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Low Wastewater Potato Starch/ Protein Production Process

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LOW WASTEWATER POTATO STARCH/PROTEIN PRODUCTION PROCESS

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents pilot plant results on a modified potato starch production process which uses significantly less water than commercial processes. The proposed process also recovers two byproducts streams for use in animal feeds. An economic analysis shows the process to be very promising. Further information on the subject can be obtained by contacting the Food and Wood Products Branch, Industrial Environmental Research Laboratory-Cincinnati.

David G. Stephan
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ABSTRACT

While potato starch has been an item of commerce for many years, traditional processing methods have incurred large volumes of high BOD effluents. The research summarized by this report has lead to a modified process which upgrades the soluble components formerly discarded in the effluent to animal feed materials in an economical manner.

The process developed starts by grinding and sieving as in the traditional process with the exception that recycled juice rather than fresh water is used to flush the starch granules from the pulp in the sieving operation. The pulp is pressed and dried as in traditional processes. The starch is separated from the juice and refined by an "elutriation" type liquid cyclone and a basket centrifuge. Water - at the rate of one kg per four kg of input potatoes - is introduced at the basket centrifuge and flows in a countercurrent manner through the cyclone system. Excess juice is heated to precipitate the heat coagulable protein. The protein is centrifuged from the juice and spray dried; the deproteinated juice is concentrated to a molasses-like feed material by reverse osmosis and multiple effect evaporation.

The report concludes with an economic summary based on a new plant. The process is shown to be economically promising with a return of investment of 40% with an assumed starch value of $0.22/kg ($.10/lb), an assumed cull potato cost of $1.65/100 kg ($0.75/cwt), and an input rate of 455 metric tons (1×10^6 pounds) per day.

This report was submitted in fulfillment of Grant No. R-803712 by the University of Massachusetts under the sponsorship of the U. S. Environmental Protection Agency. This report covers a period from July 7, 1975 to July 6, 1978, and work was completed as of September 1, 1979.

CONTENTS

Foreword iii

Abstract iv

Figures vi

Tables vii

Acknowledgments viii

1. Introduction 1

2. Conclusions 3

3. Starch Production 4

4. Juice Processing 12

5. Economics 20

References 28

Appendix - Photographs of Pilot Scale Implementation 30

FIGURES

Number		Page
1	Initial starch/protein meal process flowchart	5
2	Starch and pulp processing flowchart	7
3	Juice processing flowchart	14
A1	Washing with perforated basket and power washer	30
A2	Grinding with Fitzmill with SO_2 addition	31
A3	Feeding of slurry with peristaltic pump	32
A4	Vibratory screen used to separate pulp from starch and juice	33
A5	Screw press used to dewater pulp prior to drying	34
A6	Flow scheme at underflow of elutriation cyclone	35
A7	Steam infusion heating of juice	36
A8	Air actuated back-pressure valve	37
A9	Spray dryer used to dry protein precipitate centrifuged from the heated juice	38
A10	Vacuum evaporator used to concentrate deproteinated juice	39

TABLES

Number		Page
1	Solids Balances and Starch Whiteness Values for Last Five Pilot Scale Runs	8
2	Expected Mass Balance for Industrial Application	11
3	Spray Dried Protein Meal Composition and Digestibility	17
4	Glycoalkaloid Concentration and Mass Balance	18
5	Product SO_2 Levels	19
6	Estimated Fixed Capital Investment for Processing 455 Metric Tons of Cull Potatoes per 20-Hour Day	21
7	Annual Costs, Income, and R.O.I.	23
8	Estimated Fixed Capital Investment Under Livestock Option	25
9	Annual Costs, Income and R.O.I. for Livestock Option . . .	26
10	R.O.I. Sensitivity to Fluctuations in Income, Major Costs and Plant Size (Non-Livestock Option)	27

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SECTION 1

INTRODUCTION

Cull potatoes (i.e., those misshapen, too large or small, or with hollow heart or other defects) have been processed into starch and pulp for many years (1-6). Typically such processing involves grinding (with sulfite addition to prevent browning) and wet sieving with added water to separate starch from pulp. The pulp is dewatered by centrifuging or pressing (sometimes with added lime which improves its dewatering properties) and then dried in a rotary or flash drier for cattle feed. The starch is refined by centrifugal or multistage liquid cyclone methods. Vacuum filtration or automatic basket centrifugation is used for final starch dewatering prior to drying, grinding and bagging.

Non-starch constituents washed from the starch granules produce large BOD loadings in the effluent stream. For example, a traditional plant processing 450 metric tons of cull potatoes per day would release daily about 4500 m^3 (1.2×10^6 gallons) of effluent containing about 18000 kg (40,000 pounds) of dissolved solids. All but one of the starch processers in the New England area using cull potatoes (as opposed to starch slurries obtained from chip or french fry operations by liquid cyclone methods) as input material have closed principally due to the prohibitively expensive costs of treating these wastes.

Closing of these plants has lead to additional problems. Cull potatoes have been dumped into landfills and gravel pits as well as back onto growers' fields (which leads to potential disease propagation). Culls have been used directly for animal feed but their availability is variable and animal production facilities are often located too distant for profitable shipping and handling. Culls have been ground and dried for animal feed but, as fuel costs have risen, this outlet has become less and less attractive. Moreover, the value of such animal feed is low compared to that obtained by processing the culls into starch and by-products.

It is difficult to place estimates on cull potato production - especially since it varies drastically from year to year. Various experts have suggested that 10% of the crop is a realistic figure. This corresponds to an annual U. S. production of well over a million metric tons.

Several groups of researchers have recently investigated recovery processes for potato protein (7-14). Heat induced coagulation has been the most intensely researched method. Dutch researchers have implemented such methods to production scale but they have not publicized particulars of their methods. Researchers at the Eastern Regional Research Laboratory (ERRL) of the USDA

have extensively investigated heat coagulation methods for upgrading processing wastes from traditional starch plants (8, 12). Meister and Thompson investigated $FeCl_3$, lime and H_3PO_4, and lime and $FeCl_3$ as well as heat coagulation methods for treatment of potato chip processing wastes (13, 14). Haight et al. (9) in work supported by this project, investigated the effects of pH, coagulation temperature, time and concentration on the dewatering properties of coagulated juice protein.

In general, the methods have shown that about a third of the crude protein in the juice can be heat coagulated into a 70% protein (d.b.) concentrate. While acidification has been shown to enhance protein precipitation, this benefit is reduced at high temperature and solids concentration levels.

Section 3 of this report discusses modifications to the traditional starch production process leading to juice production with a minimum of dilution. As discussed therein, water requirements have been reduced to about 25 kg water per 100 kg of potatoes processed as opposed to former levels as high as 1000 kg of water.

Processing of the juice to yield protein meal and a molasses like concentrate and economics of the processes are discussed in Sections 4 and 5, respectively.

SECTION 2

CONCLUSIONS

1. The elutriation liquid cyclone system developed and piloted in this project can produce starch of acceptable quality at a fresh water input of 25 kg per 100 kg of input potatoes.

2. High temperature heat coagulation can produce a 70% protein meal of high lysine content from excess juice produced by the liquid cyclone system.

3. Glycoalkaloids are not concentrated to hazardous levels in the protein meal.

4. Deproteinated juice can be concentrated by reverse osmosis and multiple effect evaporation into a molasses-like ruminant feedstuff.

5. The economics of the developed systems are sufficiently promising to warrant industrial scale interest.

SECTION 3

STARCH PRODUCTION

The flow chart shown in Figure 1 summarizes the process initially investigated to minimize water usage in starch production. As shown, washed potatoes were ground with sulfite (1000 ppm SO_2) in a hammer mill fitted with a screen with 1.6 mm (1/16 inch) holes. The slurry was dewatered in a decanting centrifuge, dried, ground, sieved through a 74 µm (200 mesh) screen to remove peel fragments, and air classified to remove fines. As an option, the cake leaving the centrifuge was slurried with tap water and recentrifuged.

The process as outlined can be thought of as a combination of 2 existing concepts. First, decanting centrifuges have been installed in a number of existing full scale operations. As pointed out by Strolle et al. (8), about 60% of the undiluted juice can thus be spun off; by adding an equal weight of water to the resulting cake and recentrifuging, about 93% of the soluble solids can be removed from the starch/pulp mixture. This mixture is then processed by traditional methods to yield pulp (animal feed) and refined starch. Strolle et al. (8) also point out that the centrifuged liquids, when combined, yield a liquid containing 3.4-4.4% solids.

The second concept utilized has been outlined by Shaw and Shuey (15). Therein, potatoes are dried, ground, sieved (to remove peel and other cellulosic materials) and air classified to remove protein containing fines from the starch. Problems with the method, however, include that the resulting starch is not sufficiently clean to compete with other starches currently being marketed and nearly all of the water initially in the potato is removed in a rather energy intensive manner; i.e., by drying rather than by pressing or centrifuging followed by reverse osmosis and/or multiple effect evaporation of the juice.

By combining the two concepts discussed above, it was anticipated that a cleaner starch would be obtained, energy efficient juice processing methods could be used, and dilute process effluents would be completely eliminated.

The process was implemented with a Pfauldler ZIL decanting centrifuge and an Alpine American 100 MZR air classifier. The cleanest starch made with the process (using 40 kg of wash water per 100 kg of potatoes) tested 1.2% protein (d.b.) and had an Agtron reflectance of 75%. (In comparison, commercial potato starch produced by conventional methods is about 95% reflectance and has only traces of protein; the starch produced by the Shaw and Shuey process (without the benefit of counter-current washing as also included in their work) tested 73-91% reflectance and 4.0% protein.

