Viscosity of Corn Sirup

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Experimental corn sirup viscosity data (Hoeppler viscometer) are presented for sirups having dextrose equivalent values from 16.6 through 100, including crystalline dextrose. These tests were determined over temperatures ranging from 60° to 180° F. for sirups having dry substance values from 20 through 85. All corn sirups were produced by standard acid hydrolysis and refining techniques as practiced by the corn wet-milling industry. Sample plots of the data are given, including logarithm of the viscosity *vs.* the value dry substance/(100 − dry substance); the logarithm of viscosity *vs.* 1/*T*; viscosity *vs.* dry substance at various temperatures; viscosity *vs.* temperature at various dry substance values; and viscosity *vs.* dextrose equivalent at various dry substance values.

VISCOSITY DATA are presented for the entire range of commercial acid-hydrolyzed starch sirups and sugars. The products were obtained from two refiners. The corn sirups (noncrystallizing) used included a special sirup of limited commercial use, 17 dextrose equivalent (D.E.), and the usual commercial products—low, medium, and high conversion, 35, 42, and 50 D.E. The saccharide compositions for corn sirups produced by acid hydrolysis are given in Table I. To cover the gap between the sirups and the sugars (crystallizing), a special sirup was produced by one refiner of 75 D.E. (slowly crystallizing). The two corn sugars used were obtained in a solid form—one a refined 90 D.E. hydrolyzate used for slab sugar production or from which α-D-glucose monohydrate is crystallized; and the other, crystallized dextrose, 99.9+ D.E. All of the above products were diluted in the laboratory to produce a series of sirups from 20 to 85% dry substance (D.S.). The latter density was not always possible. Viscosity data were obtained over a temperature range from 60° to 180° F. The viscosity data were obtained using a Hoeppler viscometer. The viscosity of corn sirup has been measured for years using the falling ball technique together with Ladenburg's or Faxon's correction of Stokes' equation (*1,2,4*). Comparable viscosity data were obtained by the Hoeppler and falling ball methods. The Hoeppler method should lead to better agreement of data between laboratories, since it is easier to use.

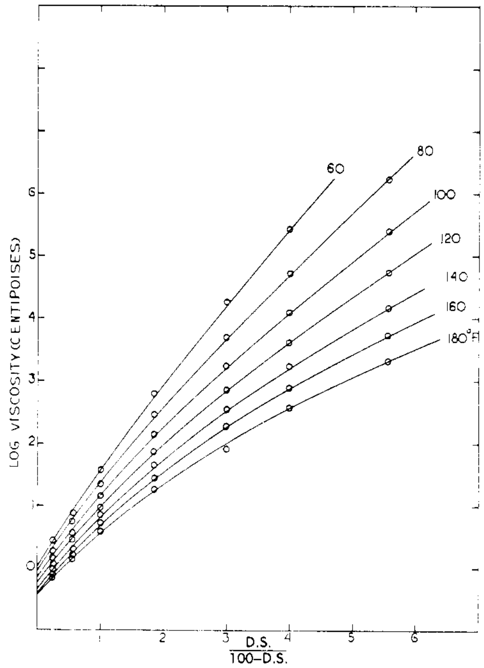

Figure 1. Viscosity vs. dry substance
D.E. 42.9

Table I. Corn Sirup Composition—Chromatographic Analysis, Carbohydrate Basis[a, b]

Dextrose Equivalent	Saccharides, %							
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Higher
10	2.3	2.8	2.9	3.0	3.0	2.2	2.1	81.7
15	3.7	4.4	4.4	4.5	4.3	3.3	3.0	72.4
20	5.5	5.9	5.8	5.8	5.5	4.3	3.9	63.3
25	7.7	7.5	7.2	7.2	6.5	5.2	4.6	54.1
30	10.4	9.3	8.6	8.2	7.2	6.0	5.2	45.1
35	13.4	11.3	10.0	9.1	7.8	6.5	5.5	36.4
40	16.9	13.2	11.2	9.7	8.3	6.7	5.7	28.3
45	21.0	14.9	12.2	10.1	8.4	6.5	5.6	21.3
50	25.8	16.6	12.9	10.0	7.9	5.9	5.0	15.9
55	30.8	18.1	13.2	9.5	7.2	5.1	4.2	11.9
60	36.2	19.5	13.2	8.7	6.3	4.4	3.2	8.5
65	42.5	20.9	12.7	7.5	5.1	3.6	2.2	5.5
67	45.1	21.4	12.5	6.9	4.6	3.2	1.8	4.5

