FACTORS AFFECTING THE PRODUCTION OF STARCH FROM THE ENDOSPERM OF SORGHUM GRAINS

by

SHIAO-HUNG CHIANG

B. S., National Taiwan University, China, 1952

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Chemical Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1955

TABLE OF CONTENTS

INTRODUCTION

The present investigation was a continuation of a series of studies on the development of an industrial process for the production of starch from sorghum grain at Kansas State College.

The primary purpose of this research was to investigate some of the factors affecting the yield and quality of the product from the continuous hydraulic milling process for the production of starch from milo maize grits.

In earlier investigations the starch was recovered from sorghum endosperm through operations quite similar to those used in the corn starch industry. Johnston (7) reported that a wet milling process was developed to obtain starch from sorghum at this College in 1942. Lately, similar reports were made by Zipt et al (11), Watson et al (10), and Kerr (8) on this subject. Taylor (9) and Hightower (6) reported in 1949 that the wet milling process for sorghum starch had been developed into full industrial scale at the Corpus Christie, Texas, plant of the Corn Products Refining Company.

With the purpose of producing starch granules of approximately the same size by avoiding direct compressing and shearing forces in grinding, Banowetz (1) and Drobot (4) made investigations of "hydraulic grinding" of sorghum grain instead of the conventional Buhrstone mill method. They reported that a starch of good quality was obtained but no satisfactory yield was achieved, probably because of the excessive grinding which is a characteristic of batch grinding. In order to overcome this defect, Fan (5) developed this process into a continuous operation. He obtained a higher yield and good quality of starch. This led to further investigations along this line which are reported here.

The process developed by Fan consisted of:

1. Steeping the grits in warm water.
2. Separating the steeped grits from the steep water.
3. Feeding the grits to the hydraulic mill with water at controlled rates.
4. Separating the overflow from the mill into a fine and a coarse fraction on a 200 mesh screen.
5. Separating bran from the coarse material.
6. Recycling unground grits to the mill.
7. Tabling the starch milk from the underflow from the screens to separate starch from gluten.
8. Filtering the bran and the gluten.
9. Drying bran, gluten, and starch.

It has been customary in the production of corn starch to steep the grain in dilute solutions of sulfurous acid at about 120° F. for 24 to 48 hours before grinding. This appears to be one of the most important factors in determining the yield and quality of the starch. For this reason much research has been done on this operation in the milling of corn. Kerr (8) reported that the time of steeping and the steeping agent, such as sulfur dioxide, were the two main factors. Sulfur dioxide is considered the most effective agent found so far (3). A report on sulfur dioxide steeping prepared by Cox et al (3) gave an extensive survey on this subject. They claimed that the proper use of sulfur dioxide in the steeping of corn would increase the yield but would slightly lower the paste viscosity, which is one of the most important qualities of starch.

This study includes an investigation of the time of steeping and of the use of sulfur dioxide in the steep water.

It was pointed out by Fan (5) that the feed rate is one of the most important factors affecting the production of starch in the continuous hydraulic milling of sorghum grits. Fan inferred that the per cent recovery of starch, as well as the capacity of the mill, should increase with increased feed rates up to a maximum.

A second important variable is the rate of supply of water with the steeped grits to the mill. This, along with the rate of feed of grits, controls the concentration of the material in the mill.

These two factors were also investigated in this study. It was believed that the concentration of solids in the mill was a more fundamental variable than the actual water rate to the mill, so that this and the rate of feed of grits were considered the independent variables.

In starting up any continuous process which included a recycle operation, a certain amount of time must elapse before the steady state is reached. The term "steady state" as used here means that the conditions at any point in the process remain constant with time. As a criterion of the attainment of the steady state, Fan (5) used the concentration, as expressed by a specific gravity measurement, of the starch milk. This was found to be lacking in sensitivity, and a more accurate criterion was needed. This was found in the mass rate of the recycle stream, which was used to indicate the steady state in this work.

In order to compare the quality of the starch produced under various operating conditions, a modification of the viscosity test devised by Barham et al (2) was developed for use as a control test.

DESCRIPTION OF EQUIPMENT

The equipment used in this investigation is shown in the flow sheets, Plates I, II, and III. The design of the equipment is best explained by a detailed account of its use.

Steeping Unit

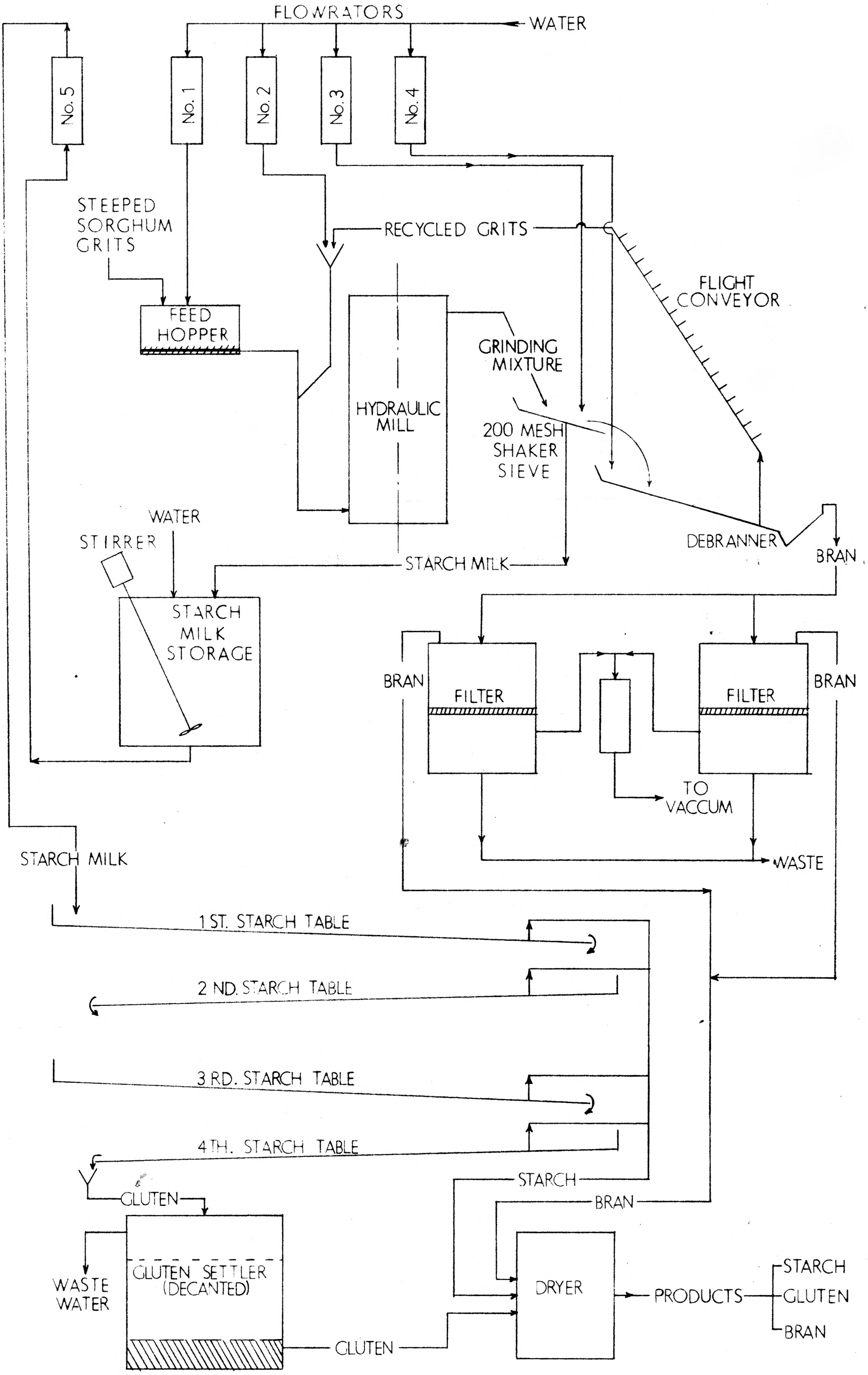
Three 15-gallon stainless steel tanks were arranged as shown in Plate IV. One of the tanks, which contained a heating coil made of copper tubing through which low-pressure steam was passed, was used to heat the steeping water. A constant temperature of $130^{\circ} \pm 5^{\circ}$ F. was maintained by a Taylor self-acting steam regulator. The hot water was pumped through a $\frac{1}{4}$-inch galvanized iron pipe by a centrifugal pump (Eastern Industries, Model D11, 1/8 Hp., 3450 rpm) to the top of the first steeping tank. The water flowed by gravity from the bottom of the first tank to the top of the next steeping tank which was at a lower level. In the same manner, the steeping water flowed from the second steeping tank back into the heating tank in order to take up heat and

EXPLANATION OF PLATE I

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

(One screen operation)

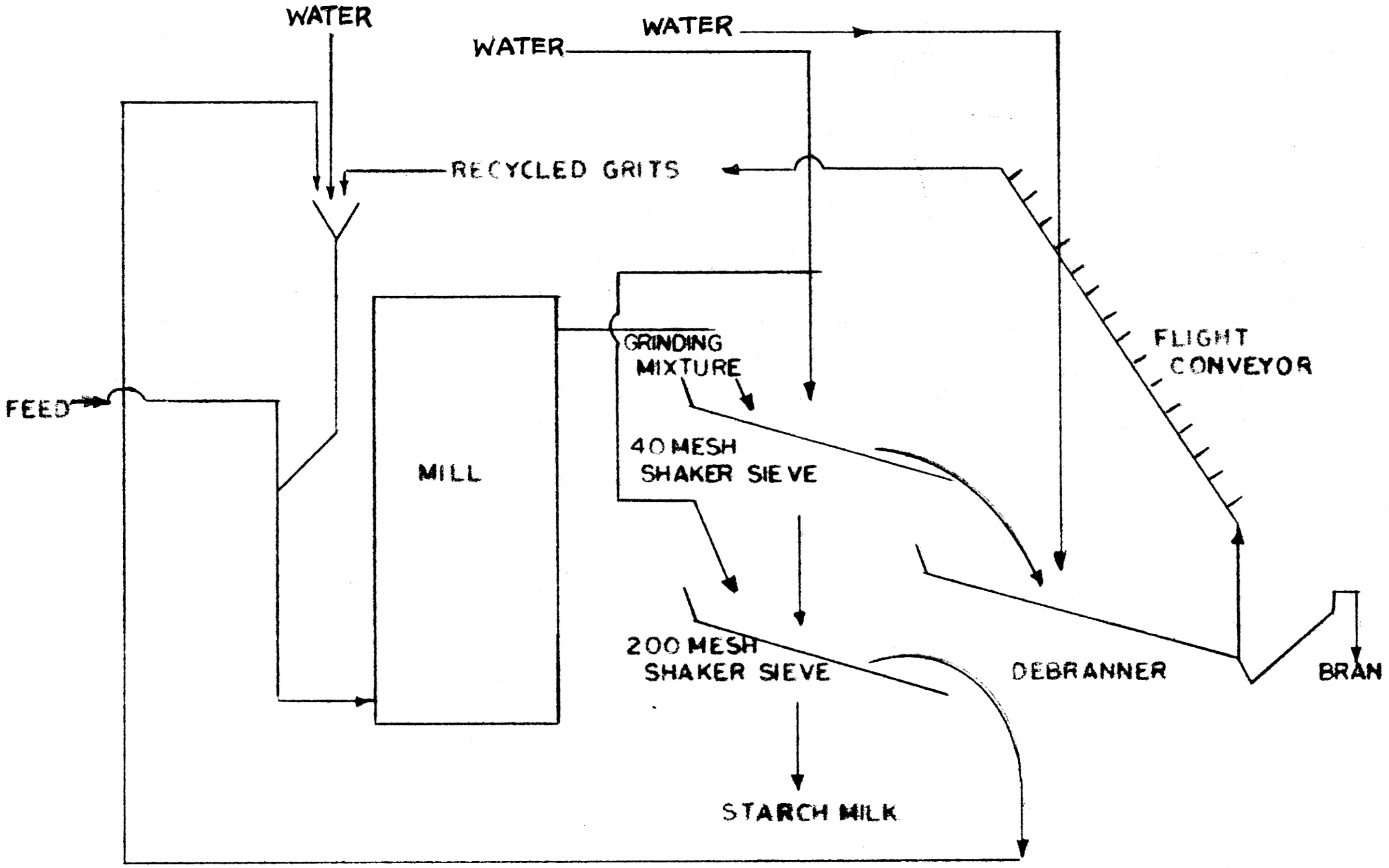
PLATE I


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
GLUTEN
STARCH
BRAN
WASTE WATER
GLUTEN SETTLER (DECANTED)
GLUTEN
DRYER
PRODUCTS
STARCH
GLUTEN
BRAN

EXPLANATION OF PLATE II

Flow sheet of two-screen operation of continuous hydraulic milling process for production of starch from sorghum grits.

PLATE II


WATER
WATER
WATER
RECYCLED GRITS
FEED
MILL
GRINDING MIXTURE
40 MESH SHAKER SIEVE
FLIGHT CONVEYOR
200 MESH SHAKER SIEVE
DEBRANNER
BRAN
STARCH MILK

EXPLANATION OF PLATE III

View of pilot plant.

1. Hydraulic mill.

2. Feed hopper.

3. Shaker screens.

4. Starch milk receiver.

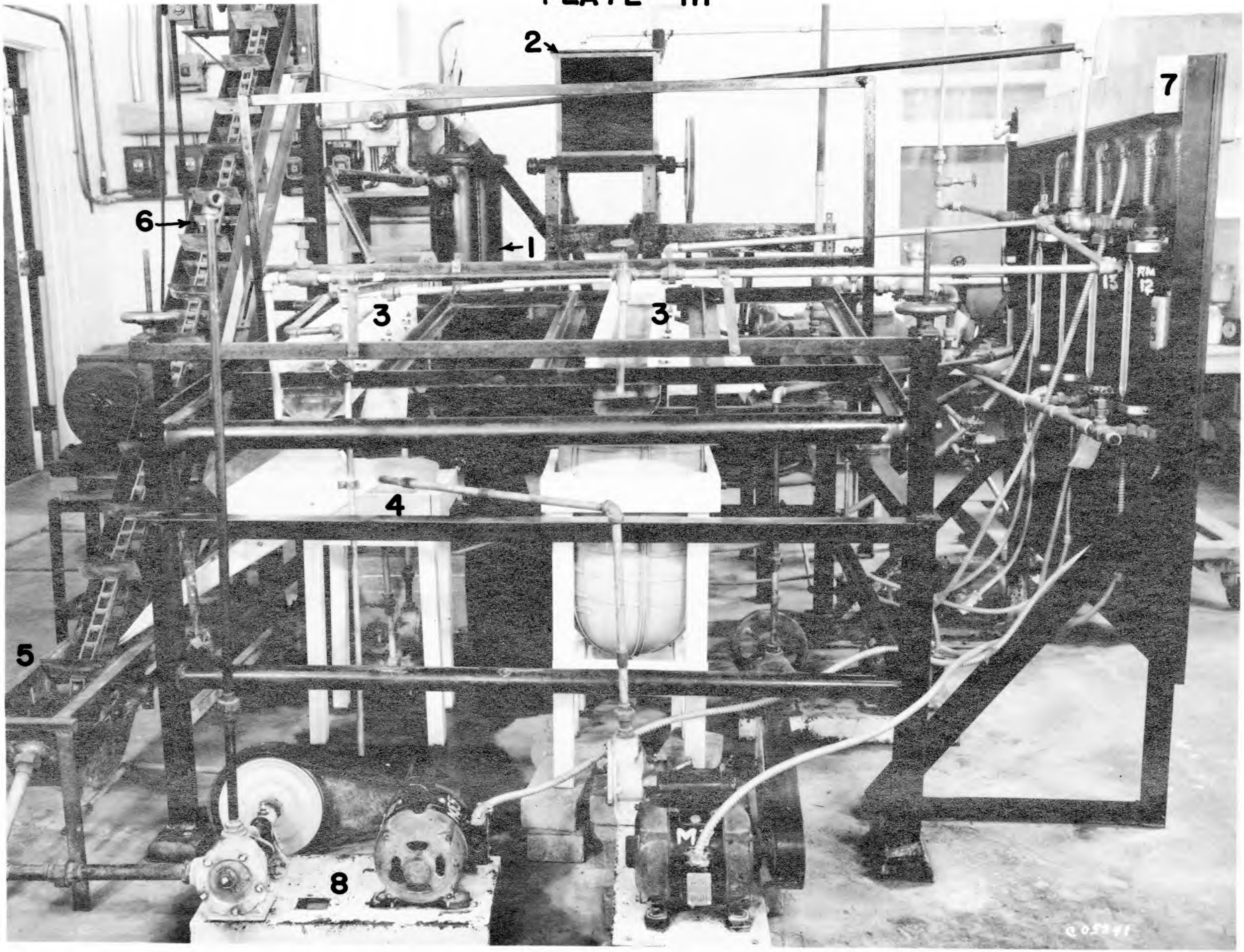
5. Debranner.

6. Flight conveyer.

7. Control panel.

8. Bran pump.

PLATE III



maintain the whole unit at nearly a constant temperature of 120 - 130° F. The steeping temperature was recorded automatically by using a Bristol temperature recorder.

Grinding Equipment

The grinding and screening equipment is shown in Plate IV.

Feeding Device. A V-shaped feed hopper was used. The capacity of the feed hopper was about 20 pounds of grits. An overhead $\frac{1}{4}$-inch galvanized iron pipe was used to lead a stream of water into the feed hopper. The steeped grits in the feed hopper were fed to the mill by a $1\frac{1}{8}$-inch by 12-inch screw conveyer. This conveyer was driven by a 1-Hp. Reeves Varimotor, and its speed was changeable from 26 to 156 rpm. At the outlet of the screw conveyer a $1\frac{1}{2}$-inch standard iron pipe was used as a downtake to lead the feed to the bottom of the hydraulic mill.

Hydraulic Mill. An elevation and a detailed drawing of the mill are shown in Plates V and VI. A vertical shaft holding horizontal blades was belt-driven by a 10-Hp. Fairbanks-Morse induction motor of 1170 rpm. The speed of the shaft was adjustable by the use of various pulley ratios. The shaft speed used throughout this work was 2240 rpm. The resulting vigorous agitation ground the steeped grits by impact and abrasion between the particles and the blades and the walls of the shell.

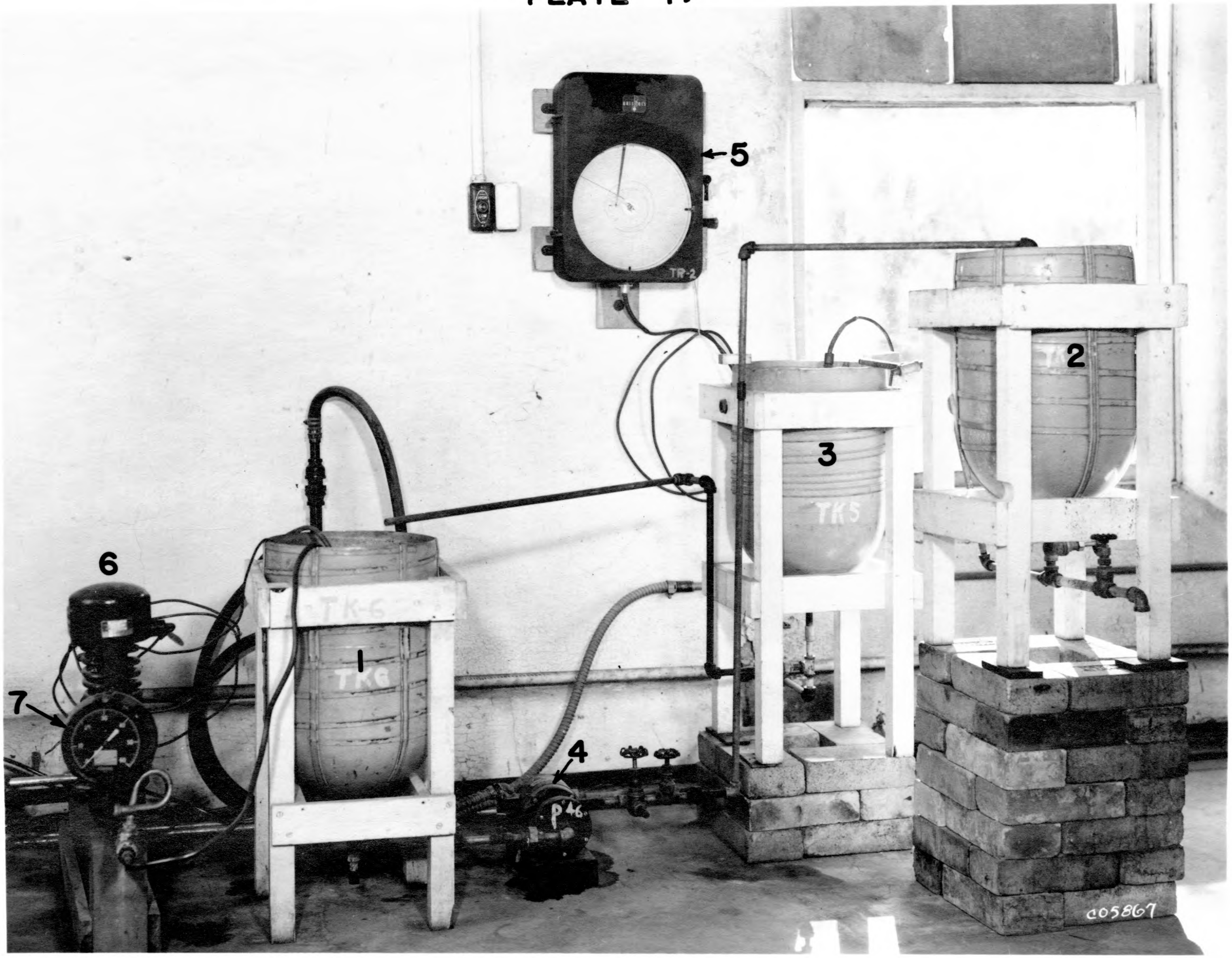
The power consumption was measured by a General Electric type V-3-A polyphase watthour meter with a watt hour constant of 7.2. A T-2 Frahm tachometer was used to indicate the speed of

EXPLANATION OF PLATE IV

Steeping equipment.

1. Heating tank.
2. First steeping tank.
3. Second steeping tank.
4. Steep water recycling pump.
5. Bristol temperature recorder.
6. Taylor self-acting steam regulator.
7. Steam pressure gauge.

