EFFECT OF SULFUR DIOXIDE IN STEEPING SORGHUM GRITS FOR THE PRODUCTION OF STARCH

by

TA-FANG CHAI

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INTRODUCTION

The production of sorghum grains in Kansas of 31,878,000 bushels in 1955 (9) was second among the states, being surpassed only by Texas. Sorghum grains hold third place in annual crop production in Kansas as compared to wheat and corn. Because the sorghum plant is adapted to the prevailing growth conditions of this hot and dry area, the utilization of sorghums in industrial products could make an economic contribution to the state.

Since starch is the principal constituent in sorghum grains, being present to the extent of approximately 70 per cent, the production of starch from sorghums was selected as the most promising industrial material.

This investigation was a continuation of a series of investigations sponsored by the Kansas Agricultural Experimental Station. The primary purpose of this work was to compare the use of sulfur dioxide as a steeping agent with plain water steeping for yield and quality of the starch. A secondary purpose was to compare the hydraulic mill with a buhrstone mill in the grinding process.

The early investigations on starch recovered from sorghum grain used processes similar to those used in the corn industry. Johnston (8) developed a wet-milling process at Kansas State College in 1942 on a laboratory scale. Banowetz (1) and Drobot (6) studied the hydraulic mill instead of the conventional buhrstone mill for use on debranned and degermed sorghum grain, or grits. Later, Fan (7) developed a continuous wet-milling process on a pilot plant scale, still using the hydraulic mill, and Chiang (4) continued to investigate the various factors affecting the yield and quality. In Chiang's investigation plain water steeping was used for the most part.

In milling corn for starch production, SO_2 is used as a steeping agent. The function of sulfur dioxide as a steeping agent has been investigated by Cox et. al. (5). They showed that the starch is embedded tightly in a protein matrix which is birefringent. During steeping the protein matrix swells and tends to form tiny globules of hydrated protein. With time, the protein loses its birefringence, tends to disperse, and finally the undispersed protein becomes so weak that after removal of starch granules it collapses against the cell walls and shows little evidence of the original network of films. Sulfur dioxide greatly accelerates this process.

It seemed that this principle could apply to the starch from sorghum grits. Chiang (4) reported that there was no favorable improvement of yield in using SO_2 as a steeping agent. His work was mainly to find the effect of various factors such as feed rate and water rates on the recovery of starch. Only four runs using 0.1 per cent of SO_2 were investigated.

It was believed that, due to the strong shearing action of buhrstone mills, the starch granules produced thereby might be seriously damaged, so that the starch quality would be lower than the quality of starch from the hydraulic mill. For this reason a few runs were made using a buhrmill.

EQUIPMENT

The equipment used in this investigation was the same as that used by Fan (7) and Chiang (4) except for minor improvements, and except for the buhrstone mill used in place of the hydraulic mill on a few runs. The flow sheet and a view of the pilot plant are shown in Plates I and II respectively.

Steeping Unit

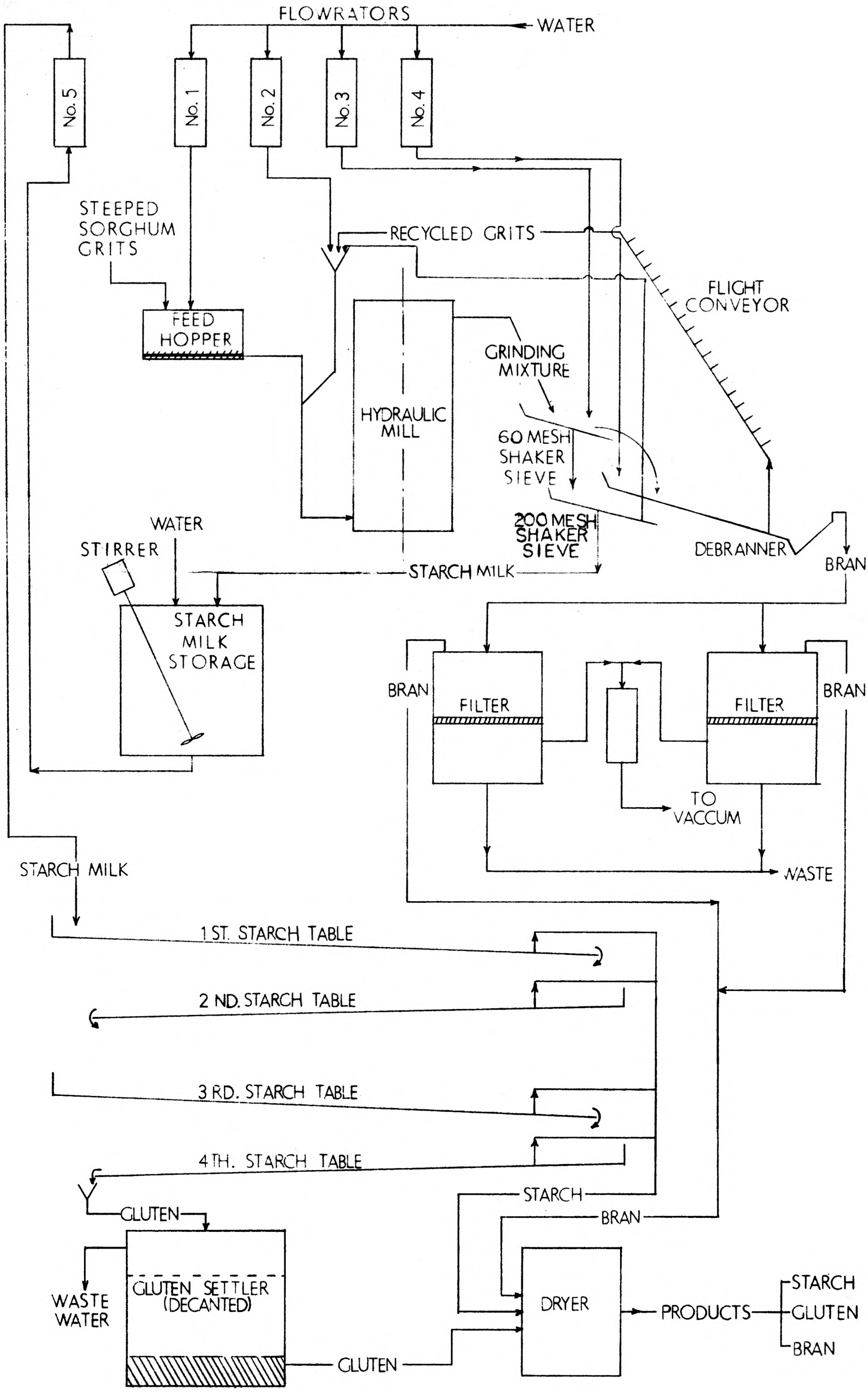
Three 15-gallon stainless steel tanks arranged as shown in Plate III were used for steeping. One of these was used to heat the steep water. This tank contained a copper coil through which low-pressure steam was passed. The water temperature was maintained 120° ± 5°F by a Taylor self-acting steam regulator. A centrifugal pump (Eastern Industries, Model D-6, 1/30 hp., 3450 rpm) was used to pump the hot water through a 1/4 galvanized iron tubo to the top of each of the other two steeping tanks. The water passed downward through the grits in the steeping tanks and flowed back into the heating tank in order to maintain a constant temperature of 120 ± 5°F in steeping. A 1/4-inch pipe carried the overflow, if any, from each of the steep tanks back to the heating tank, thus making exact control of the pumping rate unnecessary. The temperature was recorded automatically by a Bristol temperature recorder.

EXPLANATION OF PLATE I

Flow Sheet of Continuous Hydraulic Milling

Process for Production of Starch From Sorghum Grits

PLATE I



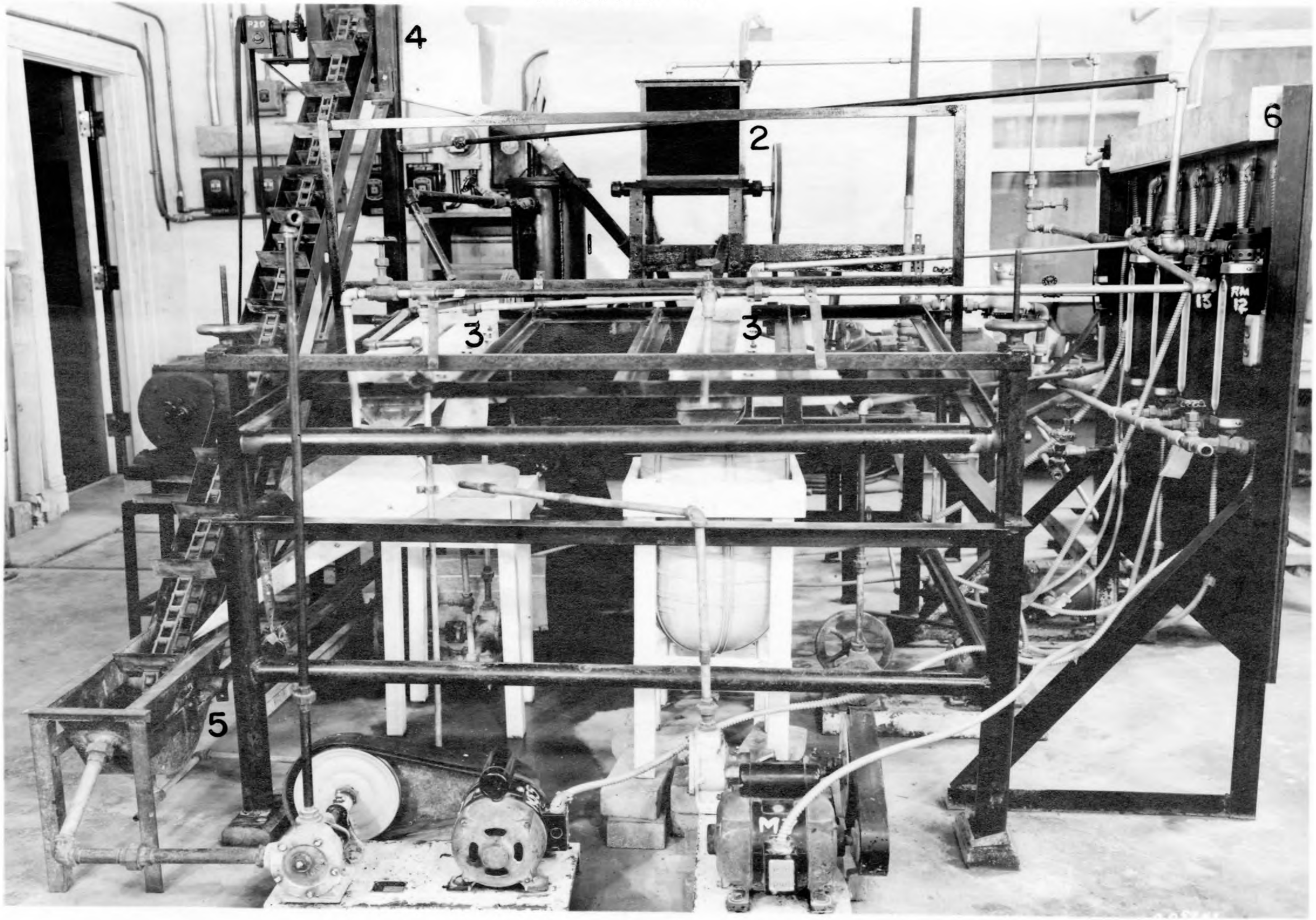
FLOWRATORS
WATER
No. 5
No. 1
No. 2
No. 3
No. 4
STEEPED SORGHUM GRITS
RECYCLED GRITS
FLIGHT CONVEYOR
FEED HOPPER
GRINDING MIXTURE
HYDRAULIC MILL
60 MESH SHAKER SIEVE
200 MESH SHAKER SIEVE
DEBRANNER
BRAN
WATER
STIRRER
STARCH MILK
STARCH MILK STORAGE
BRAN
FILTER
FILTER
BRAN
TO VACCUM
WASTE
STARCH MILK
1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

EXPLANATION OF PLATE II

View of Pilot Plant

1. Hydraulic mill
2. Feed hopper
3. Shaker screens
4. Flight conveyer
5. Debranner
6. Control panel

PLATE II

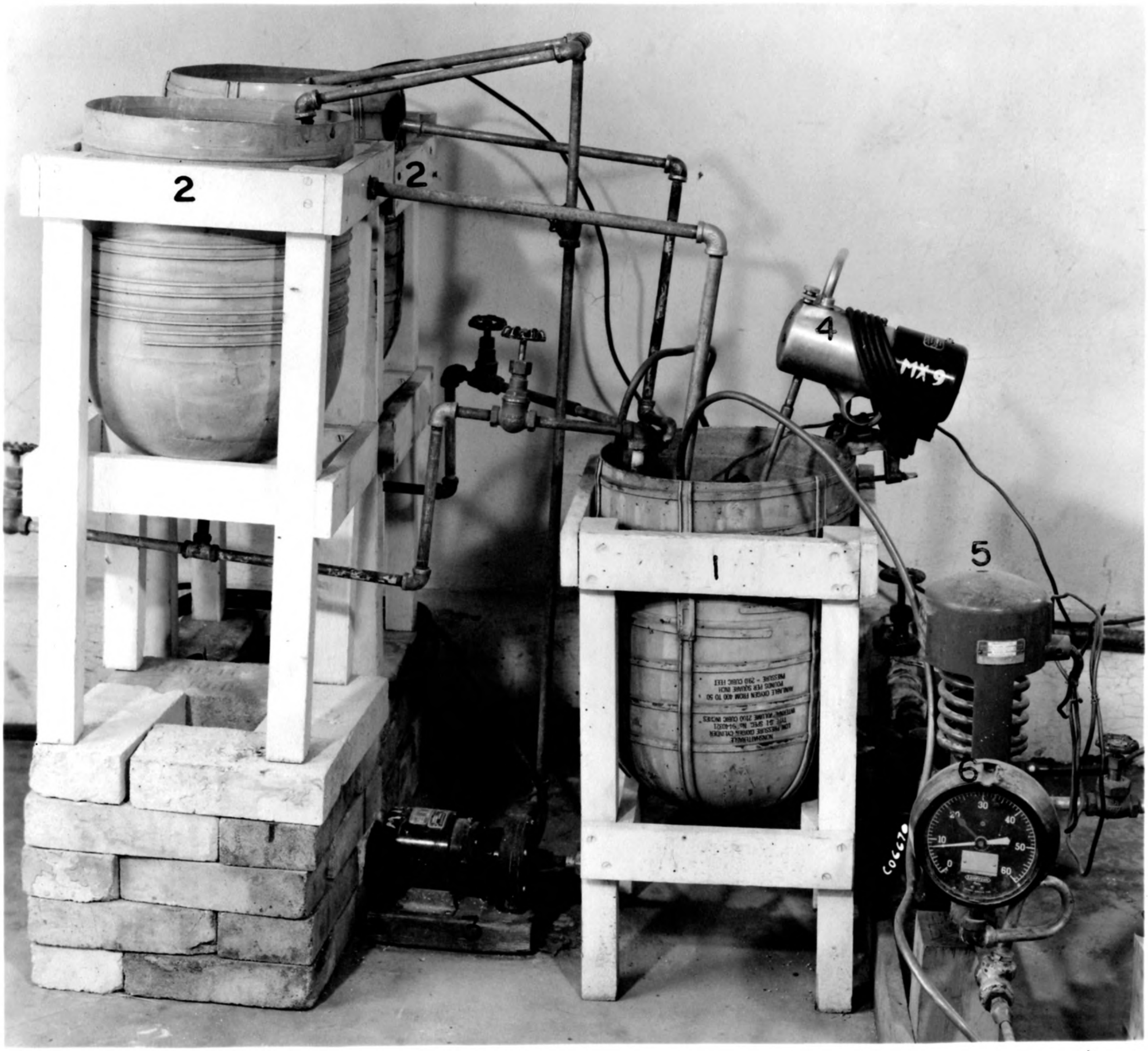


EXPLANATION OF PLATE III

Steeping Equipment

1. Heating tank
2. Steeping tanks
3. Steeping water circulating pump
4. Lightning mixer
5. Taylor self-acting steam regulator
6. Steam pressure gauge

PLATE III



Grinding Equipment

Feeding Device. A V-shaped feed hopper was used. The steeped grits were fed to the mill by a 1 1/2 inch by 12 inch screw conveyor which was driven by a 1-hp Reeves Varimotor with speeds from 26 to 156 rpm. A 1 1/2-inch standard iron pipe was connected at the outlet of the screw conveyor to the bottom of the hydraulic mill in order to lead the feed grits to the mill for grinding. A small stream of water was fed into the feed hopper through a 1/4-inch pipe to prevent the grits plugging in the feeder or the feed line to the mill.

Hydraulic Mill. An elevation and a detailed drawing of the hydraulic mill are shown in Plates IV and V. A vertical shaft with horizontal blades was driven by a 10-hp Fairbanks-Morse induction motor of 1170 rpm. The shaft speed used throughout this research was 2240 rpm although it was adjustable by the use of various pulley ratios. A T-2 Frahm tachometer was used to indicate the shaft speed of the mill. The power consumption was measured by a General Electric type V-3-A polyphase watt hour meter with a watt hour constant of 7.2. The ground material overflowed through a 1-inch standard pipe near the top of the mill onto the first of the two screens.

