STUDY OF THE CONTINUOUS GRINDING OF STEEPED ENDOSPERM FROM SORGHUM GRAIN IN THE PRODUCTION OF STARCH

by

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TABLE OF CONTENTS

INTRODUCTION AND REVIEW OF LITERATURE

The purposes of this research were to develop a continuous process for the production of starch from milo maize grits and to evaluate the effect of various factors on the yields and quality of products as well as on the energy and water consumption of the process.

Since 1945, much progress has been made in utilizing sorghum grain industrially. According to Swanson and Laude (18) the grain from the waxy varieties has been used in the production of a starch as a substitute for tapioca. The same type of starch has been used for the sizing of paper and textiles and for adhesives and more recently as the raw material in the manufacture of dextrose and syrup by hydrolysis of starch.

Furthermore, oil, wax, and protein feeds are valuable by-products that remain after the starch has been removed from the grain. Table 1 prepared by Macmasters and Rist (15) shows the potentiality of sorghum and other grains as the raw materials in the manufacture of starch and feed stock.

The production of starch from sorghum grain has been accomplished both commercially and in the laboratory by processes similar to the wet milling process used for producing corn starch. Zipt et al (22), Watson et al (21) and Kerr (12) reported on processes for wet milling of sorghum grain. Kao (11) reported a method of preparing technically pure starch from sorghums by removing the bran and germ and using air separation. A combination of fermentation and alkali steeping was used by Das Gopta (7) to get a starch of 95 per cent purity from Jowar, a variety of sorghum. In 1943, Cuccurulle (6) published a paper on chemical-technological studies of the milling products of grain sorghum. According to Macmaster and Rist (16), the following process was used during

Table 1. Chemical composition of grains[1], percent, moisture free basis.

Grain	Starch	Protein	Oil	Sugar	Ash
Wheat[2]	67.0	12.8[3]	1.6	2.36	2.25
Sorghum[2]	72.6	12.2[4]	3.4	1.46	1.65
Rice (Husked)[2]	77.2[5]	8.9	2.0	—[5]	1.9
Barley[2]	71.8	10.3[3]	1.55	—	1.71
Oats[2]	64.0	12.9[3]	8.68	—	1.93
Rye[2]	59.1	14.2[3]	1.55	—	1.96

[1]From McMasters and Rist (15).
[2]Data given are for single samples of representative varieties.
[3]Nitrogen x5.7.
[4]Nitrogen x6.25.
[5]Total carbohydrate is given under starch heading.

World War II to produce starch from waxy sorghum flour for use as a replacement for tapioca: The flour was mixed with water adjusted to a pH of 6.8-7.5 to form a flowable slurry which was passed through a dispersion mill to disperse the gluten gel to the sol state. The starch granules thus liberated were separated and recovered. Work on the properties of starches from glutinous corn and sorghum and on their relationship to the processing conditions was published by Macmasters and Hilbert (17). The results of their work showed that the adaptation of the method used for making corn starch to glutinous sorghums containing a nucellar layer yielded off-color starches. However, this difficulty could be overcome by pearling the grain to remove the pigmented layer. Varieties lacking the nucellar layer yielded white starch without the necessity for pearling. They also concluded that the glutinous type sorghum is more sensitive to processing conditions than the non-glutinous type. For instance, excessive grinding and increased concentration of sulfur dioxide in the steep water tend to lower the viscosity of the starch gel markedly for the glutinous varieties.

Reports were made by Hightower (9) and Taylor (20) on Corn Products Refining Company's new plant at Corpus Christie, Texas, which was completed in the spring of 1949. This plant was designed to produce starch and dextrose from milo maize as well as corn. Features of this new plant are the use of Rietz mills in place of the Buhr mills employed by the conventional plant for the fine grinding of steeped grain, and the application of the Merco centrifugal system to separate the gluten from the starch in lieu of conventional starch tables.

A series of investigations on the feasibility of extracting starch from sorghum grain and on the utility of by-products was started at Kansas State College in the late 1930's.

Long (14) carried out an investigation of the effect of various factors on the rate of diffusion in steeping whole sorghum grains.

A procedure similar to the conventional process for the production of corn starch was applied by Johnson (10) in his research on the production of starch from sorghum grain. Johnson's process consisted of the following main steps: Steeping of grain, coarse grinding (using a disc grinder), separation of germ, fine grinding with a Buhr mill, and finally the separation of starch. The results of this survey indicated that starch of high purity and quality is obtainable from several varieties of sorghum grains. The yields obtained by Johnson were low, but this he attributed to the small batch operation with which he was working.

It has long been recognized that the method of grinding is one of the most significant elements in the wet milling industry which affect the yield and quality of the products. As described by Stewart (19) the methods of grinding that apply direct compressing and shearing force in the cracking of the grain cause the oil to be pressed out of the germ and contaminate the endosperm. Also, the use of such methods results in over-grinding, which causes difficulties in separation of starch from gluten, thus lowering the yield and quality of starch. It was felt, therefore, that the grinding of grain for starch production should be performed by mechanisms other than a positive compressing action. This idea led to the invention of the dry milling process by Barham (2) to obtain the grits of sorghum grain and to the development of the hydraulic mill for the grinding of sorghum grits to produce starch by Banowetz (1) and Drobot (8). Although a starch of good quality was produced by the experimental conditions studied by Banowetz, a satisfactory yield was not obtained. This defect was probably due to the excessive grinding which is a characteristic of the batch milling process. The batch milling process, which is actually a type of "choke" feeding operation in size reduction, increases greatly the portion of fines and decreases the capacity of the mill, according to Brown, et al (5). Those disadvantages were overcome in part by Banowetz (1) by periodically removing a fraction of the milling mixture, screening, and returning the course fraction to the mill. A continuous process which applies the principles of closed circuit operation is more economical of power, permits smaller units for a given capacity, and produces a material with greater uniformity of size, thus preventing material from being over ground. Low labor requirement is another advantage of the continuous process over batch and semi-continuous processes.

EQUIPMENT

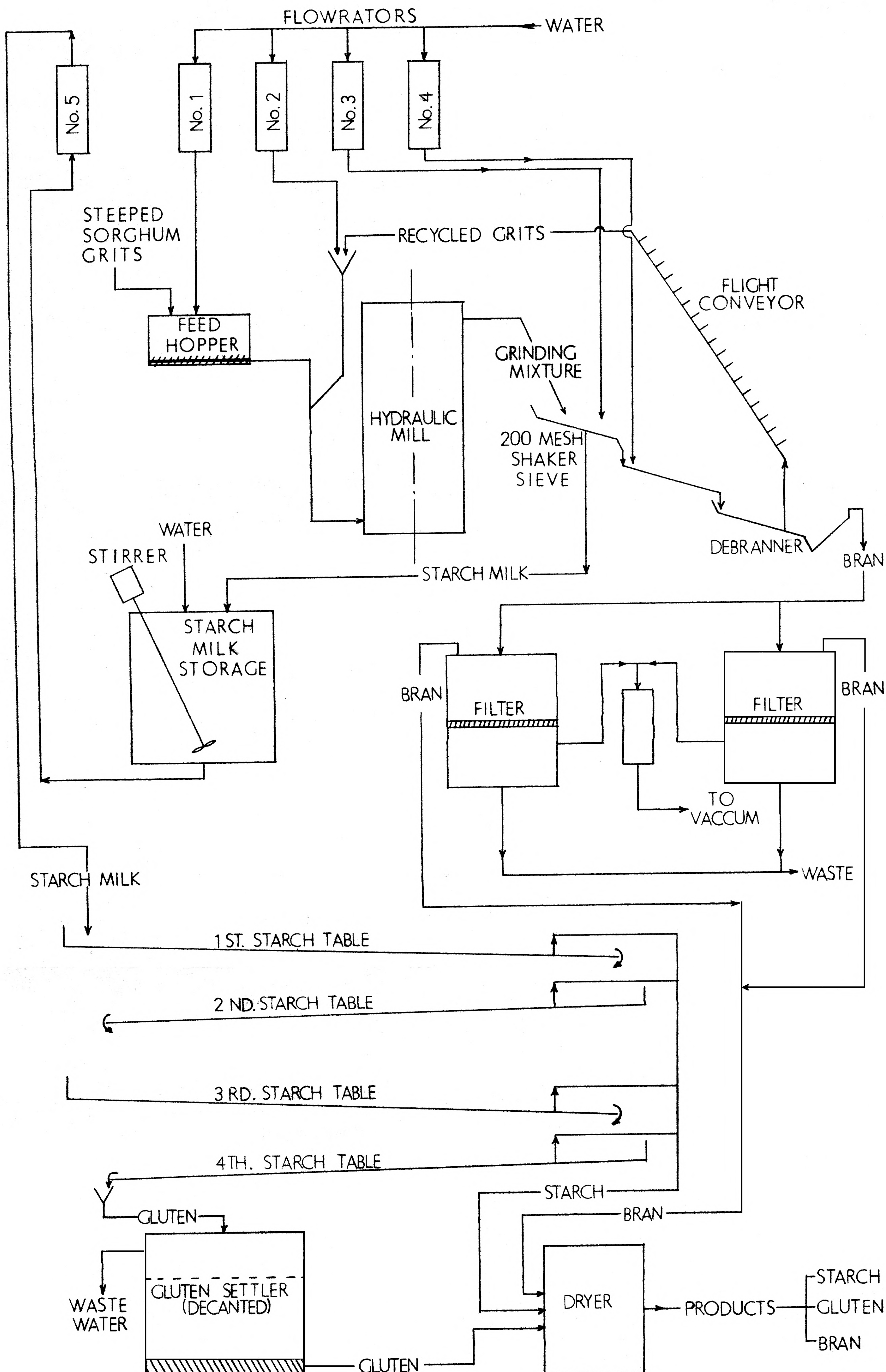
The flow sheet and a view of the pilot plant are shown in PLATE I and PLATE II respectively. Except for a few minor parts, such as the steeping equipment and the equipment for the separation of the final products, the process was entirely continous in character.

The steeping equipment (PLATE III) consisted of two small tanks, one for heating steep water and the other for actual steeping. Both tanks were made of stainless steel, were identical in shape, and had one cubic foot of internal capacity. Fifteen feet of 3/8 inch o.d. copper tubing were coiled inside the heating tank. Low pressure steam was passed through this coil. A Lightning Model F Mixer was used in the heating tank and the temperature was regulated by a Taylor self-acting steam regulator. The hot water was pumped through a 1/4 inch galvanized iron pipe by a centrifugal pump (Eastern Industries Pump Model D11, 1/8 hp, 3450 rpm) to the bottom of the steeping tank and overflowed back

EXPLANATION OF PLATE I

Flow sheet of continuous hydraulic milling process for production of starch from sorghum grits

PLATE I



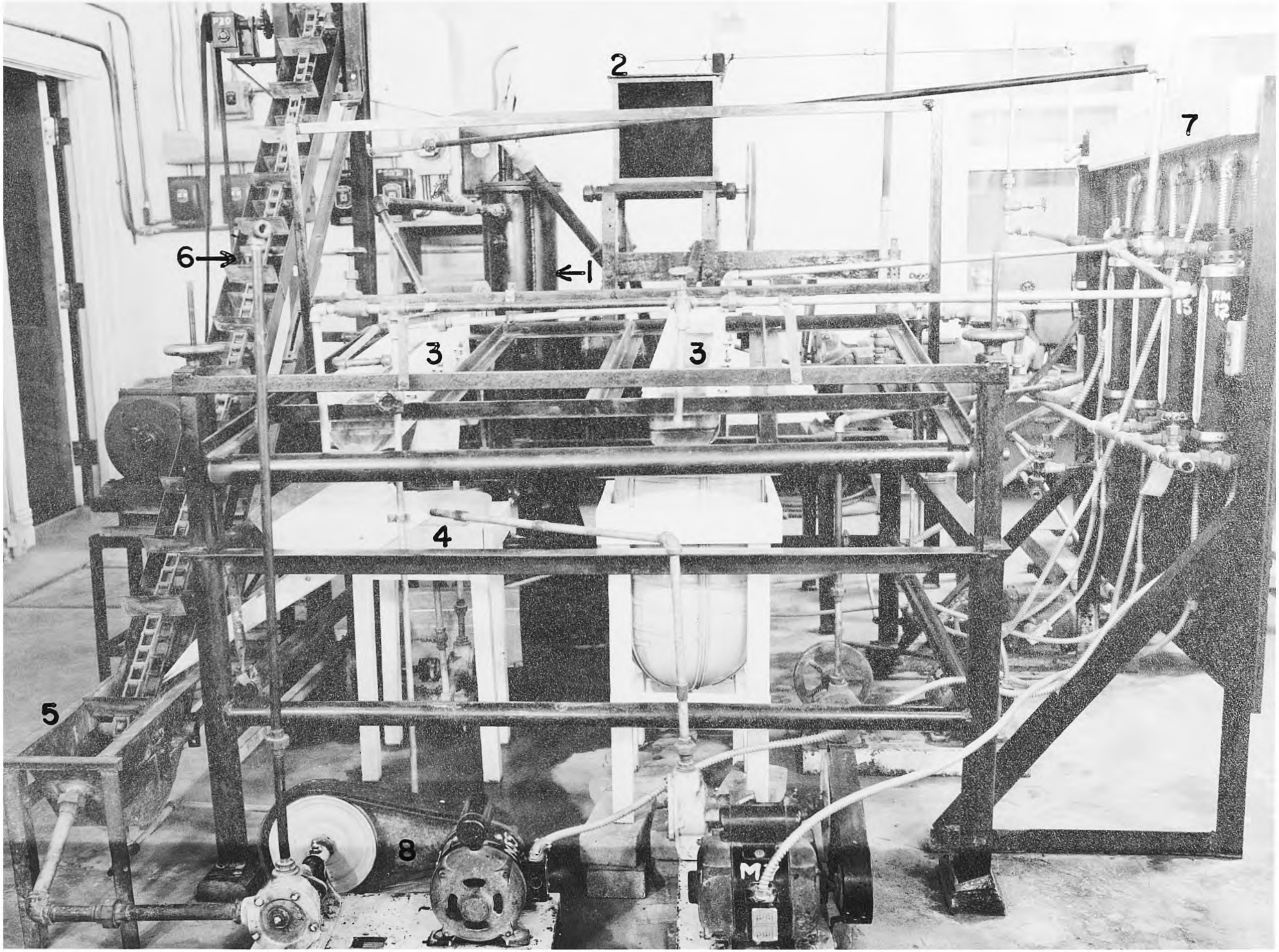
FLOWRATORS
WATER
No. 5
No. 1
No. 2
No. 3
No. 4
STEEPED SORGHUM GRITS
RECYCLED GRITS
FLIGHT CONVEYOR
FEED HOPPER
HYDRAULIC MILL
GRINDING MIXTURE
200 MESH SHAKER SIEVE
DEBRANNER
BRAN
WATER
STIRRER
STARCH MILK
STARCH MILK STORAGE
BRAN
FILTER
FILTER
BRAN
TO VACCUM
WASTE
STARCH MILK
1 ST. STARCH TABLE
2 ND. STARCH TABLE
3 RD. STARCH TABLE
4 TH. STARCH TABLE
STARCH
BRAN
GLUTEN
WASTE WATER
GLUTEN SETTLER (DECANTED)
DRYER
GLUTEN
PRODUCTS
STARCH
GLUTEN
BRAN

EXPLANATION OF PLATE II

View of pilot plant

1. Hydraulic mill
2. Feed hopper
3. Shaker sieve
4. Starch milk receiver
5. Debranner
6. Flight conveyor
7. Control panel
8. Bran pump

PLATE II

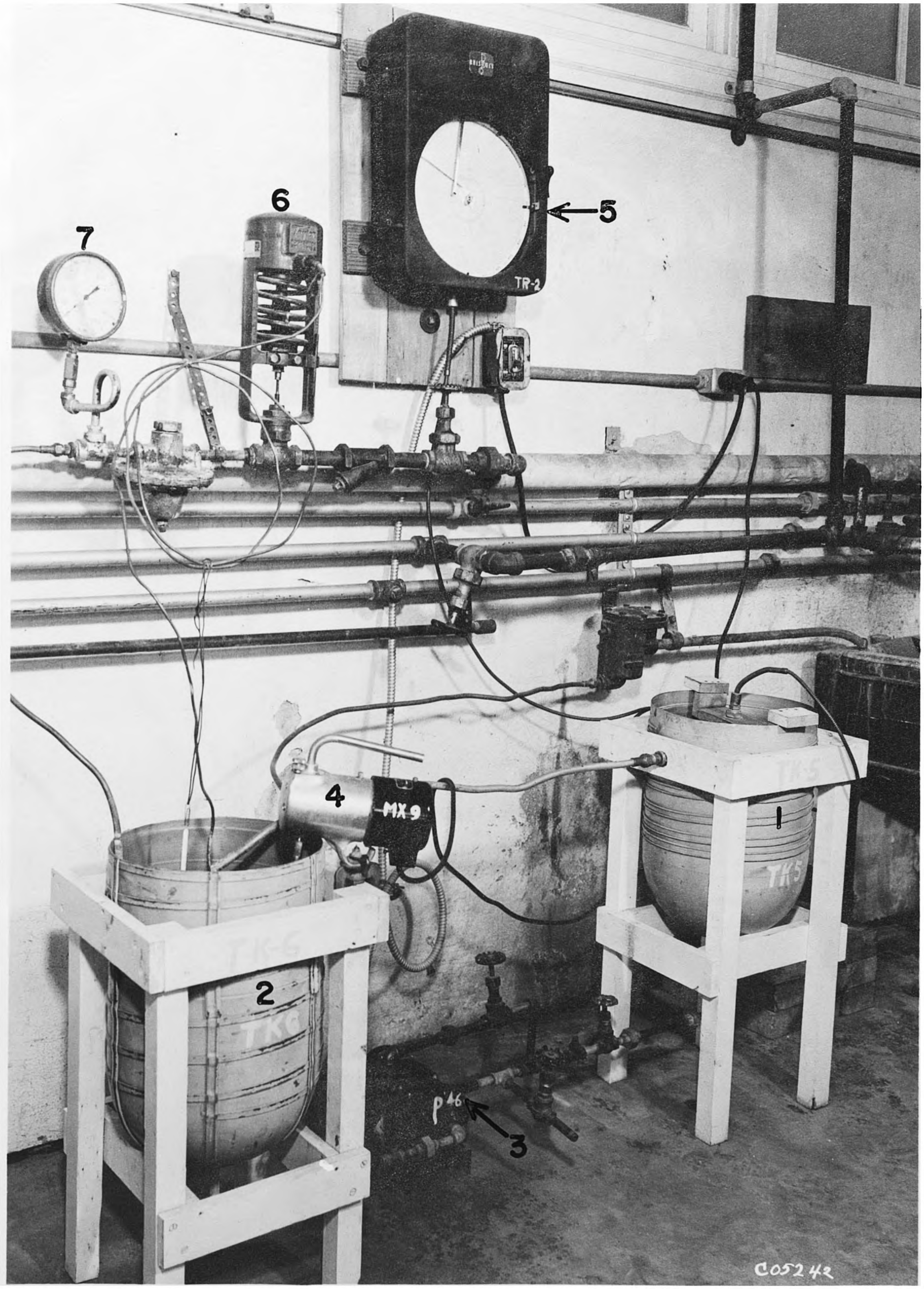


EXPLANATION OF PLATE III

Steeping equipment

1. Steeping tank
2. Heating tank
3. Steep water recycling pump
4. Agitator of heating tank
5. Bristol temperature recorder
6. Taylor self-acting steam regulator
7. Steam pressure gauge

PLATE III



through a 1/4 inch aluminum tube. The steeping temperature was recorded automatically by using a Bristol temperature recorder.