PLATE IV

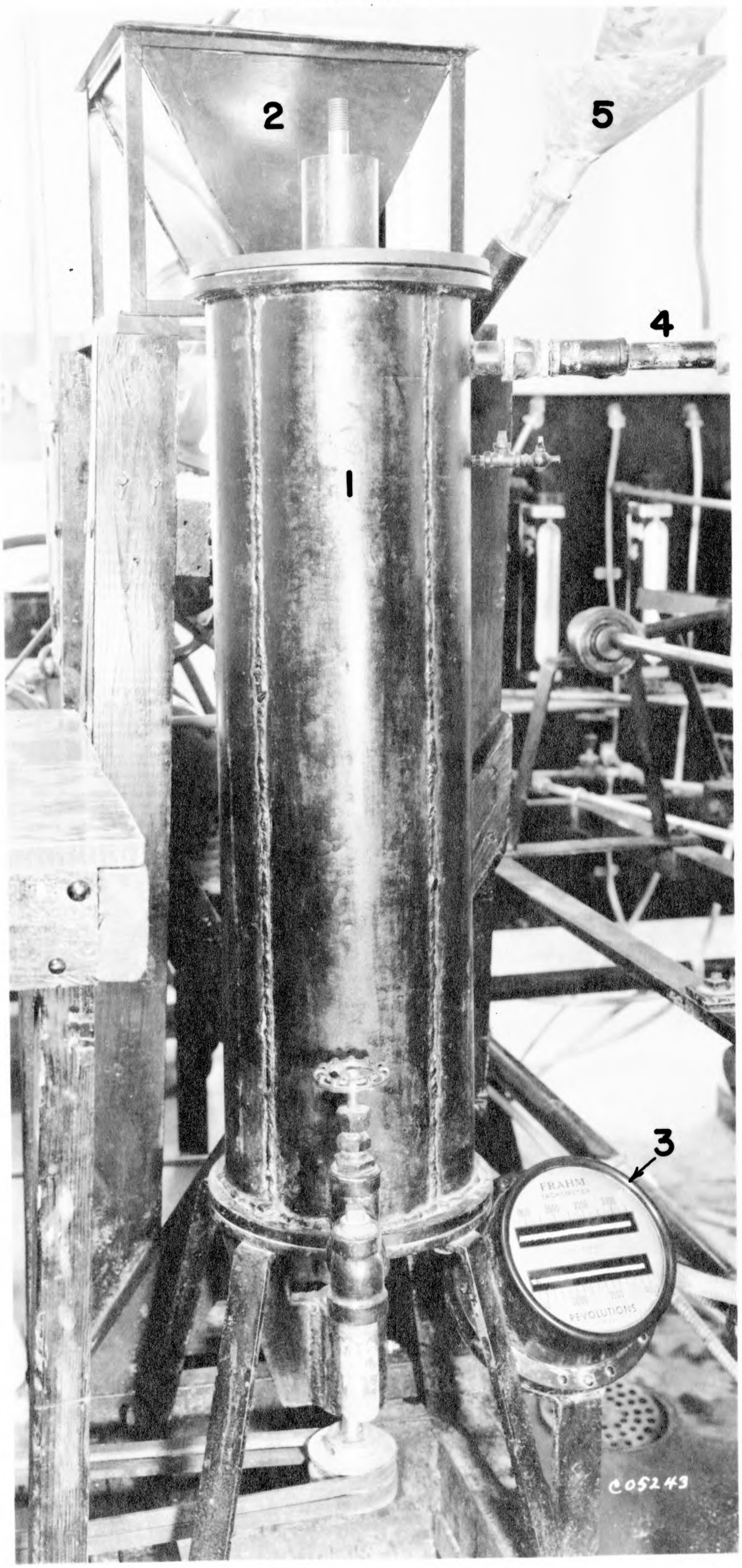


EXPLANATION OF PLATE V

Hydraulic mill.

1. Hydraulic mill.
2. Feed hopper.
3. Type T-2 Frahm tachometer.
4. Overflow from mill to screen.
5. Recycling line.

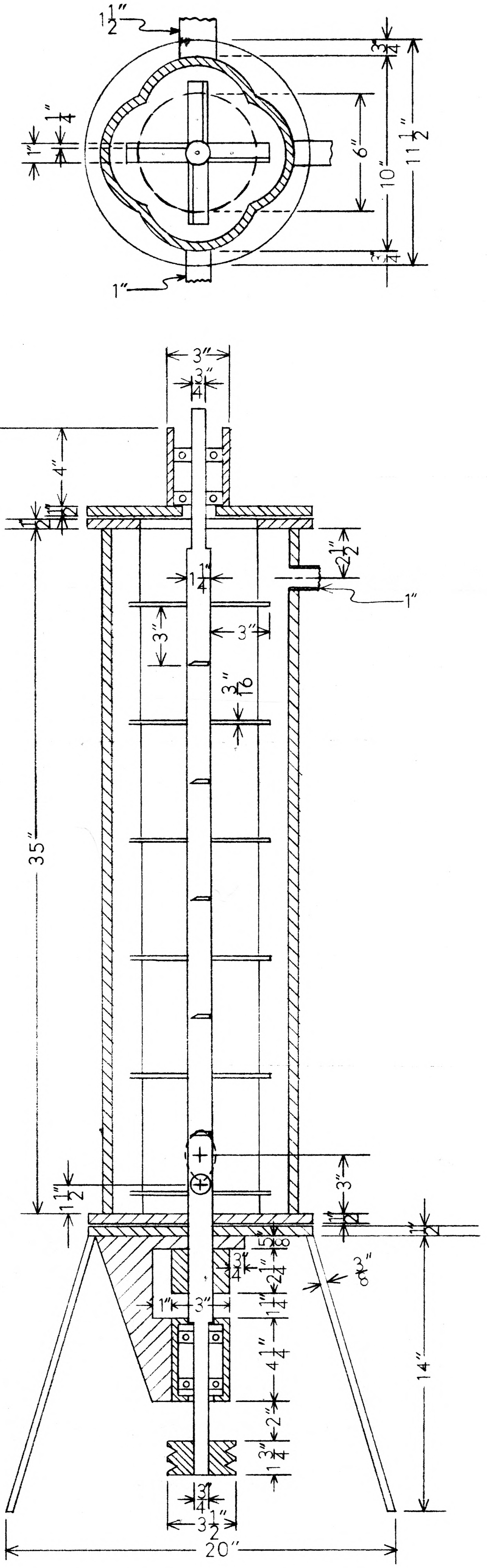
PLATE V



EXPLANATION OF PLATE VI

Detailed drawing of hydraulic mill.

PLATE VI



1 1/2"
1 1/4"
1"
3/4
6"
10"
11 1/2"
3"
3/4"
4"
55"
35"
2 1/2"
1 1/4"
3/16"
1 1/2"
5/8
3/8"
1"
2 1/4
1 1/4"
4 1/4"
2"
1 3/4"
14"
3 1/2"
20"

the stirrer of the mill. The ground material overflowed through a 1-inch standard pipe near the top of the mill onto the screen.

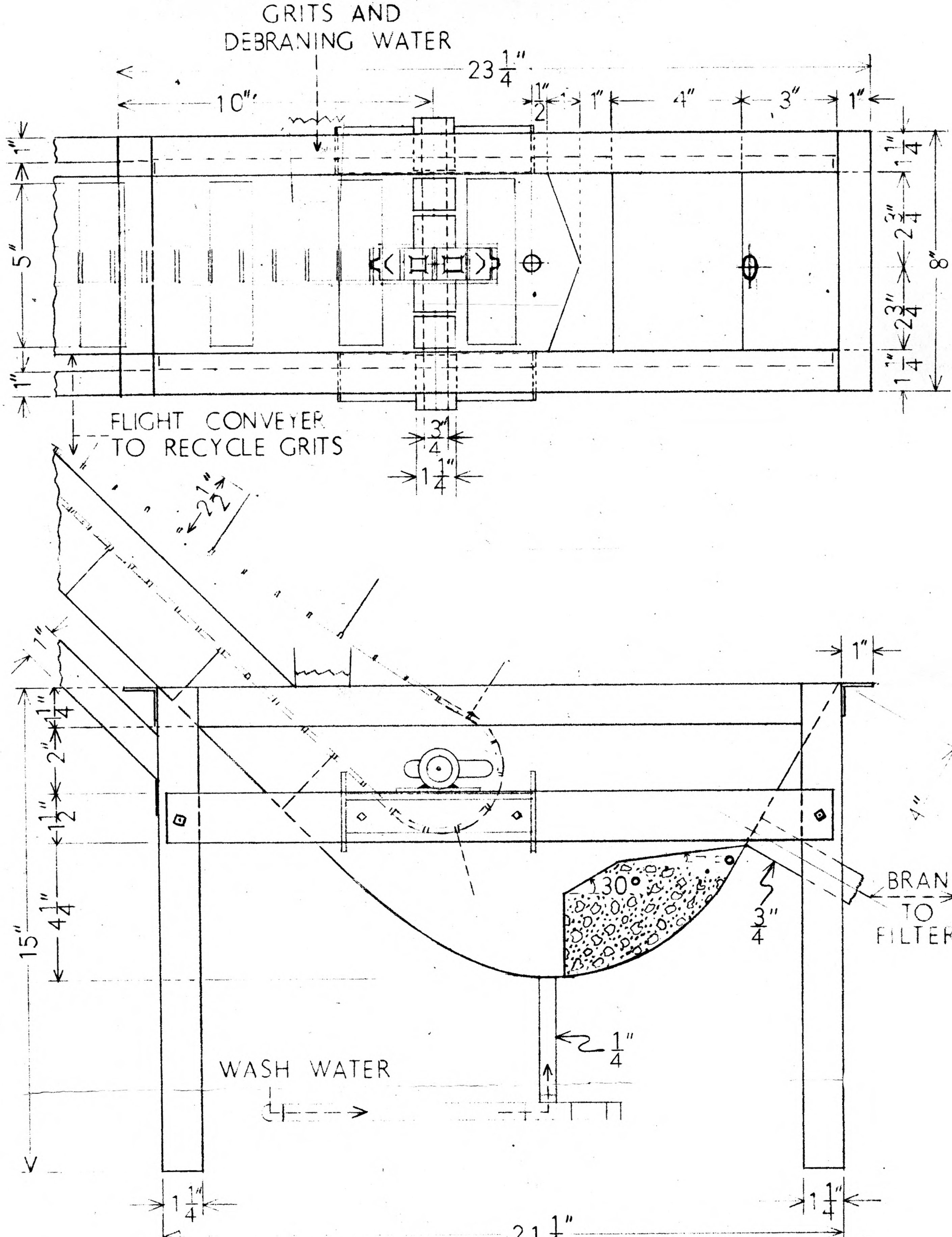
Screens. For runs IA-1 to IIB-4, one 200-mesh stainless steel screen, 31½ inches long and 4 inches wide, was used; for runs IIIA-1 to IIID-4, two screens of the same size, one of 40-mesh and one of 200-mesh, were arranged in series. In the former case, the overflow from the screen was washed off to the debranner and the underflow was pumped to the starch-milk storage. In the latter case, the overhead from the 40-mesh screen was washed into the debranner, but the underflow was pumped to the head of the 200-mesh screen. The overflow from this screen was washed off into the intake of a gear pump to be pumped back to the hydraulic mill directly, while the underflow was taken as starch milk. In both cases, the screens were mounted on a shaker which provided an oscillating motion of the screen by means of an eccentric. The oscillating frequency was 290 cycles per minute with ½-inch horizontal displacement. The slope of the screens was adjusted by means of a screw setting. A stream of wash water was introduced onto each screen through an overhead spray-nozzle. The position of the spray-nozzle was adjustable so that an efficient washing was assured.

Debranner and Flight Conveyer. The debranner, as shown in Plate VII, was part of the flight conveyer. The material in the debranner was separated by flotation, so that the light bran portion was floated out from a side outlet through a gear pump to a vacuum filter, and the unground heavy grits settled down to the

EXPLANATION OF PLATE VII

Drawing of debranner.

PLATE VII



GRITS AND DEBRANING WATER
FLIGHT CONVEYER TO RECYCLE GRITS
BRAN TO FILTER
WASH WATER
30°

bottom of the debranner and then were carried back to the mill by means of the flight conveyer. The flight conveyer used in this work had the following dimensions: width of flight, 5 inches; depth of flight, 2 7/16 inches; interval of flight, 5 inches; width of trough, 5⅛ inches; depth of trough, 3⅛ inches; length of trough, 75 inches; slope of trough, 45°. The conveyer was driven by a Reeves Varimotor through pulleys and a set of reduction gears so that the linear speed of the flight ranged from 1.5 to 9 feet per minute.

Starch Tables

Four 27-foot troughs in series were used as starch tables to separate the starch and gluten. The tables sloped alternately in opposite directions and were so arranged that the end of the first table was 10 inches above the head of the next one. The tables were 5¾ inches wide and 2⅛ inches deep. The slope of the tables was 1 inch per 10 feet.

Auxiliary Equipment

Control Panel. Flowrators (Fischer & Porter Company's Series 700, Master-Enclosed Type) were used to measure and control all of the water rates and the tabling rate of the starch milk. The flowrators were arranged as shown in the picture of the control panel, Plate VIII.

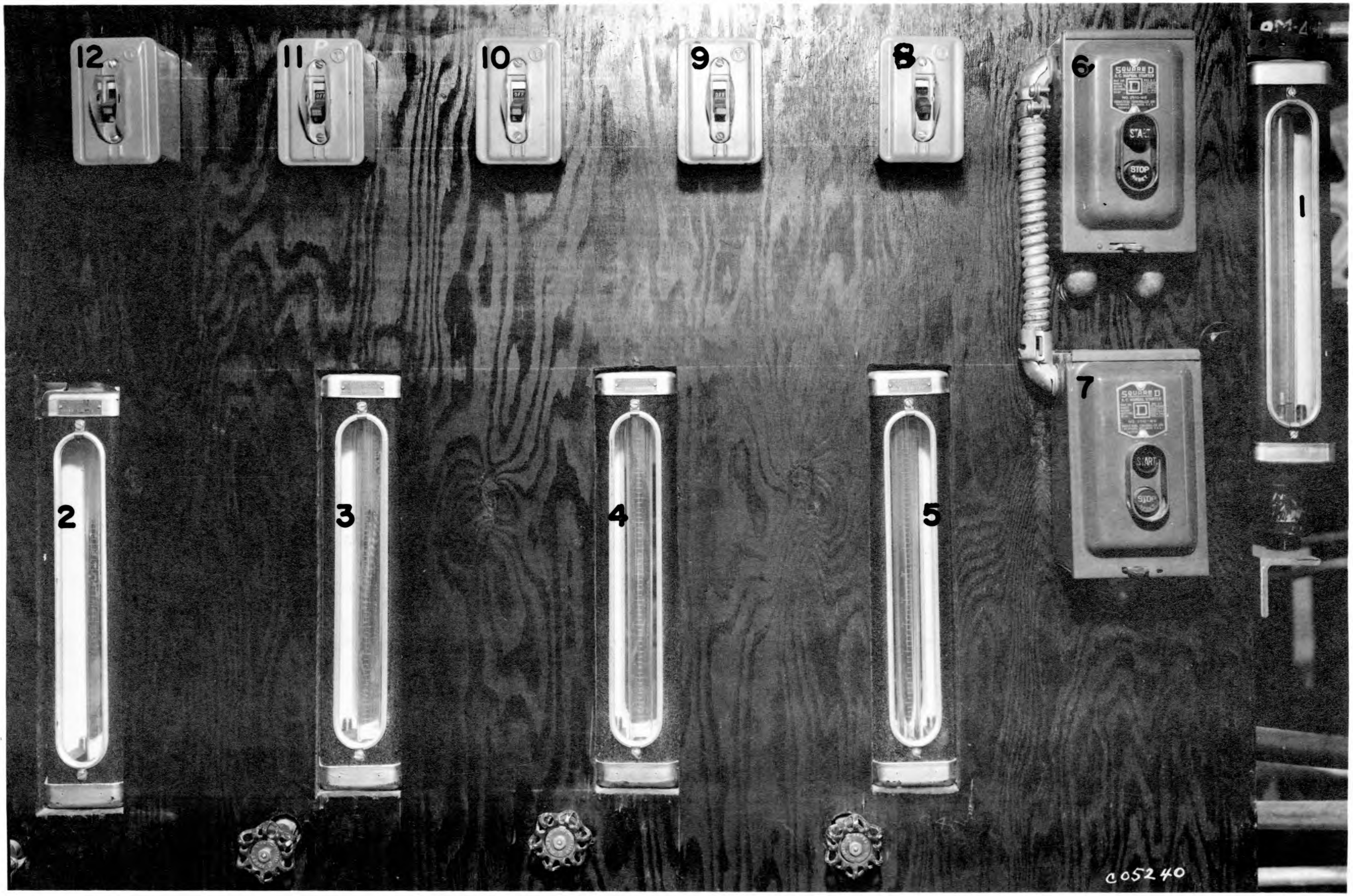
Filters. One nutsch-type filter with an area of four square feet was used for separating the bran from the flotation water. Another identical filter was used for filtering gluten and mill

EXPLANATION OF PLATE VIII

Control panel.

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

PLATE VIII



slurry. Both filters were connected to a vacuum pump (F. J. Stoke Machine Company Model 33275 reciprocating vacuum pump) which maintained a vacuum of about 25 inches of mercury.

Storage Tanks. A 55-gallon steel drum was used to store the starch milk from the screen before tabling. An agitator in the tank prevented the starch from settling out from the starch milk.

The overflow from the starch tables, which contained the protein or gluten, was stored in a 50-gallon, cone-bottom, stainless steel tank. Here the gluten settled to the bottom and the clear liquor was decanted through two 1-inch outlets on the side of the tank. The thick slurry of gluten was discharged from a 2-inch outlet in the bottom of the tank.

Dryer. The dryer used in this investigation was a tray and compartment dryer made by Geo. Koch Sons Company. Air was heated by passing over a steam coil and circulated over the trays by a blower. The temperature of the dryer was maintained at 130° F. by a Bristol pneumatic temperature controller-recorder. The size of the trays used in this dryer was 23½ inches by 17½ inches by 1½ inches.

Paste Viscosity Equipment

Barham et al (2) reported a method for determining the paste viscosity of starch by using a rotating cylinder viscometer. The rotating cylinder viscometer was built to measure continuously the changes in viscosity which take place in starch paste throughout a prescribed heating, cooking, and cooling cycle. There were two maxima which developed in the viscosity records, one in the heating period and the other in the cooling period. The ratio of these two maxima is an empirical index of starch quality.

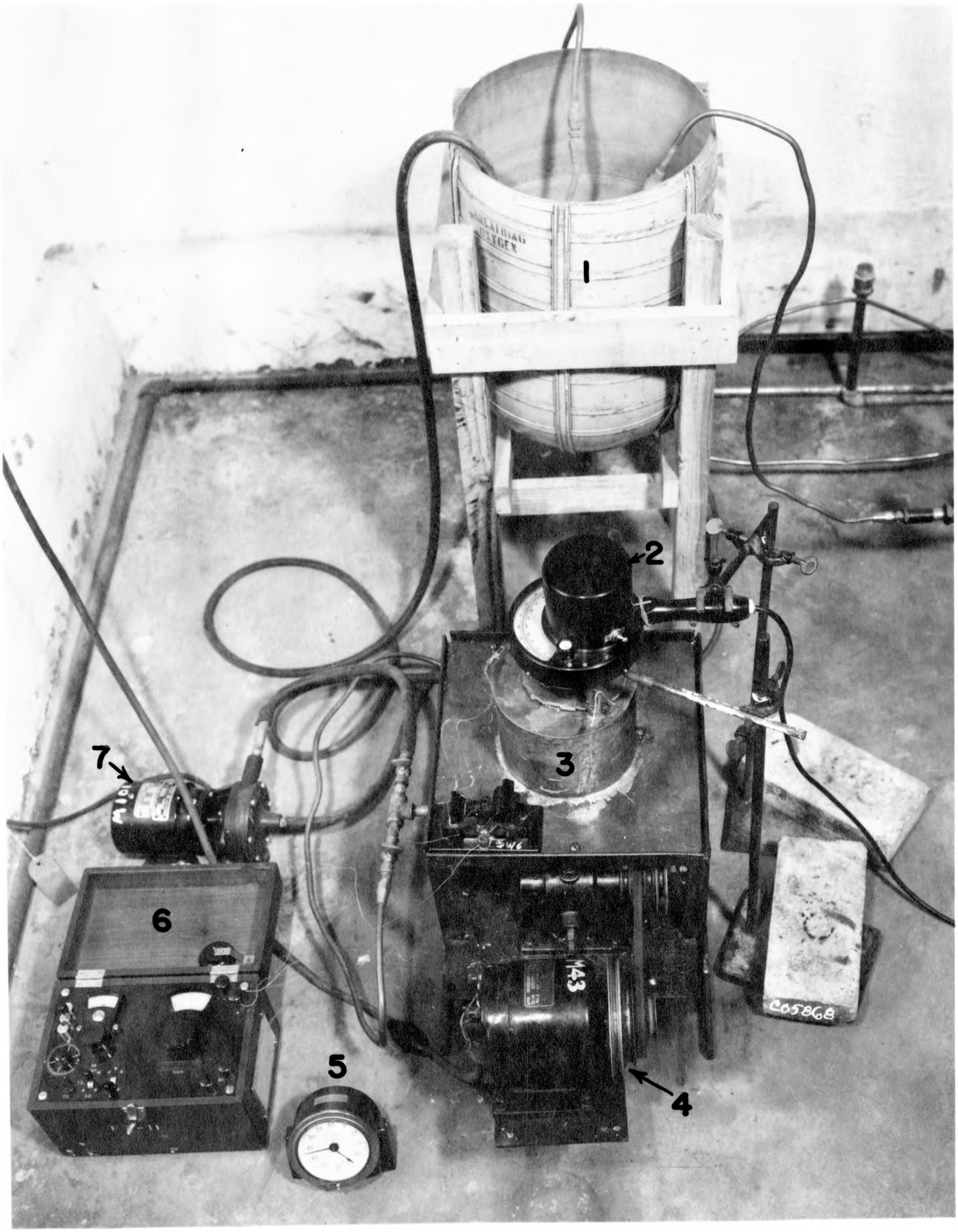
In order to use this method as a plant quality-control test, a modification of Barham's procedure was devised using the apparatus shown in Plates IX and X. The main part of this equipment is a cylindrical water-jacketed container in which the sample was heated or cooled by the circulation of heating or cooling water through the jacket. The dimensions of the cylinder are: inside diameter, 3 inches; outside diameter, 6¼ inches; height, 5 inches. A U-shape stirrer was inserted with its shaft passing through the center of the bottom of the container. This was driven by a 1/12-Hp. motor through a set of reduction gears and pulleys by which the speed of the stirrer was adjusted. The hot water was heated in an open 15-gallon tank with low-pressure steam passing through a copper steam coil inside the tank. A 1/30-Hp. centrifugal pump was used to maintain the circulation of hot water. At the inlet of the water jacket an orifice was used to control the rate of circulating water. Beyond the orifice, a tee provided the introduction of cooling water instead of hot water. A Brookfield Synchro-lectric Viscometer, Multi-speed, Model LVF, was mounted directly above the container and the spindle of the viscometer was immersed in the starch paste, so that viscosity readings of the paste were conveniently taken at rather short intervals. The temperatures of the water jacket and of the starch paste were measured by means of thermocouples which were

EXPLANATION OF PLATE IX

View of viscosity equipment.