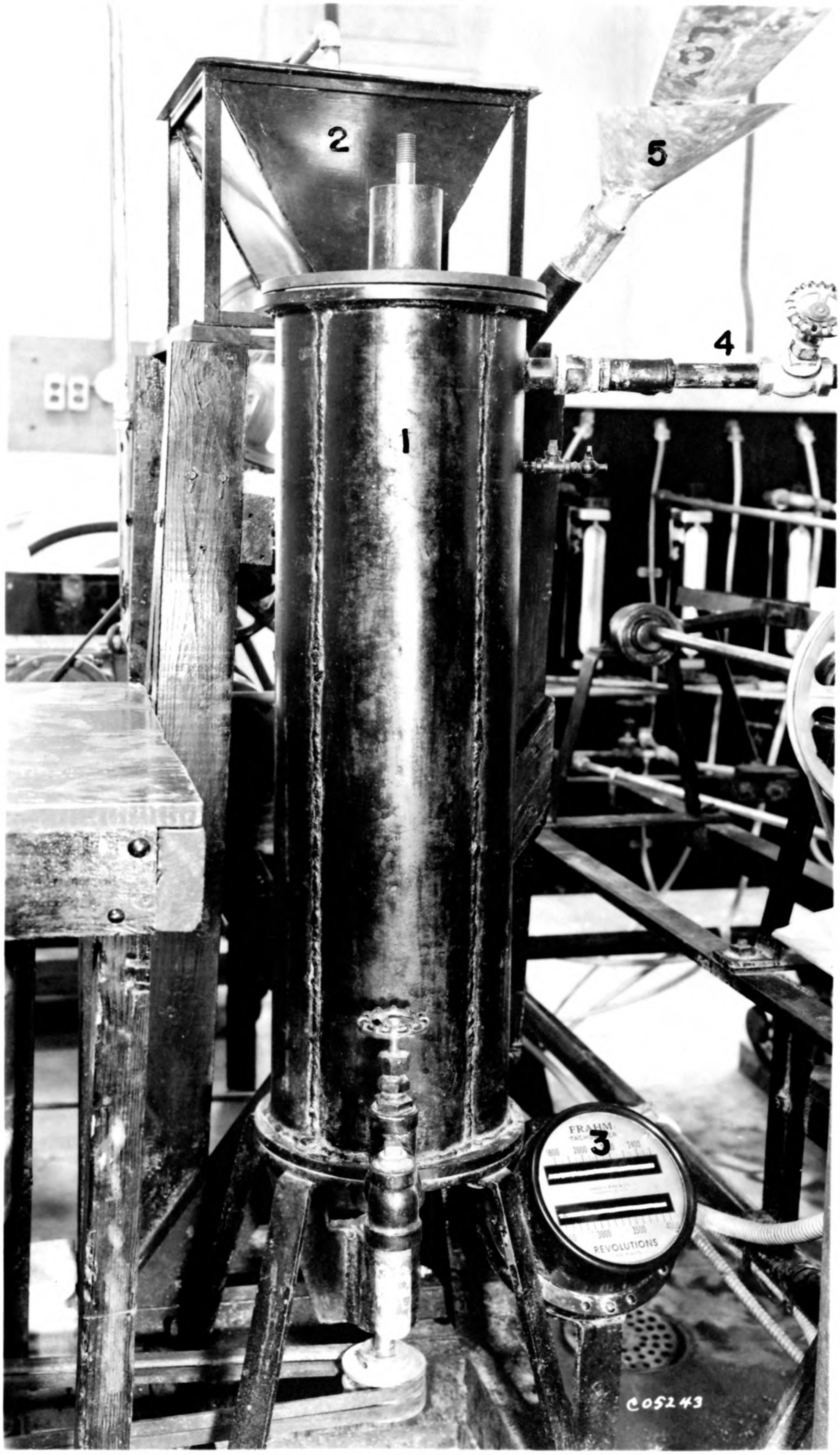
Buhrstone Mill. The buhrstone mill was a modified Ross No. 18 eight inch stone mill, as shown in Plate VI. The upper stone was mounted as a rotary part on a shaft which was driven by a 1 hp induction motor at 244 rpm. The lower stone was fixed and stationary on the frame.

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

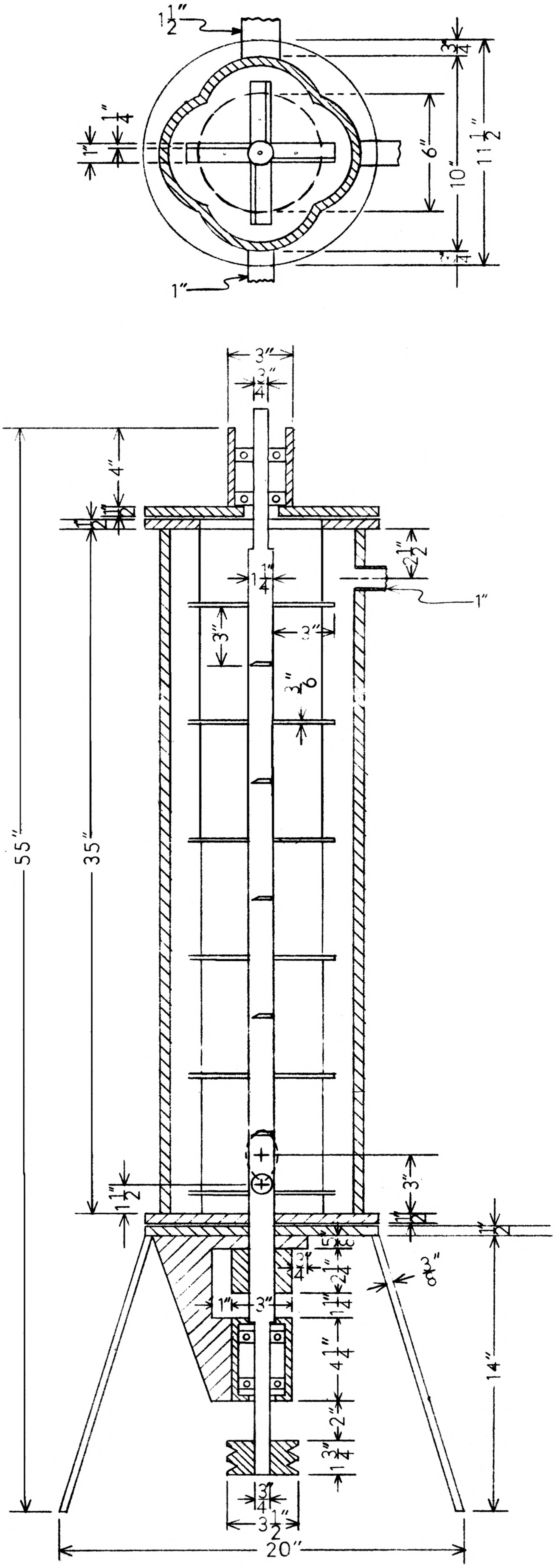
PLATE IV



EXPLANATION OF PLATE V

Detailed Drawing of Hydraulic Mill

PLATE V

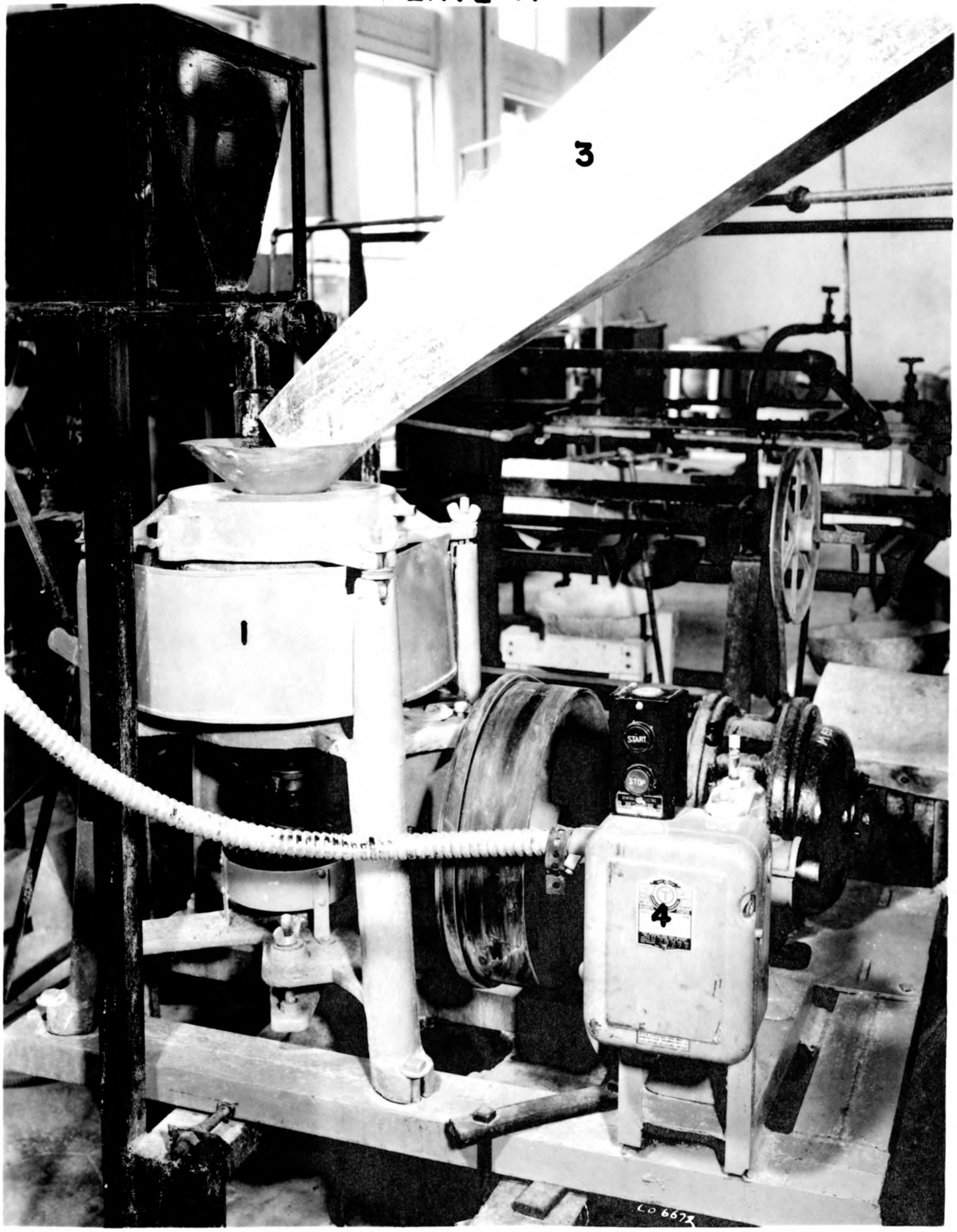


EXPLANATION OF PLATE VI

Buhrstone Mill

1. Buhrstone mill
2. Feed hopper
3. Recycling line
4. Starter
5. Motor

PLATE VI



When the buhrstone mill was rotating, there was a strong shearing action exerted on the grits. As a result of the small clearance and this shearing action, the grinding was very fine. The clearance could be adjusted by a set screw on the bottom of the frame. A gear pump was used to transfer the ground grits from the buhrstone mill to the first screen.

Screens

Two screens of the same size, one of 40-mesh and one of 200-mesh, were arranged in series. The ground material overflowed onto the 40-mesh screen. The overflow from this screen was washed into the debranner, and the underflow was pumped by a gear pump to the head of the 200-mesh screen. The overflow from this screen was washed and pumped back to the hydraulic mill for regrinding by a gear pump, while the underflow was pumped by a gear pump to the storage tank as starch milk for tabling. The screens were mounted on a shaker which provided an oscillating motion of the screens by means of an eccentric. The oscillating frequency was 290 cycles per minute with 1/2-inch horizontal displacement. The slope of the screens was adjusted by means of a screw setting. The slopes of both screens was set initially at 1.3 inches per foot. This was later increased to 1.8 inches per foot, and the slope of the coarse screen was then further increased to 2.5 inches per foot. A steam of water was introduced onto each screen through an over head spray-nozzle to wash the overhead materials.

<u>Flight Conveyor and Debranner.</u> A flight conveyer of the following dimensions was used: 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 conveyer was driven by a 1 hp Reeves Varimotor through a belt and a set of reduction gears so that the linear speed of the conveyer was in the range of 1.5 to 9 feet per minute.

The lower end of the conveyer functioned as the debranner which is shown in detail on Plate VII. The overhead coarse material washed from the first 40 mesh screen passed into the debranner and was separated by flotation. The lighter bran portion was floated out through a gear pump to a nutsch-type filter with an area of four square feet. This filter was connected to a vacuum pump (F. J. Stoke Machine Company, Model 33275 reciprocating vacuum pump) which could maintain a vacuum of about 25 inches of mercury. The unground material which settled to the bottom of the conveyer boot was carried back to the hydraulic mill for regrinding.

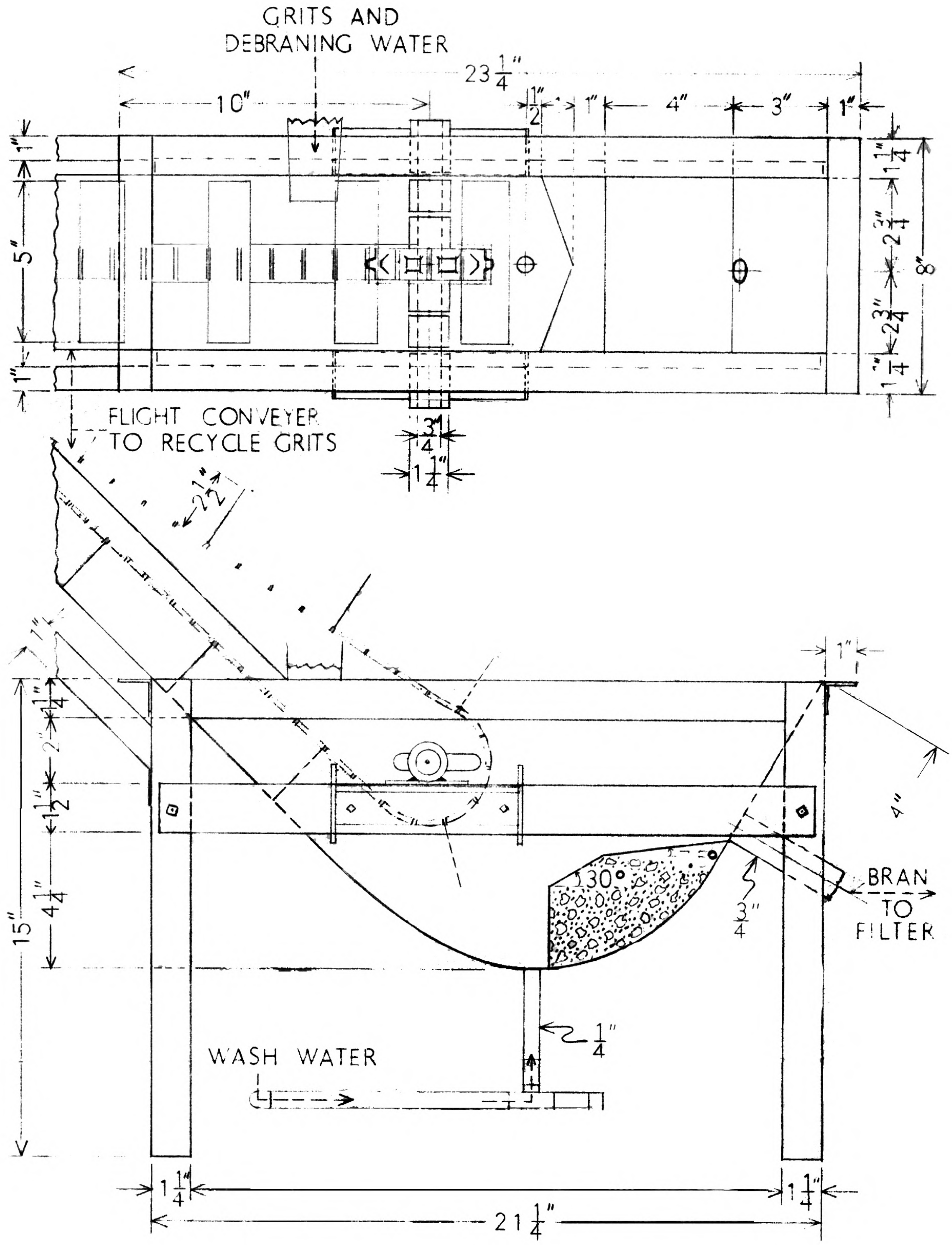
Starch Tables

Four starch tables were used to separate the starch and gluten. They were arranged in series and each was 27 feet long, 5 3/4 inches wide and 2 1/2 inches deep. The slope of the tables was 1 inch per 10 feet alternately in opposite directions.

EXPLANATION OF PLATE VII

Drawing of Debranner

PLATE VII



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

Auxiliary Equipment

Control Panel. Five flowrators and seven switches were arranged on a control panel as shown in Plate VIII in order to control the various rates of water flowing and the starch tabling operation.

SO_2 Saturating Tank. A 15 gallon stainless steel tank was used to saturate the SO_2 solution. The tank was filled with water. Then SO_2 was introduced from a gas cylinder through a reducing valve and a rubber tube until the water was saturated with SO_2 gas. A valve at the bottom of the tank was used to remove the SO_2 solution as needed for steeping.

