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Current Practice in Potato Processing Waste Treatment

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POTATO PROCESSING WASTE TREATMENT

CURRENT PRACTICE

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

DEPARTMENT OF THE INTERIOR

by

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ABSTRACT

The continued rapid growth of the potato processing industry represents a corresponding increase in waste water volume. This paper is a discussion of potato processing, waste treatment, and current and needed research in water quality control in this production field. A brief discription is given of general characteristics of the potato and the effects and importance of cultural and environmental conditions on potato processing. General descriptions of the production processes have been included and the literature has been extensively reviewed to present current and proposed waste treatment technology. The most urgent research needs are discussed together with suggested methods for meeting these needs. This report was submitted in fulfillment of Grant Number WP-01486-01 between the Federal Water Pollution Control Administration and the University of Washington.

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SECTION 1

INTRODUCTION

The potato processing industry in the United States has experienced tremendous growth during the last decade, and future projections indicate that this trend will continue. Unfortunately, such marketable products as French fries and potato chips are not the only products of the industry. Large quantities of wastes requiring disposal are produced as well. If discharged untreated or inadequately treated to our waters, these wastes may create serious pollution problems. Milner Reservoir on the Snake River in Idaho has experienced four of the nation's largest fish kills since 1960, due principally to the combined effects of inadequately treated potato waste and curtailment of the stream flow at the dam.

The predicted future growth of the potato processing industry represents a corresponding increase in waste water volumes. Since increased waste discharges to our waters cannot be tolerated, higher and higher degrees of waste treatment will be required of the potato processing industry as well as other industries. High degrees of waste treatment with the methods available today represent large economic burdens on the industry. More efficient and less costly methods for providing such treatment must, therefore, be developed.

Industrial wastes often exhibit unique characteristics such as high or low pH which create unique treatment problems. Troublesome characteristics may be common to several types of industrial waste, and may therefore have been thoroughly investigated for purposes of waste treatment. The purpose of this report is to present waste problems of the potato processing industry together with current technology and available information. Hopefully this presentation will serve as an introduction to the field for a larger group of people involved in waste treatment research and development. By discussing the capabilities and limitations of the current and proposed technology, this material should be of value to potato processors and engineers concerned with potato waste treatment.

The report contains a brief description of the general characteristics of the potato and the effects and importance of cultural and environmental conditions. General descriptions of the different processes involved have been included also. The literature has been extensively reviewed to present the current and proposed waste treatment technology and pertinent available information. Finally, the most urgent research needs have been discussed and methods have been suggested to meet these needs.

SECTION 2

THE POTATO PROCESSING INDUSTRY - IT'S GROWTH AND WASTE PRODUCTION

The total annual potato production in the United States now is approximately 15 million tons. This represents an increase of 25 per cent since 1956. While per capita consumption of potatoes in this country has remained at about 110 pounds per year during the last decade, the fraction consumed as processed potatoes has increased rapidly. In 1956 the annual per capita consumption of processed potatoes was 23.4 pounds, more than twice that in 1949. In 1964 consumption had increased by almost 54 per cent to 36 pounds. To meet the demand for processed potatoes about 35 per cent of the total crop is now used for processing. This is an increase of 147 per cent over the tonnage processed in 1956. (Talburt and Smith 1967) (Irish Potatoes 1965, 1966).

The growth of the industry is expected to continue in the future. Results of a computer analysis of the future increase in frozen potato products are shown in Table I (Kueneman 1968). In 1965 potatoes represented more than 50 per cent of all frozen vegetables. Projections for 1976 indicate that potatoes will constitute 75 per cent of the vegetables frozen and will represent about 10 per cent of all frozen foods.

TABLE I
PROJECTED FUTURE PRODUCTION AND CONSUMPTION OF FROZEN POTATO PRODUCTS

Year	Poundage Processed (Million Pounds)	Per Capita Consumption (Pounds)
1967	1660	8.35
1968	1880	9.38
1969	2110	10.44
1970	2360	11.53
1971	2610	12.64
1972	2870	13.76
1973	3130	14.88
1974	3400	16.00
1975	3680	17.11
1976	3920	18.20

In a study of the Pacific Northwest by the U. S. Department of the Interior (1966), a potato production increase of 83 per cent was predicted during the period from 1965 to 1985. During the same period the production of frozen and dehydrated potato products is expected to increase by approximately 250 per cent.

A significant fraction of the potato is rejected as waste during processing. The amount wasted depends upon the quality of the potato as well as the particular type of process, and may vary from as low as 20 per cent to more than 50 per cent. Cooley et al. (1964) analyzed the waste streams from various types of processing plants and determined their population equivalents based on biochemical oxygen demand (BOD). The results are shown in Table II.

TABLE II
POPULATION EQUIVALENTS PER TON OF RAW POTATOES PROCESSED*

Flakes (Lye Peeling)	420
Chips (No Treatment	171
Chips (With Clarifier)	84
Flour (No Treatment)	318
Flour (With Clarifier)	110
Starch	353

*Based on 0.17 lb. of 5 day 20°C biochemical oxygen demand (BOD_5) per population equivalent.

The average population equivalent of an untreated waste stream from Table II is 315 per ton of raw potatoes processed. Thus, the average daily tonnage of potatoes processed in this country at the present creates an untreated waste load equivalent to a population of about 5.5 million people. Based on projections for frozen and dehydrated potato products, 7.4 million tons of raw potatoes will be used in these two processes alone in 1977 (Kueneman 1968). This represents an untreated waste load equivalent to a population of almost 8 million people. (In 1966, 56 per cent of all processed potatoes were used for dehydrated and frozen products.) The magnitude of waste production from potato processing is indeed immense. The fact that the industry is located primarily in Idaho, Maine, and the Red River Valley of the North concentrates the problem in three relatively small areas.

SECTION 3

THE POTATO

Historical Comments

The white potato, Solanum tuberosum, has been cultivated in the Andes as far back as 200 A.D. Potatoes were a primary source of food for the Indians of Peru; they had even developed methods of dehydration to provide supplies of food for periods between successive crops when fresh potatoes were not available.

Spanish and English explorers soon recognized the food value of the potato, and it became an important source of provisions for their ships. The explorers brought the potato back to their native countries. Records have shown that a hospital in Seville, Spain, bought potatoes as early as 1573. The potato was introduced to the other European countries, but was used as food only on a limited scale. In the early years it probably was regarded a luxury, and later was reputed to cause a number of diseases, including leprosy. Nevertheless, the potato soon was cultivated extensively.

Although wild ground nuts were used by Indians in the area of the United States, the white potato was first introduced to this country in 1621, where, as in Europe, it became a major source of food.

Today, the potato is grown in almost every important agricultural country in the world, and in many countries is still a major contributor to the average man's diet. In the United States potatoes comprise 7% of the 1488 pounds of food consumed per capita annually (Mercker 1965).

Development of the Crop Potato

During the early cultivation of the potato by the Peruvian Indians no conscious efforts were made to develop varieties with specific characteristics. Natural cross-pollination resulted in new varieties which may have attracted attention and were thus replanted. In this way a number of varieties occurred.

After the potato was introduced to Europe and North America, a number of varieties of varying popularity were cultivated. At that time potatoes usually were not grown to be sold, and quality control was not important. The crop was consumed on the farm where it was grown, with low quality varieties used as livestock feed.

The first great effort to develop varieties with specific characteristics came in the middle of the 19th Century, when the crops in both North America and Europe had been largely destroyed for several reasons. Although efforts to develop a disease resistant potato failed, a number of new varieties with high cooking quality resulted, some of which remained popular for many years.

Today potatoes are available for specific purposes and environments. Varieties with characteristics such as resistance to disease, high solids content, low reducing sugar content, and thick or thin skin have been developed. New varieties are derived mainly from cross-pollination.

Research on hybridization of haploid and diploid species is under way. If successful, diploid varieties may become available, and it may be possible to add additional characteristics to the varieties while retaining the varietal characteristics. (Talburt and Smith 1967).

General Characteristics of the Potato

Anatomy of the Tuber

A potato tuber is, morphologically, a modified stem, with its axis greatly shortened and its lateral members only weakly developed, the latter forming what are known as the "potato eyes."

The outer layer, the skin, consists of a corky periderm, the purpose of which is to resist evaporation losses and attack by fungus. In the event that the potato is cut or wounded, a wound periderm is formed which apparently is more effective in protecting the tissue than the original layer. Underlying the periderm is the cortex, a narrow layer of parenchyma tissue. Between the cortex and the pith, which forms the central core of the tuber, is the vascular area. This accounts for by far the largest part of the tuber tissue, and is high in starch content. The vascular storage parenchyma tissue is divided in two unequal parts by a discontinuous ring, called the vascular ring, consisting of large polyhedral parenchyma cells in which small islets of phloem are embedded. The pith, sometimes called the "water core", is connected to each of the eyes by lateral branches. It consists primarily of large cells, containing less starch than the cells in the vascular area and the inner part of the cortex.

The eyes show the relation of the tuber to the stem. Each eye is a leaf scar, arranged in a spiral around the tuber, with 13 eyes to each 5 turns of the helix.

Composition of the Potato

An accurate description of the composition of the potato is not possible because of the great variety of potatoes, the area of growth, cultural practices, maturity at harvest, subsequent storage history and other factors. Talburt and Smith (1967) presented the following tables, based on values given by various reviewers.

TABLE III
PROXIMATE ANALYSIS OF WHITE POTATOES

	Average Percent	Range Percent
Water	77.5	63.2 - 86.9
Total Solids	22.5	13.1 - 36.8
Protein	2.0	0.7 - 4.6
Fat	0.1	0.02 - 0.96
Carbohydrate		
Total	19.4	13.3 - 30.53
Crude Fiber	0.6	0.17 - 3.48
Ash	1.0	0.44 - 1.9

TABLE IV
MINERAL CONTENT OF POTATO ASH

	Average Percent	Range Percent
K_2O	56	43.95 - 73.61
P_2O_5	15	6.83 - 27.14
SO_3	6	0.44 - 10.69
MgO	4	1.32 - 13.58
Ma_2O	3	0.07 - 16.93
CaO	1.5	0.42 - 8.19
SiO_2	1	0.16 - 8.11

Starch - Starch is, calorically, the most important nutritional component of the potato. The starch content, comprising about 65 to 80 percent of the dry weight of the tuber, influences quality parameters of processed products as well as operational conditions of the processes.

Starch is present in the raw potato as microscopic granules in cells of the parenchyma tissue, especially in the vascular area. It has been found that starch content is closely correlated to specific gravity, and an equation has been derived for the percentage starch based upon specific gravity. Other factors affecting the starch content are fertilization, cultural conditions, disease, morphology, and internal distribution.

Sugars - The sugar content of potatoes may vary from trace amounts to ten percent of the dry weight of the tuber. Different potato varieties have different sugar contents when harvested, but sugars will easily accumulate after harvesting. Factors affecting the accumulation of sugars include variety, storage temperature, maturity when harvested, and different kinds of treatment during storage.

Potatoes with a high sugar content taste sweet and have poor texture after cooking. Coloration of potato products, such as French fries, potato chips, and dehydrated potatoes is closely correlated with the content of reducing sugar in the raw potato. This results from the non-enzymatic browning reaction between the aldehyde groups of the reducing sugars and the free amino groups of the amino acids. Generally, potatoes with a reducing content above 2 percent are not considered acceptable for processing.