1. Heating tank.
2. Brookfield Synchro-lectric Viscometer.
3. Jacketed starch solution container.
4. Stirrer motor.
5. Timer.
6. Leeds & Northrup Potentiometer.
7. Hot water circulating pump.

PLATE IX

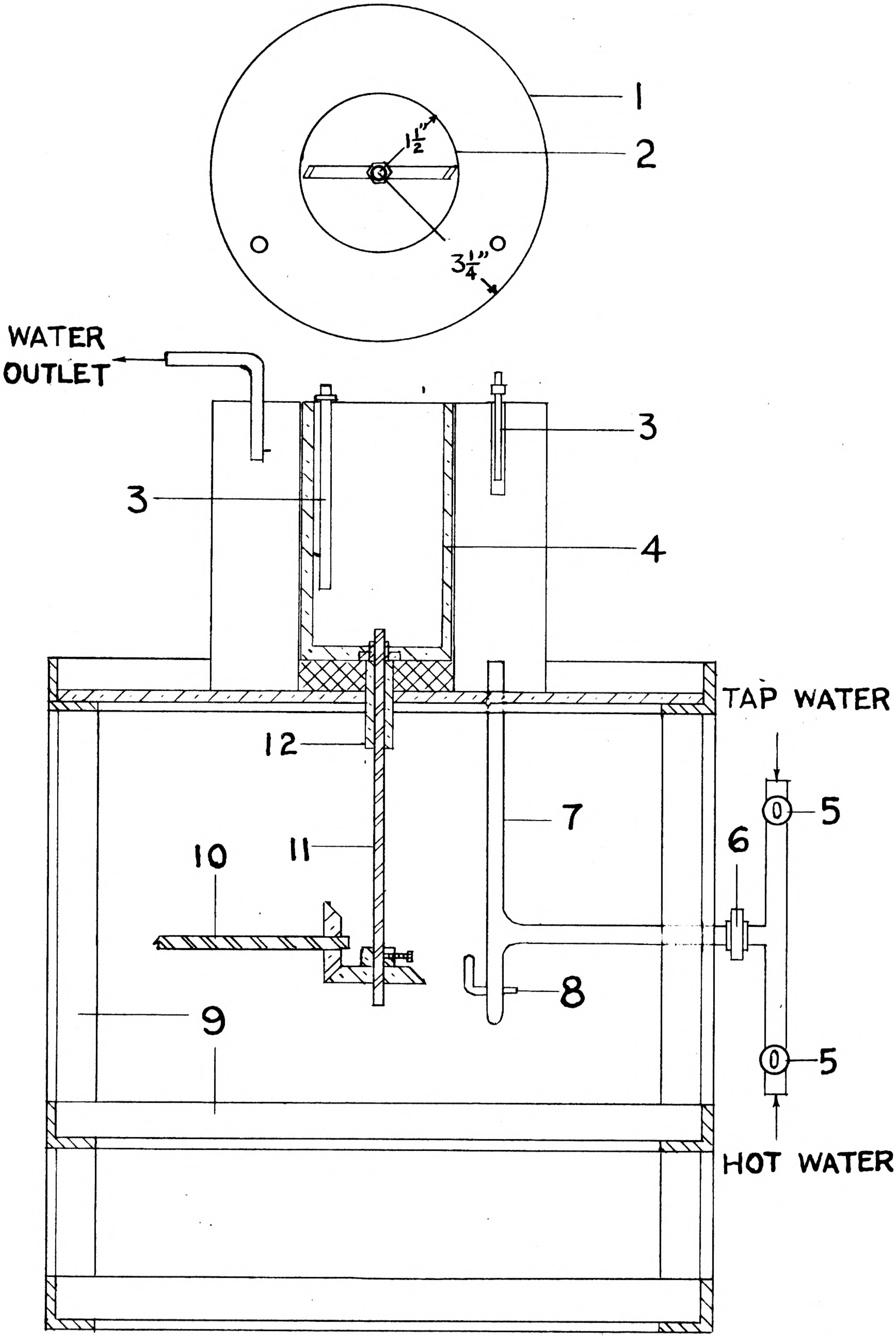


EXPLANATION OF PLATE X

Drawing of viscosity equipment.

1. Water jacket.
2. Starch solution container.
3. Thermocouples.
4. Paddle of stirrer.
5. Valves.
6. Orifice.
7. Inlet water pipe.
8. Drain valve.
9. Frame.
10. Motor driving shaft.
11. Stirrer shaft.
12. Shaft housing.

PLATE X


1
2
1 1/2"
3 1/4"
WATER OUTLET
3
3
4
TAP WATER
12
5
7
6
10
11
5
8
9
HOT WATER

connected to a Leeds & Northrup Potentiometer.

MATERIAL

The only raw material used in this investigation was milo sorghum grits which were supplied by Grain Products, Incorporated, of Dodge City, Kansas. The term "grits" used here refers to the endosperm part of the milo kernel after the removal of bran and germ. The grits were stored in 55-gallon, open-head barrels. A small amount of carbon disulfide in a 50 cc. erlenmeyer flask was placed in each drum as an insecticide. The drums were tightly covered.

The composition of the grits was slightly different from batch to batch. Three batches of grits were used in this work. The analyses of the grits, which were performed by the Chemical Service Laboratory at Kansas State College, are shown in Table 1. Grits from batch 1 were used in runs of Class I; grits from batch 2 were used in runs of Class II; and grits from batch 3 were used in runs of Class III.

Table 1. Analysis of milo sorghum grits.

Component	Weight per cent		
	1st batch	2nd batch	3rd batch
Protein	11.43	9.50	9.03
Ether extract	1.33	0.86	0.97
Crude fiber	1.06	0.58	0.64
Moisture	10.09	12.03	11.10
Ash	0.83	0.62	0.61
N-free extract	75.26	76.41	77.65
Carbohydrates	75.60	77.00	78.40
Starch	69.70	72.20	73.70

The Manhattan city water was used for both steeping and processing water. The analysis of water composition was reported by Fan (5) as shown in Table 2.

Table 2. Analysis of Manhattan city water.

Total hardness as $CaCO_3$, ppm	76
Non-carbonate hardness as $CaCO_3$, ppm	45
Total dissolved solids, ppm	218
p^H value	8.97

The only steeping agent used in this work was sulfur dioxide. A saturated solution of sulfur dioxide was made by bubbling the gas from a cylinder (Calco Chemical Division, American Cyanimide Company) through distilled water at room temperature. The actual steeping liquor containing 0.1 per cent SO_2 was obtained by dilution of the saturated solution.

EXPERIMENTAL PROCEDURE

The operation may be divided into three main steps, namely, steeping, grinding, and tabling. In addition, a paste viscosity test was conducted. These will be discussed according to their operating sequence in the following sections.

Steeping

Thirty to sixty pounds of grits were weighed out accurately and put into the steeping tank. The steeping water was previously heated in the heating tank to a temperature of 130° F. The quantity of water used was about 0.25 to 0.36 gallons per pound of grits. The steeping water was circulated by means of a centrifugal pump at a rate of ½ gallon per minute. The steeping temperature was recorded by the Bristol temperature recorder. The time of steeping ranged from 1 hour to 16 hours. In the case of sulfur dioxide steeping, the operating conditions and procedure were the same as that for pure water steeping, except that a steeping liquor containing 0.1 per cent SO_2 was employed. The concentrations of SO_2 in the initial and final steeping liquor were determined by titration. At the end of the steeping period, the steep water was drained out of the steep tank and discharged to the sewer.

Grinding

The steeped grits were transferred into the feed hopper manually. Before the feed into the mill was begun, a power reading was taken on the hydraulic mill running empty. This served as a basis for calculating the net power consumption of the mill for grinding the grits. The grits were fed into the intake of the mill by the screw conveyer. The feed rate was calculated from the average time required for feeding 10 pounds of unsteeped or steeped grits into the mill. The maximum feed rate obtained for this screw conveyer was 50 pounds of unsteeped grits or 40 pounds of steeped grits per hour. The hydraulic mill and the feed water were started at the same time as the screw conveyer. As soon as the ground grits began to overflow from the mill, the shaking screen motor was started, the flow of spray water onto the screen was begun, and the motor used for pumping the underflow from the screens to the starch milk storage was started. Finally, the flow of debranning water and the flight conveyer were started.

All processing conditions, the power reading of the mill, the temperature of the mill overflow, the density of the starch milk, and the readings of the water flowrators were taken at 5-minute intervals. The steady state was roughly indicated by the fact that the density of the starch milk approached a constant value. A more precise criterion for the steady state was the rate of overflow to the recycle elevator. When a constant recycling rate was observed, the steady state was assumed to be attained. Generally, the steady state would be attained at least 60 minutes after the beginning of the run. Until this time all product streams were sent to the sewer.

After reaching a steady state, the flow of starch milk was changed from the sewer to the starch storage tank and, at the same time, the flow of bran from the debranner was also changed from the sewer to the nutsch filter. The time of running after the steady state was reached varied from 10 to 15 minutes. The rate of production was based on this period of operation. At the middle of the run, the rate of mill overflow was measured by calibrated beakers, and a sample of the mill overflow was taken, from which the solid contents of the mill overflow was later determined. These quantities made it possible to calculate the recycle rate to the mill.

Immediately after sampling, the milling operation was stopped and the contents of the hydraulic mill was drained out into a calibrated bucket. The slurry was then filtered, and the solid portion was dried in the tray and compartment dryer. From the weight of the solid portion, the mill concentration was evaluated.

Tabling

The starch milk was pumped from the storage tank to the head of the first table through a $\frac{1}{4}$-inch galvanized pipe at a rate of 0.6 gallon per minute (in most cases). The starch settled out on the tables while the gluten suspended in the overflow liquid passed from table to table. The overflow from the last table containing the gluten fraction and some starch was pumped by a gear pump to the 50-gallon stainless steel storage tank.

Immediately after the tabling, the starch remaining on the tables was washed by introducing water to the head of the first table in the same manner as tabling but at a rate of 0.8 to 1.0 gallon per minute. The time of washing ranged from 20 to 30 minutes. After flowing over the tables, the washing water was also collected in the same storage tank where the gluten portion was stored. A small amount of saturated SO_2 solution was added to the tank to prevent fermentation, and the gluten was allowed to settle overnight. On the following day, the upper clear liquid was taken off by means of a syphon and the slurry was filtered and dried. The gluten was found to be very difficult to filter, and for this reason, the thick gluten slurry was sometimes dried without previous filtration. The dry solid thus obtained was termed "gluten".

The starch settled on the starch table was taken off manually. Its moisture content was found to be about 40 per cent. The wet starch was placed on trays and dried at 130° F. for 24 hours.

The analyses of the products were performed by the Chemical Service Laboratory of the Chemistry Department of Kansas State College. The paste viscosity of the starch was determined by the investigator. This will be discussed in the next section.

Paste Viscosity Test

The starch sample used for this test was previously dried in a vacuum oven at 65° C. for 24 hours. A dried starch sample of about 20 grams was weighed out and suspended in a measured quantity of water about 400 cc, at 21° ± 1° C., so that a starch solution of 5 per cent by weight was obtained. The water jacket of the viscometer was heated up to 98° C. before pouring the starch solution into the container. As soon as the starch solution was poured into the container, the stirrer was started. The rate of revolution of the stirrer was kept at 70 rpm. The temperature of the container was maintained around 96° C. throughout the heating period. During this period, temperature and viscosity readings were taken at 2- to 5-minute intervals. After 20 minutes, the hot water was cut off and the cool water was introduced into the water jacket by opening the cool water valve. The temperature and viscosity readings were taken at 5- to 10-minute intervals during the cooling period. The cooling period was prolonged to 140 minutes in order to assure that the maximum viscosity was attained. Since tap water was used as cooling water, the minimum temperature attainable approached the temperature of the tap water, which was almost constant at 20° ± 1° C. throughout all runs made.

EXPERIMENTAL DATA

For purposes of referring to the data collected for each of the different types of runs, a coded classification system was used to number the runs. The data were grouped into three classifications and designated by coded numbers, as IA-1, IIA-2, IIIB-3, etc., to correspond to a given area of investigation and a given run as follows:

Classification of Runs

I. General investigation runs (one screen).

   A. Preliminary runs.

      Each run was carried out for a certain quantity of feed. The run was started as the feed began and it was stopped at the end of the feeding. Therefore, the processing data and results were not based on the conditions prevailing after attainment of the steady state, but on the total time of run including the start-up period.

   B. No steeping.

      This set of runs, as well as those runs included in the next two classes, were carried out by continuous grinding, i.e., the data were taken after the steady state was attained.

II. Maximum recovery investigation runs (one screen).

All operating conditions were kept constant except feed rate and feed water rate, which were varied so as to test the theory presented by Fan (5), that the per cent recovery of starch, as well as the mill capacity, would increase with increased feed rates up to a maximum.

A. Two-hour steeping.

B. Four-hour steeping.

III. Steeping investigation runs (two screens).

A. No steeping.

B. Four-hour steeping.

C. Sixteen-hour steeping.

D. Sulphur dioxide steeping, 0.1 per cent SO_2.

Treatment of Data

All processing data were recorded in rate units, such as lb./hr., gal./hr., etc. The calculation of yields and material balances was performed on the basis of dry feed. The power consumptions for grinding were obtained by the following formula:

$$KW = \left(\frac{60 \times 7.2}{1000}\right)(R - R_e)$$

where R is the watthour meter reading in rpm during the steady state of the run. R_e is the watthour meter reading in rpm for empty mill.

$\frac{60 \times 7.2}{1000}$ is the conversion factor.

The water consumptions were directly obtained from the flowrator readings. One other calculation involved was the rate of recycling of unground grits, which was evaluated simply by subtracting the feed rate from the overflow rate of the mill.

Data

The processing data and results and the analysis of products are tabulated in Tables 3 to 10 according to the sequence listed in the classification.

Table 3. Processing data and results for runs of class IA. (Preliminary runs.)

Coded Run Number		IA-1	IA-2	IA-3	IA-4
Steeping conditions					
Temperature	°F	125	125	No	No
Time	hr.	2	2	Steep	Steep
Quantity of water/unit feed	gal./lb.	0.36	0.36		
Water recycle rate	gal./hr.	30	30		
Grinding					
Time of run	hr.	1.66	1.50	1.12	2.37
Mill temperature	°F	90	85	95	98
Energy consumption	KW	1.90	1.86	1.86	2.28
Total feed, as charged	lb.	23.4	23.4	18.9	49.6
Dry material only	lb.	21.0	21.0	17.0	44.6
Average gravity of starch milk	°Be' 60°F/60°F	2.30	2.30	3.18	3.18
Slope of screen	in./ft.	1.8	1.8	1.8	1.8
Total processing water	gal.	90	81	61	135
Tabling conditions					
Tabling rate	gal./hr.	36	36	48	54
Washing water rate	gal./hr.	36	36	48	54
Time of washing	min.	70	100	60	36
Total washing water	gal.	42	60	48	32
Yield of products, dry basis					
Starch	lb.	12.0	12.6	11.2	27.2
(Based on total dry feed)	%	57.0	59.8	65.9	61.1
Gluten portion	lb.	2.90	3.32	2.76	10.4
	%	13.8	15.8	16.2	23.4
Bran portion	lb.	4.04	2.14	1.33	3.9
	%	19.2	10.2	7.80	8.8
Total	lb.	18.9	18.1	15.3	41.5
	%	90.2	85.8	89.9	93.3
Starch recovery, dry basis					
Starch extracted	lb.	12.0	12.6	11.2	27.2
Starch in feed	lb.	16.3	16.3	13.2	34.7
Recovery	%	73.5	77.2	84.9	78.3

Table 4. Processing data for runs of class IB. (General investigation runs, no steeping.)

Coded Run Number		IB-1	IB-2	IB-3	IB-4	IB-5	IB-6	IB-7
Grinding								
Mill temperature	°F	102	91	100	104	104	110	110
Energy consumption	KW	2.22	2.46	2.36	2.15	2.04	2.32	2.28
Feed rate, wet basis	lb./hr.	18.7	50.0	33.3	28.6	20.7	37.5	33.3
dry basis	lb./hr.	16.8	45.0	30.0	25.7	18.6	33.7	30.0
Mill concentration	lb.sol./cu. ft.	-	-	-	-	-	-	-
Specific gravity of starch milk	Be'	2.42	4.62	4.49	4.08	3.26	6.11	4.62
Grits recycling rate	lb./hr.	-	-	-	-	-	-	-
Overflow rate of solid material from mill	lb./hr.	-	-	-	-	-	-	-
Slope of screen	in./ft.	1.8	1.8	1.5	1.5	1.5	1.0	1.0
Processing water consumption								
For feeding	gal./hr.	12	26	15	15	15	15	15
For screening	gal./hr.	12	9	9	9	9	9	9
For debranning	gal./hr.	18	18	12	12	12	12	12
For recycling	gal./hr.	12	9	9	9	9	9	9
Total	gal./hr.	54	62	45	45	45	45	45
Tabling conditions								
Tabling rate	gal./hr.	48	42	36	36	36	36	36
Washing water rate	gal./hr.	60	60	60	60	60	60	60
Time of washing	min.	6	17	20	15	60	14	10
Total washing water	gal.	6	17	20	15	60	14	10

Table 5. Results for runs of class IB. (General investigation runs, no steeping.)

Coded Run Number		IB-1	IB-2	IB-3	IB-4	IB-5	IB-6	IB-7
Yields of products, dry basis								
Starch	lb./hr.	9.8	25.0	17.0	14.0	10.5	15.9	16.0
	%	58.3	55.5	56.8	54.5	56.5	47.3	53.3
Gluten portion	lb./hr.	2.32	5.0	2.00	2.24	1.68	2.36	1.88
	%	13.8	11.1	6.67	8.71	9.04	7.01	6.27
Bran portion	lb./hr.	1.60	5.0	5.52	4.52	2.82	10.31	7.50
	%	9.5	11.1	18.40	17.70	15.20	30.64	25.00
Total	lb./hr.	13.7	35.0	24.5	20.8	15.0	28.6	25.4
	%	81.6	77.7	81.7	80.9	80.7	85.0	84.5
Starch recovery, dry basis								
Starch extracted	lb./hr.	9.8	25.0	17.0	14.0	10.50	15.94	16.0
Starch in feed	lb./hr.	13.1	34.9	23.2	19.9	14.40	26.1	23.2
Recovery	%	75.0	71.6	73.3	70.4	72.90	61.1	68.8
Starch accounted for, dry basis								
In starch	lb./hr.	9.64	24.84	16.89	14.90	10.44	15.79	15.79
In gluten portion	lb./hr.	1.08	2.23	0.91	0.10	0.74	0.99	0.84
In bran portion	lb./hr.	0.70	2.75	3.22	2.64	1.67	6.55	4.28
Total	lb./hr.	11.42	29.81	21.02	17.64	12.85	23.33	20.91
Total in feed	lb./hr.	13.1	34.9	23.2	19.9	14.40	26.1	23.2
Starch accounted for	%	87.2	85.4	90.6	88.7	89.3	89.2	90.0
Protein accounted for, dry basis								
In starch	lb./hr.	0.160	0.157	0.107	0.097	0.059	0.150	0.190
In gluten portion	lb./hr.	0.920	1.794	0.714	0.894	0.678	0.885	0.706
In bran portion	lb/hr.	0.376	0.753	1.032	0.956	0.630	1.650	1.270
Total	lb./hr.	1.456	2.704	1.85	1.95	1.37	2.68	2.17
Total in feed	lb./hr.	1.92	5.15	3.43	2.94	2.12	3.85	3.43
Protein accounted for	%	75.8	52.5	54.0	66.3	64.6	69.1	63.2
Energy consumption for grinding								
For unit quantity of feed	KWH/lb.	0.132	0.055	.079	.084	0.110	0.069	0.076
For unit quantity of starch	KWH/lb.	0.227	0.098	.139	.154	0.194	0.146	0.143
Water consumption of process								
Steeping water/unit feed	gal./lb.	--	--	--	--	--	--	--
Processing water/unit feed	gal./lb.	3.21	1.38	1.50	1.75	2.42	1.33	1.50
Washing water/unit feed	gal./lb.	0.38	0.38	0.33	0.58	1.08	0.71	0.53
Total/unit feed	gal./lb.	3.59	1.76	1.83	2.33	3.50	2.04	2.03
Steeping water/unit starch	gal./lb.	--	--	--	--	--	--	--
Processing water/unit starch	gal./lb.	5.51	2.48	2.68	3.21	4.28	2.82	2.81
Washing water/unit starch	gal./lb.	0.65	0.68	0.59	1.07	1.90	1.50	1.00
Total/unit starch	gal./lb.	6.16	3.16	3.24	4.28	6.18	4.32	3.81

Table 6. Processing data for runs of class II. (Maximum recovery investigation runs.)

