Refractive Index–Dry Substance Relationships for Commercial High-Fructose Corn Syrups and Blends

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A study of the refractive index–dry substance relationships has been made for a variety of high-fructose corn syrups and blends of these with sucrose, medium invert syrup, and 64 D.E. corn syrup. Dry substance levels from 0 to 80% and temperatures from 20 to 60 °C were included in this study. The results for nine product types are presented in the form of tables and of mathematical equations obtained by regression analysis. In addition, tables designed for the purpose of converting refractive index measurements to dry substance contents have been prepared and are included in this report. Finally, a general model which represents this work, earlier work on refractive index–dry substance relationships for corn syrups, and literature data for glucose, maltose, sucrose, fructose and invert syrup is described.

Introduction

Refractive index–dry substance content relationships have been established for a variety of commercial high-fructose corn syrups (HFCS) and for blends of these with sucrose, medium invert syrup, and 64 dextrose equivalent (D.E) corn syrup. This work extends the earlier work of Wartman, Hagberg, and Eliason (*7*) on commercial corn syrups. In the current study, measurements were made on nine products, each at eight or more dry substance levels ranging from 20 to 80% and at four temperatures from 20 to 60 °C for each dilution. The nine products were provided by member companies of the Corn Refiners Association, Inc. (CRA). Additional studies on solutions of pure fructose confirmed the validity of published tables (*6*).

The data for each product are available in tabular form from the Corn Refiners Association, Inc., 1001 Connecticut Avenue N.W., Washington, D.C., and are available as supplementary material. These data were fitted by regression analysis to a suitable function for each product. The results of the regression analysis are also included in the supplementary material. These functions were then used to generate convenient working tables which may be used to convert refractive index readings to dry substance values.

Analysis of the residuals (observed minus calculated values) indicates that the data are consistent internally and that the simple mathematical model previously used is capable of representing these new data as well. In addition, F. A. Kurtz at CPC International, Inc., has continued his work (*1*) on a single model to represent all syrups, blends, and solutions of individual sugars. The current status of this model is described in the Appendix; it gives further evidence that the current data are consistent with the earlier results (*7*) and it demonstrates the relationship between refractive index–dry substance behavior and composition.

Samples

Samples of three different commercial high-fructose corn syrups, a 64 D.E. corn syrup, sucrose, and a medium invert syrup were obtained from member companies of the CRA. The compositions of these are given in Table I.

Table I. Blend Stock Analysis

	%					
blend stock	fructose	glucose	DP2	DP3+	ash	dry substance
HFCS 42[a]	43.2	49.0	3.9	3.9	0.02	70.7
HFCS 55[a]	55.4	40.3	3.0	1.3	0.02	76.9
HFCS 90[a]	90.8	7.7	1.2	0.3	0.02	80.7
med invert	28.8	28.6	42.6		0.04	77.9
64 D.E. corn syrup (dual conversion)		38.2	29.7	32.1	0.63	82.0
sucrose			99.9	0.1	0.01	

[a] High-fructose corn syrups having a nominal fructose content of 42, 55, and 90% respectively.

Table II. Composition of Syrups and Blends

		%						
no.	sample	fructose	glucose	DP_2	sucrose	maltose	DP_3^+	ash
1	HFCS 42	43.2	49.0	3.9			3.9	0.02
2	HFCS 55	55.4	40.3	3.0			1.3	0.02
3	HFCS 90	90.8	7.7	1.2			0.3	0.02
4	50 HFCS 42/ 50 sucrose	22.1	24.9	50.9	50.2	0.7	2.1	0.02
5	50 HFCS 55/ 50 med inv	41.3	35.1	22.0	20.9	1.1	1.6	0.04
6	25 HFCS 42/ 75 med inv	30.9	34.3	32.4	31.8	0.6	2.4	0.04
7	50 HFCS 42/ 50 med inv	35.2	39.5	22.4	21.5	0.9	2.9	0.04
8	40 HFCS 42/ 60 CS 64 D.E.	17.2	42.9	18.9			21.0	0.38
9	25 HFCS 42/ 75 CS 64 D.E.	11.2	41.2	22.3			25.3	0.46

Blends of these were prepared and evaporated to about 80% dry substance at the Moffett Technical Center of CPC International, Inc., Argo, Ill. Samples of these products were delivered to this laboratory for the dry substance content–refractive index studies and to the laboratories of Clinton Corn Processing Co., Clinton, Iowa, A. E. Staley Manufacturing Co., Decatur, Ill., and American Maize-Products Co., Hammond, Ind., for composition analysis.

Descriptions of these products and their compositions are given in Table II. The blends were made on a weight–dry substance basis. Analysis of these products made at the Moffett Technical Center before and after the period of the study indicated that no composition changes occurred during the 3-month interval.

Fructose used in these studies was obtained from Pfanstiehl Laboratories, Inc., Waukegan, Ill., as D-fructose, NRC. Purity of this material was confirmed chromatographically at Moffett Technical Center. Glucose and sucrose reference samples were obtained from the National Bureau of Standards.

Experimental Details

The experimental details, equipment, and methods were as described previously (*7*). In this study, dry substance (D.S.)