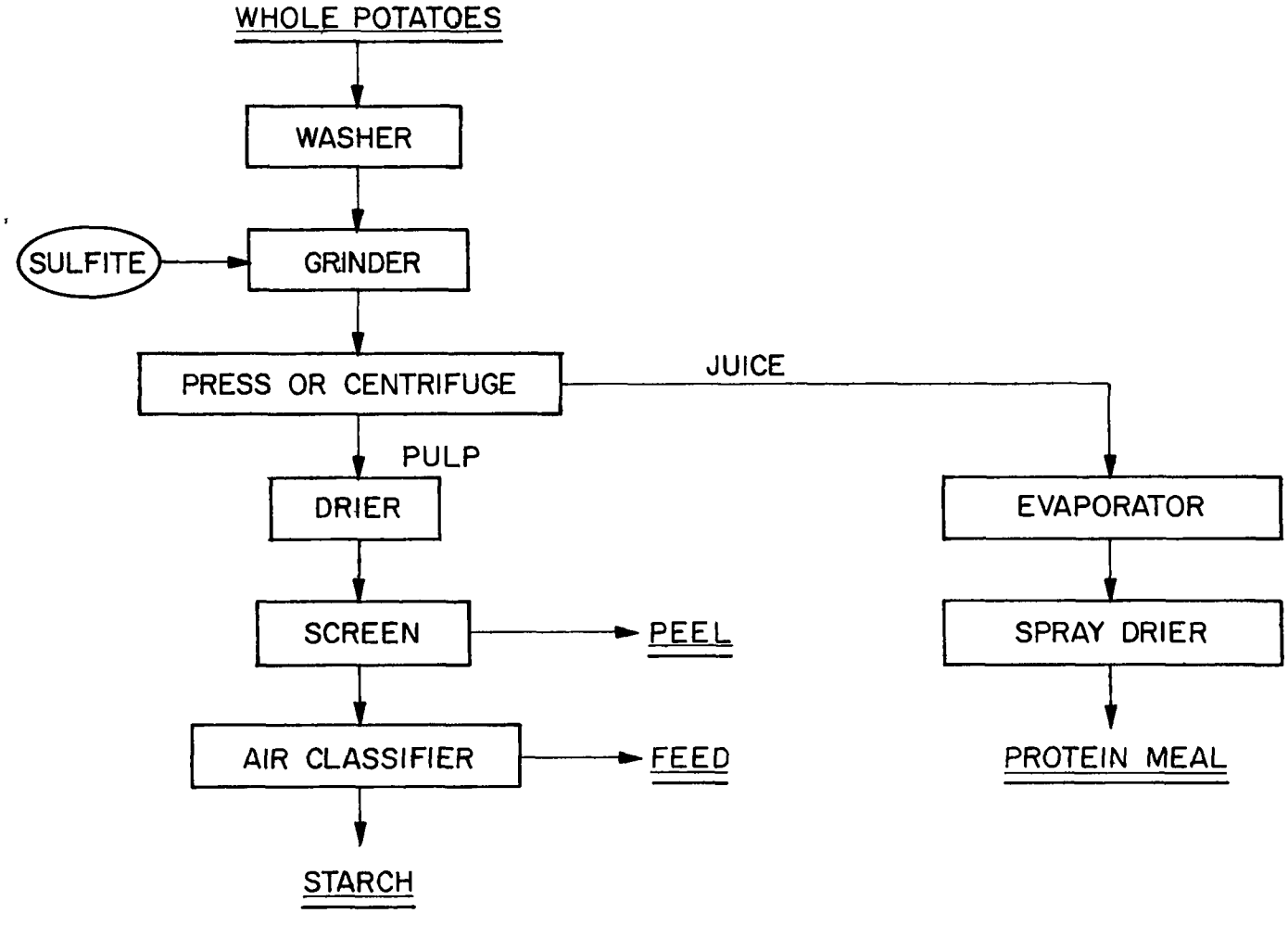

Figure 1. Initial starch/protein meal process flowchart.

Inspection of the air classified starch with a low power microscope revealed particles of pulp that were small enough to pass through the sieve with the starch but were not removed by air classification - even when preceded by an extra grinding step with an Alpine American cross flow mill adjusted to its most intensive setting. Evaluation of the starch by industrial personnel (Colby Starch Cooperative, Calibou, ME) confirmed that it would be difficult to market.

A critical review of the above results - especially in view of the ability of the traditional process to produce starch of extreme purity - combined with excellent results obtained by tangential elutriation liquid cyclone methods in the mining industry (16) led to a revised process that drastically improved starch quality, lowered wash water requirements still further and reduced capital equipment costs.

As shown in Figure 2, the revised process begins by hammer milling of the washed cull potatoes with direct addition of sulfite (see below and Section 4) to reduce browning. The slurry is then sieved, in either one or two stages, as in the traditional process. Instead of introducing water at this point to help flush the starch from the pulp, recycled juice is used. The starch/juice slurry passes through the 105 µm (140 mesh) screen(s) while the pulp passes as overflow to a dewatering press where it is dewatered to about 30% solids. It is then dried for cattle feed. It may also be fed directly without drying if a feed lot is nearby.

The starch/juice slurry is pumped to an elutriation type liquid cyclone wherein the starch is spun to the underflow while the overflow is largely recycled to the screening system. A defoaming device such as the Cornell Machine Company's (Springfield, NJ) "Versator" can be used to control foaming - a problem of major importance if frozen or especially off-grade tubers are to be processed. Silicone based defoaming agents such as Dow Corning's FG-10 are also effective but add a significant cost. The underflow from the liquid cyclone is pumped to a second liquid cyclone for thickening prior to passing to an automated basket centrifuge for final washing (with sulfited water) and dewatering. Dilute juice and wash water from the centrifuge are recycled in a counter-current fashion to the thickening cyclone and overflow therefrom is used as the elutriation flow into the primary cyclone (the design of which has been patented by the Bird Machine Company (So. Walpole, MA). Centrifuged starch (60-65% solids) would be dried in a flash dryer in commercial practice to obtain maximum whiteness. Acceptable whiteness (see Table 1) has been obtained however even with simple tray drying at 105C (220F).

The revised process was tuned and confirmed with pilot scale runs of about 500 kg (1,100 pounds). As shown in more detail by the Appendix photographs, cull potatoes obtained locally from a fresh market packer were washed by placing about 10 kg (22 pounds) of potatoes at a time in a plastic garbage can modified by cutting holes in the bottom. This was turned by hand to tumble the potatoes while spraying them with water from a 40 atm (600 psi) power washer.

It should be stated parenthetically that washing (and/or the practice of moving potatoes by fluming) does not appear to give rise to troublesome waste

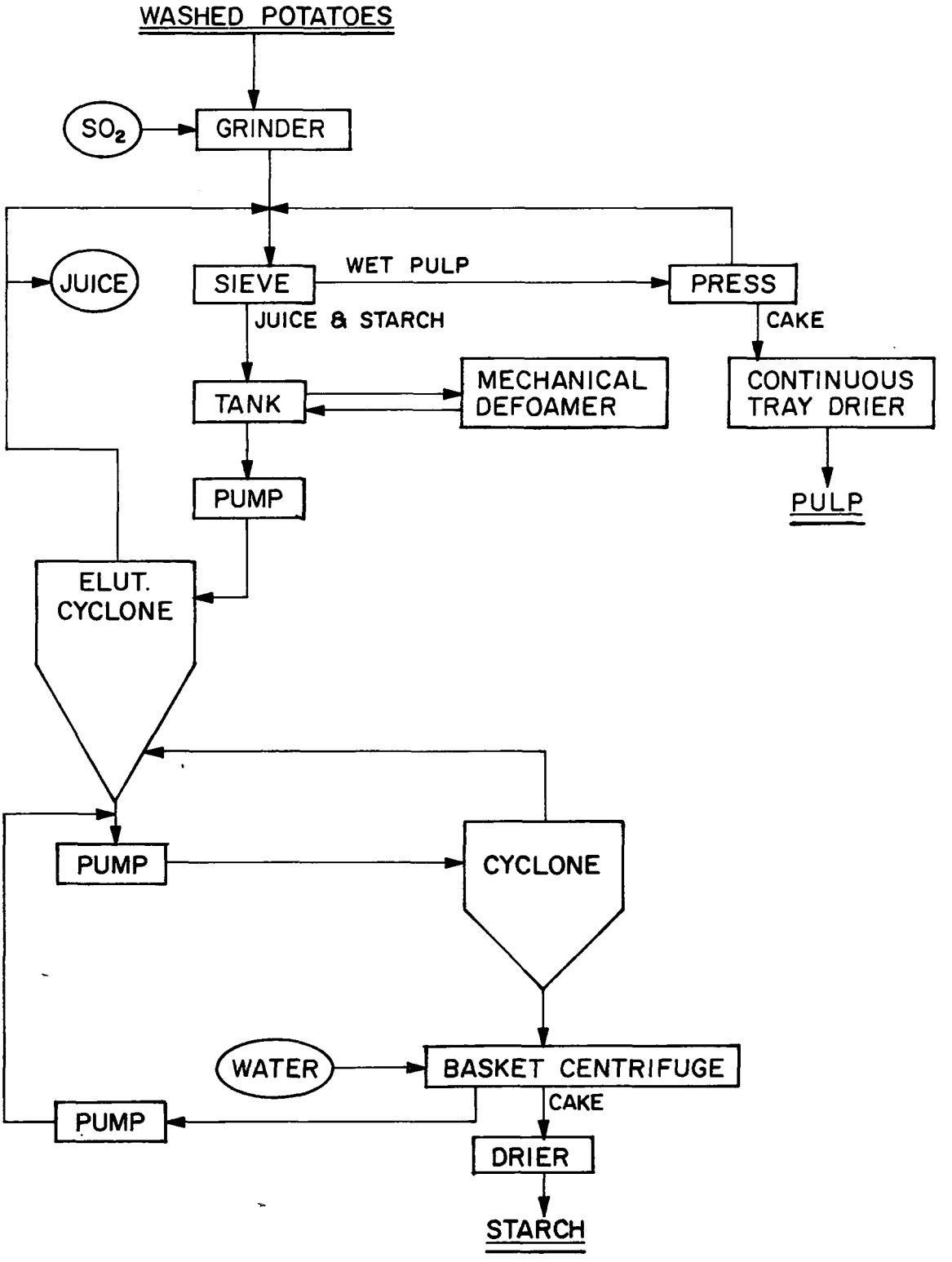

Figure 2. Starch and pulp processing flowchart

TABLE 1. SOLIDS BALANCES AND STARCH WHITENESS VALUES FOR LAST FIVE PILOT SCALE RUNS

Run	Feed (kg)	Pulp (kg)	Protein Cake[1] (kg)	Starch (kg)	Yield[2] (%)	Conc. Juice (kg)	Losses (kg)	SO_2 Level (ppm)	Reflectance (Hunter L)
F	171.2	32.5[3]	7.7	73.0[3]	71[3]	43.7	14.3	1000	91.8
G	151.5	41.6[3]	7.3	59.3[3]	67[3]	32.6	10.7	250	92.5
H	(159.5)[4]	25.9	9.1	82.9	89	35.9	5.75	0	84.0
I[5]	160.9	24.0	6.8	87.0	92	36.9	6.2	250	89.4
J[6]	173.4	27.0	7.0	78.6[7]	73[7]	37.6	23.2[7]	250	92.2[7]

1. Measured as dry weight of cake leaving the centrifuge, i.e., before spray drying.
2. Determined by estimating starch in feed as percent solids in feed less 6%.
3. Due to improperly adjusted elutriation flow rate, starch carried over into the juice. This was removed and added to the pulp stream.
4. Missing sample; solids estimated by assuming the percent solids to be the same as run G.
5. Potatoes in poor condition.
6. Potatoes in very poor condition.
7. Starch cycloned an additional time to determine effect on starch whiteness.

streams in existing commercial practice. The material removed is largely mineral in nature and settled quickly in simple dug basins, settlers, or liquid cyclones. Odor problems are not common; apparently there is sufficient aeration of the recycled water (coupled with its usual low temperature) to prevent them.

The washed potatoes were ground in a model M Fitzmill (Fitzpatrick Company, Elmhurst, IL) fitted with a screen with 1.6 mm (1/16 inch) holes. Sulfite was mixed with the potatoes by pumping a solution of sodium metabisulfite directly into the mill with a variable speed peristaltic pump.