[a] Data believed accurate ±1%. [b] Critical Data Tables of the Corn Industries Research Foundation, 1957.

The experimental data have been crossplotted in various ways: logarithm of viscosity *vs.* D.S. value/(100 – D.S.); logarithm of viscosity *vs.* $1/T$; viscosity *vs.* D.S. at various temperatures; viscosity *vs.* temperature at various D.S. values; and viscosity *vs.* D.E. at various D.S. values.

In this paper the D.S. values are used in place of the more common commercial Baumé (Bé.) method to characterize a sirup. The corresponding Bé. values can be calculated using Table XVI in the article by Fauser, Cleland, Evans, and Fetzer (*3*). The D.E. as well as the D.S. values, was determined by the standard analytical methods of the corn wet-milling industry (*5*).

DATA

The data are plotted as the logarithm of the viscosity *vs.* the quantity D.S./(100 – D.S.) as shown by sample Figure 1. This method of plotting produces a more nearly linear relationship which greatly facilitates interpolation and extrapolation at the higher D.S. levels; extended extrapolation of the data is not recommended.

The experimental data have been crossplotted in various ways: logarithm of viscosity *vs.* D.S. value/(100 – D.S.); is obtained at the following D.S. values: 85, 80, 75, 65, 50, 35, and 20 (Table II). A sample plot of the logarithm of viscosity *vs.* $1/T$ is given in Figure 2.

The data in the table were used to plot the viscosity *vs.* D.S. at various temperatures (Figure 3); the viscosity *vs.* temperature at various D.S. values (Figure 4); and finally, the viscosity *vs.* D.E. at various D.S. values (Figure 5).

RELIABILITY OF DATA

Points pertinent in a consideration of the reliability of the values for viscosity obtained in this report are: the accuracy and precision of each actual determination of viscosity on a particular sample of sirup, and the precision with which a sample is characterized (D.E., D.S.). Both points should be considered in relating the data reported to those of other investigations. As shown below, the second point seems to be the more serious limitation on the reliability of the data.

Table II. Viscosity (Centipoises) of Sirups of Different D.S. and Temperatures[a]