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Table III. Validation of Vacuum Oven-Filter Aid Method (3) at 70 °C

sample	% moisture[a]	% D.S. by wt	% D.S. by oven
fructose	0.034	38.89	38.81
fructose	0.034	64.36	64.31
glucose	0.035	51.66	51.60
sucrose	0.0087	64.41	64.41
33.23% fructose 35.04% glucose 31.73% sucrose	0.027	38.77	38.76
33.31% fructose 29.74% glucose 36.95% sucrose	0.027	64.34	64.24
53.28% fructose 46.72% glucose	0.034	65.67	65.55
87.60% fructose 12.40% glucose	0.034	67.27	67.21

[a] These were determined for the reference sugars by drying under vacuum for 5 h at 70 °C and calculated for the mixtures.

Table IV. Refractive Indices at 20 °C for Solutions of Sucrose and Glucose

% dry substance	n_D obsd	n_D lit.[a]	difference
	Sucrose (see ref 4)		
9.80	1.347 52	1.347 50	+0.000 02
19.61	1.363 14	1.363 19	−0.000 05
29.51	1.380 21	1.380 28	−0.000 06
39.45	1.398 78	1.398 88	−0.000 10
49.23	1.418 45	1.418 49	−0.000 04
61.49	1.445 28	1.445 29	−0.000 01
64.55	1.452 30	1.452 38	−0.000 08
	Glucose (see ref 9)		
9.82	1.347 45	1.347 48	−0.000 03
19.67	1.362 96	1.363 02	−0.000 06
29.45	1.379 53	1.379 55	−0.000 02
49.34	1.416 92	1.416 93	−0.000 01
59.82	1.439 02	1.438 79	+0.000 23[b]
64.40	1.448 80	1.448 85	−0.000 05

[a] By interpolation. [b] Statistical outlier.

content was determined by the vacuum oven–filter aid method (3). Because of the high levels of monosaccharides in these products, the dry substance determinations were made at 70 °C. In order to validate the procedure, we carfully prepared and analyzed known solutions containing glucose, fructose, sucrose, and mixtures.

The pure sugars were not dried prior to solution preparation. The D.S. of each solution was calculated after a separate moisture content determination was made on each pure sugar. The results of these validation experiments, given in Table III, indicate that the oven method gives satisfactory results. Refractive index measurements were made with a Bausch and Lomb Precision (sugar) refractometer equipped with a prism covering the range 1.20–1.50, using a sodium vapor lamp as light source. This instrument was standardized by using the standard glass test piece (at 20 °C); redistilled water was subsequently used to check the reading each day and at each temperature. The difference between the individual reading on water and the published value (5) was used to correct the readings on each syrup sample. These differences ranged from 0.00001 at 20 °C to −0.000 12 at 60 °C.

Measurements of refractive index were made on a series of carefully prepared solutions of reference sucrose and glucose at 20 °C. The results of these measurements are given in Table IV. This study indicates a small but systematic negative deviation of the observed values from the literature values (4, 9). Therefore in subsequent work a correction has been added to each observed value amounting to 0.000 00 at a D.S. of zero to 0.000 05 at a D.S. of 60 and proportionally for other D.S. values.

Data Reduction

The data reduction program was patterned after that used in the previous study (7). The data were fitted to the equation

$$\frac{1}{n_D} = \frac{1}{n_D,H_2O}(1 + 0.0277701s)(1 - s) + (A_1 + A_2s + A_3s^2)s + B_1 + (B_2s + B_3s^2)(t - 20) \quad (1)$$

where n_D is the refractive index of the solution at temperature t °C, n_D,H_2O is the refractive index of water at temperature t, and s is percent dry substance/100.

For each product, stepwise multiple linear regression analysis was first used to determine the temperature coefficients, B_1, B_2, and B_3. These coefficients were then used to reduce all of the data to 20 °C and stepwise multiple linear regression was again used, this time to obtain the dry substance coefficients, A_1, A_2, and A_3. Because most of the current products were of low ash content, the ash relation established in ref 7 was used to make minor corrections in the final working tables.

Results

The experimental data for the product samples obtained in this study are available as supplementary material. Equation 1 with the coefficients given in Table V (with minor corrections for ash content) were used to generate the smoothed data tables, Tables VI–XIV. The regression coefficients A_1, A_2, and A_3 were obtained for syrups and blends with compositions indicated in Tables I and II. Those compositions differed slightly from the typical compositions for high-fructose corn syrup:

	% fructose	% glucose	% disaccharides	% higher saccharides
HFCS-42	42	52	3.7	2.3
HFCS-55	55	40.5	3.2	1.3
HFCS-90	90	7	1.9	1.1

The effect of the compositional change on refractive index of the syrups and blends was determined by using the composition equation presented in the Appendix. The incremental change in refractive index was used to adjust the indices for the smoothed tables, Tables VI–XIV. Corrections and interpolations within these tables may be made easily with the use of the correction tables given in ref 1.

