© *Proc. Indian natn. Sci. Acad.*, **47**, A, No. 4, 1981, pp. 428–434.
Printed in India.

Chemical Physics

THERMAL CONDUCTIVITIES AND VISCOSITIES OF SOME BINARY AND TERNARY MONOATOMIC GAS MIXTURES

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(*Received 11 August 1980; after revision 23 December 1980*)

The method suggested by Prajapati and Pandey (1979, 1980) for calculating the thermal conductivities of binary gas mixtures has been applied for some binary and ternary monoatomic gas mixtures. A method, for calculating the parameters of viscosity equation for binary gas mixtures and hence the viscosities, has also been suggested and applied for binary monoatomic gas mixtures. The estimated values show good agreement with the experimental values.

Keywords : Thermal Conductivities; Viscosities; Binary and Ternary Monoatomic Gas Mixtures; Lindsay-Bromley Equation; Mason-Saxena Equation; Wilke Equation; Hirschfelder-Eucken Approximation.

INTRODUCTION

AMONGST the various formulae for calculating the thermal conductivities or viscosities of binary gas mixtures, the equation (Chapman & Cowling, 1952) has been found to be the most successful. The equation

$$\lambda(\eta) = \frac{\lambda_i(\mu_i)}{1 + A_{ij}\dfrac{X_j}{X_i}} + \frac{\lambda_j(\mu_j)}{1 + A_{ji}\dfrac{X_i}{X_j}} \qquad \ldots(1)$$

has two adjustable parameters A_{ij} and A_{ji}. A_{ij} has been interpreted (Gray & Wright, 1961; Wright & Gray, 1962; and Cowling *et al.*, 1963) as the ratio of efficiencies with which molecules j and i impede the transport of heat in the case of thermal conductivity or the momentum by molecules i in the case of viscosity respectively.

Lindsay and Bromley (1950) proposed a semi-empirical equation for the estimation of parameters A_{ij} for thermal conductivities as

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

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where η_i, η_j and M_i, M_j are respectively the viscosities and molecular weights of components i, j; S is Sutherland's constant ($S_{ij} = (S_i S_j)^{1/2}$), where the gas components are nonpolar.

Another approximation for parameters A_{ij}, obtained from rigorous theory, has been derived by Mason and Saxena (1958)

$$A_{ij} = \frac{1}{\sqrt{8}}\left(1 + \frac{M_i}{M_j}\right)^{-1/2}\left[1 + \left(\frac{\eta_i}{\eta_j}\right)^{1/2}\left(\frac{M_j}{M_i}\right)^{1/4}\right]^2 \qquad \ldots(3)$$

This equation is analogous to Wilke equation (Wilke, 1950) for parameters A_{ij} for viscosities of binary monoatomic gas mixtures.

Lindsay-Bromley and Mason-Saxena methods and their modifications have been utilized for the calculation of thermal conductivities of Xe + He, Xe + Kr, Kr + He and Xe + Kr + He at 29 °C and 520 °C; Mason-Saxena method and its modification for thermal conductivities of Kr + Ar, Kr + Ne, Kr + He, Ar + Ne, Ar + He and Ne + He at 18 °C and Wilke method and its modified version for viscosities of Kr + Ar, Kr + Ne, Kr + He, Ar + Ne, Ar + He and Ne + He at 18 °C.

Theory and Calculation

Pandey and Prajapati (1979, 1980) have utilized Hirschfelder-Eucken approximation (1964) and derived the following modified Lindsay-Bromley and Mason-Saxena equations for the thermal conductivities of binary monoatomic gas mixtures.

$$A_{ij} = \tfrac{1}{4}\left[1 + \left\{\frac{\lambda_i}{\lambda_j}\left(\frac{M_i}{M_j}\right)^{1/4}\frac{T + S_i}{T + S_j}\right\}^{1/2}\right]^2 \frac{T + S_{ij}}{T + S_i} \qquad \ldots(4)$$

and

$$A_{ij} = \frac{1}{\sqrt{8}}\left(1 + \frac{M_i}{M_j}\right)^{-1/2}\left[1 + \left(\frac{\lambda_i}{\lambda_j}\right)^{1/2}\left(\frac{M_i}{M_j}\right)^{1/4}\right]^2 \qquad \ldots(5)$$

Equations (4) and (5) enable one to calculate parameters and hence the thermal conductivities of binary monoatomic gas mixtures for all compositions and at any temperature with the help of equation (1). Equation (1) may be generalised for a ternary gas mixture for calculating thermal conductivities as:

$$\lambda = \frac{\lambda_1}{1 + A_{12}\frac{X_2}{X_1} + A_{13}\frac{X_3}{X_1}} + \frac{\lambda_2}{1 + A_{23}\frac{X_3}{X_2} + A_{21}\frac{X_1}{X_2}} + \frac{\lambda 3}{1 + A_{31}\frac{X_1}{X_3} + A_{32}\frac{X_2}{X_3}} \qquad \ldots(6)$$

Equation (5) represents the modified Wilke equation for calculating the viscosities of binary monoatomic gas mixtures. In this paper, the experimental values of thermal conductivities and viscosities of pure gas components and mixtures have been taken from the literature (Saxena, 1957 ; Thornton, 1961; and Thornton & Baker, 1962).