Variations in Types of Potatoes

As mentioned earlier, a wide variety of potatoes is available. Throughout Europe, 700 varieties are listed; 300 of these are suitable for industrial processing (Wiertsema 1968). The varieties in the United States also are numerous. Many of the species are of little or no importance, and the majority of the crop consists of a dozen varieties. Also, new varieties are developed continuously while others are being discontinued.

Talburt and Smith (1967) presented a general description of the older varieties which are still popular and the newer varieties which contribute to most of the present production (Tables V, VI, and VII).

Cultural and Environmental Conditions

The quality of potatoes, as well as the yield, is to a great extent determined by the cultural and environmental conditions during the growth period. Factors of influence include (1) date of planting, (2) soil type, (3) soil reaction, (4) soil moisture, (5) season, (6) location, (7) mineral nutrition of the plant, (8) cultivation and weed control, (9) spray program for control of insects and diseases, (10) temperature during the growing season, (11) time and method of vine killing and (12) time of harvest.

Since different varieties are affected to different degrees by the above mentioned factors, the choice of variety is of course very important.

Date of Planting

This factor is related to the specific gravity, or solids content, of the potato. Early planting generally means a longer growing season, resulting in a potato of greater maturity and with higher solids content at harvest than potatoes from later plantings.

Soil Type

The soil type in which potatoes are grown also may affect solids content. Characteristics of the soil such as water holding capacity, drainage, aeration, structure, temperature and fertility all may affect the dry weight of the potato. Also, they may balance each other in effect so that no change occurs. Obviously the possibilities are many. It has been stated that loam soils generally produce the highest specific gravity tubers. Probably, this is because loam soils have more nearly optimal moisture, temperature, and structural relationships for potato production than the lighter or heavier structured soils. (Talburt and Smith 1967).

Soil Reaction

Little research has been reported on the effect of pH on potato production. Smith (1937) found that potatoes grown under slightly acid conditions had higher specific gravity than tubers from neutral or slightly alkaline soils.

TABLE V

DESCRIPTION OF VARIETIES*

Variety	Year Released	Originating Agency	Maturity[1]	Tuber Shape	Depth of Eye[2]	Skin Color	Specific Gravity	Disease Resistance	Processing Rating
Bounty	1959	Nebraska	M-L	Round	M	Red	Medium		Fair
Cherokee	1951	Iowa, Indiana and Dept. of Agr.[3]	M-E	Round	M	White	High	Late blight, scab, net necrosis	Good
Chippewa	1933	Dept. of Agriculture[3]	M	Elliptical	S	White	Low	Mild mosaic	Poor
Early Gem	1953	Dept. of Agr.[3] Idaho & North Dakota	E	Long elliptical	S	Russet	Low	Scab	Poor
Haig	1957	Nebraska	E	Round	M	White-scaly, russet	High	Scab	Good
Irish Cobbler	...	Unknown	E	Round with blunt ends	D	White	High	Mild mosaic	Good
Katahdin	1932	Dept. of Agriculture[3]	M-L	Round	S	White	Medium	Mild mosaic, net necrosis	Good
Kennebec	1948	Dept. of Agriculture[3]	L	Elliptical	S	White	High	Late blight, net necrosis	Excellent
LaRouge	1962	Louisiana	M	Oval	D	Red	Low	Scab	Poor
Norgold Russet	1964	North Dakota	E	Oblong	S	Russet	High	Scab	Good
Norland	1958	North Dakota	E	Medium, oblong	S	Red	Low	Scab	Fair
Onaway	1961	Michigan and Dept. of Agriculture[3]	E	Cubicle	M	White	Low	Scab and late blight	Poor
Pungo	1950	Virginia and Dept. of Agriculture[3]	E	Elliptical, round	M	White	High	Late blight	Fair
Red LaSoda	1954	Louisiana	M-E	Round-oblong	M	Red	Low	....	Poor
Red McClure	...	....	L	Round	S	Red	Medium	....	Fair
Red Pontiac	1938	Dept. of Agr.[3] Michigan	M	Round, oblong	M	Red	Medium	Net necrosis	Poor
Russet Burbank	...	Unknown	L	Cylindrical	S	Russet	High	Scab	Excellent
Russet Rural	1903	Michigan	L	Oval, flattened	S	Russet	High	Scab	Fair
Russet Sebago	...	Wisconsin	L	Round, elliptical	S	Russet	Medium	Scab, field resistance to late blight	Fair
Sebago	1938	Dept. of Agr.[3]	L	Round, elliptical	S	White	Medium	Field resistance to late blight	Fair
Superior	1961	Wisconsin	M	Oval to long	M	White	High	Scab	Good
Viking	1963	North Dakota	M	Oblong-round	S	Red	High	Scab	Fair
White Rose	1893(?)	Private	M-L	Long-elliptical	M	White	Low	....	Poor

[1]E-early; M-medium; L-late.

[2]S-shallow; M-medium; D-deep.

[3]U.S. Dept. of Agr.

*Talburt and Smith, 1967.

TABLE VI

RANKING OF THE IMPORTANT POTATO VARIETIES IN U.S. 1955 TO 1965 ARRANGED IN ORDER OF POPULARITY IN 1965

	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
Russet Burbank.......	2	2	2	2	2	2	2	2	2	2	1
Katahdin.............	1	1	1	1	1	1	1	1	1	1	2
Kennebec.............	6	6	5	5	5	4	3	3	3	3	3
Red Pontiac..........	3	3	3	3	3	3	4	4	4	4	4
Norgold Russet.......										10	5
Irish Cobbler........	4	4	4	4	4	5	5	5	6	5	6
Norland..............				20	10	9	8	8	8	7	7
Red LaSoda...........	21	15	8	8	8	8	7	7	5	6	8
White Rose...........	5	5	6	6	6	6	6	6	7	8	9
Chippewa.............	7	7	7	7	7	7	9	9	9	12	10

TABLE VII

YIELD IN HUNDRED WEIGHTS PER ACRE AND SPECIFIC GRAVITY OF POTATOES GROWN IN OVER-STATE VARIETY TRIALS IN MICHIGAN IN 1956[1]

	Ingham Co.		Missaukee Co.		Presque Isle Co.		Bay Co.		Montcalm Co.		Delta Co.	
Variety	Yield	Sp. Gr.	Yield	Sp. Gr.	Yield	Sp. Gr.	Yield	Sp. Gr.	Yield	Sp. Gr.	Yield	Sp. Gr.
Merrimack...........	347	1.083	234	1.082	212	1.086	131	1.077	254	1.090	373	1.082
Delus...............	365	1.084	273	1.081	221	1.082	195	1.080	315	1.078	405	1.075
Saco................	495	1.082	348	1.082	303	1.084	237	1.067	394	1.084	505	1.076
Cherokee............	294	1.075	279	1.077	200	1.075	83	1.067	245	1.075	301	1.076
Kennebec............	413	1.072	252	1.073	201	1.073	173	1.066	287	1.073	374	1.074
Katahdin............	382	1.074	245	1.073	226	1.075	146	1.063	319	1.075	328	1.072
Irish Cobbler.......	348	1.072	257	1.074	174	1.072	126	1.064	294	1.075	317	1.072
Tawa................	265	1.068	218	1.072	176	1.071	111	1.065	251	1.074	297	1.073
Sebago..............	257	1.070	191	1.071	176	1.072	135	1.065	187	1.075	306	1.070
Boone...............	277	1.072	223	1.073	196	1.071	60	1.063	180	1.068	308	1.067
Red Beauty..........	258	1.068	190	1.065	139	1.065	139	1.062	246	1.081	321	1.075
Antigo..............	368	1.070	212	1.069	142	1.066	157	1.060	296	1.072	296	1.073
Red LaSoda..........	508	1.068	299	1.068	268	1.068	219	1.059	334	1.069	503	1.071
Onaway..............	369	1.067	270	1.068	199	1.065	150	1.064	312	1.068	350	1.070

[1]Courtesy of D. R. Isleib.

Soil Moisture

The effect of soil moisture on yield and solids content of potatoes is a fairly complex matter. In arid regions irrigation is necessary, while in other areas rainfall may suffice. The amount of water applied and the time and schedule of application are important factors. Temperature is another important variable.

Ample soil moisture may result in high yield of potatoes with low specific gravity. Uniform soil moisture during the growing season together with the withholding of irrigation prior to harvest has produced potatoes with high specific gravity. Excessive rainfall or irrigation late in the season results in crops with low specific gravity.

High moisture content tends to keep the soil temperature cool and stable, thereby reducing loss by respiration. High moisture content may thus prove advantageous in high temperature growing areas.

Season

Yield and solids content of the same varieties may differ considerably from season to season in the same area because of differences in soil moisture, temperature, and other environmental conditions.

Location

Solids content and reducing sugar content are greatly dependent upon location, due to differences in environmental conditions. In Sweden a study was made on the quality of potatoes grown at different latitudes (Carlson 1968A). It was clearly demonstrated that because of the difference in temperature and length of growing season, the yield and solids content were highest and reducing sugar content lowest for potatoes from the southernmost locations.

Cultivation and Weed Control

Cultivation methods affect primarily the moisture content of the soil, and thus will have the effects discussed previously. Respiration of water from leaves of weeds may reduce the moisture content of the soil rapidly, and destruction of the weeds when they are small may be important for retaining sufficient moisture in the soil. A common weed control chemical is 2, 4 - D, which has been reported to reduce yield as well as increase it. Increase in specific gravity has been reported to result from 2, 4 - D application. (Talburt and Smith 1967.)

Mineral Nutrients of the Plants

Several workers have reported that as the fertility of the soil increases, the specific gravity of the potato decreases. Nitrogen may increase the yield of potatoes but be detrimental to the quality for processing. It has been found that starch and solids content decrease with increasing application of nitrogen. The application of phosphorous has provided little or no increase in starch and solids content. Potassium, as muriate of potash (KCl), the most widely used form, reduces the solids content of potatoes when heavily applied. This is thought to result from the chloride ion rather than the potassium ion. The sulphate form of potash usually gives higher starch and solids content than the equivalent quantity of the chloride form. Magnesium often is not present in sufficient quantities to give a high yield of potatoes, especially in acid soils. Addition of magnesium have been found to increase the yield as well as the starch content of the tubers. (Talburt and Smith 1967.)

Spray Program for Control of Insects and Diseases

Spraying to control insects and diseases is necessary in almost all potato growing areas, to prevent early death of the plant, reduced yield, and poor quality. DDT is the most common insecticide used in the United States. Because of its excellent control of insects, the plants continue to grow, and do not die or mature naturally, but are killed by frost or by mechanical or chemical means. This results in poorer chemical composition of the potato for processing. Specific gravity is lowered and reducing sugar content increased.

Temperature During Growing Season

The effect of temperature has been mentioned earlier. It determines to a great extent the length of the growing season and thus the maturity and specific gravity at harvest.

Time and Method of Vine Killing

As mentioned earlier, because of insect control the potatoes continue to grow, and it often is necessary to kill the vines by mechanical or chemical methods. When the plant is left to die naturally, food in the form of sugar is transferred from the stem to the tuber, where it is converted to starch, resulting in higher specific gravity. Artificial vine killing methods give little opportunity for transfer of food, and thus a lower quality potato results. Studies have indicated that slow vine killing, i.e. by chemical means, provides better quality potatoes. Late killing appears more feasible than early killing. Other studies indicate that variations in quality during storage are different for mechanically killed plants and chemically killed plants. (Gustafson 1968).