Acknowledgment

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Appendix

Data from this study have been combined with those of the previous study (7) (samples 1–10) and literature data on glucose (9), fructose (16), maltose (8), invert (2), and sucrose (4) solutions to produce a comprehensive composition, temperature, dry substance equation or model. Stepwise, linear multiple regression analysis was used by F. A. Kurtz at Moffett Technical Center of CPC International, Inc., to give an expanded version of his earlier model (1). The exact form of this equation is given below, where n_D is the refractive index of the solution at tem-

Table V. Regression Coefficients for Equation 1

	dry substance			temperature		
sample	A_1	A_2	A_3	B_1	B_2	B_3
1	0.649 621 0	−0.001 259 5	0.001 049 8	−0.000 020 4	0.000 147 8	−0.000 045 8
2	0.649 840 3	−0.001 137 9	0.000 817 7	−0.000 018 8	0.000 144 5	−0.000 034 6
3	0.650 034 0	−0.001 599 3	0.001 359 8	−0.000 015 0	0.000 160 1	−0.000 036 5
4	0.648 947 8	−0.000 222 6	−0.001 428 4	−0.000 015 9	0.000 131 9	−0.000 032 8
5	0.649 447 7	−0.001 082 3	0.000 315 8	−0.000 015 5	0.000 142 1	−0.000 036 5
6	0.649 323 6	−0.001 087 8	0.000 203 8	−0.000 007 3	0.000 135 2	−0.000 035 8
7	0.649 272 5	−0.000 987 6	0.000 392 1	−0.000 009 9	0.000 140 8	−0.000 037 8
8	0.648 106 9	−0.000 948 0	−0.000 219 6	−0.000 004 3	0.000 131 1	−0.000 035 7
9	0.647 900 3	−0.001 409 5	−0.000 089 2	−0.000 007 2	0.000 130 2	−0.000 038 6

Table VI. High-Fructose Corn Syrup 42, 0.05% Ash (d.b.)

% dry sub-stance	refractive index			
	20 °C	30 °C	45 °C	60 °C
0	1.332 99	1.331 94	1.329 85	1.327 25
2	1.335 88	1.334 79	1.332 65	1.330 02
4	1.338 77	1.337 65	1.335 47	1.332 79
6	1.341 71	1.340 55	1.338 33	1.335 61
8	1.344 70	1.343 50	1.341 23	1.338 48
10	1.347 72	1.346 50	1.344 18	1.341 40
12	1.350 80	1.349 54	1.347 18	1.344 36
14	1.353 92	1.352 62	1.350 22	1.347 37
16	1.357 09	1.355 75	1.353 31	1.350 42
18	1.360 30	1.358 93	1.356 45	1.353 53
20	1.363 56	1.362 16	1.359 63	1.356 68
22	1.366 87	1.365 44	1.362 87	1.359 88
24	1.370 23	1.368 76	1.366 15	1.363 14
26	1.373 63	1.372 14	1.369 49	1.366 44
28	1.377 09	1.375 56	1.372 87	1.369 80
30	1.380 59	1.379 03	1.376 31	1.373 20
32	1.384 15	1.382 56	1.379 79	1.376 66
34	1.387 76	1.386 13	1.383 33	1.380 17
36	1.391 41	1.389 76	1.386 92	1.383 73
38	1.395 12	1.393 44	1.390 57	1.387 35
40	1.398 89	1.397 17	1.394 26	1.391 02
42	1.402 70	1.400 96	1.398 02	1.394 75
44	1.406 57	1.404 80	1.401 82	1.398 53
46	1.410 49	1.408 69	1.405 68	1.402 37
48	1.414 47	1.412 64	1.409 60	1.406 27
50	1.418 51	1.416 65	1.413 58	1.410 22
52	1.422 60	1.420 71	1.417 61	1.414 23
54	1.426 75	1.424 83	1.421 70	1.418 30
56	1.430 95	1.429 01	1.425 85	1.422 43
58	1.435 22	1.433 25	1.430 06	1.426 62
60	1.439 54	1.437 55	1.434 33	1.430 87
62	1.443 92	1.441 91	1.438 66	1.435 19
64	1.448 37	1.446 33	1.443 05	1.439 56
66	1.452 87	1.450 81	1.447 50	1.444 00
68	1.457 44	1.455 35	1.452 02	1.448 51
70	1.462 07	1.459 96	1.456 60	1.453 08
72	1.466 77	1.464 63	1.461 25	1.457 71
74	1.471 52	1.469 36	1.465 96	1.462 41
76	1.476 35	1.474 16	1.470 74	1.467 18
78	1.481 24	1.479 03	1.475 59	1.472 02
80	1.486 20	1.483 97	1.480 51	1.476 93
82	1.491 22	1.488 97	1.485 49	1.481 91
84	1.496 32	1.494 05	1.490 55	1.486 96

Table VII. High-Fructose Corn Syrup 55, 0.05% Ash (d.b.)

