RELATIONSHIP OF THE PHYSICAL PROPERTIES OF WHEAT FLOUR BY GRANULATION

by

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INTRODUCTION

"Wheat flour is the finely ground product obtained in the milling of wheat, and consists essentially of the starch and gluten endosperm. It contains not more than 15 percent moisture not less than one percent of nitrogen, not more than one percent of ash, and not more than 0.5 percent of fiber." This flour definition from the Northwestern Miller (1947) is promulgated for the guidance of federal inspection officials and is not concerned with grades or quality, except that it sets forth the minimum "quality" of a product that may lawfully be called "white flour". Since no specification with respect to particle size is given, except that one of the cloths through which the flour is bolted has openings not larger than 149 microns, it may be assumed that the official definition can be taken merely as a differentiation between white flour and feedstuffs.

In the normal process of flour milling, the wheat passes through a four or five break system for the purpose of removing the endosperm from the bran coat. The endosperm thus released consists of large particles. A further gradual reduction is necessary before these large particles are reduced in size so that they may pass through a flour sieve whose aperture openings are approximately 150 microns square.

Early investigation has shown that not all of the endosperm particles passing through the flour cloths approximate the size of the aperture openings of the cloth. More recent work indicates

that the particles vary in size from 150 microns to approximately five microns in diameter.

To determine if all of the sizes of flour particles have the same chemical composition, an early investigation was conducted by LeClerc, Wessling, Bailey, and Gordon (1919) who established that flour sifted through a very fine silk bolting cloth was inferior to that sifted through a coarser bolting cloth. These workers also found that the flour sifted through a coarser flour cloth was only slightly better than that sifted through the finest cloth, while the intermediate flour was found to be the best. Thus, flour quality seemed to be associated not only with medium granularity, but with a uniformly medium granularity, since the intermediate flour was better than the original flour from which the three separations were made.

By an additional over-reduction of the flour particles, Alsberg and Griffing (1925), and Shollenberger (1926) found that the more finely a flour was ground, the poorer its baking quality became. The finely ground material absorbed more water as a result of the disintegration of the starch granules, while the gluten showed a tendency toward injury. It was also found that fine grinding ruptured starch cells, making the starch more susceptible to enzyme attack.

The work of LeClerc and co-workers was substantiated by the more recent investigation of Maun (1927), Pulkki (1938), and Swanson (1938) who, in addition to showing that the flour particles passing through a fine flour cloth sieve contained less protein than coarser particles, established that the

quality of the gluten was inferior. The ash content of the particles of soft red winter wheat flours decreased with the size of the particles as a rule, but the reverse was true for hard wheat flours. An increase of amylase susceptibility was observed with a decrease in the size of the flour particles.

The difficulty of fractionating flour into well defined particle size groups was due to the tendency of flour particles to agglomerate; and to the limited fineness of flour cloths. The finest flour cloth made does not have aperture openings of a well defined size or shape. The average size aperture opening of the 25 standard cloth is 63 microns, or approximately twice the size desired in order to make a complete fractionation of flour.

In most cases, the chemical characteristics of the particle size fractions of flour have shown only trends by past investigation.

The purpose of this investigation was to make a complete fractionation of flour into many well defined particle size groups; and to determine the differences, if any, in chemical characteristics and baking qualities of the groups.

It is first necessary to know the particle size distribution in flour, or the granularity of the flour. Sieving is the method that first suggests itself. In this procedure the weight of the material which passes a screen of one size and fails to pass a screen of a smaller size is determined. Such measurements provide certain size distribution data and appear to be direct and simple. However, sieving by cloth sieves has its

shortcomings. The inexactness with which flour cloth is woven is such that the material retained on the sieves is not an accurate measure of the true amount and size of particles in the flour. A large portion of flour normally is of smaller particle size than the lowest limit in which the cloths are made. This precludes the use of flour cloths in a complete characterization of particle size distribution (Ford 1928, Pence 1933, Anderson 1938, and Lockwood 1945).

Of the many other methods described in the literature for measurement of particle size, many do not apply to flour. However, the method employing the technique which is based on the rate of sedimentation in a liquid medium is fairly satisfactory. Markley (1934), Kent-Jones (1941), and Hildebrand (1942) have employed the sedimentation technique and have found the results to be correlated with the data obtained from microscopic study.

The other possible method of making a study of the particle size distribution in flour is with an air elutriation instrument, where the air required for separation is regulated in accordance with Stokes' Law for falling bodies.

MATERIALS AND METHODS

A commercially milled hard red winter, straight grade wheat flour was obtained from the Gooch Milling and Elevator Company, Lincoln, Nebraska. This was the only flour used throughout the investigation.

The division of this investigation into three sections was

necessary. The first section involved the methods for determining the distribution of the various particle sizes in flour. The second section was devoted to the method used for obtaining in quantity the various particle size fractions from flour for further testing. The third section deals with the differences in the physical and chemical properties for the various fractions.

Particle Size Distribution in Flour

Sieving. The Ro-Tap Testing Sieve Shaker (Plate I) was found satisfactory for producing data for the granulation curve. The Ro-Tap, built for handling eight-inch diameter testing sieves, reproduces the circular and tapping motion given testing sieves in hand sieving, but with a uniform mechanical action. The Ro-Tap is durably constructed and is driven by a quarter horse power electric motor turning at 1750 revolutions each minute. The running parts operate in oil. The throw of the carriage is one inch, making approximately 340 revolutions each minute. The tapper makes 160 complete cycles each minute.

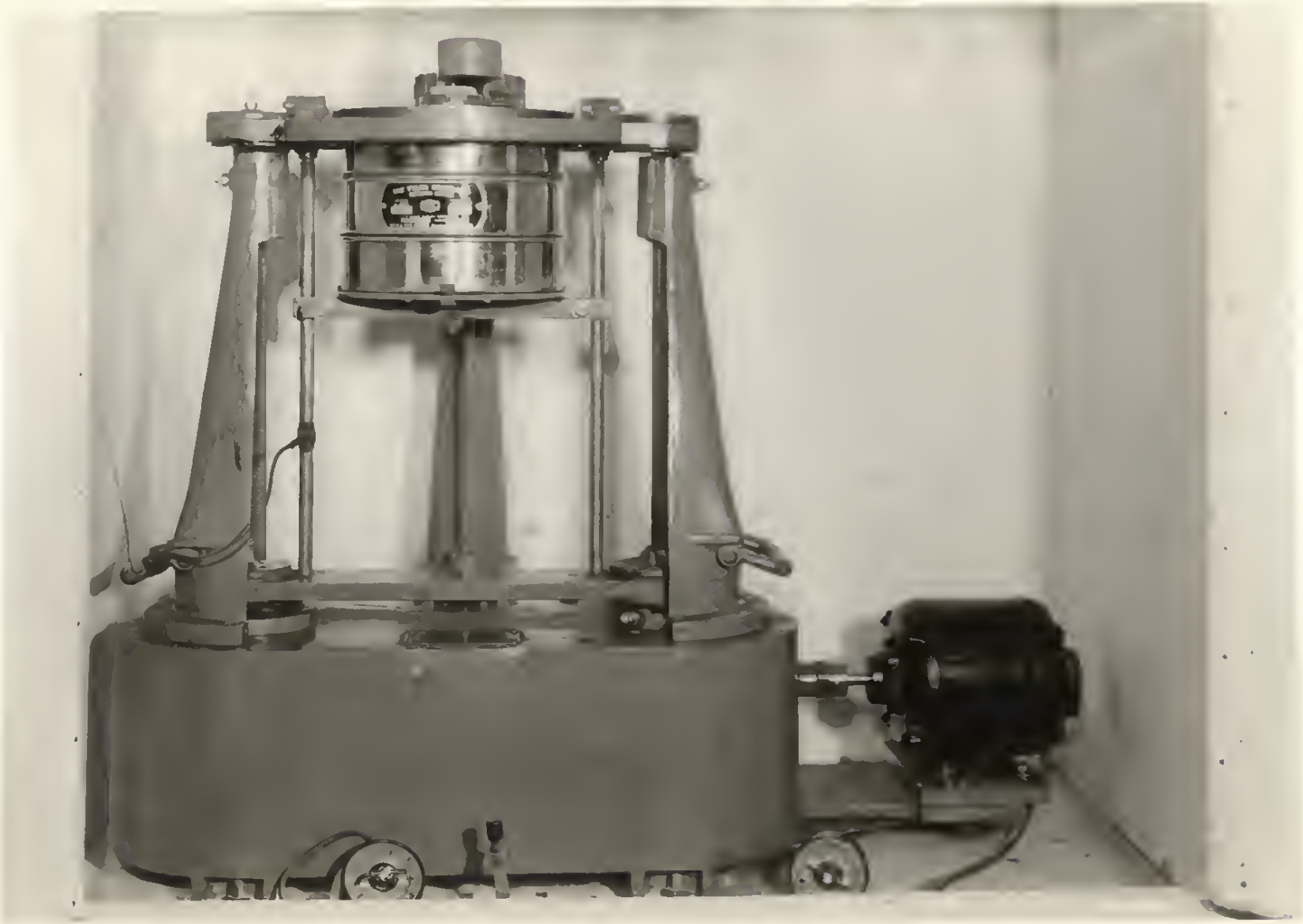
Eight wire testing sieves were selected to make the flour fractionation. These sieves were made by the Tyler Wire Company and represent the finest and the most accurate wire testing sieves available. The sieves range from 38 to 150 microns in aperture openings. The wire mesh of each sieve is uniform in weave presenting an accurate square opening determined by microscopic tests.

Only one testing sieve was used at a time. This sieve

EXPLANATION OF PLATE I

Ro-Tap shaker with testing sieves used for fractionating flour.