A V-shaped hopper and screw feeder were used to provide a uniform feed of steeped grits to the mill. This conveyor was driven by a 1 hp Reeves Varimotor and its speed was changeable from 26 to 156 rpm.

The hydraulic mill, which was originally designed by Banowetz (1) and developed by Drobot (8), is shown in PLATE IV. A detailed drawing of the mill is given in PLATE V. The grinding effect of the hydraulic mill is induced by the impact and abrasion between particles of material with each other, between particles of material and the inside wall of the mill and between particles of material and the stirring mechanism. The stirrer of the mill was driven by a 10 hp Fairbanks-Morse induction motor operating at 1,170 rpm connected by two B size V-belts. The speed of the stirrer was changed by varying the ratio of the diameter of the shaft pulley to that of the motor pulley. The rpm of the mill was measured by a type T-2 Frahm tachometer. A General Electric Company type V-3-A polyphase watthour meter with a watthour constant of 7.2 was used to measure the power consumption of the milling operation. The total energy in kilowatthours registered is equal to

$$\frac{\text{Kh x Disk Revolutions Counted}}{1000}$$

where Kh = watthour constant.

Thus the energy consumption rate in kilowatts is given by the equation

$$\frac{\text{Kh x Disk Revolutions Counted}}{1000} \times \frac{1}{\text{Time in hours.}}$$

The screening operation was carried out on a 200 mesh stainless steel screen 4 inches wide and 31 1/2 inches long. The screen was set on a shaker which provided an oscillating motion of the screen imparted by an eccentric.

EXPLANATION OF PLATE IV

Hydraulic mill

1. Hydraulic mill

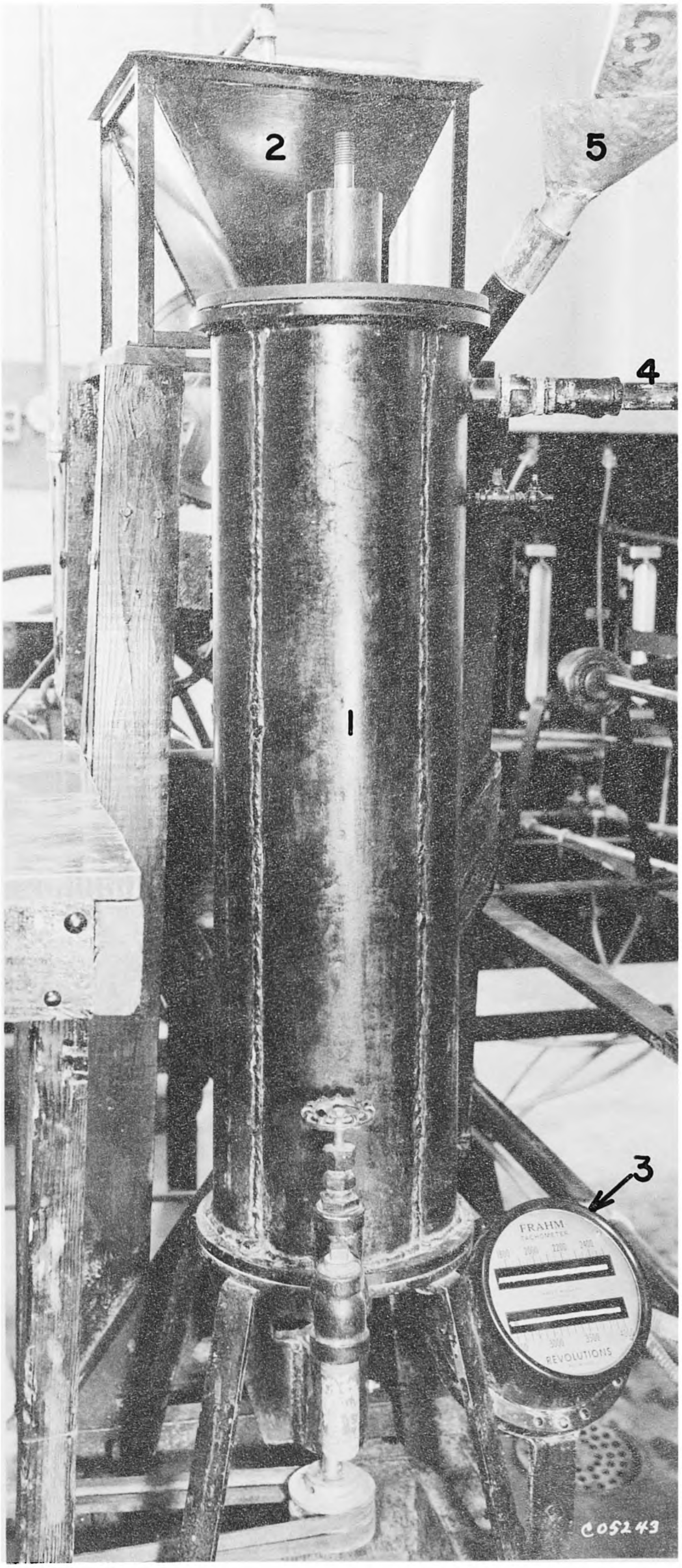
2. Feed hopper

3. Type T-2 Frahm tachometer

4. Overflow from mill to screen

5. Recycling line

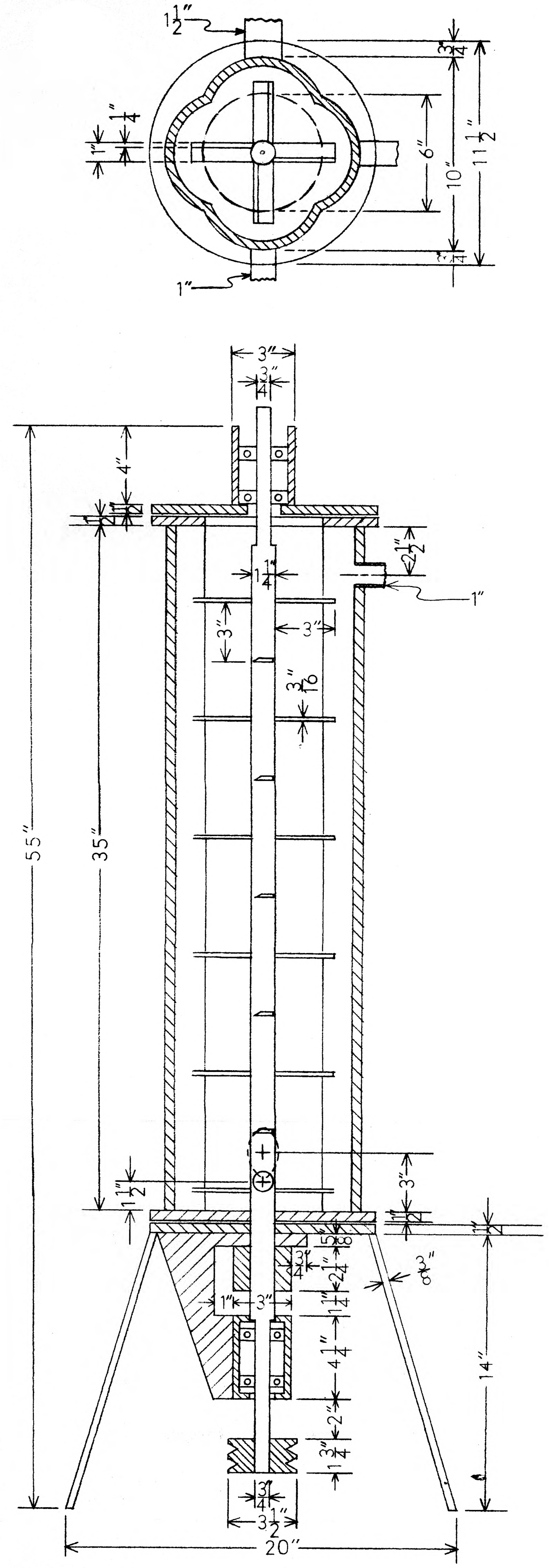
PLATE IV



EXPLANATION OF PLATE V

Detailed drawing of hydraulic mill

PLATE V



The oscillating frequency of the screen was 290 cycles per minute with 1/2 inch horizontal motion and its slope was varied by means of a screw adjustment. Two stages of water spray, one to the middle of shaker screen, the other to the end, were applied to assure complete separation of starch milk from the grinding mixture by washing.

A flight conveyor of the following dimensions was constructed to recirculate unground grits: Width of flight 5 inches, Depth of flight 2 7/16 inches, interval of flight 5 inches, width of trough 5 1/2 inches, depth of trough 3 1/2 inches, length of trough 75 inches, slope of trough 45°. The conveyor was driven at a rate of 4.2 feet per minute.

The lower end of the flight conveyor functioned as a debranner. It is shown in detail in PLATE VI.

Four conventional starch tables operated in series were used in the separation of starch and gluten. Each section was 30 feet long and its slope was 1 inch in 10 feet. The inside of the table was 5 3/4 inches wide and 2 1/2 inches deep.

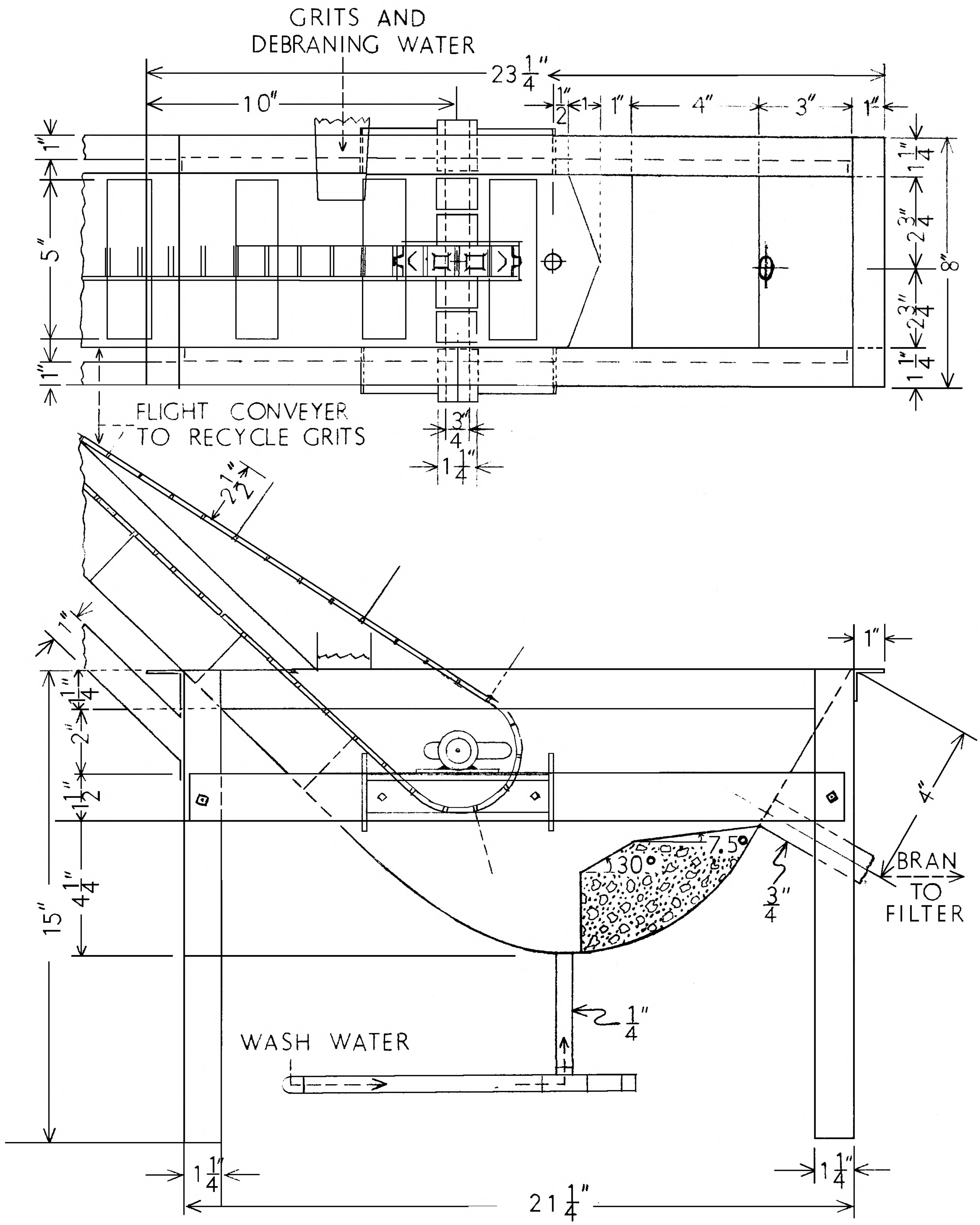
Two nutsch type filters with an area of four square feet each were used for separating the bran portion of the grits from water. Vacuum was supplied by an F. J. Stokes Machine Company Model 33275 reciprocating vacuum pump.

As shown in PLATE VII, the control panel was arranged to fascillitate the measurement and control of the flow quantities. Fischer & Porter Company's flowrators Series 700 Master-Enclosed Type were used to measure and control all of the water flow rates. Total water consumption was measured by a Rockwell Empire type water meter.

EXPLANATION OF PLATE VI

Drawing of debranner

PLATE VI

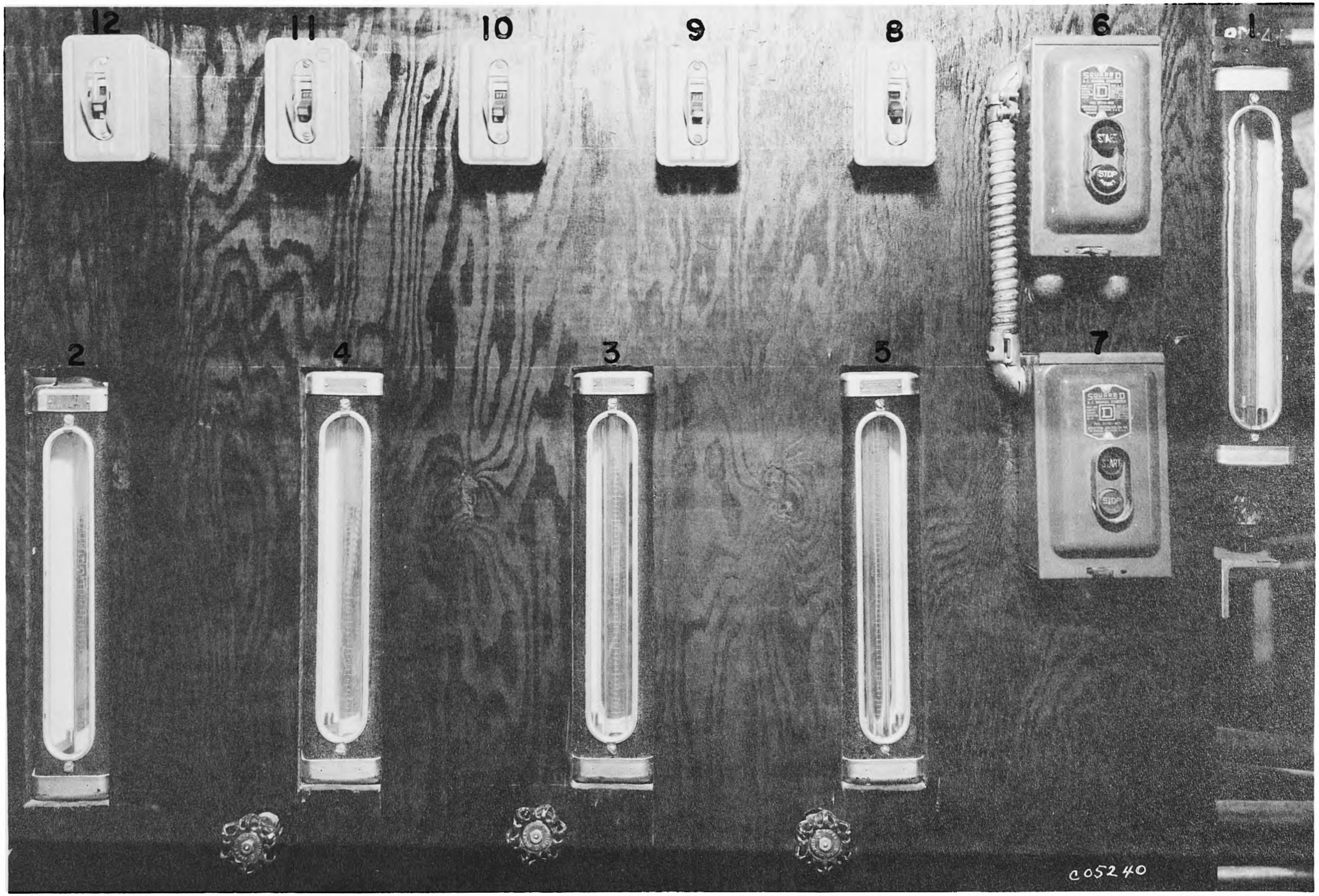

GRITS AND
DEBRANING WATER
FLIGHT CONVEYER
TO RECYCLE GRITS
BRAN
TO
FILTER
WASH WATER

EXPLANATION OF PLATE VII

Control panel

1. Flowrator for feed water
2. Flowrator for grits recycling water
3. Flowrator for water to shaker sieve
4. Flowrator for debranning water
5. Flowrator for starch milk
6. Starter for starch milk pump to table
7. Starter for motor for flight conveyor
8. Starter for feed water pump
9. Starter for motor for shaker sieve
10. Starter for starch milk pump to storage
11. Starter for starch milk pump to storage
12. Starter for bran pump

PLATE VII



MATERIALS AND PROCEDURE

The milo sorghum grits used in this work were obtained from Grain Products Incorporated of Dodge City, Kansas. The term, grits, used here refers to the endosperm parts of the milo kernel after removal of the bran and germ.

