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URBANA

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VISCOSITY STUDIES OF SYSTEM  
CaO–MgO–Al<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub>: III, 35%, 45%, and 50% SiO<sub>2</sub>

BY

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# VISCOSITY STUDIES OF SYSTEM $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ : III, 35%, 45%, and 50% $\text{SiO}_2$

BY

J. S. MACHIN, TIN BOO YEE, and D. L. HANNA

## ABSTRACT

In this continuation of previous papers on viscosity in the system  $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ , data are presented for melts containing 35%  $\text{SiO}_2$ , 45%  $\text{SiO}_2$ , and 50%  $\text{SiO}_2$  with varying percentages of the other three oxides that make up the system.

## INTRODUCTION

IN PREVIOUS papers data have been presented showing the manner in which viscosity varies with temperature and with composition in those parts of the system under consideration which contain 40%  $\text{SiO}_2$ <sup>1</sup> and which contain no  $\text{MgO}$ .<sup>2</sup> The data here presented were obtained by the methods and with the apparatus described in the previous papers and are treated in a similar manner.

## PREPARATION OF SAMPLES AND DISCUSSION OF ERRORS

In experimental work with glass where small samples are prepared from batch, it is customary to melt the samples, grind the resulting glass, and remelt it one or several times to make certain of the uniformity of the sample. In the present investigation the amount of time that would be consumed by this procedure is so great that it was decided to use other means to minimize possible error from nonuniformity of the sample. The batch materials (all -200 mesh) were mixed in a tumbling jar, put through a 20-mesh screen to break up any lumps, and then put into the tumbling jar for a further

period. The briquetted material was then melted in the crucible in which measurements were to be made. To test whether errors due to nonuniformity of samples were being made, a series of five samples was prepared in the usual manner, but in larger quantity. All these samples contained 65%  $\text{SiO}_2$  and 5%  $\text{MgO}$ . The amounts of  $\text{Al}_2\text{O}_3$  and  $\text{CaO}$  varied from 5 to 25% in the five samples. The reason for choosing these compositions is that it was considered that since the high-silica melts are usually more viscous, diffusion would be slow in them and the effects of nonuniformity of composition would be more likely to show up. One part of each of these samples was melted and the viscosity measured according to the regular procedure. A second part was melted, allowed to cool, ground through a 50-mesh screen, and remelted. The viscosity was then measured and the results compared with those from the first part.

The comparison indicated that the crushing and remelting on the average reduced the viscosity slightly. One sample was not changed appreciably. The average reduction in viscosity was about the same as the probable error of the measurements (i.e., about 4%). On any one sample it could not be said with certainty that the lowering in viscosity was due to the crushing and remelting since the difference was of the same order of magnitude as the probable error, but the fact

<sup>1</sup>J. S. Machin and D. L. Hanna, "Viscosity Studies of System  $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ : I, 40%  $\text{SiO}_2$ ," *J. Am. Ceram. Soc.*, 28 [11] 310-16 (1945); *Illinois State Geol. Survey Rept. Investigations*, No. 111 (1945).

<sup>2</sup>J. S. Machin and T. B. Yee, "Viscosity Studies of System  $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ : II,  $\text{CaO-Al}_2\text{O}_3\text{-SiO}_2$ ," *J. Am. Ceram. Soc.* 31 [7] 200-204 (1948); *Illinois State Geol. Survey Rept. Investigations*, No. 137 (1948).

TABLE I.—VISCOSITY DATA FOR THE SYSTEM  
LIME-MAGNESIA-ALUMINA-SILICA ( $\text{SiO}_2=35\%$ )

Melt No.	Composition (Wt. %)			Viscosity (poises)				
	$\text{Al}_2\text{O}_3$	CaO	MgO	(°C.)				
				1500	1450	1400	1350	1300
265	10	45	10	2.3				
266	10	40	15	2.1				
262	15	45	5	3.0	4.6	7.0		
254	15	40	10	2.7	3.9	6.0		
263	15	35	15	2.6	3.6	5.3	8.3	
18	20	40	5	4.8	7.2	11.4		
255	20	35	10	4.1	5.4	8.2	13.7	
19	20	30	15	3.9	5.7	8.9		
141	25	40	0	7.5	11.8	19.9		
256	25	35	5	6.5	9.4	15.3	25.5	
257	25	30	10	5.6	8.1	13.0	21.5	39.8
144	30	35	0	11.6	18.9	31.7		
37	30	30	5	11.2	16.6	26.0	48.2	92.4
259	30	25	10	9.2	16.7	31.4		
146	35	30	0	19.0	31.4	54.8	109	248

that the changes were all in the same direction indicates that the results would have been slightly better if all samples had been crushed and remelted.

