PILOT-PLANT STUDIES ON THE CONTINUOUS BATTER PROCESS TO RECOVER GLUTEN FROM WHEAT FLOUR[1]

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ABSTRACT

Certain variables involved in carrying out the continuous batter process for separating gluten and starch from wheat flour, such as water-to-flour ratio, retention time, temperature of mixing water, and mixer speed, were studied to determine their effect on gluten protein recovery and gluten purity. Generally, the recovery was increased by increasing the mixing-water temperature and by thickening the batter. However, the purity of the gluten product increased as the batter became thinner. Processing also appeared to be affected by ash content of the flour. As the ash content increased, less gluten was recovered, and the gluten also contained less protein.

Cost estimates for processing 200,000 lb. of flour daily to millstarch (crude starch slurry) and to wet gluten fractions indicate a plant investment cost of $316,100 and a processing cost of 26.5 cents per 100 lb. of flour processed.

A previous article describes a pilot plant for the separation of gluten and starch from wheat flour by a continuous batter process (2). Its construction and operation were simpler than other continuous or batch processes described in the literature (4,5,6). The versatility of the pilot plant was demonstrated by processing flours milled from various types of wheat. In these experiments, all processing variables were held as constant as possible, except the amount of mixing water. Further investigations were made on the effects of a number of processing variables on the recovery of the flour protein in the gluten, and other work was carried out on the processing of low-grade flours milled from hard wheat that had a wide variety of chemical and physical properties. Results of these investigations and estimates of plant investment and operating costs for carrying out the process are now being reported.

Material and Methods

Commercial, untreated, first and second clear flours milled from hard red wheat were processed in 100-lb. lots, and each continuous run lasted 1 hour. The moisture of each flour was determined by drying a sample for 4 hours at 110°C. under a vacuum of 28 in. of mercury. Protein (N × 5.7) was determined by the improved Kjeldahl method for nitrate-free samples (1). Ash was determined according

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to the official method of analysis of the AOAC (3). Solubles were determined by shaking 1 g. of flour in 100 ml. of distilled water intermittently for 30 minutes, centrifuging, and then analyzing an aliquot of the supernatant for total solids. Analytical determinations were reported on a moisture-free basis (M.F.B.).

Briefly, the continuous process involves mixing 1 part of flour with from 1 to 1.8 parts of water, depending on the flour being used, in a continuous mixer until a smooth, elastic batter is formed. This batter is withdrawn continuously to a pump, where water is added to make the ratio of water to flour about 3 to 1. Starch is washed from the batter leaving the gluten in the form of small curds. Starch and gluten are then separated on a shaker screen. The gluten curds are further washed by passing them through one or more additional pumps with added water, and the gluten is recovered on screens.

Results and Discussion

Effect of Operating Variables on the Processing of a First Clear Flour. The following process variables were investigated, using a first clear flour milled from a hard red wheat: a), water-to-flour ratio, b), holding or aging, c), r.p.m. of the washing or "cutting" pump, and d), size of screen mesh used on the shaker screen. The chemical analysis of the flour (M.F.B.) was: protein, 16.6%; ash, 0.79%; solubles, 7.4%.

Mixing water for all tests was kept at a temperature of 52°C. The temperature of the batter during mixing was usually about 43°C. The term "total mixing water" used throughout the text and tables refers to the batter composition at mixing, in lb. of water per lb. of dry flour, and includes water present in the flour. Operating data, recovery, and analysis of the products are given in Table I.

The water-to-flour ratio had the greatest effect on gluten protein recovery. When a thick batter was used, an increase of about 10% in protein recovery was attained. In some cases, this increase was accompanied by a decrease in the purity (protein content) of the recovered gluten. When a thin batter is passed through the cutting pump, the gluten is cut into smaller pieces which pass through the screen into the starch fraction. A slight increase in gluten protein recovery is possible by using a finer screen for the primary separation. This increase in recovery was obtained without seriously altering the gluten purity. Holding the thinner batter for an extra hydration period of 30 minutes before processing increased the recovery of gluten protein by almost 10%, with only a slight decrease in gluten purity. A decrease in the speed of the cutting pump when a thick batter was processed improved recovery and purity of the gluten protein.