The milo sorghum grits were stored in 55 gallon, open-head barrels, and carbon disulfide was placed inside the drum as an insecticide. The analysis data are given in Table 2 and Table 3.

Table 2. Analysis of milo sorghum grits used for runs 1 to 14.

Component	Weight percentage
Protein	10.13
Ether extract	1.26
Crude fiber	0.74
Moisture	9.29
Ash	0.74
N-Free extract	77.84
Carbohydrates	78.68
Starch	74.41

Table 3. Analysis of milo sorghum grits used for runs 15 to 16 and runs 22 to 29.

Component	Weight percentage
Protein	10.75
Ether extract	1.26
Crude fiber	0.86
Moisture	9.29
Ash	0.74
N-Free extract	77.10
Carbohydrates	77.96
Starch	73.66

Thirty pounds of the raw grits were steeped at one time. The grits were placed in the steep tank and water at 130°F was circulated up through the bed of grits by pumping water from the heating tank (PLATE III) and allowing it to overflow from the steeping tank back to the heating tank. The rate of circulation of water was about 35 gallons per hour through the bed of grits and the volume of water used for each batch was 10.8 gallons. At the end of two hours, the water was drained out from the bottom of both tanks through the circulating pump to the sewer.

Manhattan city water was used as steep water. Its average quality was as follows; total hardness expressed in parts per million as calcium carbonate, 76; non-carbonate hardness expressed in parts per million as calcium carbonate, 45; total dissolved solids expressed in parts per million, 218; PH, 8.97. The steeping temperature was kept almost constant between 128°F and 133°F for two hours.

The flow sheet for the milling operations is shown in PLATE I. The steeped grits were weighed and transferred to the hopper feeder of the hydraulic mill. The feed rate of steeped grits and the rpm of the stirrer of the mill were set for each run. The feed water, screw feeder, and the stirrer of the mill were started simultaneously. The feed was introduced into the mill near the bottom. When the mill was full and grits began to overflow onto the shaker screen, wash water to the screen was started.

The flow of water to the bran separator, the recycle elevator, and the recycle water to wash the recycled grits from the elevator into the mill were started successively after the grits began to overflow down the screen.

The bran was separated in the boot of the recycle elevator by floating it off and pumped as a slurry to two vacuum filters.

The tabling operation was begun when a quantity of starch milk had accumulated in the storage tank. The tabling rate was held at 36 gallons per hour for all runs.

The power consumption for grinding, rpm of the stirrer of the mill, the grinding temperature, specific gravity of the starch milk and all of the process water flow rates were recorded every half hour. After all process conditions became constant, it was assumed that a steady state had been reached. In other words, the rate of input of materials into the process was now equal to the rate of output of all products. The rates of output of starch milk and debranning water were then measured with calibrated buckets, and samples of starch milk, debranning water, gluten liquor, and overflow from the mill were taken. Two sets of samples were taken for each run. The solid content of each sample was determined by filtration followed by drying under a vacuum of 28 inches of mercury at 100°C.

The volume of starch milk produced was observed to be almost the same as the gluten liquor accumulated. The rate of output of starch was calculated from the equation (1).

$$(1) \quad S = (W_s - W_g) \times \frac{V_s}{v_s}$$

where S = the rate of output of starch in pounds per hour on the dry basis

$_s$ = solid content of the starch milk sample in pounds per cubic foot

$_g$ = solid content of gluten liquor sample in pounds per cubic foot

V_s = rate of output of starch milk in cubic feet per hour

v_s = volume of starch milk sample in cubic feet

Similarly, the rates of output of gluten and bran were calculated from equations

(2) and (3) respectively.

$$(2)\ G = W_g \times \frac{V_s}{v_g}$$

where G = rate of output of gluten in pounds per hour on the dry basis

v_g = volume of the gluten liquor sample

$$(3)\ B = W_b \times \frac{V_b}{v_b}$$

where B = rate of output of bran portion in pounds per hour on the dry basis

W_b = solid content of debranning water sample in pounds

V_b = rate of output of debranning water in cubic feet per hour

v_b = volume of debranning water sample

The rate of recirculation of unground grits was calculated by the following equation:

$$(4)\ R = W_o \times \frac{V_o}{v_o} - F$$

where R = rate of recirculating unground grits in pounds of dry material per hour

W_o = solid content of overflow sample from the mill in pounds of dry material

V_o = rate of overflow of water from mill in cubic feet per hour

v_o = volume of water in overflow sample in cubic feet

F = feed rate of dry grits per hour

The rate of output of each product divided by the feed rate of the dry unsteeped grits gave the yield of each product.

The starch accumulated on the starch tables was washed with tap-water at the same rate as the tabling operation for 100 minutes. The starch was then allowed to dry on the tables overnight, and then removed and dried in a steam heated air drier at 130°F. The gluten liquor was allowed to settle and the gluten was separated by decantation and dried along with the starch and bran in the drier for 24 hours. Each of the products were analyzed for starch and protein contents. The recovery of starch and the distribution of protein among the products were calculated.

The amounts of material dissolved in the steepwater, waste water, and debranning water, and materials lost by the washing operation were not accounted for in those calculations.

Several runs were made using corn meal as a raw material to investigate the possibilities of applying this process for the manufacture of starch from this source. Table 4 contains the analysis of the corn meal used. This corn meal was obtained from the Gooch Milling & Elevator Company of Lincoln, Nebraska.

Table 4. Analysis of corn meal.

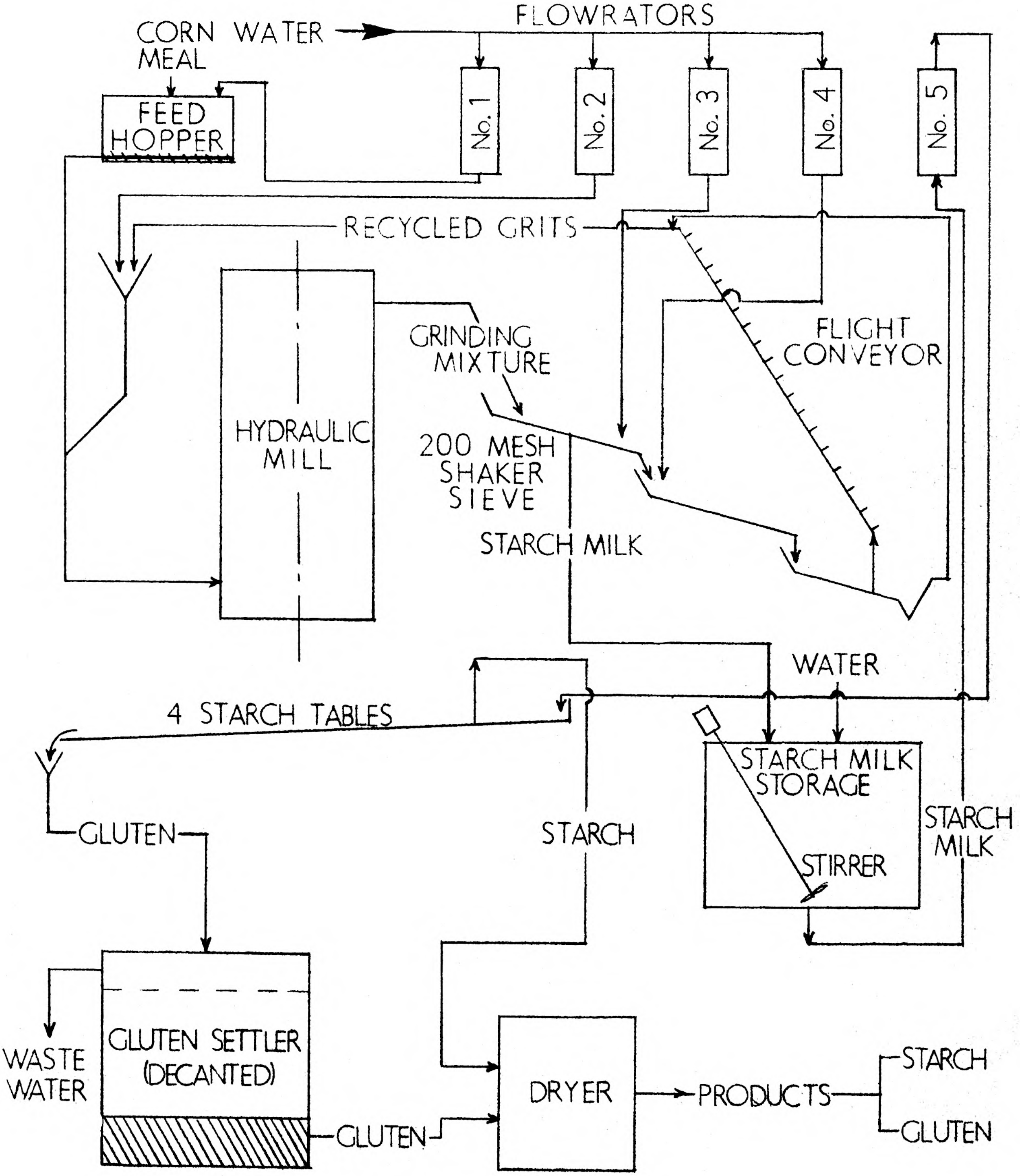
Component	Weight percentage
Protein	7.94
Ether extract	1.40
Crude fiber	0.62
Moisture	10.46
Ash	0.51
N-Free extract	79.07
Carbohydrates	79.69
Starch	77.29

Steeping and debranning operations were omitted as is shown in the flow sheet (PLATE VIII). Unground corn was returned by both the elevator and the pump which was otherwise used to pump bran to the filter.

EXPLANATION OF PLATE VIII

Flow sheet of the process used in production of starch from corn meal

PLATE VIII


CORN MEAL
WATER
FLOWRATORS
FEED HOPPER
No. 1
No. 2
No. 3
No. 4
No. 5
RECYCLED GRITS
HYDRAULIC MILL
GRINDING MIXTURE
200 MESH SHAKER SIEVE
FLIGHT CONVEYOR
STARCH MILK
WATER
4 STARCH TABLES
STARCH MILK STORAGE
STIRRER
STARCH MILK
GLUTEN
STARCH
WASTE WATER
GLUTEN SETTLER (DECANTED)
GLUTEN
DRYER
PRODUCTS
STARCH
GLUTEN

PROCESSING DATA AND RESULTS

Processing data for all runs, except for a few that had been discontinued before a steady state of operation was reached, are presented in Table 5.

Two measurements and calculations on rates of output, yields and recovery of products were carried out for each run by methods described previously. These are labeled A and B in Table 5 for two sets of samples. Because of the nature of the process, all quantities are expressed as rates, rather than in total quantities. For run 1 to run 13, the mill was operated at the speed of 1500 rpm. For the remainder of runs the mill was run at 2220 rpm.

The chemical analyses of the products and by-products were conducted by the chemical service laboratory of the Chemistry Department at Kansas State College. The protein content of the starch, and the protein and starch contents of the bran and gluten were determined.

The energy consumption rate of the mill was computed using the equation for the watthour-meter mentioned in the previous section. The net energy consumption was taken as the difference between the energy consumption for the mill running full and the energy consumption for the empty mill. The net energy consumption per unit quantity of raw grits and product were evaluated respectively. These data together with process water consumption, yields and recovery of products are listed in Table 7.

The processing data and the results of the experimental runs on corn meal are tabulated in Table 8. As mentioned previously, the steeping and debranning operations were omitted. Also two screens with the same dimensions were used in parallel.

Table 5. Processing conditions (Raw materials; Milo maize grits).

		Run No. 1	Run No. 2	Run No. 3	Run No. 4	Run No. 6	Run No. 7
Feed rate of grits, dry basis	lb./hr.	6.174	10.512	14.160	14.076	6.816	8.148
wet basis	lb./hr.	9.192	17.580	23.634	23.376	11.622	13.050
Water for feeding grits	gal./hr.	12	12	12	12	12	12
Speed of the mill stirrer	rmp	1500	1500	1500	1500	1500	1500
Grinding temperature	°F.	82	81	82	82	82	84
Net energy consumption rate for grinding (A)	K.W.	0.799	0.972	0.886	0.972	1.058	0.886
(B)	K.W.	—	—	—	0.972	—	0.886
Concentration of grinding mixture (A)	lb.sol/ /cu.ft.	4.324	5.351	6.751	6.937	4.574	4.852
(B)	lb.sol/ /cu.ft.	—	—	—	6.724	—	5.095
Overflow rate of solid materials from mill (A)	lb./hr.	22.205	27.491	34.798	35.621	23.572	24.999
dry basis (B)	lb./hr.	—	—	—	34.600	—	26.201
Slope of shaker screen	in./ft.	3	3	3	3	3	3
Water for washing grits	gal./hr.	12	12	12	12	12	12
Water for debranning	gal./hr.	31.8	30	30	30	30	30
Grits recycling rate (A)	lb./hr.	16.031	16.979	20.638	21.545	16.756	16.843
dry basis (B)	lb./hr.	—	—	—	20.524	—	18.053
Water for recycling grits	gal./hr.	12	12	12	12	12	12
Specific gravity of starch milk at 60°/60°F	°Be'	0.720	1.132	1.627	1.612	0.785	0.880
Tabling rate	gal./hr.	36	36	36	36	36	36
Wash water rate of starch tables	gal./hr.	36	36	36	36	36	36
Starch washing time	min.	100	100	100	100	100	100

Table 5. (Cont.)

		Run No. 8	Run No. 9	Run No. 10	Run No. 11	Run No. 12	Run No. 13
Feed rate of grits,							
dry basis	lb./hr.	5.820	7.338	7.302	7.944	7.758	7.338
wet basis	lb./hr.	6.426	8.106	8.070	8.778	8.574	8.106
Water for feeding grits	gal./hr.	12	12	12	12	12	12
Speed of the mill stirrer	rpm	1500	1500	1500	1500	1500	1500
Grinding temperature	°F	81	76	82	92	99	92
Net energy consumption							
rate for grinding (A)	K.W.	0.842	0.886	0.907	0.842	0.886	0.842
(B)	K.W.	0.842	0.886	0.907	0.842	0.886	0.842
Concentration of grinding							
mixture (A)	lb.sol/ /cu.ft.	4.499	4.650	4.541	4.998	4.754	5.033
(B)	lb.sol/ /cu.ft.	4.252	4.826	4.838	4.865	4.943	5.056
Overflow rate of solid							
materials from mill (A)	lb./hr.	23.191	23.934	23.408	25.699	24.461	25.908
dry basis (B)	lb./hr.	21.914	24.806	24.897	25.022	25.450	26.035
Slope of shaker screen	in./ft.	3	3	3	3	3	3
Water for washing grits	gal./hr.	12	12	12	24	6	0
Water for debranning grits	gal./hr.	30	60	45	30	30	30
Grits recirculation rate (A)	lb./hr.	17.371	16.596	16.106	17.755	17.703	18.570
dry basis (B)	lb./hr.	16.094	17.468	16.827	17.078	17.692	16.962
Water for recirculating grits	gal./hr.	12	12	12	12	12	12
Specific gravity of starch milk at 60°/60°F	°Be'	0.683	0.765	0.827	0.477	1.221	1.423
Tabling rate	gal./hr.	36	36	36	36	36	36
Wash water rate of starch tables	gal./hr.	36	36	36	36	36	36
Starch washing time	min.	100	100	100	100	100	100

Table 5. (Cont.)

		Run No. 14	Run No. 15	Run No. 16	Run No. 22	Run No.23	Run No.24
Feed rate of grits,							
dry basis	lb./hr.	6.990	12.912	12.306	9.252	12.798	18.180
wet basis	lb./hr.	7.728	14.394	13.848	10.404	14.400	20.454
Water for feeding grits	gal./hr.	12	12	12	12	12	12
Speed of the mill stirrer	rpm	2220	2220	2220	2220	2220	2220
Grinding temperature	°F	104	112	111	108	110	114
Net energy consumption							
rate for grinding (A)	K.W.	1.642	1.728	1.685	1.685	1.771	1.901
(B)	K.W.	1.642	1.728	----	1.685	1.771	1.901
Concentration of grinding mixture (A)	lb.sol//cu.ft.	2.416	3.746	3.615	2.652	3.807	5.888
(B)	lb.sol//cu.ft.	2.441	3.671	----	2.713	3.908	6.244
Overflow rate of solid							
materials from mill (A)	lb./hr.	8.346	13.280	12.306	9.252	12.850	20.620
dry basis (B)	lb./hr.	8.382	12.912	----	9.252	13.282	21.880
Slope of shaker screen	in./ft.	3	3	2	1.25	1.25	1.25
Water for washing grits	gal./hr.	12	12	12	12	12	12
Water for debranning	gal./hr.	30	30	30	30	30	30
Grits recirculation rate							
(A)	lb./hr.	1.356	0.368	0	0	0.052	2.440
dry basis (B)	lb./hr.	1.392	0	----	0	0.484	3.700
Water for circulating grits	gal./hr.	12	12	12	12	12	12
Specific gravity of starch milk at 60°/60°F	°Be'	0.948	1.472	1.757	1.274	2.035	2.723
Tabling rate of starch milk	gal./hr.	36	36	36	36	36	36
Wash water rate to starch tables	gal./hr.	36	36	36	36	36	36
Starch washing time	min.	100	100	100	100	100	100

Table 5. (Concl.)