Storage Tanks. A 50-gallon, cone-bottom, stainless steel tank was used as a storage for starch milk from the 200-mesh screen before tabling. A 1/4 hp Ligtnin mixer, Model D-1A, was used to prevent the starch from settling out.

Another 100 gallon cone bottom stainless tank was used to settle the gluten liquor which overflowed from the starch tables. After overnight settling, the upper clear liquor was taken off by means of a syphon. The thick gluten slurry was drained off from a 2-inch outlet at the bottom of the tank.

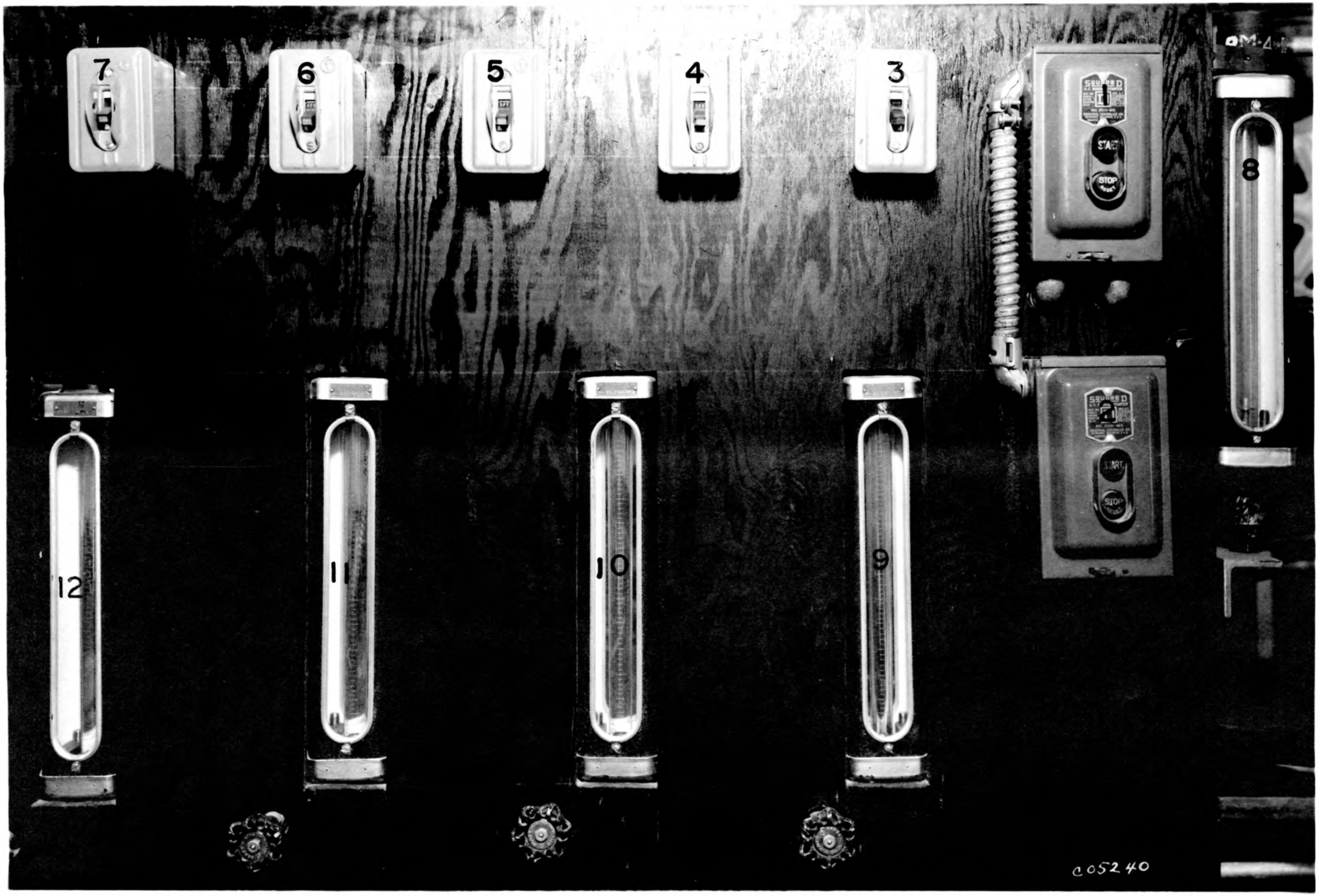
Dryer. A tray and compartment dryer made by Geo. Koch Sons Company was used for drying all the products. Air was heated by a steam coil and circulated by a blower. The temperature was maintained at 130°F by a Bristol pneumatic temperature controller recorder.

EXPLANATION OF PLATE VIII

Control Panel

1. Switch for starch milk pump to table
2. Switch for motor for flight conveyer
3. Switch for motor for screen shaker
4. Switch for recycling pump
5. Switch for starch milk pump to storage
6. Switch for bran pump to filter
7. Switch for ground grits pump to screen (for Buhrstone Mill only)
8. Flowrator for feed water
9. Flowrator for starch milk
10. Flowrator for water to screens
11. Flowrator for debranning water
12. Flowrator for grits recycling water

PLATE VIII



Viscosity Equipment. Since viscosity is one of the main characteristics for quality control of starch, viscosity tests of starch samples were conducted in this laboratory. The test used was a modification of the procedure used by Barham et. al. (2, 3) in which the viscosity of a five per cent starch paste was measured during a controlled heating, cooking and cooling cycle. A Brookfield Synchro-lectric Viscometer, Multi-speed, Model LVF was used to measure the change of viscosity of the starch throughout the heating and cooling periods. The ratio of the two maximum viscosities, is an empirical index of starch quality.

The equipment used for this purpose consisted of a water jacketed container with an inside diameter of three inches, an outside diameter of 6 1/2 inches, and a height of 5 inches. The sample was heated or cooled by the circulation of hot or cooled water through the jacket. A U-shape stirrer was inserted with its shaft passing through the center of the bottom of the container and driven by a 1/12 hp motor through a set of gears and pulleys which gave a speed of 60 rpm to the stirrer. They are shown in Plates IX and X.

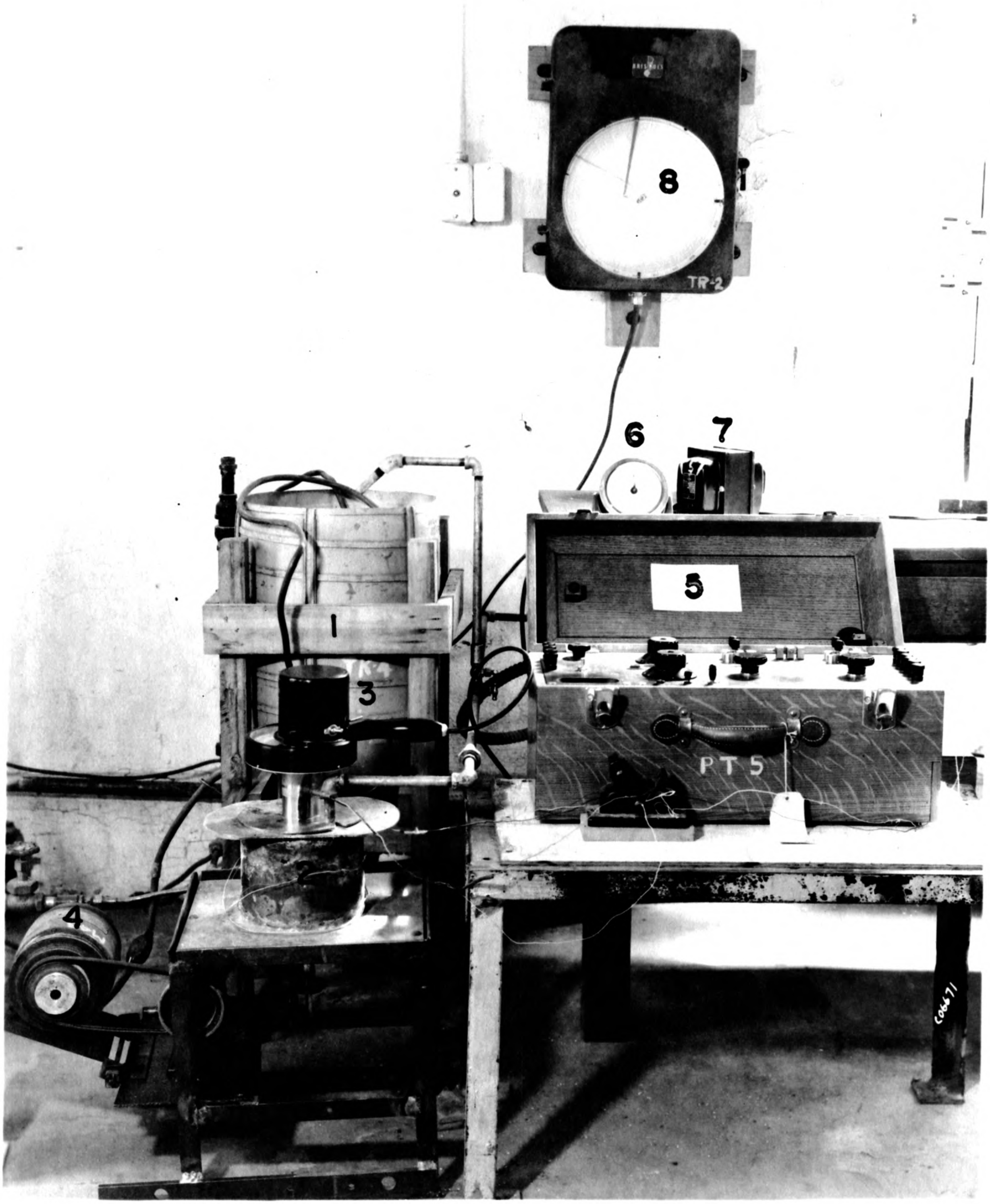
The viscometer was supported by a one inch stainless steel cylinder which ensured that the spindle of the viscometer was immersed in the starch and centered. The readings of viscosity were taken at short intervals. The temperatures of the starch paste and of the water jacket were measured by copper constantan thermocouples which were connected to a Leeds and Northrup

EXPLANATION OF PLATE IX

Viscosity Equipment

1. Heating tank
2. Jacketed starch solution container
3. Brookfield Synchro-lectric Viscometer
4. Stirrer motor
5. Leeds & Northrup Precision Potentiometer
6. Timer
7. Transformer
8. Bristol temperature recorder (for steeping use)

PLATE IX

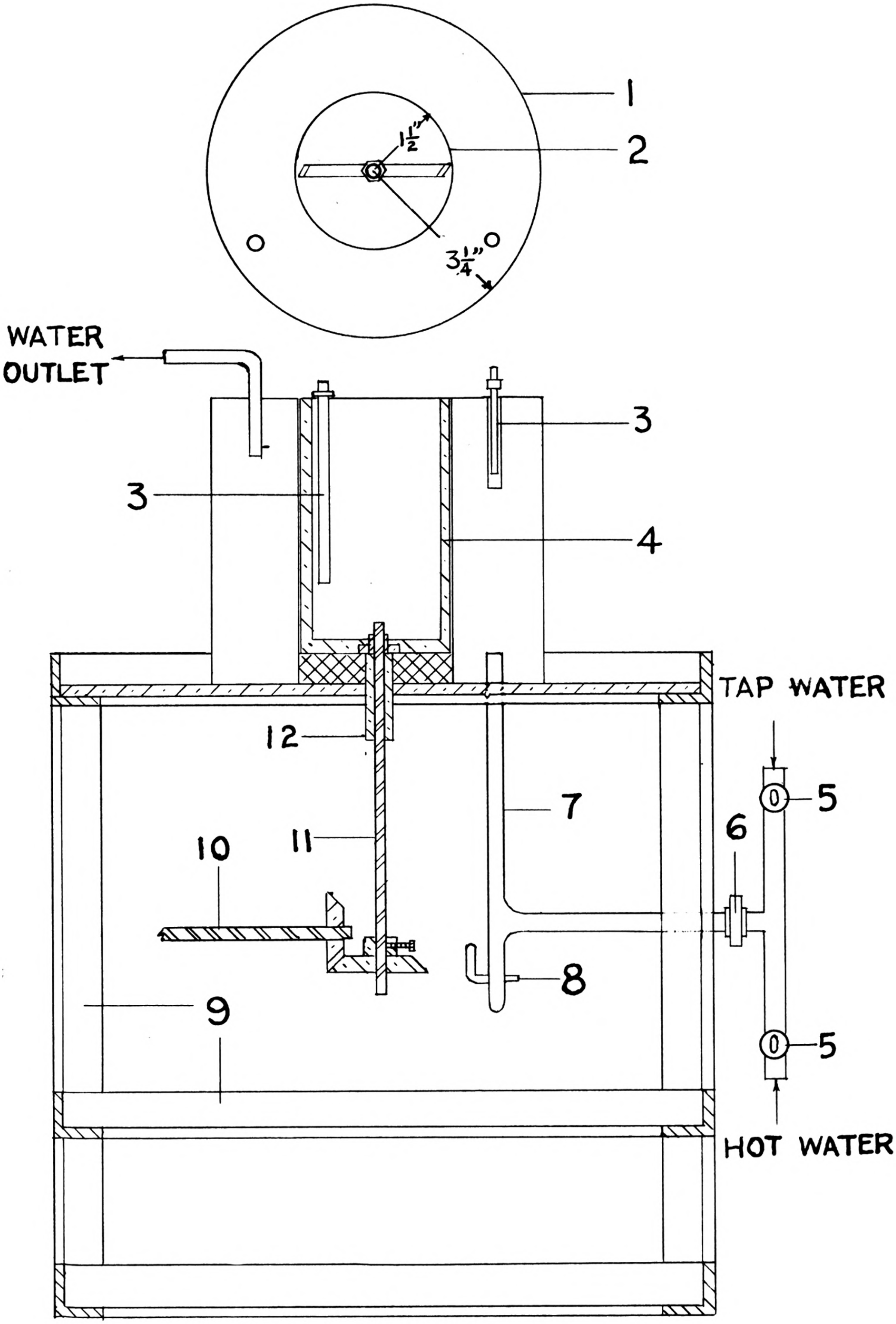


EXPLANATION OF PLATE X

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
$1\frac{1}{2}$"
$3\frac{1}{4}$"
WATER OUTLET
3
3
4
TAP WATER
12
7
5
6
10
11
8
9
5
HOT WATER

Precision Potentiometer. The millivoltages on the potentiometer were recorded and converted into temperature readings by a conventional table furnished by Leeds and Northrup Company.

MATERIAL

The milo sorghum grits were supplied from Grain Products, Incorporated, Dodge City, Kansas. As the grits arrived at the campus, they were stored in 55-gallon, opened-head barrels. A 50 cc erlenmeyer flask containing a small amount of carbon disulfide was placed in each of the barrels as an insecticide. The barrels were then covered tightly.

Four batches of grits were used. The composition of the grits was analyzed by the Chemical Service Laboratory at Kansas State College. The analyses are shown in Table 1.

Table 1. Chemical analysis of sorghum grits.

Component	Weight percentage			
	Batch 1	Batch 2	Batch 3	Batch 4
Protein	9.41	11.22	11.53	11.23
Ether extract	0.82	1.13	0.93	0.99
Crude fiber	0.73	0.79	0.81	0.74
Moisture	9.20	9.04	10.44	10.72
Ash	0.60	0.64	0.63	0.63
N-free extract	79.25	77.19	75.66	75.73
Carbohydrates	79.98	77.98	76.48	76.47
Starch	75.78	74.01	72.75	76.47

Both steeping and processing water were taken from the Manhattan City system. The analysis of water was reported by Fan as shown in Table 2.

Table 2. Analysis of Manhattan city water.

Total hardness (parts of calcium carbonate per million)	76
Non-carbonate hardness (parts of calcium carbonate per million)	45
Total dissolved (parts per million)	218
PH value	8.97

The sulfur dioxide used as steeping agent was supplied by Calco Chemical Division, American Cyanimide Company. The actual diluted steeping liquor was obtained by dilution of the saturated solution at proper ratio.

EXPERIMENTAL PROCEDURE

Three main steps, steeping, grinding and tabling formed the operation of the production of starch. The determination of paste viscosity was conducted as a minor step. They are discussed in detail in the following:

Steeping

Twenty-five to 50 pounds of grits were charged into one or two steeping tanks. The heated steeping liquor was introduced separately into these tanks from the heating tank by means of a 1/30 hp centrifugal gear pump. The steeping temperature was kept around 120 $\pm$ 5°F and recorded by a Bristol temperature recorder. The quantity of liquor used was about 0.25 to 0.36 gallons per pound of grits. The steeping time was varied from no steeping to 24 hour steeping and the steeping liquor used was plain water or various diluted SO_2 solutions from 0.05 per cent to 0.3 per cent SO_2. The concentration of SO_2 was determined by titration with iodine solution and sodium thiosulfate as reagents (Scott, 11). After steeping, the steeping liquor was drained off and discarded.

Grinding

The flow sheet for the milling operation is shown in Plate I. The steeped grits were transferred manually from the steeping tanks into the feed hopper. The feed rate, the water rate and the rpm of the stirrer of the hydraulic mill were set for each run. Before the grinding was started, a power consumption reading was taken on the mill running empty in order to calculate the net power consumption for grinding. Then the feed water, the screw conveyor and the stirrer of the hydraulic mill were started simultaneously. The starting time and ending time were recorded so that the actual feed rate could be computed.