Time of Harvest

Mature tubers are superior in quality and yield to immature tubers, and quality of processed products is improved when mature tubers are used. Therefore, harvest should be as late in the season as possible without subjecting the potatoes to low temperatures. Potatoes used for processing should not be exposed to temperatures below 40°F.

SECTION 4

THE PROCESSES

General Requirements on Raw Potatoes

High quality raw potatoes are important to the processor. Potato quality affects not only the final product, but also the amount of waste produced. Generally, potatoes with high solids content, low reducing sugar content, thin peel, and of uniform shape and size are desirable for processing. Cull potatoes sometimes are sorted for starch and flour production, but more often low quality potatoes must be wasted and thereby represent a loss to the processor.

Handling and Storage

As mentioned earlier, potato quality is dependent upon cultural and environmental conditions. Handling and storage of the crop by the grower and the processor also affect the quality to a great extent. Thus efforts to reduce losses and waste loads should include consideration of these aspects of quality control.

Harvesting is a very important operation. Bruising and other mechanical injury to potatoes during harvest often result in excessive rot during subsequent storage. Careful operation and adequate machinery obviously are very important in maintaining a low level of injury to the tubers. Numerous types of mechanical harvesters have been developed, but none has performed satisfactorily under all conditions. Improved harvesting machinery no doubt would reduce the losses and waste loads.

Transportation of potatoes for processing is another operation where improper conditions during transit may render potatoes undesirable for processing. Proper temperature is the most important consideration. During transit potatoes should be kept at temperatures between 50° and 75°F. If potatoes are held at 40°F or below for several days, reducing sugars will accumulate resulting in dark color of products such as chips and French fries. An extended period of temperatures above 75°F may cause an increase in certain types of storage rot diseases and, in fairly air-tight areas, may result in blackheart, a discolored breakdown of the tissue at the center of the tuber. (Talburt and Smith 1967).

Potatoes are shipped in bulk or containers by truck or by rail, and generally it is necessary to use trucks and railroad cars specifically designed for potato transport. Temperature must be kept constant throughout the car, and since outside temperatures may fluctuate considerably, good ventilation must be provided.

A railroad car for bulk transportation of about 90 tons of potatoes is being developed by ACF Industries (Curry 1968). Tests with outside temperatures ranging from 9° to 130°F showed that the temperature could be maintained at 60°F throughout the car.

Loading of trucks and cars must be done with care to prevent mechanical injury. Low outside temperatures during loading may create problems unless the temperature control in the car performs adequately.

Storage is necessary to provide a constant supply of tubers to the processing lines during the operating season. In storage, potato quality may be changed drastically unless adequate conditions are maintained. The major problems associated with storage are sprout growth, reducing sugar accumulation, and rotting. Reduction in starch content, specific gravity and weight also may take place.

Sprouting occurs at temperatures of 50°F and above following a rest period of several months after harvest. At lower temperatures little or no sprouting will take place, but reducing sugars will accumulate in the tubers.

One approach to maintaining high quality potatoes is to treat the crop with a sprout inhibitor in the field or in storage and then to keep the storage temperature at 50° to 60°F. A variety of sprout inhibitors have been used. Maleic hydrazide sprayed on the plants in the field has given good results. Other chemicals used are tetrachloronitrobenzene, nonanol, and CIPC, all with various degrees of success. The storage temperature and especially the storage time appear to be very important.

Gamma irradiation of potatoes at dosages of 10,000 to 15,000 REP has been found to inhibit sprouting completely for at least one year when the storage temperature is kept at 50°F.

Reconditioning of potatoes stored at low temperatures over a period of time by subsequent storage at higher temperatures for a similar length of time has the effect of reducing the sugar content. Potatoes stored at 40°F for six weeks and then removed to 70°F for six weeks had sugar contents similar to the content prior to storage. Potatoes stored at lower temperatures had higher sugar content after reconditioning.

To prevent large losses by rotting, low quality potatoes should be sorted out before the crop is placed in storage. Mechanically injured potatoes are especially susceptible to certain rot diseases and should be removed prior to storage to avoid rotting of a large portion of the load.

In summary, handling and storage of the raw potatoes prior to processing are major factors in maintaining high quality potatoes and reducing losses and waste loads during processing. Careless handling and storage may well destroy efforts to reduce and treat the waste from the process line.

Washing of Potatoes Prior to Processing

Raw potatoes must be washed thoroughly to remove sand and dirt prior to the actual processing steps. Sand and dirt carried over into the peeling operation can damage or greatly reduce the service life of the peeling equipment.

Often the incoming potatoes are washed in the water used for transport from the storage or receiving area into the plant. Fluming is an economical and effective method of transporting potatoes which results in a minimum of bruising damage. Sand and gravel are removed in stone traps in which these heavier solids settle out while the potatoes pass on. Tubers transported into the plant by other means or washed inadequately in the flume are passed through washers. A number of different types of washers are employed. Barrel-type washers are quite common. Potatoes are tumbled and rubbed against each other and against the sides of the barrel while immersed or sprayed with water. Other types use rubber brushes, rolls or paddles to loosen the adhering dirt. Following the washing operation the potatoes are allowed to drain for a short period while being carried to the next step which is usually a short inspection belt where trash and rotten potatoes are removed.

Water consumption for fluming and washing varies considerably from plant to plant. Wolters (1965) has reported flow rates to vary from 1300 to 2100 gallons per ton of potatoes. Of this volume, 2/3 is used for fluming and 1/3 for washing. Adler (1965) states that 1000 to 1800 gallons of water are used to wash one ton of potatoes. A study on the waste waters from five potato starch plants in Idaho, shows a range of flume water flow rates from 600 to 2700 gallons per ton of raw potatoes (Ambrose and Reiser 1954). The volumes reported above are based on no recirculation of the flume and wash water. Today recirculation systems are used to some extent, and the fresh water input may be reduced significantly compared to a "straight-through" system.

Depending upon the amount of dirt on the incoming potatoes, the waste water will contain from 100 to 400 lbs of solids per ton of potatoes. Organic degradeable substances are predominately in dissolved or finely dispersed form, and amount to from 2 to 6 lbs of BOD_5 per ton of potatoes (Wolters 1965). In a potato starch waste study, an average of 0.4 lbs of BOD_5 per ton of potatoes was reported (Ambrose and Reiser 1954). This value naturally depends to a great extent on the quality of the raw potatoes. Wolters (1965) states that with a recirculation system the organic matter discharged from the fluming and washing operation will be from 30 to 50 percent less than with a "straight-through" system.

The Peeling Process

Peeling of potatoes contributes the major portion of the organic load in potato processing waste. The operation determines to a great extent the yield of final product and the labor cost for subsequent triming and inspection.

Many factors must be considered when choosing the peeling method and establishing the tolerable peeling losses. Peeling requirements vary from process to process and from plant to plant. Production of potato chips, for example, requires less complete peel removal than production of French fries. Thus, disregarding potato quality, peeling losses will be less in chip factories than in French fry factories.

Potato quality is an important consideration, however. Deep eyes and thick peel result in high peeling losses if a high degree of peel removal is required. Other variables which affect peeling efficiency are age of the crop, size and shape of the tuber. With small potatoes, peeling losses are generally high because the surface area per unit weight is large.

Three different peeling methods are used extensively today. These are abrasion peeling, steam peeling and lye peeling. No one of the methods will satisfy the requirements of every type of plant. All three methods may be operated either as a batch process or as a continuous process. Small plants generally favor batch type operation due to greater flexibility. In such plants peeling losses and labor costs for trimming are usually quite high. Large plants use continuous peelers. These are much more efficient than batch-type peelers, but the capital cost is high (Talburt and Smith 1967).

Abrasion Peeling

Abrasion peelers have abrasive discs or rolls which remove peel by uniform contact with the surface of the potatoes. Peelings and potato tissue are removed from the abrasive surfaces by water sprays which also reduce the tendency of potatoes to darken through enzymatic action. The potatoes must be spun and rotated so that all surfaces are equally exposed to the abrasive surfaces. Thus it is important that tubers subjected to abrasion peeling are round. Digger cuts may cause the tuber to slide on the flat surface thus losing excessive tissue on one side. Uniformly sized potatoes will result in more evenly peeled potatoes when using this peeling method. Tubers with deep eyes are not suitable for abrasion peeling because excessive trimming will be required (Talburt and Smith 1967).

Abrasion peeling is used especially in potato chip plants where complete removal of the skin is not essential. Sijbring (1968A) said peeling losses of from 4 to 8 percent are not unusual in chip production. Smith (1964) made a survey of chip operations in the United States and found peeling losses ranging from 0 to 25 percent. Abrasion peeling has been used in the production of pre-peeled potatoes, since the heat ring, which results from high temperature exposure, does not occur with this method. High peeling losses, possibly as high as 25 to 30 percent, may be necessary to produce a satisfactory product, however.

The characteristics of the peeling waste vary with potato quality and peeling requirements. Gray and Ludwig (1943) reported the following peeling waste quality in a dehydration plant:

Flow = 600 gal/ton

BOD_5 = 20 lb/ton

Suspended solids = 90 lb/ton

Settleable solids = 15 cu. ft/ton (2 hr settling)

The organic content appears to be directly proportional to the percent peeling loss, and therefore would be minimized by feeding optimum quality potatoes. Up to 90 percent of the settleable solids appear to consist of coarse potato matter, the rest being fine starch particles.

Steam Peeling

Steam peeling yields thoroughly clean potatoes. The entire surface of the tuber is treated, and size and shape are not important factors as in abrasion peeling. The potatoes are subjected to high pressure steam for a short period of time in a pressure vessel. Pressures generally vary from 3 to 8 atmospheres and the exposure time is between 30 and 90 seconds. While the potatoes are under pressure the surface tissue is hydrated and cooked so that the peel is softened and loosened from the underlying tissue. After the tubers are discharged from the pressure vessel, the softened tissue is removed by brushes and water sprays similar to the ones used for prewashing. An increase in exposure time causes larger peeling losses and lower trimming requirements (Talburt and Smith 1967).

Because the gelation point of potato starch is surpassed in steam peeling, there will always be a heat ring. This heat ring is not always objectionable, as, for example, in the production of French fries where it is not noticeable in the finished product. Steam peeling of pre-peeled potatoes may result in enzymatic darkening under the heat ring. The ring may harden during storage, seriously affecting the quality of the product (Talburt and Smith 1967).

One disadvantage with steam peeling is the difficulty with which skin in the eyes is removed during trimming, particularly when the tubers start showing sprouts (Sijbring 1968B).

The waste water characteristics from this operation will vary with potato quality and peeling requirements. Cooley et al. (1964) reported the following characteristics from a potato flour plant peeling waste:

Flow = 625 gal/ton

COD = 52.2 lb/ton - 10,000 ppm

BOD = 32.6 lb/ton - 6,750 ppm

Total solids = 53.2 lb/ton - 10,200 ppm

Volatile solids = 46.8 lb/ton - 9,000 ppm

Suspended solids = 26.8 lb/ton - 5,150 ppm

pH = 5.3

The peelings and solids usually are removed by screens before the waste water is treated. These screenings are simply cooked potato tissue and can be used for cattle feed without additional treatment except for possibly some drying or mixing with other feed materials. Because of the relatively high temperature of the waste water, a considerable amount of starch dissolves and cannot be removed by plain sedimentation.