Coded Run Number		IIA-1	IIA-2	IIA-3	IIA-4	IIA-5	IIA-6	IIA-7	IIA-8	IIA-9	IIA-10	IIB-1	IIB-2	IIB-3	IIB-4	IIB-5
Steeping conditions																
Temperature	°F	125	120	123	120	120	125	120	120	120	122	120	122	120	120	120
Time	hr.	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4
Agent		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quantity of water/unit feed	gal./lb.	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Water recycle rate	gal./hr.	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Grinding																
Mill temperature	°F	100	106	110	104	97	108	102	104	103	92	108	110	111	100	99
Energy consumption	KW	2.12	1.99	2.42	1.94	2.16	1.99	2.07	2.08	2.29	2.02	1.94	1.99	1.82	2.20	2.60
Feed rate, wet basis	lb./hr.	23.7	23.8	35.7	26.6	32.2	32.6	42.8	33.6	34.2	45.1	24.0	28.0	28.3	27.2	33.3
dry basis	lb./hr.	20.6	20.7	31.2	23.2	28.1	28.4	37.3	29.3	29.8	39.6	21.0	24.4	24.6	23.7	29.0
Mill concentration	lb.sol./cu.ft.	11.6	11.2	20.3	8.1	9.6	10.3	18.2	8.3	8.8	17.4	9.2	11.4	11.6	8.6	8.4
Specific gravity of starch milk	Be'	4.39	3.81	6.08	3.67	4.36	4.39	5.04	4.08	4.36	4.90	3.81	4.49	4.49	3.54	3.67
Grits recycling rate	lb./hr.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Overflow rate of solid material from mill	lb./hr.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Slope of screen	in./ft.	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Processing water consumption																
For feeding	gal./hr.	12	12	12	15	15	15	15	21	21	21	12	12	12	15	21
For screening	gal./hr.	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
For debranning	gal./hr.	0	6	6	6	12	12	6	6	0	6	6	6	6	6	6
For recycling	gal./hr.	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Total	gal./hr.	30	36	36	39	45	45	39	45	39	45	36	36	36	39	45
Tabling conditions																
Tabling rate	gal./hr.	48	36	36	36	48	48	36	36	48	36	36	36	36	36	36
Washing water rate	gal./hr.	60	60	60	60	60	60	60	60	60	48	60	60	60	60	60
Time of washing	min.	20	18	20	20	20	22	20	20	20	20	20	20	20	20	20
Total washing water	gal.	20	18	20	20	20	22	20	20	20	16	20	20	20	20	20

Table 7. Results for runs of class II. (Maximum recovery investigation runs.)

Coded Run Number		IIA-1	IIA-2	IIA-3	IIA-4	IIA-5	IIA-6	IIA-7	IIA-8	IIA-9	IIA-10	IIB-1	IIB-2	IIB-3	IIB-4	IIB-5
Yields of products, dry basis																
Starch	lb./hr.	10.9	11.8	15.2	13.6	18.3	19.5	20.6	18.5	20.0	19.5	13.2	15.5	15.4	15.0	18.2
	%	52.9	57.0	48.8	58.6	65.1	68.6	55.2	63.1	67.1	49.6	62.9	63.6	62.4	63.1	62.8
Gluten portion	lb./hr.	1.2	2.8	2.5	1.0	2.0	1.9	2.8	1.2	2.0	2.5	1.5	2.2	2.1	1.5	1.6
	%	5.8	13.6	8.0	4.3	7.1	6.7	7.5	4.1	6.7	6.3	7.1	9.1	8.5	6.3	5.5
Bran portion	lb./hr.	7.8	2.1	8.4	2.8	4.2	5.3	5.6	5.8	3.5	6.4	1.9	2.4	2.7	2.7	4.2
	%	37.9	10.1	26.9	12.1	15.0	18.7	15.0	19.8	11.8	15.3	9.1	9.8	11.1	11.4	14.5
Total	lb./hr.	19.9	16.7	26.1	17.4	24.5	26.7	29.0	25.5	25.5	28.4	16.6	20.1	20.2	19.2	24.0
	%	96.6	80.7	83.7	75.0	87.2	94.0	77.7	87.0	85.6	72.2	79.1	86.5	82.0	81.0	82.8
Starch recovery, dry basis																
Starch extracted	lb./hr.	10.9	11.8	15.2	13.6	18.3	19.5	20.6	18.5	20.0	19.5	13.2	15.5	15.4	15.0	18.2
Starch in feed	lb./hr.	17.1	17.2	25.8	19.2	23.2	23.6	30.9	24.2	24.7	32.6	17.3	20.2	20.4	19.6	24.0
Recovery	%	63.7	68.6	58.9	70.8	79.0	82.6	66.7	76.5	81.0	59.8	76.3	76.7	75.5	76.5	75.9
Starch accounted for, dry basis																
In starch	lb./hr.	10.85	11.75	15.13	13.54	18.22	19.43	20.52	18.39	20.90	19.43	13.15	15.46	15.34	14.95	18.14
In gluten portion	lb./hr.	0.52	1.60	0.93	0.37	0.71	0.66	1.11	0.46	0.75	1.10	0.59	0.92	0.93	0.60	0.61
In bran portion	lb./hr.	4.71	1.20	5.73	1.80	2.46	3.16	3.76	3.80	2.18	4.20	1.08	1.37	1.60	1.80	2.67
Total	lb./hr.	16.08	14.55	21.79	15.71	21.39	23.25	25.39	22.65	23.86	24.73	14.82	17.75	17.87	17.35	21.42
Total in feed	lb./hr.	17.1	17.2	25.8	19.2	23.2	23.6	30.9	24.2	24.7	32.6	17.3	20.2	20.4	19.6	24.0
Starch accounted for	%	93.8	84.6	84.5	82.0	92.2	98.5	82.1	89.5	96.5	75.7	85.7	87.9	87.6	88.5	89.2
Protein accounted for, dry basis																
In starch	lb./hr.	0.046	0.054	0.067	0.060	0.080	0.074	0.079	0.109	0.096	0.074	0.049	0.043	0.061	0.051	0.064
In gluten portion	lb./hr.	0.470	0.800	1.153	0.435	0.895	0.842	1.178	0.529	0.821	0.963	0.669	0.945	0.875	0.680	0.738
In bran portion	lb./hr.	1.520	0.453	1.380	0.562	0.855	0.984	0.906	1.052	0.638	1.100	0.417	0.500	0.583	0.528	0.775
Total	lb./hr.	2.036	1.307	2.600	1.057	1.830	1.900	2.163	1.690	1.555	2.137	1.135	1.488	1.519	1.259	1.577
Total in feed	lb./hr.	2.25	2.26	3.39	2.52	3.06	3.10	4.06	3.16	3.25	4.28	2.28	2.66	2.69	2.58	3.18
Protein accounted for	%	90.5	57.8	76.6	42.0	59.9	61.3	53.3	53.5	47.9	50.1	49.8	56.0	56.5	48.8	49.6
Energy consumption for grinding																
For unit quantity of feed	KWH/lb.	0.103	0.096	0.078	0.084	0.077	0.070	0.056	0.071	0.077	0.052	0.092	0.082	0.074	0.093	0.090
For unit quantity of starch	KWH/lb.	0.194	0.169	0.159	0.143	0.118	0.103	0.100	0.112	0.114	0.104	0.147	0.128	0.118	0.147	0.143
Water consumption of process																
Steeping water/unit feed	gal./lb.	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Processing water/unit feed	gal./lb.	1.45	1.74	1.15	1.68	1.60	1.58	1.05	1.38	1.31	1.14	1.71	1.48	1.46	1.64	1.55
Washing water/unit feed	gal./lb.	0.97	0.87	0.64	0.86	1.71	0.77	0.54	0.68	0.67	0.41	0.95	0.82	0.81	0.84	0.69
Total/unit feed	gal./lb.	2.78	2.97	2.15	2.90	2.67	2.71	1.95	2.42	2.34	1.91	3.02	2.66	2.63	2.84	2.60
Steeping water/unit starch	gal./lb.	0.68	0.63	0.74	0.61	0.55	0.53	0.65	0.57	0.54	0.73	0.57	0.57	0.58	0.57	0.57
Processing water/unit starch	gal./lb.	2.75	3.05	2.36	2.87	2.46	2.30	1.89	2.43	1.95	2.30	2.72	2.32	2.34	2.60	2.47
Washing water/unit starch	gal./lb.	1.83	1.52	1.32	1.47	1.09	1.13	0.97	1.08	1.00	0.82	1.51	1.29	1.30	1.33	1.10
Total/unit starch	gal./lb.	5.26	5.20	4.42	4.95	4.10	3.96	3.51	4.08	3.49	3.85	4.80	4.18	4.22	4.50	4.14

Table 8. Processing data for runs of class III. (Steeping investigation runs.)

Coded Run Number		IIIA-1	IIIA-2	IIIA-3	IIIA-4	IIIB-1	IIIB-2	IIIB-3	IIIB-4	IIIC-1	IIIC-2	IIIC-3	IIIC-4	IIID-1	IIID-2	IIID-3	IIID-4
Steeping conditions																	
Temperature	°F					120	120	120	120	120	120	120	120	118	117	120	120
Time	hr.					4	4	4	4	16	16	16	16	4	4	4	4
Agent						-	-	-	-	-	-	-	-	0.1% SO_2	0.1% SO_2	0.1% SO_2	0.1% SO_2
Quantity of water/unit feed	gal./lb.					0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Water recycle rate	gal./hr.					30	30	30	30	30	30	30	30	30	30	30	30
Grinding																	
Mill temperature	°F	98	97	102	96	97	96	100	100	96	96	99	98	98	97	98	99
Energy consumption	KW	2.02	2.37	2.68	2.55	2.22	2.22	2.33	2.33	2.28	2.24	2.38	2.24	2.24	2.28	2.30	2.33
Feed rate, wet basis	lb./hr.	24.0	37.5	41.4	57.2	23.8	28.6	32.9	38.9	24.8	26.4	35.0	38.9	25.2	29.5	37.2	40.8
dry basis	lb./hr.	21.3	33.3	36.8	50.8	21.1	25.4	29.2	34.6	22.0	23.5	31.1	34.5	22.4	26.2	33.1	36.3
Mill concentration	lb.sol./cu.ft.	6.9	10.6	13.4	17.5	8.11	8.11	9.50	12.00	6.74	8.60	9.10	11.45	6.37	8.23	8.43	9.84
Specific gravity of starch milk	Be'	2.56	4.08	4.62	5.30	2.56	2.84	3.40	3.81	2.41	2.56	2.98	3.81	2.70	3.12	3.54	3.94
Grits recycling rate	lb./hr.	27.3	45.7	56.5	69.6	24.2	26.6	30.2	35.2	25.5	27.5	27.4	39.2	22.1	21.8	27.0	31.2
Overflow rate of solid material from mill	lb./hr.	48.6	79.0	93.3	120.4	45.3	52.0	59.4	69.8	47.5	51.0	58.4	73.7	44.5	51.3	60.1	67.5
Slope of screen	in./ft.	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Processing water consumption																	
For feeding	gal./hr.	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
For screening	gal./hr.	12	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
For debranning	gal./hr.	18	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
For recycling	gal./hr.	12	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Total	gal./hr.	57	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
Tabling conditions																	
Tabling rate	gal./hr.	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
Washing water rate	gal./hr.	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Time of washing	min.	21	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Total washing water	gal.	21	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20

Table 9. Results for runs of class III. (Steeping investigation runs.)

Coded Run Number		IIIA-1	IIIA-2	IIIA-3	IIIA-4	IIIB-1	IIIB-2	IIIB-3	IIIB-4	IIIC-1	IIIC-2	IIIC-3	IIIC-4	IIID-1	IIID-2	IIID-3	IIID-4
Yield of products, dry basis																	
Starch	lb./hr.	15.38	22.21	24.00	29.62	14.64	17.25	19.87	23.25	13.50	15.00	18.00	21.00	15.37	18.90	23.25	24.00
	%	72.0	66.1	65.2	58.5	69.2	67.9	68.1	67.3	61.5	63.9	57.8	60.7	68.6	72.1	71.0	66.1
Gluten portion	lb./hr.	2.63	4.50	3.36	6.00	4.12	4.72	5.62	4.50	4.87	4.50	5.85	6.75	3.00	2.63	3.00	4.87
	%	12.4	13.5	9.1	11.8	19.5	18.6	19.3	13.0	22.1	19.1	18.8	19.5	13.4	10.0	9.1	13.4
Bran portion	lb./hr.	0.75	3.75	7.50	12.66	1.87	2.63	2.81	5.25	1.87	2.25	3.75	5.34	2.25	3.00	5.01	6.00
	%	3.5	14.6	20.4	24.7	8.8	10.4	10.4	15.2	8.5	9.6	12.0	15.5	10.0	11.4	15.0	16.5
Total	lb./hr.	18.76	31.49	34.86	48.28	20.63	24.60	28.3	33.00	20.24	21.75	27.60	32.09	20.62	24.53	31.50	34.87
	%	87.9	94.2	94.7	95.0	97.5	96.9	96.8	95.5	92.1	92.6	88.6	95.7	92.0	93.5	95.1	96.0
Starch recovery, dry basis																	
Starch extracted	lb./hr.	15.38	22.21	24.00	29.62	14.64	17.25	19.87	23.25	13.50	15.00	18.00	21.00	15.37	18.90	23.25	24.00
Starch in feed	lb./hr.	17.7	27.6	30.5	42.2	17.5	21.1	24.2	28.7	18.3	19.4	25.8	28.7	18.6	21.7	27.4	30.1
Recovery	%	86.9	80.1	78.7	70.2	83.7	81.2	82.1	81.0	73.8	77.3	70.2	73.2	82.6	87.1	84.8	79.7
Starch accounted for, dry basis																	
In starch	lb./hr.	15.29	21.95	23.88	29.41	14.57	17.17	19.77	23.14	13.41	14.91	17.91	20.87	15.28	18.82	23.13	23.88
In gluten portion	lb./hr.	0.93	1.88	1.29	2.34	1.98	2.63	2.72	1.19	2.56	2.47	3.25	4.33	1.19	0.96	1.31	2.29
In bran portion	lb./hr.	0.28	3.15	5.06	9.31	0.90	1.60	1.64	3.28	0.98	1.25	2.18	3.45	1.18	1.79	3.37	3.95
Total	lb./hr.	16.50	26.98	30.23	41.06	17.45	21.40	24.13	27.61	16.95	18.63	23.34	28.63	17.65	21.57	27.81	30.12
Total in feed	lb./hr.	17.7	27.6	30.5	42.2	17.5	21.1	24.2	28.7	18.3	19.4	25.8	28.7	18.6	21.7	27.4	30.1
Starch accounted for	%	93.3	97.7	99.3	97.2	99.7	101.2	99.7	96.1	92.6	96.0	90.4	99.8	94.8	99.3	101.5	100.0
Protein accounted for, dry basis																	
In starch	lb./hr.	0.09	0.17	0.12	0.21	0.08	0.08	0.10	0.11	0.09	0.09	0.09	0.13	0.09	0.08	0.12	0.12
In gluten portion	lb./hr.	1.18	1.93	1.50	2.72	1.38	1.40	1.89	1.94	0.59	0.98	1.50	1.52	1.38	1.21	1.25	1.90
In bran portion	lb./hr.	0.14	0.75	1.15	1.59	0.32	0.42	0.48	0.75	0.33	0.37	0.60	0.87	0.37	0.47	0.73	0.86
Total	lb./hr.	1.41	2.85	2.77	4.52	1.78	1.90	2.47	2.80	2.01	1.44	2.19	2.52	1.84	1.76	2.10	2.88
Total in feed	lb./hr.	2.17	3.39	3.74	5.16	2.15	2.58	2.97	3.15	2.24	2.38	3.16	3.51	2.28	2.66	3.36	3.68
Protein accounted for	%	65.0	84.1	74.1	87.5	82.8	73.6	82.9	88.9	94.2	60.5	69.3	71.8	80.7	66.2	62.5	78.3
Energy consumption for grinding																	
For unit quantity of feed	KWH/lb.	0.095	0.071	0.073	0.050	0.105	0.088	0.080	0.068	0.104	0.095	0.076	0.065	0.100	0.087	0.070	0.065
For unit quantity of starch	KWH/lb.	0.131	0.107	0.112	0.086	0.152	0.129	0.117	0.099	0.169	0.149	0.132	0.107	0.146	0.121	0.099	0.097
Water consumption of process																	
Steeping water/unit feed	gal./lb.	-	-	-	-	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Processing water/unit feed	gal./lb.	2.68	1.62	1.47	1.06	2.56	2.12	1.85	1.56	2.46	2.30	1.74	1.56	2.41	2.06	1.67	1.49
Washing water/unit feed	gal./lb.	0.99	0.60	0.54	0.39	0.95	0.79	0.68	0.58	0.91	0.85	0.64	0.58	0.89	0.76	0.60	0.55
Total/unit feed	gal./lb.	3.67	2.22	2.01	1.45	3.76	3.16	2.78	2.39	3.62	3.40	2.63	2.39	3.55	3.07	2.48	2.29
Steeping water/unit starch	gal./lb.	-	-	-	-	0.36	0.37	0.37	0.37	0.41	0.39	0.42	0.41	0.36	0.35	0.35	0.38
Processing water/unit starch	gal./lb.	3.71	2.44	2.25	1.82	3.69	3.13	2.72	2.32	4.00	3.60	3.00	2.57	3.52	2.86	2.32	2.25
Washing water/unit starch	gal./lb.	1.37	0.91	0.83	0.68	1.36	1.26	1.01	0.86	1.48	1.33	1.11	0.95	1.30	1.06	0.86	0.83
Total/unit starch	gal./lb.	5.08	3.35	3.08	2.50	5.41	4.76	4.10	3.55	5.89	5.32	4.53	3.93	5.18	4.27	3.53	3.46

Table 10. Composition of products.

Coded run number	Starch: Protein content %	Gluten portion: Starch content %	Gluten portion: Protein content* %	Bran portion: Starch content %	Bran portion: Protein content* %
IA-1	0.50	41.31	39.50	47.59	22.31
IA-2	0.69	46.75	38.25	45.25	22.38
IA-3	0.50	43.72	34.75	36.43	22.13
IA-4	0.69	45.94	31.69	42.83	22.38
IB-1	1.63	46.67	39.69	43.46	23.50
IB-2	0.63	44.58	35.88	54.74	15.06
IB-3	0.63	45.53	35.69	58.46	18.69
IB-4	0.69	44.40	39.94	58.54	21.19
IB-5	0.53	44.06	40.44	59.09	22.63
IB-6	0.69	41.80	38.50	63.60	16.00
IB-7	1.19	44.75	37.56	61.08	18.19
IIA-1	0.42	60.35	19.50	43.02	39.16
IIA-2	0.45	56.98	21.59	57.18	28.56
IIA-3	0.44	67.21	16.43	37.16	46.25
IIA-4	0.44	60.61	20.06	37.24	43.50
IIA-5	0.44	58.76	20.38	35.49	44.81
IIA-6	0.38	59.63	18.57	34.63	44.34
IIA-7	0.38	67.21	16.19	39.67	42.06
IIA-8	0.59	65.46	20.06	38.22	44.06
IIA-9	0.48	62.42	18.19	39.20	42.06
IIA-10	0.38	65.52	17.19	43.96	38.56
IIB-1	0.37	39.26	44.63	57.05	21.97
IIB-2	0.28	41.98	43.00	57.09	20.81
IIB-3	0.41	43.13	41.69	57.11	21.63
IIB-4	0.34	40.38	45.38	63.00	19.57
IIB-5	0.37	38.13	46.13	63.56	18.47
IIIA-1	0.60	35.42	44.91	37.23	18.44
IIIA-2	0.78	41.72	42.88	64.71	15.38
IIIA-3	0.50	38.33	44.57	67.49	15.38
IIIA-4	0.70	39.03	45.35	73.59	12.57
IIIB-1	0.53	48.12	33.63	48.34	17.19
IIIB-2	0.56	55.62	29.63	60.70	15.94
IIIB-3	0.48	48.47	33.63	58.24	17.03
IIIB-4	0.48	37.79	43.19	62.54	14.32
IIIC-1	0.66	52.60	32.75	52.54	17.63
IIIC-2	0.78	54.80	21.80	55.77	16.63
IIIC-3	0.64	55.55	25.26	58.16	16.09
IIIC-4	0.60	64.14	22.57	64.65	16.25
IIID-1	0.60	39.67	45.94	52.67	16.50
IIID-2	0.45	36.42	46.13	59.82	15.75
IIID-3	0.50	43.79	41.78	67.47	14.50
IIID-4	0.52	46.97	39.00	65.78	14.29

*Protein content = nitrogen x 6.25.

The viscosity tests were made only for those samples obtained from runs of class III. The viscosity index, r, was obtained from the following equation:

$$r = \frac{W_2}{W_1}$$

where W_1 is the maximum viscosity reading during the heating period. W_2 is the maximum viscosity reading during the cooling period.

As reported by Barham et al (2), the viscosity index may be used for comparing the pasting property of different starches.

The data for the viscosity tests are presented in graphic forms in Figs. 1 to 4.

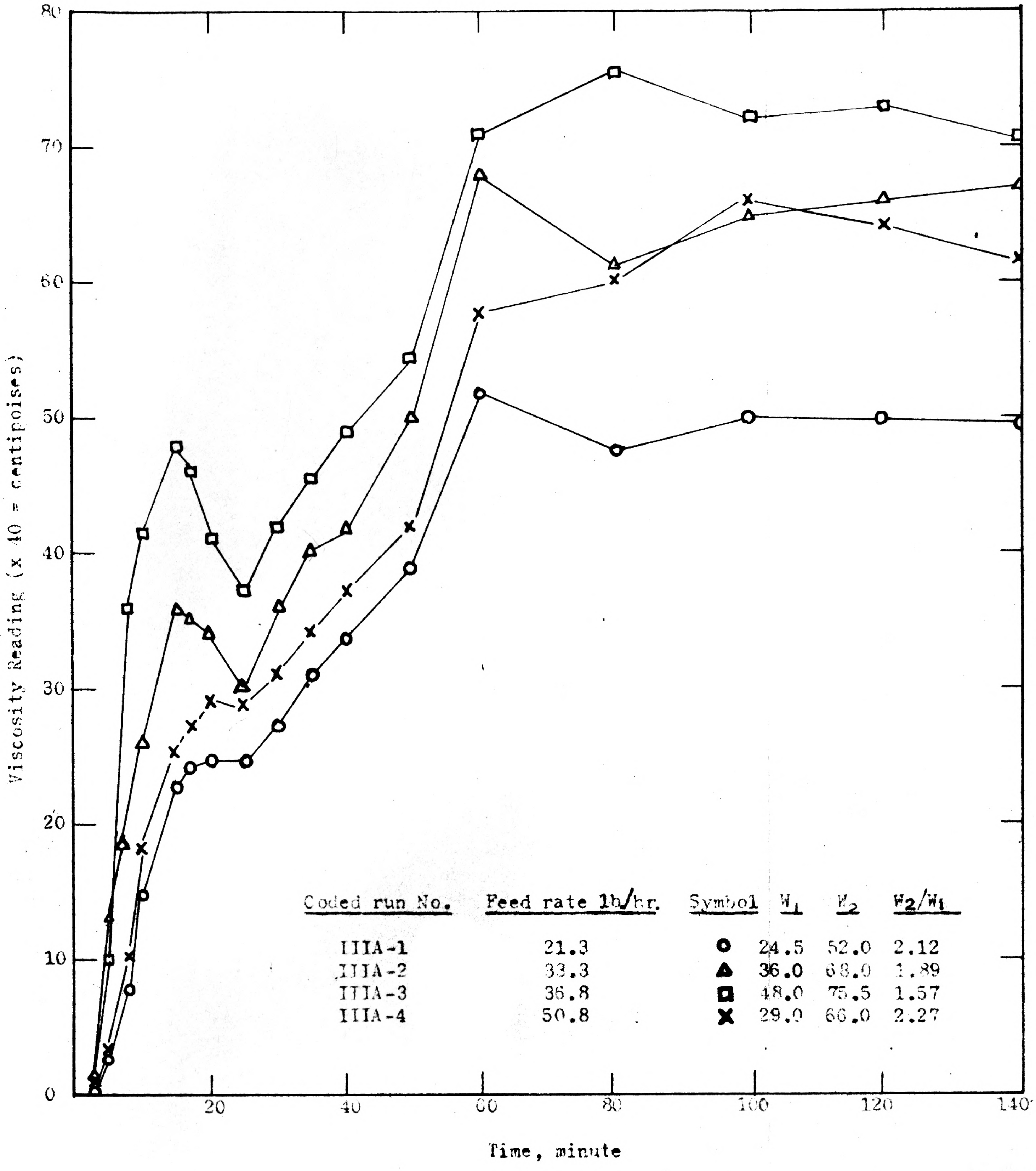


Fig. 1. Viscosity data of no steeping runs.