PLATE I



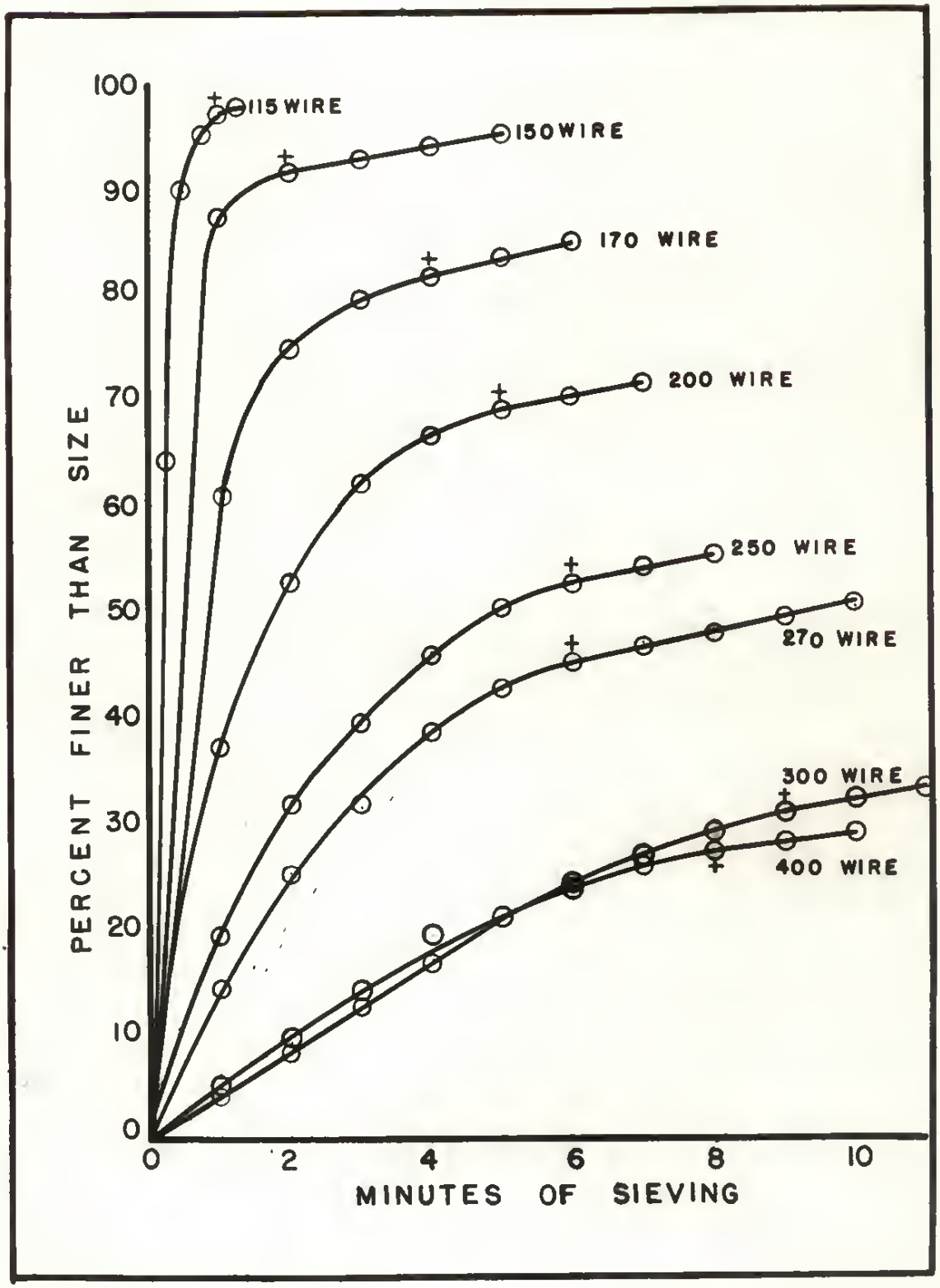
was stacked upon a coarse wire sieve carrying the under sieve cleaner brushes. These two sieves, in turn, were stacked upon the pan. A cloth cleaner was used for the top side of the testing sieve. A 50-gram sample of flour was introduced onto the top testing sieve. The sieving was then run at one minute intervals. After each minute of operation, the top sieve was carefully removed and weighed, the sieve along being previously tared. Extreme care was taken when removing and replacing the sieve over the pan so as not to disturb the "lay" of the material on the sieve. This procedure was continued, as well as plotting a running curve (Plate II) of the percentage of throughs of the sieve against each minute of sieving until a definite break in the curve resulted. A continuation of the curve resulted in a straight line, indicating that the material of the size smaller than the aperture opening of the sieve had been removed. Any additional material being removed was thus being produced by attrition reduction. All of the testing sieves, using new samples of flour, were treated in the same manner as described above. By taking the percent throughs of each sieve at the point where the break occurred, points were established which represent the particle size distribution of material making up the flour and which were used for drawing the granulation curve shown in Plate III.

Sedimentation. The liquid sedimentation method was also employed for determining the granularity of the flour. The apparatus used was the Andreasen Sedimentation Pipette, which consists of a glass cylinder about six centimeters in diameter

EXPLANATION OF PLATE II

Curves illustrating the optimal percentage of material through each wire testing sieve.

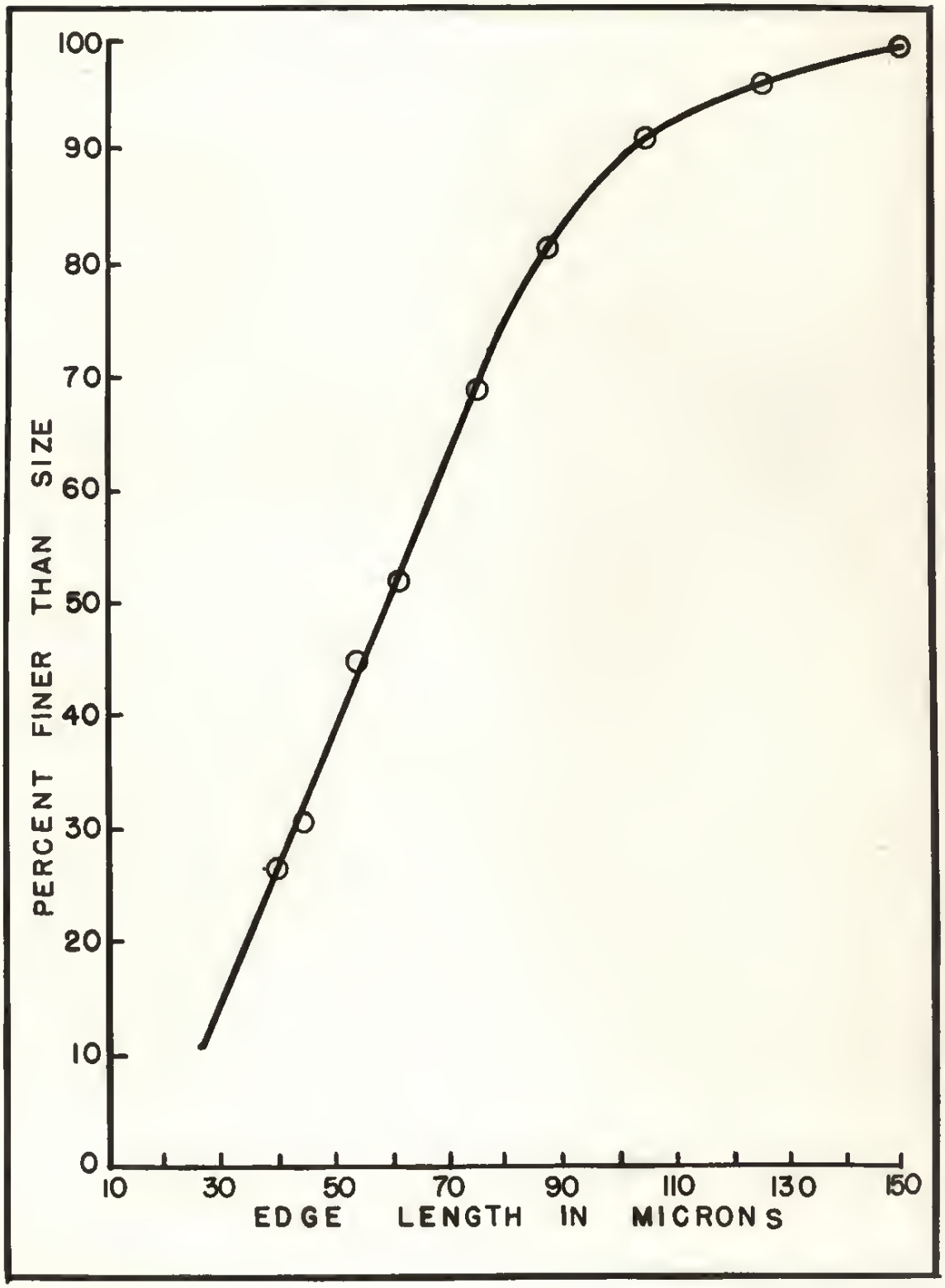
PLATE II


100
90
80
70
60
50
40
30
20
10
0
PERCENT FINER THAN SIZE
115 WIRE
150 WIRE
170 WIRE
200 WIRE
250 WIRE
270 WIRE
300 WIRE
400 WIRE
0
2
4
6
8
10
MINUTES OF SIEVING

EXPLANATION OF PLATE III

The granulation curve for the flour used in this investigation.

PLATE III


100
90
80
70
60
50
40
30
20
10
0
PERCENT FINER THAN SIZE
10
30
50
70
90
110
130
150
EDGE LENGTH IN MICRONS

having a capacity of approximately 550 ml when filled to the upper mark on the scale. It is provided with a ground glass stopper through which passes the stem of a pipette. The pipette extends 20 cm beneath the surface of the suspension and about four cm from the bottom. The tip is at the level of the zero mark on the scale, while the upper surface of the suspension is at the 20 cm mark. The pipette has a capacity of 10 ml and is provided with a three-way stopcock and spout for draining into a weighed filter paper.

Andreasen (1929) found that Stokes' Law could be applied to angular or cubical particles of the same weight as spherical particles. By calculating the grain size as the edge length of a cube of the same volume as a sphere of radius r, his grain sizes conformed to the results of sieve analysis.

The suspending medium used in the apparatus was a mixture of carbon tetrachloride and naphtha. It was necessary to determine accurately the constants of viscosity and specific gravity for substitution in Stokes' Law. The viscosity was determined by a Ubellhode viscosimeter. The specific gravity of the medium was determined by the usual method using a pycnometer. Air buoyancy corrections were applied to all weights. Having determined the specific gravity of flour, and having placed the apparatus in a constant temperature bath ($30^{\circ}C \pm 0.1^{\circ}$), a given amount of flour was introduced into the column. The liquid and flour were thoroughly mixed and an initial sample taken immediately. At predetermined time intervals, a 10 ml sample was drawn and discharged through the pipette into a weighed filter paper.

The size of the particles in the discharged fraction was computed by Stokes' equation, and a resultant granulation curve drawn.

Air Elutriation. One of the most promising methods of making particle size separations is through the use of the air elutriation principle. The Roller Particle Size Analyzer (Plate IV) employs such a principle. The determination of the particle size distribution of powdered materials below the 110 microns range is accomplished by means of a current of air carefully regulated as to its velocity. Any number of size fractions may be obtained, and the size limits may be as close as desired.

The air required for separation is regulated in accordance with Stokes' Law of falling bodies.