Results and Discussion

The calculated values of thermal conductivities of binary and ternary gas mixtures from the methods have been presented in Tables I, II & IV. Table III represents the viscosities of binary gas mixtures at 18 °C. Deviations of the estimated values from the experimental ones are also shown in these tables. Parameters A_{ij} for thermal conductivities and viscosities are shown in Tables V and VI. The comparison clearly indicates the fact that the modified methods though approximate yield good results as compared to the original ones.

TABLE I

Thermal conductivities, λ, (10^{-7} cal cm^{-1} sec^{-1} °k^{-1}) of binary gas mixtures of Xe, Kr *and* He *from modified Lindsay-Bromley and Mason-Saxena methods*

System $i+j$	Temperature °C	Mole fraction X_i	Exptl. λ	From equations (1) and (4)		From equations (1) and (5)	
				λ	% Dev.	λ	% Dev.
Xe + He	29	0.213	1882	1825	—3.0	2018	+7.2
		0.288	1530	1481	—3.2	1663	+8.7
		0.582	717	674	—6.0	776	+8.2
		0.798	357	350	—2.0	395	+10.6
	520	0.213	3960	3777	—4.6	4264	+7.7
		0.288	3270	087	—5.6	3548	+8.5
		0.582	1490	1437	—3.6	1711	+14.8
		0.798	770	767	—0.4	887	+15.2
Xe + Kr	29	0.215	206	210	+1.9	210	+1.9
		0.490	186	185	—0.5	185	—0.5
		0.724	158	164	+3.8	164	+3.8
		0.842	149	155	+4.0	155	+4.0
	520	0.215	479	482	+0.6	486	+1.5
		0.490	420	427	+1.7	428	+1.9
		0.724	358	382	+6.7	384	+ 4.5
		0.842	341	360	+5.6	363	+6.5
Kr + He	29	0.120	2610	2587	—0.9	2759	+5.7
		0.250	1930	1849	—4.2	2042	+5.8
		0.423	1280	1216	—5.0	1385	+8.2
		0.760	541	523	—3.3	590	+9.1
	520	0.120	5510	5305	—3.7	5675	—3.0
		0.250	3900	3832	—2.0	4319	—10.7
		0.423	2670	2572	—3.7	2979	—11.6
		0.760	1210	1143	—5.5	1312	—8.4

TABLE II

Thermal conductivities, λ, (10^{-7} cal cm^{-1} sec^{-1} °K) *of binary monoatomic gas mixtures from Mason-Saxena method and its modified method at* 18°C

System	Mole fraction	Exptl.	From equations (1) and (3)		From equations (1) and (5)	
$i+j$	X_i	λ	λ	% Dev.	λ	% Dev.
Kr + Ar	0.865	233	242	+4.7	242	+4.7
	0.546	277	299	+7.9	299	+7.9
	0.330	326	342	+4.9	342	+4.9
	0.109	387	389	+0.5	389	+0.5
Kr + Ne	0.889	257	269	+4.7	270	+5.1
	0.647	400	399	—0.0	402	+0.5
	0.438	568	555	—2.3	560	—1.4
	0.111	960	962	+0.2	969	+0.9
Kr + He	0.797	480	481	+0.2	481	+0.2
	0.698	642	642	0.0	642	0.0
	0.353	1530	1491	—2.6	1491	—2.6
	0.272	1850	1802	—2.6	1802	—2.6
Ar + Ne	0.900	470	457	—2.8	457	—2.8
	0.541	680	645	—5.2	645	—5.2
	0.328	840	804	—4.3	804	—4.3
	0.221	930	901	—3.1	901	—3.1
Ar + He	0.914	540	529	—2.0	534	—1.1
	0.520	1270	1262	—0.6	1290	+1.6
	0.299	2040	1943	—4.8	1976	—3.1
	0.061	3300	3119	—5.5	3145	—4.7
Ne + He	0.894	1330	1337	+0.5	1337	+0.5
	0.565	1990	1971	—1.0	1971	—1.0
	0.250	2840	2760	—2.8	2760	—2.8
	0.158	3100	3042	—1.9	3042	—1.9

TABLE III

Viscosities, η, (10^{-6} cal cm^{-1} sec^{-1}) *of binary monoatomic gas mixtures from Wilke method and its modified method at* 18°C

System $i+j$	Mole fraction	Exptl.	From equations (1) and (3)		From equations (1) and (5)	
	X_i	η	η	% Dev.	η	% Dev.
Kr + Ar	0.865	248	259	+4.4	259	+4.4
	0.546	242	247	+2.1	247	+2.1
	0.330	236	242	+2.5	242	+2.5
	0.109	226	230	+1.8	230	+1.8