The motor driving the shaker on the screens was started when the grits overflowed onto the screen. The wash water to the screens was then turned on, and the pumps for the underflow to the 200 mesh screen, for the starch milk to the storage tank, and for pumping the overflow from the 200 mesh screen back to the hydraulic mill were started successively. As the coarse material and bran from the 40-mesh screen flowed down the screen, the flight conveyer was started and the water for debranning and for the recycling grits were begun simultaneously. The bran was separated in the boot of the flight conveyer by floating it off and pumped as a slurry to the vacuum filter.

The procedure for the operation of the buhrstone mill was similar to the operation of the hydraulic mill. Since the distance traveled by the ground grits was comparatively short compared to that in the hydraulic mill, the time lag required for passing the ground grits from the mill to the screens was negligible. Hence, the shaker motor and the pumps for circulation of the fine slurry and recycling overhead material were started simultaneously.

All the process conditions were taken at 10 minute intervals. The steady state was assumed to be attained when the rate of overflow from the mill and the density of the starch milk remained constant. Before the steady state was attained, the starch milk and the bran product were pumped to the sewer. These streams were sampled for 10 to 15 minutes during the steady state and all the calculations were based on this interval.

Immediately after running, the mill was stopped and the contents of the hydraulic mill were drained out into a calibrated bucket for determination of the mill concentration.

Tabling

After the sample was taken, the starch milk was pumped through a 1/4 inch galvanized pipe to the head of the starch tables. The pump used was a 1/3 hp centrifugal pump, Eastern Industries, Model 2-F, and the rate of starch milk was controlled by a flowrator at 0.8 gpm, the optimum rate determined by Chiang (4). The starch settled out on the tables while the gluten suspended in the overflow was passed from table to table and pumped by a 1/2 hp gear pump to a 100 gallon conical bottom stainless steel tank for settling.

After all the starch milk was pumped to the table, the starch on the tables was washed with a stream of water introduced by the same pump used for the starch milk. This water rate was controlled at one gpm for 20 to 30 minutes. The washing liquor was also pumped to the gluten settling tank.

The gluten was settled overnight and a small amount of SO_2 was added to prevent fermentation. The upper clear liquor was decanted by means of a syphon. Since the slurry of the gluten portion was difficult to filter, it was sent to the dryer for drying directly.

The starch on the tables was scraped off manually and placed on a tray in the dryer. The starch, bran and gluten were dried at $130^{\circ} \pm 5^{\circ}F$ for 24 hours. The weights of these materials after drying were the basis for the calculations.

Viscosity Test

The viscosity test was a modification of that devised by Barham et. al. (2, 3). Twenty grams of dried starch were weighed out accurately and mixed well with 380 cc of water in a 600 cc of beaker. Prior to this, boiling water was introduced into the jacket of the pasting cup and the unit heated to 90°C and maintained there throughout the heating period. The starch suspensions was poured into the container, the stirrer was started, and the readings of viscosity were taken at 5 minute intervals. After 20 minutes the hot water was cut off and the cold water was introduced into the water jacket to begin the cooling period. The temperature and viscosity readings were taken at 5-10 minute intervals during this period. During the heating cycle the viscosity increased to a maximum and then dropped off. During the cooling cycle the viscosity increased again to a second maximum, considerably higher than the first, and then again began to decrease. The ratio of these two maxima is an index of the quality of the starch.

PROCESSING DATA

The process data for all runs are presented in Tables 3 to 6. The process conditions such as steeping, grinding and tabling are listed in Table 3 for the hydraulic mill, and in Table 4 for the buhrstone mill. The results, including the yield and recovery of starch, and the consumption of energy and of water are calculated in Table 5 for the hydraulic mill, and in Table 6 for the buhrstone mill.

The quantity of steeping water used was fixed at 0.36 gallons per pound of grits, equivalent to about three pounds

Table 3. Summary of process conditions for hydraulic mill.

Run Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Steeping conditions																
Temperature	°F		120	120	120	120	120	120	120	120	120	120	120	120	120	120
Time	hr		4	2	8	2	2	4	8	16	4	8	16	2	4	8
SO_2 concentration																
Before steeping	N	no	0.060	0.064	0.067	0.048	0.048	0.048	0.048	0.048	0.064	0.064	0.064	0.080	0.082	0.077
	%	steeping	0.187	0.20	0.209	0.140	0.140	0.15	0.15	0.15	0.20	0.20	0.20	0.250	0.256	0.240
After steeping	N		-	-	-	0.038	0.037	0.030	0.026	0.025	0.042	0.040	0.039	0.061	0.060	0.052
	%		-	-	-	0.119	0.117	0.094	0.082	0.078	0.131	0.125	0.122	0.190	0.187	0.163
Amount of SO_2 absorbed	% by weight		-	-	-	0.063	0.069	0.170	0.202	0.216	0.207	0.225	0.234	0.180	0.210	0.230
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
Grinding conditions																
Mill temperature	°F	-	-	96	96	101	104	100	88	92	94	83	101	97	93	93
Feed rate, W. B.	lb/hr	25.8	12.9	24.1	28.3	32.9	30.4	34.7	40.3	35.0	28.6	30.0	30.8	32	30	33.3
D. B.	lb/hr	23.1	11.5	21.5	25.4	29.6	27.3	31.3	35.1	32.1	24.9	26.6	27.7	27.9	26.6	29.5
Mill concentration	lb solid/cu ft	-	-	6.41	8.2	8.8	9.33	9.42	10.7	8.64	9.35	8.5	9.01	-	8.25	8.60
Power consumption	KW	-	-	1.69	1.69	1.84	1.80	1.91	1.98	1.73	1.57	1.68	1.63	1.73	1.54	1.68
Grits recycling rate	lb/hr	-	-	20.3	26.2	25.0	23.0	28.2	25.0	27.8	22.0	25.8	27.30	23.4	23.0	27.5
Overflow rate of solid material from mill	lb/hr	-	-	41.8	51.2	54.6	50.3	59.5	60.1	59.9	46.9	52.4	55.00	51.3	53.0	57.0
Specific gravity of starch milk	°Be	-	-	2.14	2.84	3.04	2.60	3.98	4.50	3.95	2.14	3.54	3.63	2.84	3.70	3.54
Slope of shake sieve																
for coarse screen	in/ft	1.3	1.3	1.3	1.3	1.3	1.3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
for fine screen	in/ft	1.3	1.3	1.3	1.3	1.3	1.3	1.8	1.8	1.8	1.8	1.8	1.8	2.5	2.5	2.5
Process water consumption																
For feeding	gal/hr	12	12	15	15	15	14	15	15	12	15	10	15	15	12	12
For screening	gal/hr	12	12	12	9	12	7	12	9	12	18	6	12	15	9	9
For debranning	gal/hr	18	18	12	9	9	6	6	6	6	6	6	6	6	6	6
For recycling	gal/hr	12	12	9	6	6	6	6	6	6	6	6	6	6	6	6
Tabling conditions																
Temperature of starch milk	°F	-	-	90	92	94	99	84	83	86	86	74	84	86	90	85
Tabling rate	gal/hr	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Washing water rate	gal/hr	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Washing time	min	30	30	30	20	20	30	20	20	20	20	20	20	20	20	20
Washing water consumption	gal	30	30	30	20	20	30	20	20	20	20	20	20	20	20	20

Table 3 (concl.)

Run Number		16	17	18	19	20	21	22	23	24	25	26	27	28	29
Steeping conditions															
Temperature	oF	.20	120	120	120	120	120	120	120	120		120	120	120	120
Time	hr	16	2	4	8	16	8	16	2	4		4	8	16	16
SO_2 concentration															
Before steeping	N	0.080	0.032	0.040	0.037	0.031	0.024	0.016	0.096	0.096					
	%	0.25	0.10	0.125	0.115	0.096	0.075	0.05	0.30	0.30	no	water	water	water	water
After steeping	N	0.054	0.016	0.024	0.017	0.010	0.007	0.005	0.074	0.072	steeping	steeping	steeping	steeping	steeping
	%	0.168	0.084	0.075	0.053	0.031	0.022	0.015	0.23	0.225					
Amount of SO_2 absorbed	% by weight	0.240	0.036	0.150	0.186	0.195	0.159	0.104	0.21	0.23					
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
Grinding conditions															
Mill temperature	oF	99	92	86	91	88	82	96	85	90	103	81	88	88	88
Feed rate, W. B.	lb/hr	40	35.3	31.6	26.6	36.6	41.4	44.8	42.8	33.75	32	40.4	40.0	32.0	32.0
D. B.	lb/hr	36.35	32.0	28.0	23.7	31.9	36.1	39.0	37.4	29.40	29.1	35.2	35.4	28.5	28.4
Mill concentration	lb solid/cu ft	10.51	8.93	8.8	7.65	9.80	9.8	11.8	11.3	9.54	9.10	11.0	10.9	8.10	8.00
Power consumption	KW	1.87	1.96	1.62	1.43	1.68	1.81	2.11	1.98	1.74	1.98	2.04	2.10	1.83	1.89
Grits recycling rate	lb/hr	30.3	29.8	25.3	21.2	23.4	28.2	28.8	26.0	22.5	35.2	41.2	39.6	30.0	27.5
Overflow rate of solid material from mill	lb/hr	66.65	61.8	53.3	44.9	55.3	64.3	67.8	63.4	51.9	64.3	76.4	75.0	58.5	55.9
Specific gravity of starch milk	oBe	4.22	3.98	3.10	2.84	2.84	3.70	4.50	3.70	3.40	4.00	4.21	4.36	3.78	3.50
Slope of shake sieve															
for coarse screen	in/ft	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
for fine screen	in/ft	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.8	1.8	1.8	1.8	1.8
Process water consumption															
For feeding	gal/hr	15	12	12	12	15	12	15	12	15	15	12	14	12	12
For screening	gal/hr	12	12	9	6	12	12	12	12	12	12	12	9	9	9
For debranning	gal/hr	6	6	6	6	6	6	6	6	6	6	6	6	6	6
For recycling	gal/hr	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Tabling conditions															
Temperature of starch milk	oF	96	87	80	82	81	76	86	80	80	92	75	80	82	82
Tabling rate	gal/hr	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Washing water rate	gal/hr	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Washing time	min	20	30	20	20	30	30	30	30	30	20	20	20	20	20
Washing water consumption	gal	20	30	20	20	30	30	30	30	30	20	20	20	20	20

Table 4. Summary of Process Results for Hydraulic Mill.

Run Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Yields of Products, D. B.															
Starch	lb/hr	9.70	4.28	10.91	13.70	12.20	12.50	20.00	21.20	20.00	15.60	14.80	15.00	16.30	16.00
	%	42.00	37.30	50.75	53.90	41.20	45.80	64.30	60.40	62.50	62.70	55.55	53.60	58.40	60.20
Gluten portion	lb/hr	4.50	2.79	2.66	3.89	4.87	5.00	3.00	4.41	6.00	2.90	3.00	4.10	3.40	3.00
	%	19.00	24.30	12.20	15.30	16.50	18.30	9.65	12.50	18.75	11.60	11.30	14.60	12.30	11.30
Bran portion	lb/hr	4.75	1.50	2.60	3.38	8.45	7.65	5.20	6.00	3.00	1.20	3.60	4.00	-	3.00
	%	20.00	13.00	12.20	13.20	28.60	28.00	16.70	15.70	9.38	4.80	13.55	14.20	-	11.30
Total	lb/hr	18.95	8.57	16.23	20.97	25.52	25.12	28.20	31.60	29.00	19.70	21.40	23.10	19.73	22.0
	%	82.25	74.80	75.15	82.40	86.30	92.10	90.65	88.60	91.13	79.20	80.40	82.40	70.70	82.8
Starch recovery, D. B.															
Starch extracted	lb/hr	9.70	4.28	10.91	13.70	12.20	12.50	20.00	21.20	20.00	15.60	14.80	15.00	16.30	16.00
Starch in feed	lb/hr	17.95	8.72	16.23	19.50	22.40	20.60	23.60	25.90	24.30	18.40	19.35	21.00	21.10	19.35
Recovery	%	53.00	49.10	67.10	70.50	54.50	56.00	83.20	82.00	80.50	85.00	76.50	71.50	77.50	83.00
Starch accounted for, D. B.															
In starch	lb/hr	9.65	4.25	10.78	13.69	12.10	12.38	19.64	21.02	19.58	15.47	14.68	14.87	15.94	15.91
In gluten portion	lb/hr	2.35	1.97	1.50	2.11	3.52	2.84	1.75	2.01	3.76	1.73	1.42	2.29	1.94	1.39
In bran portion	lb/hr	2.84	0.84	1.62	1.74	4.85	4.22	3.21	3.66	1.58	0.60	1.74	2.45	-	1.63
Total	lb/hr	14.84	6.06	13.90	16.44	20.47	19.44	23.60	26.69	23.92	17.80	17.84	19.61	17.89	18.93
Total in feed	lb/hr	17.95	8.72	16.28	19.50	22.40	20.60	23.60	25.90	24.30	18.40	19.35	21.00	21.10	19.35
Starch accounted for	%	82.50	69.60	85.50	84.50	92.10	94.50	100.00	102.10	98.50	96.80	92.10	93.50	85.00	97.80
Protein accounted for, D. B.															
In starch	lb/hr	0.05	0.032	0.143	0.01	0.10	0.12	0.26	0.18	0.42	0.13	0.12	0.13	0.35	0.09
In gluten portion	lb/hr	1.52	0.412	0.805	0.96	0.73	0.75	0.75	1.78	1.35	1.26	1.29	1.16	1.02	1.34
In bran portion	lb/hr	0.81	0.23	0.375	0.55	1.30	1.18	0.97	0.88	0.47	0.21	0.66	0.58	-	0.57
Total	lb/hr	2.38	0.674	1.323	1.52	2.13	2.05	1.98	1.84	2.24	1.60	2.07	0.87	1.37	2.00
Total in feed	lb/hr	2.53	0.982	2.02	2.39	2.74	2.57	3.11	3.92	3.52	2.72	2.94	3.12	3.13	2.94
Protein accounted for	%	94.00	69.50	66.10	63.50	77.60	79.80	64.00	49.50	63.60	59.1	70.50	60.00	44.20	68.00
Energy consumption for grinding															
For unit quantity of feed	KWH/lb	-	-	0.079	0.067	0.062	0.066	0.061	0.056	0.052	0.063	0.063	0.059	0.062	0.058
For unit quantity of starch	KWH/lb	-	-	0.155	0.124	0.151	0.144	0.095	0.093	0.083	0.100	0.113	0.110	0.108	0.097
Water consumption of process															
Steeping water/unit feed	gal/lb	0	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	1.90	4.18	2.23	1.54	1.42	1.21	1.46	1.03	1.12	1.81	1.05	1.46	1.50	1.24
Washing water/unit feed	gal/lb	1.30	2.87	1.52	0.79	0.68	1.10	0.72	0.57	0.62	0.80	0.75	0.72	0.72	0.75
Total/unit feed	gal/lb	3.20	7.41	4.11	2.69	2.46	2.67	2.54	1.96	2.10	2.97	2.16	2.54	2.58	2.35
Steeping water/unit starch	gal/lb	0	0.97	0.71	0.67	0.88	0.78	0.67	0.60	0.57	0.57	0.56	0.67	0.62	0.60
Processing water/unit starch	gal/lb	4.53	11.30	4.40	2.86	3.45	2.64	2.72	1.71	1.79	2.88	2.00	2.72	2.51	2.06
Washing water/unit starch	gal/lb	3.10	7.70	2.75	1.46	1.64	2.40	1.33	0.94	1.00	1.27	1.35	1.33	1.23	1.25
Total/unit starch	gal/lb	7.63	19.97	7.86	4.99	5.97	5.82	4.72	3.25	3.36	4.72	4.00	4.72	4.42	3.91

Table 4 (concl.)