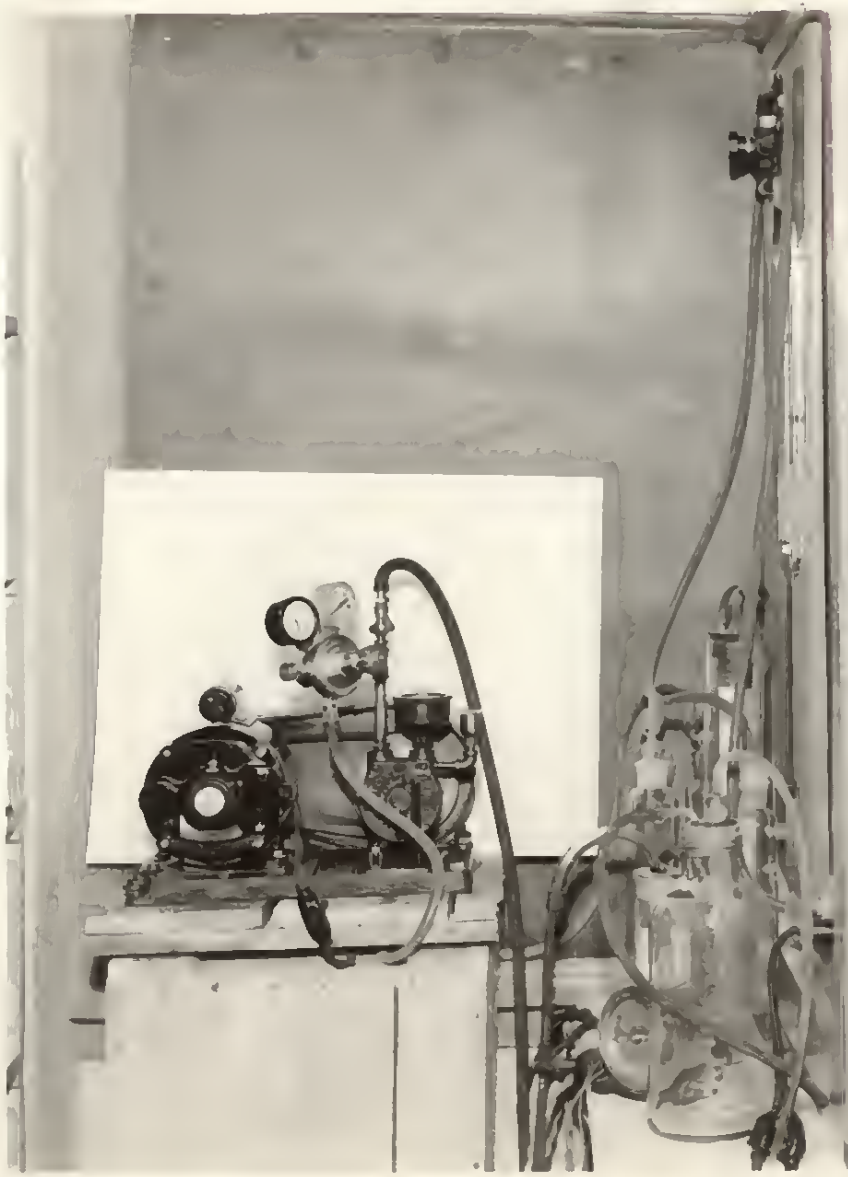
The Analyzer consists of an air jet inlet, a U-shaped glass vessel for holding the flour sample, oscillation connections for the latter, a series of four stainless steel settling chambers (9, 4-1/2, 2-1/4, and 1-1/2 inches in diameter), a collector for the size fractions, and a goose-neck connector. The air jet inlet is threaded on the inside to receive an accurately bored nozzle.

The U-shaped vessel oscillates about 200 times each minute under the action of leather-tipped fingers mounted on a motor driven shaft. These oscillations are not free, but are constrained by the action of an abutment and spring. The action is such as to cause translatory-rotary contact between the flour sample and the air which is highly efficient for the deflocculation action of the jet. The action is not such as to cause haphazard shaking of the sample, which would be detrimental.

EXPLANATION OF PLATE IV

The Roller Particle Size Analyzer used in this investigation for removing contamination or under-sized particles from the flour fractions by air slutriation.

PLATE IV



The cones of the settling chambers are tapped by a centrifugal tapper, so as to speed the downward movement of oversize material. These tappers consist of a pair of hammers rotating freely on a shaft that is belted to the main motor shaft. The entire system is grounded for static electricity.

The U-shaped container is fitted to the ends of the settling chamber by means of a large rubber tube. A screw locks the container to the chambers.

The fraction collector consists of a paper extraction thimble. This is held to the goose-neck by a fitted rubber stopper and an airtight connection is assured by the use of a rolled-up rubber sleeve.

The apparatus has a carefully calibrated flowmeter. The entire range of flour is covered by two capillaries which are interchangeable by means of a large-bore three-way stopcock. A mercury manometer measures the pressure drop across the inlet nozzle and provides a means for obtaining a flowmeter correction. This correction is applied in order to retain a constant pressure within the sample U-tube at all rates of flow.

A six-gram sample of flour was introduced into the U-shaped sample tube. The air velocity set by means of the flowmeter was such that it would remove a predetermined size of material. The completed separation was determined by calculating the rate of separation. The initial rate was taken as that amount of material being separated in a ten-minute interval. When the rate of separation was one-tenth of the initial rate, the separation was considered to have reached an end point. After determining

several points of separation for various particle sizes, a granulation curve was drawn.

Fractionation of Flour into Particle Size Groups

To obtain a large quantity of particle size groups, a method was employed using the testing sieves and the Ro-Tap testing sieve shaker. It was necessary to use the finest wire sieve first so that the coarser material would carry the finest particles to the mesh openings, permitting free bolting. A 50-gram sample of flour was sifted over the 400 wire sieve for the number of minutes previously determined to be necessary for producing the optimal percentage of throughs. The overs of the sieve were then removed and another 50-gram sample of flour was added. The overs of the sieve were again removed and the procedure continually repeated until a large quantity of the fraction was built up. The next coarser sieve, the 300 wire, was used for sifting the material taken from the overs of the 400 wire, and this procedure carried out in the same manner for all succeeding coarser wire sieves. The material passing through the 400 wire sieve constituted the 0-38 micron fraction. The material passing through the 300 wire sieve made up the 38-46 micron fraction, and so on, until a complete fractionation of flour was completed into particle size groups.

The method described for obtaining the fractions was rapid and accurate. Rebolting of the material was follwed by air elutriation in which any fine or under-sized material up to the

lower size limit of the fraction, as well as any bran fragments, dirt, or other contaminating material was removed. The resulting flour fractions were of a well defined particle size and were completely free from any contaminating material.

Microscopic observations were made as a size control check on all the fractions. The microphotographs (Plate V) illustrate the relative size and purity of the fractions.

Analysis of Physical and Chemical Characteristics

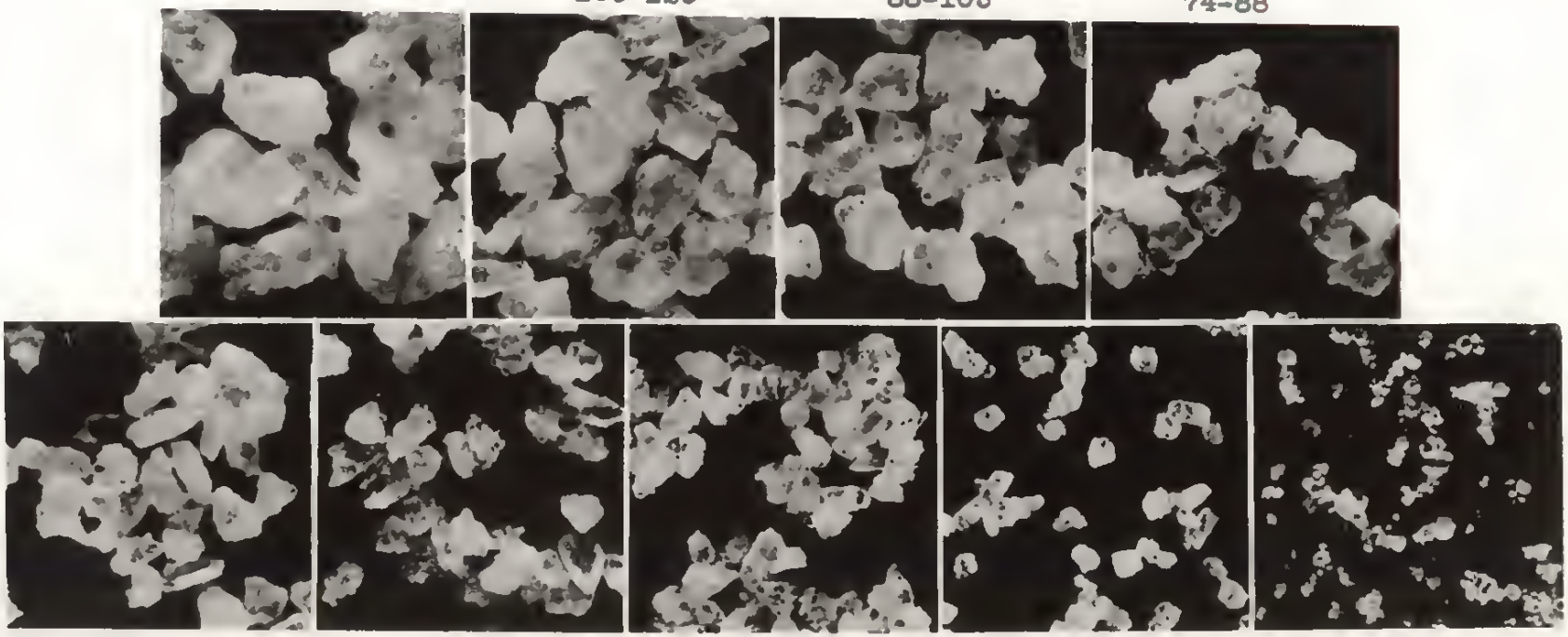
The specific gravity of each fraction was accurately determined to detect any minor differences between fractions. The results were converted to the 14 percent moisture basis. The procedure followed was the usual method employing the pycnometer, (Sharp 1927) with air buoyancy weight corrections made on all determinations. The ash, moisture, and protein determinations were run in the usual manner, with the results converted to a 14 percent moisture basis.

A full discussion of the working principles, as well as the theoretical and practical applications of the Amylograph to cereal chemical studies, was given by Anker and Geddes (1944). A smooth flour-water mixture was made by beating 65 grams of material (14 percent moisture basis) with 450 ml of distilled water at 30°C. This mixture was poured into the amylograph bowl and the kymograph adjusted to a zero time position. The thermometer was adjusted to start heating at 30°C., and the instrument started. The temperature of the suspension increased

EXPLANATION OF PLATE V

Microphotographs of the particle size fractions of flour with the particle size range in microns.

PLATE V



at a constant rate of 1.5°C. per minute until 90°C. was reached, where it was held constant.

The peak of the curve was recorded as the maximum viscosity in Brabender Amylograph Units.

The development of the farinograph and principle of its action on dough has been thoroughly discussed by Bailey (1940). Farinograms for this investigation were made according to the directions given by the Brabender Corporation. The thermostat was maintained at 30°C. and the small mixing bowl was used, employing 50 grams (14 percent moisture basis) of flour. The absorption for the normal farinogram was determined by a titration curve using distilled water and bringing all doughs to the 500 Brabender Unit consistency at the point of minimum mobility. The valorimeter was used in the same manner as described by Johnson, Shellenberger, and Swanson (1946) to determine the valorimeter value for each curve.

The National-Swanson-Working recording dough mixer or the mixograph was used for obtaining the mixogram curve patterns. Johnson, Swanson, and Bayfield (1943) fully discuss the theoretical and practical application of the mixograph to cereal chemistry studies.

The mixograph operated at 87 revolutions each minute with the number nine spring setting in an air-conditioned room maintained at approximately 80°F. Thirty-five grams of flour (14 percent moisture basis) were used with the absorptions established by the farinograph curves.

The mixogram area under the curve was measured with a pla-

nimeter for a mixing period of eight minutes.

Sandstedt and Blish (1934) developed the method for determining the gas production of a material by means of a pressure meter. Ten grams of material (14 percent moisture basis) and seven ml of water containing 0.3 grams of yeast in suspension were placed in the pressure jar which was previously warmed to 30°C. The contents were mixed, the manometer screwed on the jar, and the apparatus placed in a 30°C. water bath. The systems were adjusted to zero after five minutes, and readings taken after four, six, eight, and 24 hours.

