Recovering Useful By-Products from Potato Starch Factory Waste Effluents —A Feasibility Study

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☐ RECENT LEGISLATION mandating zero-discharge of pollutants by 1985 has changed waste treatment objectives. Emphasis is shifting from conventional methods to by-product recovery to pay for the waste treatment costs. With this as our objective we undertook a research program to evaluate possible solutions to the potato starch waste disposal problem. These studies led to the development of a process of concentrating the effluent by evaporation and then spray drying the concentrate. Possible end uses for the product are as a poultry feed component, pet food component, or fermentation medium.

We studied potato starch factory effluents for two reasons. First, potato starch manufacturing acts as the scavenger of the potato processing industry, since it disposes of culls and the continually increasing amounts of scraps from other potato processing operations. Hence, its extinction would only present us with another set of serious environmental problems. Second, potato starch factory waste effluent is similar in composition to the effluents from the cutting and chipping operations of the other potato process. Hence, the results of this study would be applicable to the rest of the potato processing industry. This industry annually processes 7.5 million tons of potatoes to flakes, granules, French fries, chips, and dehydrated dice.

Profitable by-product recovery, however, depends on many factors, the most important of which are: the potato starch manufacturing process producing the waste stream; the end use of the by-product; and the sharp rise in energy costs. In this paper we discuss the effect of these factors on profitable end use and conclude that only a high capacity, modern plant can profitably recover the solids for use in poultry rations. However, if the fermentation industry could be persuaded to use dried soluble potato solids, even low capacity plants probably could afford to recover these solids.

POTATO STARCH MANUFACTURE AND ITS WASTE EFFLUENT

The valuables thrown away are the soluble solids of the potato. Hence, the effluent actually is potato juice diluted to a degree depending on the equipment and manufacturing method used. While no two starch plants are identical, starch making essentially involves the physical separation of the starch from the pulp and soluble solids. Fig. 1 shows the two basic methods employed (Douglass, 1965). The potatoes are washed and then ground, and if processed according to method A, the starch and solubles are first separated from the pulp by either centrifugal screens or shaker screens. The pulp is reground and again screened to extract the remaining starch. The combined liquid streams from the two extractions then go to the solid-bowl centrifuge where the so-called "protein water" which now contains over 90% of the solubles is spun off; the starch cake goes to the washing and drying steps. In method B, the ground potatoes are first pumped to a solid bowl centrifuge which removes about 70% of the solubles in what is almost full strength potato juice. The pulp and starch fraction then go to the extracting, washing and drying steps; the liquid from these steps is added to the original protein water.

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Regardless of the method employed (unless the equipment is hopelessly antiquated), by use of good water conservation practices, e.g., recycling and counter-current operation, the solids content of the protein water should be 2% of higher (Stabile et al., 1971). This accounts for about 55% of the BOD leaving the starch plant; the other 45% is the pulp (Ambrose and Reiser, 1954). The latter presents no waste disposal problems because it can be used as an animal feed. Since the effluent to be treated actually is potato juice originally containing 5.0-5.5% solids diluted to 2% solids and since a ton of potatoes contains about 200 gal of juice, then about 500 gal of effluent is produced per ton of potatoes. One ton of starch requires 7.5-10 tons of potatoes, depending on the variety used; hence, 3750-5000 gal of effluent must be treated for each ton of starch produced. Obviously, with antiquated equipment or poor water usage the volume of effluent is substantially higher. If the latest technology is used to manufacture potato starch, however, effluents of around 4% solids can be produced, halving the volume of effluent. For example, Bode (1974) recently reported from Europe that high quality starch can be produced by recycling and using only 300 L of wash water per metric ton of potatoes. If the juice is about 5.5%, this means an effluent of 4% solids. Recently, Verberne (1977) and Rosenau et al. (1978) reported new processes which also produce effluents of 4% solids. The advantages of these new technologies are obvious, particularly with the rising cost of energy. In the waste stream leaving the factory there is another large volume liquid stream, i.e., the liquid from the flumes and potato washing step. However, this stream contains very little BOB, is easily treated, and should be separated from the starch processing stream.