% dry sub-stance	refractive index			
	20 °C	30 °C	45 °C	60 °C
0	1.332 99	1.331 94	1.329 85	1.327 25
2	1.335 87	1.334 79	1.332 65	1.330 02
4	1.338 76	1.337 64	1.335 46	1.332 79
6	1.341 70	1.340 54	1.338 32	1.335 61
8	1.344 68	1.343 49	1.341 22	1.338 48
10	1.347 71	1.346 48	1.344 17	1.341 39
12	1.350 78	1.349 52	1.347 17	1.344 35
14	1.353 89	1.352 60	1.350 20	1.347 36
16	1.357 06	1.355 73	1.353 29	1.350 41
18	1.360 27	1.358 91	1.356 43	1.353 51
20	1.363 52	1.362 13	1.359 61	1.356 66
22	1.366 83	1.365 40	1.362 84	1.359 86
24	1.370 18	1.368 72	1.366 12	1.363 10
26	1.373 58	1.372 09	1.369 44	1.366 40
28	1.377 03	1.375 51	1.372 82	1.369 75
30	1.380 54	1.378 97	1.376 25	1.373 14
32	1.384 09	1.382 49	1.379 73	1.376 59
34	1.387 69	1.386 06	1.383 26	1.380 09
36	1.391 34	1.389 68	1.386 84	1.383 64
38	1.395 05	1.393 36	1.390 48	1.387 25
40	1.398 81	1.397 08	1.394 16	1.390 91
42	1.402 62	1.400 86	1.397 91	1.394 62
44	1.406 49	1.404 70	1.401 70	1.398 39
46	1.410 41	1.408 59	1.405 55	1.402 22
48	1.414 38	1.412 53	1.409 46	1.406 10
50	1.418 41	1.416 53	1.413 43	1.410 04
52	1.422 50	1.420 59	1.417 45	1.414 03
54	1.426 65	1.424 71	1.421 53	1.418 08
56	1.430 85	1.428 88	1.425 66	1.422 20
58	1.435 11	1.433 11	1.429 86	1.426 37
60	1.439 44	1.437 40	1.434 12	1.430 60
62	1.443 82	1.441 75	1.438 44	1.434 90
64	1.448 26	1.446 17	1.442 81	1.439 25
66	1.452 77	1.450 64	1.447 26	1.443 67
68	1.457 33	1.455 18	1.451 76	1.448 16
70	1.461 97	1.459 78	1.456 33	1.452 71
72	1.466 66	1.464 45	1.460 97	1.457 32
74	1.471 42	1.469 18	1.465 67	1.462 00
76	1.476 25	1.473 98	1.470 43	1.466 75
78	1.481 15	1.478 85	1.475 27	1.471 56
80	1.486 11	1.483 78	1.480 17	1.476 45
82	1.491 14	1.488 78	1.485 14	1.481 41
84	1.496 24	1.493 86	1.490 19	1.486 43

$$\frac{1}{n_D} = \frac{1}{n_{D,H_2O}}(1 + 0.0277701s)(1 - s) + [C_1 + C_2 s + \sum_{i=1}^{5}(A_{i1} + A_{i2}s + A_{i3}s^2 + A_{i4}V_i)V_i]s - B_1 + [B_2V_1 + B_3V_2 + B_4(V_3 + V_4 + V_5) + B_5 s]s(t - 20)$$

perature t °C, n_{D,H_2O} is the refractive index of pure water at temperature t °C, s = grams of dry substance per gram of solution, and V_1–V_5 are the weight fractions of glucose, fructose, maltose, sucrose, and other saccharides, respectively (carbohydrate dry basis). The regression coefficients are shown in Table AI.

The differences in refractive index (at high dry substance) between tables published for the various syrups and sugars and those calculated are in Table AII and show generally good agreement.

Table VIII. High-Fructose Corn Syrup 90, 0.05% Ash (d.b.)

% dry substance	refractive index			
	20 °C	30 °C	45 °C	60 °C
0	1.332 99	1.331 94	1.329 85	1.327 25
2	1.335 86	1.334 77	1.332 63	1.329 98
4	1.338 75	1.337 62	1.335 42	1.332 74
6	1.341 69	1.340 51	1.338 27	1.335 53
8	1.344 67	1.343 45	1.341 15	1.338 38
10	1.347 69	1.346 44	1.344 09	1.341 27
12	1.350 76	1.349 47	1.347 07	1.344 20
14	1.353 88	1.352 55	1.350 09	1.347 19
16	1.357 04	1.355 67	1.353 16	1.350 22
18	1.360 25	1.358 84	1.356 28	1.353 29
20	1.363 51	1.362 06	1.359 45	1.356 42
22	1.366 81	1.365 32	1.362 67	1.359 60
24	1.370 17	1.368 64	1.365 93	1.362 82
26	1.373 57	1.372 00	1.369 25	1.366 09
28	1.377 02	1.375 42	1.372 61	1.369 42
30	1.380 52	1.378 88	1.376 03	1.372 79
32	1.384 08	1.382 39	1.379 49	1.376 22
34	1.387 68	1.385 96	1.383 01	1.379 70
36	1.391 33	1.389 57	1.386 57	1.383 23
38	1.395 04	1.393 24	1.390 19	1.386 81
40	1.398 80	1.396 96	1.393 87	1.390 44
42	1.402 61	1.400 74	1.397 59	1.394 13
44	1.406 48	1.404 56	1.401 38	1.397 88
46	1.410 40	1.408 44	1.405 21	1.401 68
48	1.414 37	1.412 38	1.409 10	1.405 53
50	1.418 40	1.416 37	1.413 05	1.409 44
52	1.422 49	1.420 42	1.417 05	1.413 41
54	1.426 63	1.424 53	1.421 11	1.417 43
56	1.430 83	1.428 69	1.425 23	1.421 52
58	1.435 08	1.432 91	1.429 40	1.425 66
60	1.439 40	1.437 19	1.433 64	1.429 86
62	1.443 78	1.441 53	1.437 93	1.434 12
64	1.448 21	1.445 93	1.442 29	1.438 45
66	1.452 71	1.450 39	1.446 70	1.442 83
68	1.457 27	1.454 91	1.451 18	1.447 28
70	1.461 89	1.459 49	1.455 72	1.451 79
72	1.466 57	1.464 14	1.460 33	1.456 36
74	1.471 32	1.468 85	1.465 00	1.461 00
76	1.476 13	1.473 62	1.469 73	1.465 70
78	1.481 00	1.478 46	1.474 53	1.470 47
80	1.485 95	1.483 37	1.479 40	1.475 31
82	1.490 96	1.488 35	1.484 33	1.480 22
84	1.496 03	1.493 39	1.489 33	1.485 19

Table IX. 50% HFCS-42/50% Sucrose, 0.05% Ash (d.b.)

