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**CALCULATED THERMAL CONDUCTIVITIES OF
PURE GASES AND GASEOUS MIXTURES AT ELEVATED TEMPERATURES**

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CALCULATED THERMAL CONDUCTIVITIES OF PURE GASES AND GASEOUS MIXTURES AT ELEVATED TEMPERATURES

SUMMARY

A method of calculating thermal conductivities of gases and mixtures of gases at elevated temperatures is presented. Results for carbon dioxide, helium, neon, nitrogen and their binary mixtures are given for the temperature range of 273°K to 800°K. The calculated results for the pure gases are in agreement with the known experimental data.

METHOD

Experimental studies of the thermal conductances of pure gases and mixtures of gases at temperature above 0°C. have been limited because of the difficulty of making reliable measurements. On the other hand, viscosity determinations through wide ranges of temperature are rather plentiful. A study of the kinetic theory of gases shows the thermal conductivity and viscosity of a pure gas to be related, and Kennard (1) points out that surprisingly good agreement between these two quantities is obtained by means of the Eucken (2) equation:

$$k_T = 1/4 [9(C_p/C_v) - 5] \eta_T C_v$$

in which k_T is the thermal conductivity (cal/cm sec deg); C_p and C_v are the specific heats at constant pressure and constant volume (cal/gm) respectively, and η_T is the viscosity of the gas (c. g. s. units). All quantities being measured at the temperature T . This equation, in conjunction with those of the specific heats and viscosities as a function of the temperature, was used to calculate the thermal conductivities of gases at various temperatures. Tables I, II, and III depict the functions employed for various gases in the calculations of the variation of the specific heats and viscosity with temperature.

TABLE I
SPECIFIC HEATS AT CONSTANT PRESSURE

Gas	Specific Heat at Constant Pressure (cal/gm)	Applicable Over Temperature Range ($^{\circ}\text{K}$)	Average Error (%)
Helium (3)	1.242	298 to 3000	< 0.1
Carbon Dioxide (4)	$0.24 + 4.91 \times 10^{-5} T - 4.64 \times 10^{-3} T^{-2}$	298 to 2500	1.5
Neon (5)	0.246	298 to 3000	< 0.1
Nitrogen (5)	$0.238 + 3.645 \times 10^{-5} T$	298 to 2500	1.0

TABLE II
SPECIFIC HEATS AT CONSTANT VOLUME

Gas	Specific Heat at Constant Volume (cal/gm)	Applicable Over Temperature Range ($^{\circ}\text{K}$)	Average Error (%)
Helium	0.747	298 to 3000	0.1
Carbon Dioxide (6)	$0.126 + 8.95 \times 10^{-5} T - 2.32 \times 10^{-8} T^{-2}$	Not Given	Not Given
Neon	0.149	298 to 3000	0.1
Nitrogen	$0.1775 + 6.07 \times 10^{-6} t + 1.11 \times 10^{-8} t^2$ ($t = ^{\circ}\text{C.}$)	Not Given	Not Given

TABLE III
VISCOSITIES

Gas	Viscosity (c. g. s. units)	Applicable Over Temperature Range ($^{\circ}\text{K}$)	Average Error (%)
Helium (7)	$2.79 \times 10^{-6} T \left[(T/5.3)^{3/4} + (T/5.3)^{-3/4} \right]^{-0.470}$	15 to 1090	0.8
Carbon Dioxide (7)	$(15.52 \times 10^{-6} T^{3/2}) / (T + 233)$	175 to 1325	1.0
Neon (8)	$\frac{11.08 \times 10^{-6} T^{0.6}}{1 + 20/T}$	293 to 523	1.0
Nitrogen (7)	$\frac{13.85 \times 10^{-6} T^{3/2}}{T + 102}$	82 to 1098	0.4

In Table IV are tabulated the thermal conductivities at various temperatures of gases as calculated by the Eucken equation.

TABLE IV
THERMAL CONDUCTIVITIES OF PURE GASES
AT VARIOUS TEMPERATURES

Gas	Temperature (°K)	$k \times 10^5$ (calc.) (c. g. s. units)	$k \times 10^5$ (Exptl) (c. g. s. units)
Helium	273.1	35.3	34.1 (1)
	375.7	43.4	40.9 (9)
	400.0	45.2	No data available
	600.0	58.7	No data available
	800.0	70.8	No data available
Carbon Dioxide	273.1	3.32	3.40 (1)
	400.0	6.13	No data available
	600.0	9.53	No data available
	800.0	12.30	No data available
Neon	273.1	11.03	11.04 (1)
	400.0	14.17	No data available
	600.0	18.37	No data available
	800.0	22.01	No data available
Nitrogen	273.1	5.6	5.66
	400.0	7.67	No data available
	600.0	10.4	No data available
	800.0	12.9	No data available

A modified equation of Wassiljew was employed to calculate the thermal conductivities of gaseous mixtures at various temperatures. Calculations of thermal conductivities of binary mixtures using this equation was found by Lindsay and Bromley (10) to give an average deviation of 1.9% from the experimental points for sixteen gas pairs at 0°C. The equation is:

$$k_{\text{mix}} = \sum_i \frac{k_i}{1 + \frac{1}{x_i} \sum_{j \neq i} A_{ij} x_j}$$

$$A_{ij} = \frac{1}{4} \left\{ 1 + \left[\frac{\eta_i}{\eta_j} \left(\frac{M_j}{M_i} \right)^{3/4} \left(\frac{1 + \frac{S_i}{T}}{1 + \frac{S_j}{T}} \right) \right]^{1/2} \right\}^2 \left(\frac{1 + \frac{S}{T}}{1 + \frac{S_i}{T}} \right)$$

$$S_i = 1.5 T_i^B \quad S_j = 1.5 T_j^B \quad S = (S_i S_j)^{1/2}$$

in which k_i is the thermal conductivity (cal/cm sec deg), η_i is the viscosity (c. g. s. units), M_i the molecular weight, T_i^B the boiling point at one atmosphere pressure, and X_i the mole fraction of the gaseous component i.