Each flour fraction was baked in an experimental baking laboratory. A straight dough procedure using the three-hour fermentation at 30°C. with two intermediate punches (machine punching and moulding) was followed by a 25-minute oven bake at a temperature of 425°F. The formula used in the bake required the following ingredients:

100	grams of flour (14 percent moisture basis)
6	grams of sugar
1-1/2	grams of salt
2	grams of yeast
3	grams of shortening
4	grams of milk
0.003	grams of bromate
---	water volume determined by farinograms.

EXPERIMENTAL RESULTS

The data for determining the optimal percent of material through a specified sieve are given in Table 1. There is a break in the curves (Plate II) after which a straight line occurs, indicating an end to the procedure.

Although the sedimentation data (Table 2) as well as air elutriation data (Tables 3 and 4) gave an indication of the particle size characterization of flour, the method proving most accurate and giving duplicable results was that employing the Ro-Tap Shaker with testing sieves. The separation of the flour into particle size fractions was made by the various testing sieves whose aperture openings were accurate in shape and size.

A "clean up" of each fraction was necessary because of the inability of sieves to remove the smallest bran, starch and dirt particles which adhere to the flour particles. This was accomplished by introducing small amounts of material into the sample tube of the air elutriation instrument and adjusting an air velocity necessary to make the desired separation in approximately 10 minutes. An ash study on the fractions obtained by sieving alone, and on the same fractions followed by air elutriation is shown in Table 6.

Figure 1 shows the percent of ash in each fraction of endosperm, which in turn is in its percentage proportion of the whole flour. The protein content of each size fraction is illustrated by Fig. 2, and the data are presented in Table 7.

Table 1. The optimal percentage of flour passing through the wire testing sieves.

Wire no.	Sifting time min.	Flour passing through percent	Sieve aperture opening microns	Wire no.	Sifting time min.	Flour passing through percent	Sieve aperture opening microns
400	1	4.8	38	250	1	18.0	61
	2	9.2			2	32.0	
	3	13.8			3	39.4	
	4	19.2			4	46.0	
	5	20.6			5	50.0	
	6	23.8			6	52.4*	
	7	25.6			7	54.0	
	8	27.2*			8	55.2	
	9	28.0					
	10	28.8		200	1	37.2	74
					2	53.4	
300	1	4.0	46		3	62.0	
	2	8.4			4	66.6	
	3	12.6			5	68.8*	
	4	17.0			6	70.2	
	5	21.0			7	71.6	
	6	24.2					
	7	26.6		170	1	61.6	88
	8	28.6			2	75.0	
	9	30.8*			3	79.4	
	10	32.0			4	81.6*	
	11	33.2			5	83.0	
	12	34.0			6	84.6	
	13	34.4					
	14	35.2		150	1	87.2	105
					2	91.8*	
270	1	15.2	53		2-1/2	92.8	
	2	25.4			3	93.8	
	3	31.6			4	94.8	
	4	38.6					
	5	42.4		115	1/4	64.2	125
	6	45.0*			1/2	89.8	
	7	46.8			3/4	95.0	
	8	47.8			1	96.8*	
	9	49.2			1-1/4	97.4	
	10	50.2					
				100	1	98.0	150
					1-1/4	99.6*	

Table 2. Granulation data of flour obtained by sedimentation.

No.	Particle size r microns	Length fall h cm.	Time fall t min. sec.	Wt. filter paper gms.	Wt. filter paper and residue gms.	Residue gms.	Finer than size percent	Material by weight percent	Fraction range microns
1	--	--	0'00"	0.8861	1.1867	300.6	100.0	--	--
2	150	20.0	1'00"	0.8867	1.1784	291.7	97.0	3.0	150
3	110	19.6	1'46"	0.9204	1.2063	285.9	95.1	1.9	110-150
4	90	19.2	2'36"	0.9303	1.2036	273.3	90.9	4.2	90-110
5	80	18.8	3'12"	0.9415	1.2028	261.3	86.9	4.0	80-90
6	70	18.4	4'04"	0.9300	1.1696	239.6	79.7	7.2	70-80
7	60	18.0	5'26"	0.9438	1.1427	198.9	66.2	13.5	60-70
8	55	17.6	6'18"	0.9385	1.1117	173.2	57.6	8.6	55-60
9	50	17.2	7'28"	0.9474	1.0946	147.2	49.0	8.6	50-55
10	45	16.8	9'00"	0.9361	1.0693	123.2	41.0	8.0	45-50
11	40	16.4	11'06"	0.9532	1.0519	98.7	32.8	8.2	40-45
12	35	16.0	14'12"	0.9476	1.0290	81.4	27.1	5.7	35-40
13	30	15.6	18'48"	0.9434	1.0086	65.2	21.7	5.4	30-35
14	25	15.2	26'24"	0.9649	1.0138	48.9	16.3	5.4	25-30
15	20	14.8	40'12"	0.9448	0.9765	31.7	10.5	5.8	20-25
16	15	14.4	69'36"	1.0332	1.0483	15.1	5.1	5.4	15-20

Table 3. Roller analyzer settings for a flour of specific gravity of 1.435.

Particle size microns	Chamber diameter inches	Capillary orifice no.	Nozzle opening inches	Air flow liters per minute	Flowmeter setting inches
5	9	1	.038	2.60	2.6
6	9	1	.042	3.72	4.9
7	9	1	.046	4.82	7.7
8	9	1	.055	6.45	13.6
9	9	1	.059	8.10	19.7
10	9	2	.070	10.40	2.8
12	9	2	.082	14.88	5.4
14	9	2	.096	19.28	8.8
16	4-1/2	1	.055	6.45	13.6
18	4-1/2	1	.059	8.10	19.7
20	4-1/2	2	.070	10.40	2.8
24	4-1/2	2	.082	14.88	5.4
28	4-1/2	2	.096	19.28	8.8
32	2-1/4	1	.055	6.45	13.6
36	2-1/4	1	.059	8.10	19.7
40	2-1/4	2	.070	10.40	2.8
48	2-1/4	2	.082	14.88	5.4
56	2-1/4	2	.096	19.28	8.8
64	1-1/8	1	.055	6.45	13.6
72	1-1/8	1	.059	8.10	19.7
80	1-1/8	2	.070	10.40	2.8
88	1-1/8	2	.082	14.88	5.4
96	1-1/8	2	.096	19.28	8.8
104	1-1/8	2	.104	25.80	15.0

Table 4. The granulation data of flour by air elutriation.

Separation time min.	Fraction size microns	Fraction separation gms.	Finer than fraction percent	Nozzle no.	Air flow liters per minute	Chamber no.	Flowmeter Uncorrected inches	Flowmeter Corrected* inches	Hg inches
50	0-36	1.841		.059	8.10	2-1/4	19.7 (1)	18.2	1.9
50	36-48	1.189	29.3	.082	14.88	2-1/4	5.2 (2)	5.1	1.4
30	48-56	0.749	48.2	.096	19.28	2-1/4	8.8 (2)	8.3	1.5
45	56-64	0.243	60.1	.055	6.45	1-1/8	13.6 (1)	12.8	1.4
30	64-72	0.361	64.0	.059	8.10	1-1/8	19.7 (1)	18.2	2.0
20	72-80	0.534	69.8	.070	10.40	1-1/8	2.8 (2)	2.7	1.3
5	80-88	0.533	78.2	.082	14.88	1-1/8	5.4 (2)	5.1	1.8
5	88-96	0.030	86.6	.096	19.28	1-1/8	8.8 (2)	8.3	1.6
5	96-104	0.005	87.2	.104	25.80	1-1/8	15.0 (2)	13.8	2.0
	Recovery	5.485#							

* Corrected flowmeter reading ($1-.04p'$) x uncorrected flowmeter inches of water, where p' is the inches of mercury.

\# 5.485 grams is 87.4 percent of total flour, since the material larger than 104 microns was previously removed by sieving.

Table 5. A comparison of wire and silk bolting cloths.

Wire sieve no.	Dufour cloth no.	Aperture openings: inches	microns	Fraction particle size range, microns
115	11 XX	0.0049	125	125-150
150	12 XX	0.0041	105	105-125
170	16 std.	0.0035	88	88-105
200	20 std.	0.0029	74	74-88
250	25 std.	0.0024	61	61-74
270		0.0021	53	53-61
300		0.0018	46	46-53
400		0.0015	38	38-46
th 400				0-38

Table 6. Effect of air elutriation on particle size fractions obtained by testing sieves in relation to ash.

Fraction particle size range microns	Percent ash*	
	Sieving only	Sieving followed by air elutriation
Flour	.439	.439
125-150	.445	.441
105-125	.360	.323
88-105	.366	.351
74-88	.374	.359
61-74	.384	.366
53-61	.409	.385
46-53	.439	.433
38-46	.531	.520
0-38	.511	---

* Results reported on 14 percent moisture basis.

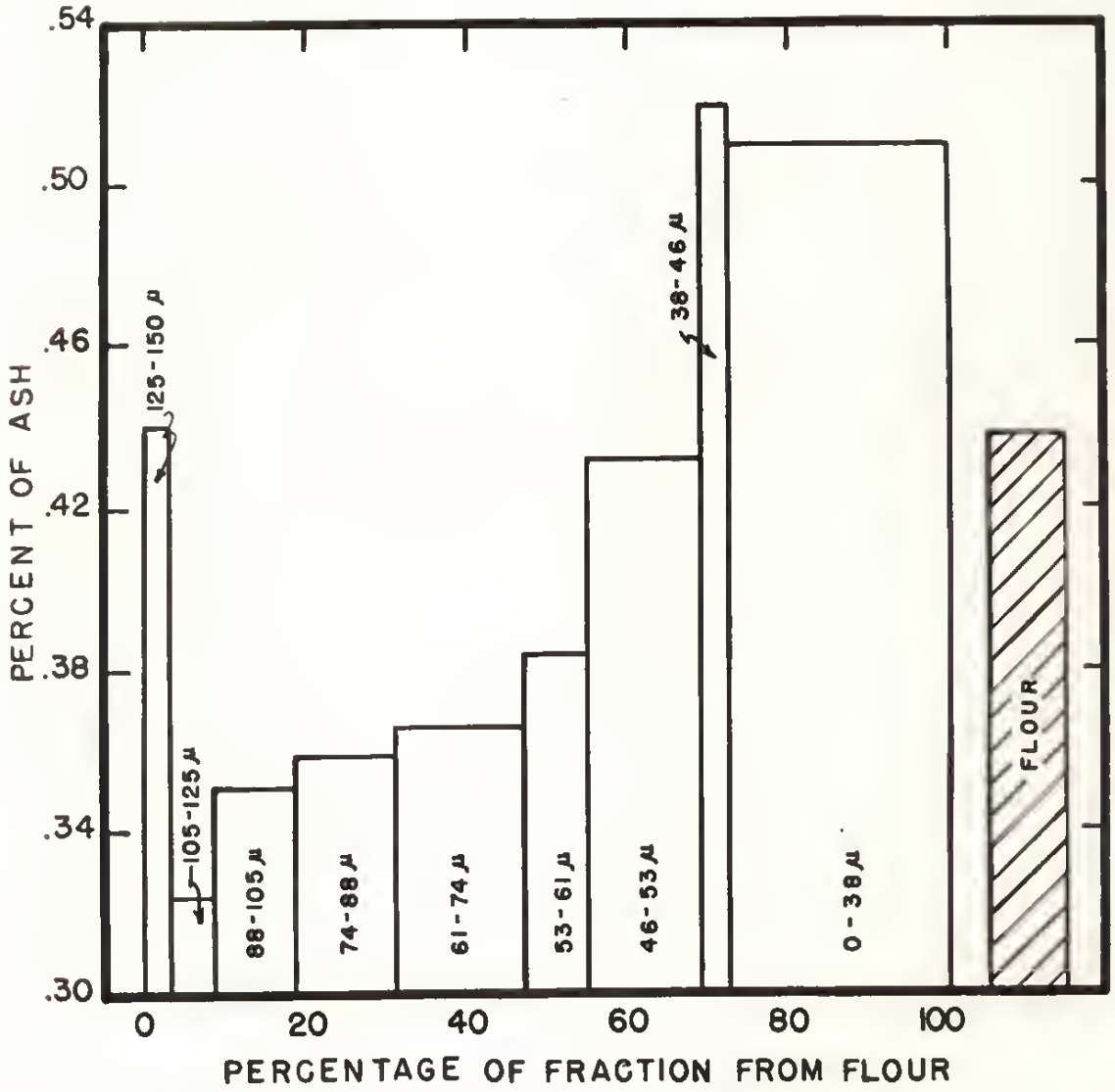


Figure 1. Relationship of ash and the particle size fractions of flour.

