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ECONOMIC ANALYSIS OF ALTERNATIVE METHODS FOR PROCESSING POTATO STARCH PLANT EFFLUENTS[1/]

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Introduction

The present requirements for the limits of pollutants in processing-plant waste water are necessary in order to preserve what is considered good water quality for natural streams. The effect of these requirements on potato starch plant operations is to place an economic burden on an industry which is already only marginally profitable. In present starch-making technology, practically all of the soluble components of the potato are released into the plant waste water. This yields an effluent which has both a high BOD level and a large daily flow. These two characteristics result in high sewage charges, that is, assuming the local sewage plant will accept the discharge at all. If the starch plant must build its own biological waste treatment plant, the costs--both capital and operating--will be substantial. An alternative method of treating the effluent is to recover the water-soluble constituents from the waste stream in usable form and sell them as byproducts. However, since the waste stream is dilute, recovery processes will have high operating costs and require considerable capital investment in relation to existing starch-plant valuation. Nevertheless, a byproduct recovery process could be justified if the selling price for the product or products resulted in a reasonable return on investment.

A preliminary economic evaluation of several potential waste treatment processes was made in order to see if any were commercially feasible. Since little pilot plant data had been obtained, this evaluation was primarily to see which process or processes deserved further investigation on the pilot-plant scale. The estimates are based on treating the waste water from a 30-ton-per-day starch plant operating 16 hours per day, 150 days per year. Five alternatives are compared. One alternative considers biological treatment of the waste with no recovery of the components of the waste as byproducts. The other four alternatives involve recovery of waste components and yield one or more byproducts. The waste stream was considered to come from a starch plant using current technology for starch recovery. The protein water waste flow used as a basis was approximately 104,000 gallons per day at a 2-percent by-

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weight dissolved solids concentration. This basis was considered an approximation of average starch plant operation using some improved water utilization.

Briefly, the five alternatives compared are: (1) biological treatment, (2) protein recovery with biological treatment, (3) concentration by evaporation, (4) protein recovery and concentration of protein-free waste, (5) protein recovery, ion-exchange and biological treatment. Let us look at the technology involved in each of the alternatives.

Alternative 1 - Biological Treatment of Waste

The treatment requirements for the waste treatment plant include at least 85-percent removal of BOD and suspended solids and complete removal of floatable and settleable solids. Other factors that must be considered for each plant location are the effect of the effluent discharge on the dissolved oxygen content of the receiving river or stream and the necessity for disinfection by chlorination. Chlorination is probably not required for starch plant waste treatment because pathogens are not present in the source of the waste.

The biological waste treatment process chosen is the activated sludge type. In this process, shown in figure 1, the raw waste is screened to remove fibrous solids, which are used as animal feed. The liquid containing