Lye Peeling

Lye peeling appears to be the most popular peeling method used in the United States today. The combined effect of chemical attack and thermal shock softens and loosens the skin, blemishes and eyes so that they can be removed by brushes and water sprays. Lye concentration, temperature and immersion time are the variables controlling this peeling method. Two general procedures are in use. One method uses lye temperatures from 190° to 220°F, well above the gelation point for potato starch. Immersion times from 2 to 6 minutes are required in lye concentrations of 15 to 25 percent. The other method is operated at temperatures from 120° to 160°F to avoid the formation of a heat ring. Longer immersion times generally are required. At temperatures below 140°F minimum immersion times are obtained at lye concentrations between 15 and 20 percent (Talburt and Smith 1967). Lye usage is less at lower lye concentrations. Sijbring (1968B) reports a usage of 15 kg of lye per ton of potatoes peeled at a lye concentration of 20 percent, while at concentrations of 10 to 13 percent the lye usage is 7 to 8 kg per ton.

If a heat ring remains on the peeled potatoes this can be removed by immersing the tubers in a second lye bath at lower temperature. It has been found that a bath at 120°F with a lye concentration of 15 to 20 percent effectively removes the heat ring caused by high temperature treatment (Harrington 1957).

Preheating of the potatoes in water before the lye bath minimizes the cooling effect of the tubers on the solution, helps to maintain a constant temperature, and increases the capacity of the peeler. A wetting agent or detergent has been found to improve peeling efficiency. (Lankler and Morgan 1944) (Sijbring 1968B)

If sludge formed in the peeler by the chemical action of lye on the potato tissue is removed by screening or settling, the service life of the lye solution can be extended markedly.

The peel, after having been softened and loosened in the lye bath, is removed by brushes and water sprays as in steam peeling. Sometimes a short period of time is allowed for the lye to work on the potato tissue before removing the peel. The tubers then must be thoroughly washed to remove any lye and lye-affected surface which will harden and cause a yellowing of the surface.

Lye peeling waste water is the most troublesome potato waste. Because of the lye, the waste water pH is very high, usually between 11 and 12. Most of the solids are colloidal, and the organic content is generally higher than for the other peeling methods. The temperature, usually from 50° to 55°C, results in a high dissolved starch content. Furthermore, the waste water has a tendency to foam. Cooley et al. (1964) reported the following waste water characteristics from a lye peeling installation in a potato flake plant:

Flow = 715 gal/ton

COD = 65.7 lbs/ton = 11,000 ppm

BOD = 40.0 lbs/ton = 6,730 ppm

Total solids = 118.7 lbs/ton = 20,000 ppm

Volatile solids = 56.4 lbs/ton = 9,500 ppm

Suspended solids = 49.7 lbs/ton = 8,350 ppm

pH = 12.6

Because this peel is extremely caustic, the pH must be lowered before the solids can be used for cattle feed. This is accomplished through microbiological action. In a primary sedimentation tank, for example, the pH of the settled solids can be lowered by controlling solids detention time in the tank so that the primary sludge can be fed directly to cattle after dewatering.

Evaluation of the Peeling Methods

As mentioned earlier no one peeling method will satisfy the requirements for every type of plant. In choosing the peeling method the processor must try to achieve the proper balance between peeling and trimming losses and raw material costs for most efficient operation. Some larger plants may install more than one type of peeler. Early in the season, when the potatoes are easy to peel, steam peeling may be advantageous. Later, when potatoes become difficult to peel, lye peeling may be more economical.

The waste production should be considered carefully because it may seriously affect the economic feasibility of a particular peeling method.

Abrasion peeling wastes do not have the high content of dissolved starch and fine and colloidal solids associated with wastes from lye and steam peeling installations, and thus can be treated to a higher degree by sedimentation. The amount of solids which must be removed from abrasion peeling waste is large, however, since the peeling losses generally are high.

In comparing lye and steam peeling wastes, the biggest difference is the pH of the two wastes. While steam peeling wastes usually are near neutral, lye peeling wastes have pH values from 11 to 12. This high pH may cause problems in receiving waters as well as in biological treatment. Furthermore, the organic content of lye peeling waste is generally higher than that of steam peeling waste. A study carried out in the Netherlands on tubers from the same lot clearly shows this (Sijbring 1968B).

	Peeling Method			
	Steam		Lye	
Date	2-27	4-4	2-27	4-4
Variety	Bintje	Bintje	Bintje	Bintje
Peeling loss, percent	14.6	20.8	21.5	26.7
Average weight of tubers, grams	170	160	170	140
Pollution, pop. equivalent/ton/day	79	114	345	240
Water consumption, m^3/ton	2.63	3.26	5.48	3.82

The study was carried out at a plant processing French fries. Thus the peeling requirements were quite high. The population equivalent was based on a BOD of 54 grams discharged per capita per day after one hour settling of the waste water.

Another study analyzed the combined waste stream from a potato flake plant in North Dakota prior to and after converting from lye to steam peeling (Olson et al. 1965):

	Caustic	Steam
pH	10.8	7.1
Total Suspended Solids	1297 mg/l	297 mg/l
Volatile Suspended Solids	1107 mg/l	201 mg/l
Fixed Suspended Solids	190 mg/l	96 mg/l
BOD_5	1265 mg/l	701 mg/l
Sample date	2/1/64	9/12/64

Oxygen demand as well as pH and solids content were substantially reduced. Similar differences in waste quality have been reported by Talburt and Smith (1967).

Potato Chips

The processing of potatoes to potato chips involves essentially the slicing of peeled potatoes, washing the slices in cool water, rinsing, partially drying, and frying them in fat or oil. White skinned potatoes with high specific gravity and low reducing sugar content are desirable for high quality chips. A flow sheet of the process is shown in Figure 1.

After conventional prewashing, the potatoes are peeled, usually by the abrasive method, washed and inspected and trimmed prior to slicing. Losses vary over a wide range. A survey of more than 50 plants in the U.S. showed that peeling and trimming losses for old potatoes varied from 2 to 20 percent and for new potatoes from 0.3 to 13 percent. Another survey showed the losses ranging from 0.5 to 25 percent and from 0 to 8 percent for old and new potatoes, respectively. Trimming losses alone may vary from negligible amounts to 10 percent (Smith 1964, 1966). The quality of waste water from the peeling operation has been discussed earlier. Trimming contributes primarily to the amount of solid waste.

Slicing yields from 15 to 20 slices per inch. Considerable amounts of starch are released in the operation and must be washed off to avoid matting and sticking of the chips during frying (Potato Chip Industry 1960). Most of the starch and slivers are removed in a washer with cool, fresh water. The combined waste water from slicing and washing has been reported to have the following characteristics (Cooley et al. 1964):

Flow = 1140 gal/ton raw potatoes

COD = 75.5 lb/ton

BOD = 21.9 lb/ton

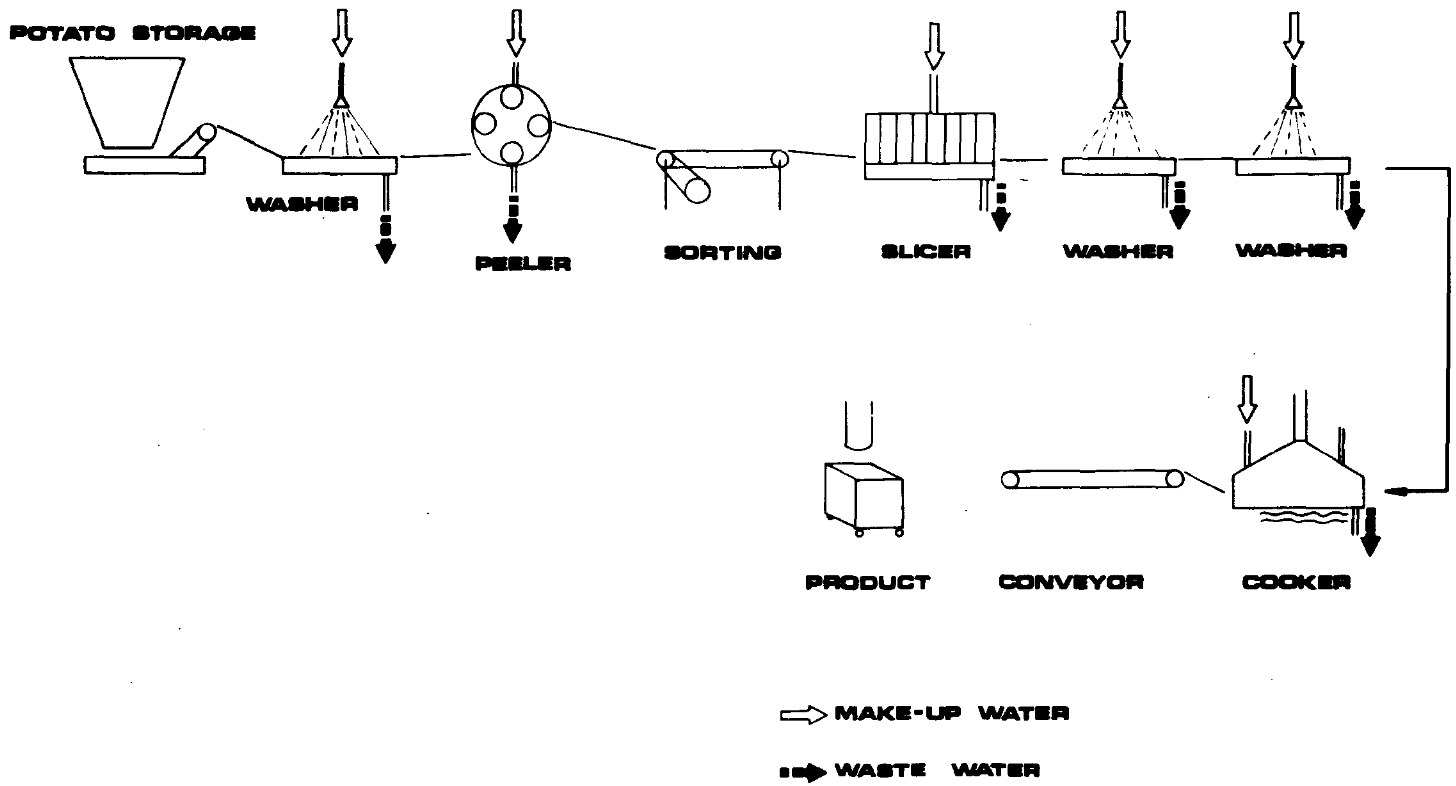
Total solids = 118.5 lb/ton

Volatile solids = 63.6 lb/ton

Suspended solids = 53.8 lb/ton

pH = 7.4

Losses during slicing and washing amounts to 0.05 to 1.0 percent of the raw potatoes (Talburt and Smith 1967). After washing, the chips are rinsed in one or two water baths to further remove starch. The waste from these steps is negligible both in volume and organic content. Drying of the chips prior to frying reduces the frying time and thus increases the capacity of the kettle. This is accomplished by a variety of methods including compressed air and perforated revolving drums. The chips also may be treated by hot water or chemicals prior to frying to prevent darkening. Chemicals used include sodium bisulfite, hydrochloric acid, phosphoric acid and citric acid.



TYPICAL POTATO CHIP PLANT

FIG. 1

Most plants now use continuous friers. Frying oil is circulated constantly through the kettle, and through a strainer so that small bits of chips and suspended particles may be removed. Because of the cost of frying oil, recirculation is essential, and the oil must be handled carefully to prevent spoilage by overheating or oxidation. The temperature of the frying oil varies at the heat source, where the chips enter, from 350° to 375°F and at the finishing end of the kettle from 320° to 345°F. The temperature is altered to fit the raw material and the conditions prevailing at the time.