TABLE I
RESULTS OF PROCESSING FIRST CLEAR FLOUR

EXPERIMENT	A	B	C	D	E	F[a]
Operating data:						
Total mixing water lb/lb dry flour	<———	1.17	———>	<———	1.28	———>
Cutting water lb/lb dry flour	<———	1.44	———>	<———	1.44	———>
Cutting pump speed, r.p.m.	600	600	200	<———	600	———>
First screen, mesh	150[b]	80[c]	150	80	150	80
Second screen, mesh	<———	100[d]	———>	<———	100	———>
Products:[e,f]						
Gluten fraction, lb.	14.4	15.4	14.6	12.5	13.1	13.9
Purity, % protein	83.6	77.4	84.8	83.5	82.8	77.5
Starch fraction, lb.	55.2	48.8	51.2	67.6	68.6	56.8
Protein content, %	2.9	3.5	3.1	5.0	4.4	3.6
Wash water solids, lb.	15.8	23.1	18.4	5.7	6.0	13.0
Protein content, %	4.95	3.5	3.3	9.2	8.5	4.5
Recovery:[f]						
Protein recovered in gluten fraction, % of total protein in flour	83.1	82.7	85.0	72.1	75.5	81.9

[a] Holding tank used in this test.
[b] Opening 0.0041 in.
[c] Opening 0.0075 in.
[d] Opening 0.0065 in.
[e] Yield based on 100 lb. of flour (12% moisture).
[f] All figures on moisture-free basis.

The recovery of crude starch was better when the thinner batter was used. However, the protein content of this starch fraction was higher than that obtained in processing the thicker batter, which resulted in decreased gluten protein recovery. The quantity of protein in the wash-water solids was approximately the same in all tests.

Optimum recovery of gluten protein was obtained from this flour when a thick batter was used, the cutting pump was operated at a slow speed, and the finer screen was employed for the primary separation.

Effect of Operating Variables on the Processing of a Second Clear Flour. To confirm the results further and also to examine them in relation to a second clear flour, a study was made testing five processing variables according to a half-factorial experimental design. The five variables considered were: a), water-to-flour ratio, b), temperature of the mixing water, c), speed of the mixer, d), retention time in the mixer, and e), speed of the cutting pump. The experiment was designed chiefly to show which variables are most important in the recovery and purity of the gluten, and for this reason the water-to-flour ratio is higher than would be used for optimum recovery.

In this experiment, a second clear flour having the following analy-

TABLE II

RESULTS FROM A HALF-FACTORIAL EXPERIMENTAL DESIGN USED ON SECOND CLEAR FLOUR IN THE PILOT-PLANT OPERATION OF THE CONTINUOUS BATTER PROCESS

Water-to-Flour Ratio	Temperature of Water to Mixer	Retention Time	Mixer Speed	Cutting Pump Speed	Gluten Protein Recovery, Percent of Total Protein in Flour, MFB[a]	Gluten Purity Percent Protein, MFB
	°C	*minutes*	*rpm*	*rpm*	%	%
1.4	52	18.5	80	200	77.0	71.4
1.4	30	23	40	600	60.0	70.1
1.4	30	18.5	40	200	69.0	72.0
1.55	30	18.5	80	200	69.5	75.3
1.4	30	18.5	80	600	60.4	75.0
1.55	30	23	40	200	68.3	72.8
1.55	52	23	40	600	74.0	68.9
1.4	52	23	80	600	77.4	71.1
1.55	52	18.5	80	600	74.9	73.8
1.4	52	23	40	200	80.3	66.3
1.4	30	23	80	200	72.3	74.6
1.55	52	23	80	200	76.2	70.1
1.55	30	18.5	40	600	57.0	70.2
1.4	52	18.5	40	600	74.3	71.3
1.55	52	18.5	40	200	74.3	67.9
1.55	30	23	80	600	38.4	68.4

[a] Moisture-free basis.

sis (M.F.B.) was used: protein, 17.3%; ash, 1.47%; solubles, 7.45%. Except for the mentioned variables, all operating conditions were held as constant as possible. The cutting water was about 1.42 parts water per lb. of dry flour, and 150-mesh screens were used for the primary separation and for the single washing of the gluten.