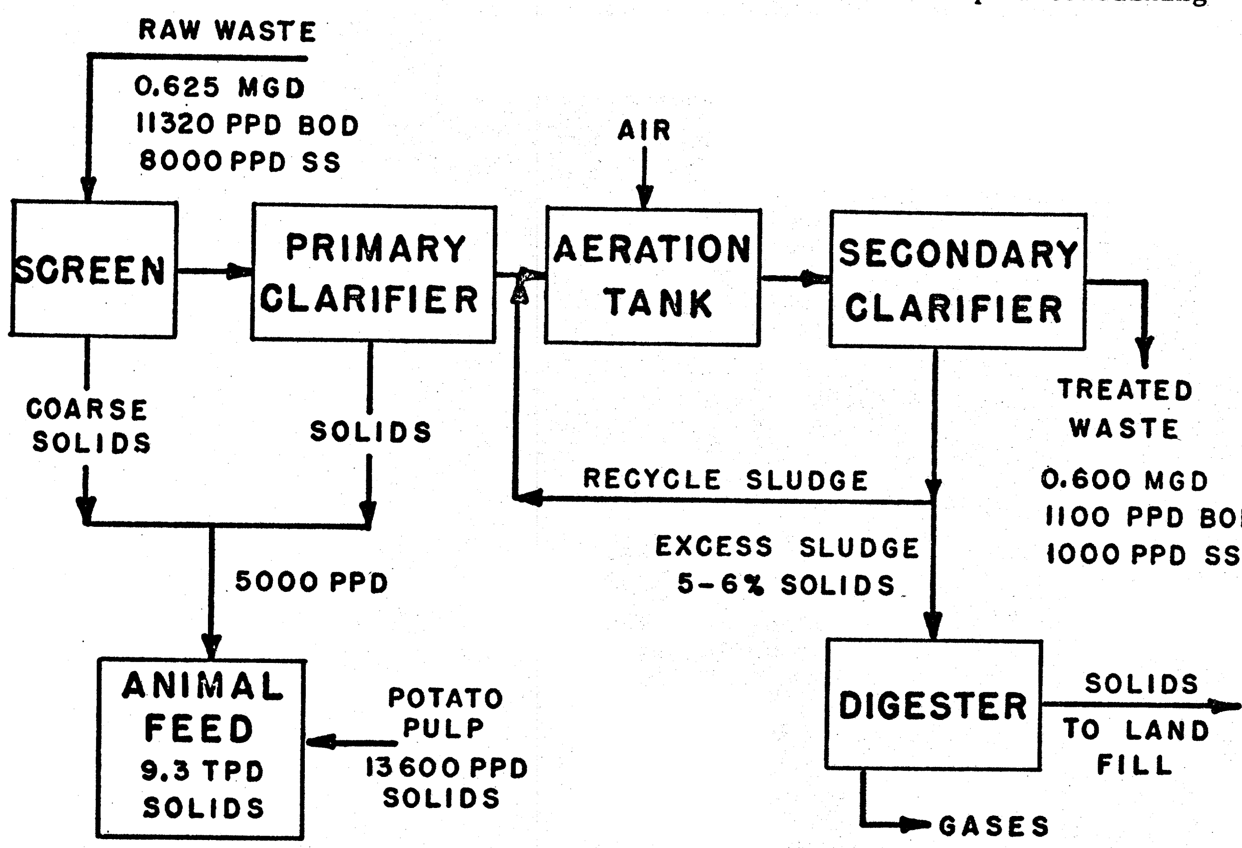

Figure 1.--Biological waste treatment by activated sludge.

suspended and dissolved solids is fed to the primary clarifier where settleable solids are removed. The solids removed from the primary clarifier are used in animal feed. The overflow from the primary clarifier goes to the aeration tank where biological degradation of the waste occurs. The effluent from the aeration tank is pumped to the secondary clarifier where the biologically active sludge is settled. Part of this sludge is returned to the aeration tank; the remainder passes to a digester where it is converted into gases and final solids by biological action. Final solids from the digester are assumed to be disposed of by land fill.

An activated sludge treatment system was selected because the design, operating procedures, and costs of this type system are well known, and also because it gives consistently high BOD removal.

The plant is assumed to process 625,000 gallons per day of waste water containing 11,320 lb. of BOD and 8,000 lb. of suspended solids. This total volume includes the combined protein water, wash waters from purifying the starch, and water used to flume and wash the raw potatoes. The treated waste sent to the river is approximately 600,000 gallons per day, containing 1,100 lb. of BOD and 1,000 lb. of suspended solids. Solids are removed from the screen and primary clarifier at a rate of about 5,000 lb. per day.

Alternative 2 - Protein Recovery and Biological Treatment

Protein recovery from protein water has been investigated by Strolle on a pilot plant scale (1). The results of this investigation were used to design a full-scale plant. The process is shown in figure 2. The protein water effluent from the starch plant, using the heated protein water from the steam injection heater, is preheated in a plate-type exchanger. After the preheating, sulfuric acid is added to an agitated tank which feeds the steam injection heater. The pH of the protein water is lowered to approximately 3.5; the exit temperature from the heater is 210° F. The precipitated proteins are removed from the slurry using a continuous rotary filter. The wet protein solids, containing about 87-percent water, are dried on a double drum dryer to about 5-percent moisture. The dried cake is ground and packed in 100-pound bags.

After de-proteinization, the waste stream is sent to a biological treatment process for removal of 80 percent of the remaining BOD, giving a final BOD of about 1,100 lb. per day. The biological process would be the same as described under alternative 1 except that incoming BOD would be reduced to 8,300 lb. per day because of the removal of the protein. Flow would be almost the same as alternative 1, and there would be no suspended solids. Therefore, a lower cost would be incurred.

Alternative 3 - Concentration by Evaporation

The basis for studying this process was to determine if it would be feasible to concentrate the entire protein water stream and make a profit by selling the concentrate for feed use.