D.S.	Temp., °F.	Dextrose Equivalent 16.6	35.4	42.6	42.9	53.7	75.4	92.4	100
85	60						457,000		
	80		7,080,000		1,410,000	537,000	83,200		
	100		1,000,000		227,000	85,200	17,000		
	120		188,000		50,100	20,000	4,270		
	140		44,900		13,000	6,310	1,660		
	160		13,000		5,190	2,290	589		
	180		4,420		1,760	944	275		
80	60				266,000	89,100	24,000		
	80		126,000	56,200	59,600	17,800	4,570		
	100		29,900	13,300	15,000	5,010	1,550		
	120		8,910	4,220	4,840	1,800	603		
	140		3,350	1,700	1,860	785	282		
	160		1,410		851	367	141		
	180		687		386	196	75.9		
75	60		39,800		18,200	7590	6,030		
	80		10,000	5,780	5390	2140	741	501	
	100		3,020	1,880	1,880	807	331	211	200
	120		1,260	776	817	372	159	106	94.4
	140		620	382	389	191	83.2	56.2	49.0
	160		325		197	103	47.9	32.4	28.6
	180		180		110	62.0	28.8	19.5	17.5
65	60		1,060		560	389	178		100
	80		398	266	237	159	77.6	56.2	44.9
	100		182	125	119	83.2	45.7	30.7	29.5
	120		108	72.8	69.2	47.3	26.3	18.6	18.0
	140		67.9	46.2	43.4	29.0	16.2	12.2	11.2
	160		43.2		26.6	18.6	10.7	8.41	7.94
	180		29.0		17.8	12.6	7.76	5.96	5.46
50	60		54.6		34.0	33.5	18.6		16.3
	80	335	30.0	20.5	19.5	18.4	11.8	9.66	9.27
	100	188	18.5	12.6	12.0	11.6	7.94	6.31	6.12
	120	44.7	12.9	9.06	8.51	7.71	5.50	4.39	4.42
	140	28.2	9.44	6.71	6.31	5.43	3.24	3.20	3.09
	160	22.4	6.92		4.49	4.03	3.02	2.50	2.41
	180	13.3	5.27		3.55	3.16	2.19	1.97	1.87
35	60		9.16		7.16	7.50	5.13		5.31
	80	25.8	6.31	4.73	4.75	4.95	3.22	3.35	3.35
	100	17.3	4.52	3.35	3.29	3.35	2.74	2.41	2.44
	120	7.59	3.35	2.58	2.51	2.51	2.07	1.78	1.83
	140	5.31	2.66	2.03	1.99	1.88	1.57	1.41	1.41
	160	4.68	2.20		1.59	1.56	1.27	1.12	1.16
	180	3.16	1.68		1.33	1.26	1.00	0.944	0.944
20	60		2.90		2.82	2.63	2.26		2.37
	80	4.59	2.24	1.91	2.04	1.94	1.70	1.72	1.68
	100	3.35	1.78	1.45	1.45	1.45	1.33	1.27	1.26
	120	2.36	1.35	1.18	1.14	1.12	1.06	1.00	1.00
	140	1.63	1.12	0.944	0.922	0.908	0.832	0.804	0.819
	160	1.37	1.00		0.759	0.794	0.692	0.689	0.661
	180	1.09	0.773		0.673	0.668	0.562	0.576	0.562

[a] Additional information and data available from Corn Industries Research Foundation, Washington, D. C.