For all the data presented in this series of papers the viscosity values are least reliable for those compositions that might develop new phases at the temperature of the experiment. The reasons for this are as follows: (1) It is possible that non-uniformity of the melt due to the formation of crystals which are not detected may result in misleading data. (2) When the sample is cooled after the preliminary melting and fining, a clear glass does not always result. In this case the crystalline phases and the glassy phase probably would differ in composition. The remelting of the sample may not then result in a uniform glass. (3) The possibility of the simultaneous existence of more than one liquid phase may not be completely ruled out. In one or two instances there

was some indication that two liquid phases were present.

The general trends noted in the previous papers<sup>1, 2</sup> continue to be apparent in the compositional regions covered by data presented in Tables I, II, and III and pictured graphically in Figs. 1, 2, and 3.

In Fig. 1 (B) and (C) the isokoms exhibit more curvature than is common in other regions of composition. The authors doubt the reality of this. The isokoms are fairly straight at 1500°C., but become curved at the two lower temperatures. This whole region is one in which the isotherms, although unknown except along the zero per cent MgO edge of the triangular diagrams, are probably quite close.

The patterns of the isokoms in Figs. 2 and 3 are logical if one reasons from the earlier data.<sup>1, 2</sup> They require no comment.

TABLE II.—VISCOSITY DATA FOR THE SYSTEM  
LIME-MAGNESIA-ALUMINA-SILICA (SiO<sub>2</sub> = 45%)

Melt No.	Composition (Wt. %)			Viscosity (poises) (°C.)					
	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	1500	1450	1400	1350	1300	1250
54	0	55	0	2.33					
55	0	50	5	2.25	3.08	4.46			
56	0	45	10	2.24	3.07	4.45			
57	0	40	15	2.10	2.89	4.11			
58	0	35	20	2.11	2.84	3.96			
59	0	30	25	1.94					
60	5	50	0	3.41	4.80				
61	5	45	5	3.81	4.91	7.47			
62	5	40	10	2.99	4.19	6.56	10.3		
63	5	35	15	2.84	3.98	5.68	9.03		
64	5	30	20	2.79	3.80	5.92			
65	5	25	25	2.46					
67	10	45	0	5.08	7.57	11.6			
68	10	40	5	4.79	6.97	10.6	16.9	29.6	57.9
69	10	35	10	4.58	6.90	10.2	16.0	27.5	
70	10	30	15	4.07	5.92	8.79	13.4	23.0	45.7
71	10	25	20	3.90	5.40	8.40			
72	10	20	25	3.67					
73	15	40	0	8.54	12.6	19.4	33.1		
74	15	35	5	7.60	11.1	17.3	28.8	50.8	102
75	15	30	10	6.76	9.80	15.1	24.3	42.4	82.1
76	15	25	15	6.68	9.45	14.4	23.3	41.1	
77	15	20	20	5.97	8.19	12.2			
78	15	15	25	5.01					
79	20	35	0	15.0	22.6	37.2	63.3	125	272
80	20	30	5	15.7	20.5	31.4	52.7	100	212
81	20	25	10	13.3	17.2	26.3	43.1	80.7	169
83A	20	20	15	9.71	14.2	21.8	36.0	66.9	
84	20	15	20	8.41	12.5	19.1	32.2		
85	20	10	25	7.72	11.4				
90	25	30	0	26.3	41.0	70.0	132		
91	25	25	5	22.3	37.9	57.2	106		
92	25	20	10	20.2	30.2	41.8	76.0	152	
93A	25	15	15	14.4	22.3	36.4	61.8	126	
94	25	10	20	12.9	20.0	31.7	51.7	105	
95	25	5	25	10.6	17.0	30.6			
96	30	25	0	70.5					
97	30	20	5	45.8	75.6				

## VISCOSITY STUDIES

TABLE III.—VISCOSITY DATA FOR THE SYSTEM  
LIME-MAGNESIA-ALUMINA-SILICA (SILICA=50%)