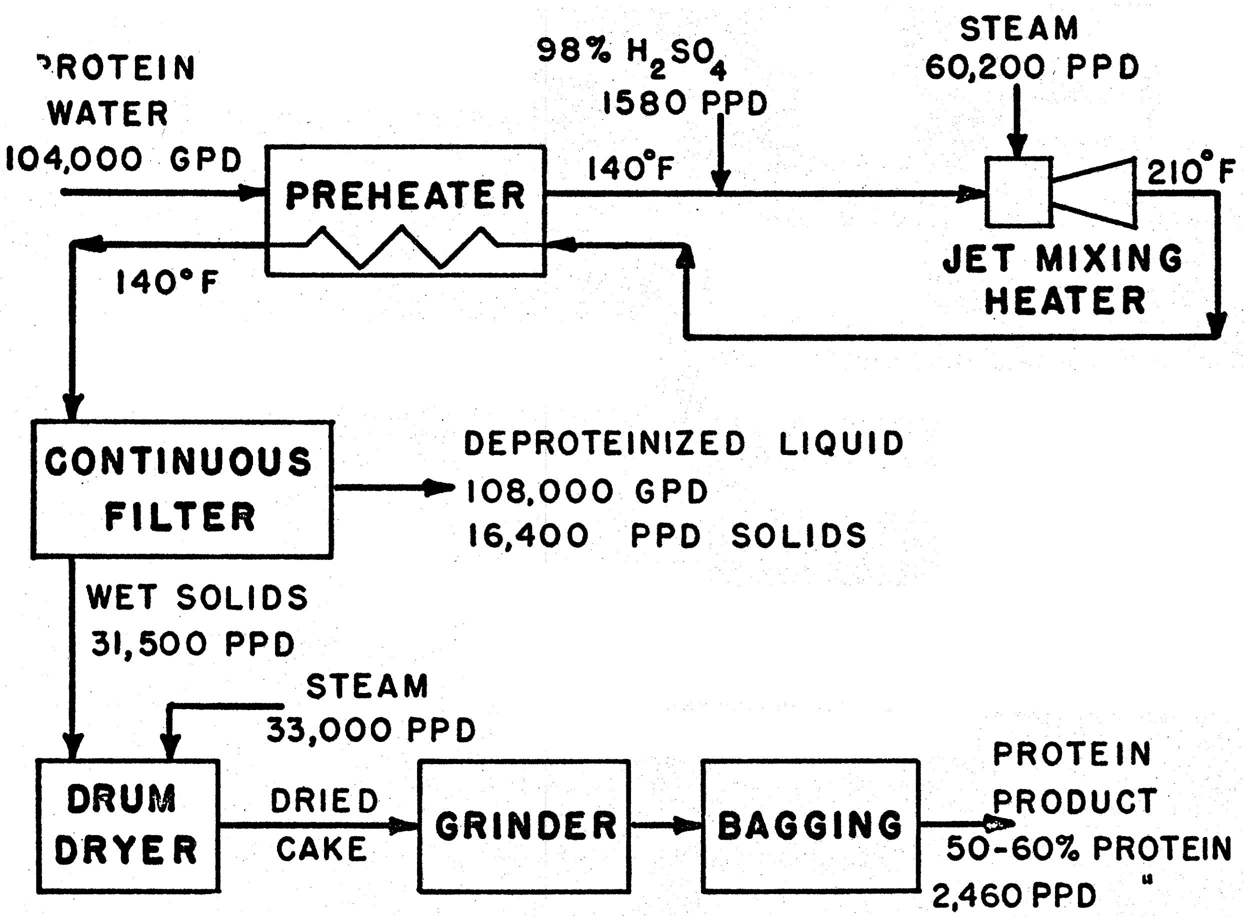

Figure 2.--Protein recovery from protein water.

The prótein water is evaporated in a triple effect evaporator to a 60-percent solids slurry, as shown in figure 3. The slurry is mixed with the dried potato pulp from the starch process and the mixture is sold as animal feed.

Approximately 320,000 pounds per day of steam would be required for the evaporation.

The capital and operating costs are based on the evaporation step only. The cost for pulp drying is considered to be recovered through the sales value of the pulp constituent in the mixed feed product.

Alternative 4 - Protein Recovery and Concentration of Protein—Free Waste

This alternative was investigated because it was anticipated that a market might exist for both the protein and protein-free solids.

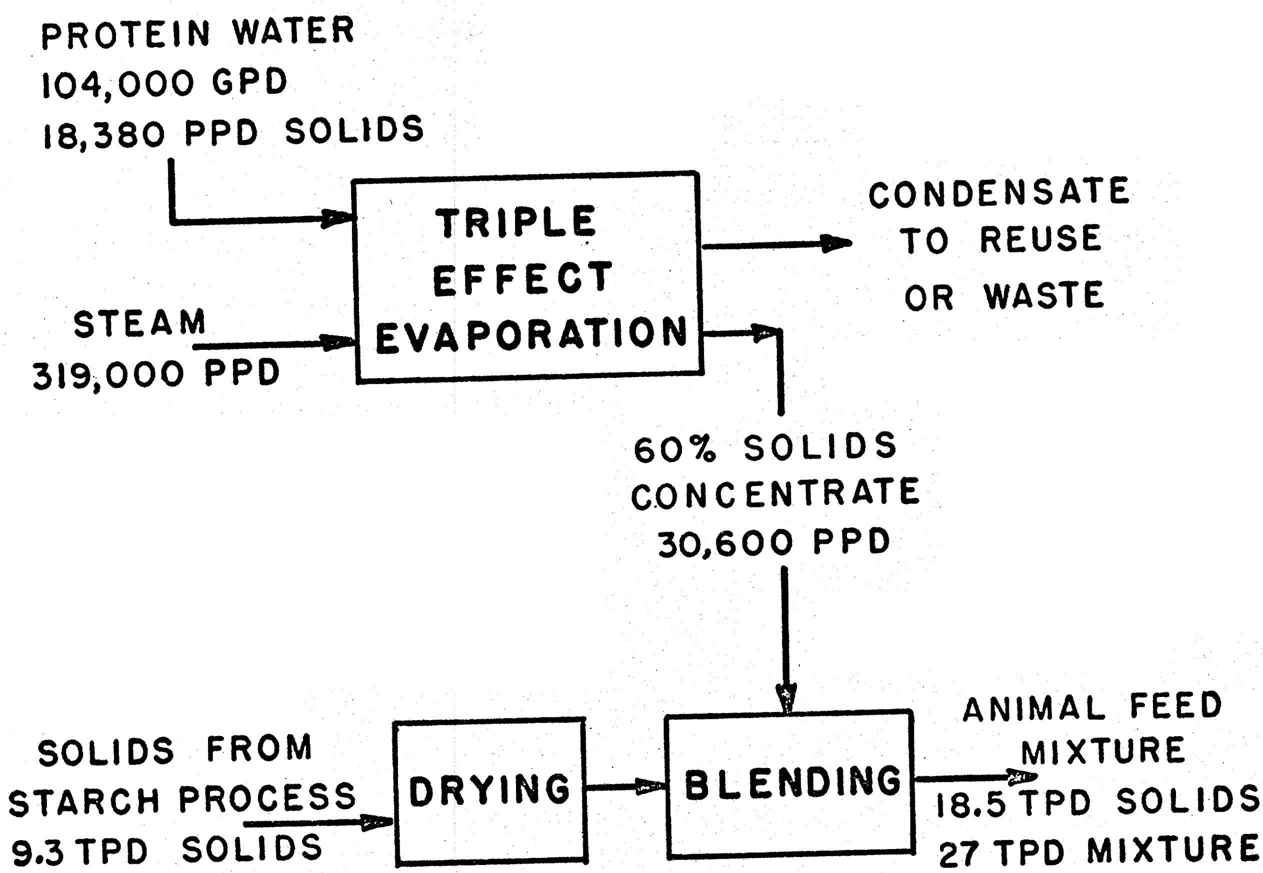

Figure 3.--Concentration of protein water by evaporation.