The ground potato slurry was then pumped with another (much larger) peristaltic pump at a rate of 180 kg (400 pounds) per hour to a mixing tee where it was mixed with four volumes of recycled juice. The mixture then flowed to a 61 cm (24 inch) diameter vibrating screen (Sweco, Inc., Los Angeles, CA) which served as a single stage wet screening system. Juice and starch passed through the 105 μm (140 mesh) screen while the pulp was retained. It was observed (see Table 1) that the fraction of starch granules separated from the pulp by the screening operation was about the same as the juice fraction removed; i.e., about 90% for the 1 to 4 ratio of feed to recycle juice used. While this would imply that a two stage counter-current screening system would be expected to extract about 99% of the starch granules, a more realistic expectation would be somewhat lower than this.

The starch/juice slurry was then pumped into a 10 cm (4 inch) diameter elutriation type cyclone (Bird Machine Company, So. Walpole, MA). This size was the smallest elutriation cyclone available. As it requires an input stream of 190 liters per minute (50 gpm) a recirculation system (including a heat exchanger to prevent heat buildup) was added to match the cyclone to the pilot scale operation.

Underflow starch was pumped, along with wash water from the following basket centrifuge, into a 10 mm diameter secondary thickening cyclone (Dorr-Oliver, Inc., Stamford, CN) with an air actuated diaphragm pump (Warren Rupp Company, Mansfield, OH). An air chamber was used to dampen the pressure fluctuations of the pump. Overflow from the secondary cyclone was used as the elutriation flow of the primary cyclone. Underflow starch from the secondary cyclone was metered therefrom with a peristaltic pump to overcome flow instabilities incurred by simple throttling. The thick starch slurry was dewatered and washed in a basket centrifuge (International Equipment Company, Needham Heights, MA) and dried in a tray drier at 105C (220F).

Pulp from the vibrating screen was dewatered to about 30% moisture in a Beloit-Jones (Dalton, MA) 7.6 cm (3 inch) diameter screw press. Juice pressed from the pulp was returned to the top of the vibrating screen. The dewatered cake was dried in a tray drier at 105C (220F).

Some comment should be made toward various difficulties encountered in the tuning and confirming pilot runs. One of these involved attempts to co-dry concentrated de-proteinated juice (see Section 4) with the pulp. This was not successful for several reasons. The concentrated juice proved to be difficult to mix with the pulp (either as wet press cake or as a dried,

ground flour). The mixture dried very slowly and stuck badly to the trays. The final material was quite hygroscopic.

Another difficulty encountered was periodic blinding of the vibrating screen. This seemed to happen especially if too much juice was bled from the cyclone/sieve system allowing air to enter the cyclone causing a foamy condition in the recycle juice. Two useful preventative measures were to carefully watch the liquid level in the balance tank under the vibrating sieve and to add a nylon scrub pad to the vibratory screen which revolved with the overflow pulp.

It was anticipated that adding the ground potato slurry directly to the vibrating screen and spraying recycled juice over the pulp rotating on the screen would give the best removal of starch. This was not the case; better results were obtained by simple mixing of feed and recycle juice followed by screening of the mixture. Apparently, the pulp entraps the starch if there is too little juice present and prevents its migration to the screen surface. This is further confirmed by the observation that starch was not present in the juice separated from the pulp by the screw press.

Various attempts were made to eliminate the thickening cyclone and operate only with the elutriation cyclone. Such operation seemed unstable - either starch would back up in the cyclone to the point of appearing in the overflow juice or, upon increasing the underflow rate, too much of the juice was removed with the starch causing problems of low whiteness due to the presence of too much colloidal material not removed by the centrifugal washing step. When the secondary cyclone was used as depicted in Figure 2, problems with stability were greatly reduced. Even in this mode, however, flow settings had to be very closely monitored to prevent starch back-up or poor whiteness. Table 1 presents results of the last fine pilot scale runs and shows that even after previous experience with five tuning runs, starch overflowed the primary cyclone with the juice due to operational errors during portions of runs F and G. Some of these errors might be expected; during start-up of each run, flow rates have to be constantly adjusted. Moreover, it was not early appreciated how much the potatoes tended to segregate in the holding cans used between grinding and processing. In the last runs, the entering potato-slurry was mixed to minimize variations in the feed material. In commercial practice, density controls are available which simply adjust the underflow rate to control the starch concentration of the same.

In conclusion of this section, a few explanatory comments should be made concerning trends shown in Table 1 which includes solids balances as well as starch reflectance values of the last five pilot runs: (1) whiteness has been measured as the L value obtained with a Hunter color difference meter. In our comparisons with the reflectance values obtained with the commonly used Agtron readings, we found the Hunter to read about a percentage point lower; (2) it can be noted by comparing the first three runs that the SO_2 content of the feed and wash water (both were sulfited to the same level) can be reduced to 250 ppm without reducing whiteness; (3) runs I and J were made with potatoes in poor and very poor condition; (4) to determine the effect of an additional cyclone step on starch whiteness, the starch of run J was passed through the cyclone system a second time. In this run, the mass

balance closes poorly and the starch yield dropped substantially. While it is tempting to blame both results on the extra cyclone step, carry-over of starch into the juice was not observed. Moreover, the solids contents of the pulp, protein meal, and concentrated juice streams were not increased. The high level of losses thus remains undertermined and cannot be simply explained by the extra cyclone step.

In the juice processing system, 35% of the crude juice protein is precipitated to yield a 70% protein (d.b.) meal and the residual juice is concentrated to produce a molasses-like material (see next section). If potatoes of 19% solids are used, commercial implementation of the process should achieve the yields shown in Table 2 assuming a starch extraction efficiency of 96%.

TABLE 2. EXPECTED MASS BALANCE FOR INDUSTRIAL APPLICATION

MATERIAL	MASS (kg)	SOLIDS (%, w.b.)
Input feed	100.	19.
Output starch	15.22	82.
Output pulp	3.09	90.
Output protein meal	1.04	90.
Output conc. juice	4.31	65.

SECTION 4

JUICE PROCESSING

Various options are available for concentrating and upgrading the 3.9% solids juice produced by the starch processing system described in the previous section into animal feeds. One obvious system would include ultrafiltration to separate and concentrate a protein stream in a similar manner as is now widely used for upgrading cheese whey. Potato protein, however, like soybean protein, contains trypsin inhibitors which should be inactivated with heat. Also, the juice often contains a large microorganism load which can easily be reduced with heat. Finally, with little more heat than required for trypsin inhibitor inactivation and pasteurization, the heat coagulable protein - roughly one third of the total crude protein of the juice - can be precipitated. This protein can be centrifuged from the juice as a 20% solids material ready for spray drying. It thus seems pointless to include a superfluous ultrafiltration step.

Another system for juice processing consists of concentration without fractionation by multiple effect evaporation (with or without a reverse osmosis preconcentration step) and drying with a spray or drum dryer. The ERRL has investigated this concept at some length. The dried juice is very hygroscopic unless lime is added before the drying step. Sufficient heating again must be done to inactivate the trypsin inhibitor. Chick feeding trials performed by R. Gerry at the University of Maine have shown that inclusion of this material at levels above 6% of the diet slows growth rates.

E. O. Strolle (ERRL), in attempting to pinpoint the cause of this poor performance, has measured losses of available lysine of as high as 80% in batch evaporation at 60C. In earlier work, however, Strolle performed feeding trials with coagulated protein obtained by steam injection heating and obtained protein efficiency ratios equal to casein. This suggests that, if rapidly heated, the coagulable protein will precipitate fast enough into a form wherein Maillard browning is inhibited thus yielding protein of high lysine availability. Braverman's text on food chemistry (17) supports the idea that reaction rates are slow for insoluble materials as compared to rates for the same materials in solution. In addition, Maillard browning is reduced under dilute, acidic conditions. Thus, if the protein is separated from the juice before concentration at or below its natural pH of 6.0, lysine availability should be enhanced.

The concepts discussed above suggest that rapid heat coagulation be included in systems upgrading juice to animal feed. As pointed out in the introduction, several groups of researchers have investigated this area. The general results of these investigations show that protein is best separated by

acidification to pH 5.5 and below, heating to 100C or higher, and using as high a solids concentration as possible. Haight et al. (9) found that these same conditions enhanced the dewatering properties of the curd. They found, however, that more solids were precipitated with the curd if the pH was not reduced by acid addition. Strolle et al. (8) and Meister and Thompson's data (13) point out that the benefits of acid addition on protein precipitation are reduced by high temperature coagulation. Acid addition also make increased demands on equipment corrosion resistance - especially if a concentration step is included.

A disadvantage of high temperature coagulation systems is that they are energy intensive unless some manner of heat recovery is devised. This has been included in the flowchart of Figure 3. As shown, juice is heated to 60C (140F) by regenerative heating in a plate heat exchanger. While many industrial plate heat exchanger systems have 90% or greater heat recovery, attempts to obtain this with a rented plate heat exchanger lead to excessive fouling. By keeping the heated juice temperature at or below 60C (140F), this fouling would be eliminated. Following regenerative heating, steam is mixed with the juice to heat it further to 121C (250F) to coagulate protein and the mixture is piped to a second heat exchanger where it is cooled to 66C (151F). The heat recovered at this stage is used to heat the pulp drier. The 66C juice then is passed to a nozzle centrifuge to separate the protein precipitate. The hot protein sludge centrifuged from the juice is spray dried to give a 70% protein (d.b.) powder. The deproteinated overflow is returned to the first plate heat exchanger, cooled therein to 19C (66F), and pumped into the reverse osmosis system for concentration. If the reverse osmosis system is operated at 27 atm (400 psi), it will concentrate the juice to 10% solids. (Pilot operation at 41 atm (600 psi) concentrated the juice to 15% solids but led to apparent membrane compaction - the lower pressure should ensure a one-year membrane life.) The reverse osmosis system produces 73.8 kg of water for every 100 kg of cull potatoes processed. This can be used as wash water at the centrifugal starch washing step (25 kg per 100 kg of potatoes) and as boiler make-up water (10.6 kg per 100 kg of potatoes). Excess water (38.2 kg per 100 kg of potatoes processed) should be suitable for direct discharge as it will have been produced by passage through a highly retentive membrane. The juice is then further concentrated to 65% solids in an evaporator, thus producing a high crude protein (43% d.b.) molasses suitable for ruminant feeding. An additional 23.7 kg of water per 100 kg of cull potatoes processed is produced in this step. This water should also be suitable for direct discharge having been produced by an evaporation/condensation process. As an option, the 10% solids concentrate from the reverse osmosis step could be fed to cattle directly if the plant were located near a feedlot.