After frying the chips are passed over a shaker screen to remove free oil, then salted or flavored, and finally cooled and inspected before packaging.

Cooley et al. (1964) presented the following figures for the combined waste from a potato chips plant:

BOD_5 = 29.2 lbs/ton potatoes

COD = 78.4 lbs/ton potatoes

Volatile Solids = 68 lbs/ton potatoes

Fixed Solids = 115 lbs/ton potatoes

Suspended Solids = 59.8 lbs/ton potatoes

pH = 7.4

A survey by Porges and Towne (1959) on four chip plants showed an average of 50 lbs of BOD_5 and 66 lbs of suspended solids discharged per ton of potatoes processed. The average waste flow was 3980 gallons per ton.

New methods for frying chips are being developed. The microwave oven has been used to dry chips partially fried in oil. It was found that potatoes of high reducing sugar content could be processed to acceptable colored chips in this way while complete oil frying produced dark colored chips.

A vacuum frier for chips has been developed at Wageningen, the Netherlands. This frier enables the processor to fry the chips at lower temperatures, thus improving the color of the chips. The vacuum frier has been tested on a large scale basis with good results (Sijbring 1968C).

Frozen French Fries and Other Frozen Potato Products

Of the 1966 crop, 32 percent of the potatoes processed were used for frozen French fries. Including other frozen potato products the figure amounted to 37 percent. (Irish Potatoes 1967) The grade and quality of potatoes processed into frozen products vary over a wide range. For French fry production large potatoes of high specific gravity and low reducing sugar content are most desirable. Large potatoes result in lower peeling losses and larger yield of long French fry cuts. High specific gravity insures higher yield per ton of potatoes processed and low reducing sugar content improves the color of the finished product.

After prewashing, the potatoes are peeled by the steam or lye method. The peeling requirements on potatoes for French fry processing are high, and the abrasion peeling would result in excessive losses. Peeling and trimming losses vary with potato quality and range from 15 to 40 percent (Talburt and Smith 1967). On the trimming belt low quality potatoes are diverted from the process line and small tubers may be removed for processing into co-products like potato patties, hash brown or mashed potatoes.

The strip cutter produces, besides French fry cuts, slices and nubbins which must be removed. This is usually accomplished by shaker screens or rotating reels having slots through which the smaller pieces pass. These pieces may then be diverted to the co-product processing lines. The removal of slivers and nubbins may amount to an additional loss of 10 percent, reducing the overall yield of raw French fry cuts to within the range of 50 to 75 percent of the tonnage of potatoes processed.

After cutting and sorting, the strips usually are water blanched. Advantages of blanching include (a) more uniform color of the finished product, (b) reduction of fat absorption through gelatinization of the surface layer of starch, (c) reduced frying time because the potato is partially cooked by blanching, and (d) improved texture of the final product (Talburt and Smith 1967).

Because the blanching water is relatively warm, its leaching effect may result in a high dissolved starch content in the waste water.

Surface moisture from the blanching step is removed by hot air prior to frying. This reduces the frying time and improves the texture of the strips.

The French fry cuts are carried through the frier by a conveyor. The temperature of the frying fat usually is maintained within the range from 350° to 375°F. Frying time is adjusted to meet the requirements of the consumers. Institutions usually finish frying in deep fat to develop color and crispness and thus desire a minimum of frying by the processor. French fries for the home consumer are fried more completely so that subsequent deep fat frying is unnecessary.

After frying, the free fat is removed on a shaker screen and by hot air streams. The fries then are frozen and packaged.

Table VIII gives the waste water characteristics from a French fry plant in Maine (Sproul 1965). This plant used the lye peeling method. The spray washer, which removes the loosened skin, contributes the bulk of the pollution load. Of the 22 lbs of BOD per ton of potatoes processed, 20 lbs came from the lye peeler. The table shows also that

TABLE VIII
POTATO PROCESSING WASTE CHARACTERISTICS FOR FRENCH FRIES
(All results in mg/L except pH)

Operation	BOD	COD	Solids		Alkalinity		Total PO_4	pH	Total Nitrogen as N
			Total	Suspended	Phenol.	Total			
Spray Washer	1950	2830	14900	2470	2480	3360	81	11.5	60
Trimming	30	45	270	7	----	165	27	6.9	--
Cutting	77	150	880	16	----	220	29	7.2	--
Inspection	5	32	260	15	----	163	14	6.9	--
Blanching	1020	1470	2283	60	----	---	160	4.7	--
By-products & blanching (combined)	500	870	1310	140	----	260	120	5.7	--
Plant Composite	1150	1790	8100	1310	1380	1840	80	11.1	20

Notes: Raw potatoes processed - 8.8 tons/hour

Plant BOD - 22#/ton potatoes

Plant suspended solids - 25#/ton potatoes

Water use - 2310 gal/ton potatoes

Data from Sproul (1965)

the by-products contribute a minor part of the waste. This would of course depend upon the number and kinds of by-products and upon the fraction of the potatoes diverted to the by-product line. Figure 2 is a flow diagram of the French fry process.

Dehydrated Diced Potatoes

Dehydrated potato dice are becoming increasingly important in today's food industry. The major part of the production is used in processed foods, primarily canned meats.

Potatoes with white flesh color and low reducing sugar content are desirable for dice production. Exposure of peeled potatoes to the atmosphere results in increased darkening of the finished product. This is overcome by using water sprays and dips and by preventing undue delays along the process line.

After washing and preliminary inspection to remove tubers showing "light greening", rot, mechanical injury and other defects, the potatoes are peeled by the steam or lye method. Minimum losses amount to about 10 percent.

The use of electronic sorting machines for removing blemishes and discolored dried dice has reduced the amount of inspection required at the trim table. One important factor during trimming is minimizing the exposure time. The surfaces therefore should be kept wet by water sprays along the trim table. (Talburt and Smith 1967)

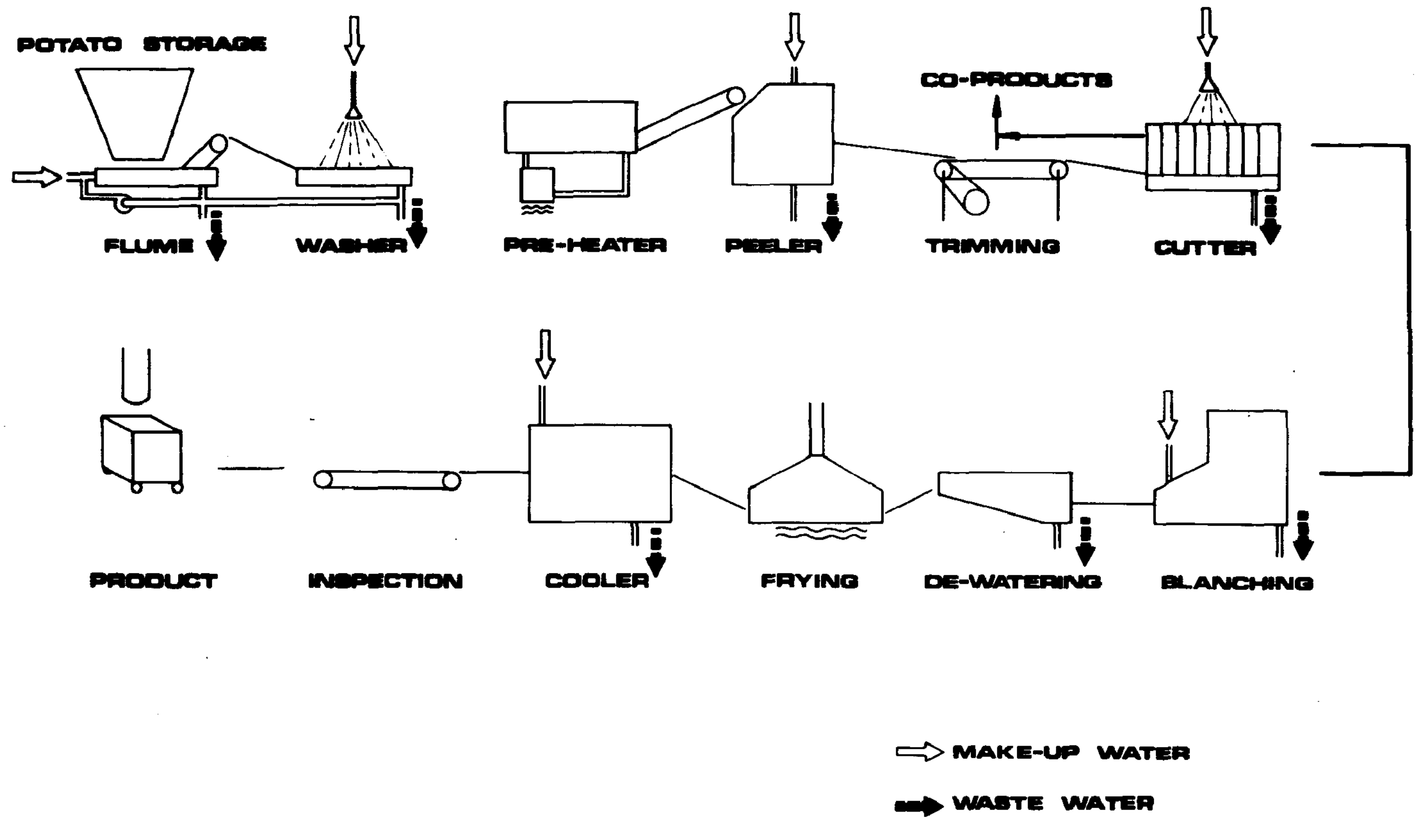
The tubers are cut into different size pieces. Losses in cutting appear to be directly related to the degree of subdivision. Simon et al. (1953) report a range of cutting and washing losses from 9 percent for the larger pieces to 14 percent for the smaller pieces.

After cutting and washing, the dice are blanched with water or steam at 200° to 212°F. Blanching results in better and more even surface color and also reduces microbiological contamination. A small solids loss, up to 1.5 percent, is associated with the blanching operations.

Following blanching a carefully applied rinsing spray removes surface gelatinized starch to prevent sticking during dehydration.

Sulfite usually is applied at this point as a spray solution of sodium sulfite, sodium bisulfite or sodium metabisulfite. Sulfiting protects the product from non-enzymatic browning and scorching during dehydration and increases the storage life of the product under adverse temperature conditions.

Calcium chloride often is added concurrently with sodium bisulfite or sodium metabisulfite. This has the effect of firming the dice and preventing sloughing. Sodium sulfite and calcium chloride should not be added concurrently since a precipitate is formed.



TYPICAL FRENCH FRY PLANT

FIG. 2

Modern continuous belt dehydrators dry the product to the desired moisture content in 6 to 8 hours. Since storage life has been found to be closely related to moisture content, it is important to dry the product to as low moisture content as is economically feasible. Piece size greatly affects the drying rate. The thicker the pieces, the slower the rate of drying.

Following drying the potato dice are screened to remove small pieces and bring the product within size specification limits. Sorting to remove discolored pieces is done either manually or by electronic sorters. Finally the dice are packaged in cans or bags.

Dehydrated Mashed Potatoes - Potato Granules

Potato granules are dehydrated single cells or aggregates of cells of the potato tuber dried to about 6 to 7 percent moisture content. They can easily be made into mashed potatoes by mixing with hot or boiling liquid. Because of the increasing popularity of convenience foods, potato granule production has grown steadily since about 1950.