		Run No. 25	Run No. 26	Run No. 27	Run No. 28
Feed rate of grits, dry basis	lb./hr.	18.106	19.512	20.004	18.516
wet basis	lb./hr.	20.928	21.954	22.500	20.832
Water for feeding grits	gal./hr.	12	12	12	12
Speed of the mill stirrer	rpm	2220	2220	2220	2220
Grinding temperature	^{o}F	118	110	108	90
Net energy consumption rate for					
grinding (A)	K.W.	2.030	1.966	2.095	2.093
(B)	K.W.	1.987	1.966	2.095	2.138
Concentration of grinding					
mixture (A)	lb.solid/cu.ft.	5.932	6.348	6.192	3.372
(B)	lb.solid/cu.ft.	5.837	6.274	5.837	3.833
Overflow rate of solid materials					
from mill (A)	lb./hr.	20.140	22.160	21.280	18.516
dry basis (B)	lb./hr.	20.100	21.302	20.004	20.287
Slope of shaker screen	in./ft.	1.25	1.25	1.25	1.25
Water for washing grits	gal./hr.	12	12	12	12
Water for debranning	gal./hr.	6	18	12	18
Grits recirculation rate (A)	lb./hr.	2.034	2.648	1.276	0
dry basis (B)	lb./hr.	1.994	1.808	0	1.771
Water for circulating grits	gal./hr.	12	12	12	24
Specific gravity of starch milk					
at $60^{o}/60^{o}F$	$^{o}Be'$	2.814	2.692	3.283	2.019
Tabling rate of starch milk	gal./hr.	36	36	36	36
Wash water rate to starch tables	gal./hr.	36	36	36	36
Starch washing time	min.	100	100	100	100

Table 6. Products analyses (raw material; milo maize grits).

Run No.	Starch	Gluten Portion		Bran Portion	
	Protein content %	Starch content %	Protein content %	Starch content %	Protein content %
1	0.38	41.74	39.75	54.42	18.44
2	0.44	44.54	36.56	50.90	19.44
3	0.50	44.86	33.38	50.01	19.50
4	0.44	45.02	35.88	54.38	18.69
6	0.38	44.37	34.31	48.07	19.67
7	0.38	48.28	32.69	52.78	19.44
8	0.44	45.80	35.31	54.29	19.06
9	0.25	40.77	35.25	63.54	16.56
10	0.40	47.07	36.38	59.43	18.19
11	0.50	39.04	41.88	52.13	20.44
12	0.44	45.15	35.13	55.48	19.63
13	0.38	45.99	36.63	62.68	17.44
14	0.44	44.26	37.31	63.83	18.06
15	0.38	43.27	36.69	67.52	15.75
16	0.38	39.90	40.69	66.22	16.81
22	0.47	39.38	38.00	50.25	21.75
23	0.44	42.26	40.38	50.79	23.25
24	0.44	39.81	43.50	52.07	23.75
25	0.50	40.82	41.44	50.51	24.38
26	0.38	37.76	43.81	51.78	23.13
27	0.44	39.64	42.50	58.35	20.81
28	0.81	45.58	36.06	53.40	23.31

' Nitrogen x 6.25

Table 7. Results of runs (Raw material; milo maize grits).

		Run 1		Run 2		Run 3		Run 4	
		A	B	A	B	A	B	A	B
Yields of products[1], D. B.[2]									
Starch	lb/hr	3.700	---	6.791	---	9.218	---	9.690	8.052
	%	66.24	---	64.60	---	65.10	---	69.00	57.35
Gluten portion	lb/hr	0.798	---	1.629	---	1.897	---	1.472	2.172
	%	14.30	---	15.50	---	13.40	---	10.50	15.47
Bran portion	lb/hr	0.862	---	1.188	---	1.657	---	1.686	1.986
	%	15.43	---	11.30	---	11.70	---	12.00	14.15
Total	lb/hr	5.360	---	9.608	---	92.772	---	12.846	12.210
	%	95.97	---	91.40	---	90.20	---	91.50	86.97
Starch recovery, D. B.									
Starch extracted	lb/hr	3.700	---	6.791	---	9.218	---	9.690	8.052
Starch in feed	lb/hr	4.594	---	8.639	---	11.648	---	11.545	11.545
Recovery	%	80.54	---	78.61	---	79.14	---	82.93	69.74
Starch accounted for, D. B.									
in starch	lb/hr	3.686	---	6.761	---	9.172	---	9.956	8.017
in gluten portion	lb/hr	0.333	---	0.726	---	0.851	---	0.662	0.978
in bran portion	lb/hr	0.469	---	0.605	---	0.826	---	0.917	1.080
Total	lb/hr	4.488	---	8.092	---	10.849	---	11.535	10.075
Total in feed	lb/hr	4.594	---	8.639	---	11.648	---	11.545	11.545
Starch accounted for	%	97.69	---	93.67	---	93.14	---	99.91	87.27
Protein accounted for, D. B.									
in starch	lb/hr	0.014	---	0.030	---	0.046	---	0.043	0.035
in gluten portion	lb/hr	0.317	---	0.596	---	0.633	---	0.527	0.779
in bran portion	lb/hr	0.159	---	0.231	---	0.323	---	0.315	0.372
Total	lb/hr	0.490	---	0.857	---	1.002	---	0.885	1.186
Total in feed	lb/hr	0.625	---	1.176	---	1.586	---	1.572	1.572
Protein accounted for	%	78.40	---	72.87	---	63.18	---	56.30	75.45
Energy consumption for grinding									
for unit quantity of feed, W.B.[3]	KWH/lb	0.1294	---	0.0837	---	0.0566	---	0.0626	0.0626
for unit quantity of starch, D.B.	KWH/lb	0.216	---	0.143	---	0.096	---	0.100	0.121
Water consumption of process									
for unit quantity of feed, W.B.[3]	gal/lb	13.039	---	8.045	---	6.576	---	4.614	4.614
for unit quantity of starch, D.B.	gal/lb	21.755	---	13.746	---	11.166	---	10.591	12.230

1. % yields are based on total dry matter in feed. 2. D. B. = dry basis. 3. W. B. = wet or as-fed basis

Table 7. (Cont.)

		Run 6		Run 7		Run 8		Run 9	
		A	B	A	B	A	B	A	B
Yields of products, D. B.									
Starch	lb/hr	4.143	---	5.006	5.070	3.846	3.723	4.156	3.584
	%	60.78	---	61.44	62.23	66.08	63.97	56.63	48.84
Gluten portion	lb/hr	0.764	---	0.787	0.940	0.596	0.793	0.832	0.788
	%	12.21	---	9.66	11.53	10.24	13.62	11.33	10.74
Bran portion	lb/hr	0.894	---	0.936	1.108	0.710	0.828	1.598	1.635
	%	13.11	---	11.49	13.60	12.20	14.23	21.76	22.28
Total	lb/hr	5.801	---	6.729	7.118	5.152	5.344	6.586	6.007
	%	85.12	---	82.59	87.36	88.52	91.82	89.72	81.86
Starch recovery, D. B.									
Starch extracted	lb/hr	4.143	---	5.006	5.070	3.846	3.723	4.156	3.584
Starch in feed	lb/hr	5.608	---	6.697	6.697	4.782	4.782	6.032	6.032
Recovery	%	73.78	---	74.75	75.71	80.43	77.85	68.90	59.42
Starch accounted for, D. B.									
in starch	lb/hr	4.127	---	4.987	5.051	3.829	3.707	4.146	3.575
in gluten portion	lb/hr	0.339	---	0.380	0.454	0.273	0.363	0.389	0.369
in bran portion	lb/hr	0.430	---	0.494	0.585	0.385	0.450	1.015	1.039
Total	lb/hr	4.896	---	5.861	6.090	4.487	4.520	5.550	4.983
Total in feed	lb/hr	5.608	---	6.697	6.697	4.782	4.782	6.032	6.032
Starch accounted for	%	87.30	---	84.83	90.94	93.83	94.52	92.01	82.61
Protein accounted for, D. B.									
in starch	lb/hr	0.016	---	0.019	0.019	0.017	0.016	0.010	0.009
in gluten portion	lb/hr	0.262	---	0.257	0.307	0.210	0.280	0.293	0.278
in bran portion	lb/hr	0.175	---	0.182	0.215	0.135	0.158	0.265	0.271
Total	lb/hr	0.453	---	0.458	0.541	0.362	0.454	0.568	0.558
Total in feed	lb/hr	0.763	---	0.912	0.912	0.651	0.651	0.821	0.821
Protein accounted for	%	59.37	---	50.22	59.32	55.61	69.74	69.18	67.97
Energy consumption for grinding									
for unit quantity of feed,W.B.	KWH/lb	0.1404	---	0.0984	0.0984	0.1311	0.1311	0.1039	0.1039
for unit quantity of starch, D.B.	KWH/lb	0.256	---	0.177	0.175	0.219	0.226	0.2131	0.247
Water consumption of process									
for unit quantity of feed, W.B.	gal/lb	11.118	---	9.693	9.693	12.632	12.632	14.203	14.203
for unit quantity of starch,D.B.	gal/lb	20.220	---	17.427	17.208	21.107	21.805	27.702	32.121

Table 7. (Cont.)

		Run 10 A	Run 10 B	Run 11 A	Run 11 B	Run 12 A	Run 12 B	Run 13 A	Run 13 B
Yields of products, D. B.									
Starch	lb/hr	4.176	4.366	4.666	4.000	4.694	4.193	3.642	3.409
	%	57.19	59.79	58.73	50.39	60.50	54.05	49.63	46.46
Gluten portion	lb/hr	0.875	0.845	0.890	0.835	0.957	1.378	0.674	0.688
	%	11.98	11.57	11.20	10.51	12.33	17.76	9.19	9.38
Bran portion	lb/hr	1.496	1.729	1.394	1.315	1.251	1.318	1.927	2.006
	%	20.49	23.68	17.55	16.55	16.25	16.98	26.26	27.34
Total	lb/hr	6.547	6.940	6.950	6.150	6.912	6.889	6.243	6.103
	%	89.66	95.04	87.48	77.45	89.08	88.79	85.08	83.18
Starch recovery, D. B.									
Starch extracted	lb/hr	4.176	4.366	4.666	4.000	4.694	4.193	3.642	3.409
Starch in feed	lb/hr	6.005	6.005	6.532	6.532	6.380	6.380	6.032	6.032
Recovery	%	69.54	72.71	71.43	61.24	73.57	65.72	60.38	56.52
Starch accounted for, D. B.									
in starch	lb/hr	4.158	4.347	4.643	3.980	4.673	4.175	3.628	3.396
in gluten portion	lb/hr	0.386	0.372	0.347	0.326	0.432	0.622	0.310	0.316
in bran portion	lb/hr	0.889	1.028	0.727	0.686	0.700	0.731	1.208	1.257
Total	lb/hr	5.433	5.747	5.717	4.992	5.805	5.528	5.146	4.969
Total in feed	lb/hr	6.005	6.005	6.532	6.532	6.380	6.380	6.032	6.032
Starch accounted for	%	90.47	95.70	87.52	76.42	90.99	86.65	85.31	82.38
Protein accounted for, D. B.									
in starch	lb/hr	0.018	0.019	0.023	0.020	0.021	0.018	0.014	0.013
in gluten portion	lb/hr	0.318	0.307	0.373	0.350	0.336	0.484	0.247	0.252
in bran portion	lb/hr	0.272	0.315	0.285	0.269	0.248	0.259	0.336	0.350
Total	lb/hr	0.608	0.641	0.681	0.639	0.605	0.761	0.597	0.615
Total in feed	lb/hr	0.817	0.817	0.889	0.889	0.869	0.869	0.821	0.821
Protein accounted for	%	74.42	78.46	76.60	71.88	69.62	87.57	72.72	74.91
Energy consumption for grinding									
for unit quantity of feed, W.B.	KWH/lb	0.1124	0.1124	0.0960	0.0960	0.1033	0.1033	0.1039	0.1039
for unit quantity of starch, D. B.	KWH/lb	0.217	0.208	0.181	0.211	0.189	0.211	0.231	0.247
Water consumption of process									
for unit quantity of feed, W. B.	gal/lb	12.330	12.330	11.246	11.246	9.358	9.358	9.022	9.022
for unit quantity of starch, D.B.	gal/lb	23.939	28.186	21.157	24.679	17.093	19.136	20.080	21.452

Table 7. (Cont.)

		Run 14		Run 15		Run 16		Run 22	
		A	B	A	B	A	B	A	B
Yields of products, D. B.									
Starch	lb/hr	3.810	3.850	5.180	4.725	5.203	---	5.159	5.247
	%	54.51	55.07	40.12	36.59	42.28	---	55.76	56.71
Gluten portion	lb/hr	0.680	0.748	0.752	0.757	1.087	---	1.399	1.379
	%	9.73	10.70	5.82	5.87	8.84	---	15.11	14.91
Bran portion	lb/hr	2.853	2.737	5.824	5.039	4.898	---	1.313	1.854
	%	40.87	39.15	45.10	39.02	39.80	---	14.19	20.04
Total	lb/hr	7.343	7.334	11.755	10.521	11.189	---	7.870	8.480
	%	105.06	104.92	91.04	81.48	90.92	---	85.06	91.66
Starch recovery, D.B.									
Starch extracted	lb/hr	3.810	3.850	5.180	4.725	5.203	---	5.159	5.247
Starch in feed	lb/hr	5.750	5.750	10.658	10.658	10.200	---	7.664	7.664
Recovery	%	66.26	66.96	48.60	44.33	51.01	---	67.31	68.46
Starch accounted for, D.B.									
in starch	lb/hr	3.641	3.679	5.160	4.707	5.183	---	5.135	5.222
in gluten portion	lb/hr	0.301	0.331	0.325	0.328	0.434	---	0.551	0.543
in bran portion	lb/hr	1.821	1.748	3.932	3.402	3.244	---	0.660	0.932
Total	lb/hr	5.763	5.758	9.417	8.437	8.861	---	6.346	6.697
Total in feed	lb/hr	5.750	5.750	10.658	10.658	10.200	---	7.664	7.664
Starch accounted for	%	100.23	100.14	88.36	78.32	86.87	---	82.80	87.38
Protein accounted for D.B.									
in starch	lb/hr	0.017	0.017	0.020	0.018	0.020	---	0.024	0.025
in gluten portion	lb/hr	0.254	0.279	0.276	0.278	0.442	---	0.532	0.524
in bran portion	lb/hr	0.515	0.494	0.917	0.794	0.824	---	0.286	0.403
Total	lb/hr	0.786	0.790	1.213	1.090	1.286	---	0.842	0.952
Total in feed	lb/hr	0.783	0.783	1.458	1.458	1.405	---	1.118	1.118
Protein accounted for	%	100.38	100.89	83.20	74.76	91.53	---	75.31	85.15
Energy consumption for grinding									
for unit quantity of feed, W.B.	KWH/lb	0.2124	0.2124	0.1201	0.1231	0.1217	---	0.1619	0.1619
for unit quantity of starch, D.B.	KWH/lb	0.431	0.426	0.334	0.366	0.324	---	0.327	0.321
Water consumption of process									
for unit quantity of feed, W.B.	gal/lb	10.900	10.900	6.784	6.784	7.126	---	8.704	8.704
for unit quantity of starch, D.B.	gal/lb	22.110	21.882	18.852	20.667	18.965	---	17.464	17.258

Table 7. (Cont.)

		Run 23		Run 24		Run 25		Run 26	
		A	B	A	B	A	B	A	B
Yields of products, D. B.									
Starch	lb/hr	8.282	8.090	12.379	10.930	12.541	12.475	13.365	12.673
	%	64.72	63.21	68.09	60.12	69.26	68.90	68.50	64.95
Gluten portion	lb/hr	1.782	1.864	2.696	2.577	2.689	2.669	2.672	2.672
	%	13.92	14.57	14.83	14.18	14.85	14.74	13.69	13.69
Bran portion	lb/hr	2.946	2.119	3.165	2.669	3.103	2.861	4.479	4.556
	%	23.02	16.56	17.41	14.68	17.14	15.80	22.96	23.35
Total	lb/hr	13.010	12.073	18.240	16.176	18.332	18.005	20.517	19.901
	%	101.66	94.34	100.33	88.98	101.25	99.44	105.15	101.99
Starch recovery, D. B.									
Starch extracted	lb/hr	8.282	8.090	12.379	10.930	12.541	12.475	13.365	12.673
Starch in feed	lb/hr	10.607	10.607	15.066	15.066	15.416	15.416	16.171	16.171
Recovery	%	78.08	76.27	82.17	72.55	81.35	80.92	82.65	78.37
Starch accounted for, D.B.									
in starch	lb/hr	8.246	8.090	12.325	10.882	12.478	12.413	13.314	12.624
in gluten portion	lb/hr	0.753	0.788	1.073	1.026	1.098	1.089	1.009	1.009
in bran portion	lb/hr	1.496	1.076	1.648	1.390	1.567	1.445	2.219	2.359
Total	lb/hr	10.495	9.954	15.046	13.298	15.413	14.947	16.542	15.992
Total in feed	lb/hr	10.607	10.607	15.066	15.066	15.416	15.416	16.171	16.171
Starch accounted for	%	98.94	93.84	99.87	88.26	99.98	96.96	102.29	98.89
Protein accounted for, D. B.									
in starch	lb/hr	0.036	0.036	0.054	0.048	0.063	0.062	0.051	0.048
in gluten portion	lb/hr	0.720	0.753	1.173	1.121	1.114	1.106	1.171	1.171
in bran portion	lb/hr	0.685	0.473	0.752	0.634	0.756	0.698	1.036	1.056
Total	lb/hr	1.441	1.282	1.979	1.803	1.933	1.866	2.258	2.275
Total in feed	lb/hr	1.548	1.548	2.199	2.199	2.250	2.250	2.360	2.360
Protein accounted for	%	93.09	82.82	93.39	81.99	85.91	82.93	95.31	96.40
Energy consumption for grinding									
for unit quantity of feed, W.B.	KWH/lb	0.1230	0.1230	0.0929	0.0929	0.0970	0.0950	0.0895	0.0895
for unit quantity of starch, D.B.	KWH/lb	0.214	0.219	0.162	0.159	0.162	0.159	0.147	0.155
Water consumption of process									
for unit quantity of feed, W. B.	gal/lb	6.276	6.276	3.367	3.367	3.367	3.367	4.820	4.820
for unit quantity of starch, D.B.	gal/lb	10.913	11.172	5.619	5.648	5.619	5.648	7.915	8.348

Table 7. (Concl.)