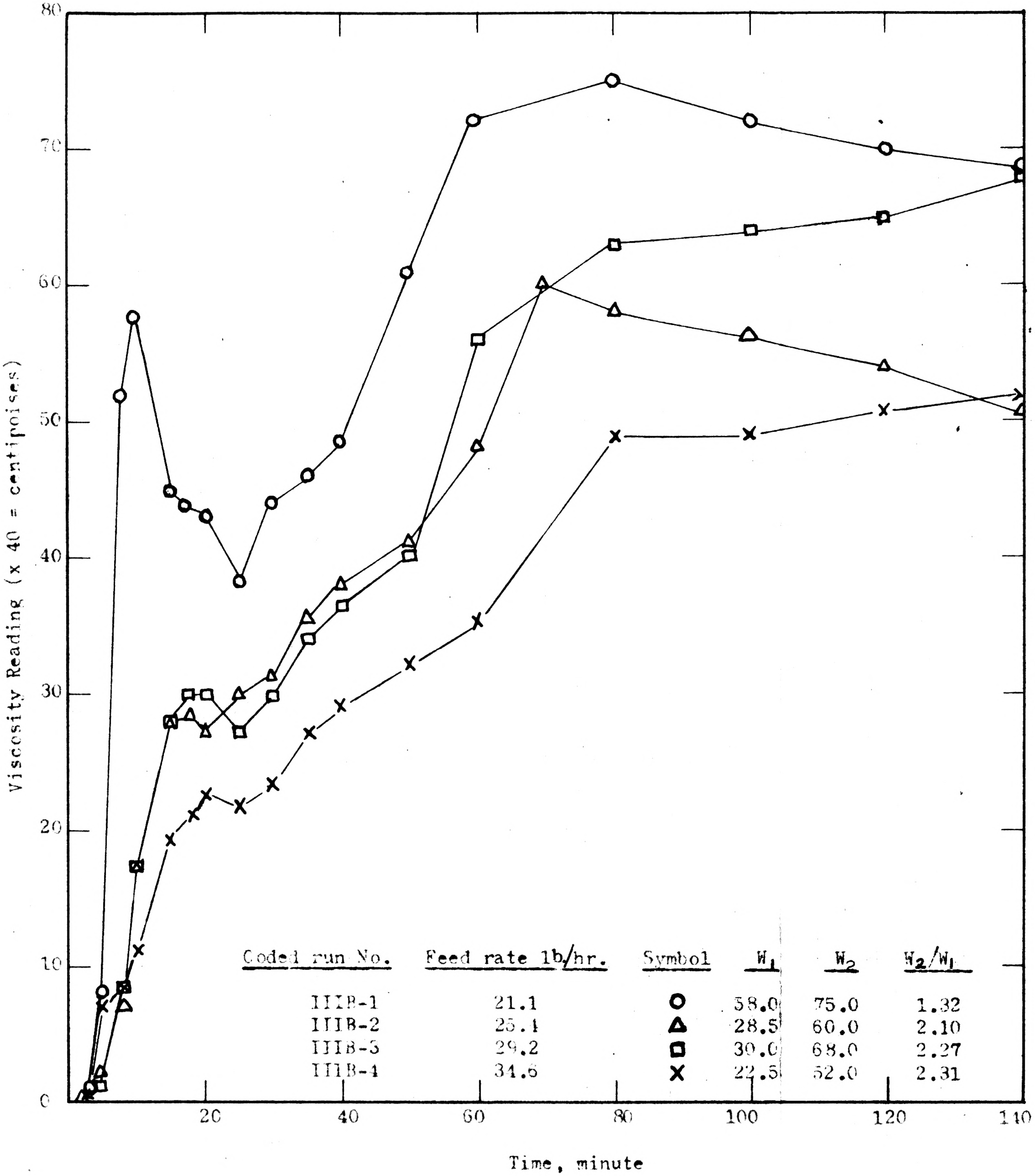


Fig. 2. Viscosity data of 4-hour steeping runs.

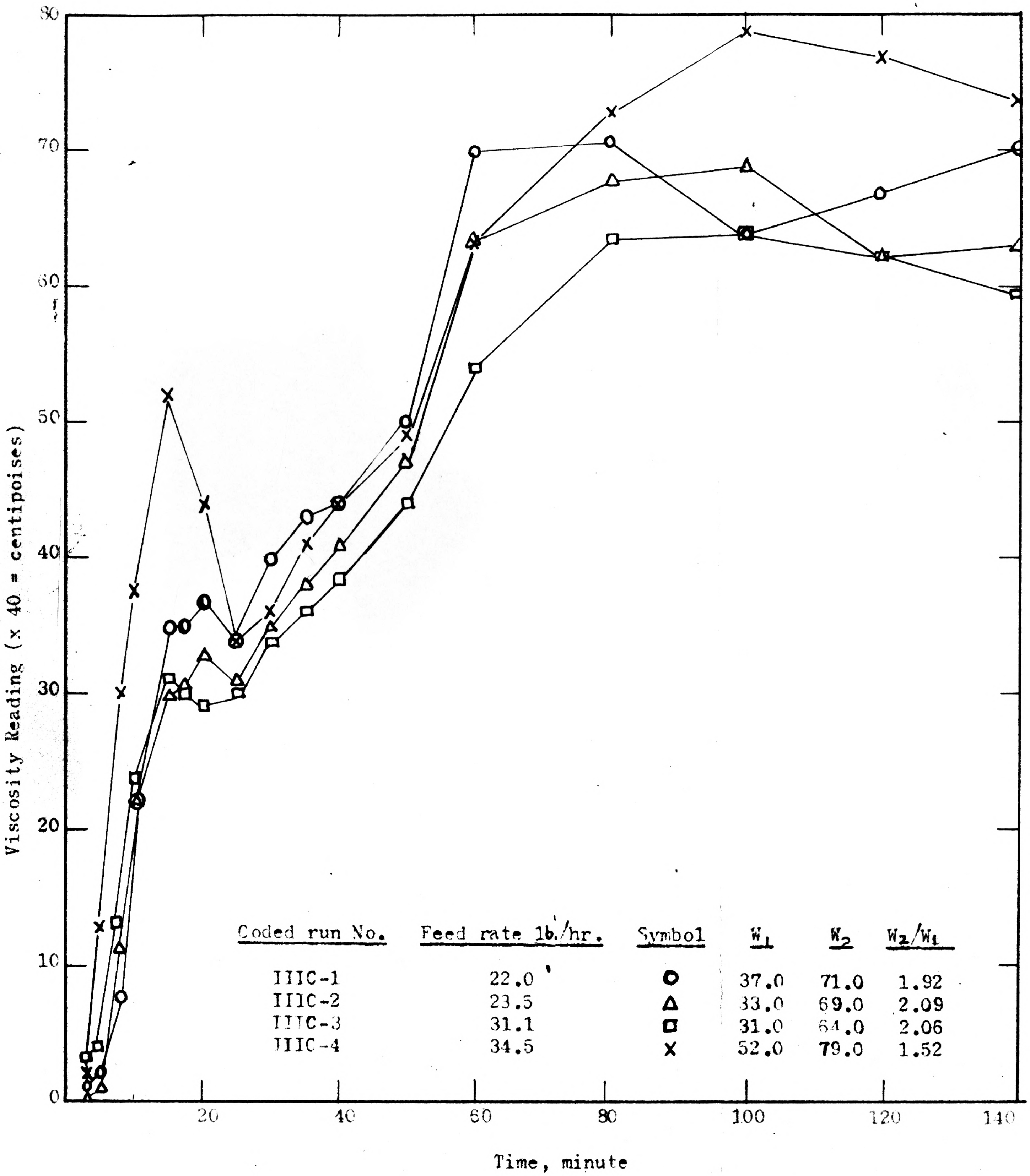


Fig. 3. Viscosity data of 16-hour steeping runs.

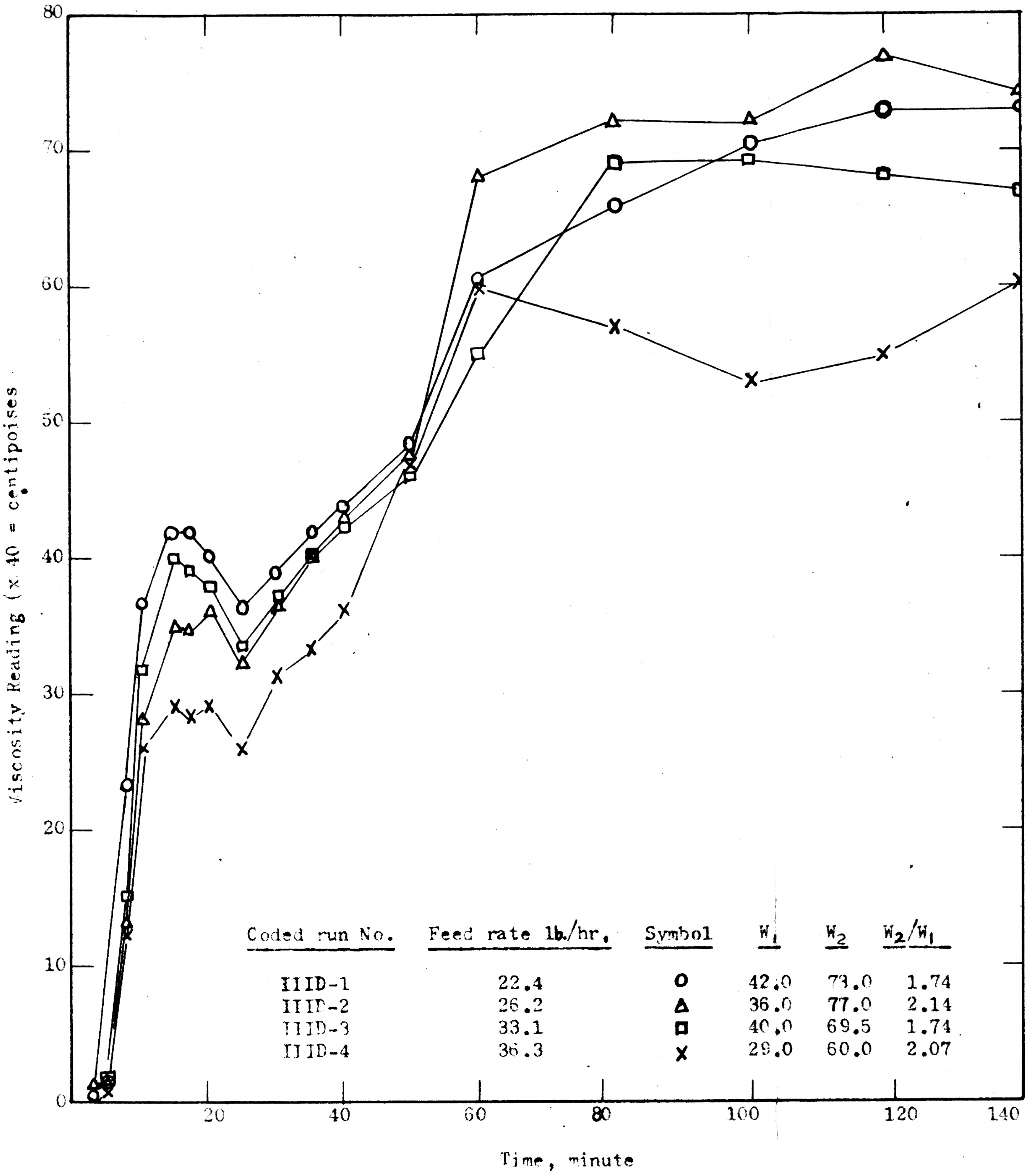


Fig. 4. Viscosity data of 0.1% SO_2 steeping runs.

DISCUSSION OF RESULTS

This investigation was designed to search for the optimum operating conditions for obtaining the highest yields and the best quality of products. Since it appeared that the feed rate and the conditions of steeping were the most important factors in the production of starch from sorghum grits by this continuous hydraulic grinding method, these two variables received most attention in this work. One other factor included in this work was the screen capacity. At the increased feed rates used, the screen area previously used appeared inadequate. In addition, another minor point covered was the quantity of washing water on the starch table. This was of interest because it was desirable to reduce the total consumption of processing water as much as possible.

General Investigation Runs

For the first four runs the data were taken for the entire run including the unsteady period during the early part of the run. Unsteeped grits were used for two of these runs. A preliminary comparison between steeped (2 hr.-steeping) and unsteeped grits was made. The results as presented in Table 3 showed that the rate of production for unsteeped grits was no less than for the steeped grits. The yield was even favorable to the unsteeped grits, but this may have been caused by the different length of the runs.

Following that, seven runs were conducted without steeping the grits. No quantitative correlation was made between these runs because different operating conditions had been used for these runs in order to carry out a general observation. The highest feed rate used was 45 pounds per hour (dry basis). The corresponding starch production rate was 25 pounds per hour (dry basis). The recovery was only fair. This may have been due to the ineffectiveness of screening as observed during the operation.

The maximum concentration of starch milk obtained was as high as 6° Be' at room temperature, which is comparable to the value reported by Kerr (8) for the conventional wet milling process for corn starch. The water consumption was reduced to a minimum of 3.1 gallons per pound of starch produced. The average water consumption for corn starch milling is about 2.1 gallons per pound of starch (8). The power consumption ranged from 0.15 to 0.2 KWH per pound of starch produced, which was about the same as reported by Fan (5). Further reduction of both water and power consumptions was achieved by increasing the recovery of starch by the use of two screens rather than only one.

The quantity of water used by Fan (5) for washing the starch on the starch tables ran as high as 50 per cent or more of the total processing water. Therefore, any possible reduction of the quantity of washing water would effectively reduce the total water consumption. Experiments with the use of less water were carried out in runs of class I-B. Increasing the washing rate to 60 gallons per hour and reducing the total quantity of washing water from 60 gallons to 20 gallons, thus decreasing the washing time from 100 minutes to 20 minutes, produced a starch of acceptable gluten content. A plot of gluten content against total quantity of washing water is shown in Fig. 5. The curve indicates that further reduction of washing water would give undesirable high gluten contents. For this reason, 20 minutes washing at a water rate of 60 gallons per hour was used for all succeeding runs.

Maximum Recovery Investigation Runs

It was pointed out by Fan (5) that a high feed rate was favorable for both production rate and recovery. Since his work covered only the low feed rate range from 6 to 20 pounds per hour, it appeared desirable to expand the investigation to the high range.

Feed rates used in this set of runs ranged from 20 to 40 pounds per hour. A series of changes of feed water rate was made at constant screw conveyer setting. This caused difficulties in correlating the data, since the actual feed rate varied somewhat with changes in feed water rate. However, curves were obtained for the correlation between the recovery and the feed rate at constant feed water rate as shown in Fig. 6. The effect of feed water rate is evident, but no general relationship between the recovery and feed rate can be seen from this figure. As mentioned previously, the grinding action was due to impact and abrasion between the particles of material as well as between the particles and the wall of the mill. It seems likely, therefore, that the mill concentration would be a direct factor affecting the grinding. A correlation was made, therefore, of the starch re-

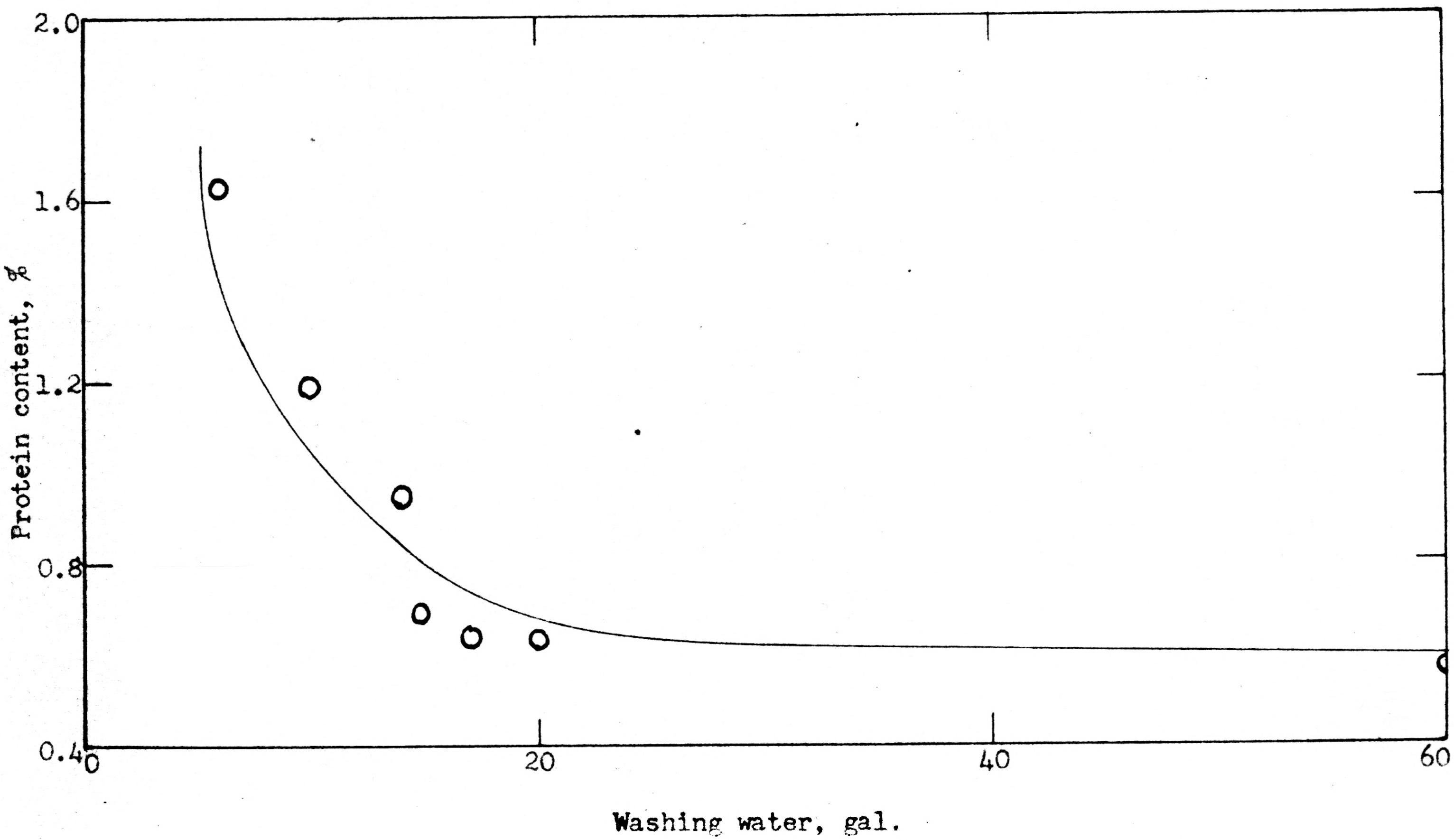


Fig. 5. Effect of quantity of washing water on protein content of starch at washing rate of 60 gal/hr.

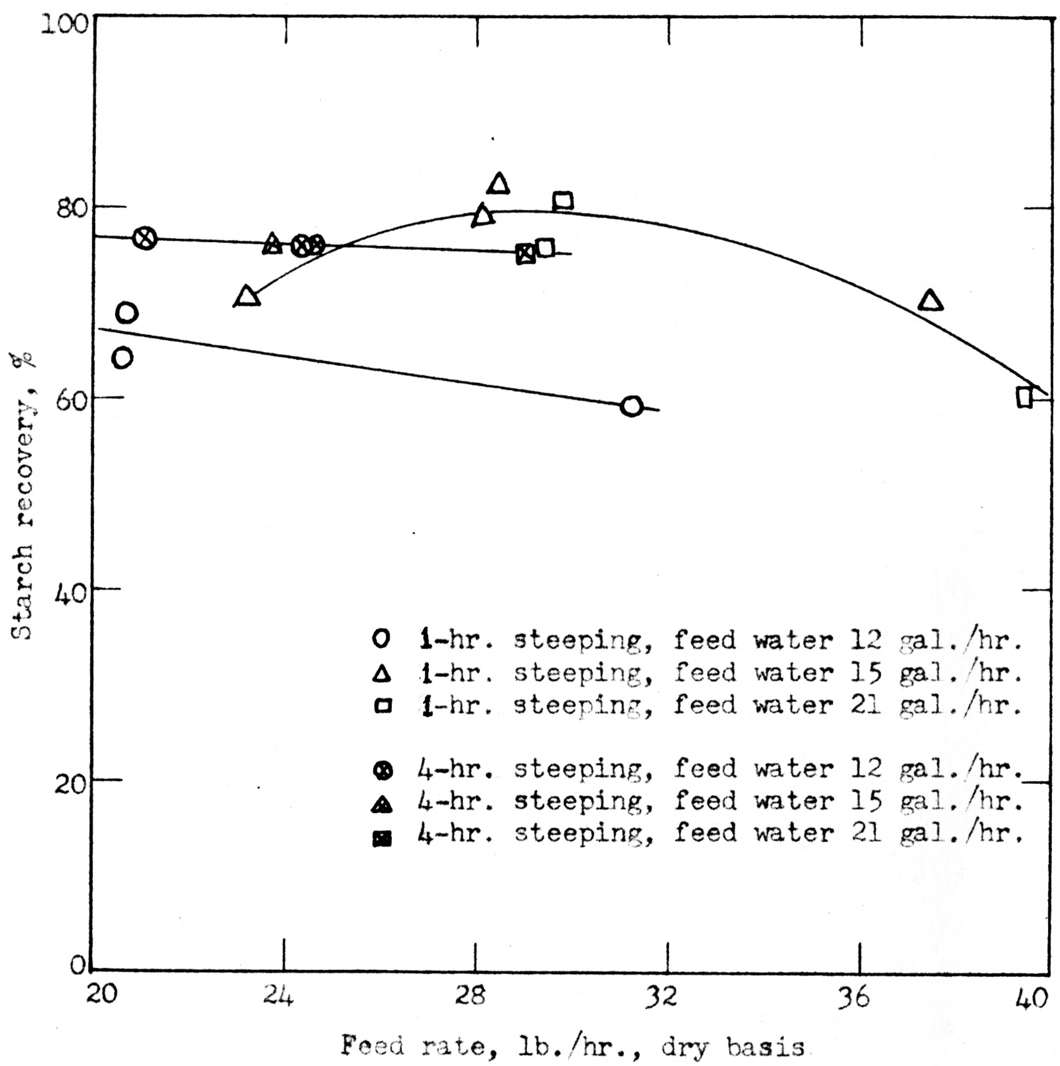


Fig. 6. Effect of rate of feed of grits at constant feed water rates on the starch recovery.

covery with respect to the mill concentration as shown in Fig. 7. From this figure a general comparison of runs of different feed rate and feed water rate is shown by a concave downward curve with a fairly broad maximum portion. The maximum recovery is represented by the maximum of the curve which corresponds to the mill concentration from 6 to 11 pounds per cubic feet. Since the mill concentration was almost directly proportional to the feed rate at a constant water rate, as shown in Fig. 8, the optimum feed rate range can be estimated from one of the lines in the figure.