The composition of the soluble solids varies with the potato variety used in starch making. Table 1 shows the composition of a typical Maine starch factory effluent. The high sugar content is characteristic of potatoes exposed to low temperatures, under which conditions, the starch is converted to sugars. Scraps from other processing operations used in starch making produce effluents with less sugars, since the potatoes have been preconditioned to a low sugar content. These would be easier to handle, particularly with regard to hygroscopicity. The most important component of the soluble solids is the protein fraction, which ranges roughly from 33 to 41%. Amino acid determinations (Kaldy and Markakis, 1972) have shown this protein to be of high nutritional quality. The other major component is the mineral content which, when determined as ash, accounts for around 20% of the solids. Most of this is potassium.

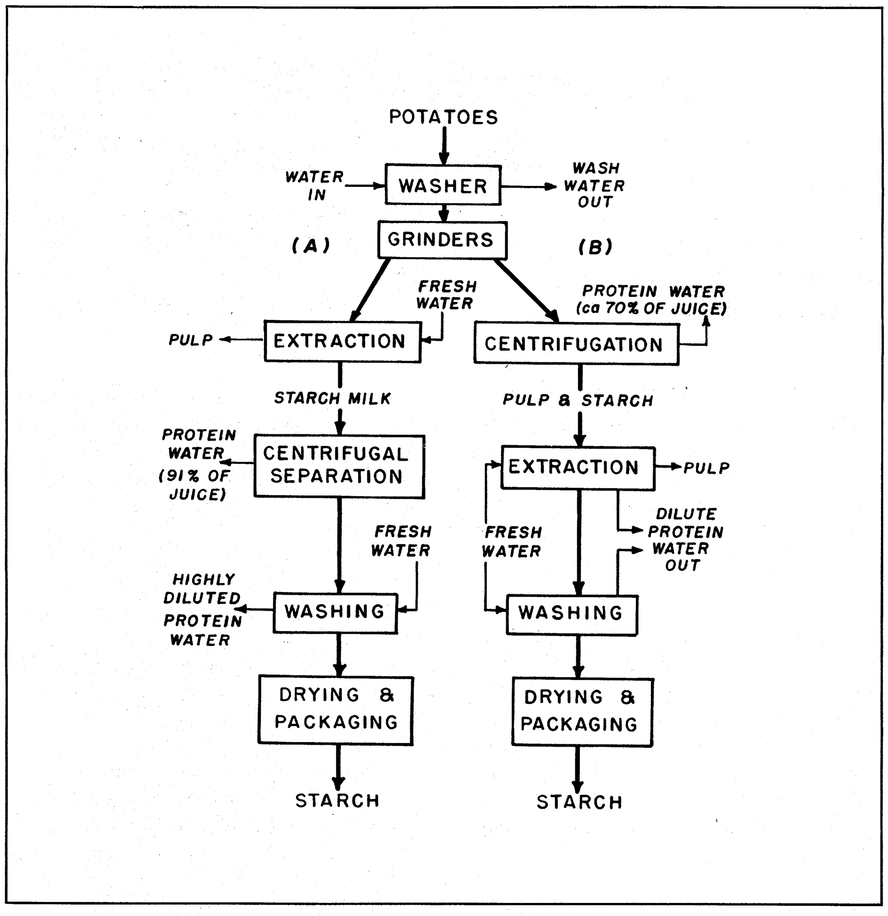

Fig. 1—**METHODS OF MANUFACTURING POTATO STARCH** *are shown in this schematic diagram*

PILOT PLANT AND UTILIZATION STUDIES

• **Previous Research Approaches.** Earlier work done at this laboratory showed that potato solubles can be fractionated by ion-exchange to yield amino acids, organic acids, and potassium (Heisler et al., 1959, 1962, 1970, 1972; Schwartz et al., 1972). This procedure, however, requires that virtually all the protein be removed before ion-exchange, since protein concentrations above 180 ppm cause precipitation in the ion-exchange columns. Because the protein water produced in American starch plants contains 1500 to 4000 ppm of protein, a process for removing the protein was developed (Strolle et al., 1973).

