Sieve Tests and Fineness Modulus of Granulated Sugar

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The users of sugar, especially the commercial users, are making increased demands for sugars of various types based on grain size. Some candy makers want coarse sugar because it handles better in their kettles, bakers want fine sugar because it creams more easily in cake batter, and many housewives want an intermediate size which is neither coarse nor fine. If the sugar manufacturers are to supply sugar to meet these demands, it is necessary to have a standardized method for determining the grain size, and to set up specifications for the various typos. It is also necessary to decide on the types which most nearly meet various market demands and to produce these types as standard products. It is highly desirable, though perhaps a bit idealistic, that the standard types be produced by all manufacturers so that a uniform product is available everywhere.

It is the purpose of this discussion to make tentative suggestions concerning the solution of these problems.

Sieve Tests

The determination of particle size by sieve tests is familiar to everyone. To the writer's knowledge, very little effort has been made in the sugar industry to standardize the type of sieves to be used or the methods of using them. The first step, therefore, is to decide on the type and sizes of sieves. A number of sieve series are available, but it is desirable that one be selected which is generally accepted as standard. The American Society for Testing Materials has adopted the National Bureau of Standards sieve series and the practically identical Tyler Standard Screen Series of sieves.

The Tyler scale has as its base an opening of .0029 inch which is the opening in the 200-mesh sieve using 0.0021-inch wire; the opening increases in the ratio of the square root of 2, or 1.414. The area of the openings, therefore, increases in the ratio of 2. For closer sizing intermediate sieves are available. In the complete series the sieve openings increase in the ratio of the fourth root of *2,* or 1.189, and the area increases in the ratio of 1.414.

The U. S. sieve series, designed by the Bureau of Standards, uses a 1-mm. opening as the base, the opening varying in the same ratio as the Tyler series. The result is that the two series are practically identical. It is suggested that either of these series may be adopted as

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standard. The writer's laboratory uses the TyJer series. In both the U. S. and Tyler series the sieves arc designated by number and not, as is usually the case, by the number of openings per linear inch.

The set of sieves listed in table 1 has been selected as suitable for use in testing sugars:

Table 1.

Sieve No.	Openings per inch	Diameter of openings	
		Inches	mm.
12	10	.065	1.651
16	14	.046	1.168
20	20	.0328	.833
30	28	.0232	.589
40	35	.0164	.417
50	48	.0116	.295
60	60	.0097	.246
70	65	.0082	.208
80	80	.0069	.175
100	100	.0058	.147
140	150	.0041	.104
200	200	.0029	.074

For the average run of granulated sugar, sieves Nos. 30 to 100 are ail that are required. Tf very close sizing is desired, sieves Nos. 35 and 45 may be included in the series since about 70 percent fall in the range of -30 +50. However, for routine tests such sizing is of doubtful value. The intermediate series, 60 and 80, have little value in tests on average sugars as produced but are included because of their use in establishing suggested commercial types to be discussed later.

The method of making sieve 1ests has been standardized and the following procedure is recommended:

A Tyler Ro-Tap Sieve Shaker has been adopted as the screening apparatus. Eight-inch-diameter, half-height sieves are used. One hundred grams of sugar are weighed into the coarsest of the nest of sieves, which is placed in the Ro-Tap and shaken for 10 minutes. The various fractious are weighed and the results reported in the usual way. When testing the product from factory screens where the size range lies within narrow limits, a 50-gram sample should be used to avoid overloading the sieves. It is particularly important to avoid overloading the finer sieves, No. 60 and under. This method has been found to give reproducible results when the same 100-gram sample is recombined and retested, as is Indicated in table 2.

The most serious difficulty in obtaining accurate sieve tests is in getting a truly representative sample. This is especially difficult when the range of grain size is large and the size distribution uneven,

Table 2.