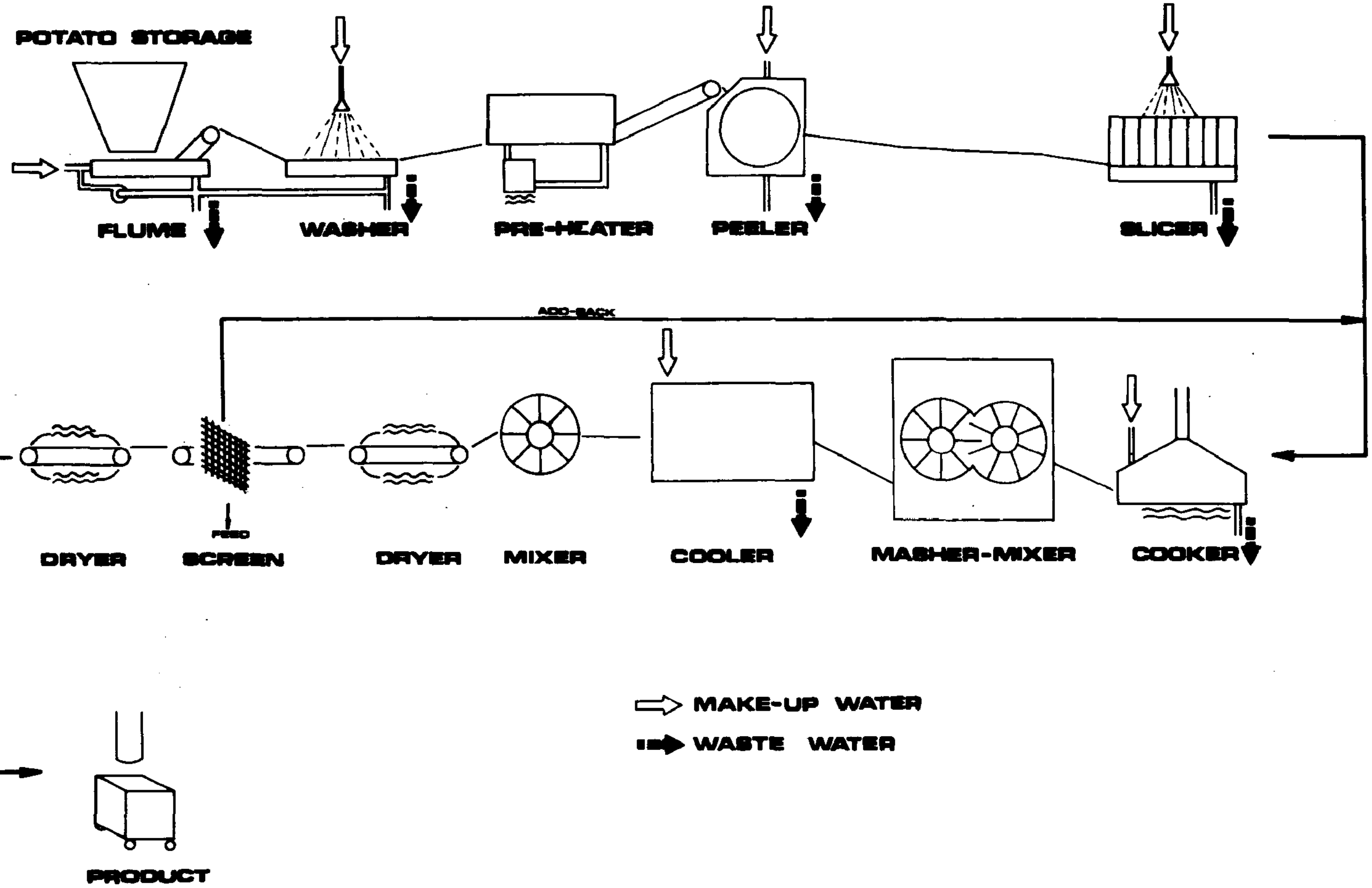
Since coloration of the finished product is a problem, potatoes of low reducing sugar content are desirable. Also the low reducing sugar content minimizes scorching during drying.

A flow diagram of the "add-back" process, which is used in the United States, is shown in Figure 3. After peeling and trimming, the potatoes are sliced to obtain more uniform cooking. The slices are cooked in steam at atmospheric pressure for about 30 to 40 minutes. Cooking usually is a continuous process where the slices are carried on a moving belt. After cooking is completed, the slices are mixed with the dry add-back granules and mashed to produce a moist mix. This mix is cooled and conditioned by holding for about one hour before further mixing and dried to about 12 to 13 percent moisture content. The powder then is screened, and granules coarser than 60 to 80 mesh are returned as add-back together with some of the finer powder. Very coarse material, retained on a 16-mesh screen, is removed from the process since it does not absorb moisture from the cooked slices rapidly enough to be helpful. About 12 to 15 percent of the material is removed for final drying to about 6 percent moisture content and packaged (Talburt and Smith 1967).

Two very important factors in the process are (1) minimum cell rupture, and (2) satisfactory granulation. Cell rupture releases excessive amounts of starch, resulting in a sticky or pasty product. Unsatisfactory granulation results in a lumpy and grainy finished product.

Potato Flakes

Potato flakes are a form of dehydrated mashed potatoes which have been dried on a steam-heated roll as a thin sheet and then broken into small pieces for packaging. Potatoes for flake processing should have



TYPICAL POTATO GRANULE PLANT

FIG. 3

the same characteristics as those for potato granule processing. It is important in this process, also, to keep cell rupture to a minimum.

A flow diagram of the process is shown in Figure 4. After prewashing, the potatoes are lye- or steam-peeled. Losses and waste water from these operations have been described earlier. Following trimming the tubers are sliced into 0.25 - 0.50 in. slices and washed prior to precooking in water at 160° to 170°F for about 20 minutes (Cooley et al., 1964). The water used for precooking may be treated with certain additives, such as sodium acid pyrophosphate, to prevent graying of the potatoes. Fresh make-up water is added, and the overflow stream is high in solids but low in volume. The potatoes are then cooled in fresh water for about 20 minutes. The purpose of the precook and cooling is to improve the texture of the finished product. Cooley et al. (1964) have reported the following characteristics for the combined waste from the slicer, washer, precooker and cooler:

Flow = 1540 gal/ton potatoes

COD = 56.2 lbs/ton potatoes

BOD = 38.4 lbs/ton potatoes

Total solids = 125.6 lbs/ton potatoes

Volatile solids = 53.3 lbs/ton potatoes

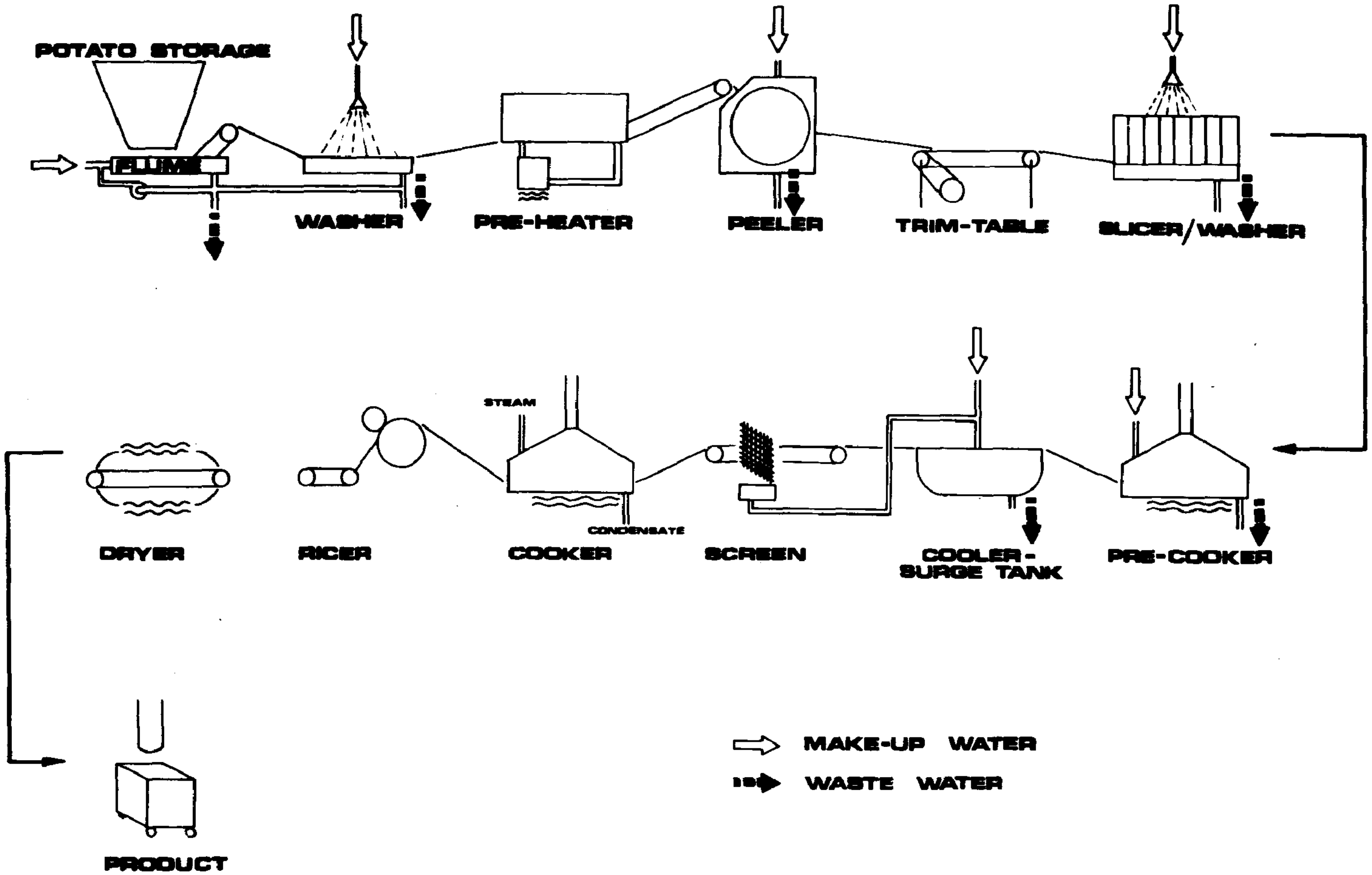
Suspended solids = 16.4 lbs/ton potatoes

pH = 5.2

Using steam at atmospheric pressure the cooled potatoes are given a final cook in a continuous cooker until they are just soft enough for ricing. This requires about 30 minutes for potatoes of high starch and solids content and about 40 minutes for varieties of lower solids content. The only waste stream from the cooker is the steam which condenses on the potatoes and drains off. This waste water is high in solids but very low in volume.