Figure 4 shows a schematic flow sheet of the process. The protein water goes first to the protein recovery process as described under alternative 2. The deproteinized liquid is evaporated in a triple effect evaporator as described under alternative 3.

Alternative 5 - Protein Recovery, Ion—Exchange and Biological Treatment

This alternative consists of the combination of the protein recovery process already described under alternative 2, an ion-exchange process which recovers potassium salts, amino acids, and organic acids (both as ammonium salts), and the biological treatment process described under alternative 1. Figure 5 shows these three sections of the process combined to form this alternative.

The protein water is first sent to the protein recovery process (4). It is necessary to remove the proteins first because they will precipitate on the ion-exchange columns if their concentration is 180 parts per million or more.

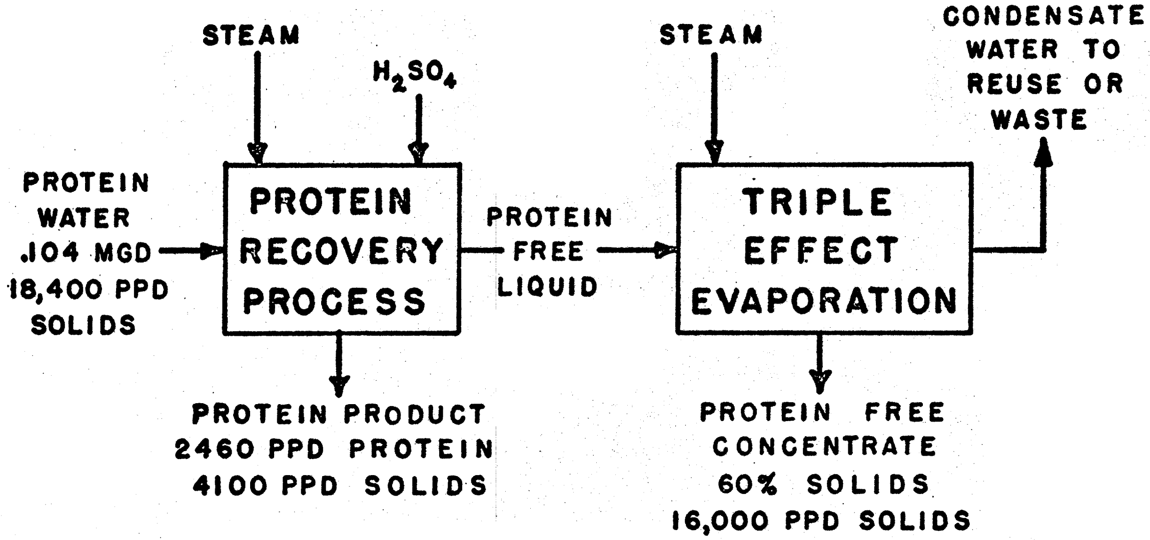

Figure 4.--Protein recovery and concentration of protein-free waste.