The maximum recovery obtained in this series of runs was 81 per cent. This was low as compared with that obtained in producing corn starch. Fan (5) obtained a recovery of 84 per cent using the same equipment, but operating at lower feed rates. At the higher feed rates used here, the capacity of the single screen used was inadequate. This was believed to be the main cause for this low recovery. In order to improve the screening condition, two screens operated in series were, therefore, used for later runs.

Steeping Investigation Runs

With the exceptions of the 16-hour steeping runs and run IIIA-4, in which an extremely high feed rate was used, all runs included in this class gave a rather satisfactory recovery with a maximum of 87 per cent and an average of 80 per cent, which was a clear indication of the effectiveness of the two-screen operation.

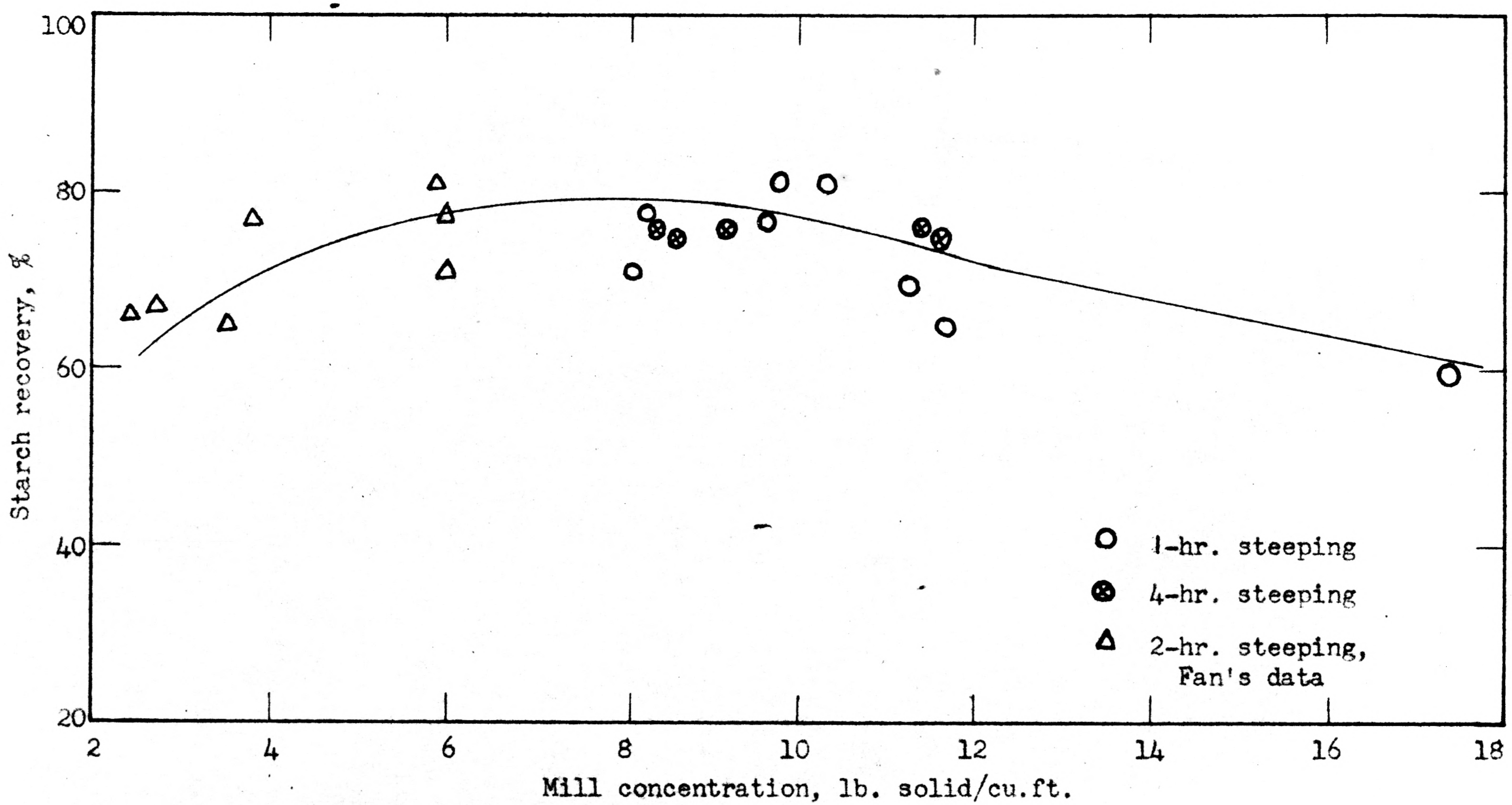


Fig. 7. Effect of mill concentration on the starch recovery.

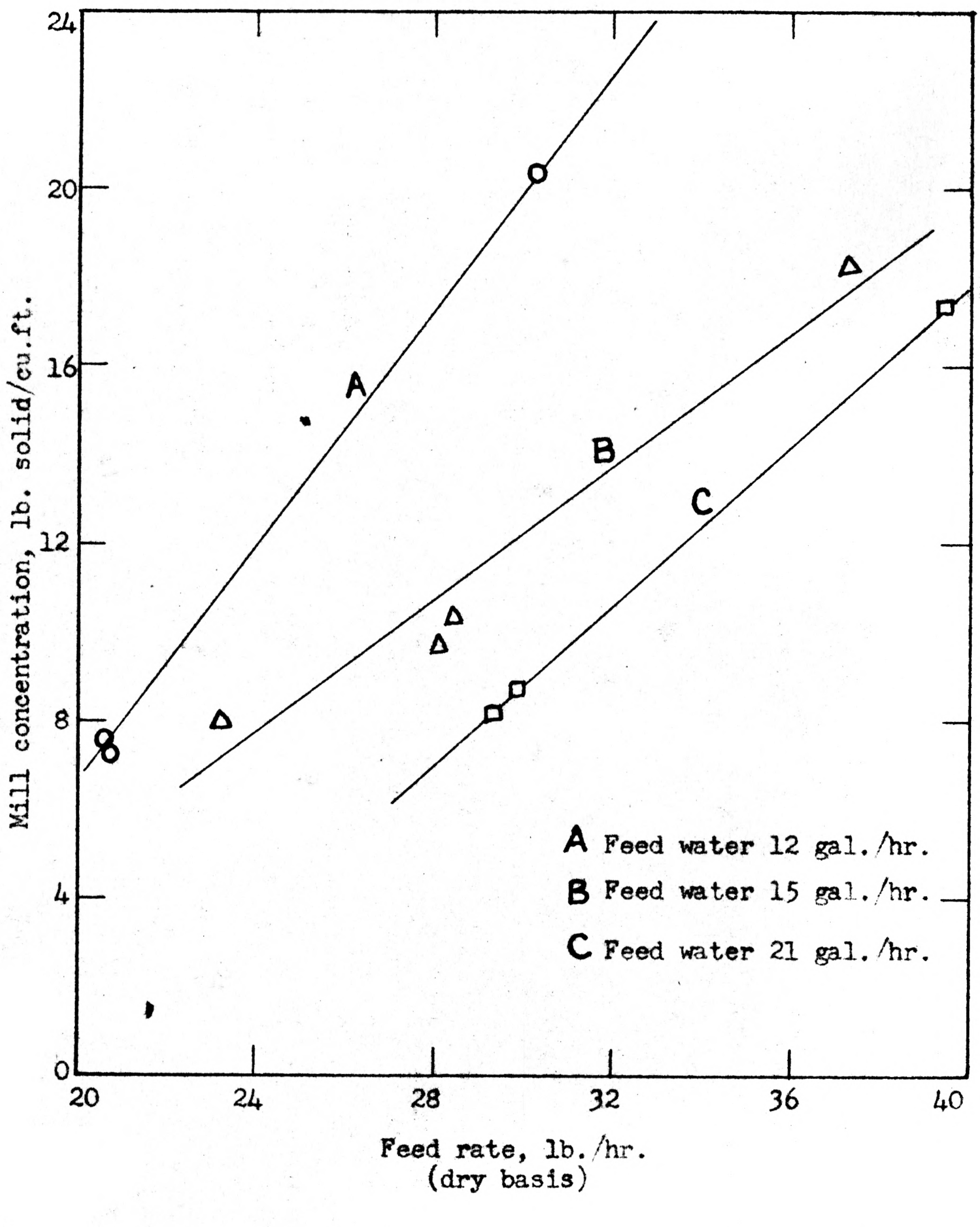


Fig. 8. Effect of feed rate on mill concentration at constant feed water rates(1-screen).

No improvement in the concentration of starch milk was made, for it was limited by the maximum possible feed rate provided by the screw conveyer. However, a further reduction of water consumption to a minimum of 2.5 gallons per pound of starch produced was attained due to the increased recovery.

The lowest energy consumption for grinding obtained was 0.086 KWH per pound of starch.

The protein content of the starch was somewhat higher than the value reported by Fan (5). However, an average value of 0.584 for 16 runs was still less than the average value for sorghum starch of 0.68 given by Kerr (8).

Severe fermentation of the grits occurred during the 16-hour steeping. This probably was the main cause of the low yields for these runs.

All correlations were made with either feed rate or mill concentration as the independent variable at constant steeping conditions so that both factors appear in the same plot and their cross effects can be readily seen. In addition, several correlations included curves of constant screening condition, thus giving comparisons between 1-screen and 2-screen runs. For the sake of clarity, each correlation is presented separately in the following.

Relationship between Feed Rate and Mill Concentration. A plot of mill concentration against feed rate is shown in Fig. 9. In general, the slope of the curves is positive, and the slopes tend to increase with feed rate. Curve B in the figure indicates

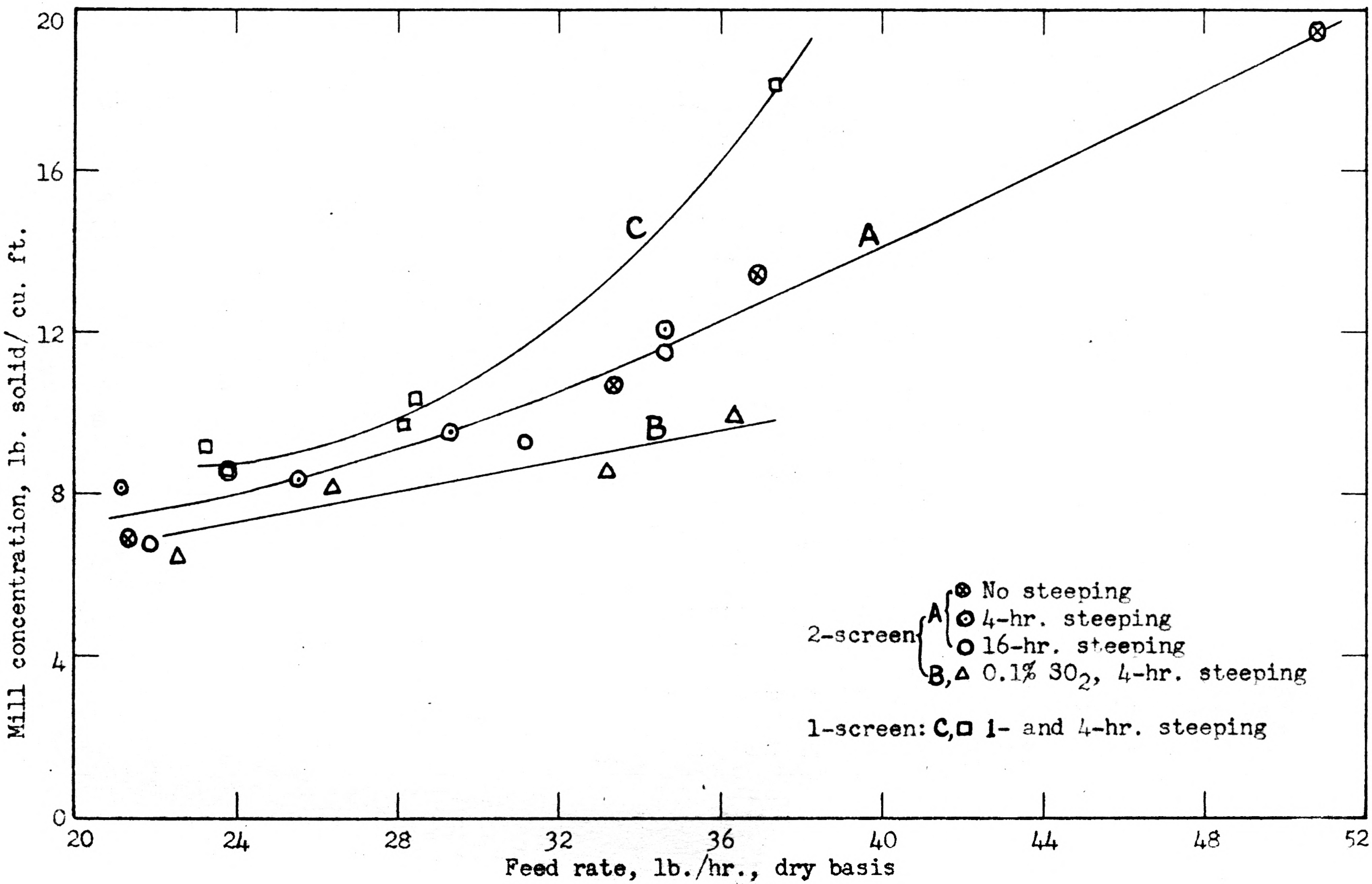


Fig. 9. Effect of feed rate on mill concentration.

that the grits steeped in 0.1 per cent sulfur dioxide gave a somewhat lower mill concentration and a lower slope than the others. This was probably due to the greater softness of the SO_2-steeped grits. Curve C shows that the mill concentration was higher for the 1-screen operation than that for the 2-screen operation. This fact indicates that 1-screen operation had a higher recycling rate of grits which was caused by the overloading of the single screen. In other words, some starch actually fine enough to pass through the 200-mesh screen was being recycled to the mill.

Rate of Production of Starch. Figure 10, which includes all data of class III, shows that the production rate increased with feed rate, but the rate of increase tended to decrease as the feed rate increased. A comparison of production rates at different steeping conditions is shown by Curve A and B. Curve B indicates a lower production rate for grits steeped 16 hours, which was anticipated because of the severe fermentation observed during steeping. No difference in production rate was found among the other three conditions.

The production rates of 1-screen and 2-screen runs is compared in Fig. 11. The data for the 1-screen runs were taken from run IIA-4, IIA-5, IIA-6, IIA-7, IIB-4, and Fan's runs 26 and 27. Again, Curve B shows that 1-screen operation was inferior to 2-screen operation.

Starch Recovery. The effect of feed rate on the recovery of starch was slight, as shown in Fig. 12. This is especially true

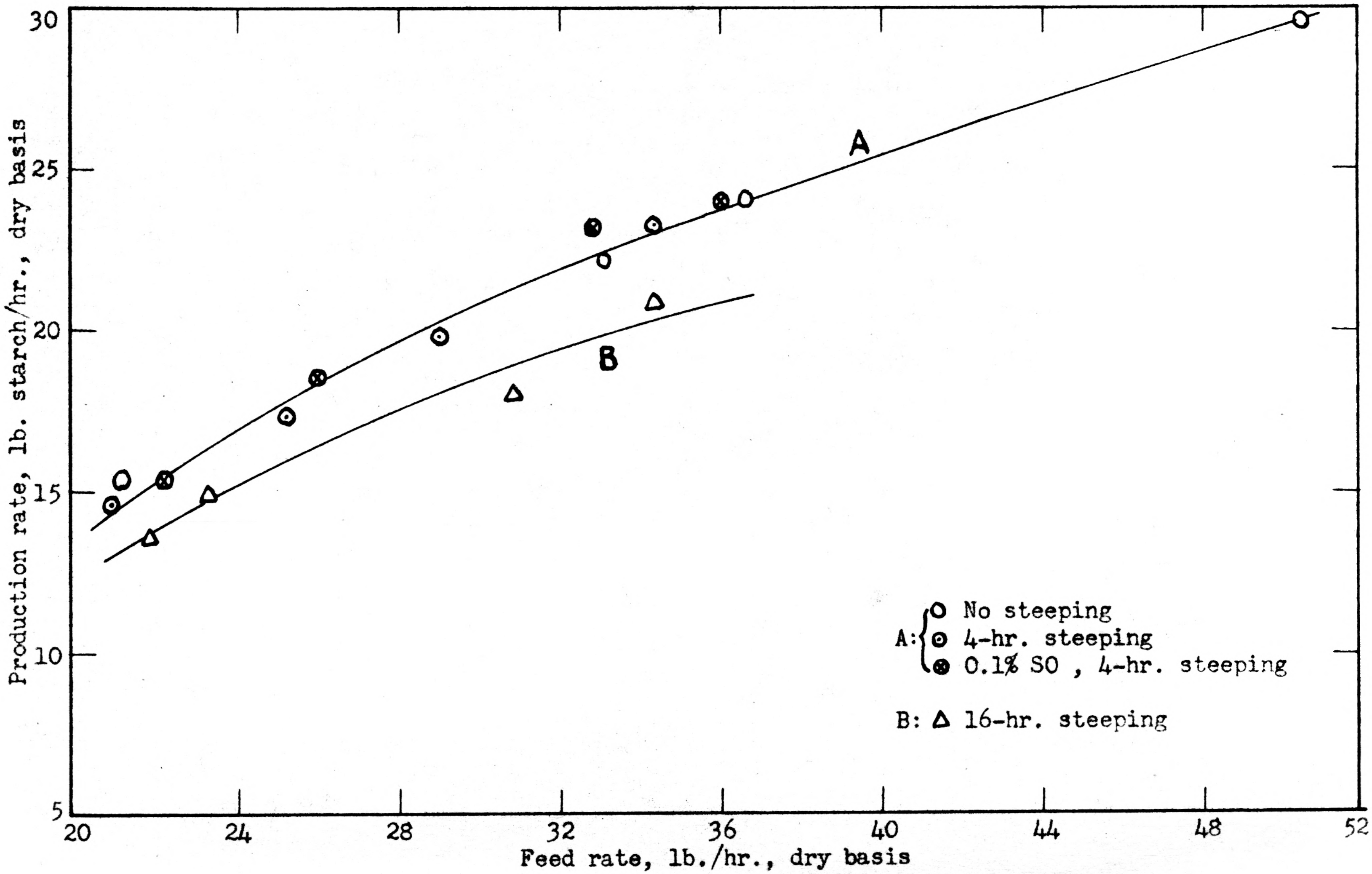


Fig. 10. Effect of feed rate on the production rate.

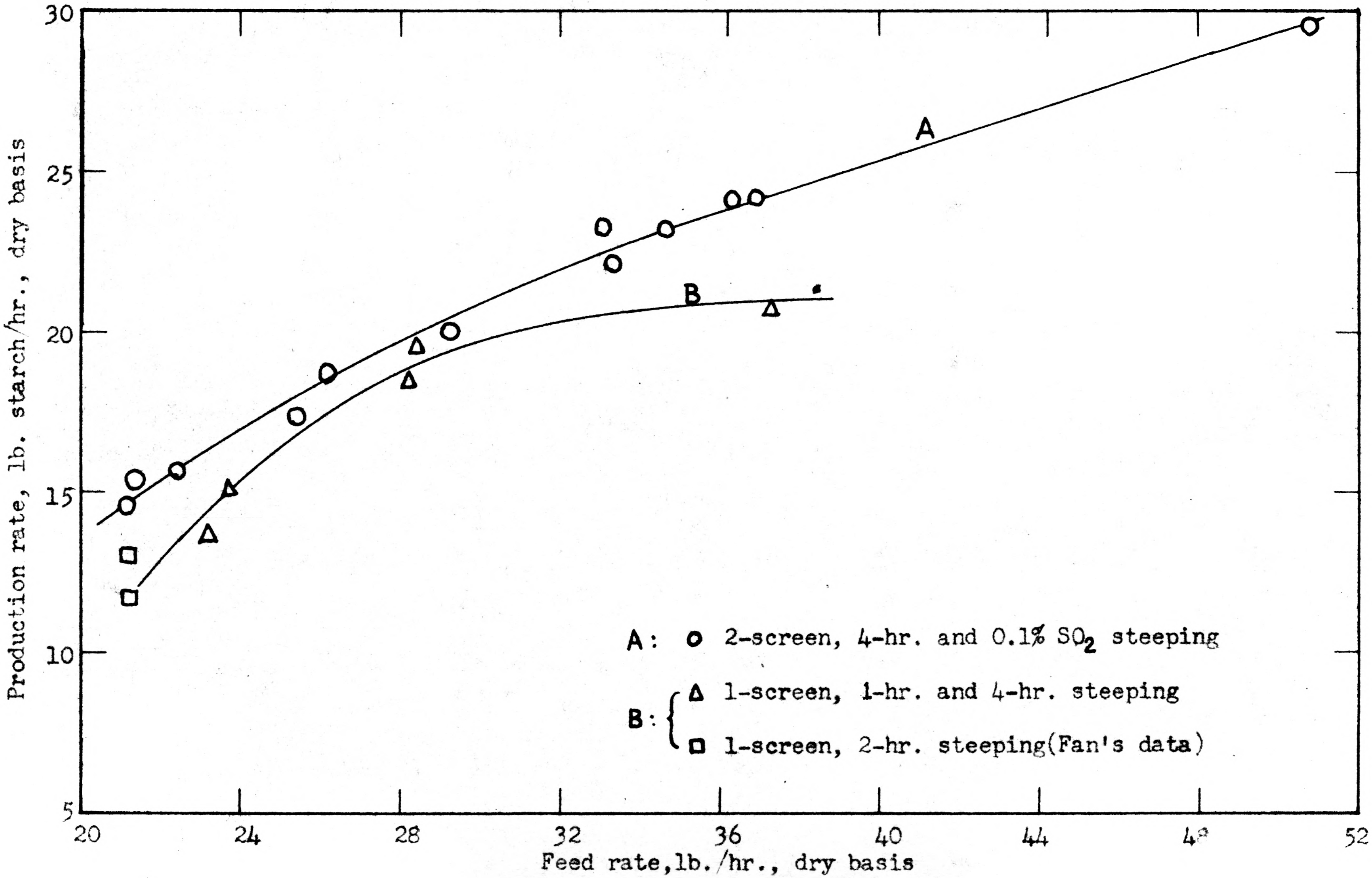


Fig. 11. Effect of feed rate on the production rate.

