Evaluation of Factor For Conductance of Water in Presence of Sugar

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Introduction

The conductivity of sugar solutions is generally recognized as a quick method, of estimating the ash content of sugars. In its simplest form a relationship, called the ''C'-ratio", is established between the sulfated ash Jess 10 percent and the electrical, conductivity. The sulfated ash and electrical conductivity are determined for a number of representative samples and the quotient of the sulfated ash less 10 percent divided by the specific conductance is termed the C-ratio. For beet sugars Lange *(2)*[2] proposed the use of solutions having a concentration of 5 g in 100 ml. His studies indicated that the C-ratio of German beet sugars slowly increased; but up to a concentration of about 1 percent ash (sulfated ash less 10 percent) he found a nearly constant average ratio equal to 1786. Hence, by multiplying the conductance in reciprocal ohms by the C-ratio value of 1786, he arrived directly at the ash value. While Lange's value is admittedly not representative of the C-ratios for all beet sugars, it does give a useful estimate of the ash for most beet sugars.

Conductance, as measured on a sugar solution, is a composite of a number of varying influences; e. g., conductivity of the water us?d in preparing the solution, concentration of the solution, nature of the ash constituents, and effect of the non-electrolyte (sugar) on the conductivity of the water, and of the ash constituents. Most of these variables are held constant by the use of a single concentration of sugar (5 g in 100 ml) or are constant by postulate if one accepts the C-ratio value of 1786 as given by Lange. Under his conditions the relation simplifies down to the following:

$$LA = Ls - f\,Lw$$

$$\%\ Ash = La \times 1786 \times 10^{-6}$$

where LA = specific conductance of the ash constituents in the sugar; Ls == specific conductance of the sugar solution ; Lw == specific conductance of the water used in preparing the sugar solution; t = a factor converting the conductance of water to its conductance in the presence of 5 g sugar / 100 ml; 1786 is Lange's evaluation of the C-ratio. Ash is expressed in terms of sulfated ash less 10 percent and specific conductance in terms of reciprocal megohms.

The correction factor, f, has been evaluated for these conditions by Lange (2), Toedt (3) and others with generally agreeing results

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[2]Italic numbers in parentheses refer to literature cited.

of about 0.9. Zerbau and Sattler (4), working witli cane sugars, also give data from which f can be calculated as a variable which approaches 0.9 in the range of low conductance water. Such a result is equivalent to a, value for a of approximately 0.03 in the fundamental formula of Arrhenius (1). His formula is $K=Ko(1—a\ P/2)^2$, where K is the specific conductance of a solution to which P volume percent of a non-electrolyte has been added. Ko is the specific conductance of the aqueous salt solution and a is a constant whose value depends on the nature and concentration of the electrolytes and non-electrolytes. For a sucrose solution of 5 g, 100 ml the volume concentration (weight divided by specific gravity) is 5/1.59 or 3.15 percent. Especially significant in the work of these investigators is the fact that in all cases the ash content was very high, on the order of 10 to 100 times that prevailing in a solution of granulated beet sugar (5 g/100 ml) where the ash rarely runs over 0.020 percent on sugar.

The American Crystal Sugar Company has been estimating sulfated ash less 10 percent in granulated sugars from conductivity measurements by the use of Lange's factor for a number of years with generally satisfactory results. To correct the conductivity of the water to its conductance in the presence of 5g of sucrose / 100 ml a factor of 0.91 was used, which is the generally accepted value. For some time, however, it has been common knowledge amongst technicians in the Company laboratories that a lower ash value would be calculated if the sugar were dissolved in a water of high conductance, say 10 reciprocal megohms, than if it were dissolved in a water of low conductance, say 1 or *2* reciprocal megohms. Accordingly, it was decided to investigate the factor under the conditions dominant in our tests, i. e., water having conductance in the range of 1 to 10 reciprocal megohms and granulated beet sugar with ash values under 0.020 percent.

Procedure

A brief survey of the literature showed that previous investigators had all followed essentially the same pattern. As detailed by Lange (2). a molasses solution was prepared and to this was added various quantities of a purified sugar. The value of Ko was determined for the original molasses solution and K for each of the solutions with added sugar. From these and the weight of sugar in the solution it was a simple matter to calculate the factor, f.

We chose to depart from this procedure in favor of what appears to be a more direct approach. In this we take advantage of the fact that the equation $LA == Ls — fLw$ is that of a straight line having a slope f. Accordingly, if one should hold LA constant by using a single sugar and then vary the conductance of the water, the conductance of the solution should be a direct function of the conductance of the water.