Melt No.	Composition (Wt. %)			Viscosity (poises) (°C.)					
	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	1500	1450	1400	1350	1300	1250
149	0	45	5	3.08					
150	0	40	10	2.86	3.90	5.71			
151	0	35	15	2.68	3.74	5.39	8.29		
152	0	30	20	2.61	3.56	5.10	7.68		
153	0	25	25	2.80	3.76				
131	5	45	0	4.78					
175	5	40	5	4.76	6.52	9.70			
176	5	35	10	4.40	6.08	9.07	14.2	23.8	
177	5	30	15	4.15	5.60	8.19	12.6	20.5	
178	5	25	20	3.93	5.53	8.08	12.1	23.6	
179	5	20	25	3.79	5.22				
126	10	40	0	8.23	12.1	19.2			
186	10	35	5	7.53	10.9	16.9	27.1	46.2	89.9
185	10	30	10	7.09	9.92	15.0	23.8	39.1	75.0
184	10	25	15	6.71	8.90	13.1	20.9	33.8	67.2
183	10	20	20	5.88	8.12	12.2	19.5		
182	10	15	25	5.49	7.97				
121	15	35	0	14.3	21.9	34.8	57.1	105	209
194	15	30	5	15.2	20.4	31.5	49.6	92.2	183
193	15	25	10	12.8	18.6	27.9	43.8	80.3	160
192	15	20	15	10.9	16.2	24.3	37.8	69.4	137
191R	15	15	20	9.51	13.7	21.4	35.0		
190	15	10	25	8.20	12.6				
189	15	5	30	8.61					
117	20	30	0	30.2	42.3	70.9	126	247	529
199	20	25	5	25.2	37.3	64.3	115	227	485
198R	20	20	10	22.2	33.8	53.8	93.0	178	381
197R	20	15	15	17.0	26.3	41.9	71.1	134	277
196	20	10	20	14.3	21.4	33.9	57.7	112	
195	20	5	25	13.2	20.3	33.0	52.7		
140	25	25	0	57.7	99.8				
203	25	20	5	41.6	69.4	121			
202	25	15	10	34.1	53.3	93.0	172	396	
201	25	10	15	26.6	40.6	71.2	132	265	591
200	25	5	20	21.0	33.3	54.9	102	202	



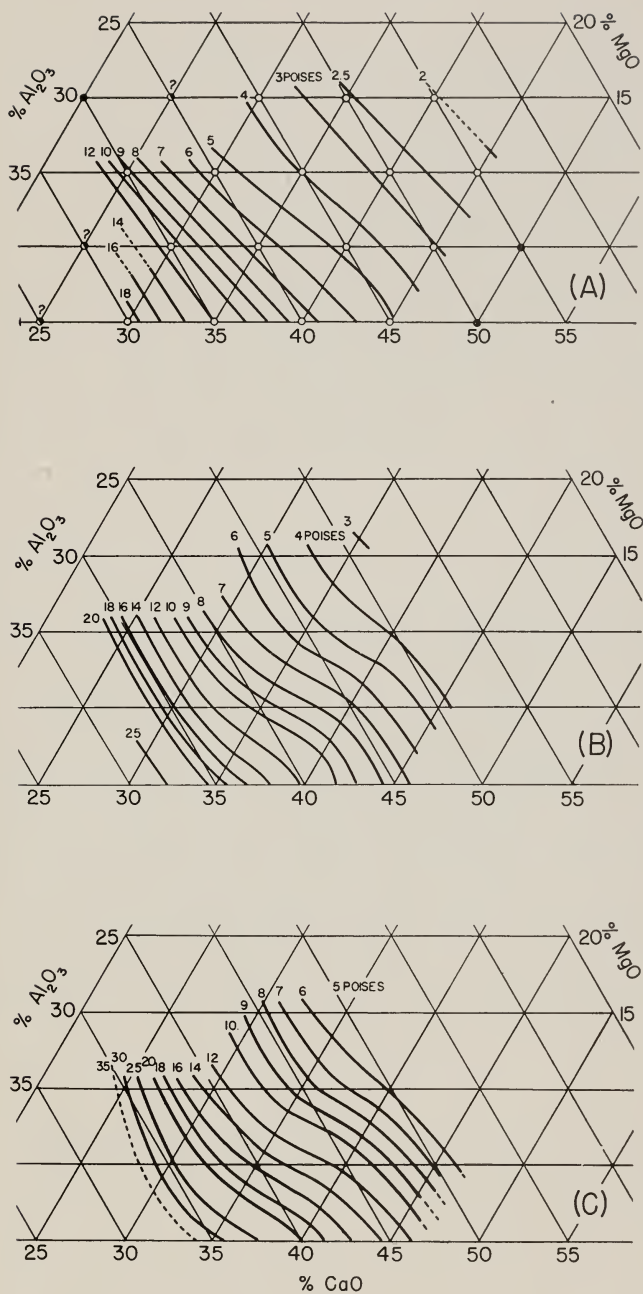


FIG. 1.—(A) Isokoms, 1500° C. (35% SiO<sub>2</sub>). Solid circles indicate experimental compositions not molten at 1500° C.; hollow circles indicate experimental compositions molten at 1500° C. or lower. (B) Isokoms, 1450° C. (35% SiO<sub>2</sub>). (C) Isokoms, 1400° C. (35% SiO<sub>2</sub>).