% dry substance	refractive index			
	20 °C	30 °C	45 °C	60 °C
0	1.332 99	1.331 94	1.329 85	1.327 25
2	1.335 90	1.334 82	1.332 69	1.330 06
4	1.338 82	1.337 71	1.335 54	1.332 88
6	1.341 79	1.340 65	1.338 44	1.335 75
8	1.344 80	1.343 63	1.341 39	1.338 67
10	1.347 85	1.346 65	1.344 37	1.341 63
12	1.350 95	1.349 72	1.347 41	1.344 63
14	1.354 10	1.352 84	1.350 49	1.347 69
16	1.357 29	1.356 00	1.353 62	1.350 79
18	1.360 53	1.359 21	1.356 79	1.353 94
20	1.363 82	1.362 47	1.360 02	1.357 13
22	1.367 16	1.365 78	1.363 29	1.360 38
24	1.370 54	1.369 14	1.366 61	1.363 68
26	1.373 98	1.372 54	1.369 99	1.367 03
28	1.377 47	1.376 00	1.373 41	1.370 43
30	1.381 01	1.379 51	1.376 89	1.373 88
32	1.384 60	1.383 08	1.380 42	1.377 39
34	1.388 24	1.386 69	1.384 00	1.380 95
36	1.391 94	1.390 36	1.387 64	1.384 57
38	1.395 70	1.394 09	1.391 34	1.388 24
40	1.399 51	1.397 87	1.395 09	1.391 97
42	1.403 37	1.401 71	1.398 90	1.395 76
44	1.407 30	1.405 61	1.402 76	1.399 60
46	1.411 28	1.409 57	1.406 69	1.403 51
48	1.415 32	1.413 58	1.410 67	1.407 47
50	1.419 42	1.417 66	1.414 72	1.411 50
52	1.423 59	1.421 80	1.418 83	1.415 59
54	1.427 81	1.426 00	1.423 00	1.419 74
56	1.432 10	1.430 26	1.427 24	1.423 96
58	1.436 46	1.434 59	1.431 54	1.428 25
60	1.440 88	1.438 98	1.435 91	1.432 60
62	1.445 37	1.443 45	1.440 34	1.437 01
64	1.449 92	1.447 97	1.444 84	1.441 50
66	1.454 54	1.452 57	1.449 42	1.446 06
68	1.459 24	1.457 24	1.454 06	1.450 69
70	1.464 00	1.461 98	1.458 78	1.455 39
72	1.468 84	1.466 80	1.463 56	1.460 17
74	1.473 75	1.471 69	1.468 43	1.465 02
76	1.478 74	1.476 65	1.473 37	1.469 95
78	1.483 81	1.481 69	1.478 39	1.474 95
80	1.488 95	1.486 81	1.483 48	1.480 04
82	1.494 17	1.492 01	1.488 66	1.485 20
84	1.499 47	1.497 29	1.493 92	1.490 45

Table X. 50% HFCS-55/50% Medium Invert, 0.05% Ash (d.b.)

% dry substance	refractive index			
	20 °C	30 °C	45 °C	60 °C
0	1.332 99	1.331 94	1.329 85	1.327 25
2	1.335 88	1.334 80	1.332 66	1.330 03
4	1.338 79	1.337 67	1.335 49	1.332 82
6	1.341 73	1.340 58	1.338 36	1.335 66
8	1.344 73	1.343 54	1.341 28	1.338 54
10	1.347 77	1.346 55	1.344 25	1.341 47
12	1.350 85	1.349 60	1.347 26	1.344 45
14	1.353 99	1.352 70	1.350 31	1.347 48
16	1.357 16	1.355 84	1.353 42	1.350 55
18	1.360 39	1.359 04	1.356 57	1.353 67
20	1.363 66	1.362 28	1.359 77	1.356 84
22	1.366 98	1.365 57	1.363 02	1.360 06
24	1.370 35	1.368 90	1.366 32	1.363 32
26	1.373 77	1.372 29	1.369 67	1.366 64
28	1.377 24	1.375 73	1.373 07	1.370 01
30	1.380 76	1.379 22	1.376 52	1.373 43
32	1.384 33	1.382 76	1.380 02	1.376 91
34	1.387 96	1.386 35	1.383 57	1.380 44
36	1.391 63	1.389 99	1.387 18	1.384 02
38	1.395 36	1.393 69	1.390 84	1.387 65
40	1.399 14	1.397 44	1.394 56	1.391 34
42	1.402 98	1.401 25	1.398 33	1.395 08
44	1.406 87	1.405 11	1.402 16	1.398 89
46	1.410 82	1.409 03	1.406 04	1.402 74
48	1.414 82	1.413 01	1.409 98	1.406 66
50	1.418 89	1.417 04	1.413 98	1.410 64
52	1.423 01	1.421 13	1.418 04	1.414 67
54	1.427 18	1.425 28	1.422 15	1.418 76
56	1.431 42	1.429 49	1.426 33	1.422 92
58	1.435 72	1.433 76	1.430 57	1.427 14
60	1.440 08	1.438 09	1.434 87	1.431 42
62	1.444 51	1.442 49	1.439 23	1.435 76
64	1.448 99	1.446 94	1.443 66	1.440 17
66	1.453 54	1.451 47	1.448 15	1.444 64
68	1.458 16	1.456 05	1.452 71	1.449 18
70	1.462 84	1.460 71	1.457 33	1.453 79
72	1.467 58	1.465 43	1.462 02	1.458 46
74	1.472 40	1.470 21	1.466 78	1.463 20
76	1.477 28	1.475 07	1.471 61	1.468 02
78	1.482 23	1.480 00	1.476 51	1.472 90
80	1.487 26	1.485 00	1.481 49	1.477 86
82	1.492 35	1.490 07	1.486 53	1.482 89
84	1.497 52	1.495 21	1.491 65	1.488 00