Run Number		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Yields of Products, D. B.																
Starch	lb/hr	14.00	15.20	11.28	15.00	14.00	19.40	17.00	19.00	22.00	14.80	12.00	19.00	15.00	10.80	11.50
	%	47.50	41.90	35.20	53.50	59.10	60.90	47.00	48.70	58.80	50.40	41.40	54.00	42.30	38.00	40.50
Gluten portion	lb/hr	2.10	1.94	7.52	3.00	3.00	4.40	3.00	1.00	3.20	6.40	1.00	4.00	6.20	4.00	5.60
	%	7.10	5.35	21.40	10.70	12.65	13.80	8.30	2.60	8.55	21.80	3.44	11.35	17.50	13.20	19.70
Bran portion	lb/hr	1.00	14.10	11.28	3.00	4.00	6.16	9.00	10.00	10.00	3.00	10.00	5.00	6.00	5.00	5.00
	%	3.40	38.80	35.20	10.70	16.90	19.40	24.90	26.00	26.75	10.20	34.40	14.20	16.90	17.50	17.50
Total	lb/hr	17.10	31.25	30.68	21.00	21.00	29.97	29.00	30.00	35.20	24.20	23.00	28.00	27.20	19.80	22.10
	%	58.00	86.05	92.00	74.90	88.65	94.70	80.50	76.30	94.00	82.40	79.24	79.35	76.70	68.70	77.70
Starch recovery, D. B.																
Starch extracted	lb/hr	14.00	15.20	11.28	15.00	14.00	19.40	17.00	19.00	22.00	14.80	12.00	19.00	15.00	10.80	11.50
Starch in feed	lb/hr	21.45	26.50	24.20	20.40	17.20	23.60	26.20	28.80	27.60	21.80	21.66	25.30	25.30	23.00	22.90
Recovery	%	65.40	58.00	46.00	73.50	81.50	82.20	64.80	66.00	80.00	68.00	55.50	75.00	59.40	47.00	50.20
Starch accounted for, D. B.																
In starch	lb/hr	13.93	15.02	11.17	14.92	13.88	19.22	16.75	18.85	21.80	14.57	11.92	18.80	14.90	10.70	11.46
In gluten portion	lb/hr	1.04	0.95	-	1.35	1.36	1.84	1.67	0.48	1.69	3.81	0.42	2.18	3.32	2.03	2.87
In bran portion	lb/hr	0.51	9.20	8.50	1.80	2.16	2.98	6.67	6.10	5.75	1.45	5.45	3.22	3.22	2.62	2.54
Total	lb/hr	15.48	25.17	19.67	18.07	17.40	24.04	25.09	25.43	28.24	19.83	17.79	24.20	21.44	15.35	16.87
Total in feed	lb/hr	21.45	26.50	24.20	20.40	17.20	23.60	26.20	28.80	27.60	21.80	21.66	25.30	25.30	23.00	22.90
Starch accounted for	%	72.00	95.10	81.40	88.60	101.00	104.50	95.60	88.60	102.50	91.10	82.40	95.90	85.00	66.90	73.50
Protein accounted for, D. B.																
In starch	lb/hr	0.07	0.18	0.11	0.08	0.12	0.18	0.25	0.15	0.20	0.23	0.08	0.20	0.10	0.10	0.04
In gluten portion	lb/hr	0.80	0.71	-	1.32	1.23	1.77	0.99	0.40	1.10	1.67	0.40	1.27	2.01	1.39	1.87
In bran portion	lb/hr	0.22	1.88	1.51	0.55	0.73	1.02	1.25	1.70	1.57	0.49	1.29	0.72	1.26	1.00	1.00
Total	lb/hr	1.09	2.77	1.62	1.95	2.08	2.97	2.49	2.25	1.87	2.39	1.77	2.19	3.37	2.49	2.91
Total in feed	lb/hr	3.26	3.31	3.00	3.10	2.68	3.48	4.16	4.35	4.17	3.24	3.27	3.96	3.98	3.20	3.19
Protein accounted for	%	33.50	83.50	54.00	63.20	79.50	85.50	60.05	51.70	44.90	73.6	53.20	55.30	84.70	78.00	91.00
Energy consumption for grinding																
For unit quantity of feed	KWH/lb	0.060	0.057	0.061	0.058	0.060	0.053	0.050	0.054	0.053	0.059	0.062	0.058	0.059	0.064	0.064
For unit quantity of starch	KWH/lb	0.126	0.136	0.174	0.108	0.101	0.082	0.106	0.110	0.090	0.117	0.149	0.107	0.139	0.168	0.160
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	0.36	0.36	0.36	0.36
Processing water/unit feed	gal/lb	1.14	1.07	1.12	1.17	1.13	1.22	1.00	1.00	0.96	1.33	1.34	1.02	1.00	1.16	1.16
Washing water/unit feed	gal/lb	0.68	0.55	0.91	0.71	0.85	0.94	0.83	0.77	0.80	1.03	0.69	0.57	0.56	0.71	0.71
Total/unit feed	gal/lb	2.18	2.98	2.39	2.24	2.34	2.52	2.19	2.13	2.12	2.72	2.03	1.95	1.92	2.23	2.23
Steeping water/unit starch	gal/lb	0.76	0.86	1.02	0.67	0.61	0.59	0.77	0.74	0.61	0.71	0	0.67	0.85	0.95	0.89
Processing water/unit starch	gal/lb	2.39	2.54	3.18	2.20	1.91	2.01	2.13	2.05	1.64	2.60	2.41	1.89	2.36	1.87	1.75
Washing water/unit starch	gal/lb	1.43	1.31	2.66	1.33	1.43	1.55	1.76	1.58	1.36	2.02	1.24	1.05	1.33	3.06	2.86
Total/unit starch	gal/lb	4.58	4.71	6.86	4.20	3.95	4.15	4.66	4.37	3.61	5.33	3.65	3.61	4.54	5.88	5.50

Table 5. Summary of process conditions for Buhrstone Mill.

Run Number		30	31	32	33	34	35	36	37	38	39	40	41
Steeping conditions													
Temperature	°F		120	120	120	120	120	120	120	120	120	120	120
Time	hr		4	16	4	24	8	2	4	4	8	16	24
SO_2 concentration													
Before steeping	N		water	water	water	water	water	0.027	0.064	0.043	0.071	0.064	0.048
	%	no	steeping	steeping	steeping	steeping	steeping	0.084	0.200	0.134	0.220	0.200	0.150
After steeping	N	steeping						0.023	0.043	0.025	0.046	0.051	0.022
	%							0.072	0.134	0.078	0.143	0.159	0.069
Amount of SO_2 absorbed	% by weight							0.036	0.198	0.175	0.228	0.230	0.242
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
Grinding conditions													
Mill temperature	°F	67	74	78	75	73	76	81	75	76	71	80	78
Feed rate, W. B.	lb/hr	25	16.35	20.0	28.8	32.4	25.9	12.5	13.05	20.0	30	22.5	24.7
D. B.	lb/hr	22.2	14.50	17.75	25.8	28.8	22.9	11.1	11.55	17.75	26.4	19.90	21.8
Power consumption	KW	0.432	0.432	0.432	0.503	0.525	0.432	0.432	0.432	0.432	0.478	0.432	0.455
Grits recycling rate	lb/hr	18.2	13.60	16.40	20.1	23.0	20.0	6.0	6.50	9.40	15.0	10.30	10.80
Overflow rate of solid material from mill	lb/hr	40.4	28.10	34.15	45.9	51.8	42.9	17.1	18.15	27.15	41.4	30.20	32.60
Specific gravity of starch milk	°Be	1.98	1.63	1.75	2.13	2.50	2.00	1.64	1.80	2.30	3.40	2.80	2.70
Slope of shake sieve													
for coarse screen	in/ft	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
fine fine screen	in/ft	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Process water consumption													
For feeding	gal/hr	10	12	6	10	10	8	3	5	6	8	10	9
For screening	gal/hr	12	12	12	6	9	9	9	12	9	9	9	12
For debranning	gal/hr	6	6	6	6	6	6	6	6	6	6	6	6
For recycling	gal/hr	6	6	6	6	6	6	6	6	9	9	6	6
Tabling conditions													
Temperature of starch milk	°F	64	68	72	71	71	71	72	70	69	70	71	73
Tabling rate	gal/hr	48	48	48	48	48	48	48	48	48	48	48	48
Washing water rate	gal/hr	60	60	60	60	60	60	60	60	60	60	60	60
Washing time	min	20	20	20	20	20	20	20	20	20	20	20	20
Washing water consumption	gal	20	20	20	20	20	20	20	20	20	20	20	20

Table 6. Summary of Process Results for Buhrstone Mill.

Run Number		30	31	32	33	34	35	36	37	38	39	40	41
Yields of Products, D. B.													
Starch	lb/hr	11.00	7.00	7.50	11.40	11.50	9.25	4.00	6.50	9.00	12.00	9.60	9.20
	%	49.50	48.40	42.20	44.20	40.00	40.00	36.10	56.30	50.20	44.80	48.20	42.20
Gluten portion	lb/hr	3.00	2.80	2.50	3.80	4.00	4.00	1.52	1.70	3.00	4.85	5.00	4.00
	%	13.50	16.50	14.10	14.70	13.90	17.50	13.70	14.70	16.90	18.10	25.10	18.40
Bran portion	lb/hr	4.00	2.10	2.00	6.20	3.20	4.25	2.00	1.50	2.00	4.00	4.00	4.00
	%	14.00	13.30	11.20	24.00	11.10	18.50	18.00	13.00	11.25	14.90	20.10	18.40
Total	lb/hr	18.00	11.90	12.00	21.40	18.70	17.50	7.52	9.70	14.00	22.85	18.60	17.20
	%	76.50	78.50	67.40	82.90	65.00	76.00	67.80	84.70	78.90	89.60	93.40	79.00
Starch recovery, D. B.													
Starch extracted	lb/hr	11.00	7.00	7.50	11.40	11.50	9.25	4.00	6.50	9.0	12.00	9.60	9.20
Starch in feed	lb/hr	16.10	10.50	12.85	18.65	20.80	16.65	8.04	8.35	12.80	19.10	14.35	15.70
Recovery	%	68.50	66.70	58.30	61.00	55.50	55.50	49.90	78.00	70.40	62.80	67.00	58.60
Starch accounted for, D. B.													
In starch	lb/hr	10.90	6.95	7.40	11.39	11.40	9.20	3.94	6.40	8.86	11.90	9.55	9.13
In gluten portion	lb/hr	1.49	1.61	1.50	2.16	2.47	2.46	0.77	0.84	1.49	2.77	3.68	2.64
In bran portion	lb/hr	2.55	1.16	1.17	4.15	2.13	2.79	1.24	0.94	1.23	2.68	2.54	2.70
Total	lb/hr	14.94	9.66	10.07	17.61	16.00	14.45	5.95	8.18	11.58	17.35	14.77	14.47
Total in feed	lb/hr	16.10	10.50	12.85	18.65	20.80	16.65	8.04	8.35	12.80	19.10	14.35	15.70
Starch accounted for	%	93.00	92.00	83.50	94.50	77.00	87.00	74.00	98.00	90.30	91.00	103.00	96.00
Protein accounted for, D. B.													
In starch	lb/hr	0.10	0.05	0.10	0.10	0.10	0.05	0.06	0.10	0.14	0.10	0.05	0.07
In gluten portion	lb/hr	0.99	0.85	0.72	1.14	1.06	1.12	0.57	0.64	1.14	1.54	1.02	0.89
In bran portion	lb/hr	0.76	0.59	0.42	1.10	0.55	0.80	0.41	0.27	0.39	0.73	0.72	0.73
Total	lb/hr	1.85	1.49	1.24	2.34	1.71	1.97	1.14	1.11	1.67	2.37	1.79	1.69
Total in feed	lb/hr	2.68	1.62	2.04	2.88	3.23	2.59	1.25	1.27	2.00	2.97	2.19	2.44
Protein accounted for	%	69.10	92.00	61.00	81.50	53.00	76.00	91.20	87.50	83.60	80.00	81.80	69.50
Energy consumption for grinding													
For unit quantity of feed	KWH/lb	0.019	0.030	0.024	0.019	0.018	0.019	0.039	0.037	0.024	0.018	0.022	0.021
For unit quantity of starch	KWH/lb	0.038	0.062	0.057	0.043	0.045	0.047	0.108	0.066	0.048	0.040	0.046	0.050
Water consumption of process													
Steeping water/unit feed	gal/lb	0	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	1.51	2.48	1.69	1.06	1.08	1.27	2.16	2.51	1.69	1.21	1.56	1.49
Washing water/unit feed	gal/lb	0.90	1.38	1.12	0.78	0.70	0.87	1.80	1.73	1.13	0.76	1.01	0.92
Total/unit feed	gal/lb	2.41	4.22	3.17	2.20	2.14	2.50	4.32	4.60	3.18	2.33	2.93	2.77
Steeping water/unit starch	gal/lb	0	0.75	0.82	0.81	0.90	0.90	0.72	0.46	0.51	0.57	0.54	0.61
Processing water/unit starch	gal/lb	3.06	5.12	4.00	2.40	2.70	3.16	2.33	3.18	2.40	1.83	2.32	2.40
Washing water/unit starch	gal/lb	1.82	2.86	2.66	1.76	1.75	2.18	2.62	2.19	1.61	1.21	1.51	1.57
Total/unit starch	gal/lb	4.88	8.73	7.48	4.97	5.35	6.24	6.77	5.83	4.52	3.61	4.37	4.58

of water per pound of grits. The concentration of sulfur dioxide in the water expressed as percentage by weight was determined both before and after steeping by the iodine titration method (Scott, 11). The pounds of sulfur dioxide absorbed per 100 pounds of grits was then obtained from the differences between these two figures multiplied by three.

Because of the nature of the process all quantities are expressed as rates and calculated on the dry basis. The water consumption and tabling rate were recorded directly from flowrators. The feed rate was determined from the time required to transfer all the feed from the screw conveyor into the hydraulic mill. The feed rate was obtained by dividing the total weight of grits (dry basis) by the time. The net energy consumption rate of the mill was computed from the following equation:

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

Where R = the r.p.m. of the watt hour meter during the steady state of the run.

Re = the r.p.m. of the watt hour meter for the empty hydraulic mill

$\left(\frac{60 \times 7.2}{1000}\right)$ = the conversion factor

Since the buhrstone mill could not be operated empty, the energy consumption was taken during the steady state of the run assuming the energy consumption of the empty mill to be zero.

All the chemical analyses of the starch, gluten and bran as determined by the Chemical Service Laboratory of the Chemistry Department at Kansas State College, are presented in Table 7. The data includes the protein content of the starch and the starch and protein contents of the bran and gluten.

The paste viscosity data are presented in Table 8. The values of the hot maximum W_1, and the cold maximum W_2, and the ratio of the two, W_2/W_1, are given. The viscosity figures are scale readings from the viscometer. They may be converted to centipoises by miltiplying by 200.

The ratio of these two maxima is an important quality factor in starch. The ratio is related to the "shortness" or, in an opposite sense, to the "length" of a paste (Barham, et. al. 2). The lower the initial viscosity maximum and the higher the cold viscosity maximum, the shorter is the paste.

DISCUSSION OF THE RESULTS

In the manufacture of corn starch, the corn is steeped in dilute sulfur dioxide solution for 24 to 48 hours before grinding. Kerr (10) reported that the time of steeping and the concentration of SO_2 were the two main factors affecting the yield and recovery of starch. Cox, et. al. (5) gave an extensive survey of the effect of sulfur dioxide in steeping. Their results are shown in Table 9, (10).

Table 9 shows that the yield of corn starch increased to a considerable extent as the sulfur dioxide concentration

Table 7. Analysis of products.

Run Number	Starch: Protein content %	Gluten portion: Starch content %	Gluten portion: Protein content %	Bran portion: Starch content %	Bran portion: Protein content %
1	0.63	51.66	33.81	59.78	17.13
2	0.75	70.58	14.75	55.93	15.38
3	1.31	56.79	30.25	61.18	14.25
4	0.75	54.59	24.63	51.78	16.13
5	0.81	73.70	14.88	57.81	15.44
6	0.56	54.35	31.63	56.09	15.06
7	1.31	58.02	32.25	61.70	14.50
8	0.63	45.69	40.38	61.01	14.63
9	2.00	63.62	22.44	52.69	15.75
10	0.81	41.88	43.50	50.00	17.31
11	0.81	47.31	43.00	48.25	18.38
12	0.88	57.17	29.13	59.86	15.50
13	2.13	56.18	29.63	--	--
14	0.56	46.32	44.81	54.31	18.81
15	0.50	49.44	38.13	51.19	21.69
16	1.19	49.10	36.44	65.75	13.31
17	1.00	--	--	69.31	13.31
18	0.56	45.09	44.06	60.07	18.25
19	0.88	45.41	41.06	54.10	18.31
20	0.94	41.84	40.25	48.37	16.50
21	1.44	55.96	32.94	74.11	13.94
22	0.88	47.69	39.56	61.44	17.00
23	1.31	47.69	34.38	61.44	15.69
24	1.56	56.18	29.63	48.50	16.19
25	0.56	41.87	39.94	69.43	12.94
26	1.06	54.48	31.81	64.98	14.44
27	0.56	53.67	32.69	45.69	21.06
28	0.69	50.57	34.75	52.39	20.00
29	0.81	51.28	33.50	58.92	19.50
30	0.88	53.20	33.06	63.75	19.00
31	0.69	57.64	30.19	55.38	28.38
32	1.50	59.99	28.56	58.75	21.00
33	0.38	56.79	30.19	66.82	17.75
34	0.44	61.91	26.56	66.53	17.06
35	0.44	61.61	27.88	65.97	18.94
36	1.69	50.89	37.31	62.47	20.81
37	1.75	49.14	37.31	62.76	19.00
38	1.56	49.53	37.38	61.82	19.50
39	0.44	57.07	31.81	67.46	18.31
40	0.44	73.65	20.50	68.83	18.06
41	0.63	66.05	22.06	67.50	18.44

Table 8. Viscosity index of starch.

Run Number	Hot Maximum W_1*	Cold Maximum W_2*	W_2/W_1
1	8.5	40	4.71
2	10.5	28.5	2.71
3	7.5	28.5	3.80
4	10.0	27.0	2.70
5	6.5	27.5	4.23
6	8.0	25.0	3.12
7	8.0	19.0	2.38
8	9.0	24.5	2.72
9	9.0	19.0	2.12
10	5.5	17.5	3.18
11	9.5	20.0	2.10
12	9.0	18.5	2.06
13	7.5	25.0	3.06
14	8.0	27.0	3.38
15	12.0	43.0	3.58
16	8.5	25.0	2.94
17	6.5	22.5	3.47
18	7.5	26.0	3.47
19	6.0	19.0	3.17
20	8.0	30.0	3.75
21	8.0	27.0	3.38
22	7.5	23.5	3.14
23	7.0	26.5	3.78
24	8.5	24.5	2.88
25	6.0	24.0	4.00
26	11.0	28.5	2.59
27	13.0	27.0	2.08
28	11.0	30.0	2.73
29	12.5	33.0	2.64
30	10.5	31.5	3.00
31	10.5	30.0	2.86
32	10.5	20.5	1.95
33	11.5	28.5	2.48
34	20.5	37.0	1.80
35	9.5	21.5	2.26
36	11.5	33.0	2.87
37	12.5	26.0	2.08
38	17.0	43.0	2.53
39	11.0	25.5	2.31
40	12.0	25.0	2.08
41	11.0	22.5	2.05

*To convert to centipoises, multiply by 200.