Various aspects of the pilot scale implementation of the flowchart of Figure 3 should be mentioned. In early pilot runs, a rental plate heat exchanger (American Heat Reclaiming Corporation, New York, NY) was used as a conventional regenerative heater using 121C (250F) juice to preheat the incoming cold juice prior to steam injection. The system was started using tap water and after steady state was achieved, switched to juice. While the unit operated successfully, regenerative performance declined in the course of the run and the pressure drop through the unit increased markedly. At the

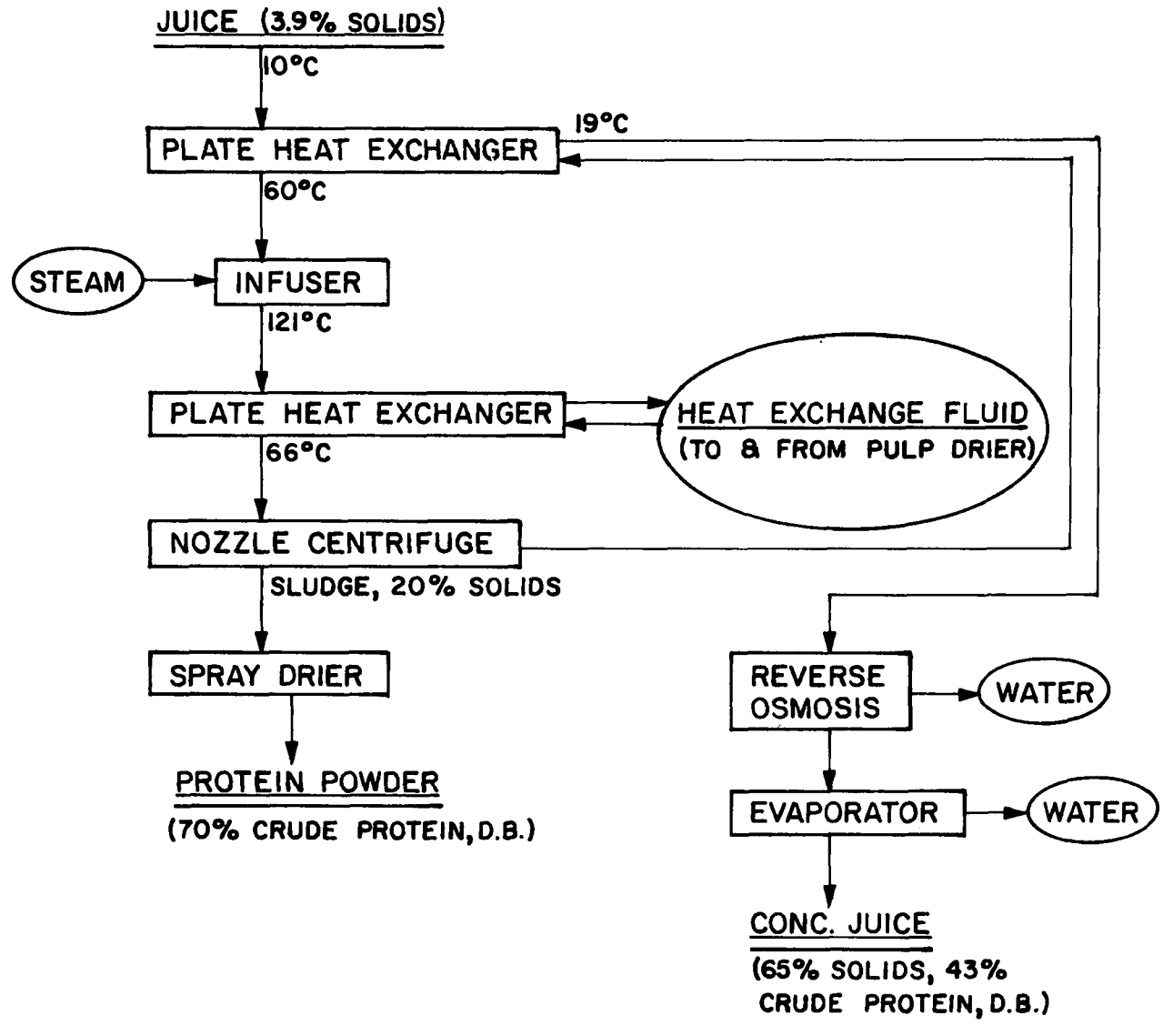

Figure 3. Juice processing flowchart

finish of the run, the plate exchanger was opened and inspected. Extreme protein fouling was noted. The turbulence generating plate configurations were not sufficient to prevent fouling. The fouling could not be removed by clean-in-place procedures but had to be laboriously cleaned manually. All of the fouling took place on the heating side of the plates. This implies that the hot juice could be used in a plate heat exchanger to heat a heat exchanger fluid which in turn could be used to heat the pulp drier. The heat required by the pulp drier is such that the hot juice would be reduced to about 66C (151F). At this point, it could be used as shown in Figure 3 to heat the incoming cold juice to 60C (140F). Under these conditions, fouling due to protein precipitation would not occur.

In light of the above, the later pilot scale tests were conducted without the plate heat exchanger using a steam infuser (Crepaco, Inc., Chicago, IL) to heat the juice directly to 121C (250F). An air actuated valve (controlled by a float in the infuser) was used to provide the necessary back pressure. The juice was allowed to flash to atmospheric pressure upon passing through the valve. While the infusion system worked well, it had to be closely adjusted and monitored to prevent sticking of the float control valve. In retrospect, it would seem that a simple, relatively inexpensive, steam injector would work as well.

Following heating, the juice was allowed to cool overnight. Most of the protein precipitate was removed with a basket centrifuge fitted with a nylon liner. Overflow juice was recentrifuged using a cream separator modified by removing the disks. The protein cake was ground in a blender - a process which completely changed its physical form from a dry cake to an easily pourable liquid without adding additional water except for a small amount used for start-up purposes. The protein cake slurry was dried in a small spray drier (Bowen Engineering, Somerville, NJ) using a rotating disk atomizer.

In the early pilot runs, the deproteinated juice was concentrated with a 3.0 m^2 (33 ft^2) reverse osmosis module fitted with a membrane rated at 97% NaCl retention (Osmonics, Inc., Minneapolis, MN). The module was operated at 41 atm (600 psi) - the highest pressure suggested by the manufacturer. In the first few runs, the flux rate varied with concentration in agreement with the manufacturer's literature for glucose solutions. Concentration was continued with the retentate returned and mixed with the feed until the solids in the juice reached 15%. The juice temperature was maintained by cooling the jacketed tank with tap water. After the first few runs, however, flux rates declined and could not be reestablished even with extensive enzymatic cleaning as suggested by the manufacturer. It is believed that simple membrane compaction is the cause of the decline in flux rates. Supporting this belief is the observation that the membrane is used commercially at 27 atm (400 psi) rather than 41 atm (600 psi). When used at this reduced pressure, the manufacturer guarantees a one-year life. At this pressure, concentration to 10% solids should be straightforward.

Following the reverse osmosis step, the retentate was further concentrated to 65% solids in a single effect evaporator (Arthur Harris, Chicago, IL). (In the last pilot runs, due to the decline in flux rate of the reverse osmosis

membrane, the unconcentrated juice was taken directly to the evaporator without preconcentrations.) Evaporation was straightforward with only a moderate tendency towards foaming.

An attempt was made to mix the molasses-like 65% solids concentrate with the pulp followed by co-drying. This was not very successful; the resulting mixture was slow drying, glassy, and hygroscopic. It seems more logical to handle dry pulp and concentrate as separate solid and liquid feed ingredients. The concentrate has remained stable with no sign of fermentation after several months of room temperature storage.

To further examine the concept that high heat coagulation should preserve lysine availability, samples of spray dried protein meal were analyzed for lipid content, crude protein content, protein digestibility and available lysine. The results are shown in Table 3. The digestibility values obtained are comparable to those usually obtained with commercial soybean meal. The levels of available lysine obtained are about the same as the total lysine of commercial soybean meal. The concept of rapid heating would thus seem to be valid. The value of such potato protein meal should be at least equal to that of soybean meal on a price per pound of protein basis.

In addition to these aspects of protein quality, possible concentration of toxic materials into one of the product streams must be considered. The principal toxic materials associated with potatoes are the glycoalkaloids solanine and chaconine. ("Solanine" is also used to denote the whole family of approximately twenty different compounds.) Dutch researchers found up to half of the glycoalkaloids associated with the heat coagulated protein. The results obtained in this work, however, do not confirm this (see Table 4). Rather, the glycoalkaloids seem to act as if they were soluble (although they are not) and can be found in the various output streams in rough proportion to their water content at the points of separation. In particular, the glycoalkaloid content of the protein meal is about the same, on a dry weight basis, as the parent potatoes. The deproteinated juice is enriched in glycoalkaloids but not so extensively as to cause problems. For example, if the pulp and molasses were blended, the mixture would contain about twice the glycoalkaloids (on a dry weight basis) as the parent potatoes. This, according to personal conversations with T. J. Fitzpatrick and S. F. Osman (ERRL) who have worked extensively with glycoalkaloids, should not cause problems in ruminant feeding especially when blended with other feedstuffs.

In addition to naturally occurring toxic substances, care must be taken to ensure that the added SO_2 in its various forms is not concentrated to hazardous levels. The reverse osmosis membranes used for deproteinated juice concentration are highly retentive toward SO_3^{--} and HSO_3^-. Moreover, no acid (which would tend to drive off SO_2 in the evaporation step) is added in the process. Thus, it is reasonable to assume that the added SO_2 appears in the output streams in proportion to their water content at the various points of separation. The results of this mass balance are shown in Table 5 wherein SO_2 contents of the product streams are given on a dry weight basis for an in-process level of 250 ppm SO_2 (w.b.) in both the ground potato slurry and the starch wash water stream.

TABLE 3. SPRAY DRIED PROTEIN MEAL COMPOSITION AND DIGESTIBILITY

Run	Lipid % d.b.	Protein[1] % d.b.	Digestibility[2] %	Available lysine[3] g/100g crude protein
F	1.9	67.8	84	6.31
G	2.1	79.7	90	6.14
H	2.9	75.1	85	6.07
I	5.0	69.9	83	6.20
K	4.1	69.2	84	6.20

1. 6.25 x Kjeldahl nitrogen.

2. As measured by Pepsin digestion, AOAC, 11th ed., Section 7.040.

3. As measured by microbial assay, AOAC, 11th ed., Section 39.128.

TABLE 4. GLYCOALKALOID CONCENTRATION AND MASS BALANCE

Run	Feed ppm,d.b.	Pulp ppm,d.b.	Pulp %[1]	Protein Meal ppm,d.b.	Protein Meal %[1]	Molasses ppm,d.b.	Molasses %[1]	Losses %[1]
G	711	411	16	230	1.6	2781	84	-2
H	-[2]	489	-[2]	449	-[2]	1493	-[2]	-[2]
I	331	353	16	457	5.9	887	61	17
J	310	425	21	209	2.7	1102	77	-1

1. Percent of total glycoalkaloids of feed.

2. Missing feed sample.

In evaluating the hazard associated with the listed SO_2 levels, it is necessary to include how the products might be used and what levels of SO_2 in the final diet are likely to cause problems. It is fortunate that rather large amounts of SO_2 can be injested without toxic effects. For example, rats have been given 750 ppm SO_2 drinking water for three generations without effect (18). In other experiments, diets including 615 ppm SO_2 had no effect on rats (18).