Table XI. 25% HFCS-42/75% Medium Invert, 0.05% Ash (d.b.)

% dry substance	refractive index			
	20 °C	30 °C	45 °C	60 °C
0	1.332 99	1.331 94	1.329 85	1.327 25
2	1.335 87	1.334 78	1.332 65	1.330 02
4	1.338 77	1.337 66	1.335 49	1.332 83
6	1.341 72	1.340 58	1.338 37	1.335 68
8	1.344 72	1.343 54	1.341 30	1.338 57
10	1.347 76	1.346 55	1.344 27	1.341 51
12	1.350 85	1.349 61	1.347 29	1.344 50
14	1.353 98	1.352 71	1.350 35	1.347 54
16	1.357 16	1.355 86	1.353 46	1.350 62
18	1.360 39	1.359 06	1.356 62	1.353 76
20	1.363 66	1.362 30	1.359 83	1.356 94
22	1.366 99	1.365 60	1.363 09	1.360 17
24	1.370 36	1.368 94	1.366 40	1.363 45
26	1.373 78	1.372 33	1.369 76	1.366 78
28	1.377 25	1.375 77	1.373 16	1.370 16
30	1.380 77	1.379 27	1.376 62	1.373 60
32	1.384 35	1.382 81	1.380 14	1.377 09
34	1.387 98	1.386 41	1.383 70	1.380 63
36	1.391 65	1.390 06	1.387 32	1.384 22
38	1.395 39	1.393 77	1.390 99	1.387 87
40	1.399 17	1.397 53	1.394 72	1.391 58
42	1.403 02	1.401 34	1.398 50	1.395 34
44	1.406 91	1.405 21	1.402 34	1.399 15
46	1.410 87	1.409 14	1.406 23	1.403 03
48	1.414 88	1.413 12	1.410 19	1.406 96
50	1.418 94	1.417 16	1.414 20	1.410 95
52	1.423 07	1.421 26	1.418 27	1.415 00
54	1.427 26	1.425 42	1.422 40	1.419 12
56	1.431 50	1.429 64	1.426 59	1.423 29
58	1.435 81	1.433 92	1.430 85	1.427 53
60	1.440 18	1.438 27	1.435 16	1.431 83
62	1.444 61	1.442 67	1.439 54	1.436 19
64	1.449 10	1.447 14	1.443 98	1.440 62
66	1.453 66	1.451 68	1.448 49	1.445 11
68	1.458 29	1.456 28	1.453 07	1.449 68
70	1.462 98	1.460 94	1.457 71	1.454 30
72	1.467 74	1.465 68	1.462 42	1.459 00
74	1.472 56	1.470 48	1.467 20	1.463 77
76	1.477 46	1.475 35	1.472 05	1.468 61
78	1.482 43	1.480 30	1.476 97	1.473 52
80	1.487 46	1.485 31	1.481 97	1.478 51
82	1.492 58	1.490 40	1.487 04	1.483 56
84	1.497 76	1.495 56	1.492 18	1.488 70

Table XII. 50% HFCS-42/50% Medium Invert, 0.05% Ash (d.b.)

% dry substance	refractive index			
	20 °C	30 °C	45 °C	60 °C
0	1.332 99	1.331 94	1.329 85	1.327 25
2	1.335 87	1.334 79	1.332 66	1.330 02
4	1.338 78	1.337 67	1.335 49	1.332 82
6	1.341 74	1.340 59	1.338 37	1.335 67
8	1.344 74	1.343 55	1.341 29	1.338 56
10	1.347 78	1.346 56	1.344 26	1.341 50
12	1.350 87	1.349 62	1.347 28	1.344 48
14	1.354 01	1.352 72	1.350 34	1.347 51
16	1.357 19	1.355 87	1.353 45	1.350 59
18	1.360 42	1.359 07	1.356 61	1.353 72
20	1.363 69	1.362 31	1.359 82	1.356 89
22	1.367 02	1.365 61	1.363 07	1.360 12
24	1.370 39	1.368 95	1.366 37	1.363 39
26	1.373 81	1.372 34	1.369 73	1.366 72
28	1.377 29	1.375 78	1.373 13	1.370 09
30	1.380 81	1.379 27	1.376 59	1.373 52
32	1.384 38	1.382 82	1.380 09	1.377 00
34	1.388 01	1.386 41	1.383 65	1.380 53
36	1.391 68	1.390 06	1.387 26	1.384 12
38	1.395 42	1.393 76	1.390 93	1.387 76
40	1.399 20	1.397 51	1.394 65	1.391 45
42	1.403 04	1.401 32	1.398 42	1.395 20
44	1.406 93	1.405 19	1.402 25	1.399 01
46	1.410 88	1.409 11	1.406 14	1.402 87
48	1.414 88	1.413 08	1.410 09	1.406 79
50	1.418 95	1.417 12	1.414 09	1.410 77
52	1.423 07	1.421 21	1.418 15	1.414 81
54	1.427 24	1.425 36	1.422 27	1.418 91
56	1.431 48	1.429 57	1.426 45	1.423 07
58	1.435 78	1.433 84	1.430 69	1.427 29
60	1.440 14	1.438 17	1.434 99	1.431 57
62	1.444 56	1.442 57	1.439 35	1.435 92
64	1.449 04	1.447 02	1.443 78	1.440 33
66	1.453 59	1.451 54	1.448 27	1.444 81
68	1.458 20	1.456 13	1.452 83	1.449 35
70	1.462 88	1.460 78	1.457 46	1.453 96
72	1.467 62	1.465 50	1.462 15	1.458 63
74	1.472 43	1.470 28	1.466 91	1.463 38
76	1.477 31	1.475 14	1.471 74	1.468 20
78	1.482 26	1.480 06	1.476 64	1.473 08
80	1.487 28	1.485 06	1.481 61	1.478 04
82	1.492 37	1.490 12	1.486 65	1.483 07
84	1.497 53	1.495 26	1.491 76	1.488 18