From the data obtained in the protein recovery work and the ion-exchange studies, the economic feasibility of the ion-exchange process appeared doubtful, and a cost study comparing it against other possible treatments was made (Stabile et al., 1971). Five alternatives were considered: (1) the ion-exchange recovery process; (2) conventional biological oxidation of the waste by the most recently developed process applicable; (3) protein recovery by the process developed at this laboratory followed by biological oxidation of the remaining solids; (4) protein recovery as in (3) above and concentration of the remaining solids to 60%; and (5) concentrating the entire effluent to 60% solids by multi-effect evaporation (Heisler et al., 1959).

This study indicated that the process of concentrating the effluent to 60% solids (Method 5) had the best economic possibilities. Linear parametric programming (Taylor et al., 1968), based on 1972 prices, further showed that as a poultry feed component, dry matter from the total effluent could command a price of $120/ton. At this price the recovered solubles could be disposed of at a profit.

Pilot plant studies were therefore undertaken to develop a process for making a 60% concentrate. However, these showed two shortcomings of this approach. Above 50%, the concentrates were usually too viscous at room temperature for practical handling, and, while the concentrates above 50% solids are resistant to bacterial action, they are chemically unstable at room temperature. A 3-mo storage test revealed evidence of protein decomposition accompanied by the evolution of CO_2, apparently enzymatic in nature (DellaMonica et al., 1975). Hence, to ensure product stability, a drying step is required.

Table 1—**COMPOSITION OF SOLUBLE SOLIDS** *from a typical Maine starch factory*

Component	Relative amount (MFB) (%)
Total "protein" (N × 6.25) (true protein about ⅓, ⅔ amino acids, amides)	33-41
Total sugars	35
Reducing sugars	28-32
Sucrose	1-7
Organic acids	4.0
Minerals	20
Other (probably carbohydrate)	6-9

remain constant (30% of the total costs). Hence, the first two costs balance each other—that is, vapor compression systems use less energy but they cost more than conventional evaporators.

In the long run, with the prospect of continually increasing energy costs, it would probably be wiser to choose the mechanical vapor recompression equipment. This is purely academic, however, since the overall cost of conventional waste treatment would have to increase at a much higher rate than energy costs, and this hardly seems probable. The only place where we could significantly reduce overall evaporation costs is in Items 1 and 4, the fixed costs. For example, if, instead of 150 days, we had a starch plant using the latest technology operating the equivalent of 300 days/yr with two daily shifts, we could reduce the cost by about 2.5¢/lb and bring the net product cost down to slightly less than 4¢/lb based on a return of 6.65¢/lb as a poultry feed. Other considerations then, such as sludge disposal from bio-oxidation processes and overall increase in feed prices which DSPS could replace would then have to be weighed. The nature of the potato starch industry is such that an extended operating period is hardly likely.

The best approach is to find an end-use bringing a higher return. For the dried soluble potato solids such a possibility does exist. This is to use the soluble solids as a fermentation medium. During a company's tests of concentrated potato juice in 1971, it was estimated that the solids were worth 10¢/lb as a fermentation medium. Of course, now they should bring a higher price. Using the product as a fermentation medium could readily absorb the potential output, but its use is contingent on a steady supply and uniform composition to ensure reproducibility of results in the more demanding fermentation industry. The solids would command an even higher price as a bacterial medium. In fact, one biochemical supplier is actively seeking such a product. However, his annual requirement would account for only a small fraction of the total output of a 30 ton/day starch plant.

Obviously, if a profitable end-use cannot be developed, conventional waste treatments have to be used. In addition to the bioxidation methods, recent developments in land disposal by spray or flood irrigation (Sirrine, 1978) should be considered, possibly even in conjunction with processes recovering proteins (Strolle et al., 1973) or producing single cell protein as an animal feed.