		Run 27 A	Run 27 B	Run 28 A	Run 28 B
Yields of products, D. B.					
Starch	lb/hr	12.416	11.124	9.464	10.359
	%	62.07	55.61	51.11	55.94
Gluten portion	lb/hr	3.605	3.342	2.370	2.318
	%	18.02	16.71	12.80	12.52
Bran portion	lb/hr	3.889	3.490	2.614	3.064
	%	19.44	17.44	14.12	16.54
Total	lb/hr	19.909	17.955	14.449	15.741
	%	99.53	89.76	78.03	85.01
Starch recovery, D. B.					
Starch extracted	lb/hr	12.416	11.124	9.464	10.359
Starch in feed	lb/hr	16.574	16.574	15.345	15.345
Recovery	%	74.91	67.12	61.67	67.51
Starch accounted for, D. B.					
in starch	lb/hr	12.361	11.075	9.387	10.275
in gluten portion	lb/hr	1.421	1.325	1.080	1.057
in bran portion	lb/hr	2.269	2.036	1.396	1.636
Total	lb/hr	16.059	14.436	11.863	12.968
Total in feed	lb/hr	16.574	16.574	15.345	15.345
Starch accounted for	%	96.89	87.10	77.31	84.51
Protein accounted for, D.B.					
in starch	lb/hr	0.055	0.049	0.077	0.084
in gluten portion	lb/hr	1.532	1.420	0.855	0.836
in bran portion	lb/hr	0.809	0.726	0.609	0.714
Total	lb/hr	2.396	2.195	1.541	1.634
Total in feed	lb/hr	2.419	2.419	2.239	2.239
Protein accounted for	%	99.05	90.74	68.83	72.99
Energy consumption for grinding					
for unit quantity of feed, W.B.	KWH/lb	0.0931	0.0931	0.1006	0.1026
for unit quantity of starch, D.B.	KWH/lb	0.169	0.188	0.221	0.206
Water consumption of process					
for unit quantity of feed, W.B.	gal/lb	3.760	3.760	5.078	5.078
for unit quantity of starch, D.B.	gal/lb	6.814	7.605	11.177	10.213

Table 8. Processing data and results for corn meal grinding.

		Run 19	Run 20	Run 21
Feed rate of corn meal, dry basis	lb/hr	27.798	11.652	11.232
wet basis	lb/hr	31.578	13.236	12.768
Water for feeding grits	gal./hr.	12	12	12
Speed of the mill stirrer	rpm	2220	2220	2220
Grinding temperature	°F	96	102	100
Energy consumption rate for grinding	KW	2.376	2.160	2.117
Concentration of grinding mixture	lb-solid/cu.ft.	10.527	7.336	5.454
Overflow rate of solid material from mill, cry basis	lb/hr	65.940	38.460	27.885
Slope of screen	in/ft.	1.25	1.25	1.25
Water to screen	gal/hr	0	0	0
Solid material recycling rate dry basis	lb/hr	38.142	26.808	16.653
Water for recycling	gal/hr	30	24	24
Specific gravity of starch milk at 60°/60° F	°Be'	6.728	2.188	1.813
Tabling rate of starch milk	gal/hr	36	36	36
Starch washing rate	gal/hr	36	36	36
Starch washing time	min.	60	100	60
Drying temperature of products	°F	130	130	130
Drying time of products	hr.	24	24	24
Protein content of starch	%	0.88	1.03	0.97
Starch content of gluten portion/	%	50.25	50.79	52.07
Protein content of gluten portion	%	21.75	23.25	23.75
Yields, dry basis				
Starch	%	54.07	67.34	43.63
Gluten	%	11.10	22.92	25.17
Total	%	65.17	90.26	68.80
Not accounted for	%	34.83	9.74	31.20
Starch recovery, dry basis				
Starch extd.	lb/hr	15.031	7.846	4.901
Starch in feed	lb/hr	24.400	10.227	9.866
Recovery	%	61.60	76.718	49.98

DISCUSSION AND CONCLUSIONS

Starch recoveries up to 84 per cent, which correspond to a yield of 70 per cent of the total dry matter in the raw milo grits, were accomplished in this investigation. Since about 70 per cent of the whole grain appears as grits, this represents a recovery of about 50 per cent of the original grain as starch. This is a considerable improvement over the previous work on hydraulic grinding of sorghum grains carried out by Drobot (8) and Banowetz (1) and is only slightly less than the percentage yield of starch reported by Kerr (12) for the processing of one million bushels of sorghum grain by a conventional corn milling process.

The separation of starch and gluten by tabling was satisfactory, and the starch obtained was uniformly pure, as shown by the protein analyses in Table 6. The range of 0.25 per cent to 0.50 per cent protein except in run 28 compares favorably with the figures reported by Kerr (12) of an average of 0.68 per cent and minimum of 0.41 per cent protein in the starch from sorghum grain. He also indicated that this content of protein was not materially reduced by further purification in Merco centrifuges. It is possible that the lower protein content of the starch produced under the various processing conditions in this investigation resulted from the careful control of steeping and tabling conditions as well as from the unique grinding method used. Kerr (12) pointed out that the desired physical state of the gluten for the tabling separation is attained by proper steeping and milling.

Starch recovery as high as 84 per cent also indicated the effectiveness of the relatively short time of steeping used in the absence of sulfur dioxide. Low recovery of starch in some runs should be attributed to the ineffectiveness of the separation of starch on the screen and an excess of debranning under certain processing conditions. The particularly high starch content in the bran portion and the results of the study of the screening and debranning operations which are discussed in the succeeding part of this paper will prove this point of view. A table prepared by Kerr(12) which shows the effect of steeping adjuncts and conditions on corn starch production is listed for the sake of comparison.

Table 9. Effect of steeping adjuncts and conditions on corn starch production at 40°C.

Steeping medium	Steeping time, hours	Recovery of Starch, %
Distilled H_2O	24	64
0.1% SO_2	24	82
0.2% SO_2	24	83
0.3% SO_2	24	88
0.4% SO_2	24	89
Acetic acid	24	70
Hcl	24	56

The gluten and bran by-products accounted for 30 to 50 per cent of the grits fed and their composition showed them to be valuable as feed. Kerr (12) reported 35.6 per cent as the average yield of feed in the production of starch from the sorghum grains and Bartling (4) reported 29.8 per cent as the average yield of feed in the wet milling of corn. The protein contents of gluten, which varied from 33 to 43 per cent is comparable to the value reported by Kerr (12). The starch content of the bran portion ranged from 48 to 68 per cent under various conditions of operation. This accounts for the major part of the unrecovered starch. As is discussed later, however, this unrecovered starch could be reduced greatly by properly adjusting the screening and debranning conditions.

The low specific gravity of the starch milk produced in the early runs is indicative of the high process water consumption for producing a unit quantity of starch. According to Bartling (4) and Kerr (12), the specific gravity of starch milk at the room temperature is 3^{o}Be' to 6^{o}Be' in the ordinary wet corn milling process, and the use of liquor as high as 6^{o}Be' requires the handling of 30 gallons of water per bushel of corn milled. This corresponds to an average consumption of 2.14 gallons of process water per pound of starch produced, provided no water is recycled. The water consumption in this work ranged from 5 gallons to 30 gallons per pound of starch produced.

The energy used in grinding ranged from 0.096 KWH to 0.256 KWH per pound of starch produced. This is considerably higher than the present-day corn milling process. But, as is shown later, both the energy and water consumption could be further reduced by operating the mill at higher feed rates. The mill was apparently operated much under its capacity. It is also obvious that the process water consumption can be readily reduced by recycling some of the water from the gluten liquor to the steeping operation.

The quality of starch produced was evaluated by the viscosity record method of Barham et al (3) for run No. 8 and run No. 24. The ratios of viscosity maxima during the heating and cooling of the starch pastes indicates that the starches had good pasting properties. The viscosity records are shown in PLATE IX.

Though good material balances were not obtained in the milling of corn meal and the recoveries of starch were generally poor, the 77 percent recovery in run 20 indicates the value of further investigation of this method of producing corn starch.

In the following the effect of various factors of the processing conditions are discussed separately for the sake of clarity, although these factors are

EXPLANATION OF PLATE IX

Viscosity records of starches

——————run 8

$W_1 = 434$

$W_2 = 1135$

$W_2/W_1 = 2.62$

$GS = 1687$

$$\frac{(GS-W_2)}{W_2}100 = 48.63$$

- - - - - - - -run 24

$W_1 = 376$

$W_2 = 739$

$W_2/W_1 = 1.97$

$GS = 1715$

$$\frac{(GS-W_2)}{W_2}100 = 132.07$$

W_1; initial maximum Viscosimeter reading during the heating, in grams

W_2; final maximum Viscosimeter reading during the cooling, in grams

GS; gel strength, in grams


PLATE IX
1000
800
600
400
200
0
Weight (W) in grams
Cook
30 min
70
80
90
← 93 →
90
80
70
60
50
40
30
Temperature °C

interdependent, particularly in continous processing.

Effect of Feed Rate of Raw Grits

The concentration of the grinding mixture in the mill and the rate of recycling unground grits at constant rates of water to the mill supply is plotted in Fig. I (A) and Fig. I (B). These two figures include the data of all experimental runs listed in Table 5, except run 28, in which the water for recirculating the grits was doubled. It was predicted that the concentration of the grinding mixture and the rate of recycling grits would be profoundly influenced by the rate of feed of raw grits. Fig. I (C) and Fig. I (D) show that the concentration of starch milk increased markedly as the feed rate of raw grits increased, however, the yield and recovery of starch increased only slightly as the feed rate of raw grits increased. Fig. I (C) and Fig. I (D) were plotted for the data of runs 1, 2, 3, 4, 6, 7, 8, and runs 22, 23, 24 respectively. In these runs all conditions except the feed rate were constant.

Fig. I (E), which includes data for all experimental runs, shows that the protein content of the gluten tended to increase as the concentration of the starch milk increased. This is taken to mean that the tabling operation was more efficient at the higher concentrations over the range of these experiments, since less starch passed off the tables into the gluten.

The power consumption for grinding in the hydraulic mill changed only slightly with change of feed rate of raw grits in the range studied. Both the energy and water consumed in producing a unit quantity of starch, therefore, were reduced as the rate of feed of raw grits was increased. At higher feed rates the grinding mixture was more concentrated as described previously. Low

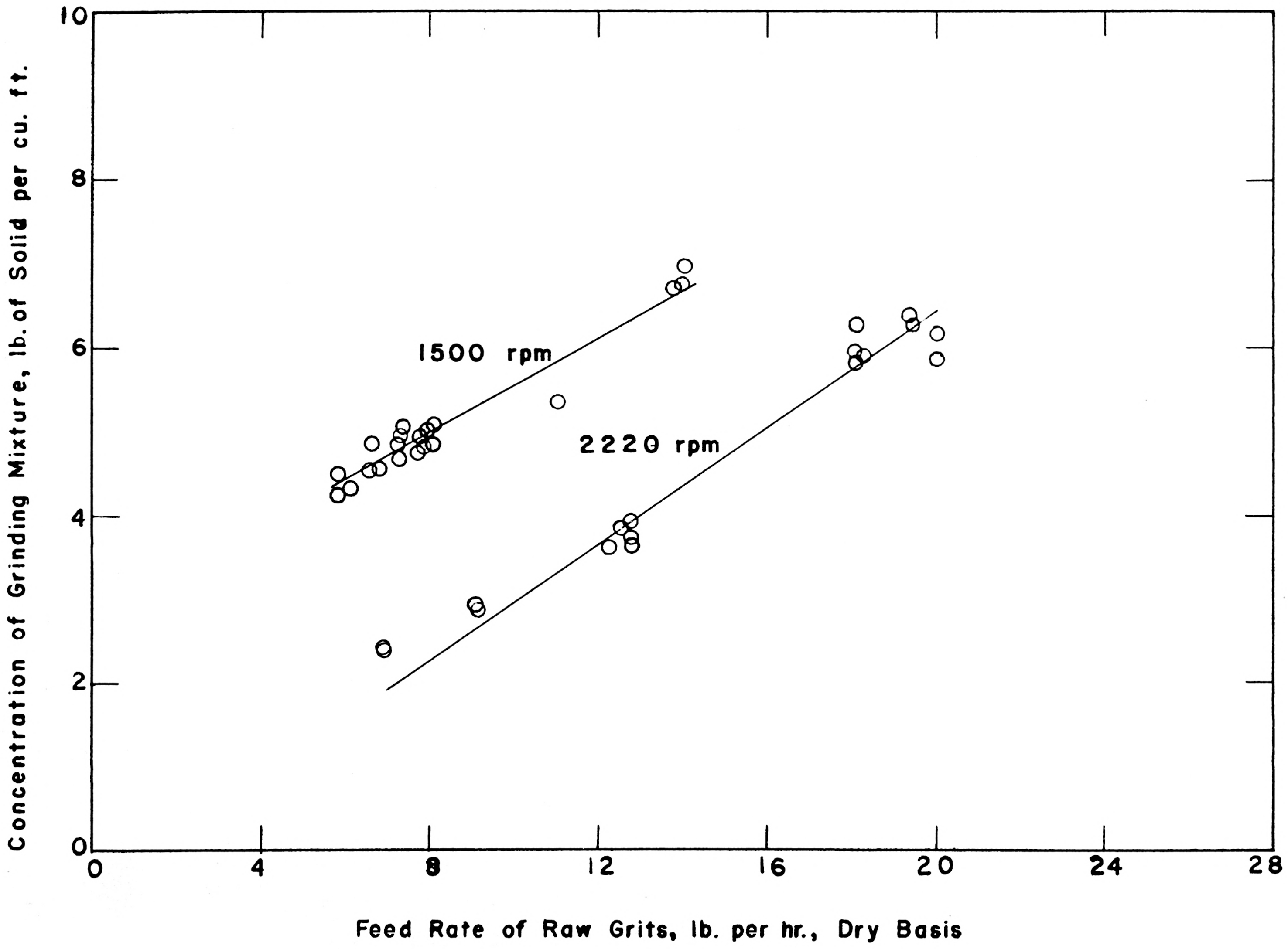


Fig. 1.(A) Effect of feed rate of raw grits.

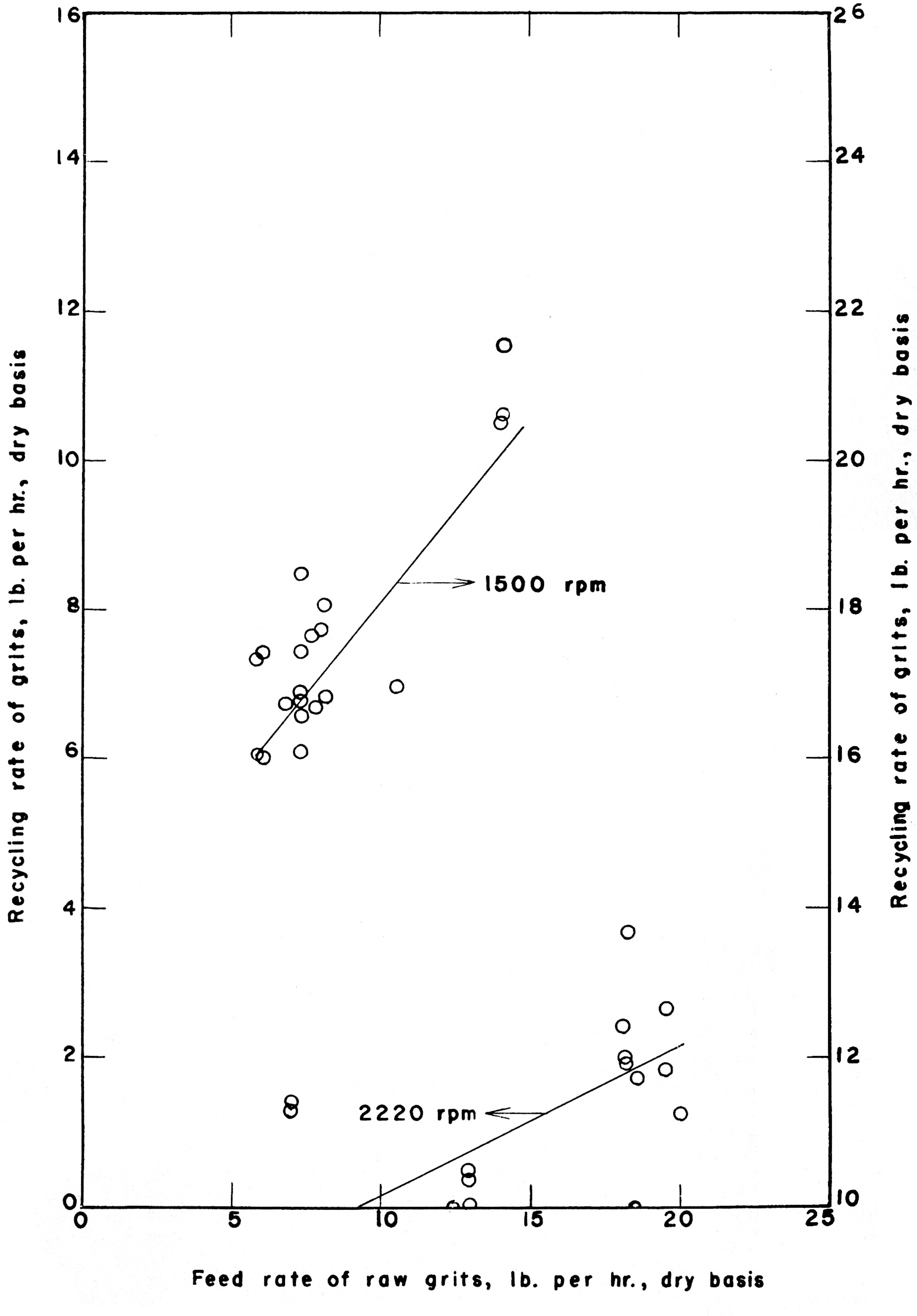


Fig. I. (B) Effect of feed ro raw grits.