Table XIII. 40% HFCS-42/60% 64 D.E. Corn Syrup, 0.50% Ash (d.b.)

% dry substance	refractive index			
	20 °C	30 °C	45 °C	60 °C
0	1.332 99	1.331 94	1.329 85	1.327 25
2	1.335 91	1.334 82	1.332 70	1.330 07
4	1.338 86	1.337 75	1.335 58	1.332 92
6	1.341 85	1.340 71	1.338 51	1.335 82
8	1.344 90	1.343 72	1.341 49	1.338 77
10	1.347 98	1.346 78	1.344 51	1.341 76
12	1.351 12	1.349 89	1.347 58	1.344 80
14	1.354 30	1.353 04	1.350 69	1.347 89
16	1.357 52	1.356 23	1.353 85	1.351 03
18	1.360 80	1.359 48	1.357 07	1.354 22
20	1.364 12	1.362 78	1.360 33	1.357 45
22	1.367 49	1.366 12	1.363 64	1.360 74
24	1.370 92	1.369 52	1.367 00	1.364 08
26	1.374 39	1.372 96	1.370 41	1.367 46
28	1.377 91	1.376 46	1.373 88	1.370 90
30	1.381 49	1.380 00	1.377 39	1.374 40
32	1.385 12	1.383 61	1.380 96	1.377 95
34	1.388 80	1.387 26	1.384 58	1.381 55
36	1.392 53	1.390 97	1.388 26	1.385 20
38	1.396 32	1.394 73	1.392 00	1.388 92
40	1.400 17	1.398 55	1.395 78	1.392 68
42	1.404 07	1.402 42	1.399 63	1.396 51
44	1.408 03	1.406 36	1.403 53	1.400 39
46	1.412 04	1.410 35	1.407 49	1.404 34
48	1.416 11	1.414 39	1.411 52	1.408 34
50	1.420 25	1.418 50	1.415 60	1.412 40
52	1.424 44	1.422 67	1.419 74	1.416 53
54	1.428 69	1.426 90	1.423 94	1.420 72
56	1.433 01	1.431 19	1.428 21	1.424 97
58	1.437 39	1.435 55	1.432 54	1.429 28
60	1.441 83	1.439 97	1.436 93	1.433 66
62	1.446 34	1.444 45	1.441 39	1.438 11
64	1.450 91	1.449 00	1.445 92	1.442 62
66	1.455 55	1.453 62	1.450 51	1.447 20
68	1.460 26	1.458 30	1.455 17	1.451 86
70	1.465 03	1.463 06	1.459 90	1.456 58
72	1.469 88	1.467 88	1.464 71	1.461 37
74	1.474 80	1.472 77	1.469 58	1.466 24
76	1.479 79	1.477 74	1.474 53	1.471 17
78	1.484 85	1.482 78	1.479 55	1.476 19
80	1.489 99	1.487 90	1.484 65	1.481 28
82	1.495 20	1.493 09	1.489 82	1.486 45
84	1.500 49	1.498 36	1.495 07	1.491 69

Table XIV. 25% HFCS-42/75% 64 D.E. Corn Syrup, 0.50% Ash (d.b.)