U. S. sieve No.	Repeated tests on the same 100-gram sample (1)	(2)	(3)
+30	1.0	0.9	0.8
−30 +40	21.1	21.2	21.1
40 +50	48.6	48.4	48.5
−50 +60	13.0	13.2	13.3
−60 +70	8.8	8.5	8.3
−70 +80	4.3	4.3	4.3
−80 +100	2.4	2.3	2.5
−100	1.2	1.2	1.2

as is the case for practically all unscreened factory sugars. No amount of mixing or, so far as the writer knows, no method of mixing will prevent some segregation so that successive portions taken from the same sample may show rather wide variations. When the size range is narrow, as in the case of factory-screened sugars, this difficulty materially decreases and satisfactorily concordant results can he obtained.

Too little work has been done to establish the range of variations due to sampling. Some indications as to the character of the problem are illustrated by some tests made recently in the writer's laboratory. The sugar from the sieve tests of 57 samples was recombined into a. single composite and the weighted average sieve test calculated. The entire composite was placed in a closed container and thoroughly mixed. A series of tests was made on the mixture. After each two or three tests the whole sample was remixed. A total of eight tests and three mixings were made. After this the samples were again recombined, remixed, and passed through a "Jones" ore sampler until the weight had been reduced to approximately 100 grams. On the last pass through the sampler there were, of course, two such portions (a) and (b). Sieve tests were made on both. Data for the above tests are shown in table 3.

It is noted that samples taken from the mixed composite invariably indicated the sugar to be finer than it really was, while the samples obtained from the "Jones" sampler checked the calculated composition very closely. When an accurate test on a given sample of sugar is desired, this method is recommended.

The results of a sieve test reported in the usual manner are difficult to interpret. It is desirable, therefore, to express the average fineness or average grain size by a single number which may be called the "fineness modulus". There are numerous methods of calculating the average particle size ; each one is mathematically sound and each one gives a different result. The point is to choose the method of calculation which suits the purpose for which the figures are to be

Table 3.

U.S. sieve No.	Weighted average of 57 samples	Eight tests on composite of 57 samples			Final, split from "Jones" sampler	
		Minimum	Weighted Average	Maximum	(a)	(b)
+30	2.5	2.1	2.1	2.1	2.4	2.8
-30 +40	28.3	25.7	26.3	26.9	28.3	28.6
-40 +50	44.1	42.2	43.4	44.4	44.2	42.8
-50 +60	11.0	11.6	11.7	11.4	11.2	10.9
-60 +70	6.8	7.8	7.8	7.5	6.9	6.0
-70 +80	3.4	4.5	4.0	3.9	3.5	3.7
-80 +100	2.6	3.7	3.0	2.6	2.4	2.6
-100	1.3	2.4	1.7	1.3	1.1	1.5
Avg. diam. of crystal, mm.	0.373	0.356	0.362	0.365	0.371	0.371
Fineness modulus	51.6	45.1	47.4	46.0	51.1	51.1

used. For the present purpose it is desirable to use a modulus which will express the relative grain size as it appears to the eye and one which is simple to calculate. After considerable exploratory work, such a modulus has been devised ; the derivation is explained in the following paragraphs.

Tn the first place it is necessary to determine 1 he average grain size in any given sieve fraction, for example, the average grain size which passes No. 40 sieve and is retained on No. 50. A number of calculations were tried, but the one which appears to meet the conditions best is the simple geometric mean of the adjacent sieve openings.

Mean Diam. = $D \times d$ where D and d are diameters of the sieve openings.

The reason for adopting this value is shown in figure 1. The sieve openings in mm. are plotted against the sieve number on a semi-log scale. The plot is, of course, a straight line. It will be noted that the geometric mean of any two sieves falls on the line at exactly the midpoint between the sieves. This method of calculating the mean therefore conforms to the characteristics of the sieve series. The mean values for the entire series are given in figure 1.

In order to simplify future calculations, the values of the mean diameters are rounded off as indicated under the heading "Modulus Factor" in figure 1.