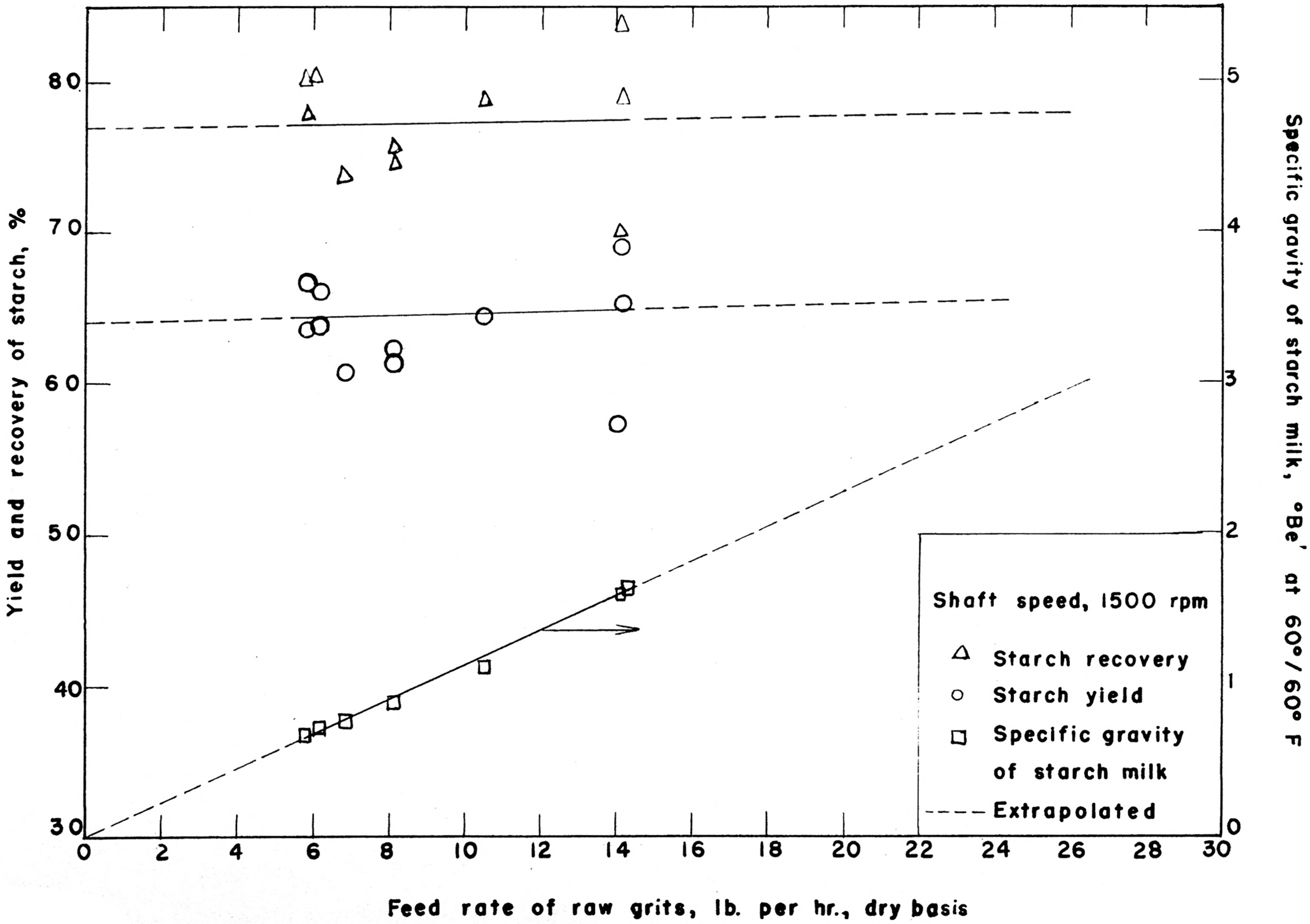


Fig. I. (C) Effect of feed rate of raw grits.

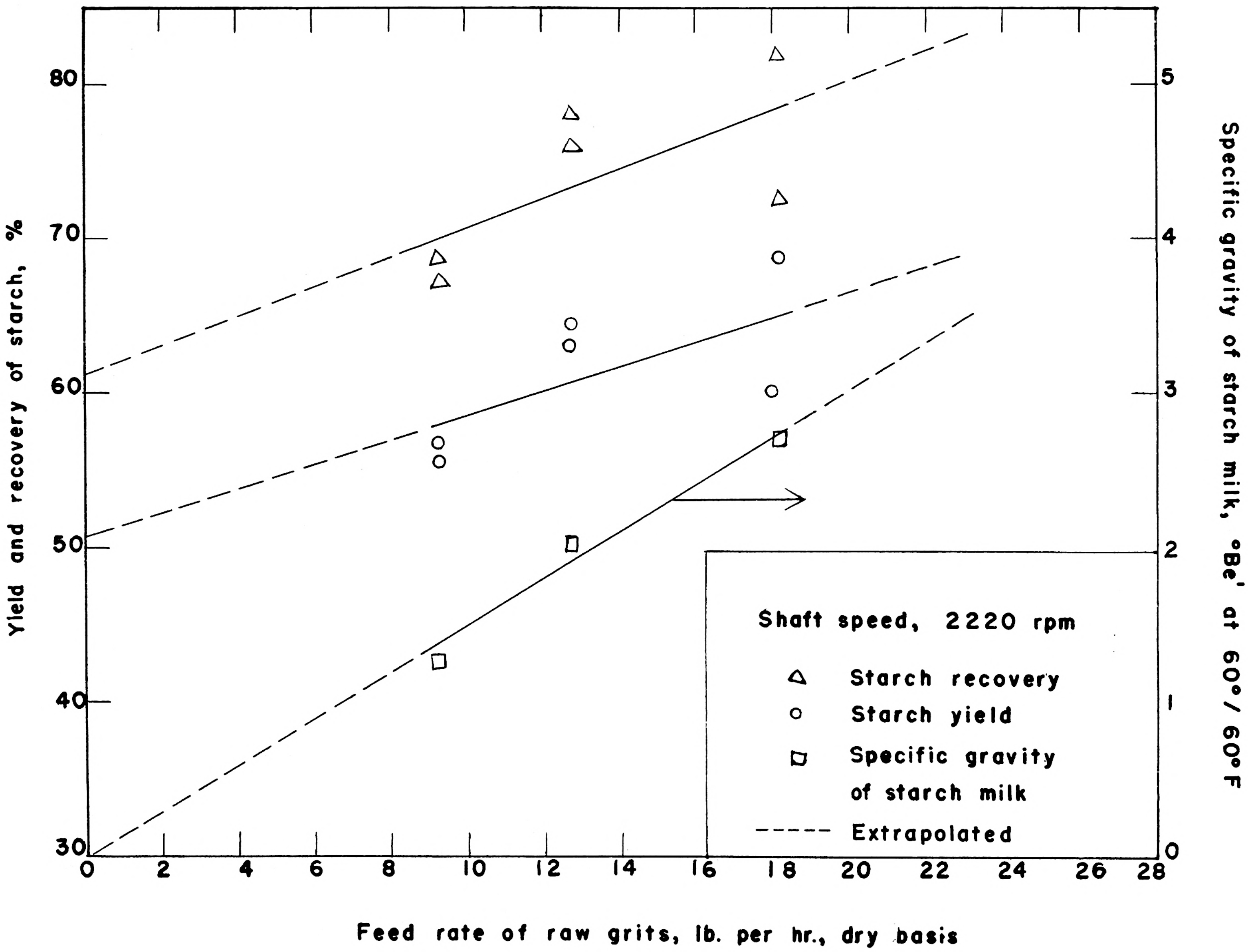


Fig. 1. (D) Effect of feed rate of raw grits.

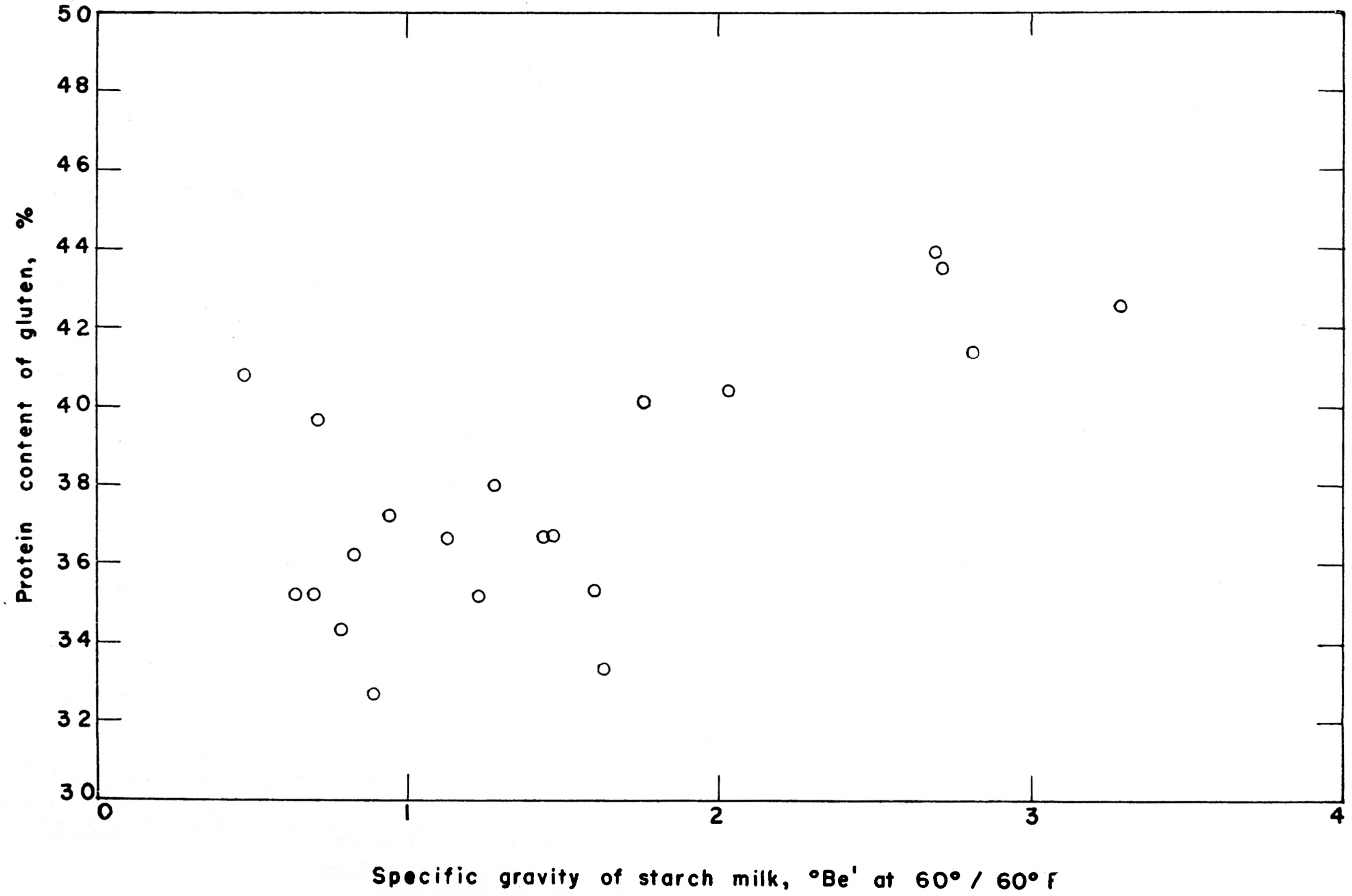


Fig. I. (E) Effect of feed rate of raw grits

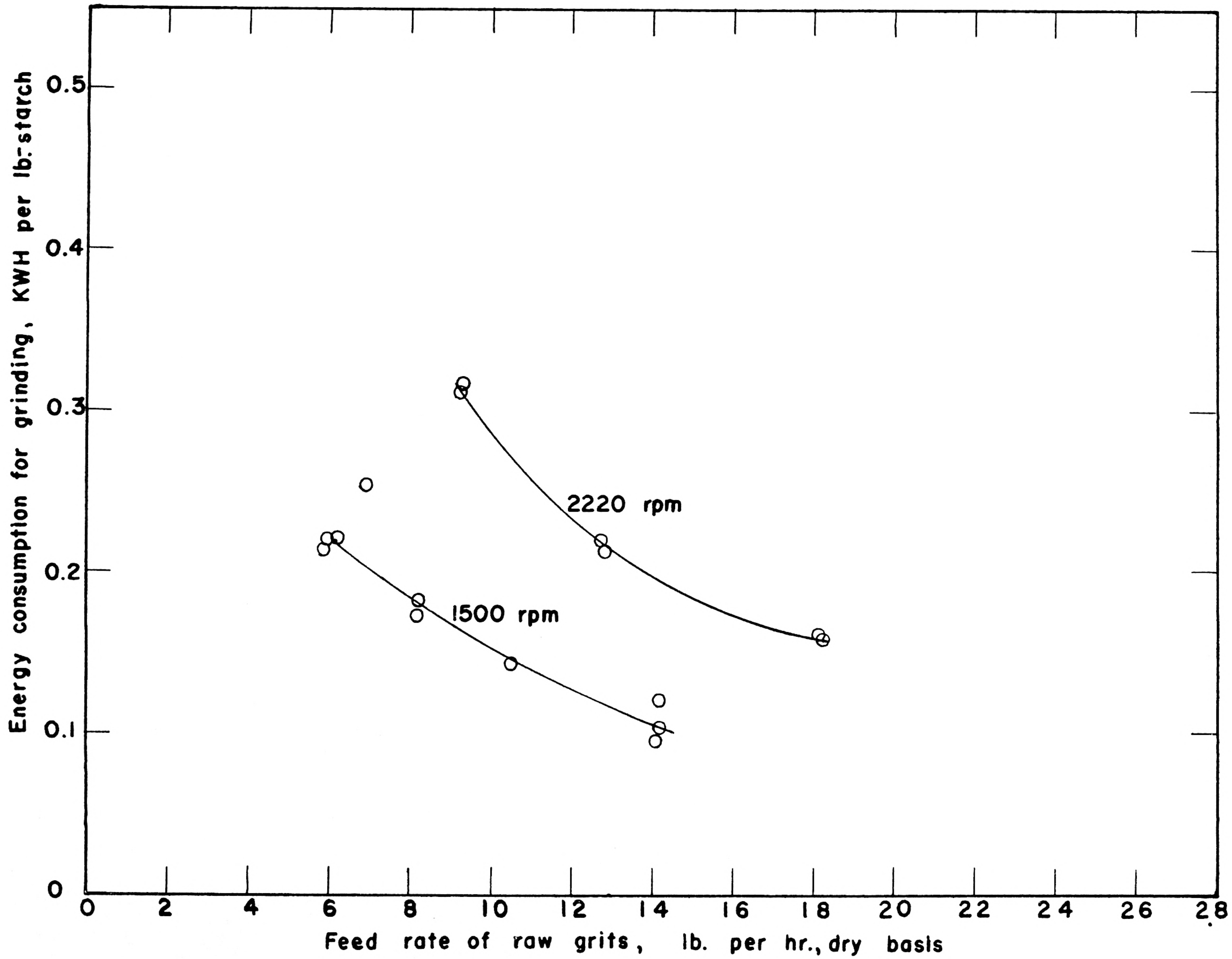


Fig. 1. (F) Effect of feed rate of raw grits.

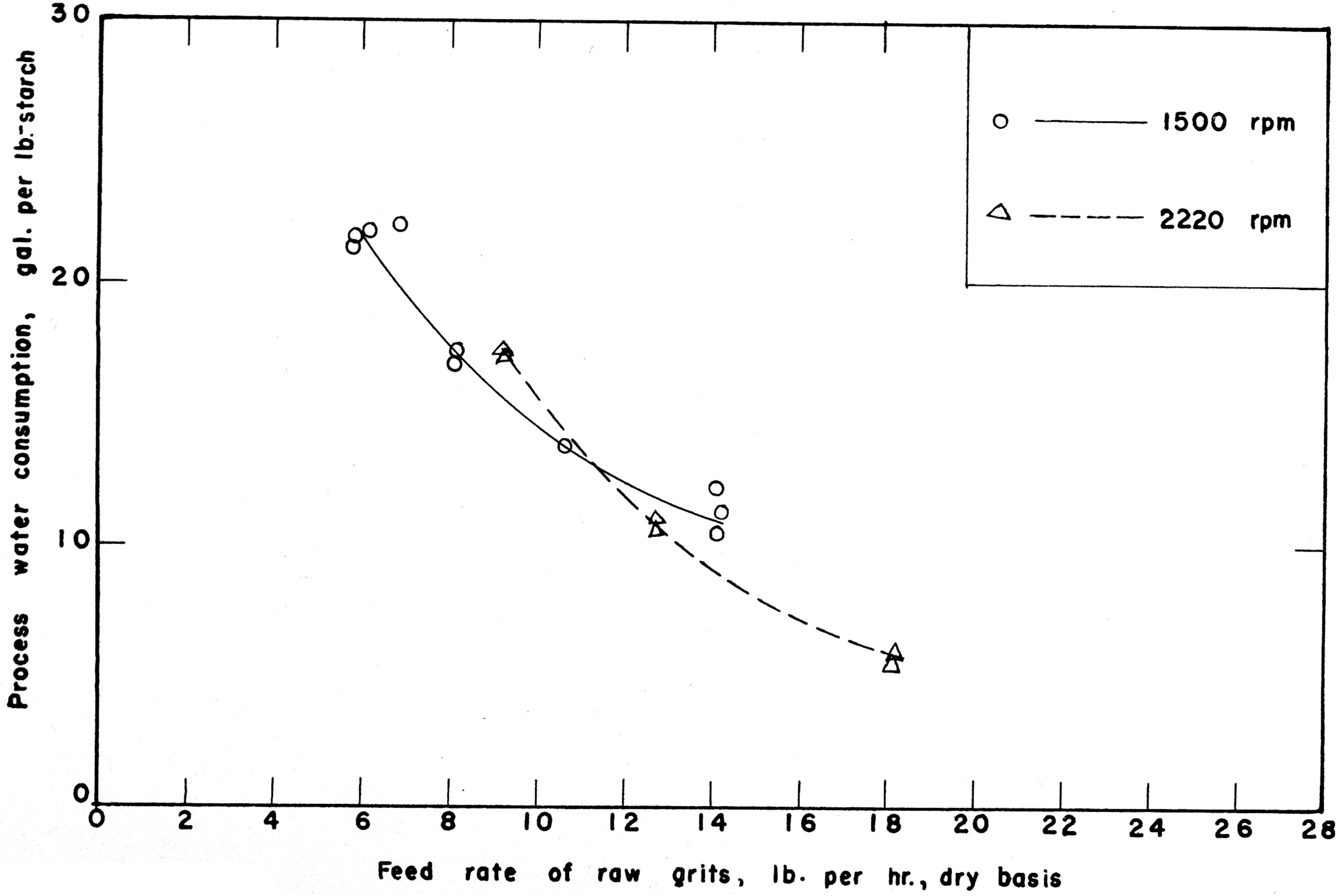


Fig. 1. (G) Effect of feed rate of raw grits.

energy consumption was probably due to the fact that the grinding action in the hydraulic mill depends upon theabrasion and impact between the particles of grain and thus appears to be more efficient in grinding at higher concentrations of grinding mixture.