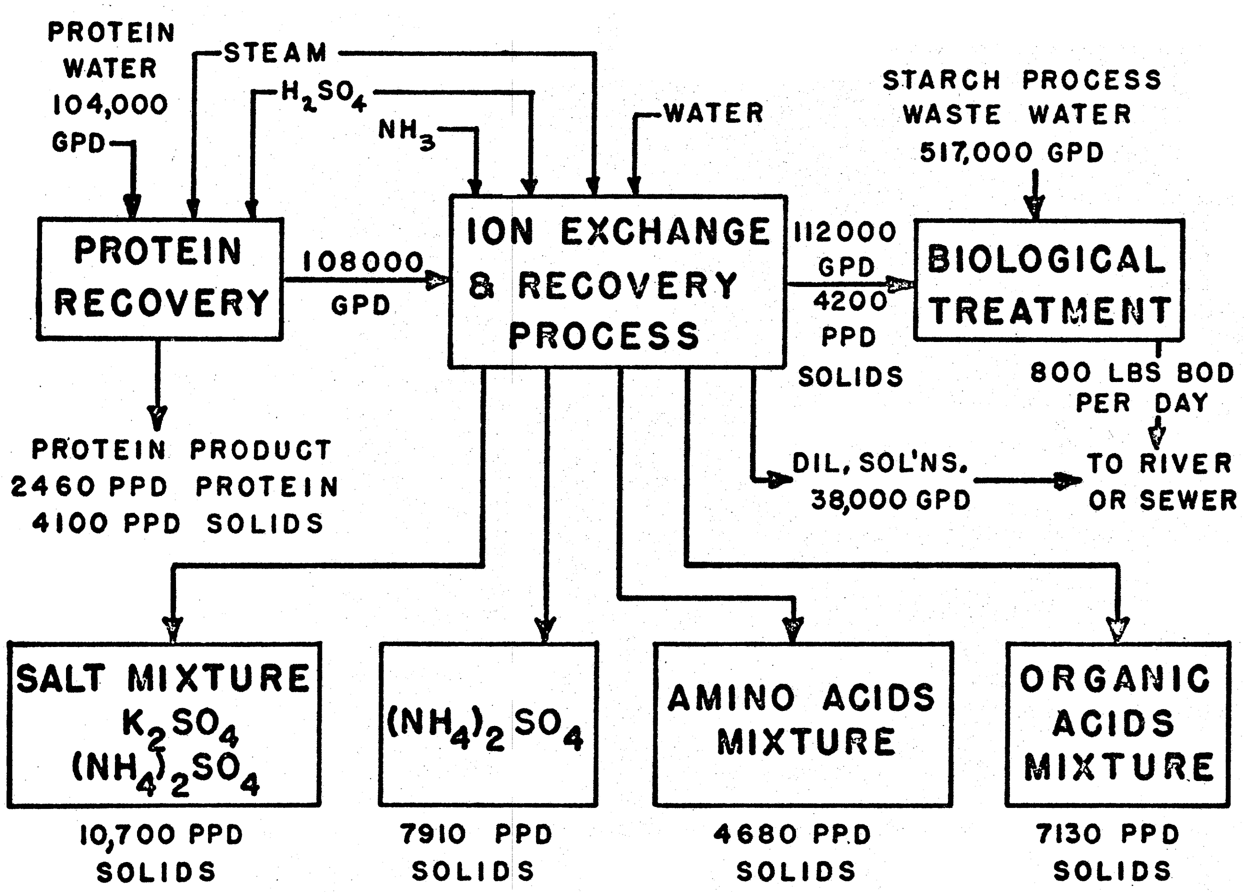

Figure 5.--Combination protein recovery, ion-exchange treatment, and biological waste treatment.

After protein removal, the waste is treated by the ion-exchange columns, which remove mainly potassium ions, amino acids, and organic acids from the waste stream (1, 2, 3). A final biological treatment removes most of the remaining dissolved solids, which are chiefly sugars.

Figures 6, 7, and 8 are schematic flow sheets showing the processing involved in the ion-exchange part of this alternative. In each of the three sets of ion-exchange columns, two columns are in series at one time performing adsorption and one column is being eluted and regenerated. Also, each byproduct solution resulting from ion-exchange is evaporated to 60-percent concentration before drum drying to 4-percent moisture. Figure 6 shows the potassium-ion removal by cation exchangers and recovery of solids by evaporation. After absorption and elution with sulfuric acid, an acidic solution is obtained which is neutralized with ammonia. The potassium and ammonium sulfate solution is evaporated and dried, yielding the mixed salt solid.

Figure 7 shows the amino acid removal from the potassium-free stream by cation exchangers. The adsorbed amino acids are eluted using ammonium hydroxide. The columns are regenerated with sulfuric acid. The amino acid and ammonium sulfate solutions are evaporated and dried. The amino acids are obtained as the ammonium salts.

Figure 8 shows the organic acid removal from the amino acid free stream by anion exchangers. The adsorbed acids are eluted using ammonium hydroxide solution. The organic acid solution is evaporated and dried to obtain the ammonium salts of the organic acids.

Costs

Capital and operating costs were calculated for each of the alternatives in order to determine which ones should receive further study.

Table 1 lists the capital costs of the alternatives in order of increasing fixed capital. Concentration of the protein water by evaporation requires the least fixed capital, with biological treatment next. Alternatives 2 and 4 are next, both requiring almost the same investment, alternative 4 being higher by about 10 percent. Alternative 5 requires an investment that is outside the range of the other four alternatives at $2,550,000.

Table 2 shows the operating costs for the alternatives, again in the order of increasing costs. The biological treatment process involves the least operating cost. Among the byproduct alternatives, concentration by evaporation incurs the least operating cost. The difference in operating cost between each consecutive alternative, as listed, is considerable, and much greater than the probable error involved in estimating the costs in this category.