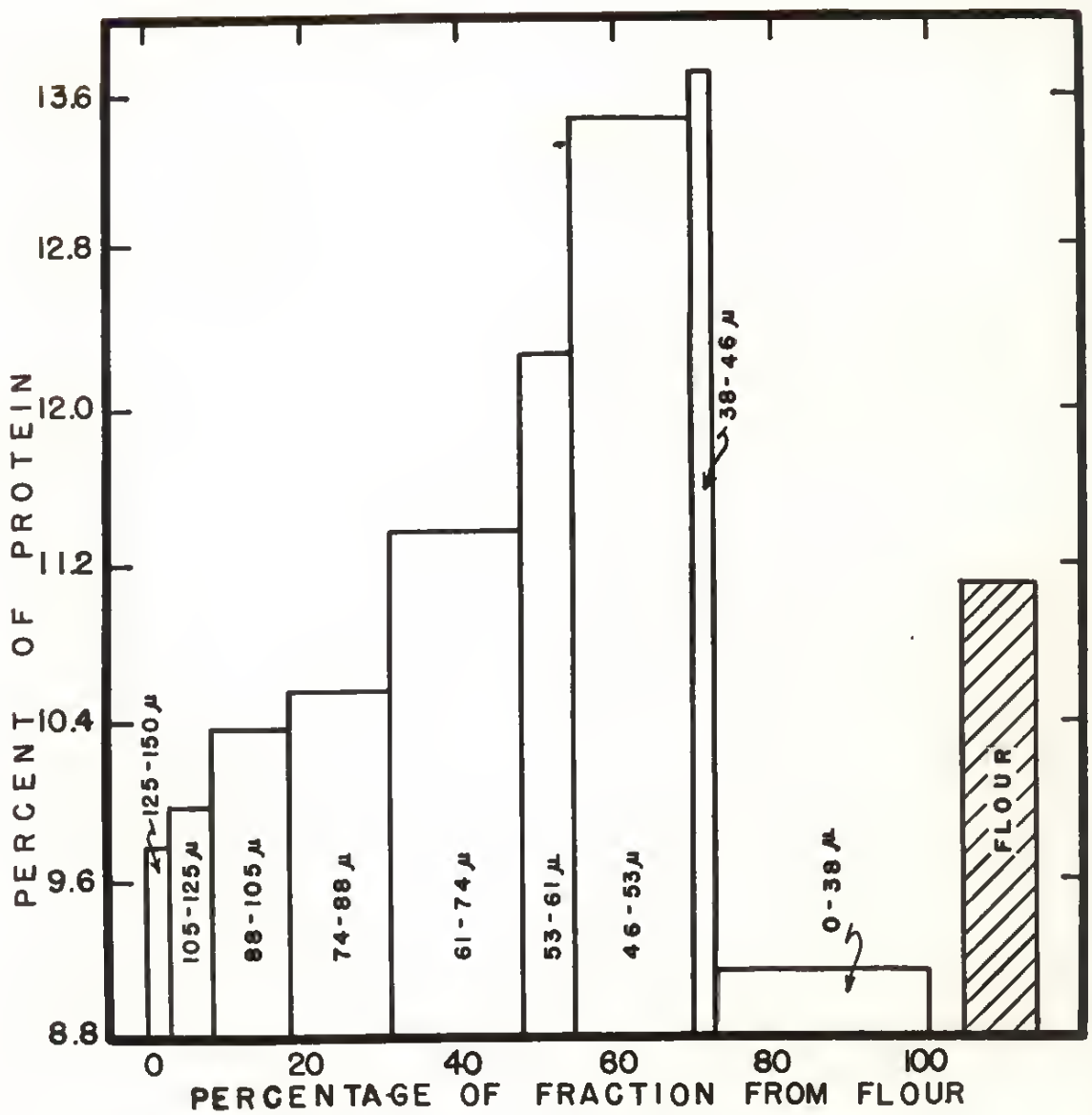


Figure 2. Relationship of protein and the particle size fractions of flour.

Table 7. The relationship of the protein content to the particle size fractions of flour.

Fraction particle size range microns	Protein content percent*
Flour	11.1
125-150	9.7
105-125	10.0
88-105	10.4
74-88	10.6
61-74	11.4
53-61	12.3
46-53	13.5
38-46	13.7
0-38	9.1
0-105	11.1
38-150	11.9
38-105	12.0

* Results reported on 14 percent moisture basis.

A measure of the availability of the fractions to enzyme activity was determined by the gassing power values. Results are shown in Table 8 and Fig. 3. A measure of the viscosity of each fraction using the amylograph produced data illustrated by curve heights in Fig. 4 and data in Table 9.

The relationship of the specific gravity to the particle size of each fraction of flour is given by data in Table 10.

The mixogram curves (Plate VI) were run to determine the mixing time, tolerance to overmixing and the general inherent qualities of each fraction. The area under the curves (Table 11) was determined by a planimeter.

The farinogram curves (Plate VII) were run on each fraction to determine the water optimum absorption requirement. The colorimeter was used to obtain data (Table 12) for relating the curve patterns to each other.

DISCUSSION OF EXPERIMENTAL RESULTS

Fractionating Flour

The term "fractionating flour" in this investigation refers to the removal of a given size range of flour particles from the flour. This constitutes one fraction. The fractionating of flour in this study resulted in 13 well defined particle size ranges of flour.

The first attempts to fractionate flour were made by using a Federal Air Classifier system, and a set of silk bolting cloths.

Table 8. The relationship of gas production to the particle size fractions of flour containing no malt, and supplemented with malt.

Fraction particle size range microns	Gas production in mm of mercury							
	Unmalted				1% malt added			
	4 hours	6 hours	8 hours	24 hours	4 hours	6 hours	8 hours	24 hours
Flour	306	333	366	535	499	595	666	1050
105-125	209	222	238	339	381	442	500	928
88-105	221	238	252	352	408	473	523	846
74-88	232	251	267	379	415	481	533	896
61-74	224	241	255	362	408	473	523	874
53-61	227	242	257	351	418	476	536	889
46-53	250	266	284	386	440	501	557	891
38-46	290	309	330	447	470	545	602	926
0-38	417	462	506	682	495	697	821	1141
0-105	320	351	385	561	503	603	672	1055
38-150	242	267	277	383	422	480	532	840
38-105	243	265	279	387	433	505	555	861

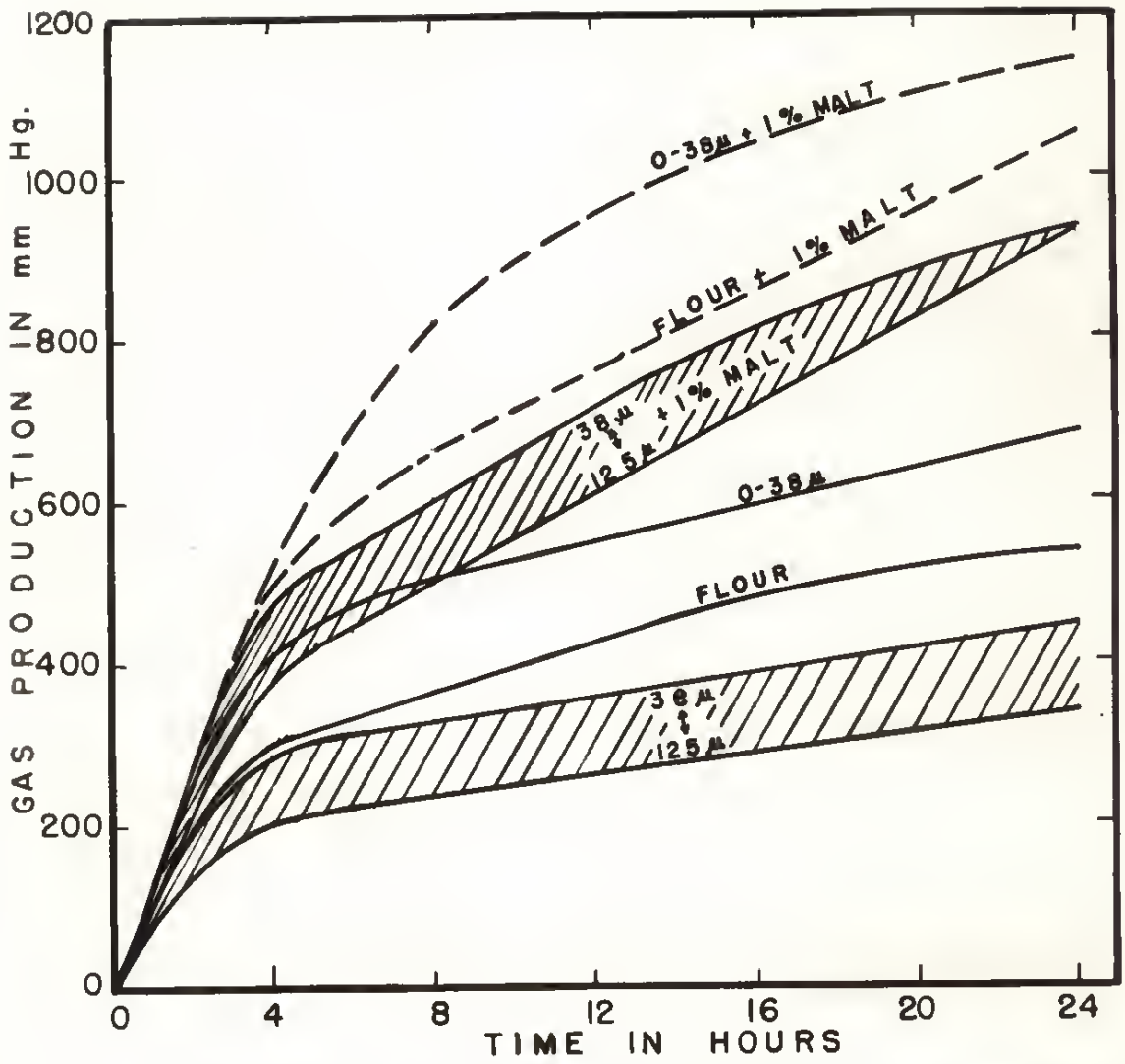


Figure 3. Relation of gas production to unmalted and malted particle size fractions of flour.