Effect of Shaft Speed of the Mill

It would be expected that increasing the shaft speed of the mill would increase the capacity of the mill. From Fig. I (A) and Fig. I (B) used in the previous discussion, it is evident that the recycling rate of the grits and the concentration of the grinding mixture were much lower at shaft speeds of 2220 rpm than at 1500 rpm at the same operating conditions. This indicates that more of the grits were ground in a single pass through the mill at the higher speed, and since this resulted in a lower recycle rate, the concentration of grits in the mill was lower.

Fig. 2 (A) shows the yield of starch and bran, and Fig. 2(B) shows the starch and protein contents of the bran as a function of feed rate for runs in which all other factors except mill speed were constant. Runs 2, 3, 4, 5, 7, and 8 at 1500 rpm and runs 14 and 15 at 2220 rpm are included.

The lower yield obtained at the higher mill speed may be explained by a difference observed in the screening of the product from the mill. At the low mill speed, this overflow consisted of finely divided starch and coarse, unground grits, through which the wash water moved readily, and which moved down the screen easily. At the higher mill speed, much more grinding occurred so that the material which was too coarse to pass through the 200 mesh screen, was nevertheless much finer than at the low speed. This reduced the efficiency of

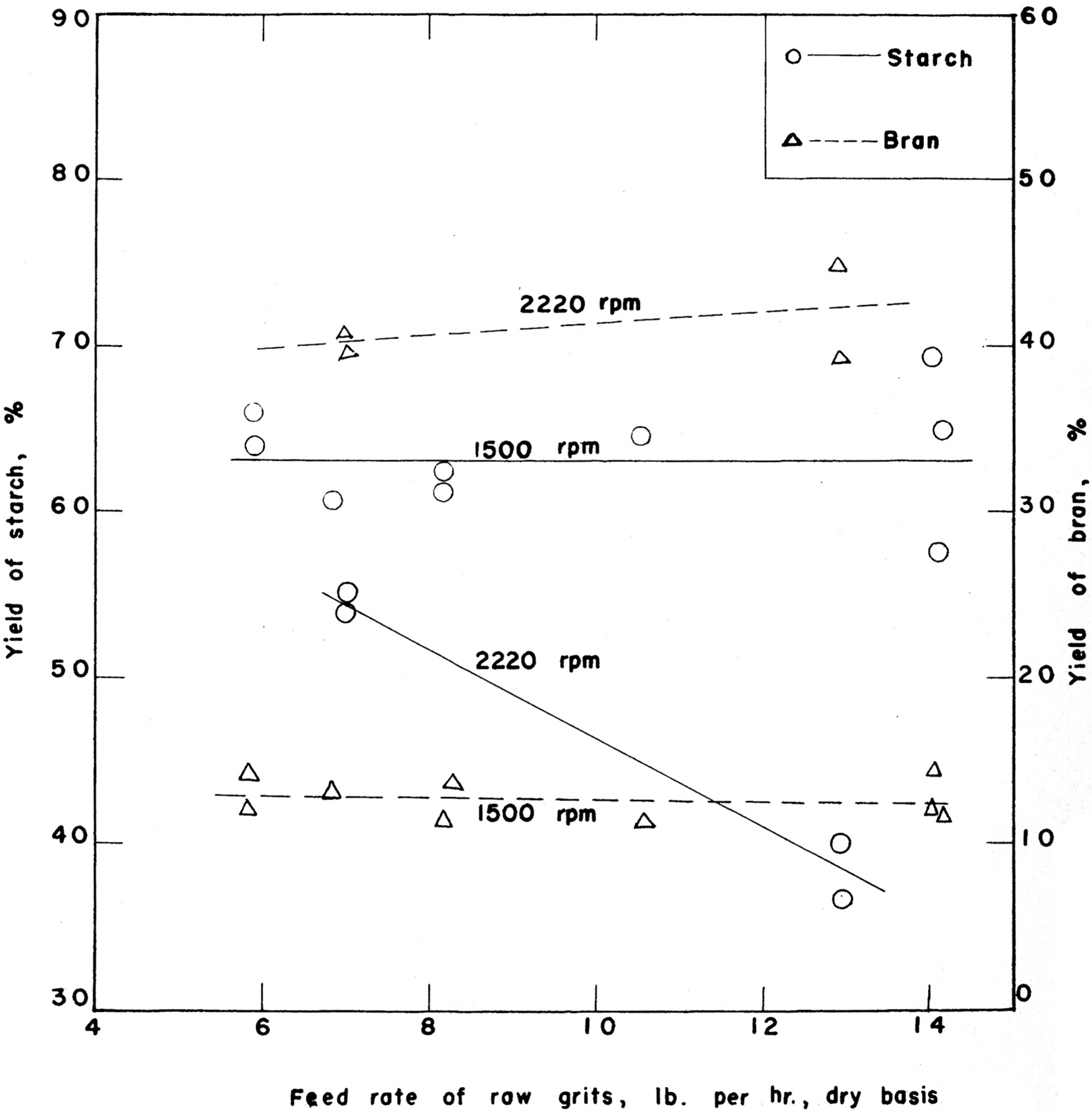


Fig. 2. (A) Effect of shaft speed of mill.

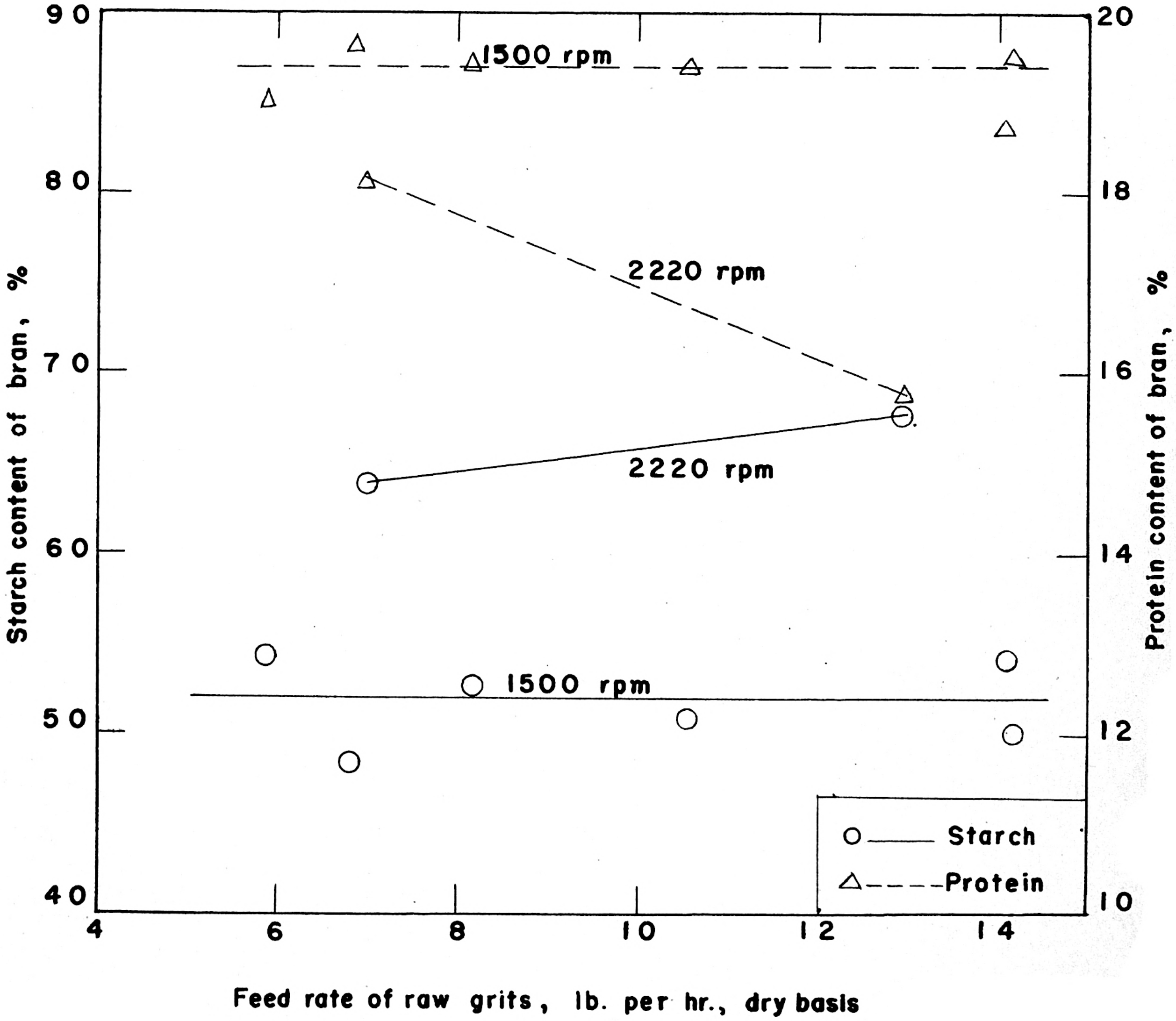


Fig. 2. (B) Effect of shaftspeed of mill.

the wash water and tended to blind the screen, so that some of the starch was not removed on the screen, but passed to the debranner where it was separated from the recycle stream by the debranning operation.

The condition was corrected by adjusting the slope of the screen as is shown in a later section.

The lower value of the viscosity maxima ratio (W_2/W_1) for the starch sample processed at the higher mill speed than that processed at the lower mill speed was probably caused by inhibition of the starch, resulting from protein distributed over the surface of the starch granules. This resulted from over-grinding.

Effect of Water Spray to Shaker Screen

As cited previously two stages of water spray were applied on the shaker to assure complete separation of starch milk from the coarse grits. It is desirable to reduce this spray to a minimum to conserve water and maintain the concentration of the starch milk as high as possible.

As shown in Fig. 3 (A) and Fig. 3 (B), or from the data in Table 10, there existed a critical rate of spray water supply which appeared to be about 12 gallons per hour for the conditions in the experimental runs listed in Table 8. It appears that insufficient washing of the grits on the screen, resulting in the loss of starch in the debranning operation, occurred below this critical rate while at rates above this critical rate the yield of starch was not increased materially.

Table 10. Effect of water spray to shaker sieve.

Run		13		12		7		11	
Rate of spray water supply to shaker screen	gal/hr	3		6		12		24	
Consumption of spray water	gal/lb-starch	0.370		0.699		1.333		2.724	
Yield of starch	%	49.63	46.46	60.50	54.05	61.44	62.23	68.09	60.12
Yield of gluten	%	9.19	9.38	12.33	17.76	9.66	11.53	14.83	14.18
Yield of bran	%	26.26	27.34	16.25	16.98	11.49	13.60	17.55	16.55
Recovery of starch	%	60.38	56.52	73.57	65.72	74.75	75.71	82.17	72.55
Water consumption	gal/lb-starch	20.080	21.452	17.093	19.136	17.427	17.208	21.157	24.679
Protein content in starch	%	0.38		0.44		0.38		0.50	
Starch content in gluten	%	45.99		45.13		48.28		39.04	
Protein content in gluten	%	36.63		35.13		32.69		41.88	
Starch content in bran	%	62.68		55.48		52.78		52.13	
Protein content in bran	%	17.44		19.63		19.44		20.44	
Specific gravity of starch milk at $60^{o}/60^{o}F$	^{o}Be	1.423		1.221		0.880		0.477	

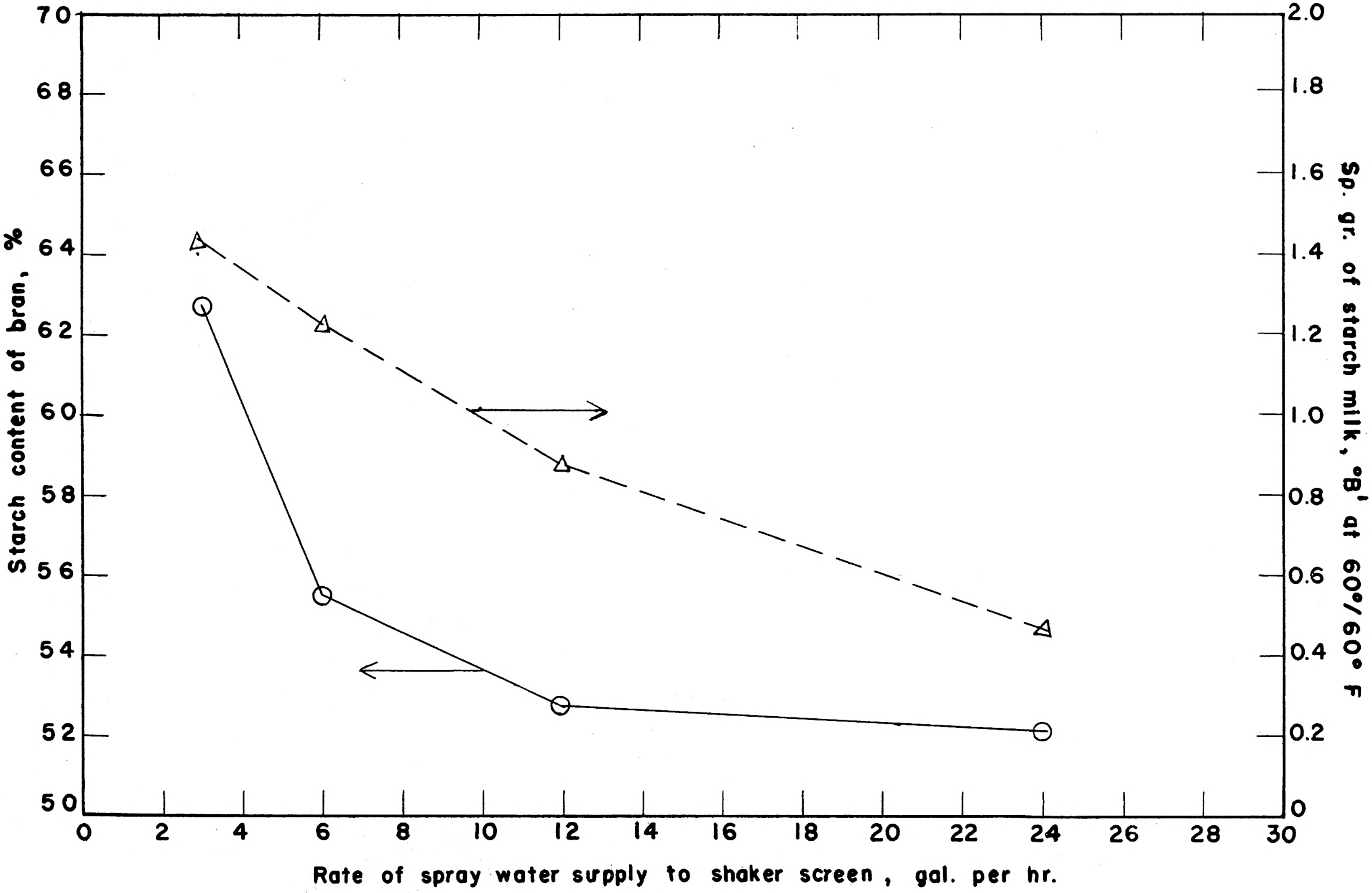


Fig. 3. (A) Effect of water spray to shaker screen.