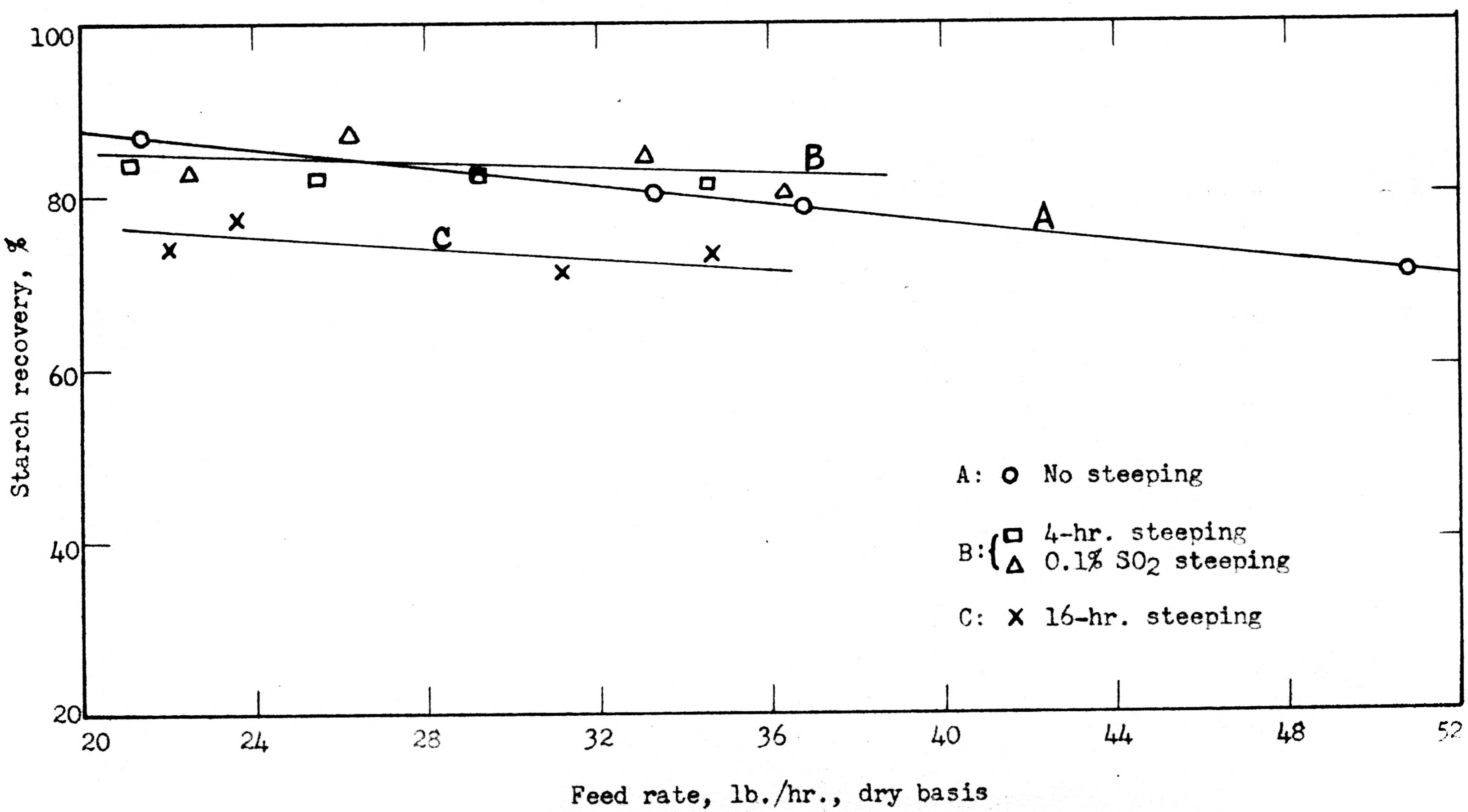


Fig. 12. Effect of feed rate on starch recovery.

for 4-hour steeping and sulfur dioxide steeping. Curve A indicates that the recovery of unsteeped grits had a greater tendency to decrease as the feed rate increased. The grits steeped 16 hours, represented by Curve C, showed a considerably lower recovery than the others. This was again due to the fermentation which occurred.

The effect of screen capacity on recovery is shown in Fig. 13, in which the correlation is made with respect to mill concentration so that the comparison between runs of different feed rate and different feed water rate is possible. The recoveries of 1-screen runs, represented by Curve B, were lower than those of 2-screen runs. This probably was caused by the loss of starch with the bran in the debranning operation, as a result of insufficient screen capacity.

Recycling Rate. It was anticipated that unsteeped grits would have the highest recycling rate, and that the sulfur dioxide-steeped grits would give the lowest recycling rate, since the grinding efficiency was believed to be mainly dependent upon the softness of the ground material. Curves in Fig. 14 justify this prediction.

Density of the Starch Milk. Within the range of feed rates covered, the density of the starch milk was almost a linear function of the feed rate. As shown in Fig. 15, the unsteeped grits gave a starch milk of highest density, while the grits steeped 16 hours gave a starch milk of lowest density, and the grits from the other two steeping conditions produced starch milks having

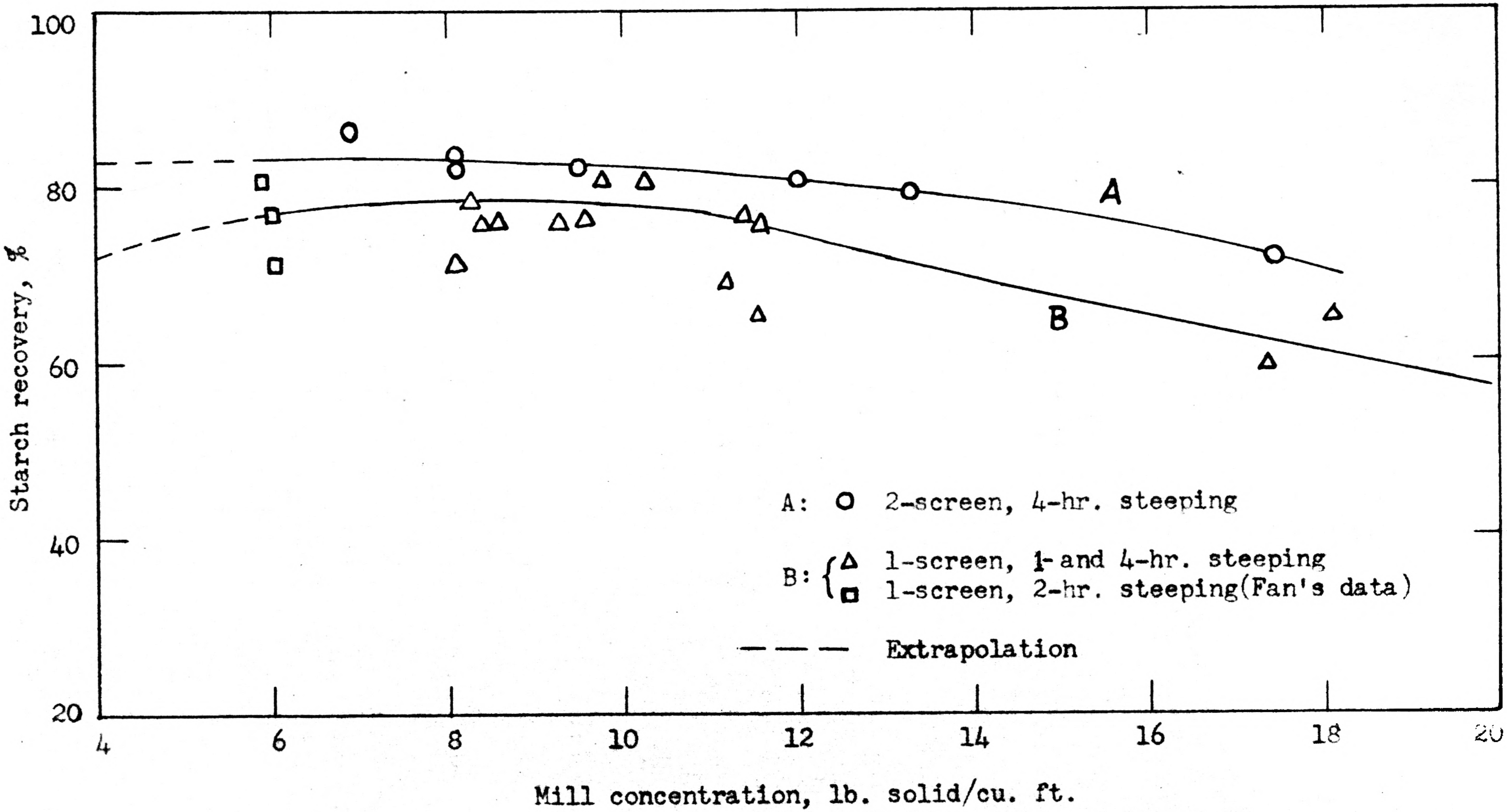


Fig. 13. Effect of screening procedure on starch recovery.

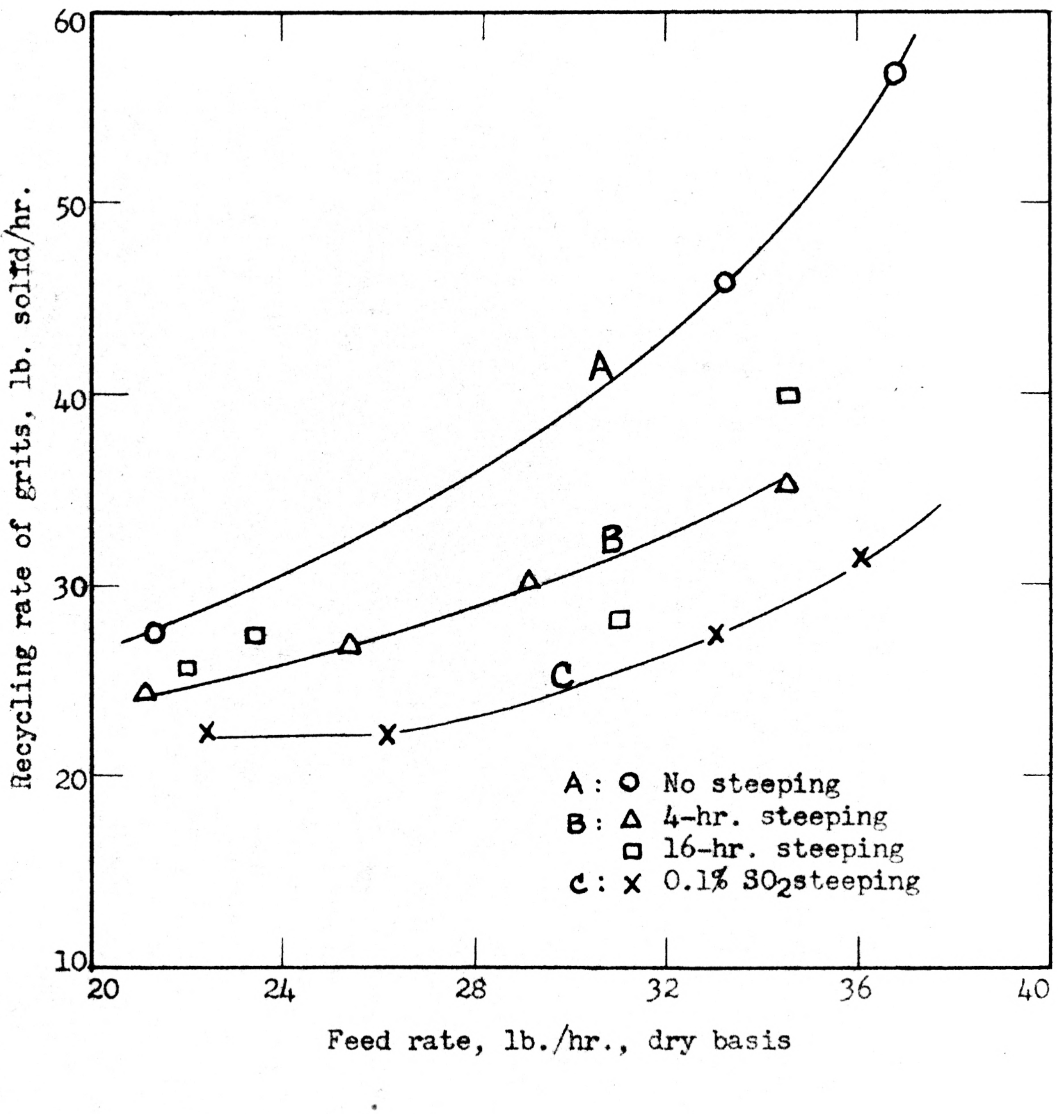


Fig. 14. Effect of steeping on recycling rate.

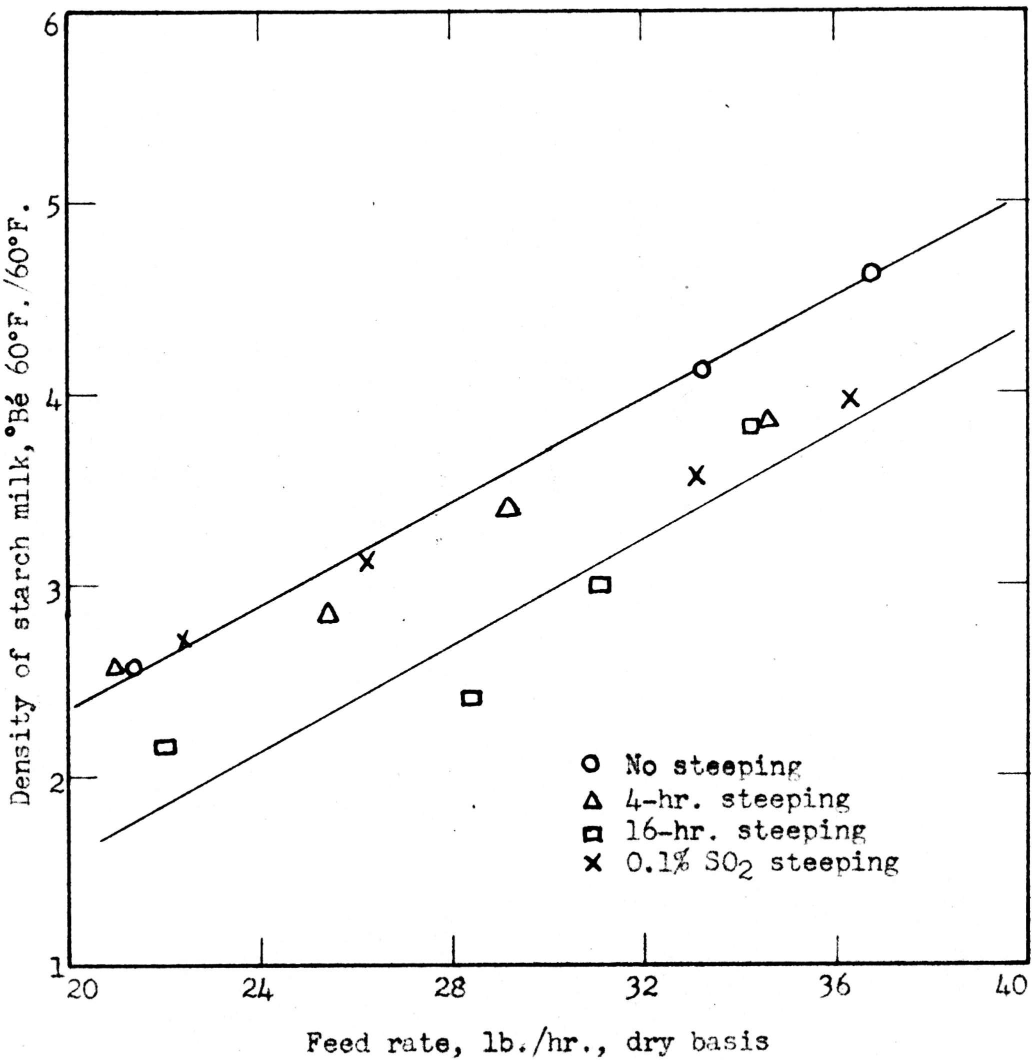


Fig. 15. Effect of feed rate on the density of the starch milk.

densities between these two extreme limits. The high density of unsteeped grits may be due to the soluble material in the grits which went into starch milk instead of being extracted during steeping. On the other hand, the low density of 16-hour steeped grits is probably the result of starch losses through fermentation.

Power and Energy Consumption per Unit Product. In Fig. 16, a very slight increase of power used as the feed rate increases is shown, and no apparent difference due to steeping conditions can be detected. From this fact, it was predicted that the energy consumption per pound of starch produced would depend only upon the production rate. Figure 17 shows that the higher power consumption of the 16-hour steeped grits, which had a lower production rate, is in agreement with the foregoing statement.

Water Consumption. The water consumption per pound of starch produced should be directly proportional to the production rate when constant processing water was used, which was the case in all runs under class III. A plot of water consumption against feed rate is shown in Fig. 18. Again, the low yields of starch in the 16-hour steep runs show up as a high water consumption rate. The low water consumption of unsteeped grits was due, of course, to the fact that no steeping water was used.

Starch Lost into Bran Portion. Since the bran was the portion which contained most of the lost starch, a correlation between the per cent of the starch charged in the grits, which was

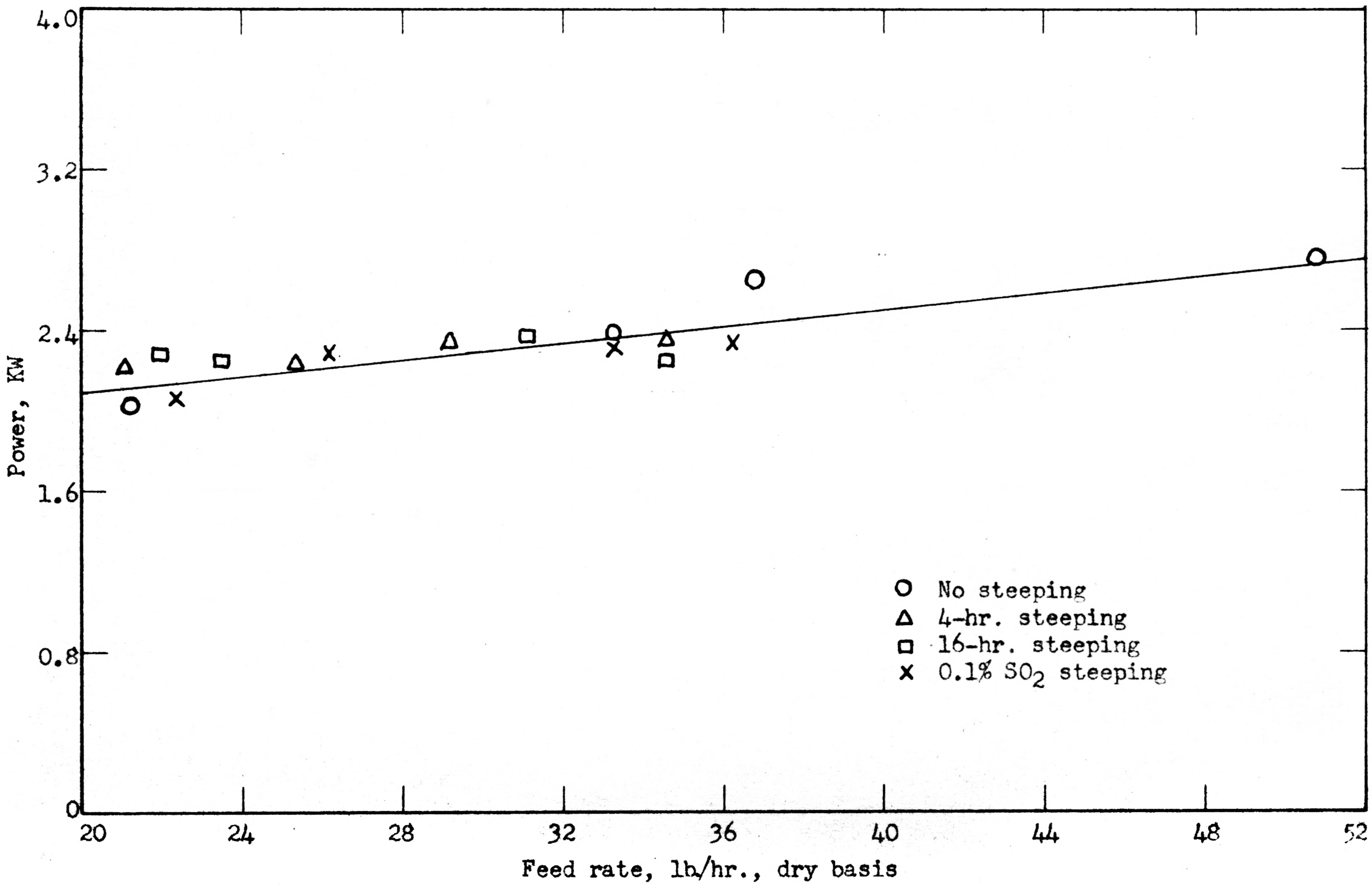


Fig. 16. Effect of feed rate on power.