All of the products shown in Table 5 would be used by blending with other ingredients to the point where there should be no hazard due to high SO_2 levels. For examples, in dairy rations, molasses is commonly mixed with grain at levels up to 10%. The grain mixture forms about half of the total ration. Thus, even if the concentrated juice were used to replace molasses at its highest use level, it still would not be likely to cause toxic effects.

TABLE 5. PRODUCT SO_2 LEVELS*

Product	SO_2 Concentration (ppm,d.b.)
Starch	147
Pulp	695
Protein Meal	1070
Juice Concentrate	9450

*For SO_2 levels in the ground potato slurry and the starch wash water of 250 ppm., w.b.

SECTION 5

ECONOMICS

Implementation of the methods described in this report would most likely be performed by established potato processing companies. For such companies, the process would probably not entail construction of a new facility but be installed as an addition to existing processing equipment and buildings. The economics of such an addition are somewhat different from those of an independent operation. Nevertheless, it is useful to perform an economic analysis as if a new independent facility were to be constructed. Departures to fit existing operations can easily be made.

The analysis that follows is based on a cull potato input of 455000 kg (500 short tons) per day (20 hours) for a 200-day season. Such a plant would process roughly a tenth of the U. S. cull potato production and would appear to be the largest practicable - especially in light of recent advances in potato flour and granule processes which upgrade small potatoes to food use. On the other hand, the 69 metric tons of starch produced by the described plant is small when compared to corn starch plants in this country or potato starch plants in Europe. Another perspective of the chosen plant size is given by noting the few remaining, traditional style, starch plants in the U. S. each produces about 50 tons of starch per day. These plants are located in processing centers such as northern Maine, California, and Idaho and handle culls from several (competing) plants producing various frozen potato products. Thus, the plant discussed herein would be a replacement for such existing plants.

Estimated capital costs based on references (9-23), personal estimates, and telephone calls to selected suppliers are shown in Table 6. An M&S cost index of 520 was used (19). Table 7 shows the resulting annual costs and returns as well as the resulting return on investment (R.O.I.) of 40%.

As an option to the above, if the processing center were located near a ruminant feedlot of the equivalent of at least 2500 dairy cows (or vice versa), the pulp and concentrated juice from the reverse osmosis system could be used directly without drying or vacuum concentration. The water in the concentrate would substitute for the normal daily intake of 60 liters per animal. The concentrate would contain all the crude protein required by the animals. (The concentrate protein would not be well balanced in amino acids but ruminants do not require balanced protein.) The pulp drier and vacuum evaporator as well as some ancillary equipment would be eliminated by this option which would require trucking of 42 metric tons of wet pulp and 130 metric tons of 10% solids concentrated juice from the plant to the feedlot daily.

TABLE 6. ESTIMATED FIXED CAPITAL INVESTMENT FOR PROCESSING 455 METRIC TONS OF CULL POTATOES PER 20-HOUR DAY

ITEM	COST, $	COST, $
I. Process Equipment:		
Flume pump	5,000	
Washer pump	3,000	
Washer	20,000	
Destoner	20,000	
Mill	50,000	
Metering feeder for $Na_2S_2O_5$	4,000	
Sieve system	60,000	
Mechanical defoamer	24,700	
Press	50,000	
Pulp drier	60,000	
Pulp mill	10,000	
Pulp air conv. system	5,300	
Pulp bins (2)	10,000	
Cyclone pumps (5)	15,000	
Elut. cyclones (8)	5,600	
Thick cyclone pumps (5)	15,000	
Thick cyclones (4)	800	
Pump, centrif. to cyclones	1,000	
Basket centrif.	98,800	
Starch drier	16,800	
Starch mill	10,000	
Starch conv. system	5,500	
Starch screen	6,000	
Plate heat exchanger	20,000	
Steam injector	2,000	
Boiler (12000 lb/hr)	25,400	
Fuel tank	16,900	
Nozzle centrif.	100,000	
Spray drier	23,700	
Rev. osmosis modules	87,000	
Rev. osmosis feed pump	15,800	
Rev. osmosis cir. pumps (3)	12,000	
Evaporator	118,600	
Concentrate pumps (2)	8,000	
Concentrate tank	16,900	
Balance tanks (4)	25,200	
Protein meal bin	5,000	
Truck scale	9,500	
Total Process Equipment		983,000

(continued)

TABLE 6. (continued)

		COST, $	COST, $
II.	Installation (30% of I)		295,000
III.	Piping, Wiring, and Control Systems (40% of I and II)		511,000
IV.	Engineering and Contractors' Fees (20% of I, II, and III)		358,000
V.	Contingencies (15% of I, II, and III)		268,000
VI.	Trucks:		
	Concentrate truck	70,000	
	Protein truck	40,000	
	Pickup truck	7,000	
	Trucks Total		117,000
VII.	Land		40,000
VIII.	Buildings:		
	Office	35,000	
	Incoming storage	63,800	
	Process area	168,000	
	Warehouse	60,000	
	Buildings Total		327,000
IX.	TOTAL FIXED COSTS		2,900,000

TABLE 7. ANNUAL COSTS, INCOME, AND R.O.I.

ITEM	COST OR INCOME, $
I. Costs:	
Rev. osmosis module replacement	42,000
Direct labor (10 months, 3 shifts of 5)	185,000
Indirect labor (12 months, 1 shift of 7)	140,000
Potatoes (at $0.75/cwt.)	1,500,000
Oil ($13.40 per barrel, 75% effic.)	153,000
Electricity ($0.025 per kwhr)	28,000
Maintenance (land and buildings at 2%)	7,000
Maintenance (equipment at 6%)	152,000
Taxes and insurance (3% of fixed costs)	87,000
Depreciation on buildings (4%)	13,000
Depreciation on equipment (10%)	253,000
Interest on working capital	20,000
General plant overhead (50% of maintenance and direct labor)	172,000
Total Costs	2,750,000
II. Income:	
Starch ($0.10 per pound)	3,040,000
Pulp ($100. per ton)	309,000
Protein meal ($215. per ton)	224,000
Conc. juice ($78. per ton)	335,000
	3,910,000
III. R.O.I.: 40%	

The cost figures for this option are shown in Tables 8 and 9, and yield a 43% R.O.I. under the assumption that the feedlot would pay for the feed value of the pulp but not for that in the concentrated juice.

It can be seen from Tables 7 and 9 that the major portion of income is from starch. As shown in Table 10, departure from the assumed $0.22/kg ($0.10/pound) (18% moisture, w.b.) will have a great effect on the R.O.I. A company planning expansion into the potato starch processing area should therefore investigate carefully how the price of various unmodified starches will vary in coming years as starches from a variety of sources can be chemically modified in a number of ways to substitute for many of the traditional uses of potato starch.

On the other hand, examination of Tables 6 and 8 will also show that the largest production cost is that associated with the input cull potatoes. If significant departures from the assumed $0.0165/kg ($0.75/cwt) are made (i.e., some experts have advised that cull potatoes should (and will) be considered a waste liability rather than an asset); this too will have a large effect on the R.O.I. as shown in Table 10.

The final entry of Table 10 shows that the third most important factor (after starch and cull potato prices) on R.O.I. is plant size. This sensitivity implies that plants smaller than the assumed will not be profitable unless the value of cull potatoes changes drastically from the assumed $1.65/100 kg. ($0.75/cwt.).

To summarize, both options (livestock and non-livestock) would appear to offer an attractive (or at least acceptable) R.O.I. under the constraint of new plant construction. Actual implementation will involve more detailed data involving the local region, existing equipment and buildings, and a detailed guess at future market expectations.

TABLE 8. ESTIMATED FIXED CAPITAL INVESTMENT UNDER LIVESTOCK OPTION

	ITEM	COST, $
I.	Equipment: Same as Table 1 less pulp drier, hammer mill, conv. sys., and bins; less evaporator; use of smaller sizes of boiler and fuel tank; but with larger conc. juice tank.	772,000
II.	Installation (30% of I.)	232,000
III.	Piping, wiring, and control systems (40% of I and II)	401,000
IV.	Engineering and contractors' fees (20% of I, II and III)	281,000
V.	Contingencies (15% of I, II, and III)	211,000
VI.	Trucks: Same as Table 1	117,000
VII.	Land	40,000
VIII.	Buildings (somewhat smaller processing area than used in Table 1)	297,000
X.	TOTAL FIXED COSTS	2,350,000

TABLE 9. ANNUAL COSTS, INCOME AND R.O.I. FOR LIVESTOCK OPTION

ITEM	COST OR INCOME, $
I. Costs:	
Rev. osmosis module replacement	42,000
Direct labor (10 months, 3 shifts of 5)	185,000
Indirect labor (12 months, 1 shift of 7)	140,000
Potatoes (at $0.75 per cwt.)	1,500,000
Oil ($13.40 per barrel, 75% effic.)	66,000
Electricity ($0.025 per kwhr)	26,000
Maintenance (land and buildings at 2%)	7,000
Maintenance (equipment at 6%)	121,000
Taxes and insurance (3% of fixed costs)	71,000
Depreciation on buildings (4%)	12,000
Depreciation on equipment (10%)	201,000
Interest on working capital	20,000
General plant overhead (50% of maintenance and direct labor	156,000
Total Costs	2,550,000
II. Total Income: Same as Table 3 but less income from conc. juice	3,570,000
III. R.O.I.: 43.%	

TABLE 10. R.O.I. SENSITIVITY TO FLUCTUATIONS IN INCOME, MAJOR COSTS, AND PLANT SIZE. (NON-LIVESTOCK OPTION)

ITEM	CHANGE[1] IN R.O.I. FOR A 10% CHANGE IN LISTED ITEM (%)
Starch	10.5
Conc. juice	1.2
Pulp	1.1
Protein meal	0.8
Potatoes	-5.3
Process equipment	-1.9
Labor	-1.4
Oil	-0.5
Electricity	-0.1
Plant size[2]	3.7

[1]The change listed is the actual (as opposed to relative) change in the R.O.I. For example, a change in R.O.I. from 40% to 41% is shown as 1% rather than 2.5%.

[2]Based on equipment costs assumed proportional to capacity raised to the 0.6 power; utilities, proportional to output; and labor, constant.

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APPENDIX

PHOTOGRAPHS OF PILOT-SCALE IMPLEMENTATION

Figure A1. Washing with perforated basket and power washer.