After cooking, the potatoes are riced or mashed and the mash is then dried on a single drum drier. The dried product is in the form of a sheet a few thousandths of an inch thick. The sheet is broken into flakes of convenient size for packaging. Olson et al. (1965) analyzed the combined waste from 3 different flake plants and reported the following values:

		Plant A Steam Peeling	Plant B Lye Peeling	Plant C Lye Peeling
pH		7.1	11.4	11.4
Total solids	(mg/l)	5173	8746	12930
Volatile solids	(mg/l)	889	2543	5497
Fixed solids	(mg/l)	4284	6203	7433
Total suspended solids	(mg/l)	297	1055	5248
Total volatile solids	(mg/l)	201	885	4255
Total fixed solids	(mg/l)	96	170	993
5-day BOD	(mg/l)	701	1774	3855
COD	(mg/l)	2142	3548	7148
Nitrogen	(mg/l)	26.9	86	105



TYPICAL POTATO FLAKE PLANT

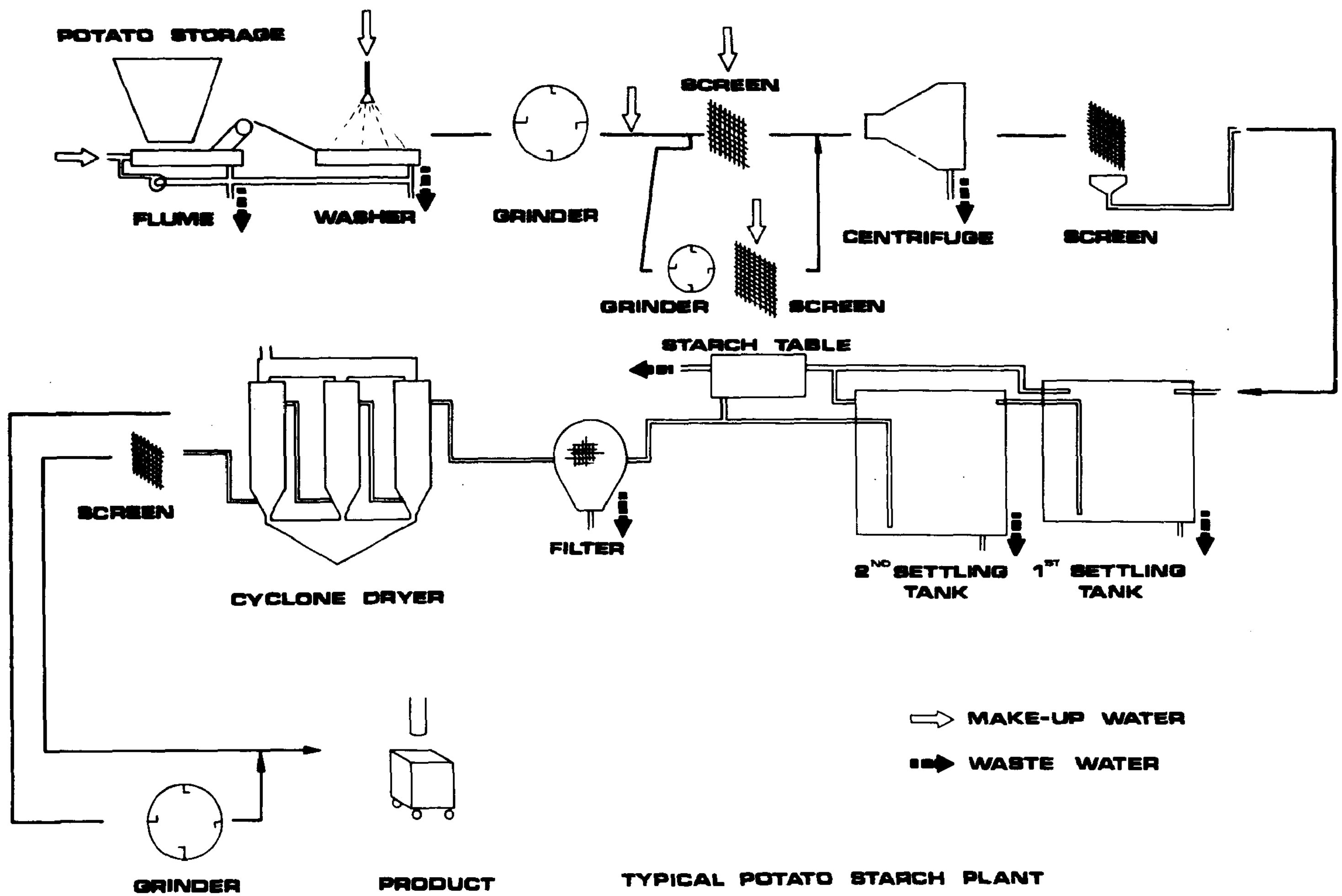
FIG.4

Potato Starch

Potato starch is a superior product for most of the applications for which starch is used. Because of its high phosphorous content it has much greater swelling capacity than either tapioca or corn starch. Two factors which prevent the industry from capitalizing on these advantages are the unstable supply of raw potatoes and the price paid for starch. Since the raw material for starch manufacture is primarily cull and surplus potatoes, starch production is closely tied to fluctuations in the potato industry, and adequate supplies of low-priced potatoes are often not available during short crop years. (Douglass 1965) (Harp 1965) The principal use of potato starch is for paper sizing and coating. Another important application is textile sizing, and it is used also in the baking industry, in fine laundering, as a thickening agent, and in adhesives.

The bulk of the starch plants in the United States is located in Maine and Idaho. Figure 5 shows a flow diagram of a typical Idaho starch plant. After fluming and washing the potatoes are fed to a grinder or hammer mill and disintegrated to a slurry which is passed over a screen to separate the freed starch from the pulp. The pulp is passed to a second grinder and screened for further recovery of starch. The starch slurry which passed through the screens is fed to a continuous centrifuge to remove the protein water which contains solubles extracted from the potato. Process water is added to the starch, and the slurry is passed over another screen for further removal of pulp. Settling vats in series are used to remove remaining fine fibers. The pure starch settles to the bottom while a layer of impurities, known as "brown starch," forms at the top. The brown starch is removed to the starch table consisting of a number of settling troughs for final removal of white starch. The white starch from the settling tanks and the starch table is dried by filtration or centrifugation to a moisture content of about 40 percent. Drying is completed in a series of cyclone driers by contact with hot air. The starch which now has a moisture content of 17-18 percent is screened and then packaged. (Ambrose and Reiser 1954) (Talburt and Smith 1967)

Ambrose and Reiser (1954) made a survey of 5 starch plants in Idaho and found the average values for the waste streams, as shown in Table IX. The protein water and the pulp accounts for about 95 percent of total organic load. If the pulp is retained and not wasted, the organic load is significantly reduced, as shown in Table X. The population equivalent values are based on 0.167 pounds of 5-day BOD per capita per day.



TYPICAL POTATO STARCH PLANT

FIG. 5

TABLE IX
STARCH PLANT WASTE CHARACTERISTICS

	Flow Rate Gal/ton	BOD		COD		Solids Content % wt.	Protein in Solids, wt%
		ppm	lb/ton	ppm	lb/ton		
Flume Water	1740[a]	100	0.4	260	1.5		
Protein Water	670	5400	30.1	7090	40.3	1.70	38.5
First Starch Wash Water	155	1680	2.2	2920	3.3	0.46	31.1
Second Starch Wash Water	135	360	0.4	670	0.8		
Brown Starch Water	30	640	0.2	1520	0.4	0.81	
Starch Water	25	150	0.0	290	0.0		
Pulp (Dry basis)[b]			24.8		56.8		

(a) No recirculation

(b) An average of 55.5 lbs of pulp (on dry basis) were produced per ton of potatoes processed.

TABLE X
ORGANIC LOAD FROM STARCH PLANTS

	Plant I	Plant II	Plant III	Plant IV	Plant V	Average
Potatoes processed, tons/day	200	250	150	62.5	180	
TOTAL ORGANIC LOAD WITHOUT PULP:						
5-day BOD, lbs/ton	45.3	27.7	26.2	31.7	35.0	33.3
BOD population equivalent/ton	271	166	158	190	210	200
BOD population equivalent of plant	54,200	41,500	23,700	11,900	25,200	
TOTAL ORGANIC LOAD INCLUDING PULP:						
5-day BOD, lbs/ton	70.1	52.5	51.0	56.5	59.8	58.1
BOD population equivalent/ton	420	314	305	338	358	348
BOD population equivalent of plant	84,000	78,500	45,800	21,200	43,000	

Potato pulp has proven to be a valuable feed for livestock when mixed with other ingredients and thus represents a valuable by-product. (Dickey et al. 1965)

The protein water is difficult to treat because of the high content of soluble organic matter.

Potato Flour

Potato flour is the oldest commercial processed potato product. Although widely used in the baking industry, production growth rates have not kept pace with most other potato products.

The potato flour process is based on the efficient dehydration of peeled cooked potatoes on a drum drier and is quite similar to the potato flake process. The main difference is the cooking step which generally is one continuous cook in steam at atmospheric pressure rather than the precook, cooling and final cook in the flake process.

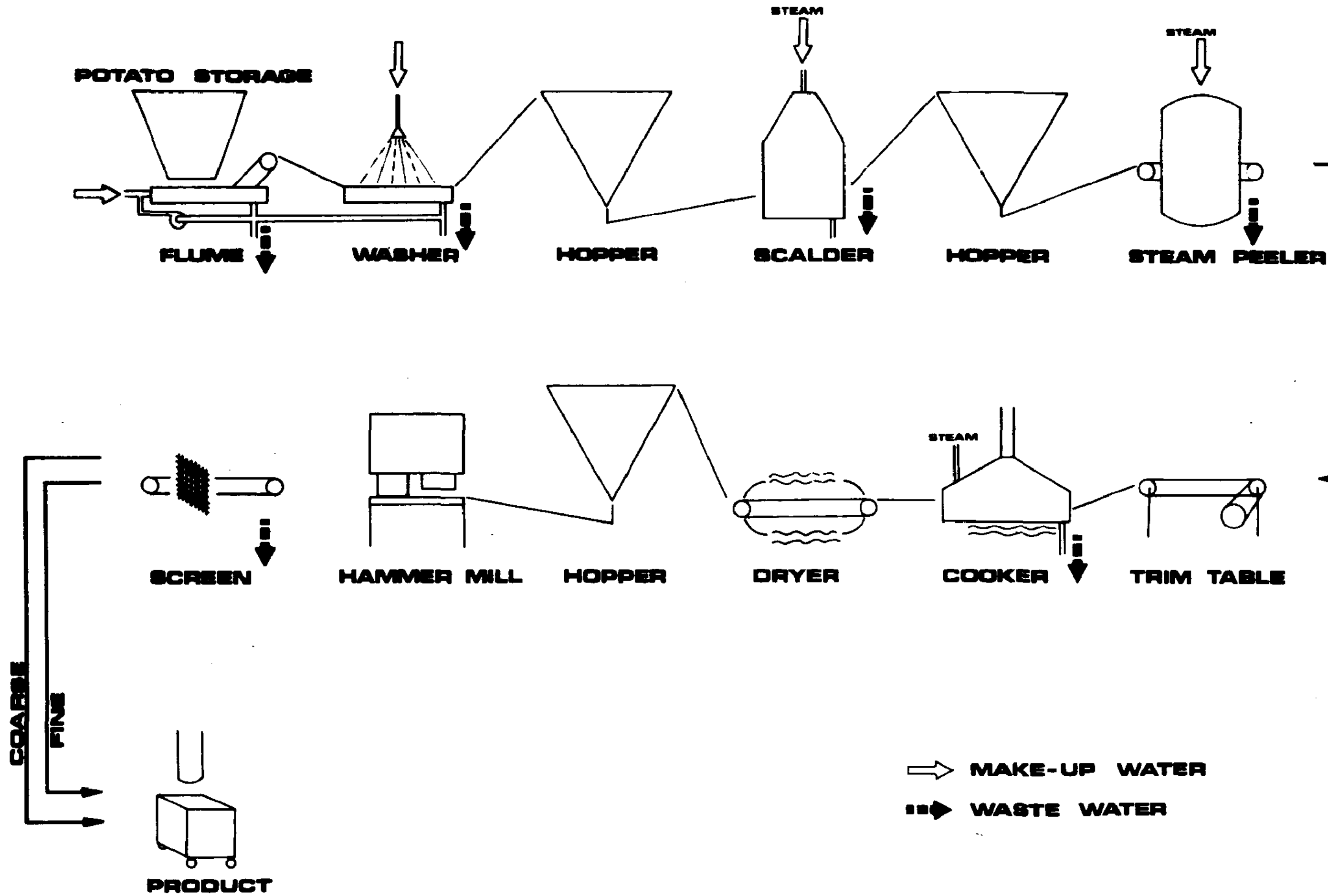
Raw material for potato flour consists primarily of very large potatoes, small potatoes and potatoes having surface defects.