Having established the mean grain size for each sieve fraction, it still remains to calculate a "fineness modulus" for any given sieve test. The simplest and for the present purposes the most practical

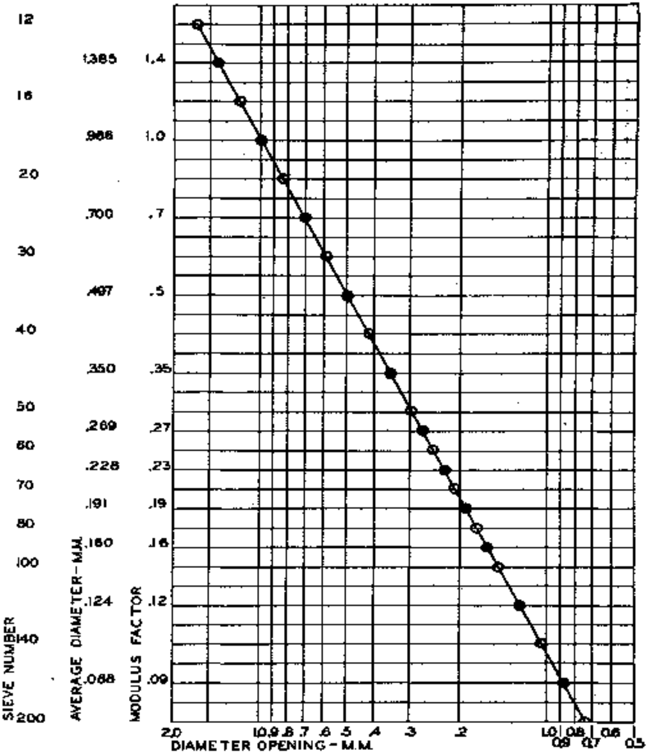

Figure 1.—

method is to take the arithmatical average of the mean grain size of all the sieve fractions. This is done by taking the product of the percentage and the modulus factor for each fraction and dividing the sum of the products by 100. This method is illustrated by the following example :

Sieve test		Modulus factor	(2) x (3)
Sieve No.	Percentage		
(1)	(2)	(3)	(4)
−20 +30	1.2	0.7	.84
−30 +40	34.2	0.5	17.10
−40 +50	43.2	0.35	15.12
−50 +60	9.0	0.27	2.43
−60 +70	4.8	0.23	1.10
−70 +80	3.8	0.19	.72
−80 +100	2.4	0.16	.38
−100	1.4	0.12	.17
			37.86

$$\text{Avg. diam. of grain} = \frac{37.80}{100} = 0.3786 \text{ mm.}$$

It may appear inconsistent to use the geometric mean for determining the average grain size between successive sieves and the arithmetical mean for the overall average. This is done for the sake of simplicity. The geometric mean appears to be more accurate, but the difference is very small and its use involves constant reference to a table of logarithms. Briefly, the method is to use the log of the mean sieve opening as the modulus factor, which is applied in the same manner as illustrated above. The. overall mean grain size is the anti-log of the sum of the products.

At this point the question arises as to the best method of expressing the results in terms of a "fineness modulus" so that the modulus will be consistent with the appearance to the eye. The first thought is to use the mean grain size or a multiple of it as the modulus. This puts the modulus on the basis of a linear function, that is, the diameter of the crystal. The chief objection is that there is a very small spread in the modulus of many sugars so that judgment of what constitutes a significant difference becomes difficult. This objection can be overcome by stating the modulus in terms of the volume of the average crystal. This is done by taking the cube of the average diameter as determined above. In order to avoid unwieldy fractions the cube of the average diameter is multiplied by 1,000 and only one figure to the right of the decimal point is carried in the final result. The method of calculation is expressed by this equation:

$$M = \left(\frac{FW}{100}\right)^3 1000$$

M = Fineness modulus
F = Modulus factor
W = Percentage in each fraction

Referring to above example:

$$M = \frac{(37.86)^3}{(100)} 1000 = 54.3$$

Table 4 will illustrate the foregoing points. The figures were obtained from actual sieve tests on run-of-factory sugars.

Table 4.