% dry substance	refractive index 20 °C	30 °C	45 °C	60 °C	% dry substance	refractive index 20 °C	30 °C	45 °C	60 °C
0	1.332 99	1.331 94	1.329 85	1.327 25	44	1.408 41	1.406 75	1.403 96	1.400 85
2	1.335 92	1.334 84	1.332 71	1.330 08	46	1.412 45	1.410 77	1.407 95	1.404 82
4	1.338 88	1.337 77	1.335 61	1.332 95	48	1.416 54	1.414 85	1.412 00	1.408 85
6	1.341 89	1.340 75	1.338 55	1.335 86	50	1.420 70	1.418 98	1.416 11	1.412 95
8	1.344 94	1.343 77	1.341 54	1.338 82	52	1.424 92	1.423 18	1.420 28	1.417 11
10	1.348 04	1.346 84	1.344 57	1.341 83	54	1.429 21	1.427 44	1.424 52	1.421 33
12	1.351 19	1.349 96	1.347 66	1.344 89	56	1.433 55	1.431 76	1.428 82	1.425 62
14	1.354 38	1.353 13	1.350 79	1.347 99	58	1.437 96	1.436 15	1.433 18	1.429 97
16	1.357 63	1.356 34	1.353 97	1.351 15	60	1.442 43	1.440 60	1.437 61	1.434 39
18	1.360 92	1.359 60	1.357 20	1.354 35	62	1.446 97	1.445 11	1.442 10	1.438 87
20	1.364 26	1.362 92	1.360 47	1.357 61	64	1.451 57	1.449 70	1.446 67	1.443 43
22	1.367 64	1.366 28	1.363 80	1.360 91	66	1.456 25	1.454 35	1.451 30	1.448 05
24	1.371 08	1.369 69	1.367 18	1.364 27	68	1.460 99	1.459 07	1.456 00	1.452 74
26	1.374 58	1.373 15	1.370 62	1.367 68	70	1.465 80	1.463 86	1.460 77	1.457 50
28	1.378 12	1.376 67	1.374 10	1.371 14	72	1.470 68	1.468 72	1.465 61	1.462 34
30	1.381 71	1.380 24	1.377 64	1.374 66	74	1.475 63	1.473 65	1.470 53	1.467 25
32	1.385 36	1.383 86	1.381 23	1.378 23	76	1.480 65	1.478 66	1.475 52	1.472 24
34	1.389 06	1.387 54	1.384 88	1.381 86	78	1.485 75	1.483 74	1.480 58	1.477 30
36	1.392 82	1.391 27	1.388 58	1.385 54	80	1.490 93	1.488 89	1.485 72	1.482 44
38	1.396 63	1.395 05	1.392 34	1.389 28	82	1.496 18	1.494 13	1.490 94	1.487 65
40	1.400 50	1.398 90	1.396 15	1.393 08	84	1.501 51	1.499 44	1.496 24	1.492 95
42	1.404 42	1.402 80	1.400 03	1.396 93					

Table AI. Regression Coefficient for Equation A1

i	A_{ij} $j=1$	$j=2$	$j=3$	$j=4$	B_i	C_i
1	0.000 000 0	0.002 856 4	0.000 000 0	−0.000 187 3	0.000 012 4	0.649 547 5
2	0.000 596 7	0.000 000 0	0.002 267 6	0.000 205 7	−0.000 124 8	−0.002 455 5
3	−0.005 633 6	0.000 000 0	0.000 000 0	0.003 374 3	−0.000 164 2	
4	−0.001 115 1	−0.000 426 6	0.000 000 0	0.000 721 9	−0.000 127 2	
5	0.000 000 0	−0.002 873 3	0.000 000 0	−0.005 194 6	0.000 037 5	

Table AII. Comparison of Refractive Indices from Publications and by Calculation

material	% dry substance	published	calculated	difference
This Study				
1 HFCS (42)	80	1.486 20	1.486 20	0.000 00
2 HFCS (55)	80	1.486 11	1.486 08	−0.000 03
3 HFCS (90)	80	1.485 95	1.486 11	+0.000 17
4 50% HFCS (42)/50% sucrose	75	1.476 24	1.476 08	−0.000 15
5 50% HFCS (55)/50% med inv	80	1.487 26	1.487 07	−0.000 19
6 25% HFCS (42)/75% med inv	80	1.487 46	1.487 53	+0.000 07
7 50% HFCS (42)/50% med inv	80	1.487 28	1.487 11	−0.000 17
8 40% HFCS (42)/60% 64 D.E. corn syrup	80	1.489 98	1.490 07	+0.000 09
9 25% HFCS (42)/75% 64 D.E. corn syrup	80	1.490 90	1.491 06	+0.000 16
10 fructose	80	1.485 10	1.485 38	+0.000 28
Previous Study (7)				
1 28 D.E. corn syrup	70	1.472 83	1.472 53	−0.000 30
2 42 D.E. corn syrup	84	1.507 88	1.507 97	+0.000 09
3 55 D.E. corn syrup	84	1.505 26	1.505 23	−0.000 03
4 32 D.E. corn syrup	84	1.510 40	1.510 33	−0.000 07
5 42 D.E. corn syrup	84	1.508 28	1.508 45	+0.000 17
6 50 D.E. corn syrup	84	1.506 80	1.506 71	−0.000 09
7 63 D.E. corn syrup	84	1.503 38	1.503 61	+0.000 23
8 70 D.E. corn syrup	84	1.501 96	1.502 23	+0.000 27
9 95 D.E. corn syrup	74	1.471 77	1.471 83	+0.000 06
10 HFCS (42)	74	1.471 73	1.471 53	−0.000 20
Pure Sugars				
Dextrose (9)	60	1.439 18	1.439 21	+0.000 03
Maltose (8)	50	1.421 70	1.421 82	+0.000 12
Sucrose (4)	70	1.465 39	1.465 36	−0.000 03
Levulose (6)	70	1.461 50	1.461 48	−0.000 02
Invert (2)	70	1.461 66	1.461 56	−0.000 10

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Supplementary Material Available: Data and regression analysis of the refractive indices of nine commercial corn syrups at 20, 30, 45, and 60 °C (9 pages). Ordering information is given on any current masthead page.