Table 5—**EFFECT OF EVAPORATOR TYPE ON COSTS** *(2% solids in effluent)*

Item	2-stage evap.	Thermal recomp.	M.V.R.
Total cost (¢/lb)	17.10	17.19	17.90
Market value of product (¢/lb)	6.65	6.65	6.65
Net product cost (¢/lb)	10.45	10.54	11.25
Waste treatment cost (¢/lb)	4.00	4.00	4.00

Table 6—**EFFECT OF EVAPORATOR TYPE ON COSTS** *(4% solids in effluent)*

Item	2-Stage evap.	Thermal recomp.	M.V.R.
Total cost (¢/lb)	12.69	12.79	12.99
Market value of product (¢/lb)	6.65	6.65	6.65
Net product cost (¢/lb)	6.04	6.14	6.34
Waste treatment cost (¢/lb)	4.00	4.00	4.00

Table 7—**BREAKDOWN OF TOTAL COST** *to produce DSPS from 4% effluent*

Item	2-Stage evap.	Thermal recomp.	M.V.R.
Capital related costs, %	26	31	36
Utility cost, %	44	39	34
Other variable costs, %	19	19	19
Fixed cost, %	11	11	11
Total	100	100	100

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dried soluble potato solids (DSPS) or less were not significantly different from the control in both weight gain and feed efficiency; above 8%, the differences were significant.

The powder used in the next three feeding tests was made in our own pilot plant spray dryer. In the second test, rations containing 5 and 7% DSPS were significantly different from the control in weight gain; the birds were too small. There was no significant difference in feed efficiency at these levels but this only reflected the fact that the birds just were not eating the ration with 5 and 7% DSPS. This material had been prepared by evaporation at 160°F; it was quite low in trypsin inhibitor activity and very low in available lysine. We concluded that excessive damage had been done to the essential amino acids. Henceforth, we decided to evaporate at temperatures below 130°F.

• **Reduction of Hygroscopicity.** The dried soluble potato solids were too hygroscopic, and, unless this was significantly reduced, use of DSPS in poultry rations was precluded. We found that by adding $Ca(OH)_2$ so that the powder contained 5-7.5% CA^{++}, hygroscopicity was reduced to a manageable level. The control powder caked at 5.4% moisture; powder with 5% Ca^{++} added as the hydroxide did not cake until a moisture content of 8.1% was reached; and powder containing 7.5% Ca^{++} caked between 8.1 and 8.7% moisture. This was considered a practical solution, since the added calcium could replace part of the calcium normally added to poultry rations. To confirm this, poultry tests Nos. 3 and 4 were made with added calcium. The results are shown in Table 2. As in Test No. 2, No. 3 was carried out on dried soluble potato solids at 4 levels: 0, 3, 5, and 7%. Up to 7% DSPS, there was no significant difference in weight, but unfortunately at the 7% level the feed efficiency had decreased to a value significantly different from the control. As pointed out previously, this means a significant increase in feed cost. At the 5% level there was no significant difference in weight of feed efficiency. Five percent is the minimum level which the poultry feed men feel is practical to handle. Test No. 4 was a large-scale test on 200 birds at two levels only: 0 and 5% DSPS. This test confirmed the results of the third test. At this level the value of the dried potato solids then equals the value of the corn meal and soybean meal that it replaces (Jones et al., 1975).

Table 4—**COMPARISON OF PRODUCTION COSTS**[a]—*1973 and 1976*

Item	Year	
	1973[b]	1976
Total cost (¢/lb)	6.50	17.10
Utilities (¢/lb)	1.54	9.21
All others (¢/lb)	4.96	7.89
Utilities (% of total)	23.7	53.8
Value as poultry feed (¢/lb)	6.00	6.65
Net product cost (¢/lb)	0.50	10.45
Conventional waste treatment (¢/lb)	2.90	4.00

[a]Based on 2% effluent.
[b]Based on a proposal submitted to EPA for a demonstration plant capitalized at $800,000.

COSTS AND RETURNS

Of the three factors, starch manufacturing process, end-use of the recovered soluble solids, and energy requirements, the last has the most influence on profitability. As the subsequent discussion shows, the steep rise in energy costs starting in 1973 drastically changed the economics of the process. Producing a poultry ration from the effluent is no longer economically feasible. Either another use must be found for the dried solids, or else less costly disposal methods must be employed.