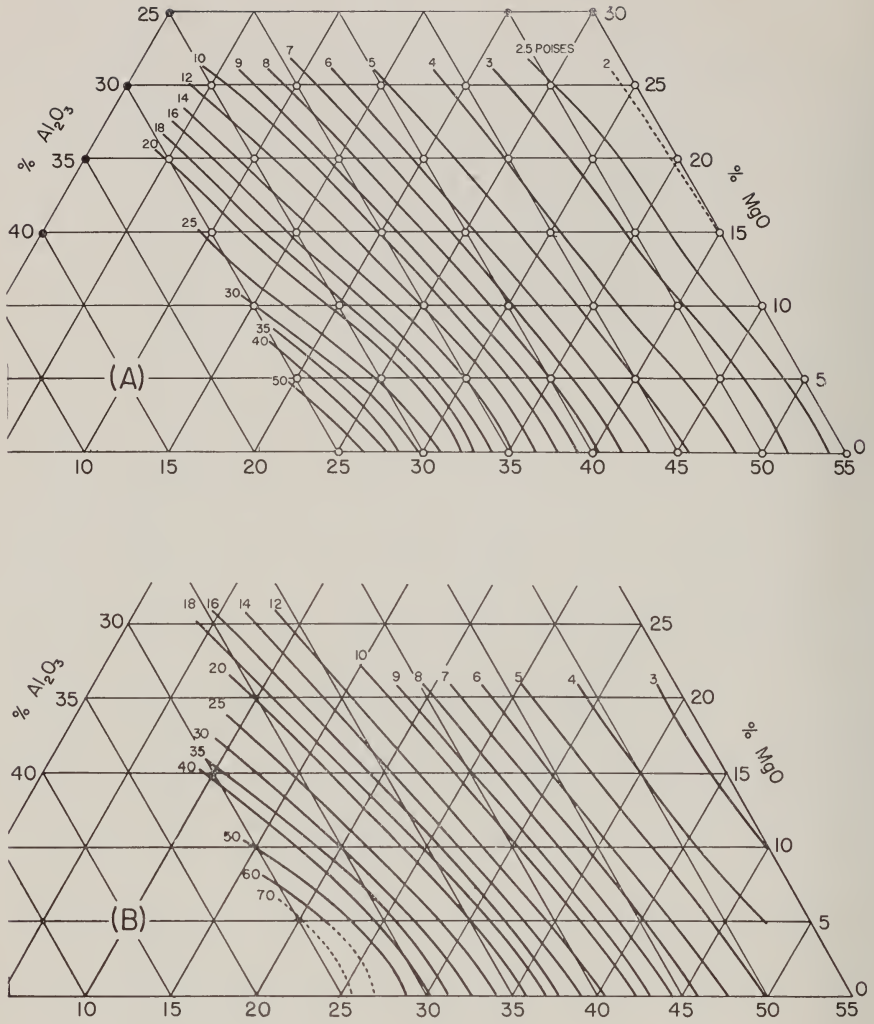


FIG. 2.—(A) Isokoms, 1500° C. (45%  $\text{SiO}_2$ ). Solid circles indicate experimental compositions not molten at 1500° C.; hollow circles indicate experimental compositions molten at 1500° C. or lower. (B) Isokoms, 1450° C. (45%  $\text{SiO}_2$ ). (C) Isokoms, 1400° C. (45%  $\text{SiO}_2$ ). (D) Isokoms, 1350° C. (45%  $\text{SiO}_2$ ).



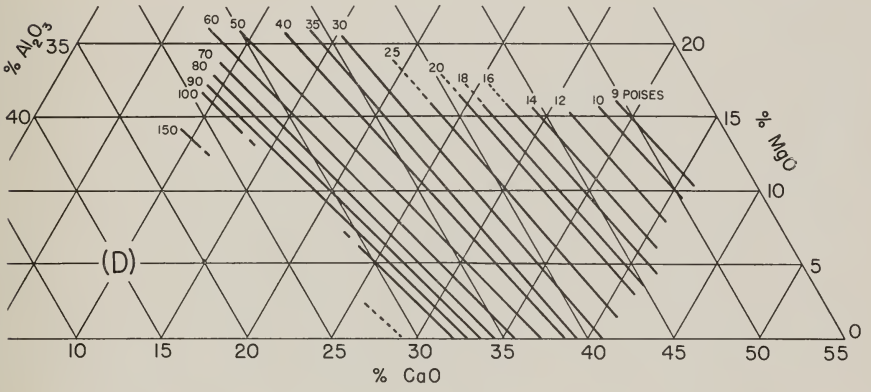


FIG. 2—Continued.