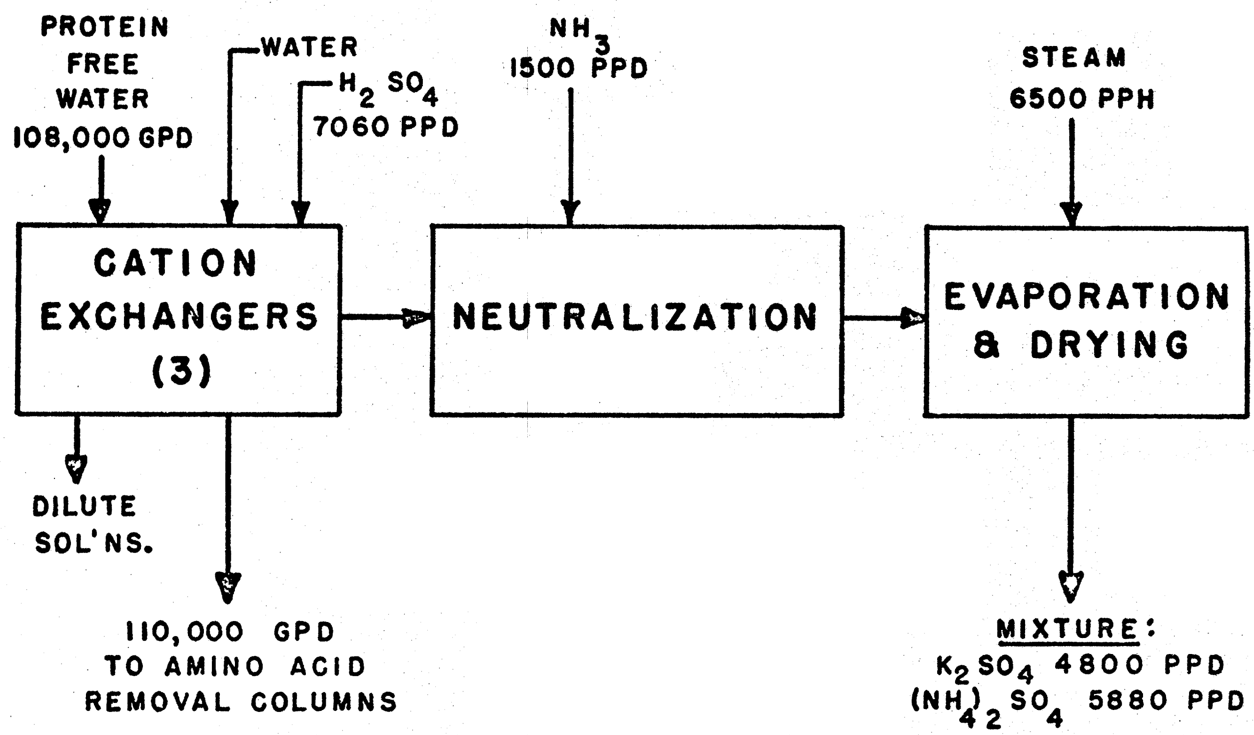

Figure 6.--Potassium ion removal and evaporation of solids.

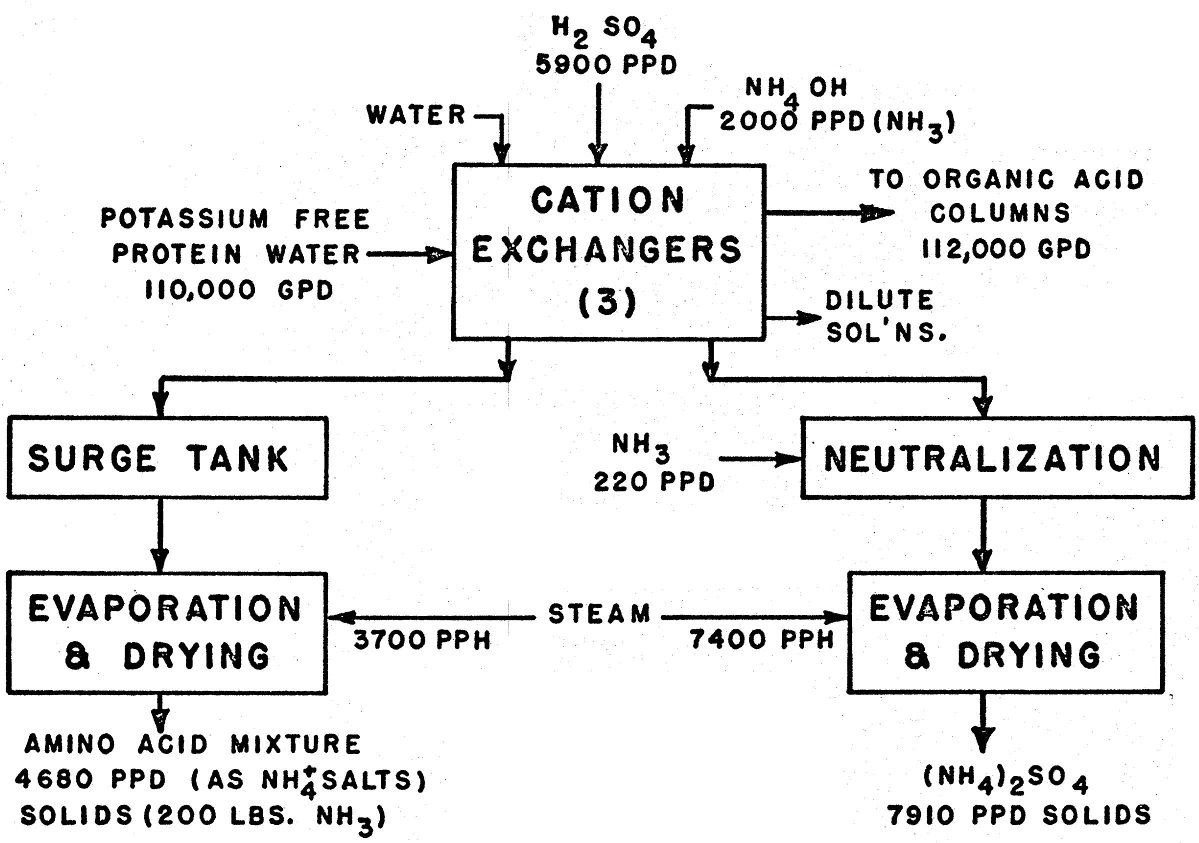

Figure 7.--Removal of amino acids by cation exchangers.