Table 4 shows why the original cost projections went awry. Since the complete cost analysis contains too many details, only the high points have been included. Anyone interested in a detailed breakdown should write to this laboratory. The cost figures shown are based on a 30 ton/day starch plant, working two shifts, 150 days annually, and discharging around 9 tons of solubles per day in an effluent containing 2% solids. The value of the poultry feed was calculated by linear parametric programming (Taylor et al., 1968). The cost/lb of dried powder for conventional waste treatment was based on information supplied by a starch manufacturer and represents what he would probably have to pay in order to comply with the latest anti-pollution requirements in his area. This cost can then be compared with the net product cost (production cost minus value if sold as poultry ration). In 1973 the starch manufacturer would have lost ½¢/lb recovering and selling the solubles for poultry feed. However, the cost of conventional treatment was almost 6 times the net production cost. Hence, recovering the soluble solids from the effluent would have been the wiser course of action. In 1976 the situation reversed itself. The table shows clearly the impact of the energy cost increase. In 1973 utilities for the process were 1.54¢/lb as opposed to 9.21¢/lb in 1976. They accounted for 23.7% of the total production cost in 1973, while in 1976 they were 53.8% of the cost. Another factor contributing to the increased utility cost is that in 1973 we were counting on using evaporating temperatures of 160°F in the last effect; this would have enabled us to use a four-effect evaporator plus thermo-compression. As shown previously, temperatures above 130°F caused too much damage to the available lysine.

At this point a question arises regarding the evaporation method. Because of increased energy costs, thermo-compression and mechanical vapor recompression evaporation have recently received a great deal of attention. Interestingly enough, the type of evaporator has practically no effect on the final cost of dried soluble potato solids. Tables 5 and 6 show the effect of evaporator type on the total cost for effluents containing 2 and 4% solids, respectively. The latter represents an effluent from a plant using the latest technology. Hence, the last column in Table 6 shows the effect of the best available technology (latest starch production method plus the least energy intensive evaporator). The data show that even with the best technology it is still cheaper to use conventional treatment rather than recover the solids for use as a poultry ration.

Table 7 shows why the type of evaporator had a comparatively small effect on the final costs. In this table, the costs are broken down into four component costs. Only the capital related costs and the utility costs vary. The other variable costs and the fixed costs

• **Preparation of Protein Water.** Simulated starch factory effluents for experimental work were prepared by expressing potato juice and diluting it to the desired concentration. The potatoes were washed and then ground into a slurry, which was pumped to a continuous solid-bowl centrifuge yielding practically full strength juice. Additional solubles were recovered by rewetting the cake, regrinding, centrifuging the slurry and adding the liquid thus obtained to the juice from the first centrifugation. The method employed recovered about 93% of the solubles originally present, and the protein water covered a range of concentrations from 1.5 to 5.5% solids.

• **Evaporation Studies.** Evaporations were carried out in a forced circulation evaporator having 11.4 ft^2 of heating surface. We found that the evaporating temperature is critical in maintaining a high level of available lysine. Potato juice also contains trypsin inhibitors (Sohonie and Ambe, 1955; Sawada et al., 1974), toxic factors similar to the trypsin inhibitor found in soybean meal and which interferes with protein digestibility. Our studies showed that the potato trypsin inhibitors could be readily inactivated by evaporation at temperatures of 140°F or higher. At the same time, however, the available lysine was also significantly reduced. At 130°F, the available lysine remained unchanged, but only about 30% of the inhibitors were inactivated. Obviously, with large scale batch evaporations, it is impossible to produce material high in available lysine and low in trypsin inhibitor activity. Therefore, we studied high temperature-short time heating of the juice followed by rapid cooling, to see if we could inactivate trypsin inhibitor without significant loss of available lysine. This proved ineffective. The rate of trypsin inhibitor inactivation was practically the same as the rate of lysine destruction. Fortunately, as the subsequent discussion of the poultry feed tests show, loss of available lysine is a more critical factor than trypsin inhibitor activity at the levels suitable for use of potato solids in poultry rations.