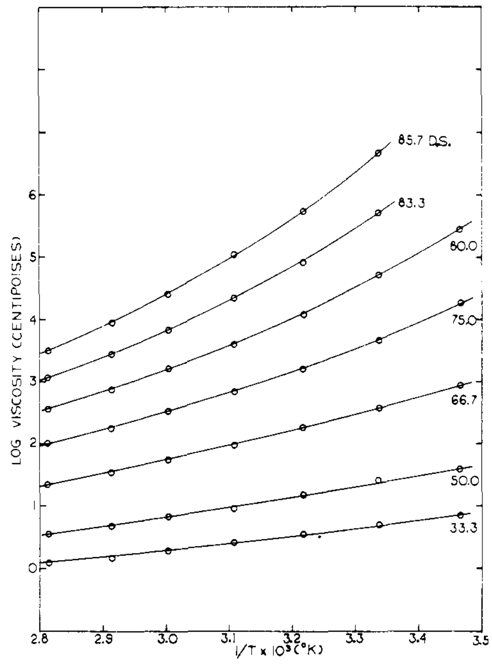

Figure 2. Viscosity vs. temperature
D.E. 42.9

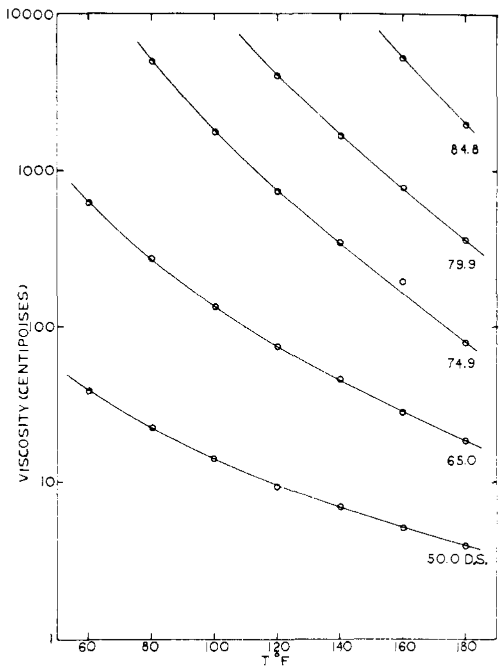

Figure 3. Viscosity vs. dry substance
D.E. 42.9

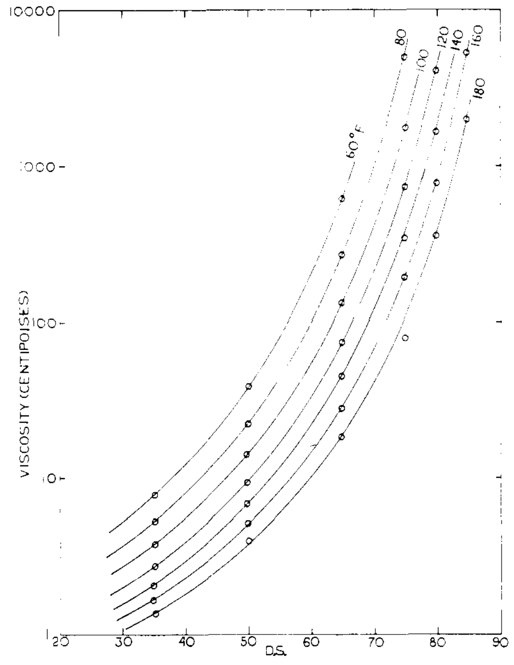

Figure 4. Viscosity vs. temperature
D.E. 42.9

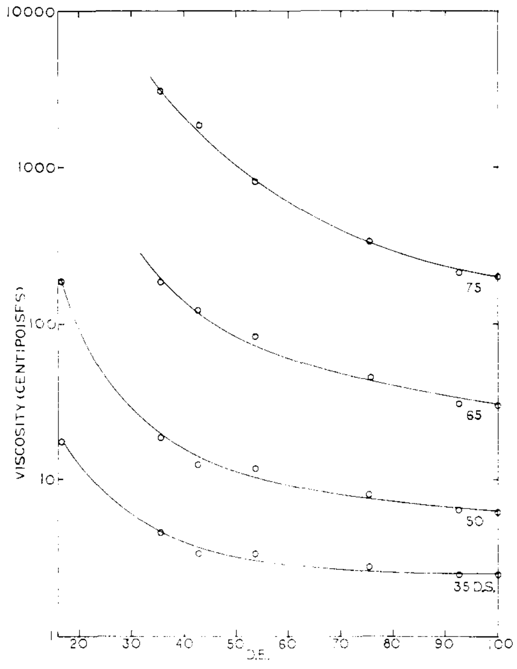

Figure 5. Viscosity vs. dextrose equivalent
100° F.

The accuracy and precision of the actual viscosity determinations are controlled by the calibration of the Hoeppler viscometers, the determination of the density of the samples, the accuracy of the fall time determination, and the control of the temperature of the sample during the run.

Two Hoeppler viscometers were used for the determination. Each viscometer was supplied by the manufacturer with a calibration certificate. Satisfactory results were obtained when several spot checks were made with oil obtained from the Bureau of Standards.

The viscosity of a sirup is equal to (the fall time) × (density of ball − density of sirup) × (a constant for the Hoeppler instrument). The densities of the corn sirups were determined with a pycnometer of a nominal 25-ml. capacity. They are accurate to the third decimal place, and any limitation on accuracy from this factor is negligible.

The fall times range from 30 to 300 seconds, except for the most viscous samples. Seven to ten falls were recorded in each case and the average was used. Deviations from the values ranged from 0.1 to 0.3%; these may be taken as good indications of the reliability of the fall times.

Finally, temperature control was of the order of ±0.005° except at the highest temperature, where it was about ±0.01°. The bath temperature was determined with ASTM certified thermometers which could be read to within 0.02° C. Thus, temperature accuracy is of the order of

0.02° C. The percentage change in viscosity for a 0.02° C. change in temperature varies from a high of 0.26 at the lower temperature and higher D.S. values to a low of 0.03 at the higher temperature and lower D.S. values.

