UNCLASSIFIED

OAK RIDGE NATIONAL LABORATORY
Operated By
UNION CARBIDE NUCLEAR COMPANY

POST OFFICE BOX P
OAK RIDGE, TENNESSEE

External Transmittal
Authorized

ORNL
CENTRAL FILES NUMBER

CF-57-1-93

DATE: January 17, 1957

COPY NO. 30

SUBJECT: Estimation of the Thermal Conductivity and
the Viscosity of Gases at High Pressure

TO: Distribution

FROM: R. N. Lyon

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

NOTICE

This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

UNCLASSIFIED

843-1

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

DO NOT
PHOTOSTAT

ESTIMATION OF THE THERMAL CONDUCTIVITY AND
THE VISCOSITY OF GASES AT HIGH PRESSURE

Few data exist for the thermal conductivity and viscosity of gases at very high pressure. The possibility of using gases for heat transfer media at pressures up to 100 atmospheres and above raises the problem of estimating variations in the conductivity and viscosity at high pressures. Generalized plots are presented which are based on the work of Enskog, Eucken, and Hirschfelder et al. Some pertinent data from Hirschfelder et al. and from Hilsenrath et al. are also presented.

The developments of Enskog¹ as reviewed by Chapman and Cowling² and rearranged by Hirschfelder, Curtiss and Bird³ leads to the following dimensionless expressions for a monatomic gas based on the hard sphere molecular theory:

$$\frac{\mu}{\mu_0} \cdot \frac{\tilde{V}}{b_0} = \frac{1}{y} + .8 + 0.761y$$

$$\frac{\lambda}{\lambda_0} \frac{\tilde{V}}{b_0} = \frac{1}{y} + 1.2 + 0.755y$$

where

$\frac{\mu}{\mu_0}$	is the ratio of viscosity at pressure to viscosity at low pressure but the same temperature
$\frac{\lambda}{\lambda_0}$	is the similar ratio for thermal conductivity of monatomic gas
$\tilde{V}$	is the molal volume of the gas
b_0	is the effective molecular volume
y	is a function of $\frac{\tilde{V}}{b_0}$ and can be computed using the virial coefficients.

For polyatomic gases, the Eucken correction⁵ (see Hirschfelder et al., p.498-501) can be adapted to high pressures to give*

$$\lambda = \frac{1}{Y} \left(\frac{c_v}{k} + \frac{9}{4} \right) \frac{k}{m} \mu_0 + \frac{15}{4} \frac{b_0}{\tilde{V}} (1.2 + 0.755y) \frac{k}{m} \mu_0$$

where $Y = y \cdot \frac{\tilde{V}}{b_0}$

c_v is the heat capacity at constant volume

k is the Boltzmann constant

m is the mass of a molecule

and where

c_v and k/m have the same units.

Dividing by the Eucken equation and substituting R , the gas constant, for k/m gives

$$\frac{\lambda}{\lambda_0} \frac{\tilde{V}}{b_0} = \frac{1}{y} + \frac{15/4}{(c_v/R + 9/4)} (1.2 + 0.755y)$$

Since y is a function of $b_0/\tilde{V}$, a plot can be made showing μ/μ_0 as a function of $b_0/\tilde{V}$, and a plot can be made showing λ/λ_0 as a function of $b_0/\tilde{V}$ and c_v/R . These are given in Figures 1 and 2 respectively.

Using values of molecular radius given by Hirschfelder, b_0 divided by molecular weight was computed for several gases and are given in Table I to assist in finding values of μ/μ_0 and λ/λ_0 at a given density. Listed also are a few values of c_v/R and, some values of μ_0 and λ_0 as given by Hilsenrath, et al.⁴

*A similar adaptation by Hirschfelder, et al. p. 646 lists the first term on the right as $\frac{1}{Y} \left(\frac{c_v}{k} - \frac{9}{4} \right) \frac{k}{m} \mu_0$. It is believed that the minus sign is a typographical error.

TABLE I
Properties of Gases

Gas	b_0/MW (cc/gm)	Temp. °K	c_v/R			μ at 1 Atm in millipoises	λ at 1 Atm.	
			1 Atm	Pressure 10 Atm	100 Atm		Btu/hr ft ² °F/ft (all times 10 ⁻²)	
Air	2.17	300	2.50	2.51	2.57	0.185	1.52	
		1000	2.99	2.99	2.98	0.415	3.90	
		1800	3.49	3.49	3.48	0.583	-	
		2500	4.88	4.23	3.98	-	-	
Argon	1.34	>300	1.5	1.5	1.5	°K 300	0.230	1.02
		"	"	"	800	0.468	2.12	
		"	"	"	1200	0.611	2.76	
		"	"	"	1500	0.709	3.18	
CO ₂	1.69	300	3.49	3.59	-	0.150	0.956	
		360	-	3.85	3.88	0.176	1.23	
		400	4.00	-	4.29	0.193	1.42	
		500	-	-	4.32	0.232	1.94	
		700	4.98	4.96	-	0.301	-	
		1000	-	-	5.53	0.389	-	
		1400	-	-	5.98	0.489	-	
		1500	5.98	5.98	-	0.511	-	
He	5.35	>300	1.5	1.5	1.5			
H ₂	15.52	>300	2.5	2.5	2.5	300	0.096	10.5
						500	0.127	15.7
						700	0.159	20.7
						1000	0.202	-
Ne	1.31	>300	1.5	1.5	1.5			
N ₂	2.358	300	2.5	2.52	2.57	(See Table II)	1.52	
		1100	3.01	3.01	2.99		3.98	
		3000	3.45	3.45	3.46			
O ₂	1.738	300	2.54	2.55	2.61	0.206	1.55	
		730	2.98	2.99	3.00	0.386	2.80	
		1800	3.50	3.49	3.49	0.698		
		3000	3.80	3.81	3.81	-		

UNCLASSIFIED

TABLE II

Viscosity of N₂ (Millipoise)
From Hilsenrath et al.

Temp. °K	1 Atm	10 Atm	40 Atm	80 Atm	100 Atm*
300	0.179	0.179	0.184	0.194	0.199(0.201)
500	0.257	0.258	0.260	0.265	0.267(0.270)
1000	0.400	0.400	0.401	0.404	0.405
1500	0.505	0.506	0.507	0.508	0.510

*The values in parentheses were computed using densities given by Hilsenrath et al., the value of b_0/MW given above, and Figure 1.

Fig. 1. Effect of Gas Density on Viscosity

Fig. 2. Effect of Gas Density on Thermal Conductivity

843

7

UNCLASSIFIED

8.

REFERENCES

1. Enskog, D., Kangliga Svenska Vetenskapsakademiens Handlingar 63, No. 4 (1922).
2. Chapman, S. and Cowling, T. G., "The Mathematical Theory of Non Uniform Gases," Chapter 16, Cambridge University Press (1939).
3. Hirschfelder, J. O., Curtiss, C. F. and Bird, R. B., "Molecular Theory of Gases and Liquids", John Wiley and Sons, New York (1954).
4. Hilsenrath, J., Beckett, C. W., Benedict, W. S., Fano, L., Hoge, H. J., Masi, J. F., Nuttall, R. L., Touloukian, Y. S., Woolley, H. W., "Tables of Thermal Properties of Gases, National Bureau of Standards Circular 564", Issued Nov. 1, 1955.
5. Eucken, A., Physik, z. 14, 324 (1913).

UNCLASSIFIED

843

8