• **Drying Studies.** Early in our studies we eliminated drum drying and concentrated on spray drying. Drum drying, even with drying aids added, destroyed over 90% of the available lysine. Preliminary studies made on a small table model spray dryer showed that concentrates containing 28-48% solids could be dried to a moisture content of 4% or less at air inlet temperatures of 300-400°F.

We then made a large-scale drying run on a 7-ft commercial dryer. In addition to providing enough powder to conduct a poultry feeding test, data were obtained for a firm cost analysis. This test showed that at air temperatures of 300-400°F inlet and 200-220°F outlet, powder with less than 4% moisture and with 95% available lysine could be produced on a commercial scale. Additionally, the tests pointed up the necessity of using secondary air for cooling the hygroscopic powder to prevent lumpiness. Finally, it showed that some provision must be made to prevent excessive sticking of the powder to the walls. Hygroscopicity was a serious problem in the feeding tests and had to be controlled. This is discussed more fully later.

• **Poultry Feeding Tests.** Four specific tests were carried out at the University of Maine, and, since Gerry (1977) gives the complete details, only the objectives and results will be presented. These are summarized in Table 2. Table 3 contains the proximate analyses of the powders. In addition to the breakdown of the various components, which one must know in order to formulate rations for poultry, content of original available lysine and amount of trypsin inhibitor are included. While the method of trypsin inhibitor determination developed by Kakade et al. (1974) for soy products was found to be suitable, available lysine determinations by the Kakade-Liener method (1969) gave erratic results. Hence, a modified method was developed (DellaMonica et al., 1976).

For a practical feeding test to be meaningful, two equally important factors must be considered: weight gain and "feed efficiency" defined as the pounds of feed consumed per pound of weight gained. An increase in the numerical value of the "feed efficiency" means increased feeding costs. When the numerical values increase, feeding efficiency actually decreases. The Duncan Multiple Range test was used to compare means at the 5% probability level. The first test showed that rations containing 8%

Table 2—**POULTRY FEEDING TESTS**

Test	No. 1	No. 2	No. 3	No. 4
Levels DSPS (% of ration)	0,2,4,8,12,16 No calcium	0,3,5,7 No calcium	0,3,5,7 5% Ca^{++}	0,5 5% Ca^{++}
Available lysine	High	Low	High	High
Trypsin inhibitor	High	Low	High	High
Results[a]				
Weight gain	No S.D. up to 8%[b]	No S.D. at 3%[b] S.D. at 5, 7%[b]	No S.D. up to 7%[b]	No S.D.[b]
Feed efficiency	No S.D. up to 8%[b]	No S.D. up to 7%[b]	No S.D. up to 5%[b] S.D. at 7%[b]	No S.D.[b]

[a]Duncan Multiple Range Test used.
[b]S.D. = Significant differences.

Table 3—**PROXIMATE ANALYSES OF DSPS** *used in Maine poultry feeding tests*

Constituent	Test No. I	II	III	IV
Protein (N × 6.25), %	39.0	36.3	32.2	33.3
Sugars, %	31.6	37.7	30.4	30.5
Ash, %	18.9	17.6	29.1[a]	27.4[a]
Moisture, %	4.7	3.1	3.5	2.6
Other (carbohydrates, etc.), %	5.8	5.3	4.8	6.2
Total	100.0	100.0	100.0	100.0
Available lysine (a.l.)	76.2[b]	29.3[b]	262.0[c]	222.0[c]
% of a.l. in juice	95.0	30.0[d]	90.0	95.0
Trypsin inhibitor (TUI/g)	60,000	5,800	38,000	24,000

[a]5% Ca^{++} by wt added before drying.
[b]μ Moles/gram solids (Kakade-Liener, 1969).
[c]μ Moles/100 mg total N_2 (dialysis method) (DellaMonica et al., 1976).
[d]Based on subsequent studies this figure is too high.