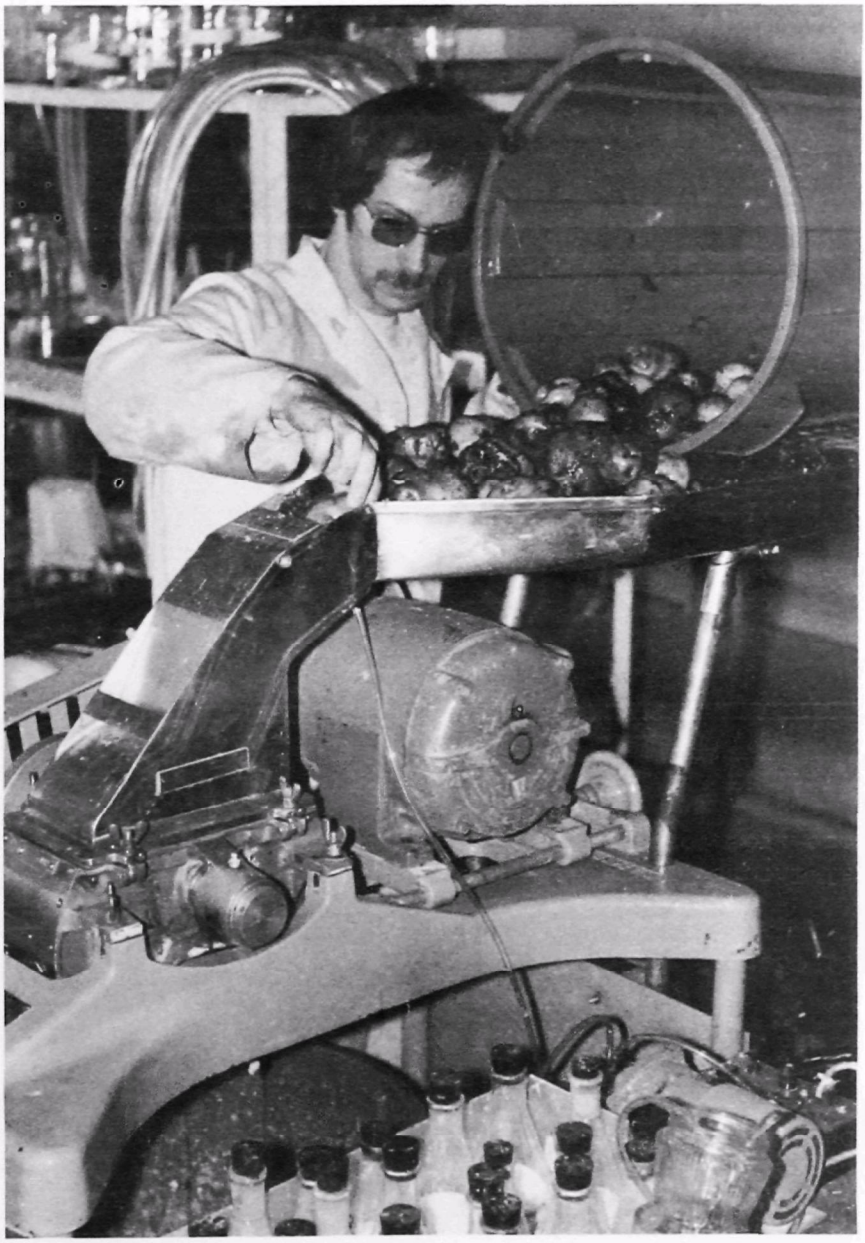

Figure A2. Grinding with Fitzmill with SO_2 addition.

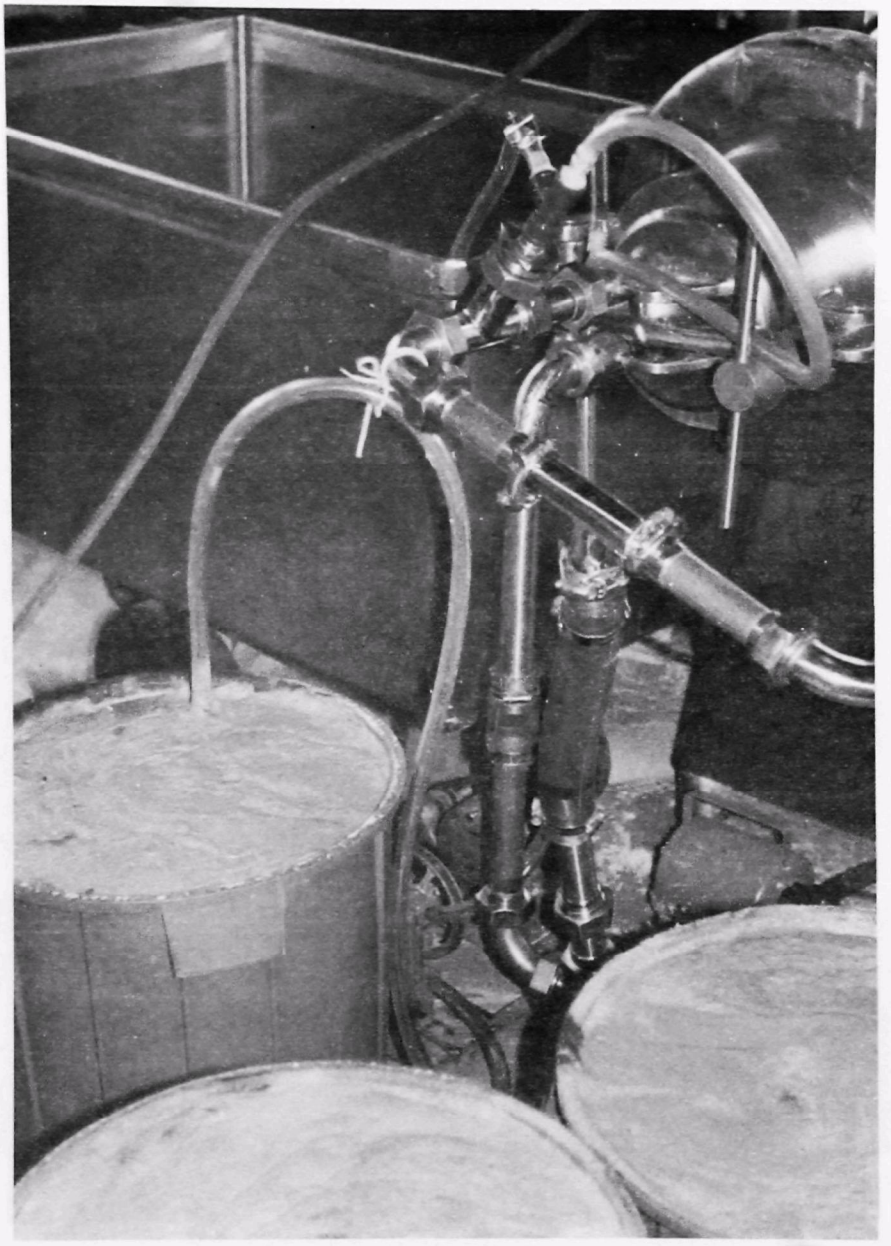

Figure A3. Feeding of slurry with peristaltic pump. Also shown is the overflow juice tank, recycle piping, and the tubular heat exchanger used to prevent temperature rise due to pumping.

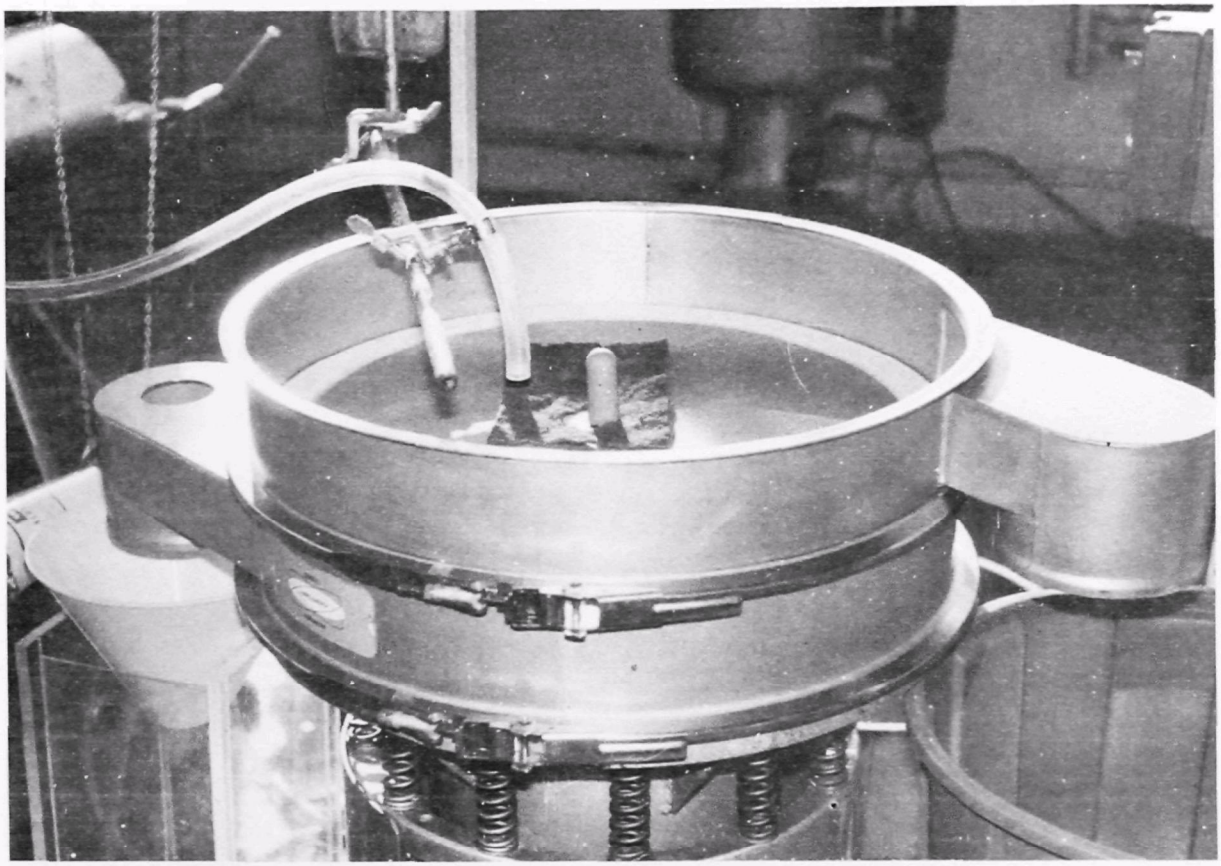

Figure A4. Vibratory screen used to separate pulp from starch and juice.