In the work reported here two analysts working in different laboratories carried out similar tests, each using three different sugars, a total of six sugars, with ash contents ranging from about .020 down to .005. In both laboratories. Oxnard and Mason City, a series of waters was prepared such that their specific conductances covered a range of about 8 down to 1 reciprocal megohms (125,000 to 1,000,000 ohms). At Oxnard five walers were used and at Mason City eight waters. Each of the three sugars were dissolved in the various waters (5 g in 100 ml) and the conductivities of the solutions and the waters carefully determined at temperatures close to 20.0° C. The tests were repeated on successive days, giving 23 determinations for each sugar at Oxnard and 24 for each at Mason City.

Table 1.—Specific conductances* of water and sugar solutions, Oxnard laboratory.

Sugar	A		B		C	
Specific conductance	Lw	Ls	LW	LS	LW	LS
Day 1	1.37	4.36	1.37	7.10	1.37	12.2
	1.38	4.27	1.38	6.94	1.38	12.0
	2.43	5.07	2.43	7.71	2.43	1.2.8
	4.1S	0.40	4.18	9.05	4.18	14.1
	5.44	7.48	5.44	10.20	4.27	14.3
Day 2	2.71	5.33	1.40	6.99	2.71	13.0
	3.10	5.82	2.71	8.17	3.10	13.3
	3.34	5.01	3.10	8.31	3.20	13.2
	4.27	G.42	4.27	9.10	5.44	15.0
	7.51	9.37	7.51	11.90	7.51	17.0
Day 3	1.40	4.28	2.53	7.82	1.40	12.0
	2.53	5.17	3.20	8.39	2.53	12.8
	3.02	0.21	3.34	8,38	3.92	13.8
	4.14	0.37	4.14	9.07	4.14	14.0
	0.03	7.88	6.03	10.56	0.03	15.5
Day 4	2.54	5.11	2.54	7.88	i.40	12.1
	3.20	5.41	3.92	8.80	3.15	13.3
	4.30	0.52	4.30	9.19	3.33	13,0
	5.28	7.22	5.28	9.90	3.34	13.3
	6.44	8.22	6.44	10.80	5.28	15.0
Day 5	1.40	4.19	1.40	6.98	2.54	13.0
	3.15	5.39	3,15	8.18	4.30	14.4
	3.33	5.00	3.33	8.48	6.44	16.1

*ReciprocaI megohms at 20.0° C

Apparatus

The apparatus used at both laboratories consisted of the No. 4961 Leeds and Northrup Sugar Ash Bridge and the No. 4924 Leeds and Northrup Conductivity Cell. The ash bridge is a, portable conductivity indicator with an alternating current galvanometer incorporated in it. A circular slide wire has its scale directly calibrated in terms of conductance in reciprocal megohms. A built-in temperature compensator was used to correct observed conductances for the few tenths of a degree by which the solutions varied from the standard temperature of 20.0° C. This instrument also has a cell-constant compensator so that all readings were obtained directly as specific conductances in reciprocal megohms at 20.0° C.

Data

The data are tabulated in tables 1 and 2. At Oxnard no effort was made to use the same waters from day to day or even for all three sugars on the same day. Accordingly, the specific conductance of water is shown corresponding to each solution tested. At Mason City, on the other hand, eight waters were prepared in large enough amounts so that three complete series of tests could be made. As a result only one value for water is shown opposite tests on a group of the three sugars.

Evaluation of the Factor

The data in tables .1 and 2 were summarized by the method of least squares into equations for six straight lines, one for each sugar.

Table. 2.—Specific conductances* of water and sugar solutions, Mason City Laboratory.

Sugar		D	E	F
Specific conductance	Lw	Ls	Ls	Ls
	.07	4.47	6.43	9.67
	1.78	5.05	7.04	10.23
	2.93	5.90	7.86	11.24
	3.87	6.54	8.45	11.67
Day 1	4.52	7.05	8.92	12.30
	5.63	7.96	9.72	13.09
	6.74	8.95	10.70	14.00
	8.07	9.98	11.72	15.10
	.05	4.48	6.44	9.65
	1.75	5.04	6.92	10.21
	2.91	5.86	7.84	11.16
Day 2	3.84	6.53	8.48	11.70
	4.49	7.04	8.94	12.20
	5.50	7.87	9.72	13.00
	6.68	8.88	10.73	14.00
	8.04	9.98	11.73	15.20
	.01	4.42	6.30	9.62
	1.64	4.97	6.88	10.14
	2.92	5.88	7.87	11.14
	3.85	6.51	8.52	11.66
Day 3	4.46	7.03	8.90	12.20
	5.58	7.90	9.73	12.90
	6.66	8.87	10.67	13.90
	8.03	10.01	11.74	15.10

*Reciprocal megohms at 20.0° C.