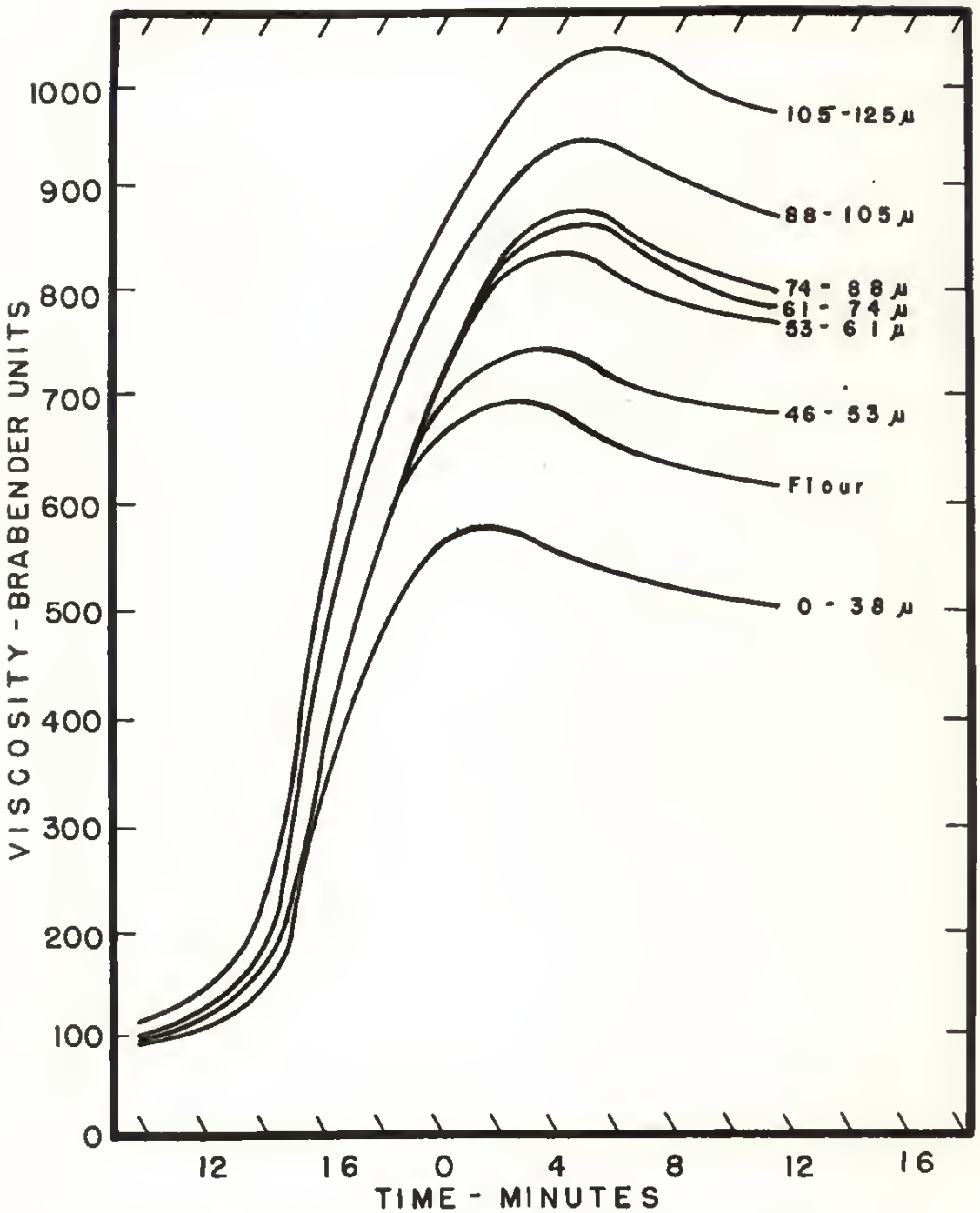


Figure 4. Relationship of viscosity and the particle size fractions of flour.

Table 9. The relationship of the maximum viscosity in Brabender Units to the particle size fractions of flour.

Fraction particle size range microns	Maximum viscosity in Brabender Units
Flour	695
105-125	1020
88-105	935
74-88	880
61-74	875
53-61	830
46-53	735
0-38	570
0-105	695
38-150	695
38-105	845

Table 10. The relationship of specific gravity to the particle size fractions of flour.

Fraction particle size range microns	Specific gravity*
Flour	1.438
125-150	1.421
105-125	1.439
88-105	1.419
74-88	1.422
61-74	1.430
53-61	1.419
46-53	1.421
38-46	1.445
0-38	1.444
0-105	1.454

* Results reported on 14 percent moisture basis.

EXPLANATION OF PLATE VI

Farinograph curves of flour fractions used in this investigation. The particle size range in microns is given for each fraction.

PLATE VI

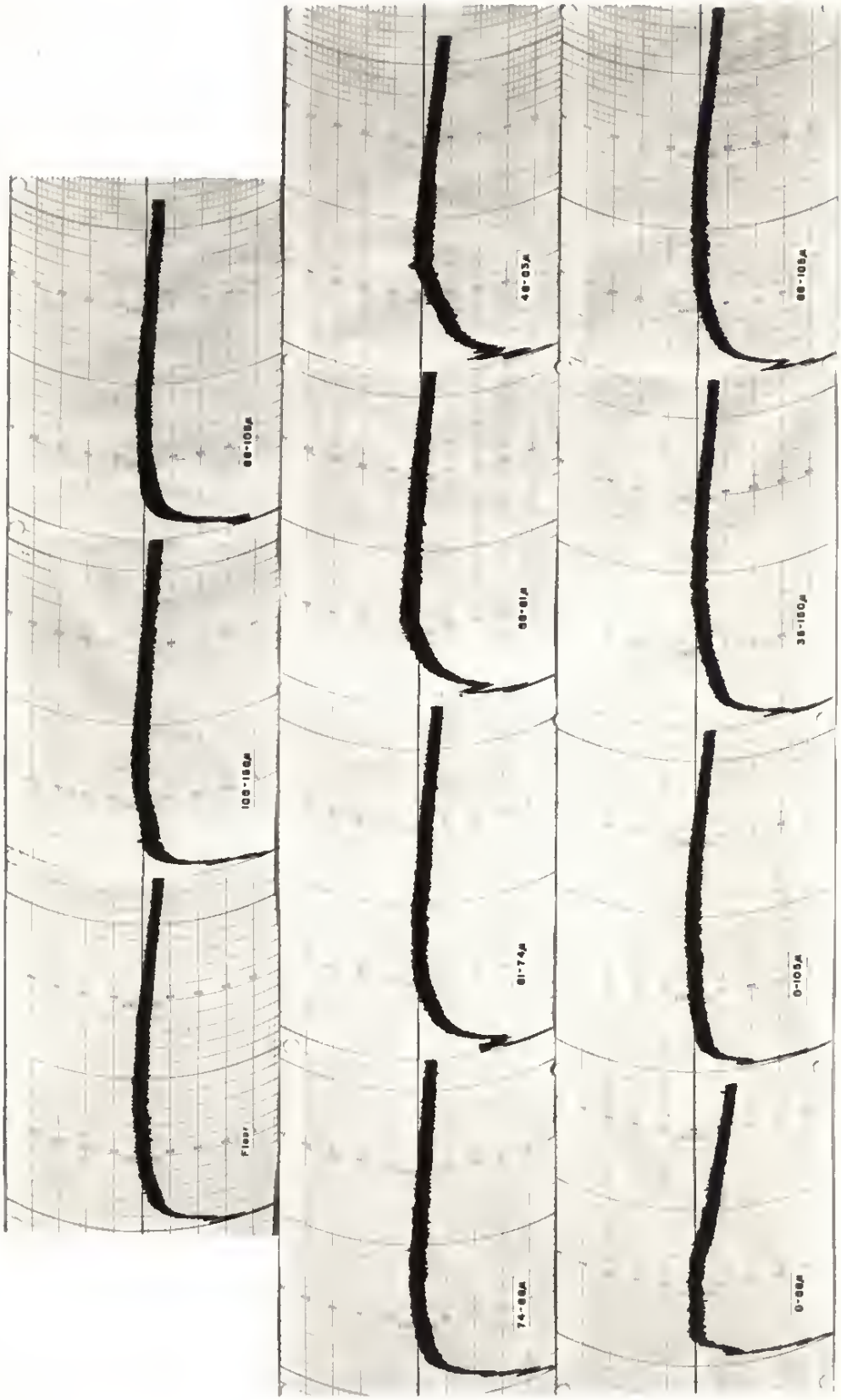

88-105μ
105-150μ
Floor
48-63μ
63-81μ
81-74μ
74-88μ
88-105μ
35-150μ
0-105μ
0-88μ

Table 11. The relationship of the area under the mixogram curve and the optimal mixing times to the particle size fractions of flour.

Fraction particle size range microns	Mixogram	
	Area under curve in cm^2	Mixing time in minutes
Flour	77.4	3
105-125	71.7	3-1/2
88-105	72.3	3-1/2
74-88	72.3	3-1/2
61-74	74.2	3-1/2
53-61	79.4	3-1/4
46-53	83.8	3-1/2
0-38	65.0	4-1/4
0-105	76.2	3-1/2
38-150	74.6	3-1/2
38-105	79.2	3-1/4

EXPLANATION OF PLATE VII

Swanson-Working-National micro dough mixer curves of flour fractions used in this investigation. The particle size range in microns is given for each fraction.