## VISCOSITY STUDIES

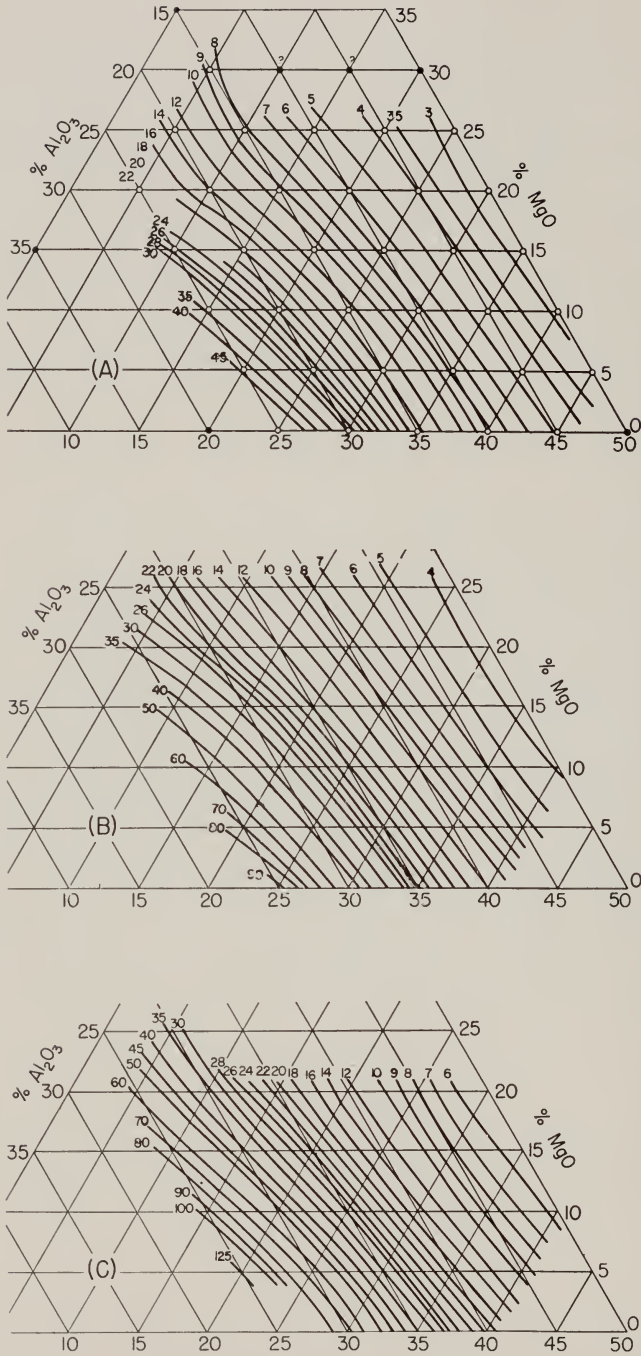


FIG. 3.—(A) Isokoms, 1500° C. (50% SiO<sub>2</sub>). Solid circles indicate experimental compositions not molten at 1500° C.; hollow circles indicate experimental compositions molten at 1500° C. or lower. (B) Isokoms, 1450° C. (50% SiO<sub>2</sub>). (C) Isokoms, 1400° C. (50% SiO<sub>2</sub>). (D) Isokoms, 1350° C. (50% SiO<sub>2</sub>).

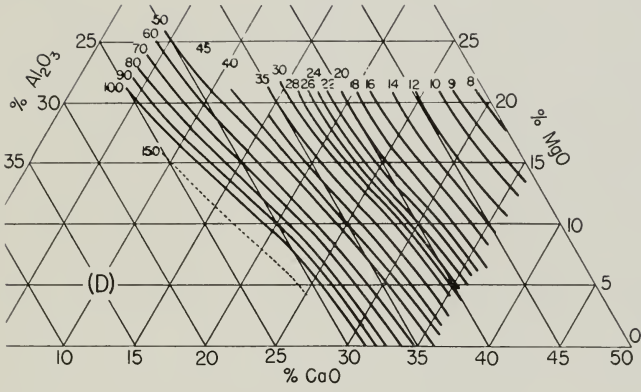


FIG. 3—Continued.