The pattern selected for this experimental design and the results of the 16 experiments carried out under it are given in Table II. Results, expressed in terms of gluten protein recovery and gluten purity, show that optimum recovery is achieved under conditions requiring greater energy input. Recovery is increased toward the maximum obtainable by increases in the temperature of the mixing water, decreases in the water-to-flour ratio, and increases in energy input per lb. of batter during the mixing, in that order of importance. Increasing the speed of the cutting pump seriously reduces gluten recovery when the temperature of the mixing water is low or a thin batter is used. When the temperature is optimum for the operating conditions or when a thicker batter is used, an increased pump speed improves the purity of the gluten with little sacrifice in its recovery.

Effects of Ash Content and Physical Characteristics on the Processing of Second Clear Flours. Second clear flours milled from hard wheat possessing different ash contents and varying in some of their physical characteristics were processed in the continuous pilot plant.

TABLE III

RESULTS OF PROCESSING SECOND CLEAR FLOURS IN THE CONTINUOUS PILOT PLANT
(All figures on moisture-free basis)

	Flours				
	A	B	C	D	E
	%	%	%	%	%
Flour composition:					
Protein	16.3	16.1	17.3	19.8	19.8
Ash	0.84	1.26	1.47	1.89	1.95
Solubles	7.04	9.07	7.45	10.93	11.61
Soluble protein	2.77	3.30	3.20	4.06	4.26
Gluten protein recovery, percent of total protein in flour	80.3	79.5	81.5	77.8	77.6
Gluten purity, percent protein	76.7	75.1	74.9	73.8	73.0

TABLE IV

FIXED CAPITAL INVESTMENT FOR A PLANT PROCESSING 50 MILLION POUNDS OF FLOUR ANNUALLY

Land and Improvements	$ 7,500	
Building (100 ft. × 60 ft. × 12 ft.)	72,000	
		$ 79,500
Equipment delivered:		
1 Ribbon blender, about 50 cu. ft., SS., 10 hp.	$10,000	
1 Flour feeder, gravimetric, belt type, capacity 20-600 cu. ft./hr., ½ hp.	8,600	
2 Shakers, gyratory, 5 ft. × 10 ft. screen area, SS, 3 hp.	10,000	
2 Shakers, gyratory, 5 ft. × 7 ft. screen area, SS, 2 hp.	9,200	
1 Shaker, vibrating, 48-in. diam., 1 hp.	3,000	
1 Tank, 3,000 gal., SS	8,000	
1 Tank, agitated, 15,000 gal., SS.	21,000	
1 Bin, flour, 8 ft. × 8 ft. × 6 ft., steel	1,000	
1 Pump, positive displacement, 75 gpm., SS., 5 hp.	3,500	
2 Pumps, positive displacement, 30 gpm., SS., 2 hp.	4,000	
1 Pump, positive displacement, 40 gpm., SS., 3 hp.	2,500	
1 Pump, centrifugal, 60 gpm., SS., 2 hp.	1,160	
2 Pumps, centrifugal, 25 gpm., SS., 1 hp.	2,000	
1 Conveyor, screw, steel, with elevator, 11 hp.	2,000	
1 Conveyor, screw, 6 ft. × 30 in. diam., SS., 3 hp.	5,000	
3 Flowmeters, 0–30 gpm.	1,000	
1 Flowmeter, 0–40 gpm.	350	
1 Flowmeter, 0–12 gpm.	190	
1 Water softener system, 25 gpm., for removing 24,000 grain hardness/hr.	10,000	
1 Water heater, instantaneous type, with control, 25 gpm.	2,000	
		$104,500
Equipment installed, 30% of delivered equipment		31,400
Piping, wiring, instrumentation, 30% of installed equipment		40,700
Contingencies, 15% of installed equipment complete with piping, wiring, etc.		26,500
Engineering fees, 15% of installed equipment complete with wiring, piping, etc.		26,500
Contractor's fees, 4% of installed equipment complete with piping, wiring, etc.		7,000
Fixed capital investment		$316,100