PLATE VII

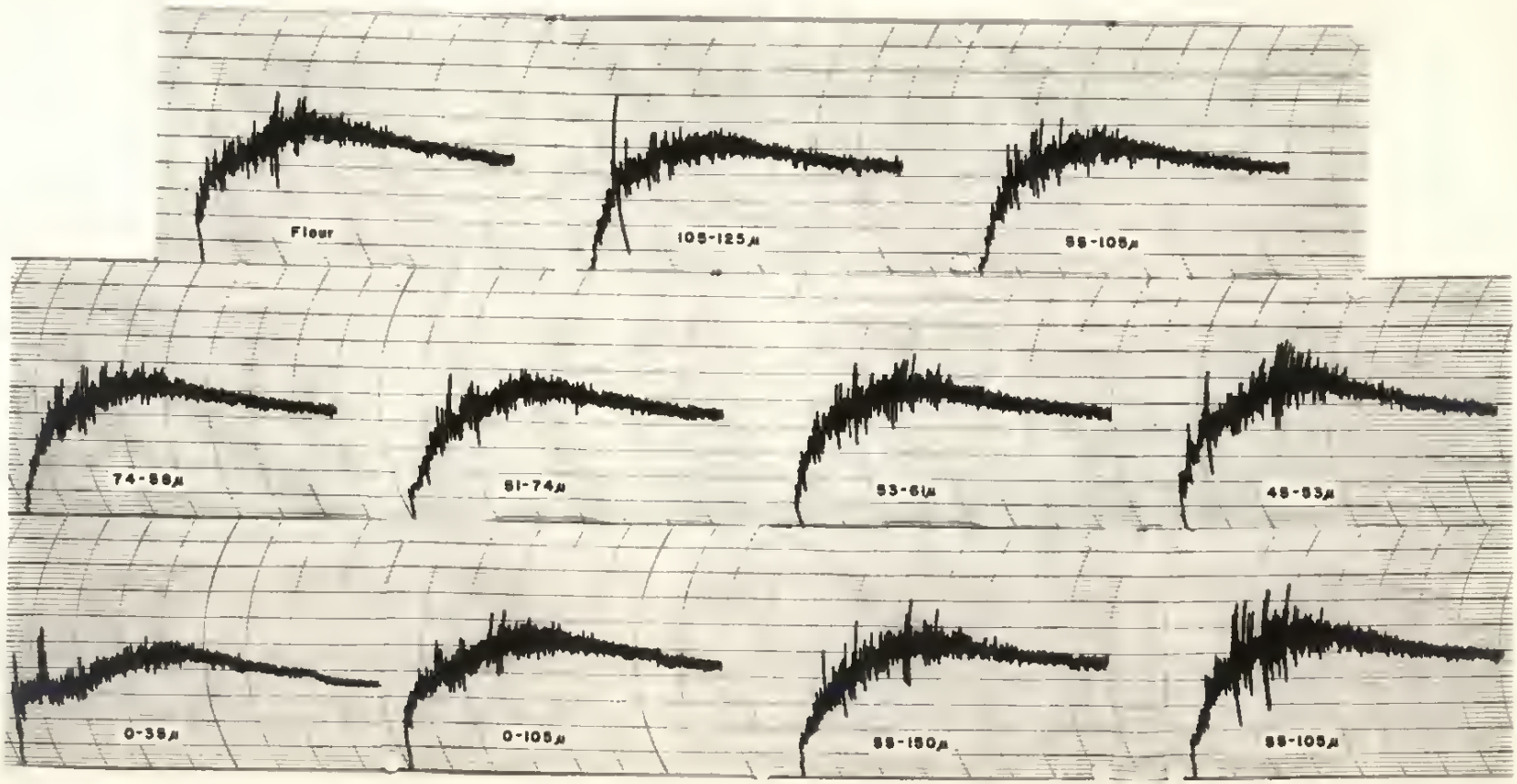

Flour
105-125μ
88-105μ
74-88μ
61-74μ
53-61μ
45-53μ
0-38μ
0-105μ
88-150μ
88-105μ

Table 12. The relationship of absorption and valorimeter value to the particle size fractions of flour.

Fraction particle size range microns	Farinogram	
	Absorption* percent	Valorimeter value units
Flour	61.6	78
105-125	58.9	74
88-105	60.3	77
74-88	60.1	77
61-74	60.6	76
53-61	61.7	66
46-53	64.3	74
0-38	61.5	57
0-105	62.1	82
38-150	62.1	80
38-105	62.1	85

* Results reported on 14 percent moisture basis.

Since neither well defined particle size fractions nor a small size range of fractions were obtained, other equipment was necessary.

Flour separation into well defined particle size fractions was accomplished by using a set of Tyler wire testing sieves and a Ro-Tap Shaker. The fractions were subjected to air elutriation as a "clean up measure" in order to remove undersized flour and starch particles and foreign material. All fractions were found to be classified quite accurately as to particle size. This was checked by microscopic observation.

The granulation curve drawn from the wire sieving data varied from those curves produced by liquid sedimentation or air elutriation data. The data from the sieving procedure was more reproducible than that from the sedimentation procedure.

The air elutriation method for determining flour granularity requires further operational investigation. Although duplicable results are obtainable on fraction removals, an unequal moisture loss is encountered on the fractions. Attrition reduction accounts for inaccurate curve points for the coarser particles, since these particles remain in the sample tube longer than any other fraction.

There is sufficient evidence given by the Roller Analyzer to indicate that commercial separation of flour particles by air elutriation is quite possible and highly desirable.

The removal of the small free starch granules from flour by using the 400 wire sieve is possible only under the optimum laboratory conditions, and is not very probable on a commercial

scale. Since this free starch fraction can impart a detrimental effect to the flour (pointed out later in the discussion), the only commercial means of removing this material is by carefully controlled air velocities in air expansion chambers on a continuous flow system. The desirability of such a system is the flexibility of selection of the particle size of material, sieve and sub-sieve size, to make up a specified flour.

Ash

Table 6 and Fig. 1 show the relation of ash to the particle size fractions of flour. A decrease in size of the endosperm particle is accompanied by an increase of ash of the particles. Since the flour fractions have been subjected to air elutriation where the removal of contaminating material is completed, the resulting ash of the flour fractions is apparently an inherent characteristic of the particles in the fraction. The largest particle size fraction should then have the lowest ash. This fraction, however, contained such large size chips of bran that an air velocity required to remove this bran would also have removed the flour particles. Table 6 shows that by subjecting the flour fractions to air elutriation the ash was lowered by a few points. Microscopic observation showed that this air separated discharge material contained high ash materials such as bran chips, hairs, and dirt. Consequently, the entire amount of all fractions was subjected to the air treatment so that the physical and chemical characteristics of the fractions were

due only to the inherent properties of the flour particle sizes.

Several other commercial flours were fractionated and the ash alone determined on the resultant fractions. In each flour, the relationship of an increased ash with a decrease in particle size existed. However, the 0-38 micron fraction, containing a concentration of free starch granules, had a marked increase of ash in one flour over its normal curve trend; while in another flour, the ash of this fraction decreased sharply from the normal curve. It was concluded that in some hard wheat flours a decrease in the size of the flour particle is accompanied by a normal increase in ash content, but that the free starch granules, which normally constitute 25-30 percent of the total flour, may vary markedly in ash and have a strong influence on the final ash of the whole flour.

Protein

The relationship of protein to the particle size fractions of flour is shown in Table 7 and Fig. 2. A decrease in the size of the endosperm particle is accompanied by an increase of the protein content. The 0-38 micron fraction is composed predominately of free starch granules and contains a very low protein content. This protein is probably due to a partial overlap of some very small flour particles with a high protein content.

Gas Production

The relation of gas production to unmalted and malted particle size fractions of flour is shown in Table 8 and Fig. 3. The production of gas was least on the unmalted fraction whose particles were largest in size. With a decrease in the size of the flour particle an accompanying increase in gas production was obtained. This same relation existed when the fractions were supplemented with malted wheat flour. Since the increase in height of these curves is nearly all proportionate over the curves presenting the unmalted fractions, there is no indication of a concentration of the amylase enzymes in any one fraction. The difference in gas production is then due to the susceptibility of the flour particles to the enzyme attack. With a decrease in size of the flour particle, the susceptibility of the particles becomes greater, allowing an increased amount of the gas to be formed. The 0-38 micron fraction shows the highest rate of gas production in both unmalted and malted fractions. This is probably due to a concentration of starch granules, some of which are ruptured and therefore are highly susceptible to alpha and beta amylase action.

Amylogram Curves

The relation of the maximum viscosity determined by the Amylograph to the particle size fractions is illustrated in Fig. 4. The viscosity is least for the smallest particle size

fraction. With an increase in size of the flour particles there is an accompanying increase in the viscosity. Anker and Geddes (1944) pointed out that the maximum viscosity of flour pastes depends upon several variables such as starch content, particle size, inherent starch characteristics, extent of mechanical injury of the starch, pH, amylase activity, and the rupture of the swollen granules.

A lack of influence of amylase activity in any one fraction was shown by the gas production curves and data. This precludes any further influence of the enzyme for curve degradation in the Amylograph. Thus the marked differences in the viscosity curve heights probably are due to the various sizes of particles of flour. As the temperature of the slurry increases and gelatinization of the starch granules begins there is an accompanying increase in hydration of the starch granules causing a closer packing of the particles. Since the flour particle does not immediately lose its size identity during gelatinization, the larger particles of flour being hydrated become more closely packed resulting in an increase in the viscosity of the paste.

Since the 0-38 micron fraction is largely composed of starch granules, some of which are ruptured from mechanical operation, the amylase enzyme is permitted to cause a liquefaction in opposition to the increase in viscosity of gelatinization, thereby resulting in a low viscosity curve.

The low viscosity curve of the whole flour is explained by the fact that there are relatively small amounts of the

coarse particles with a high viscosity curve, and a large amount of the small particles with a low viscosity curve in the flour.

Specific Gravity

Table 10 shows that the specific gravity for all particle sizes of flour is approximately the same. Extreme care and accuracy of measurement in determining the specific gravities were taken to detect any slight differences which might accompany the ash, moisture, or protein variation.

The basis upon which the air elutriation principle is founded is that the same specific gravity exists for all particle sizes of flour. Thus a change in air velocity is required to remove the different size particles having a uniform specific gravity.

Farinogram and Mixogram Curves

The relation of farinogram and mixogram curve characteristics to the particle size fractions of flour is shown in Plates VI and VII. Only small differences between curve patterns are noted except for the 0-38 micron fraction curve pattern. Since the protein content of a flour is one of the most important factors in determining the farinogram and mixogram patterns, the low protein content of the 0-38 micron fraction accounts for the poor curve produced. The 500 unit line is reached in the farinogram curve pattern after two minutes of

mixing of the largest particle size fraction. With a decrease in size of the particles, the time required for the curve to reach the 500 unit line is lengthened. Six minutes elapse before the line is reached by the 46-53 micron fraction. This increase in time is probably the result of an increase of protein in the fraction. The mixogram curve patterns gradually increase in height as the particle size decreases. This curve rise is again due to an increase of protein in the smaller size fractions. Table 11 shows the total area under each curve and the mixing time required for each fraction. The area increase is attributed to protein increase.

The farinogram curves are primarily important for giving the water requirements to center the curve on the 500 unit line. There is a general trend for the water absorption to be increased with a decrease in size of the particle. (Table 12). Little relation between the valorimeter reading of the curves and particle size fractions was observed.

The 0-105 micron fraction is flour with only the largest particles removed; the 38-150 micron fraction is flour with only the smallest particles removed; while the 38-105 micron fraction is flour with both the smallest and the largest particles removed. Each of these fractions produced a curve pattern having more desirable characteristics than whole flour. The fraction with the smallest and the largest particles both removed compared favorably with the curve characteristics of the 46-53 micron fraction.

Bake

A comparison of the loaves of bread baked from the particle size fractions is shown in Plate VIII with a summary of the baking data given in Table 13.

Perhaps the most important characteristic sought in a loaf of bread is its loaf volume, assuming that the loaf grain and texture are good. Since loaf volume is directly related to the protein content of the flour, the loaf volume is low for the flour fractions whose protein content is low. An increase in volume of loaf is obtained as the protein content increases. This relationship is shown diagrammatically in Fig. 5.

Since the largest particles of flour have the lowest protein content, the resultant half shell-topped loaves are obtained. The smallest flour particles produced a loaf of bread whose volume was the greatest because of its high protein content. The grain and texture were good with the crumb color a creamy white. Since this flour was unbleached, the whiteness of the cell structure must largely be due to the small particles of flour making up the fraction. With an increase in size of the flour particles the cell structure takes on a yellow cast, giving the appearance of a concentration of the carotin pigment in the flour.