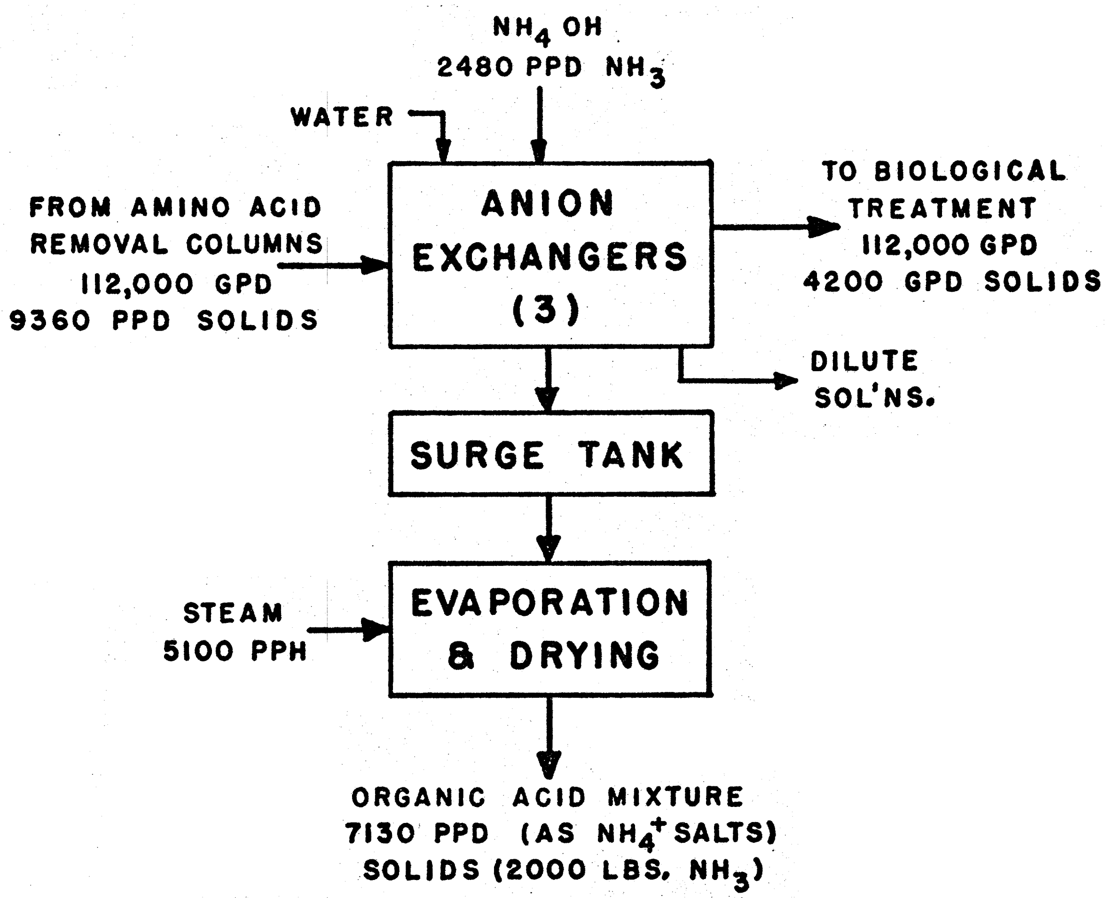

Figure 8.--Removal of organic acids by anion exchangers.

TABLE 1.--Fixed Capital Costs

Alternative No.	Alternative	Fixed capital ($)
3	Concentration by evaporation	514,000
1	Biological treatment	550,000
2	Protein recovery + biological treatment (Protein recovery = $382,000)	807,000
4	Protein recovery + concentration by evaporation	881,000
5	Protein recovery + ion-exchange + biological treatment (Biological treatment = $350,000)	2,550,000

TABLE 2.--Operating costs

Item	Alt. No. 1 Biol. treatment	Alt. No. 3 Conc. by evap.	Alt. No. 2 Prot. rec. + biol. treatment	Alt. No. 4 Prot. rec. + conc.	Alt. No. 5 Prot. rec. + ion exch. + biol. treatment
Daily					
Deprec.	238*	227**	347	383	1,538
Op. Ex.	367	764	974	1,494	3,500
Total	605	991	1,321	1,877	5,038
Yearly					
Deprec.	35,700**	34,000	52,100	57,500	230,750
Op. Ex.	55,000	114,500	146,000	224,000	525,000
Total	90,700	148,500	198,100	281,500	755,750

*Biological treatment, amortized at 7 percent for 20 years.

**Depreciation for alternatives 2, 3, 4, 5: Straight line method, bldgs. - 20 years, equipment - 15 years.

Table 3 shows the uses and estimated probable sales prices for the products obtained from the alternatives. The protein would be used for

TABLE 3.--Uses and estimated prices for products

Alt. No.	Alternative	Product	Use	Price (¢/lb.)
1	Biol. treatment	None	--	--
2	Protein rec. + biol. treatment	Protein	Feed or food	12.0
3	Conc. by evap.	Concentrate with protein	Animal feed	6.7
4	Protein rec. + conc. by evap.	A. Protein	Feed or food	12.0
		B. Concentrate without protein	Feed	5.0
5	Protein rec. + ion exch. + biol. treatment	A. Protein	Feed	12.0
		B. Amino acid mixt.	Feed or food	15.0
		C. Organic acid mixt.	Beverages	31.0
		D. K_2SO_4-$(NH_4)_2SO_4$	Fertilizer	2.2
		E. $(NH_4)_2SO_4$	Fertilizer	2.25

animal feed or possibly human food. The concentrate from the concentration-by-evaporation step is mixed with the potato pulp from the starch process, in the proportions in which they are produced, and used as cattle or poultry feed. The concentrate without protein, alternative 4, is also used as a feed additive, the price for this concentrate being lower than the concentrate with protein. The amino acid mixture could be used in feed or food. The price for this was estimated from current prices for amino acids. The organic acid mixture would be used in beverages as an acidulant. The price is considered comparable to similar acid mixtures used for this purpose.