In Table V are shown the thermal conductivities of gaseous mixtures at various temperatures as calculated by the above equation. Figures I, II, and III depict graphically the variation of thermal conductivities of the mixtures with temperature.

Most of the calculations were performed by B. Spangler of the Statistics Department.

TABLE V
HELIUM-CARBON DIOXIDE

<u>Mole Fraction Helium</u>	<u>$k \times 10^5$ at 273°K</u>	<u>$k \times 10^5$ at 400°K</u>	<u>$k \times 10^5$ at 600°K</u>	<u>$k \times 10^5$ at 800°K</u>
0	3.3	6.1	9.5	12.3
0.25	6.9	10.8	15.1	18.5
0.50	12.1	17.6	23.1	27.7
0.75	20.0	27.2	35.6	42.7
1.00	35.3	43.4	58.7	70.8

NEON-CARBON DIOXIDE

<u>Mole Fraction Neon</u>	<u>$k \times 10^5$ at 273°K</u>	<u>$k \times 10^5$ at 400°K</u>	<u>$k \times 10^5$ at 600°K</u>	<u>$k \times 10^5$ at 800°K</u>
0	3.3	6.1	9.5	12.3
0.25	3.9	7.5	11.0	13.9
0.50	6.1	9.1	12.8	15.8
0.75	8.2	11.3	15.2	18.4
1.00	11.0	14.2	18.4	22.0

HELIUM-NEON

<u>Mole Fraction Helium</u>	<u>$k \times 10^5$ at 273°K</u>	<u>$k \times 10^5$ at 400°K</u>	<u>$k \times 10^5$ at 600°K</u>	<u>$k \times 10^5$ at 800°K</u>
0	11.0	14.2	18.4	22.0
0.25	15.5	19.9	25.7	30.7
0.50	20.9	26.6	34.4	41.3
0.75	27.3	34.9	45.2	54.3
1.00	35.3	43.4	58.7	70.8

NITROGEN-CARBON DIOXIDE

<u>Mole Fraction N₂</u>	<u>k x 10⁵ at 273°K</u>	<u>k x 10⁵ at 400°K</u>	<u>k x 10⁵ at 600°K</u>	<u>k x 10⁵ at 800°K</u>
0	3.3	6.13	9.94	12.30
0.25	3.82	6.33	10.07	13.39
0.50	4.39	6.65	10.28	13.97
0.75	4.80	7.08	10.49	13.89
1.00	5.60	7.67	10.40	12.90

NITROGEN-HELIUM

<u>Mole Fraction N₂</u>	<u>k x 10⁵ at 273°K</u>	<u>k x 10⁵ at 400°K</u>	<u>k x 10⁵ at 600°K</u>	<u>k x 10⁵ at 800°K</u>
0	35.3	45.2	58.7	70.8
0.25	23.9	30.0	38.3	46.4
0.50	15.9	20.1	25.5	31.1
0.75	10.0	13.7	16.7	20.7
1.00	5.6	7.67	10.4	12.9

NITROGEN-NEON

<u>Mole Fraction N₂</u>	<u>k x 10⁵ at 273°K</u>	<u>k x 10⁵ at 400°K</u>	<u>k x 10⁵ at 600°K</u>	<u>k x 10⁵ at 800°K</u>
0	11.03	14.17	18.37	22.01
0.25	9.2	12.0	15.6	18.9
0.50	7.8	10.2	13.5	16.4
0.75	6.6	8.9	11.8	14.5
1.00	5.6	7.67	10.4	12.9

- (1) Kennard, "Kinetic Theory of Gases," 1st Ed., p. 180, (1938).
- (2) Eucken, Physic Z. 14, 324 (1913).
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- (8) Trantz and Binkele, Ann. Physik 5, 561-80 (1930).
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FIGURE I

CALCULATED THERMAL CONDUCTIVITIES OF
HELIUM AND CARBON DIOXIDE MIXTURES

FIGURE II

CALCULATED THERMAL CONDUCTIVITIES OF
NEON AND CARBON DIOXIDE MIXTURES

FIGURE III

CALCULATED THERMAL CONDUCTIVITIES OF
HELIUM AND NEON MIXTURES

FIGURE IV

CALCULATED THERMAL CONDUCTIVITIES OF
NITROGEN AND CARBON DIOXIDE MIXTURES

FIGURE **V**

**CALCULATED THERMAL CONDUCTIVITIES OF
NITROGEN AND HELIUM MIXTURES**

FIGURE VI
CALCULATED THERMAL CONDUCTIVITIES OF
NITROGEN AND NEON MIXTURES