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

Steeping medium	Steeping time, hrs.	Recovery of starch,%
Distilled water	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

increased.

The maximum recovery of 85 per cent of the starch using sulfur dioxide steeping on sorghum grits was about the same as Chiang (4) obtained without sulfur dioxide. Sulfur dioxide does prevent bacterial growth, but in the short steeping cycles used for the sorghum grits this is not a real problem. The increased costs resulting from the corrosive action of sulfur dioxide solutions is therefore difficult to justify.

The average protein content of the starch from SO_2-steeped grits produced in the hydraulic mill was 0.98 per cent, and the average protein content in the starch from the buhrstone mill was 1.04 per cent. These figures are somewhat higher than that allowed for corn starch. Values as low as 0.4 per cent protein were obtained in some runs, however, and it seems probable that a more careful washing of the starch on the tables would have produced a satisfactory protein content.

The gluten and bran portions accounted for 25 to 50 per cent of the feed and contained 5 to 35 per cent of total starch.

This constituted the major loss of starch. More efficient screening and debranning would reduce this loss.

The energy consumption for grinding the grits ranged from 0.083 to 0.174 KWH per pound of starch made from hydraulic mill. This figure was considerably lower than that reported by Chiang (4) and Fan (7) for grits steeped without SO_2. This indicates that the use of SO_2 in steeping softened the grits, making them easier to grind. The energy consumption for the buhrstone mill was much lower than for the hydraulic mill.

The viscosity tests showed that the starch produced by this milling process had good viscosity characteristics. As discussed later, long steeping times in plain water would decrease the viscosity index value due to bacterial action. The use of SO_2 would prevent this action, however, exposure to sulfur dioxide tends to degrade starch molecules into smaller molecules, thus changing its properties also.

For the sake of clarity, the correlations are presented separately in the following:

Effect of Sulfur Dioxide in Steeping

It was reported that using sulfur dioxide as a steeping agent would increase the recovery of starch in wet milling corn (Cox, et. al. 5). This investigation showed that there was a tendency to increase the recovery of starch in milling sorghum grits by using sulfur dioxide in steeping the grits. Figure 1 shows the relation between the recovery of starch and

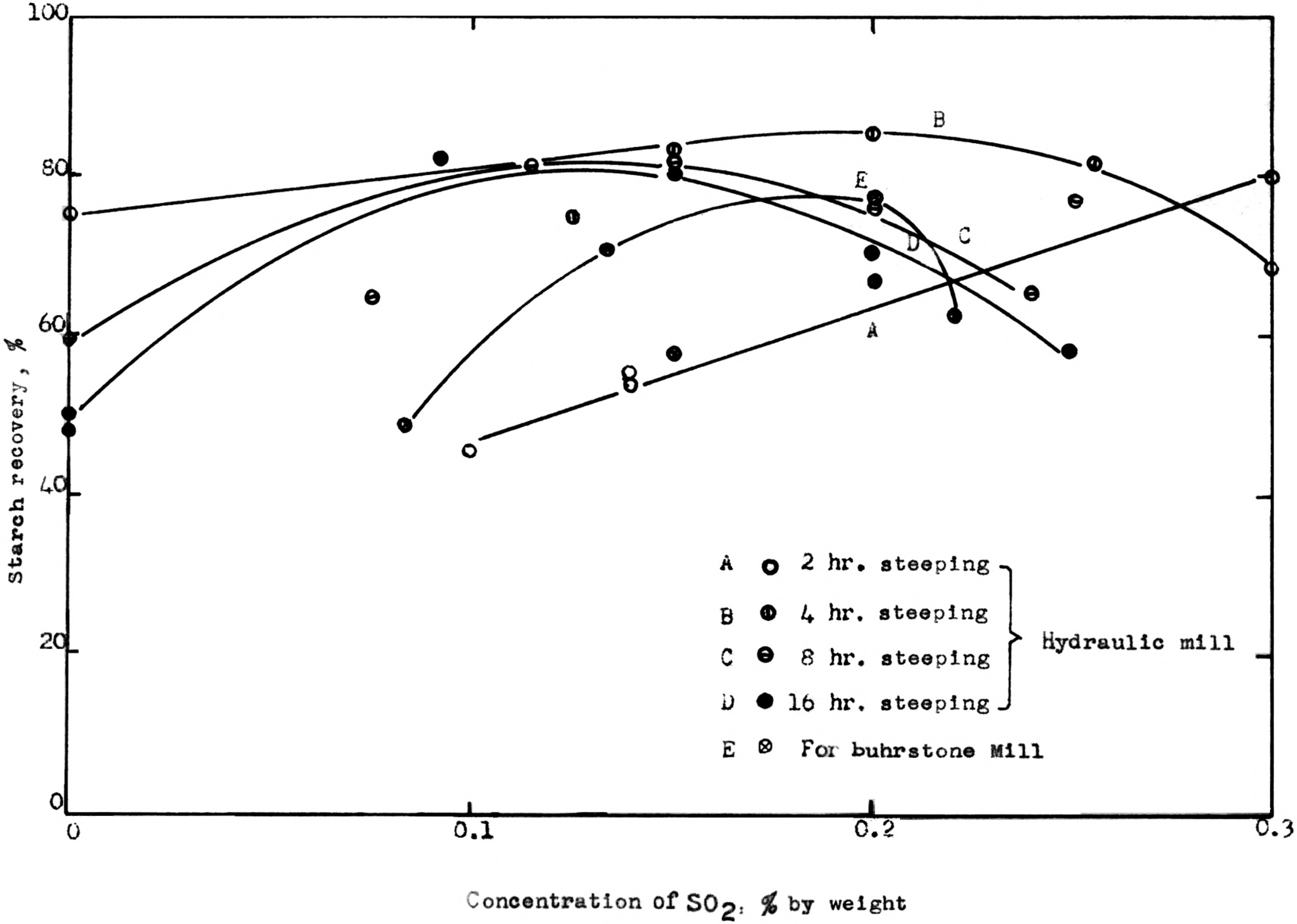


Fig. 1 Effect of concentration of SO_2 on recovery of starch

the concentration of SO_2 in the steeping water for different steeping times. The tendency for the recovery to increase reached a maximum at between 0.1 and 0.2 per cent SO_2. The decrease at higher concentrations may result from the destruction of starch molecules by excess SO_2. The absorption of SO_2 is plotted against the concentration in Fig. 2, and the recovery of starch is plotted versus the absorption in Fig. 3. These figures show that the amount of absorption increased with the concentration of SO_2 and with the steeping time. Also, the recovery was lowered sharply by the absorption of more than 0.2 pounds of SO_2 per pound of grits. The best recovery was attained at 0.18 to 0.21 pounds SO_2 absorbed per 100 pounds grits.

One of the advantages in using sulfur dioxide as a steeping agent was to prevent fermentation during steeping. Chiang (4) found distinct indications of bacterial action during a 16-hour steeping cycle in the form of odors, discoloration, and low starch yields. When using dilute SO_2 solutions for steeping, there was no indication of bacterial action, even with a 24-hour steeping cycle.

Effect of Feed Rate

The production rate was directly proportional to the feed rate, as shown in Fig. 4. The recovery of starch appears to decrease slightly with feed rate, though the data are too erratic for definite conclusions to be drawn.

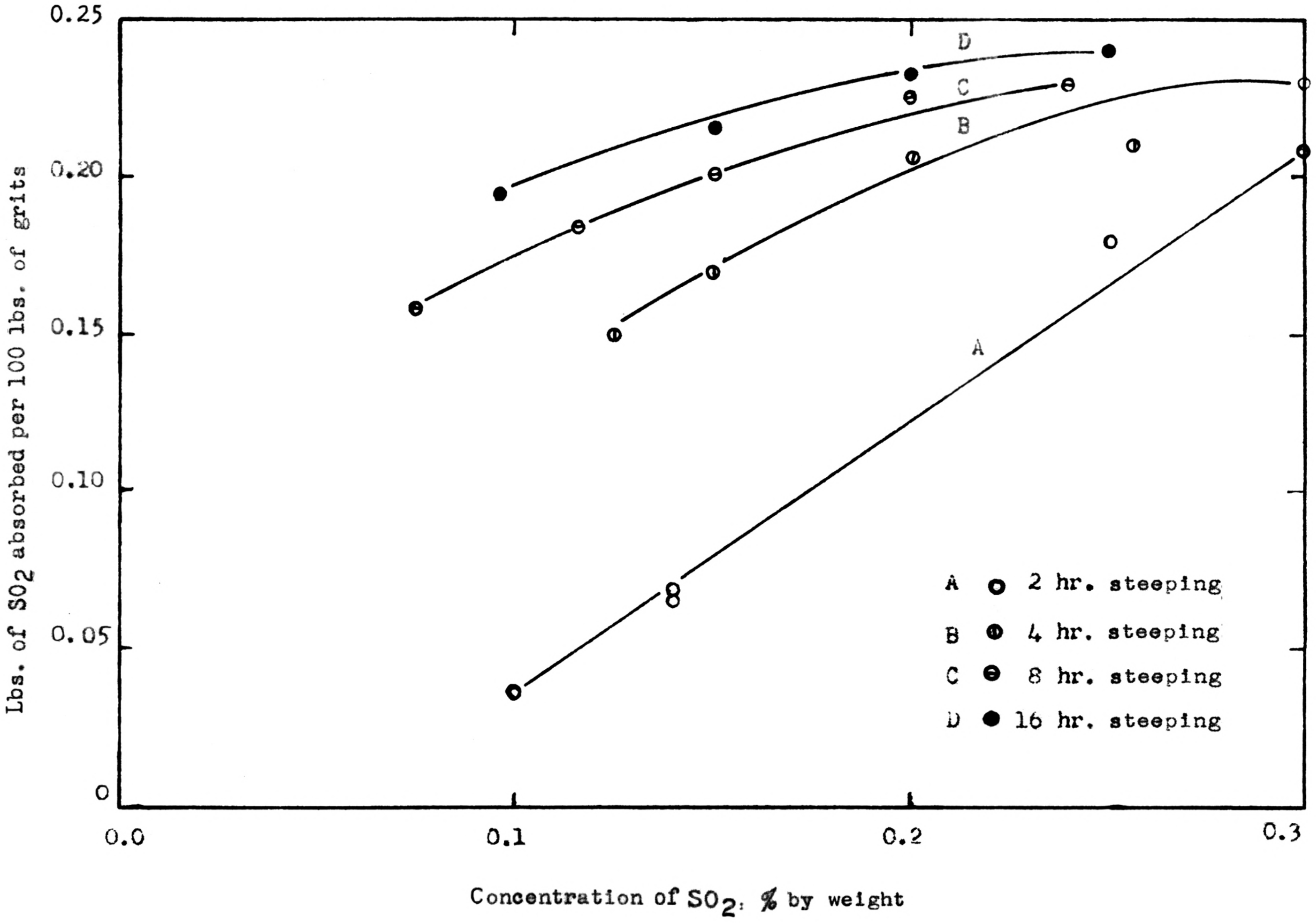


Fig. 2 Amount of SO_2 absorbed by the grits

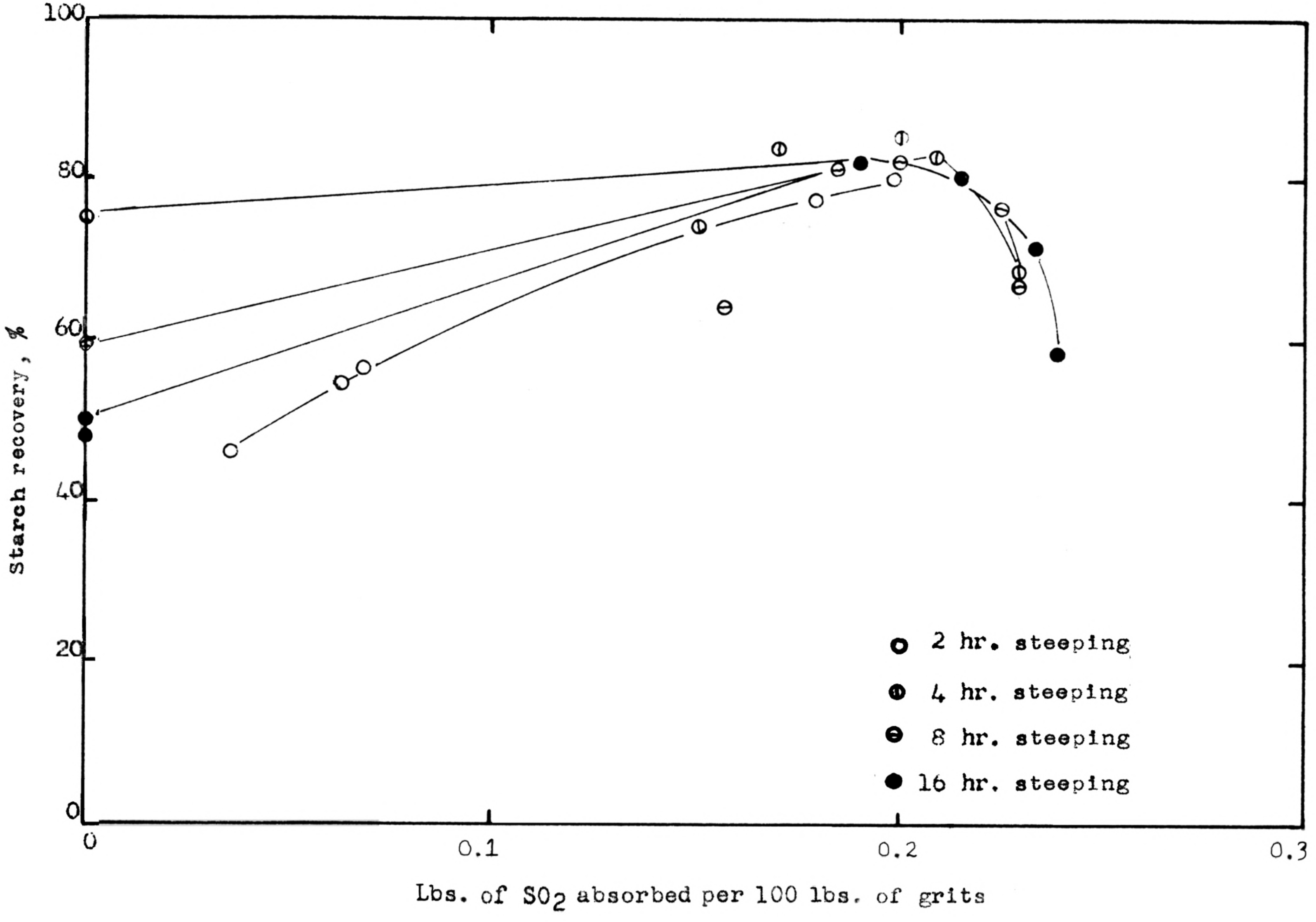


Fig. 3. Effect of SO_2 absorption on starch recovery

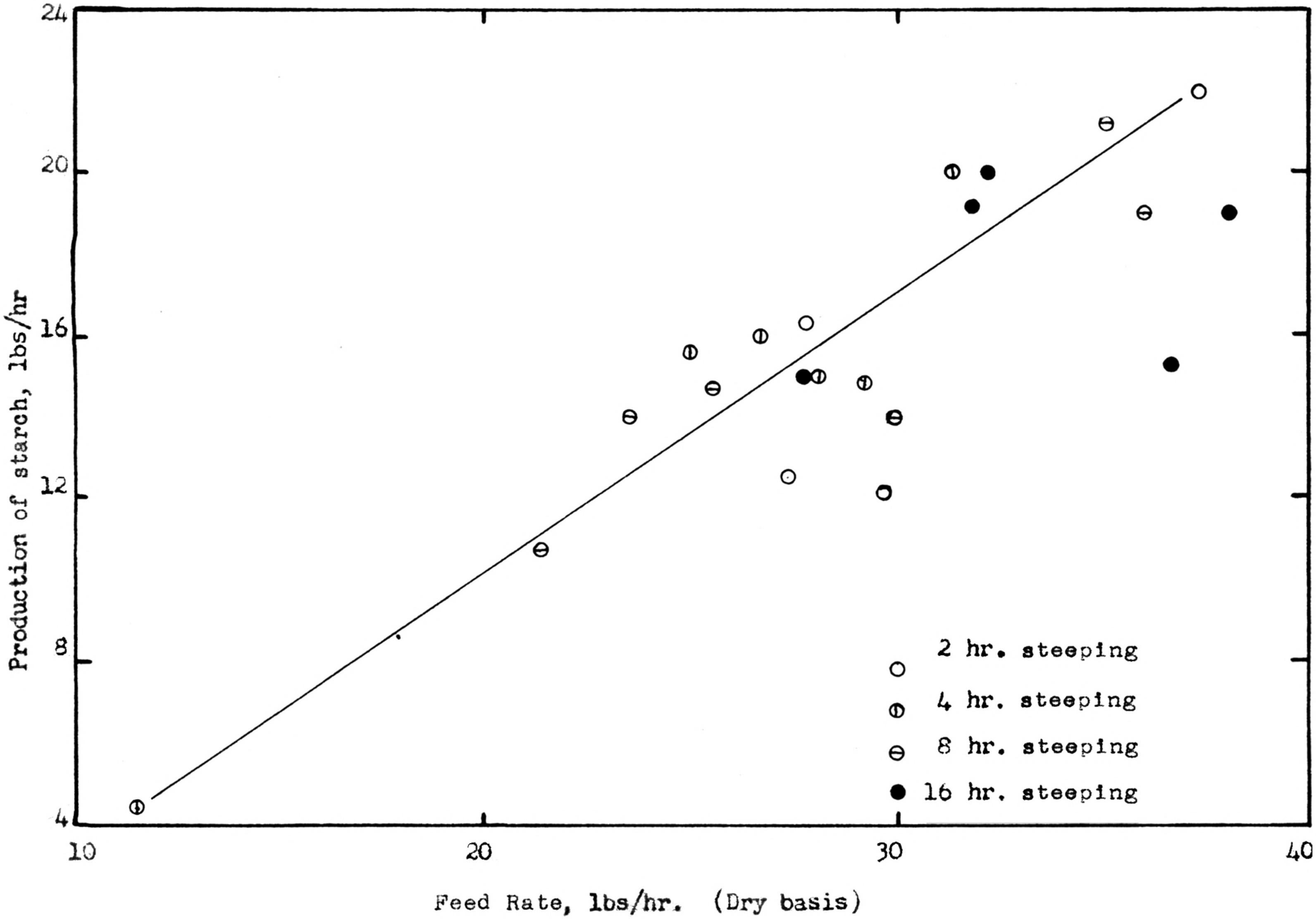


Fig. 4. Effect of feed rate on the production rate of starch

Figure 5 shows the recovery of starch from the buhrstone mill as a function of feed rate. Here a definite trend for a slight decrease in recovery with increasing rate of feed is found.