Sample No.	Avg. diam. mm.	Fineness modulus	Sample No.	Avg. diam. mm.	Fineness modulus
1	.321	33.1	13	.364	48.0
2	.326	35.5	14	.366	48.8
3	.332	36.6	15	.370	50.5
4	.333	36.8	16	.374	52.0
5	.341	39.6	17	.379	54.2
6	.342	40.0	18	.384	56.5
7	.345	41.1	19	.389	59.0
8	.354	44.5	20	.392	60.8
9	.356	45.1	21	.396	61.6
10	.358	45.9	22	.399	63.7
11	.359	46.2	23	.415	71.5
12	.363	47.9	24	.428	78.1

An objection to the use of this modulus is that it becomes quite large when applied to coarse sugars. This is illustrated by the examples given in table 5.

Table 5

Sieve No.	Percentage (W)	Modulus factor (F)	Modulus
−12 +16	100.0	1.4	2,744.0
−16 +20	100.0	1.0	1,000.0
−20 +30	100.0	0.7	343.0
−30 +40	100.0	0.5	125.0

It should be noted that astronomical figures occur only when dealing with special sugars which are a very minor part of the total production. It does not seem logical to discard an otherwise satisfactory method on this account. The writer's laboratory has, therefore, tentatively adopted this method of reporting "fineness modulus" pending further developments.

Standard Types of Commercial Sugars

Tn the beginning of this paper reference was made to selecting and setting up specifications for commercial types of sugar based on grain size. With full realization of the controversial aspects which are involved, the writer suggests the following five types as meeting a large majority of the commercial and household demand.

The fraction -12 +20 designated as "Sanding"
-20 +40 designated as "Standard. Granulated"
-40 + 60 designated as "Table"
-60 +80 designated as "Bakers"
-80 +200 designated as "Dessert"

The fineness modulus, assuming an ideal distribution of size in each fraction, are :

"Sanding" 1,728.0
"Standard" 216.0
"Table" 29.8
"Bakers" 9.3
"Dessert" 2.7

The foregoing description of the types is based on the assumption that 100 percent falls within the sieve limits designated and that there is a uniform size distribution in each sieve fraction. These conditions, of course, are impossible of attainment in commercial practice. Therefore it is necessary to complete the specifications by setting up limits of tolerance. The lack of sufficient data on the performance of commercial sieves makes this difficult to do at the present time. In order to get preliminary data on allowable variations, synthetic mixtures of each of the types were made up, varying the percentage oversize and undersize, as well as the size distribution. The example given in table 6 will serve to illustrate the results.

Table 6

	"Table Sugar" Rated sieve size —40 +60				
Actual composition	Example (1)	Example (2)	Example (3)	Example (4)	Example (5)
-30 +40	5	5	5	5	0
—40 +50	60	20	50	30	50
—50 +60	30	60	30	50	50
-60	5	5	15	15	0
Avg. diam. mm.	.330	.306	.315	.299	.310
Modulus	35.9	28.7	31.3	26.7	20.8

Observation of slides projected on a screen gave visual evidence that No. 1 was coarse and No. 4 fine than No. 5. Very little difference could be distinguished between Nos. 2, 3, and 5. On the basis of these observations the following tentative tolerances were set up, subject to change as further data are accumulated :

	Modulus	
	Minimum	Maximum
Sanding	1,400	2,000
Standard	2.00	225
Table	27	33
Bakers	8.5	10
Dessert	2.3	3

The limits, of course, become less for the finer types. It is possible to have sugars fall within the given modulus range which would not conform to the classification indicated, because of wide size variation. Therefore in applying these specifications it is understood that at least 80 percent falls within the rated sieve range.

Tt was stated in the beginning that the purpose of this discussion is to propose a standardized method for determining the average grain size of granulated sugars, and to suggest specifications for standard types which will meet the growing demand of the commercial and household users. Tt is fully realized that much yet remains to be done, but it is hoped that through cooperation of the industry as a whole a mutually satisfactory solution of the problems will be reached.

Summary

The Tyler Standard Screen Series or its equivalent is recommended for making sieve tests on granulated sugar. A standard method of making the tests is described. A numerical expression for the average crystal size is derived and termed the "fineness modulus". Five commercial types, based on fineness, which most nearly meet various consumer demands, are suggested and their specifications set up.