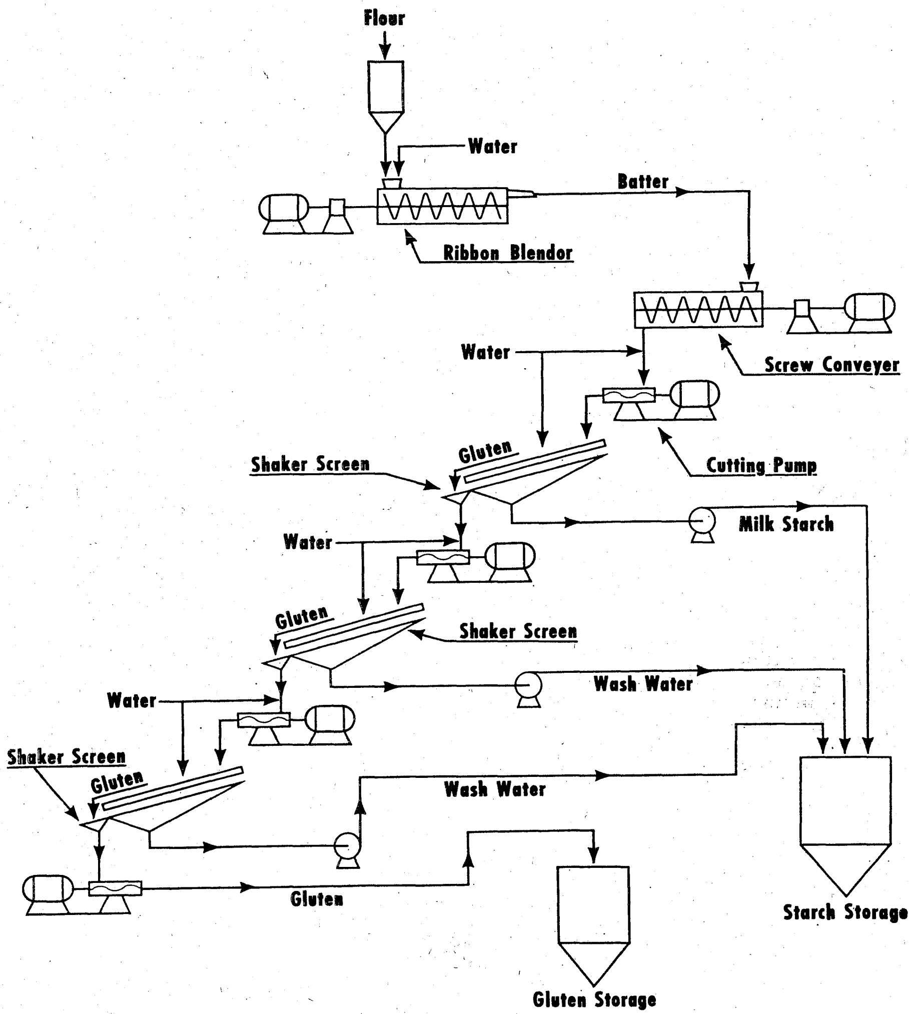

Fig. 1. Flowsheet for processing wheat flour by the continuous batter process.

The chemical composition of five of these flours and test results are listed in Table III.

These flours varied in ash content from 0.84 to 1.95%. The amount of solubles and soluble protein present in the flours increased as the amount of ash increased. The flours were processed under the optimum conditions selected on the basis of previous work. These conditions are: mixing water temperature, 52°C.; total mixing water, 1.15 lb. per lb. dry flour; mixer speed, 66 r.p.m.; retention time in mixer, 18.5

TABLE V

ESTIMATED COST OF PRODUCTION (EXCLUDING RAW MATERIALS) FOR A PLANT WITH A CAPACITY FOR PROCESSING 50 MILLION POUNDS OF FLOUR ANNUALLY
(20 hours per day, 250 days per year)