Energy and Water Consumptions

Some reduction of power consumption in manufacturing starch was made due to using sulfur dioxide as steeping agent. This is in agreement with the observation that SO_2 steeping tends to soften the grits. The hydraulic mill energy consumption rates in KW were plotted against the feed rate in Fig. 6. This shows that the power used by the mill was directly proportional to the feed rate. Also, when energy consumptions in KWH per pound of starch produced are plotted against the concentration of SO_2 in the steeping water in Fig. 7, it is apparent that the power requirements are somewhat lower for SO_2-steeped grits than for grits steeped in plain water.

The water consumption as a function of the concentration of SO_2 used is shown in Fig. 8.

Protein Content in Starch

The protein content of starch is an important factor in controlling its properties. The protein contents obtained in this work were high when the optimum amount of water as determined by Chiang for washing the starch on the tables was used. There did not appear to be a definite relationship between the variables studied and the protein content. However the difficulty

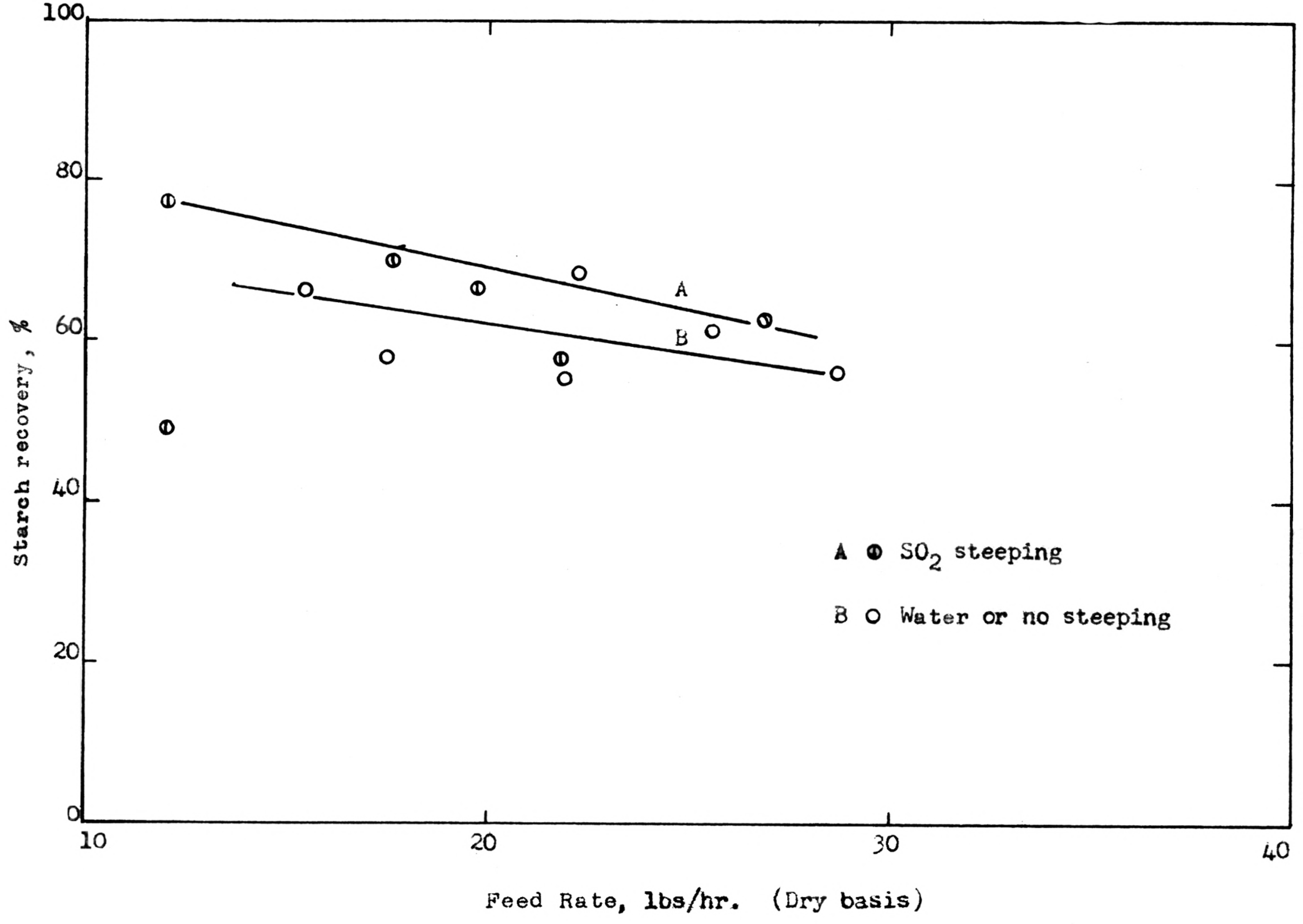


Fig. 5 Effect of feed rate on the recovery of starch (For Buhrstone Mill)

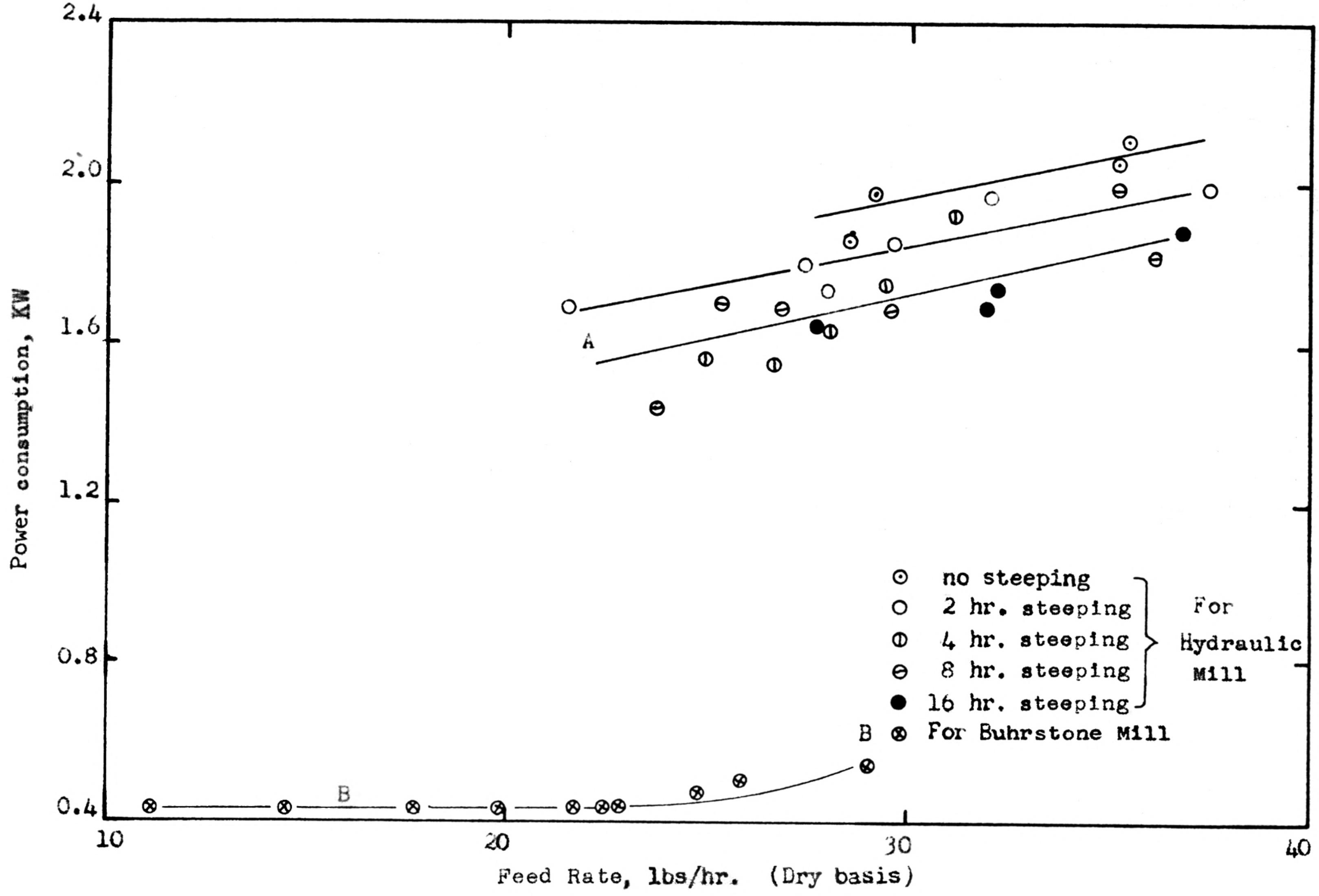


Fig. 6 Power consumed in grinding

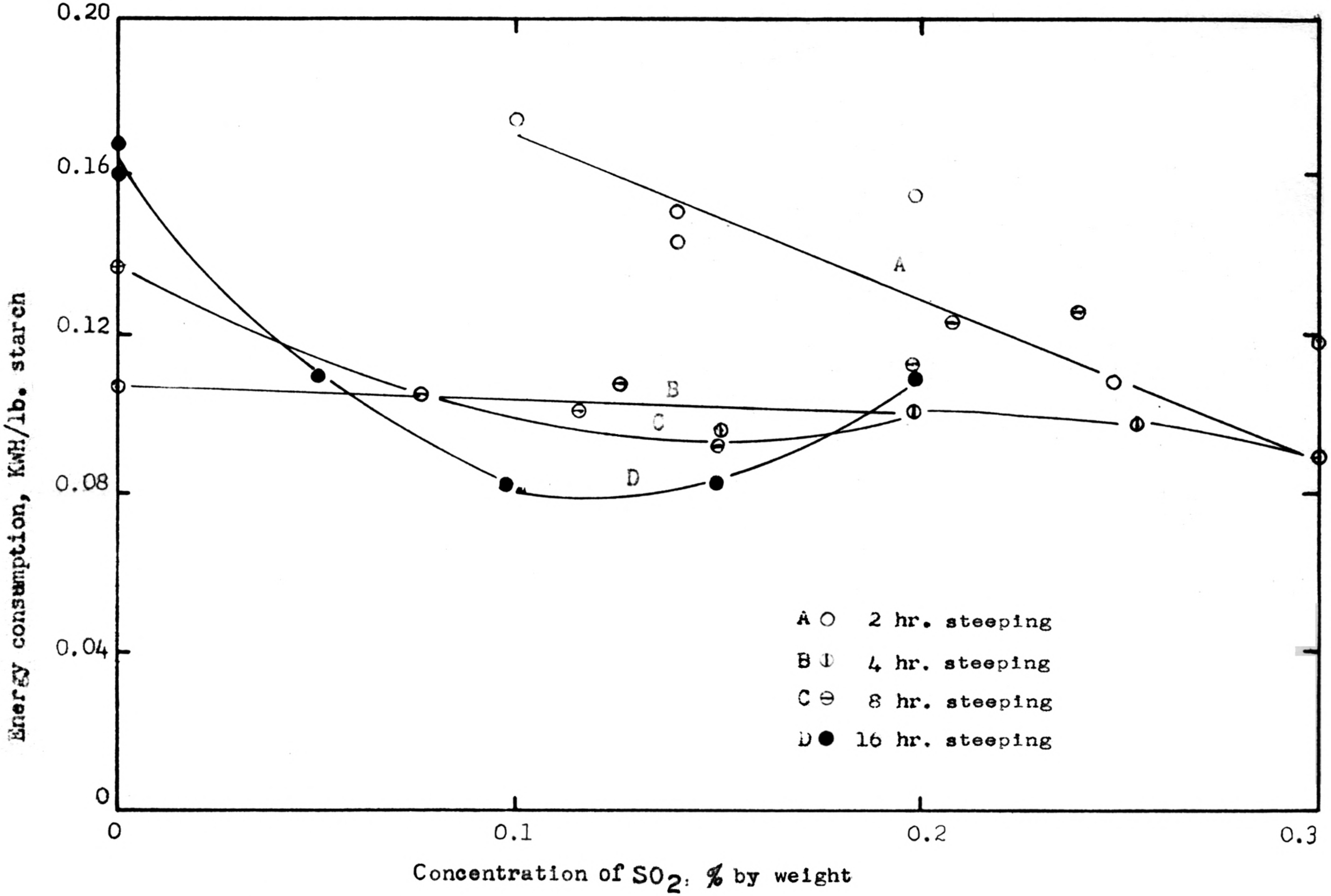


Fig. 7 Effect of SO_2 concentration on the energy consumption for grinding

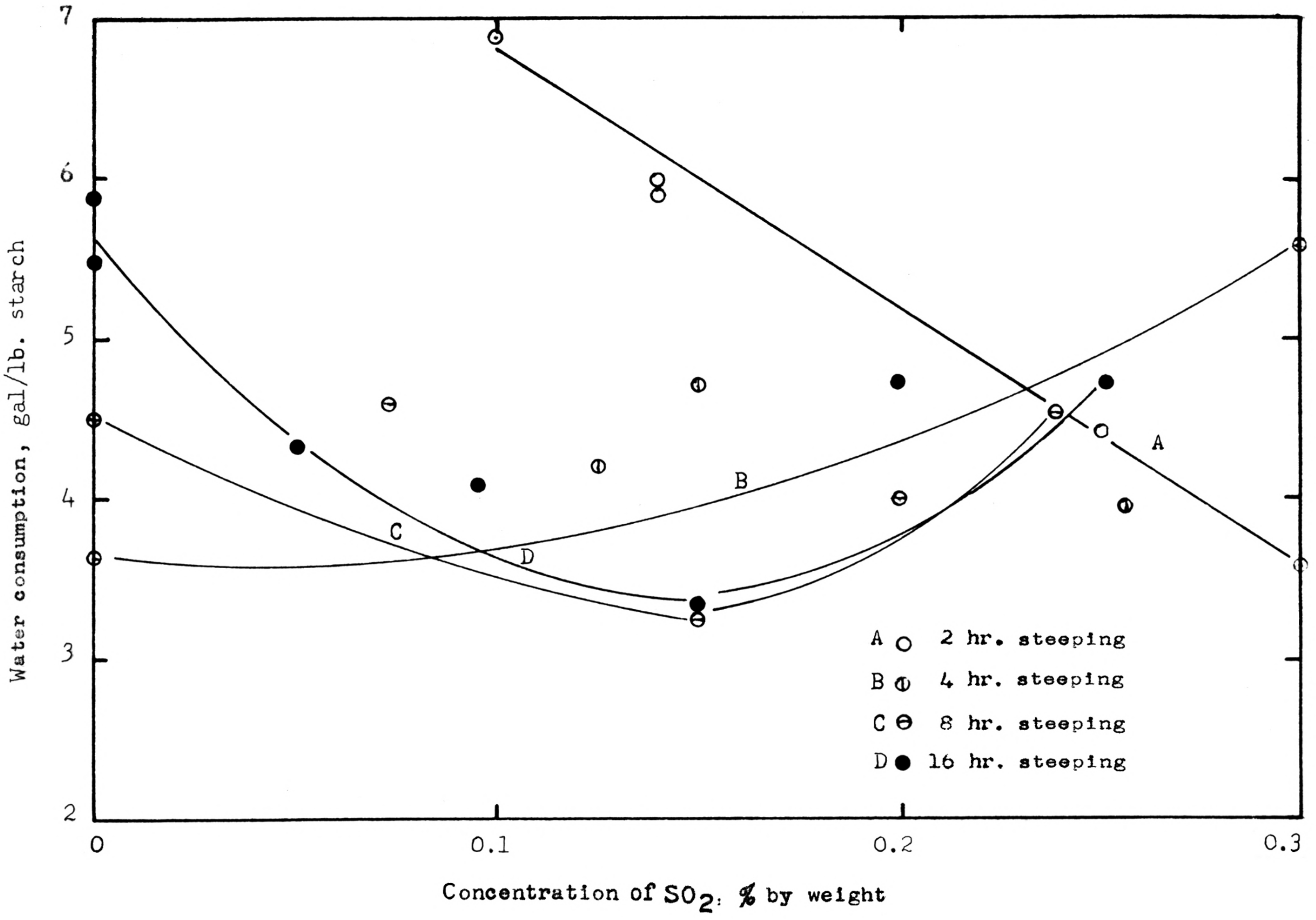


Fig. 8 Effect of SO_2 concentration on water consumption

of separating the protein from the starch appeared to increase with the concentration of SO_2 used in steeping. The highest protein content of 2.1 per cent was attained when a 16 hour steep with 0.25 per cent SO_2.