The characterization of the sirup is essential for the comparison of data and ultimately for the usefulness of the data. The precision and accuracy of the determination of both the D.S. and the D.E. are estimated to be of the order of 0.1 unit each. The percentage change in viscosity for a 0.1 change in D.E. varies in those cases calculated from a high of 1.1 at the lower D.E., lower temperatures, and higher D.S. values to a low of 0.05 at the higher D.E., lower D.S., and higher temperature values. The percentage change in viscosity for a 0.1% change in D.S. varies from a high of 8.9 at the higher D.S. and lower temperature values to a low of 0.29 at the lower D.S. and higher temperature values. Of the three variables (temperature, D.S., and D.E.) which affect the fourth variable (viscosity), the D.S. determination at the higher values becomes the most significant factor.

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Heats of Mixing of Liquids for the System Ethanol-Benzene–*n*-Hexane

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Heats of mixing at 25° C. and 1 atm. are reported for the binary and ternary liquid mixtures of ethanol, benzene, and *n*-hexane.

IN THE COURSE of investigation of the thermodynamic properties of solutions, measurements were made of the heats of mixing of the following liquid mixtures at 25° C. and 1 atm.: ethanol-benzene, ethanol-*n*-hexane, benzene-*n*-hexane, and ethanol-benzene-*n*-hexane. The purpose here is primarily presentation of the data. The data on the binary systems were obtained to test the reliability of the calorimeters employed and to establish new values where discrepancies existed among data in the literature. The ternary data were determined along constant x_i/x_j lines as shown in Figure 1.

Brass calorimeters with thermistors as temperature-sensing elements were employed. Each calorimeter consisted of two compartments of various sizes, separated by a tinfoil diaphragm. Mixing and stirring were achieved with a gold-plated plunger actuated by a solenoid which was energized in a R-C rectified circuit. Fisher Calrod heaters and a Fisher Unitized bath control provided continuous and intermittent heating of the bath. Two Fisher Versatile stirrers and a continuous cooling source facilitated temperature control at 25° ± 0.01° C. The design of the calorimeter was similar to that reported by Lama and Lu (5) and the same experimental procedure was followed. In the determination of ternary data, a premixed binary mixture of known composition was placed in one of the compartments of the calorimeter and the third component was placed in the other before the mixing process. In all the determinations, heats of mixing were observed to be endothermic.

Absolute alcohol (Canadian Industrial Alcohol and Chemicals, Ltd.), spectro grade benzene, and research grade *n*-hexane (Matheson, Coleman and Bell) were used without further purification. The refractive indices of these chemicals determined at 25° C. agree with those available in the literature.

BINARY DATA

Experimental data obtained for the three binary systems are presented in Table I, and are compared with available literature values in Figures 2, 3, and 4.

Table I. Heats of Mixing Data for Binary Systems at 25° C.

Ethanol-Benzene		Ethanol–*n*-Hexane		Benzene–*n*-Hexane	
x_1	ΔH^M, cal./gram mole	x_1	ΔH^M, cal./gram mole	x_1	ΔH^M, cal./gram mole
0.0250	75.2	0.0395	71.9	0.1519	102.9
0.0586	112.0	0.0497	78.5	0.2136	129.8
0.1615	190.0	0.0726	78.3	0.3575	185.5
0.2673	216.5	0.0730	89.1	0.4678	209.7
0.4668	197.0	0.1509	116.7	0.5242	213.5
0.5602	168.4	0.1773	124.6	0.6427	207.5
0.7018	117.0	0.2707	129.5	0.6497	205.2
0.7074	114.8	0.3757	139.6	0.6957	196.1
0.9058	37.8	0.4043	138.6	0.7211	189.3
		0.5680	123.7	0.8075	155.3
		0.6318	116.6	0.9157	82.8
		0.7749	87.0		
		0.8399	69.3		
		0.9526	37.9		
		0.9483	27.3		