	ANNUAL COST		CENTS/100 LB. FLOUR PROCESSED
Utilities:			
Electricity 196,000 kw. hr. at $0.015/kw. hr.	$ 2,940		
Water 27,000,000 gal. at $0.075/1,000 gal.	2,025		
Steam 2,500,000 lb. at $0.80/1,000 lb.	2,000		
		$ 6,965	1.4
Labor and supervision:			
3 operators $2.50/hour total, 24 hours/day	15,000		
9 laborers $2.00/hour total, 72 hours/day	36,000		
1 mechanic $2.50/hour, 1/3 time	1,666		
1 superintendent $9,000/year, 1/3 time	3,000		
1 foreman $5,500/year, 1/3 time each shift	5,500		
1 chemist $5,500/year, 1/3 time	1,834		
Overhead	9,450		
		$72,450	14.5
Maintenance:			
Equipment 5%/year	11,830		
Building, 2%/year	1,590		
		$ 13,420	2.7
Fixed charges:			
Depreciation			
Equipment, 10%/year	23,660		
Building, 3%/year	2,160		
Taxes and insurance, 3%/year	9,480		
		$ 35,300	7.0
Miscellaneous operating supplies	$4,500		
		$ 4,500	0.9
		$132,635	26.5

minutes; cutting pump speed, 200 r.p.m.; amount of cutting water, 1.40 lb. per lb. dry flour; the gluten was washed twice.

Purity of the gluten product decreased slightly with an increase in flour ash. Gluten from the flour with the higher ash was more difficult to wash; this was attributed partly to the increased amount of bran present: when ground whole wheat was processed under similar conditions, it was difficult to obtain gluten purity of over 50%. However, in all cases, the crude starch produced was comparable to that from good flours.

Gluten protein recovery also decreased slightly with an increase in ash content; this was caused partially, it is believed, by the increased solubles and soluble protein contents of the flour. Generally, gluten protein recovery of about 80% has been attained when these flours have been processed.

Cost Estimates. Operating and investment costs have been estimated for the plant-scale fractionation of wheat flour to a millstarch slurry (crude starch) and a wet gluten fraction by the continuous batter process. A general flowsheet is given in Fig. 1. Table IV lists the land, building, and equipment needed for a plant processing 50 million lb. of flour annually (second clears, 16% protein, M.F.B.), 20 hours per day, 250 days per year. The total estimated plant investment cost is $316,100, including complete installation of all equipment. This plant would of necessity be operated in conjunction with a starch-refining and a gluten-drying facility, so that some of the equipment and personnel would be shared. In this cost estimate no recovery of the solubles fraction was contemplated even though it amounts to as much as 10% of the total flour used, and any disposition of the solubles is charged to the starch-refining and gluten-drying facility.

The estimated plant production costs for this plant are given in Table V. This cost amounts to $132,635 annually or 26.5 cents per 100 lb. of flour processed. These are plant production costs only and do not include any charges for flour, working capital, profits, income tax, selling expense, or administration.

This processing cost is independent of the type of flour being processed. However, the recovery of gluten protein would vary, depending on the particular flour used. Table VI gives typical gluten and crude starch recoveries from several flours of different types and composition. Since the gluten product is much more valuable than the

TABLE VI

RECOVERY OF GLUTEN AND CRUDE STARCH FROM FLOURS OF DIFFERENT TYPES AND COMPOSITION

Type of flour	Patent, Soft White Winter	Patent, Soft Red Winter	Patent, Hard Red Winter	First Clear, Hard Red Winter	Second Clear, Hard Red Winter
Composition of flour					
Protein, % MFB[a]	9.2	11.2	14.3	16.6	17.3
Ash, % MFB	0.39	0.34	0.41	0.79	1.47
Gluten recovery					
Recovery from 100 lb. flour (about 12% moisture), lb. MFB	7.0	9.8	13.0	14.6	16.6
Gluten purity					
% Protein, MFB	81.0	81.0	80.7	84.8	74.9
Crude starch recovery					
(Average 3% protein) recovery from 100 lb. flour (about 12% moisture), lb. MFB	76.5	72.1	73.0	69.6	67.7

[a] Moisture-free basis.

starch product, the most desirable flours to process are those with the highest protein content. Low-grade flours, such as second clears, generally contain greater amounts of protein and are also available at less cost.

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