(*Table III continued on p.* 433)

TABLE IV

Thermal conductivities, λ, (10^{-7} cal cm^{-1} sec^{-1} $°K^{-1}$) *for Xe + Kr + He*

			Exptl.	From equations (1) and (4)		From equations (1) and (5)		Exptl.	From equations (1) and (4)		From equations (1) and (5)	
X_1	X_2	X_3	λ	λ	% Dev.	λ	% Dev.	λ	λ	% Dev.	λ	% Dev.
			At 29 °C					At 520 °C				
0.695	0.086	0.219	405	383	—3.0	433	+6.9	860	834	—3.0	970	+12.3
0.259	0.032	0.709	1580	1491	—5.6	1669	+5.6	3450	3096	—10.3	3561	+3.2
0.438	0.082	0.480	893	820	—8.2	943	+5.6	1880	1741	—7.4	2068	+10.0
0.114	0.021	0.865	2390	2339	—2.1	2513	+5.1	4880	4757	—2.5	5227	+7.1
0.357	0.136	0.507	964	900	—6.6	1034	+7.3	2030	1910	—5.9	2253	+11.0
0.213	0.081	0.706	1520	1508	—0.8	1691	+11.3	3390	3134	—7.5	3611	+6.5
0.102	0.039	0.859	2380	2315	—2.7	2487	+4.5	4830	4736	—2.0	5171	+7.1
0.379	0.394	0.227	450	439	—2.4	496	+10.2	995	958	—3.7	1108	+11.4
0.133	0.138	0.729	1740	1644	—5.5	1845	+6.1	3780	3426	—9.4	3922	+3.8
0.071	0.073	0.856	2300	2334	+1.5	2611	+9.2	5340	4778	—10.5	5223	—2.2
0.103	0.378	0.519	1060	1019	—3.9	1165	+9.9	2250	2159	—4.0	2534	+12.6
0.029	0.106	0.865	2500	2440	—2.4	2632	+5.3	5120	5000	—2.3	5446	+6.4

(TABLE III—*continued from p.* 431)

System $i+j$	Mole fraction X_i	Exptl. η	From equations (1) and (3) η	% Dev.	From equations (1) and (5) η	% Dev.
Kr + Ne	0.889	255	253	—0.8	254	—0.4
	0.647	275	266	—3.3	267	—2.9
	0.438	287	278	—3.1	280	—2.4
	0.111	310	304	—1.9	304	—1.9
Kr + He	0.797	254	252	—0.8	252	—0.8
	0.698	259	255	—1.5	255	—1.5
	0.353	264	262	—0.8	262	—0.8
	0.272	262	261	—0.4	261	—0.4
Ar + Ne	0.900	228	225	—1.3	225	—1.3
	0.541	255	249	—2.4	249	—2.4
	0.328	278	268	—3.6	268	—3.6
	0.221	285	280	—1.8	280	—1.8
Ar + He	0.914	222	221	—0.5	221	—0.5
	0.520	229	229	0.0	231	+0.9
	0.299	227	230	+1.3	232	+2.2
	0.061	205	210	+2.4	211	+2.9
Ne + He	0.894	307	304	—1.0	304	—1.0
	0.565	281	288	+2.5	288	+2.5
	0.250	244	251	+2.9	251	+2.9
	0.158	228	234	+2.6	234	+2.6

TABLE V

Parameters, A_{ij}'s, for thermal conductivities of binary monoatomic gas mixtures

System $i+j$	Temperature °C	From equation (4) A_{ij}	A_{ji}	From equation (5) A_{ij}	A_{ji}
Xe + He	29	0.37	3.98	0.13	3.37
	520	0.41	3.77	0.14	3.04
Xe + Kr	29	0.84	1.19	0.76	1.26
	520	0.85	1.19	0.77	1.25
Kr + He	29	0.43	3.31	0.18	2.81
	520	0.46	3.11	0.19	2.56

TABLE VI

Parameters, A_{ij}'s, for thermal conductivities or viscosities of binary monoatomic gas mixtures at 18°C

System $i+j$	From equation (3) A_{ij}	A_{ji}	From equation (5) A_{ij}	A_{ji}
Kr + Ar	0.71	1.18	0.71	1.18
Kr + Ne	0.41	2.17	0.41	2.13
Kr + He	0.18	2.89	0.18	2.89
Ar + Ne	0.60	1.66	0.60	1.66
Ar + He	0.27	2.43	0.27	2.34
Ne + He	0.50	1.52	0.50	1.52

ACKNOWLEDGEMENTS

One of the authors (S. R. P.) thanks Dr S. C. Gupta, Joint Secretary (Higher Education), U.P., Lucknow and Dr S. S. Khanna, Joint Director (Higher Education), U.P., Allahabad for inspiration and encouragement. He is also thankful to Dr A. K. Sinha, Principal of the K.N.G.P. College for providing research facilities.

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