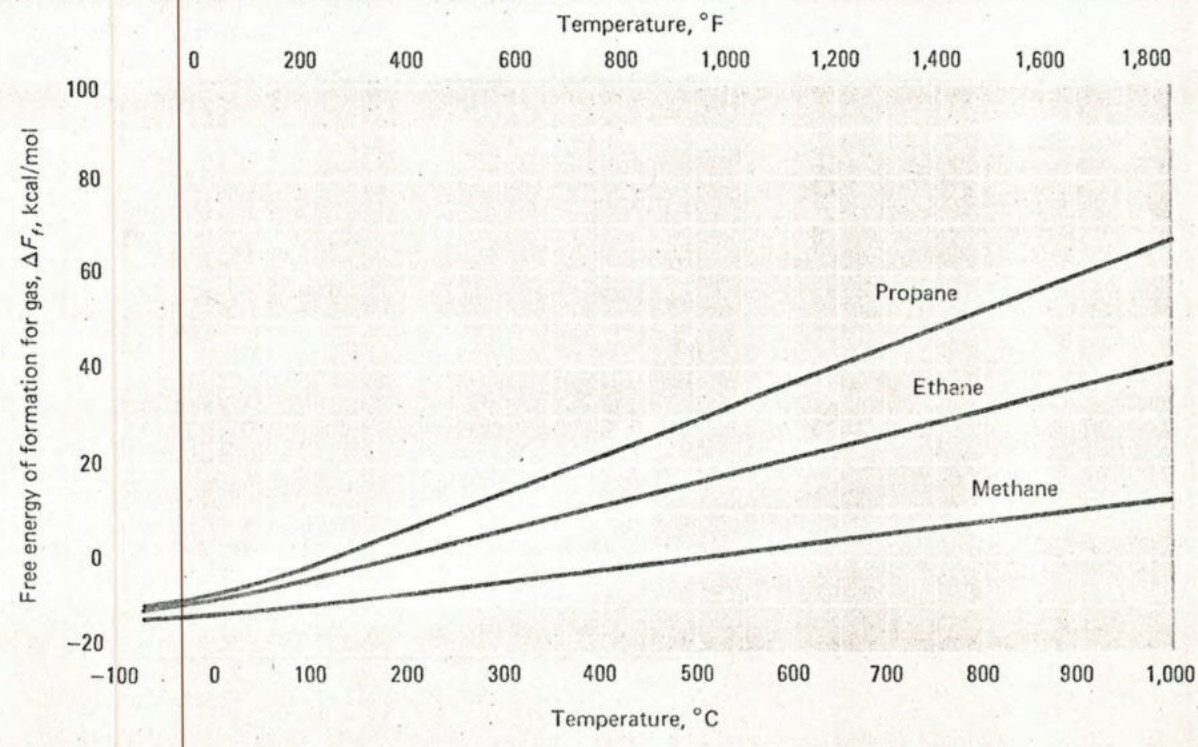
Fig. 11–11	Temperature Range, °C		References
	0–500	500–1,000	
Methane	▨	▨	15,417,461
Ethane	▨	▨	15,417,447,461
Propane	▨	▨	15,417,447,461

■ Laboratory data ▨ Laboratory plus correlations □ All correlated data

Fig. 11–12	Temperature Range, °C		References
	0–500	500–1,000	
Methane	▨	▨	15,417,461
Ethane	▨	▨	15,417,447,461
Propane	▨	▨	15,417,447,461

■ Laboratory data ▨ Laboratory plus correlations □ All correlated data

Free Energy of Formation for Gas – Fig. 11–12



(Eq. 10—1) for hydrocarbon gases at atmospheric pressure. The correlation fits the data with an average deviation of only 2.3%.

Liquid-viscosity data have been extended with the Guzman-Andrade relationship (Eq. 1—6) for log viscosity vs. reciprocal temperature. Two straight lines are sufficient to fit the data for each alkane. Liquid viscosities from the relationship and experimental data agree, with average deviation of 6%, 5.5% and 6.3% for methane, ethane and propane, respectively.

Thermal Conductivity—Fig. 11—9, 11—10

Gas-phase thermal conductivity has been extended beyond experimental data with the Misic and Thodos correlation (Eq. 10—2). Deviations from the data are 3.3%, 1.8% and 4.1% for methane, ethane and propane, respectively.

Liquid-thermal-conductivity data—which are available for each alkane—were extended for full liquid-phase coverage with the modified Stiel and Thodos relation (Eq. 10—3). The modified relation fits the data adequately. Deviations are 6% or less at temperatures below the critical point.

Heat and Free Energy of Formation—Fig. 11—11, 11—12

Data for heat and Gibbs' free energy of formation for the ideal gas agree well. The recent results of API Project 44 [*417,447*] and Bureau of Mines [*461*] investigations were selected. Average deviations for heat of formation are ±0.1, 0.5 and 0.3 kcal/mol for methane, ethane and propane, respectively. Deviations for Gibbs' free energy of formation are smaller, these being ±0.24 kcal/mol, or less. #

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References 1 through 443 are listed in Parts 1 through 10 of this series.

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Prior Parts of the Series

This article on the alkanes methane, ethane and propane—11th part of the series on the physical and thermodynamic properties of industrially important chemicals—has been preceded by the following ones, published on the dates indicated:

Part 1 (June 10, 1974): Halogens (Cl_2, Br_2, F_2, I_2)
Part 2 (July 8, 1974): Sulfur Oxides (SO_2, SO_3)
Part 3 (Aug. 19, 1974): Nitrogen Oxides (N_2O, NO, NO_2)
Part 4 (Sept. 30, 1974): Carbon Oxides (CO, CO_2)
Part 5 (Oct. 26, 1974): Halogen Acids (HCl, HF, HBr, HI)
Part 6 (Nov. 25, 1974): Ammonia and Hydrazine
Part 7 (Dec. 23, 1974): Water and Hydrogen Peroxide
Part 8 (Jan. 20, 1975): Diatomic Gases (H_2, N_2, O_2)
Part 9 (Feb. 17, 1975): Helium, Neon and Argon
Part 10 (Mar. 31, 1975): Olefins (C_2H_4, C_3H_6, 1-C_4H_8)

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There is a trend toward substituting G_f for F_f as the symbol for free energy of formation, so as to honor J. Willard Gibbs. In this article, F_f is retained so as to remain consistent with parts of the series already published.