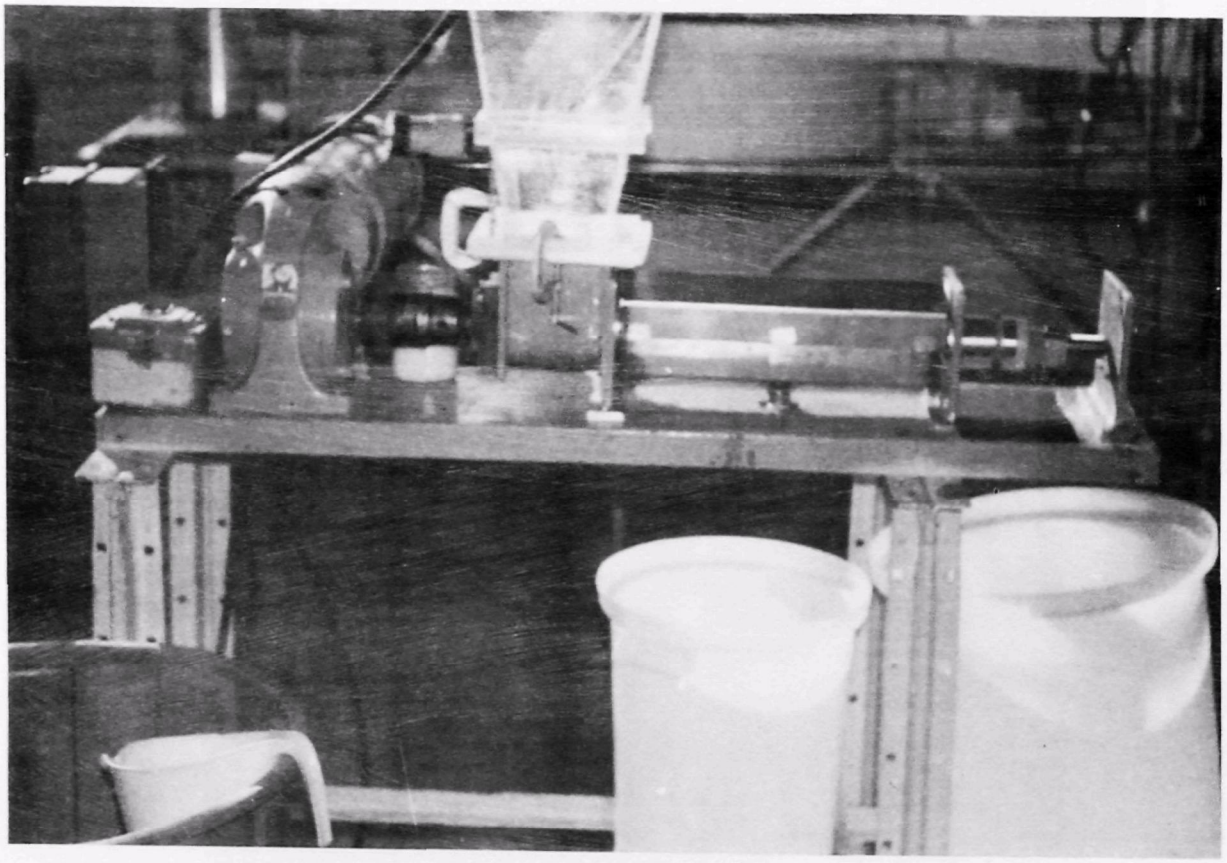

Figure A5. Screw press used to dewater pulp prior to drying.

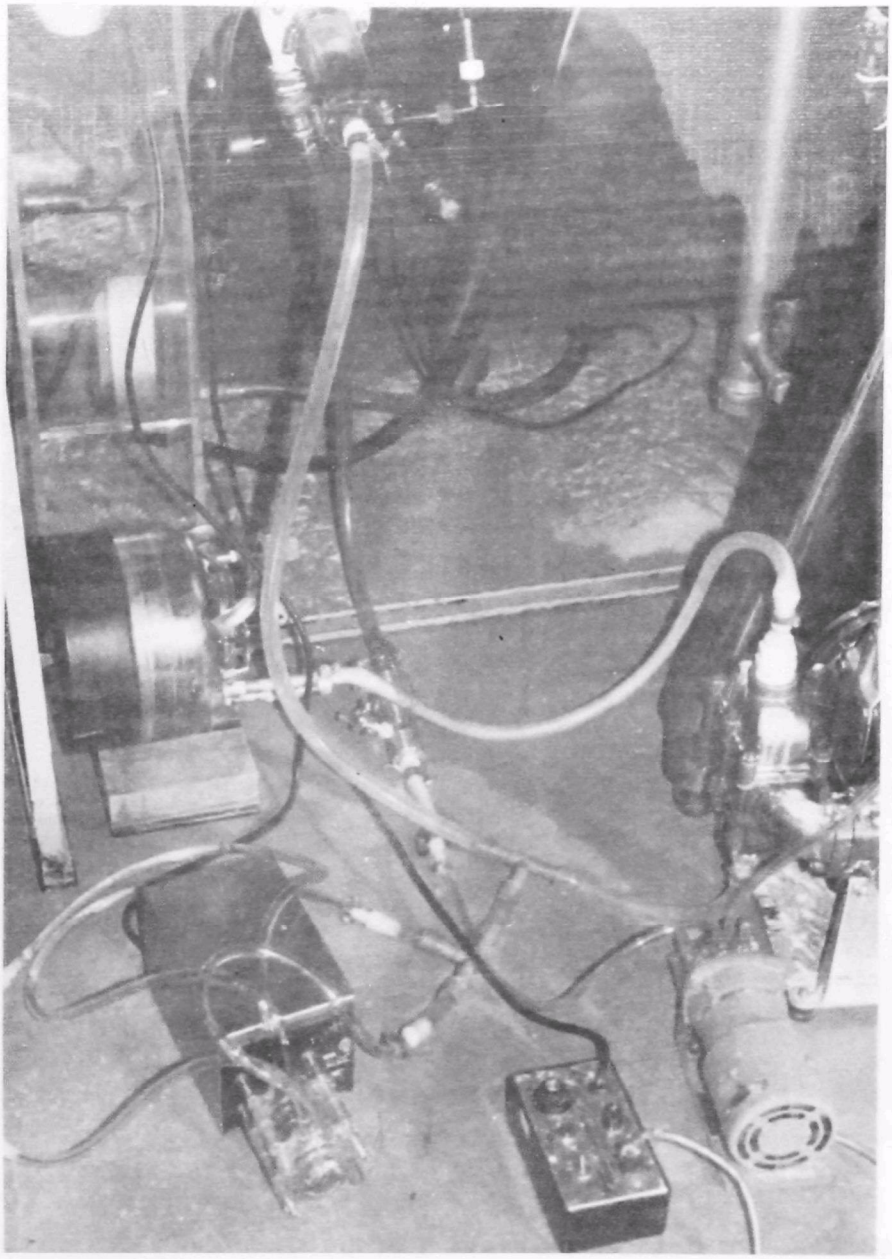

Figure A6. Flow scheme at the underflow of the elutriation cyclone. The underflow, together with wash water from the basket centrifuge, is pumped through the surge vessel into the small secondary cyclone. Overflow from the secondary cyclone provides the elutriation flow of the primary cyclone.

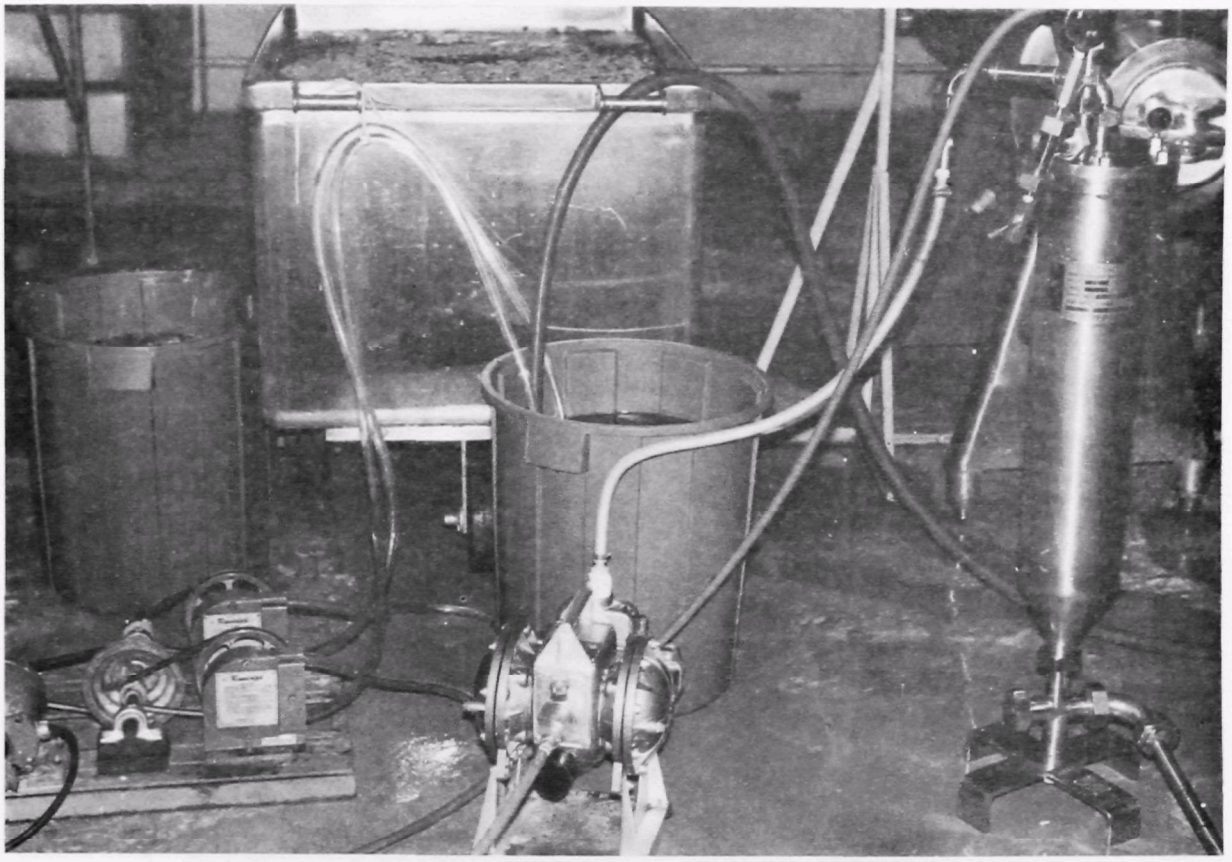

Figure A7. Steam infusion heating of juice. The juice is metered with the peristaltic pump through the diaphragm pump into the infuser shown at the right. The level of hot juice in the infuser is maintained by a float which controls the actuating air of the back-pressure valve shown in Figure A8. The hot juice leaves the infuser through the pipe at the lower right.