The protein contents of the starch produced from the buhrstone mill were about the same as for the hydraulic mill.

Viscosity Index of the Product of Starch

Although long time steeping softened the grits noticeably, the fermentation occurring changed the starch materially so that its pasting properties were affected adversely. The use of SO_2 in steeping could prevent such fermentation by destroying bacteria. The effect of SO_2 on the pasting properties of starch is therefore of real interest. The viscosity index is shown as a function of the SO_2 concentration in Fig. 9. The index for the longer steeping times appear to increase slightly as the concentration of SO_2 used increases, but at the high concentration, where relatively large quantities of SO_2 were absorbed, the index drops off. The high values obtained where no steeping at all was used probably indicates that the starch was incompletely separated from protein and is therefore inhibited to some extent. The starch viscosity test as here used is not a very reproducible test, and it is impossible to draw accurate conclusions from the data.

For the buhrstone mill, the viscosity index was generally lower than that from hydraulic mill as shown in Fig. 10, although

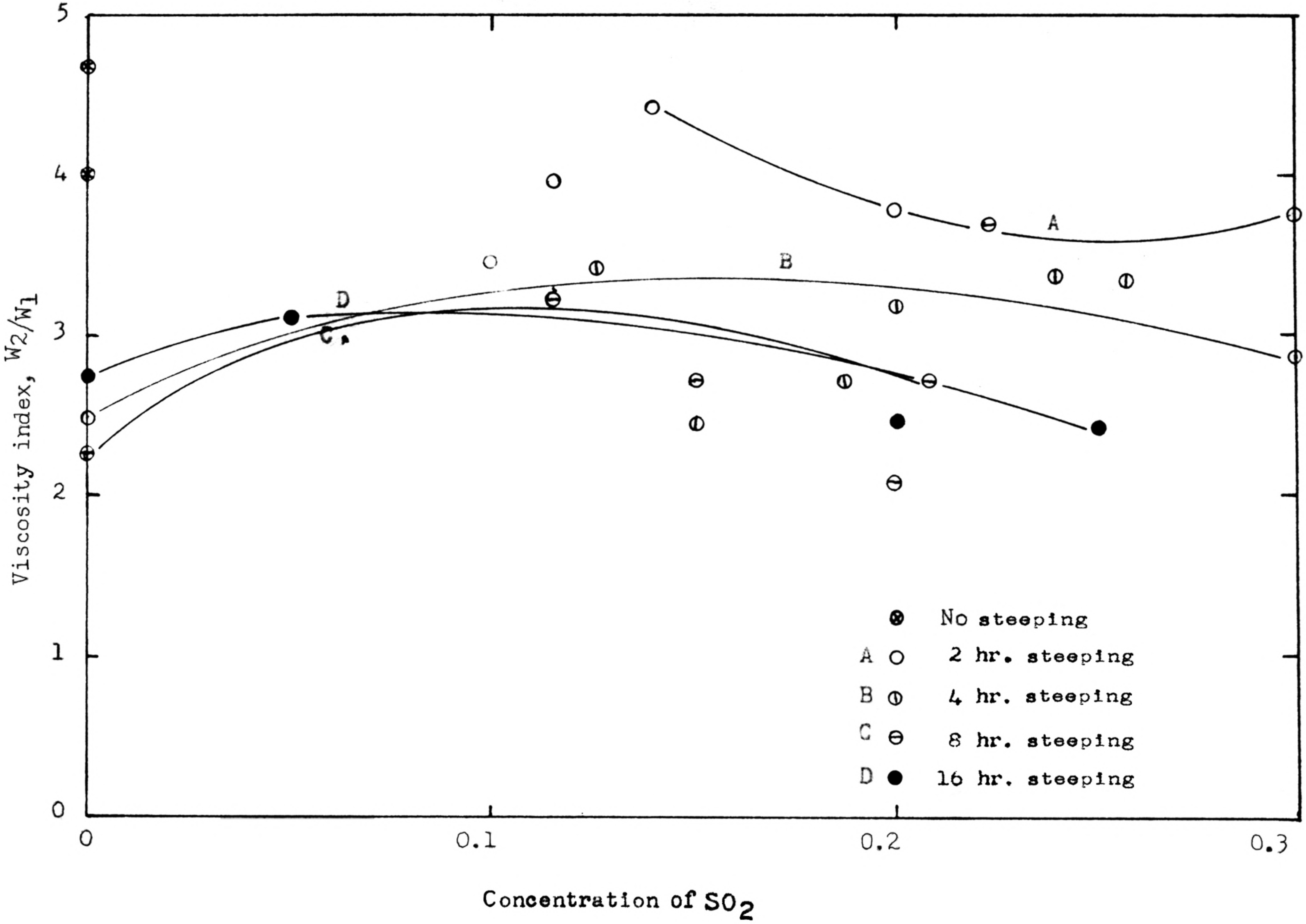
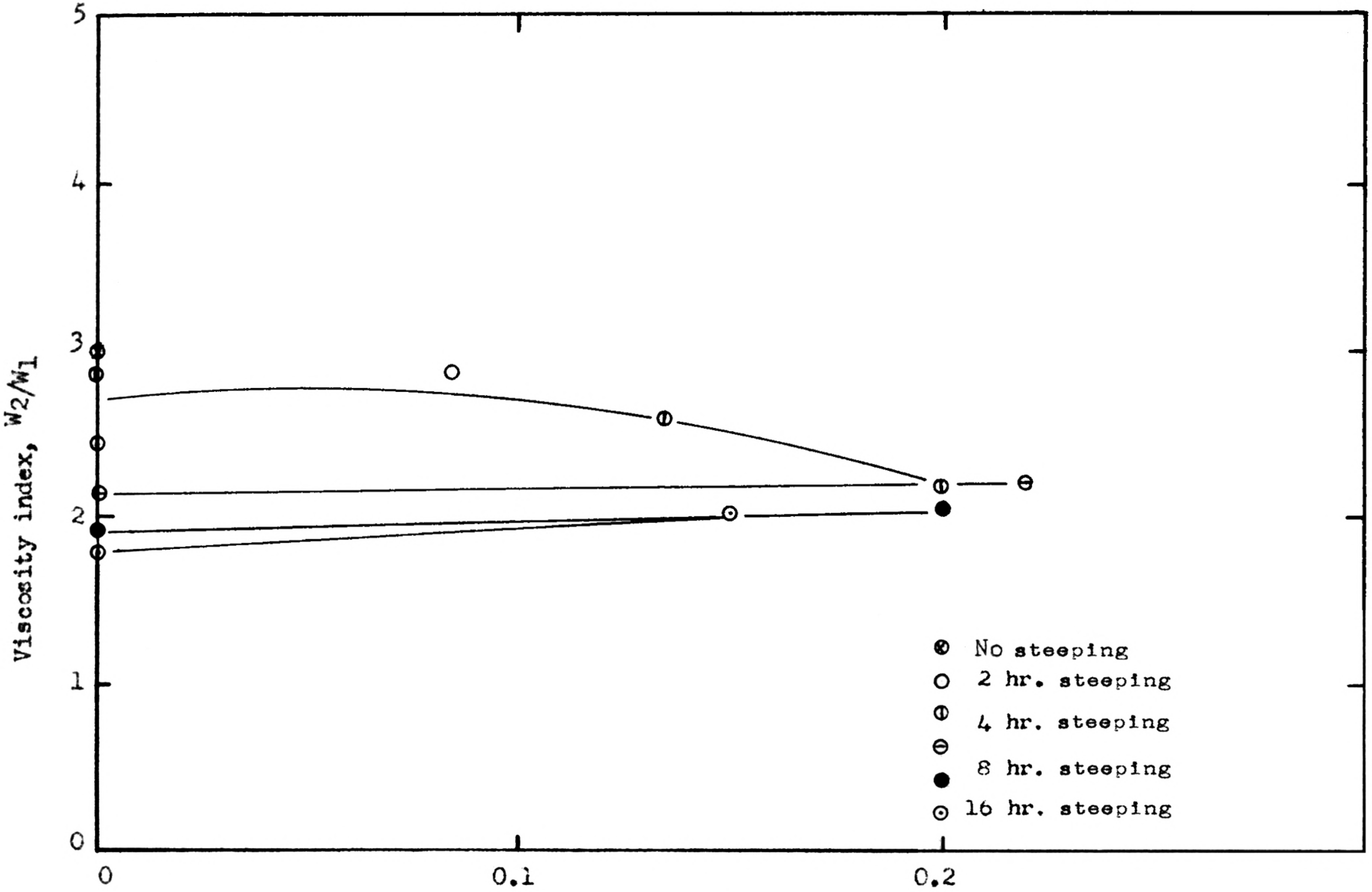


Fig. 9 Effect of SO_2 on the viscosity index of starch (For Hydraulic Mill)



Concentration of SO_2: % by weight

Fig. 10 Effect of SO_2 concentration on the viscosity index of starch
(For Buhrstone Mill)

the effects of SO_2 steeping and long time water steeping were similar to those for the hydraulic mill. The strong shearing action in the buhrstone mill probably lowered the viscosity index by mechanical breakage of the starch granules.

Starch Losses

Since the bran portion contained most of the unrecovered starch, more efficient operation of the first screen and the debranner would improve the recovery of starch. A plot showing the starch lost in the bran as a function of feed rate is shown in Fig. 11. A general increase was found. The longer steeping times reduce this loss. However, in each case a more efficient operation of the first, or coarse, screen would have decreased the loss by decreasing the amount of starch milk going into the debranner.

CONCLUSIONS

The starch recovery of 85 per cent attained using SO_2 steeping was about the same as that without SO_2. The power consumption when SO_2 was used was reduced somewhat, due to the softening of the grits by the SO_2. However, the viscosity index, which is the most important quality factor considered, was also reduced slightly. Hence, using sulfur dioxide for steeping sorghum grits is feasible but not recommended.

The other results obtained from this investigation are summarized in the following;

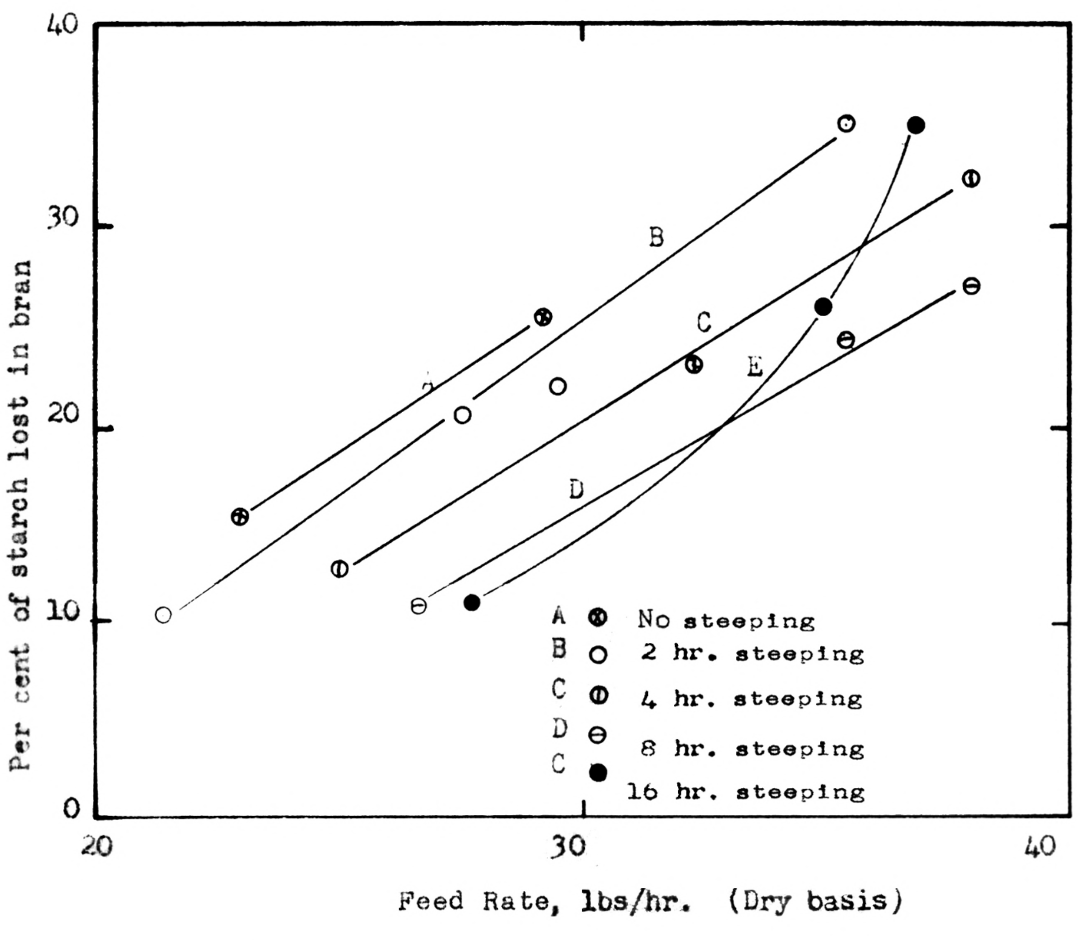


Fig. 11 Starch lost in bran

1. The recovery of starch when using SO_2 in steeping is related to the absorption of SO_2 in the grits. The maximum recovery was attained at absorption rates of 0.17 to 0.21 pounds of SO_2 per 100 pounds of grits.

2. The highest viscosity index was attained with no steeping at all. Long steeping times without SO_2 decreased the index value, due to fermentation. Sulfur dioxide prevented fermentation, but also tended to lower the viscosity index value.

3. Some reduction of power consumption was attained by the use of SO_2 in steeping.

4. The strong shearing action in the buhrstone mill decreased the viscosity index value. The power consumption in the buhrstone mill was considerably less, however, than for the hydraulic mill.

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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. Agri. Expt. Sta. Bul. 61. March, 1946.

3. Barham, H. N., J. A. Wagoner, and G. N. Reed.
Viscosity measurement of starch, Ind. Eng. Chem. 34, 1490-1495, 1942.

4. Chiang, S. H.
Factors affecting the production of starch from the endosperm of sorghum grains. Unpublished thesis, Kansas State College, Manhattan, Kansas, 1955.

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

6. Drobot, W.
The industrial recovery of starch from sorghum grits. Unpublished thesis, Kansas State College, Manhattan, Kansas, 1950.

7. 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.

8. Johnston, R. W.
The production of starch from grain sorghums. Unpublished thesis, Kansas State College, Manhattan, Kansas, 1942.

9. Kansas State Board, Division of Statistics Bulletin, March 13, 1956.

10. Kerr, R. W.
Chemistry and industry of starch. Second edition, New York, Academic Press, 1950.

11. Scott, W. W.
Standard Methods of Chemical Analysis, Vol. I, 4th ed., New York, D. Van Nostrand Company, Inc., 1939.

The primary purpose of this investigation was to compare the use of sulfur dioxide as a steeping agent with plain water steeping for yield and quality of starch. A secondary purpose was to compare the hydraulic mill with a buhrstone mill in the grinding process.

The previous work on this subject were mainly concerned with plain water steeping. However, a dilute sulfur dioxide solution is used as a steeping agent in most conventional corn wet milling processes.

Grits were steeped in 0.05 to 0.3 per cent sulfur dioxide solutions at 120°F for 2 to 24 hours. Then, the steeped grits were fed continuously into the mills through a V-shaped feed hopper for grinding. The ground grits were separated by a series of two screens. Fine particles which passed through a 200-mesh screen were stored as starch milk. The coarse particles were passed through a debranner where bran was separated and the unground material was recycled for regrinding. The starch milk was pumped to four starch tables where gluten was separated and the final starch product was collected from these tables.

The recovery of 85 per cent of the starch in the grits using sulfur dioxide steeping was about the same as that using plain water steeping. The power consumption was slightly reduced due to softening action of sulfur dioxide. However, because of corrosion problems associated with the use of sulfur dioxide plain water steeping appears to be more economical in milling sorghum grits.

The other results are summarized in the following:

1. Viscosity index, which is one of the most important quality factors of starch, was lowered when sulfur dioxide was used as a steeping agent. This may be caused by decomposition of the starch by the sulfur dioxide.

2. The protein content in the starch was high. This probably could be improved by better operation of the tabling process.

3. The strong shearing force of the buhrstone mill decreased the viscosity index. However, the power consumption for grinding in the buhrstone mill was much lower than for the hydraulic mill.