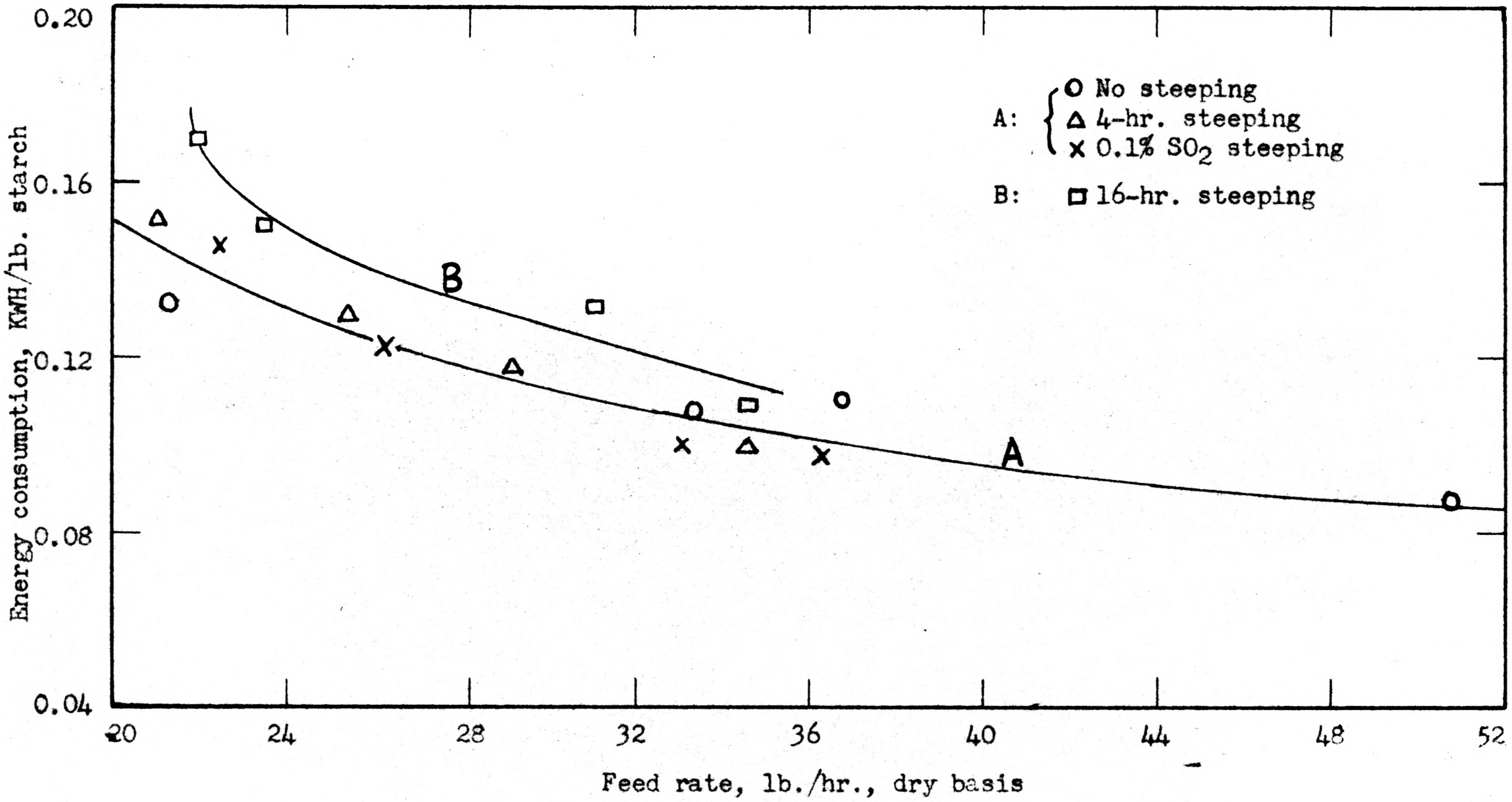


Fig. 17. Effect of feed rate on the energy consumed in grinding per pound of starch produced.

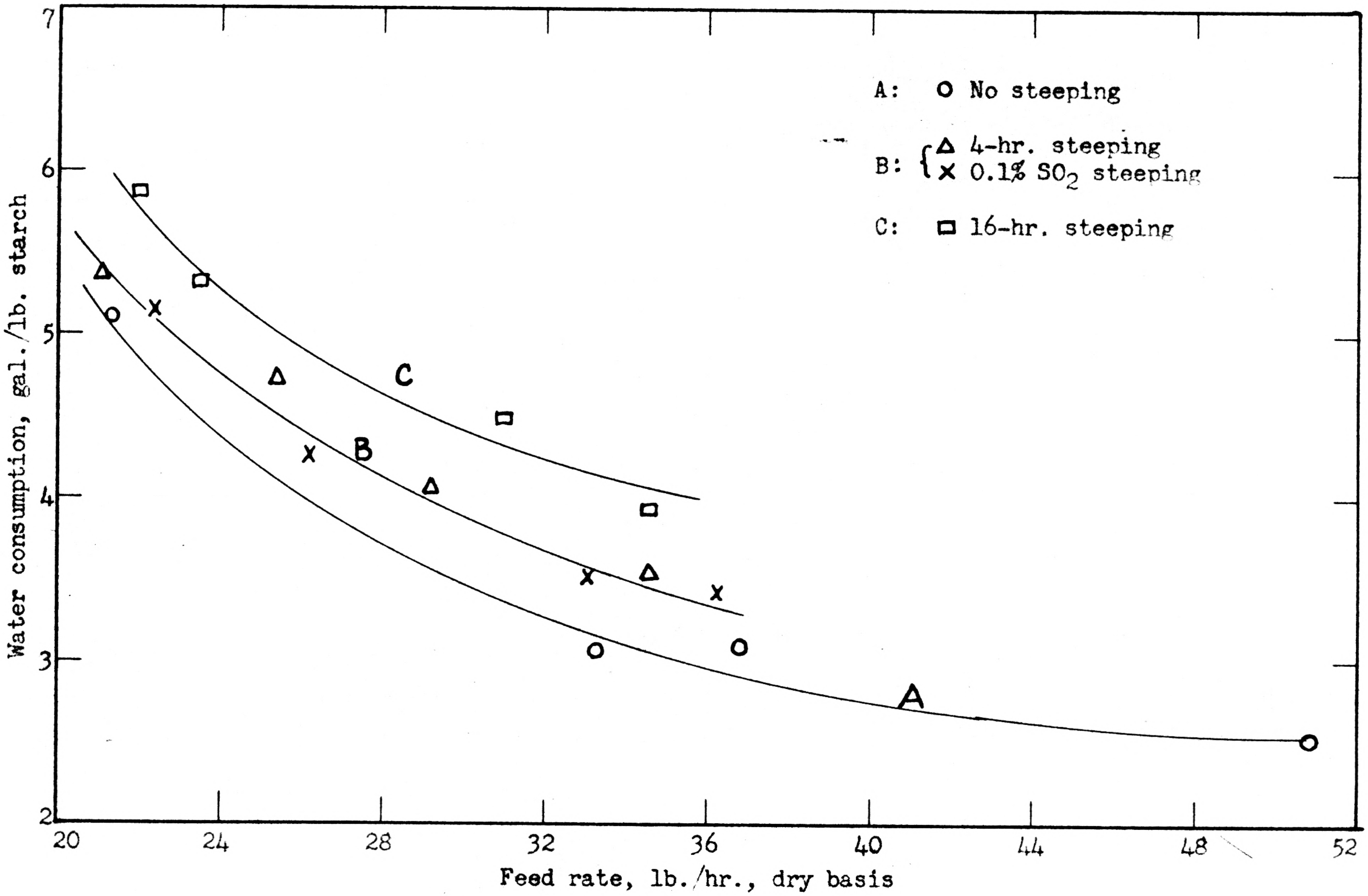


Fig. 18. Effect of feed rate on water consumption.

lost in the bran, and the feed rate was made. In Fig. 19, a general increase of starch loss is shown. Probably, the best way to minimize the loss of starch in the bran is to reduce the quantity of starch milk going into the debranner to a minimum. This can be achieved by an efficient screening operation. A proper adjustment of the mill concentration so that uniform starch particles are produced and a screen system providing sufficient capacity are the two most important factors to assure a good screening operation.

Viscosity Tests

The data recorded in Figs. 1, 2, 3, and 4 may be taken as evidence that the pasting behavior of sorghum starch produced by the hydraulic milling process is affected appreciably by the feed rate. A cross plot, Fig. 20, for starch of different steeping conditions at nearly constant feed rate (33.1 lbs./hr. to 34.6 lbs./hr.) shows significant differences due to the change of steeping conditions. Though obvious differences are shown in each case, unfortunately no general correlation can be made with respect to either feed rate or steeping conditions. This may be explained by the following reasoning.

It has been found (Barham et al, 2) that the paste behavior of the starch is associated with such granule characteristics as the average diameter, density, water-holding capacity, the amount of absorbed organic substances, etc. All of these characteristics are not only affected by the operating conditions, such as steeping, grinding, etc., but are also predetermined by the va-

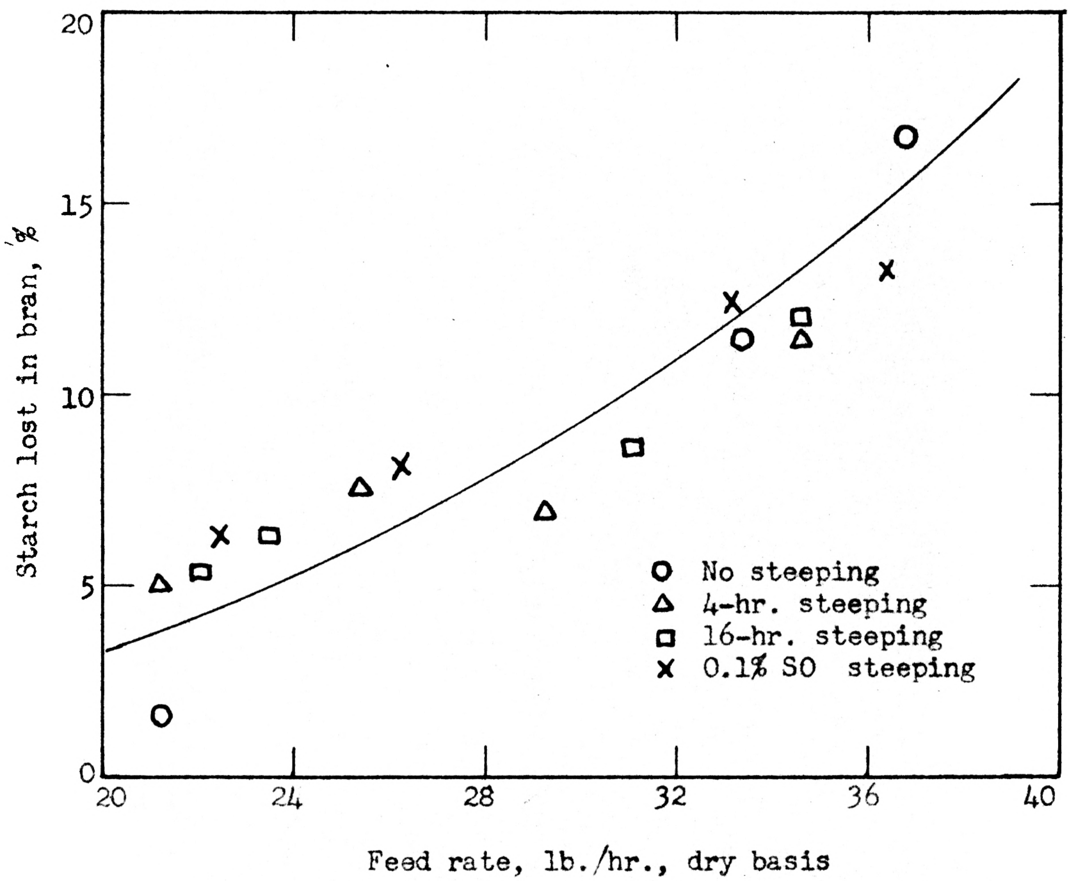


Fig. 19. Effect of feed rate on starch lost in the bran

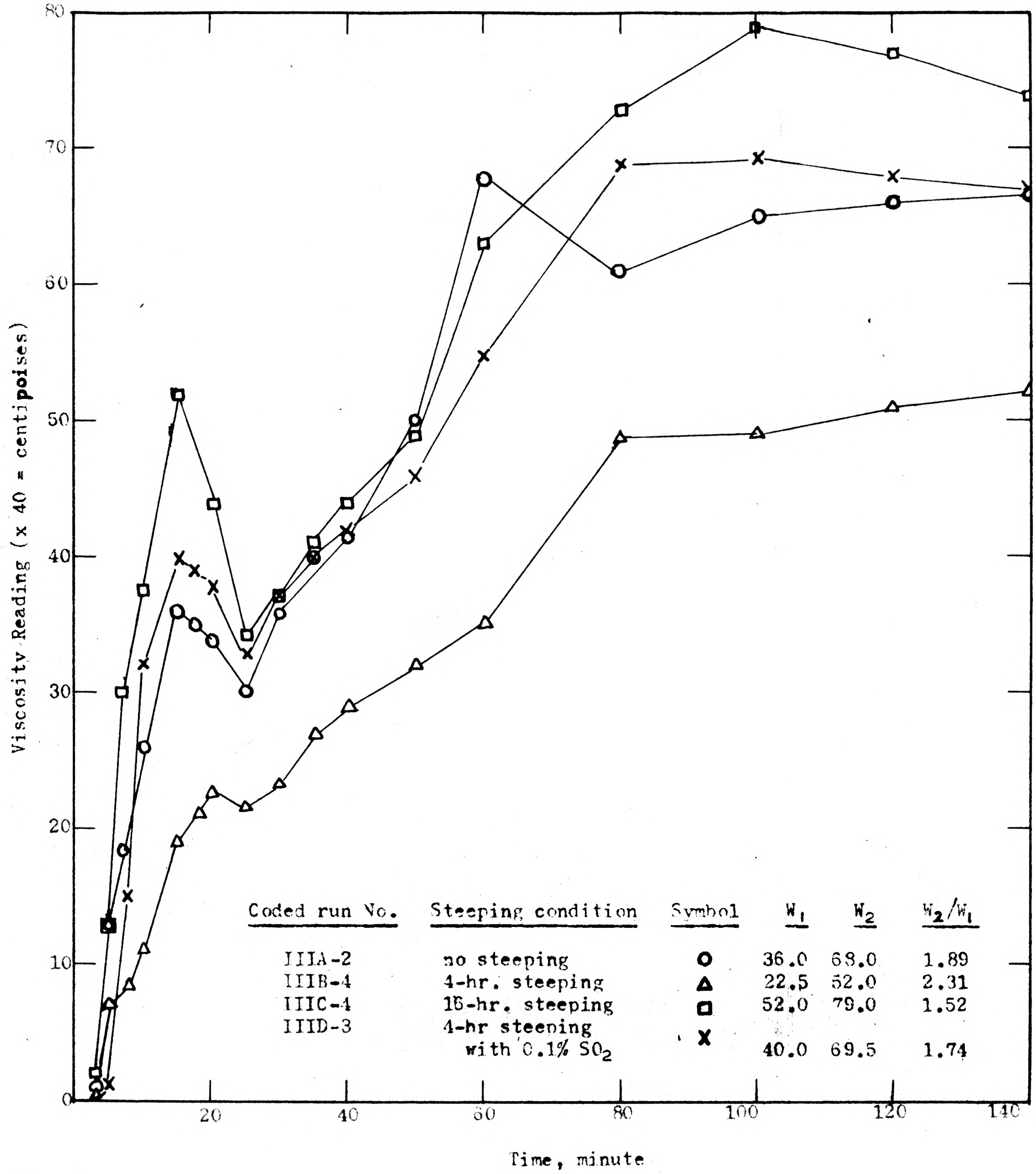


Fig. 20. Comparison of viscosity of different steeping runs at constant feed rate.

riety of grits used. The grits used in this investigation were produced from field-run milo, and therefore may not have been uniform in nature, even within the same batch. Another possibility is that all processing conditions were not completely controlled. All known factors of this sort were held constant, but it is possible that some unknown variable in the process caused the fluctuations in the pasting characteristics.

However, it was found through duplicate tests on five samples that the average deviations of the measurements using the present equipment were $\pm$ 2.0, $\pm$ 2.9, and $\pm$ 5.1 per cent for the heating period maximum, cooling period maximum, and the viscosity index, respectively. With this precision, it is believed that this method is suitable for ordinary industrial quality-control tests. Further investigation on individual factors affecting the viscosity is desirable in order to establish a general correlation which could serve as a basis for the comparison of different starches.

CONCLUSIONS

In general, high recoveries of more than 85 per cent with relatively low water and power consumptions of 2.5 gallons per pound of starch (dry basis) and 0.086 KWH per pound of starch (dry basis), respectively, were attained. The protein content of the starch produced averaged less than 0.6 per cent. These facts indicate that this process for producing sorghum starch is at least as satisfactory as the conventional wet milling process for corn starch.

Other results obtained in this investigation are summarized as follows:

1. A maximum starch recovery was observed as the feed rate increased in both 1-screen and 2-screen operations. The maximum, which was about 80 per cent for 1-screen operation and about 85 per cent for 2-screen operation, occurred at a feed rate range which corresponded to mill concentrations of 6 to 11 pounds of solids per cubic foot.

2. Screen capacity is a sensitive factor in determining the production rate and the recovery of starch, so that a proper adjustment of screen capacity relative to the feed rate is necessary to insure the optimum recovery and production rate.

3. Short steeping times are suitable for sorghum grits. Even unsteeped grits seemed practical for industrial use. Severe fermentation occurring during 16-hour steeping is the main drawback of the long steeping. Sulfur dioxide steeping is not superior to plain water as it is for the steeping of corn.

4. From duplicate measurements of the viscosity of the starch, it was found that the average errors of measurement of the heating period maximum, cooling period maximum, and the viscosity index were $\pm$ 2.0, $\pm$ 2.9, and $\pm$ 5.1 per cent, respectively.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the Kansas State Agricultural Experiment Station for making this study possible, and to Professor William H. Honstead for his help and guidance in carrying out the study of this problem.

BIBLIOGRAPHY

(1) Banowetz, L. F.
Hydraulic grinding of sorghum grains in the preparation of starches. Unpublished Thesis, Kansas State College, Manhattan, Kansas, 1950.

(2) Barham, H. N., and others.
The chemical composition of some sorghum grains and the properties of their starches. Kans. Agr. Expt. Sta. Bul. 61. March, 1946.

(3) Cox, Mary J., M. M. MacMaster, and G. E. Hilbert.
Effect of the sulfurous acid steep in corn wet milling. Cereal Chemistry. 21(6):447-465. November, 1944.

(4) Drobot, Walter.
The industrial recovery of starch from sorghum grits. Unpublished Thesis, Kansas State College, Manhattan, Kansas, 1950.

(5) Fan, L. T.
A study of continuous grinding of steeped endosperm from sorghum grain in the production of starch. Unpublished Thesis, Kansas State College, Manhattan, Kansas, 1954.

(6) Hightower, J. V.
The new corn product plant, it makes wet milling history. Chemical Engineering. 56(6):144-7. June, 1949.

(7) Johnston, Rodney Wm.
The production of starch from grain sorghums. Unpublished Thesis, Kansas State College, Manhattan, Kansas, 1942.

(8) Kerr, R. W.
Chemistry and industry of starch. 2nd ed. New York: Academic Press, 1950.

(9) Taylor, Robert L.
Manufacture of starch from sorghum. Chem. Inds. 64:932-5. 1949.

(10) Watson, S. A., C. B. Williams, and R. D. Wakely.
Manufacture of starch. Cereal Chemistry. 28:105-18. 1951.

(11) Zipt, R. L., R. A. Anderson, and R. L. Slotter.
Starch production from sorghum. Cereal Chemistry. 27:463-76. 1950.

FACTORS AFFECTING THE PRODUCTION OF STARCH FROM THE ENDOSPERM OF SORGHUM GRAINS

by

SHIAO-HUNG CHIANG

B. S., National Taiwan University, China, 1952

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Chemical Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1955

The primary purpose of this research was to investigate some of the factors affecting the yield and quality of the product from the continuous hydraulic milling process for the production of starch from milo maize grits.

The three most important factors which received attention in this work are: (1) conditions of steeping; (2) feed rate, and (3) screen capacity. The investigation of conditions of steeping included the effect of time and the use of sulfurous acid. No steeping, 4-hour, and 16-hour steeping were used for the time effect study. The sulfurous steeping was carried out with 0.1 per cent SO_2 solution for four hours.

The feed rate study was conducted by systematically changing the speed of the screw feeder.

A comparison of runs made with two screens, one of 40-mesh and the other of 200-mesh, operated in series, to those made with only one 200-mesh screen, showed the effect of screen capacity.

The first step in the process was steeping the grits in warm water with or without SO_2. The steeped grits (or unsteeped grits in the case of no-steeping runs) were fed into the hydraulic mill, continuously. The ground material overflowed from the mill and was separated by a screen (or screens). Fine particles of starch and gluten passing through the 200-mesh screen were taken as starch milk, while the coarse material was washed into the debranner where the bran was separated from the unground grits, which were recycled back to the mill. The starch suspended in the starch milk was finally separated from the gluten by using conventional starch tables. The starch collected from the table was dried at 130° F. to give the finished product.

A paste viscosity test on the starch was conducted. The aim of this test was to develop a quality control method. A cylindrical, water-jacketed container with a stirrer was used to heat and cool the starch paste. The viscosity was measured by a Brookfield Synchro-lectric Viscometer at short intervals. There were two maximum viscosity readings developed for each test, one in the heating period and the other in the cooling period. The ratio of these two maxima was used as an empirical index of starch quality.

The results of the present investigation are summarized as follows:

1. Good recoveries of starch of more than 85 per cent were attained, with relatively low water and power consumptions of 2.5 gallons per pound of starch (dry basis) and 0.086 KWH per pound of starch (dry basis), respectively. The protein content of the starch produced averaged less than 0.6 per cent. These facts indicate that this process for producing sorghum starch is at least as satisfactory as the conventional wet milling process for corn starch.

2. Short steeping times are suitable for sorghum grits. Even unsteeped grits seemed practical for industrial use. Severe fermentation occurring during 16-hour steeping is the main drawback of the long steeping. Sulfur dioxide steeping was not superior to plain water as it is for the steeping of corn starch.

3. A maximum starch recovery was observed as the feed rate

increased in both 1-screen and 2-screen operations. The maximum, which was about 80 per cent for 1-screen operation and about 85 per cent for 2-screen operation, occurred at a feed rate range which corresponded to mill concentrations from 6 to 11 pounds of solids per cubic foot.

4. Screen capacity is a sensitive factor in determining the production rate and the recovery of starch, so that a proper adjustment of screen capacity relative to the feed rate is necessary to insure the optimum recovery and production rate.

5. The results of the starch paste viscosity tests were found to be reproducible with considerable precision. However, the data appeared to be erratic and could not be easily correlated with process variables.