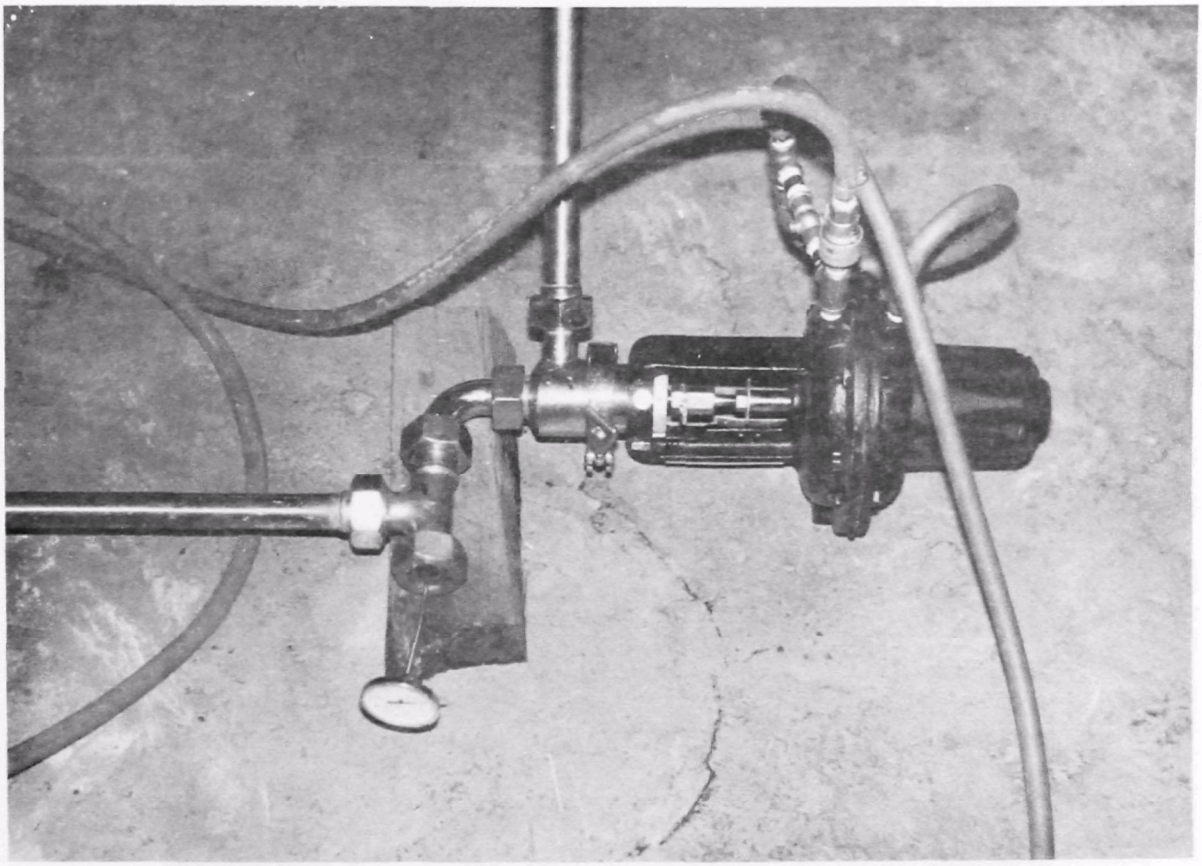

Figure A8. Air actuated back-pressure valve. The hot juice (121C) flashes to atmospheric pressure as it leaves the valve.

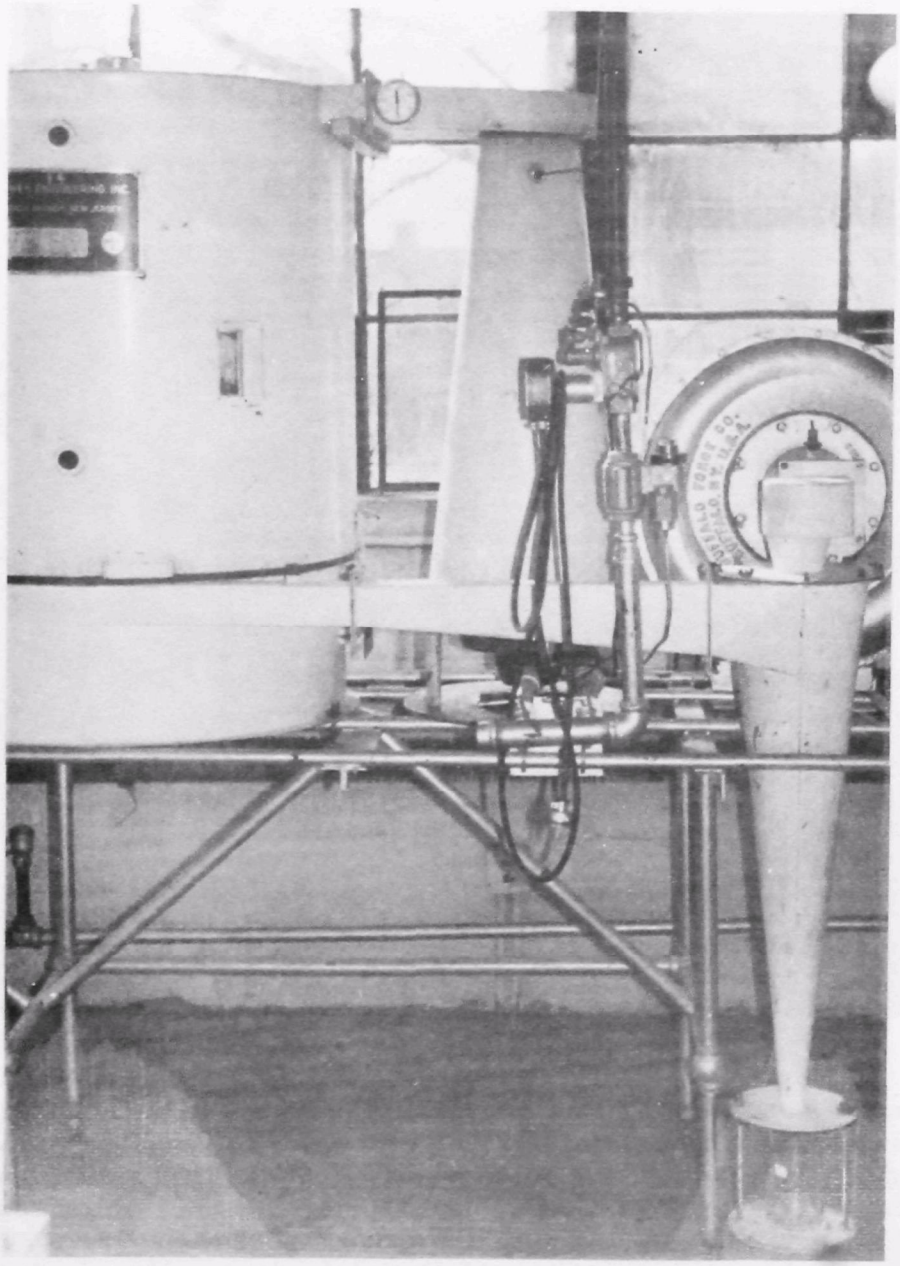

Figure A9. Spray dryer used to dry the protein precipitate centrifuged from the heated juice.

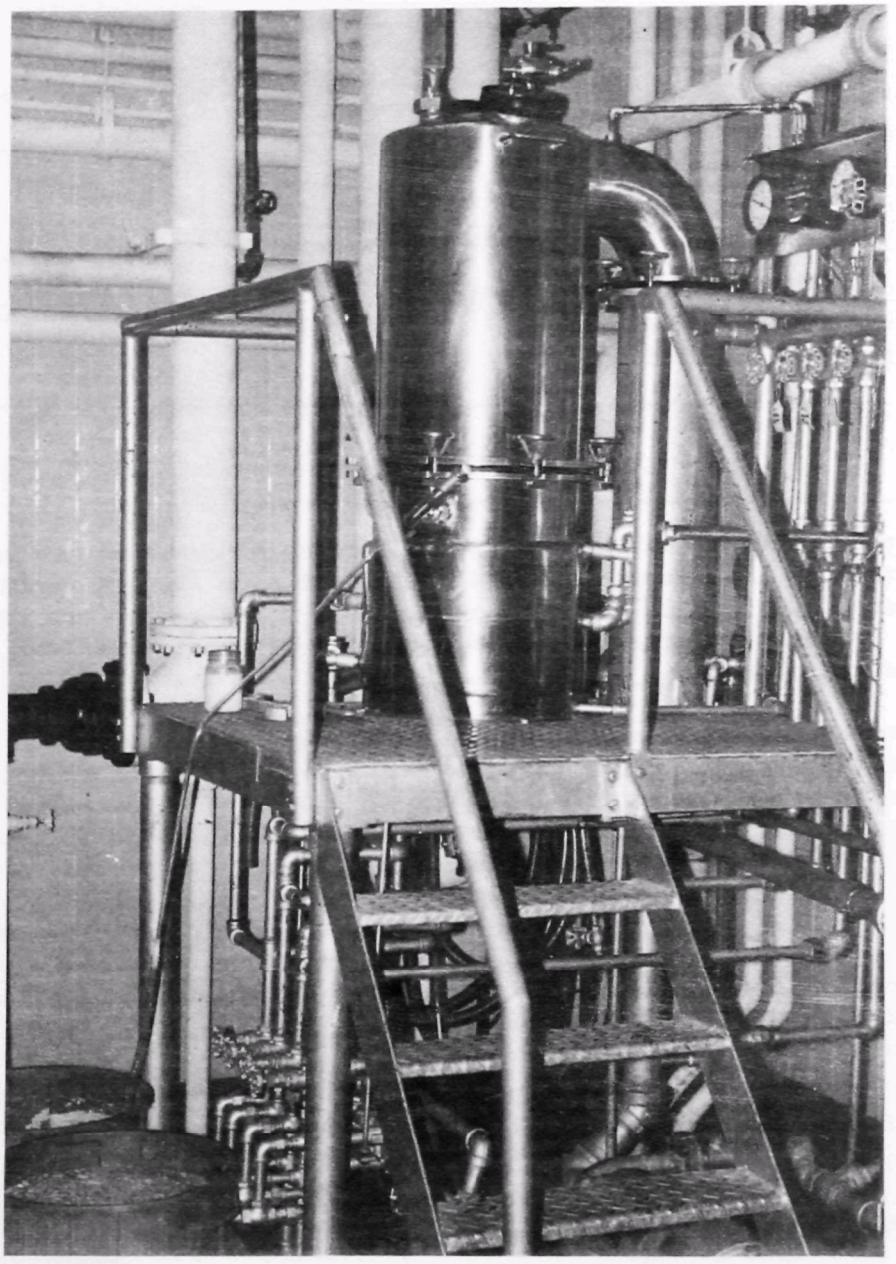

Figure A10. Vacuum evaporator used to concentrate the deproteinated juice to a 65% solids molasses-like material.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-79-208	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE LOW WASTEWATER POTATO STARCH/PROTEIN PRODUCTION PROCESS		5. REPORT DATE December 1979 issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) John R. Rosenau and Lester F. Whitney		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Food Engineering University of Massachusetts Amherst, MA 01003		10. PROGRAM ELEMENT NO. 1BB610 11. CONTRACT/GRANT NO. R-803712
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory Office of Research and Development U. S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED Technical 1975-79 14. SPONSORING AGENCY CODE EPA/600/ 12
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

While potato starch has been an item of commerce for many years, traditional processing methods have incurred large volumes of high BOD effluents. The research summarized by this report has lead to a modified process which upgrades the soluble components formerly discarded in the effluent to animal feed materials in an economical manner.

The process developed starts by grinding and sieving as in the traditional process with the exception that recycled juice rather than fresh water is used to flush the starch granules from the pulp in the sieving operation. The pulp is pressed and dried as in traditional processes. The starch is separated from the juice and refined by an "elutriation" type liquid cyclone and a basket centrifuge. Water - at the rate of one kg per four kg of input potatoes - is introduced at the basket centrifuge and flows in a counter-current manner through the cyclone system. Excess juice is heated to precipitate the heat coagulable protein. The protein is centrifuged from the juice and spray dried; the deproteinated juice is concentrated to a molasses-like feed material by reverse osmosis and multiple effect evaporation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
TUBERS, STARCH, PROCESSING, WASTES, BYPRODUCTS, PROTEINS, HYDRAULIC CYCLONES.		13H

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