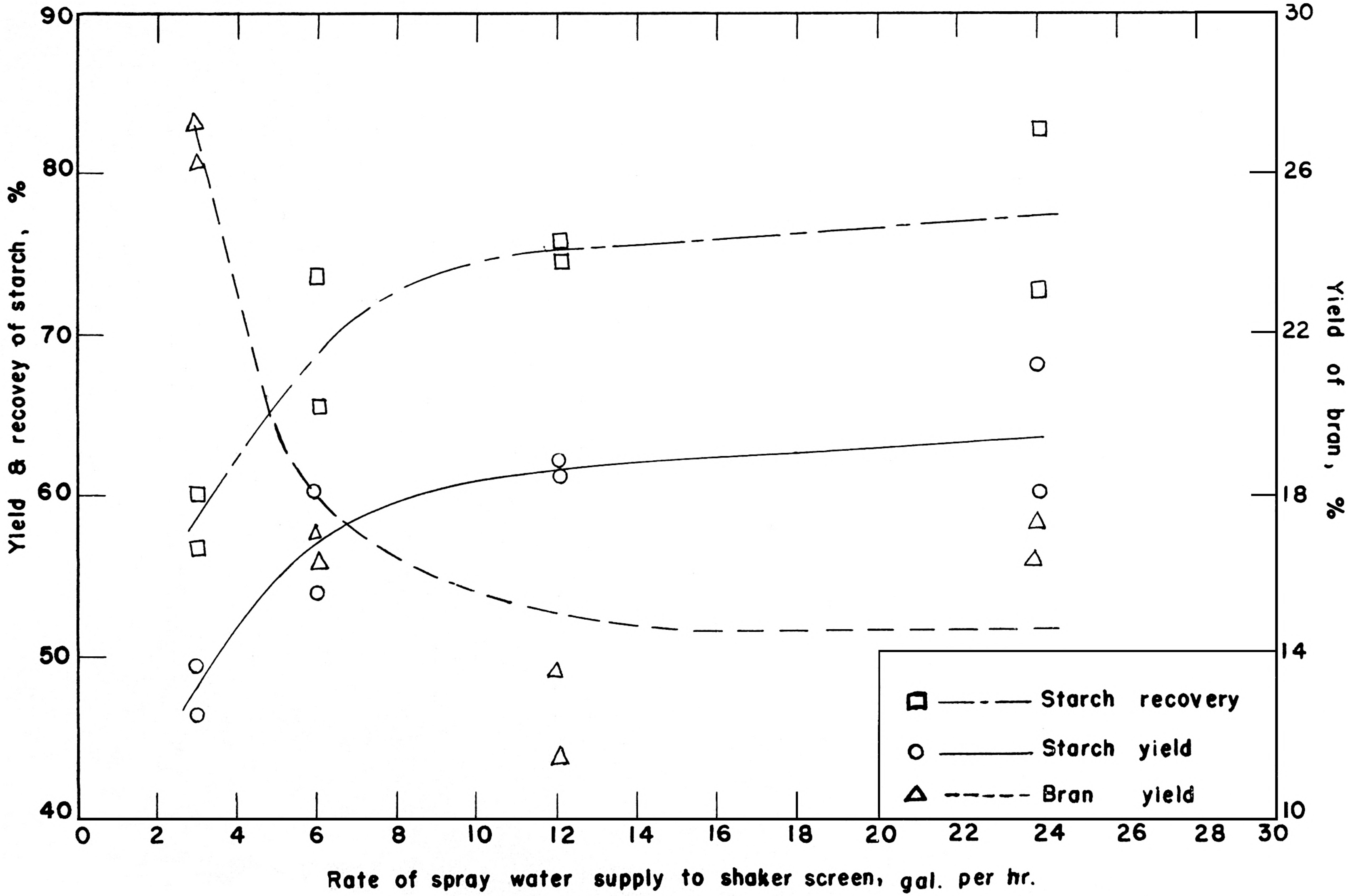


Fig. 3. (B) Effect of water spray to shaker screen.

Effect of Slope of Shaker Screen

The effect of the slope of the shaker screen in separating the starch milk from the grinding mixture was studied by systematically changing the slope of the screen at essentially constant processing conditions. Slopes of 3 inches per ft., 2 inches per ft., and 1.25 inches per ft. were used. The curves in Fig. 4 (A), 4 (B), and Fig. 4 (C), which represent the results of runs 15, 16, 23, and 24, indicate clearly that the lower slope gave the highest recovery of starch.

Effect of the Debranning Water Rate

The rate of flow of water to the debranner was the principal factor affecting the efficiency of debranning in this work. For the type of debranner used, increasing the rate of flow of water increased the loss of starch to the bran portion. As shown in Table 11, there was general increase in yield of starch with a decrease in the flow of water to the debranner.

Table 11. Effect of debranning water.

Shaft speed of the mill 1500 rpm				Shaft speed of the mill 2220 rpm			
Run No.	Rate of debranning water supply, gal/hr	Starch recovery % A	Starch recovery % B	Run No.	Rate of debranning water supply, gal/hr	Starch recovery % A	Starch recovery % B
7	30	82.59	87.36	25	6	81.35	80.92
10	45	69.54	72.71	26	18	82.65	78.37
9	60	68.90	59.42	24	30	82.17	72.55

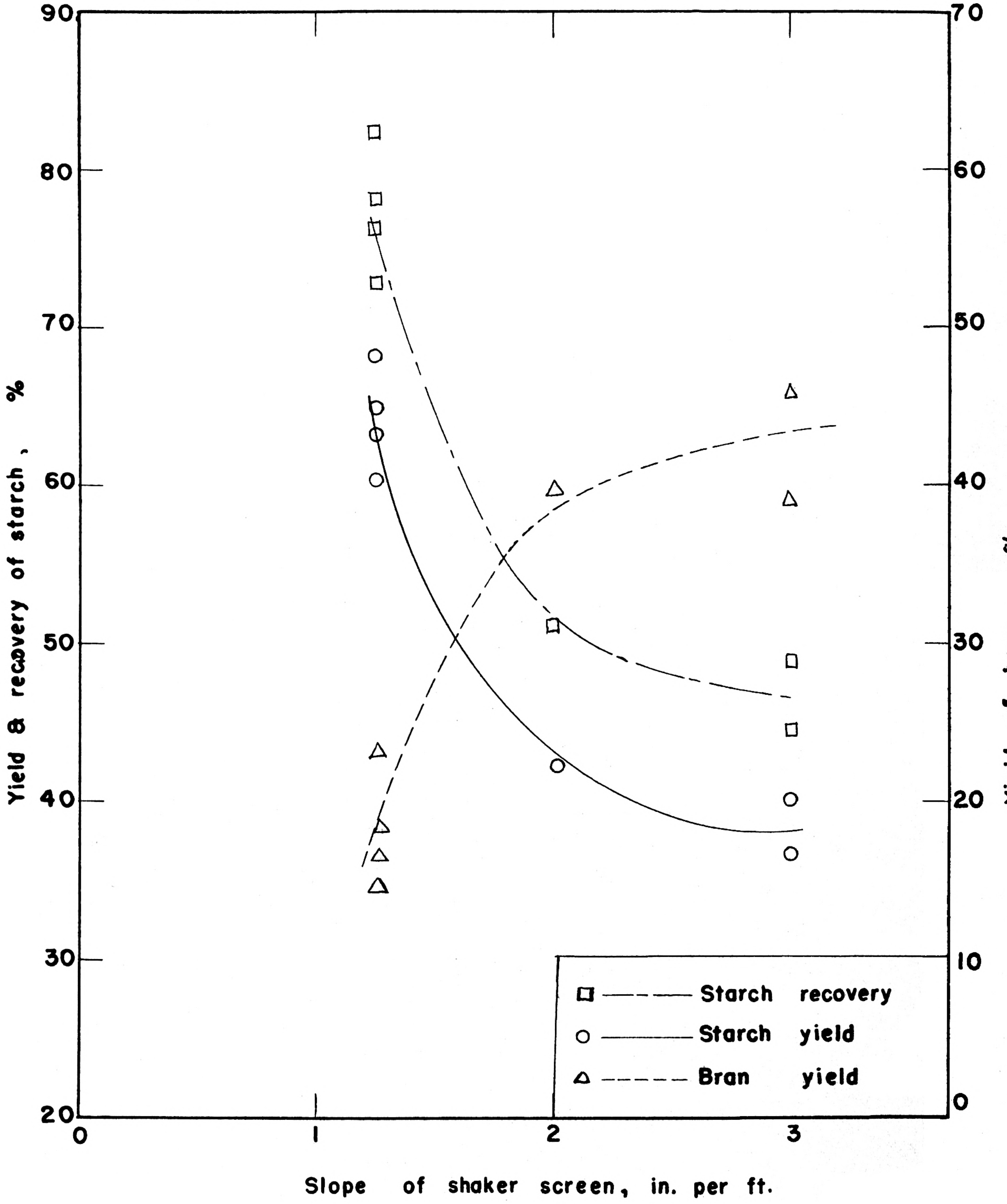


Fig. 4. (A) Effect of slope of shaker screen.

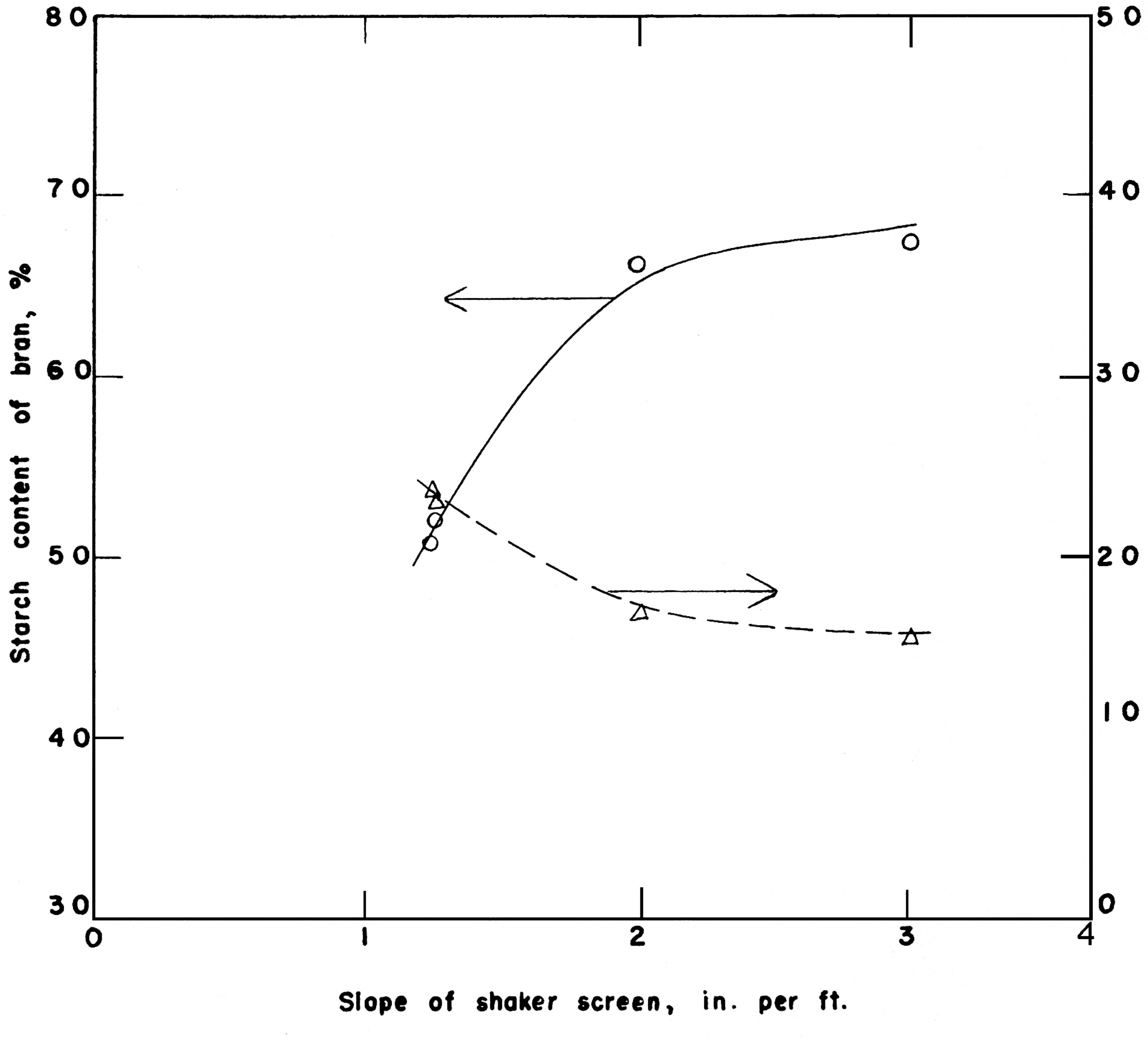


Fig. 4. (B) Effect of slope of shaker screen.

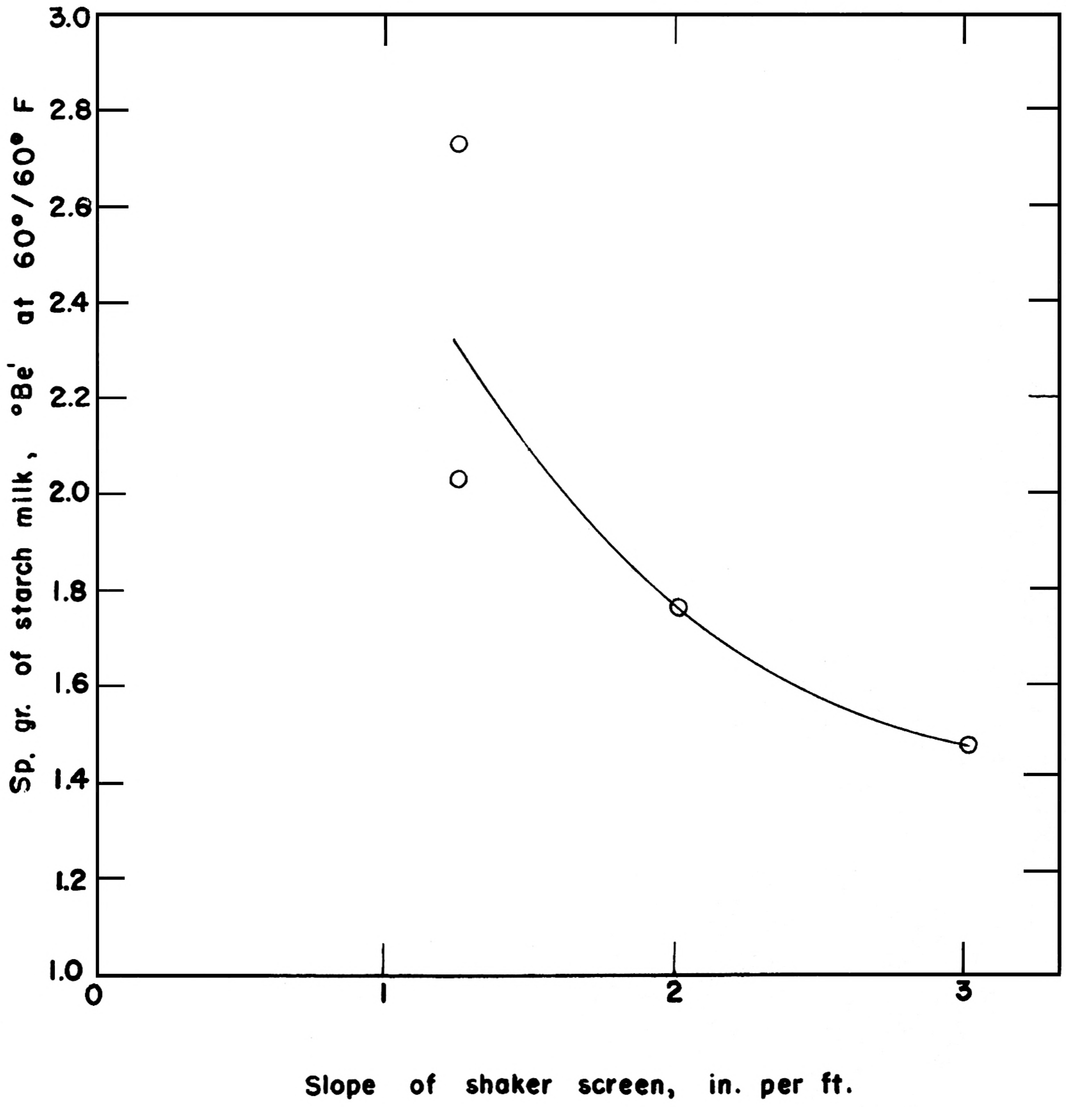


Fig. 4. (C) Effect of slope of shaker screen.

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STUDY OF THE CONTINUOUS GRINDING OF STEEPED ENDOSPERM FROM SORGHUM GRAIN IN THE PRODUCTION OF STARCH

by

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B. S., National Taiwan University, 1951
Taiwan (Formosa), China

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OF A THESIS

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requirements for the degree

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1954

The purposes of this research were to develop a continuous process for the production of starch from the endosperm fraction of milo grain, commonly called milo grits, and to evaluate the effect of various factors on the yields and quality of the products as well as on the energy and water consumption of the process.

Previous experiments on the production of starch from sorghum grain at Kansas State College have been conducted on the laboratory and pilot plant scale by batch and semi-continuous hydraulic grinding.

The batch grinding process, which is a type of ''choke'' feeding operation in size reduction, increases greatly the portion of fines produced and decreases the capacity of the mill. A continuous process which applies the principles of closed circuit operation is more economical of power, permits smaller units for a given capacity, and produces a material with greater uniformity of size, thus preventing overgrinding. Low labor requirement is another advantage of the continuous process over batch and semi-continuous processes.

A hydraulic mill, whose grinding mechanism depends on impact and abrasion, was used for grinding. Grits were first steeped in hot water at 130°F for 2 hours without using any steeping agent such as SO_2. The steeped grits were continuously fed into the hydraulic mill through a V-shaped feed hopper.

The ground overflow from the mill passed over a 200 mesh shaking screen where a starch suspension was separated from unground material. The so-called starch milk was pumped continuously onto the starch tables on which the starch settled out while the gluten remained in suspension and flowed off the end of the tables to a settling tank.

The bran was separated from the unground grits in the debranner by a stream of water which carried the bran to the filters. After filtration the bran was dried in a steam heated tray dryer. The remaining unground grits were recycled back to the mill through a flight conveyor.

Starch accumulated on the starch tables was washed with water and transferred into the dryer. After settling the water was decanted from the gluten which was then also dried.

Somewhat higher recoveries of starch were obtained in this investigation compared to recoveries obtained in the previous work on the hydraulic grinding of sorghum grits. The recoveries were actually very close to the yield of starch from the industrial scale processing of sorghums by a conventional corn milling process.

The starch obtained was uniformly pure, and the viscosity record tests indicate that it was of good quality and pasting property.

As was expected, the capacity of the mill was markedly increased by increasing the shaft speed of the mill. Shaft speeds of 1500 rpm and 2220 rpm were used. The lower value of the viscosity maxima ratio for the starch processed at the higher shaft speed probably was due to the inhibition of the starch by protein which was evenly distributed over the starch granules.

It was found that there was a critical rate of wash water spray to the shaker screen. It appeared that insufficient washing of the grits on the screen resulting in the loss of starch in the debranning operation occurred below this critical rate while at rates above this critical rate the recovery of starch was not increased materially.

It was also shown that a very low slope of the shaker screen gave the maximum recovery of starch for constant processing conditions.

The rate of flow of water to the debranner was the principal factor affecting the efficiency of debranning. For the type of debranner used, increasing the rate of flow of water increased the loss of starch to the bran portion.

Several runs were conducted using corn meal as a raw material. It was necessary to make some slight modification in the process before successful runs were achieved. Though good material balances were not obtained in the milling of corn meal, and the recovery of starch was generally poor, the yield in at least one run was high enough to warrant further study of the process.