EXPLANATION OF PLATE VIII

Comparison of loaves baked from the partiole size fractions of flour.

The legend for the symbols is as follows:

Fraction partiole size	
flour, 0-150 microns,	A
105-125 microns,	B
88-105 microns,	C
74-88 microns,	D
61-74 microns,	E
53-61 microns,	F
46-53 microns,	G
0-38 microns,	H
0-105 microns,	I
38-150 microns,	J
38-105 microns,	K

PLATE VIII

Table 13. Summary of the baking data for the particle size fractions used in this investigation.

Fraction particle size range microns	Loaf letter	Loaf volume cc.	Loaf weight grams	Crumb[1] color score	Texture[2] grain score	Shred and break appearance
Flour	A	760	149	75 cy	83 c	good
105-125	B	775	148	84 cy	78 c	poor, half shell top
88-105	C	775	147	85 cy	81 c	poor, half shell top
74-88	D	775	148	88 cw	82 c	poor, half shell top
61-74	E	795	148	90 cw	85 c	fair, half shell top
53-61	F	860	149	90 cw	88 c	good
46-53	G	920	150	88 cw	90 c	good
0-38	H	610	150	78 cy	75 o	v.p., half shell top
0-105	I	785	150	78 cy	86 c	fair to good
38-150	J	805	150	80 cy	87 c	fair to good
38-105	K	835	150	80 cy	88 c	fair to good

1/ Crumb color, cy = creamy yellow, cw = creamy white.

2/ Texture grain, c = close, o = open.

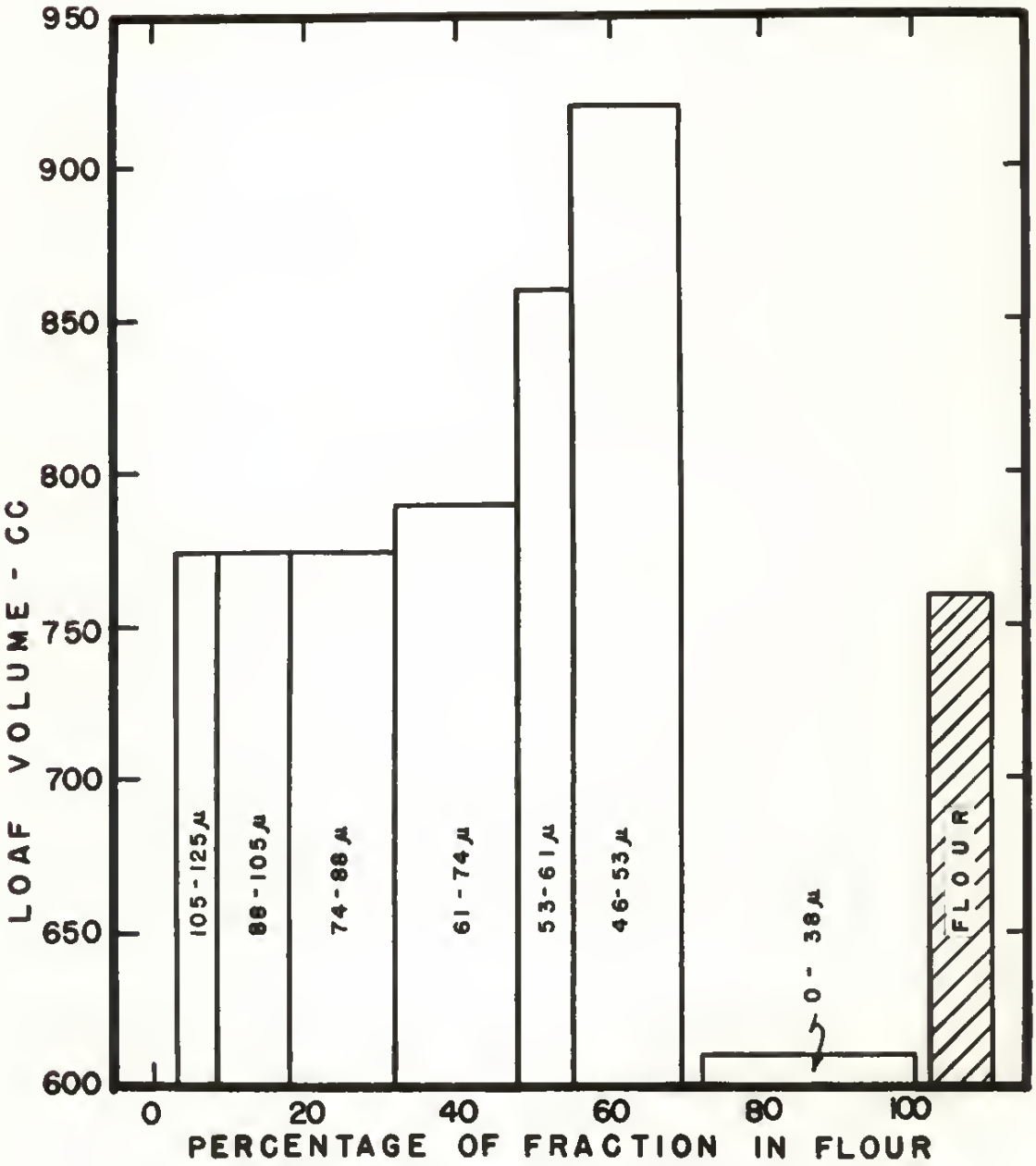


Figure 5. Relation of loaf volume to the particle size fractions of flour.

SUMMARY AND CONCLUSIONS

A commercial hard wheat flour was fractionated by means of wire sieves and by air elutriation into 13 different ranges of flour particle sizes. Chemical and physical tests performed upon the various fractions showed a wide range in characteristics due to the size of the flour particles. An increase of ash, protein, water absorption, gassing power, area under mixogram curves and loaf volume was found with a decrease in the size of the flour particles to the lower limit of approximately 38 microns. The 0-38 micron fraction size was largely composed of free starch granules with a slight overlap of the very finest flour particles, resulting in a fraction of very low protein, viscosity, area under mixogram curve, and loaf volume; and high ash and gassing power. The specific gravities remained the same for all particle size fractions. Baking tests on each fraction were closely related to flour quality as determined by the various physical and chemical tests. The conclusions reached in this investigation are:

1. The amount of protein in a flour fraction is the most influential characteristic of the physical properties of the fraction. The protein content is in an inverse relation to the size of the flour particle. Increased loaf volumes, the farinogram and mixogram curve characteristics, and water absorption are due to the increased amounts of protein found in the smaller flour particle fractions.

2. The amylase enzymes are equally distributed in all

the fractions of flour. Thus, differences of the fractions shown by gassing power values are due to the susceptibility of the particle according to size.

3. The amylogram curve heights are not influenced by enzyme activity in this investigation, but by starch hydration during gelatinization in direct relation to the size of the flour particle. The largest particles are packed closest together during hydration causing this paste to be the most viscous.

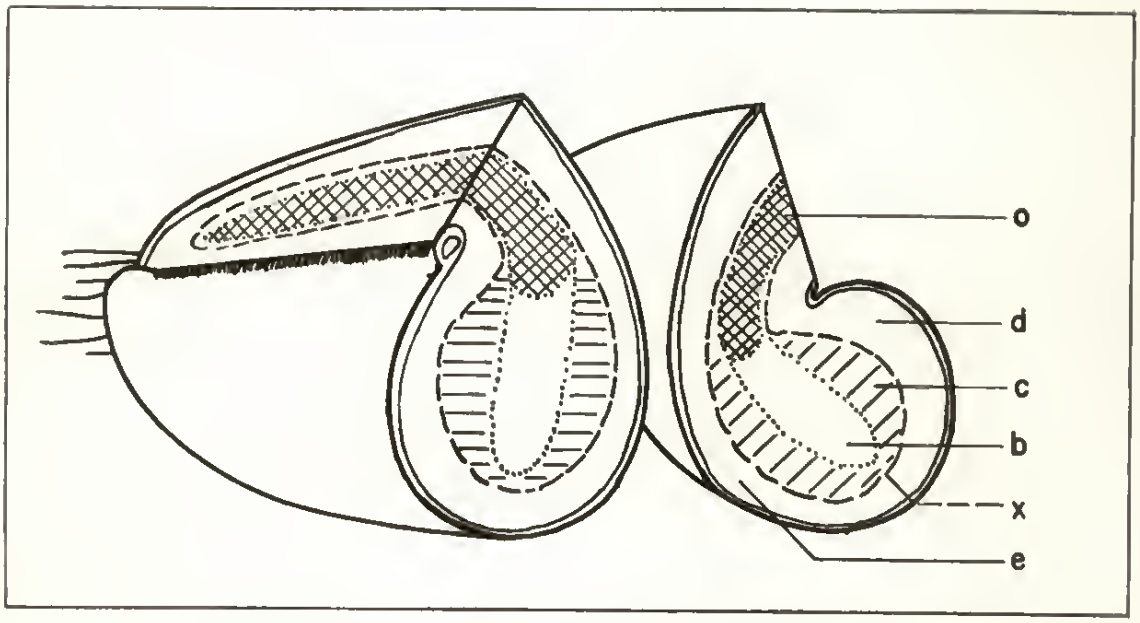
4. The fraction of flour with the finest and the coarsest particles removed compares quite favorably with the 46-55 micron flour fraction whose inherent quality characteristics were best.

5. Morris, Alexander and Pascoe (1946) removed various zones of endosperm from the wheat kernel using a dentist drill. Their purpose was to free the endosperm in the zones shown in Fig. 6, with no possible contamination by bran chips, dirt, or hairs. The granularity of the flour removed was not a factor.

Morris, Alexander and Pascoe found that the innermost zone produced a flour whose ash and protein content were lower than any other zone. As the zones radiated toward the bran coat, the flours increased in their ash and protein contents

The particle size investigation presented herein shows that the largest flour particles contain the lowest ash and protein content. The smallest flour particles (38-46 microns) contain the highest amount of ash and protein.

The relationship of particle size to ash and protein is indicative of the zonal source of these particles. The largest



SECTIONAL VIEW OF BRUSH HALF OF KERNEL

Figure 6. Portion of kernel included in various fractions. Central zone: (o) "center over crease", (b) "center in cheek," (c) cheek. Peripheral zone: (d) endosperm next to crease, (e) outer endosperm, (x) line of separation between crease and outer portions of peripheral zone and bran fractions. (Morris, Alexander and Poscoe, 1946).

particles come from the innermost "center over crease" zone, while the succeeding smaller particles come from the zones "center in cheek", cheek, endosperm next to crease, and outer endosperm.

Apparently the innermost zone is more vitreous, thereby remaining in larger particle sizes when passing through reduction rolls. Conversely, the outer endosperm zone is least vitreous, resulting in small particle sizes when subjected to the rolls.

Many factors undoubtedly influence the granularity of flour. Wheat conditioning is no doubt of major importance because of the relationship existing between particle size and the zonal origin of the particles. Since this is a basic investigation on the characteristics of granularity of flour, further investigation is desirable.

ACKNOWLEDGMENTS

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