The actual manipulation of the data will not be described here since the least squares method is the accepted method, for evaluating a line of best fit. Table 3 and the accompanying graph summarizes these lines of best fit as well as other information useful in judging the goodness of fit.

Inspection of table 3 shows that in the general equation $Ls = LA + fLw$ the value of f varies from a low of 0.746 to a high of 0.799 for sugars ranging from a specific conductance of 10.9 down to 3.1 reciprocal megohms (.0195 to .0055 calculated ash). By having the work done at different laboratories by different technicians it was hoped that any important difference in technic or apparatus which might effect the value of the factor would be indicated. Inspection of the data does not indicate such a difference; for, even though the factors evaluated from Mason City data are slightly lower than those based on Oxnard data, the differences do not appear significant. Important also in judging the usefulness of the factors is information concerning how well the data fit the calculated line. The coefficient of correlation, r, and the measure of scatter about the line SLs, shown also in table 3, both indicate high degrees of fit in all cases. Further, in plotting the data no evidence of curvature was indicated. From these considerations it would appear that the average value of 0.773 is closer to the true value of the correction factor for the conductance of water in the presence of 5 g/100 ml of granulated beet, sugar- at 20° C. than values previously reported.

Table 3.

Instrument	Line of best fit	r	SLs	LA	Ash	f
			Low ash sugars			
Oxnard	Ls= 3.093+.799Lw	.995	.132	3.093	.0055	.799
Mason City	Ls= 3.634+.777Lw	.999	.053	3.634	.0065	.777
			Medium ash sugars			
Oxnard	Ls= 5.881+.775Lw	.995	.128	5.881	.0105	.775
Mason City	Ls= 5.650+.746Lw	.999	.076	5.650	.0101	.746
			High ash sugars			
Oxnard	Ls=10.894+.782Lw	.990	.183	10.894	.0195	.782
Mason City	Ls= 8.865+.761Lw	.990	.055	8.865	.0158	.761

Note: Sugars used at Oxnard were not the same as those used at Mason City.
Average value of factor, f=.773.

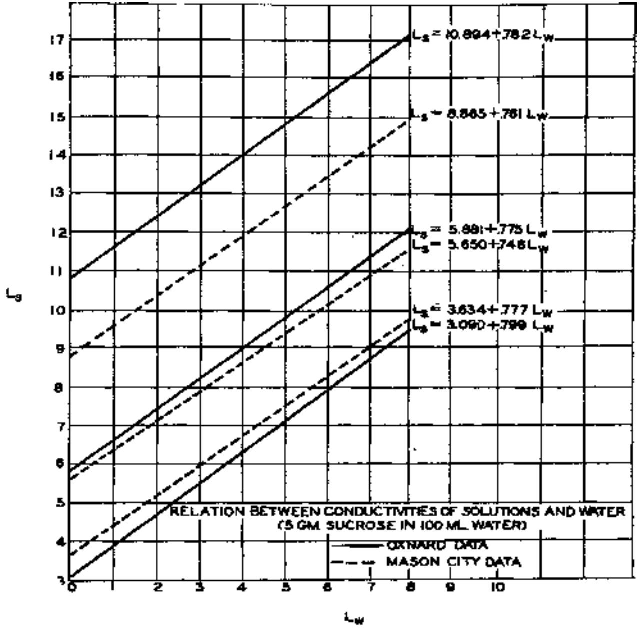
Formulae

$Ls = LA + fLw$

$Ash = LA \times 1786 \times 10^{-6}$

Nomenclature

Ls = Speeifie conductance of the solution.
LA—Specific coductance of the sugar.
Lw= Specific conductance of the water.
f=A factor correcting the conductance of water for the effect of sugar.
r—Coefficient of correlation, a measure of the goodness of.fit.
SLs—Measure of scatter about the line.



Substitution of 0.773 in the Arrhenius equation now gives a value for a of .077 as compared with previously reported values approximating .03. This is not so surprising, however, when it is considered that the older value was obtained on solutions of very much higher ash content than would be present in solutions of granulated beet sugars of today.

Literature Cited

1. Arrhenius, Z. Physik, Chem. 9: 509. 1892.
2. Lange, Z. Ver. Dent. Zucker-lnd. 60:359. 1910.
3. Toedt, Z. Ver. Dent. Zucker-lnd. 75: 429. 1925.
4. Zerban and Sattler. Facts About Sugar. 21: 1158. 1926.