The potassium sulfate-ammonium sulfate mixture and the ammonium sulfate salts would be used as fertilizer. The prices were estimated from current prices for these chemicals.

Table 4 shows the daily and yearly sales using the prices for the products shown in table 3. The alternatives are listed in order of decreasing sales dollars. The differences in sales between alternatives as listed is probably greater than error in estimating the sales figures. Total operating costs from table 2 are subtracted from sales to give the gross income as shown in table 5.

It should be noted that the operating expense figures do not include an allowance for a return on the investment. Therefore, Federal income taxes are not included in the operating expenses. Thus, the net income after taxes for alternative 3 would be the amount shown in table 5 reduced by an amount equal to the Federal income tax. Also, the loss shown for the other alternatives would reduce the overall Federal income tax of the company by an amount equal to the loss shown times the tax rate.

TABLE 4.--Sales

Alt. No.	Alternative	Daily ($)	Yearly ($)
5	Protein recovery + ion exchange + biological treatment	2,960	444,000
3	Concentration by evaporation	1,244	186,700
4	Protein recovery + concentration by evaporation	1,100	165,000
2	Protein recovery + biological treatment	295	44,000
1	Biological treatment	None	None

TABLE 5.--Gross income or (loss)

Alt. No.	Alternative	Daily ($)	Yearly ($)
3	Concentration by evaporation	255	38,200
1	Biological treatment	(605)*	(90,700)
4	Protein recovery + concentation by evaporation	(777)	(116,500)
2	Protein recovery + biological treatment	(1,026)	(153,800)
5	Protein recovery + ion exchange + biological treatment	(2,078)	(311,750)

*Parenthesis indicates loss.

Table 5 shows the gross income or loss for each alternative in order of decreasing income (or increasing loss). Alternative 3, Concentration by Evaporation, shows the highest gross income, by far, of all the alternatives listed. Here again, the difference between the figures is greater than error in calculating the figures shown. After the alternative of concentration by evaporation, the biological treatment process has a smaller loss than the remaining byproduct recovery processes. From table 5 it is apparent that concentration by evaporation offers the only possibility for making an income, assuming the estimated selling prices for the various byproducts are reasonably correct.

Table 6, which shows selling prices for various levels of profitability, can be used to compare the effects of different prices on the commercial feasibility of the alternative.

TABLE 6.--Selling prices for various levels of profitability

Alternative	Product	Product selling price, ¢/lb.		
		To equal biol. treatment loss	To break even	Estimated market price
1. Biol. treatment	None	--	--	--
2. Protein rec. + biol. treatment	Protein	29.1	53.7	12.0
3. Conc. by evap.	Concentrate with protein	2.07	5.3	6.7
4. Protein rec. + conc. by evap.	A. Protein	13.9	35.1	12.0
	B. Conc. without protein	5.8	6.3	5.0
5. Protein rec. + ion exch. + biol. treatment	A. Protein	30.2	37.7	12.0
	B. Amino acids	37.7	47.1	15.0
	C. Organic acids	31.0	31.0	31.0
	D. K + NH_4 salts	2.20	2.20	2.20
	E. $(NH_4)_2SO_4$	2.25	2.25	2.25

For alternative 2, the table shows that the protein must be worth almost 54 cents per pound for no loss to occur. This is greater than the estimated selling price of 12 cents per pound. This means that, at current prices for protein, the process is not commercially feasible. In contrast, alternative 3 has a break-even price lower than the estimated price of 6.7 cents per pound. Of course, any price between 5.3 cents, the break-even price, and 6.7 cents will involve no loss or some income will be earned. Thus, there is a likelihood for income for alternative 3 with current prices for feed. The nutritive value of the feed consisting of pulp mixed with protein concentrate was estimated at 20 percent above that of corn at $47 per ton. On this basis, the concentrate alone was estimated to be worth $73.50 per ton at 60-percent solids or 6.7 cents per pound of moisture-fre- solids. It is possible that a higher price could be obtained if the concentrate were fed to nonruminant animals, since the protein is of excellent quality (5).

Under alternative 5, only the prices for protein and the amino acid mixture were varied in order to obtain the additional income required for the condition of "break-even" and for the condition of "loss-equal-to-biological-treatment."

Table 6 also shows the selling prices of the products for the condition where the gross loss for the alternative would equal the loss for the biological treatment alternative. There is only one alternative shown where the estimated actual market price exceeds both the break-even price and the loss-equivalent-to-biological-treatment price, and that alternative is concentration by evaporation.

Conclusion

We have seen the results of a preliminary economic evaluation of a number of possible methods of treating the waste effluent from potato starch plants.

Conventional biological treatment of the waste water appears to have both rather high capital and operating costs.

Four of the treatment processes yield products, and revenue from the sale of these products would help offset the operating costs. Only one of these processes, however, appears economically feasible at this time--namely, concentration of the effluent by evaporation. Our laboratory is, therefore, investigating this process on the pilot plant scale. These studies will enable us to project commercial feasibility with greater confidence and also make available samples of the product for testing and evaluation. When further information on this process has been obtained, we will publicize the results.

Development of the protein recovery process on a pilot plant scale was carried out in our Engineering and Development Laboratory by E. O. Strolle. The ion-exchange processes for recovery of inorganics, amino acids, and organic acids were carried through the laboratory scale by E. G. Heisler, J. Siciliano, and J. H. Schwartz of our Plant Products Laboratory. Much of the basic data needed for process design in our economic analysis were provided by these individuals.

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