A flow diagram of the process is shown in Figure 6. After the pre-wash the potatoes are peeled, usually with steam. Trimming requirements are not as high as for most potato products due to the "scalping" action of the applicator rolls on the drum drier. Rot, green end and other discolorations must be trimmed off, however.

The "flaking" operation requires well cooked potatoes. A cooking time of 45 to 60 minutes with steam at atmospheric pressure usually is adequate. (Talburt and Smith 1967) The tubers are conveyed directly from the cooker to the dryer, where 4 to 5 applicator rolls along one side of the drum contribute a thin layer of potato mash. The mash is rapidly dried and scraped off the drum at the opposite side by a doctor knife.

The dried sheets are passed to the milling system where they are comminuted by a beater or hammer mill and then screened to separate granular and fine flour. The moisture content of the final product is generally from 7 to 9 percent.

The waste water from the peeling operation accounts for the major part of the organic load. Another source of organic waste is the drum drier, where peel fragments and other solids tend to accumulate. The waste water characteristics show much variation from plant to plant as is the case with all potato processing. The values in Table XI have been reported by Cooley et al. (1964) and Olson et al. (1965):



TYPICAL POTATO FLOUR PLANT

FIG. 6

TABLE XI
RAW SCREENED POTATO FLOUR PROCESSING WASTE CHARACTERISTICS

	Cooley et al. (1964)	Olson et al. (1965)
pH	4.2	6.9
Total Solids *	11792	7493
Volatile Solids	10614	5572
Fixed Solids	1178	1921
Total Suspended Solids	6862	4398
Volatile Suspended Solids	6480	3019
Fixed Suspended Solids	382	1379
5-day BOD	7420	3314
COD	12582	8314

*mg/l except for pH

Canned Potatoes

The production of canned potatoes has increased steadily during the postwar years as a result of the increasing demand for convenience foods. Potatoes are canned in several different forms, but whole potatoes account for the major part of the production.

Potatoes used for canning are primarily the smaller sizes not suitable for fresh market. An important requirement of canning potatoes is that they should not slough or disintegrate during processing. Potatoes of high specific gravity are most likely to slough. Sloughing usually can be prevented in specific gravity lots of 1.075 to 1.095 by adding calcium chloride. (Talburt and Smith 1967)

After conventional prewashing the potatoes are peeled. Lye, steam, and abrasion peeling as well as combinations of these are used in the canning process. Abrasion peelers sometimes are used rather than lye or steam peelers to give the potatoes a smoother surface. Because the heat ring may present a problem, low rather than high temperature lye-peeling appears to be more suitable for canning.

Since canned potatoes are a low cost product, only a minimum of trimming is allowed. Some processors prefer to sort out the potatoes which need trimming and send them through the peeler a second time. (Talburt and Smith 1967)

If the potatoes have not been size graded previously, this is done following the trim table inspection. Larger size tubers are usually not canned whole but cut to make diced, sliced, shoe string or julienne potatoes.

The whole and cut potatoes are then filled in cans, and boiling water or brine containing 1.5 to 3.0 percent salt is added. A salt tablet is used with boiling water. The salt, calcium chloride, has a firming effect on the product.

The cans are closed at a temperature of 160°F or above and then processed at 240° to 250°F for about 25 to 50 minutes depending upon the can size. Following processing the cans are water-cooled promptly to about 100°F.

Pre-Peeled Potatoes

As a result of the demand for convenience foods and the high cost of hand labor, prepeeled potatoes are becoming increasingly popular. Restaurant operators generally find it more economical to purchase pre-peeled potatoes than to invest in labor for hand peeling or in peeling machinery. Pre-peeled potatoes also have gained popularity in the household.

Potatoes are pre-peeled for sale as whole potatoes as well as for French-fry cuts, chips, hash browns and others. The selection of raw material is to a great extent dependent on the final product and the same factors discussed earlier must be considered.

The pre-peeling processes do not differ significantly from the processes discussed earlier, and the waste streams are consequently similar. Peeling methods which involve temperatures above 160°F, the gelation point of potato starch, generally are not feasible in pre-peeling processes. Abrasion and low-temperature lye peeling are therefore the most popular peeling methods in use. Trimming and cutting requirements do not differ from what has been described previously.

Discoloration of pre-peeled potatoes takes two forms. The first type is the enzymatic formation of melanin, a dark pigment. The second type is the non-enzymatic "after-cooking darkening". Black-spot or black-heart may also occur. Microbial spoilage furthermore limits the shelf-life of pre-peeled potatoes.

To prevent discoloration, addition of chemicals is helpful. The most common additive is sulphur dioxide. Garrick (1968) reports that 50 ppm of SO_2 delays browning of peeled potatoes up to 2 days at 20°C and up to 14 days at 4°C. Microbial deterioration may be controlled for 10 to 14 days by keeping the peeled potatoes under refrigeration. (Talburt and Smith 1967)

Alcohol

Alcohol production from potatoes in the United States is small compared with the volume produced from grain. In Europe potato alcohol production is important.

In fermentation plants, the potatoes are washed, steamed at about 135-140°C and cooled to 62-65°C. The starch is hydrolyzed by barley malt or by a mold amylolytic enzyme preparation. The resulting mash, of 17-20% dry matter, is subjected to alcohol fermentation for 2-3 days. The residue after distillation (120-140 kg/100 kg potatoes, of 4.5% dry matter) is a valuable feed for cattle. Waste water from distilleries has been reported to have a 5-day BOD of about 530 mg/l (Szebiotko 1965). Joint production of starch and alcohol is carried out in Poland, Russia, and Czechoslovakia. The pulp and protein water from the starch production is used for alcohol fermentation, and the distillery residue is fed directly to livestock. This allows for disposal of all wastes. (Szebiotko 1965).

SECTION 5

METHODS FOR REDUCING THE WASTE LOAD

The importance of in-plant efforts to reduce the total waste load can hardly be overemphasized. In many cases the reduced losses, improved product recovery, and reduced water usage have more than offset the cost of the treatment facilities.

Water Re-use and Conservation

The capital and operational costs of waste treatment facilities are closely related to the volume of waste that has to be treated. Reduced waste volumes will significantly reduce the size of the treatment units and hence the overall cost of treatment. Excessive use of water where it is not strictly necessary often occurs in processing plants. The processor, therefore, should examine every point of water use within the plant to determine where water may be conserved or re-used.

There are several areas in the day-to-day operation where water is wasted unnecessarily into the waste stream from the processing plant. The following corrective steps have been suggested by the National Canners Association:

1. All water hoses should have automatic shut-off valves to prevent wastage of water when hoses are not in use. A running hose can discharge up to 300-400 gallons of water per hour.

2. Use low-volume, high-pressure nozzles rather than low-pressure sprays for clean-up.

3. Avoid unnecessary water overflow from equipment, especially when not in use. Automatic fresh water make-up valves should be provided.

4. Avoid using water to flume the product or solid waste where the material can be moved effectively by dry conveyors.

5. Avoid using water in excess of amount needed to accomplish the job, e.g., reduce cooling water flow to the minimum needed to accomplish the necessary product cooling.

6. Divert rain water run-off from buildings away from the factory and do not allow it to collect inadvertently in the waste disposal system.

7. Certain water used in the plant which is not re-used and which meets the purity requirements of the State may be discharged directly into streams without prior treatment through a waste disposal system. In some cases this may amount to over 50 percent of the total water used.

Reduced water usage may result not only in reduced waste volumes. In a vegetable processing plant it was found that the heat loss in the plant was reduced significantly as a consequence of reduced water use. (Weckel 1969)

Re-use of process water reduces the waste load as well as the water usage. In England, biologically treated effluents sometimes must be partially re-used because of limited water supply and restrictive water quality criteria. This practice will undoubtedly become more common in the future. (Gallop 1965)

A large percentage of the process water does not require biological treatment before re-use. Flume and wash water are low in BOD and dissolved solids, and may be reused, in most cases, following treatment by settling. Water for recirculation must not be allowed to undergo anaerobic decomposition since, besides being corrosive and odorous, it may affect the quality of the final product. Thus, the detention time in the settling tanks should not be excessive, and chlorine should be added to prevent putrefaction. Wolters (1965) suggested that detention times of about one hour are sufficient, while Dickinson (1965) claimed two hours of quiescent settling are required to clarify potato wash water. The constant velocity channel, or grit chamber, designed for water velocities of one foot per second, is a suitable device for removing sand and inorganic solids. Mechanical screening should be used to remove larger organic debris. In two of the largest starch plants in southern Germany, 90 percent of the flume and wash water is re-used after treatment in sedimentation tanks with continuous sludge removal. The contaminated water discharged from the system is replenished by fresh water. A dosage of 19 mg of chlorine is added per gallon of wash water. Chlorination requires close attention, however, since chlorine promotes the formation of the dark pigment, melanin. (Adler 1965)

Bacterial growth can be controlled by environmental factors. Acidification of such water with citric acid or other edible acids to pH 3-4 has been found to reduce greatly the growth rate of bacteria. Equally effective may be reduction of the water temperature. (Rose 1965) Such precautions permit recirculation of the water until build-up of physical or chemical components preclude further use. Recirculation may reduce the organic load from the fluming and washing operation by 30 to 50 percent. (Wolters 1965)

An example of efficient re-use of cooling water and process water in a potato granule plant has been described by Berry (1967). Fresh water is pumped from a well for use in 3 separate systems: (1) sanitary-potable water system, (2) equipment cooling - potato fluming and washing system, and (3) process water system. Waste water from the first system is not reused and is discharged to a sanitary septic tank with a tile drain field. The equipment cooling water is pumped under high pressure into a rotary drum washer for removing dirt from the potatoes. The water from the drum washer then is used for transporting the potatoes by flume to the process operations. The flume water is passed through a 20 mesh vibrating screen and piped to a settling pond for silt removal prior to disposal by spray irrigation. Process water, after having been used for steam generation, cooling, and plant clean-up, is passed through a 40 mesh stationary screen to remove solid waste and peel which is used as cattle feed. The screened water is piped to the spray irrigation system for final disposal.

Others reporting on the effects and importance of re-use of process water include Ambrose and Reiser (1954), Atkins and Sproul (1964), Eckenfelder (1969), Gallop (1968), Kueneman (1965), and Mercer (1969).

Re-use of a large percentage of the process water will be necessary in the future as water and waste problems become much more important factors in the survival and growth of food processing plants. Gallop (1965) indicated that industry could manage with 10-15 percent of the present usage of water for processing without loss of product quality. One of the largest Idaho plants has reduced the water usage to 200-400 gallons per ton of potatoes by considerable recirculation, and it is expected that this amount can be reduced by about 75 percent within a few years. (Kueneman 1965)

Counter-Current Flow of Process Water

Another method for water conservation and waste concentration is counter-current flow of product and process water. In this system, water from the last product fluming or washing operation, instead of being wasted, is collected and passed back in a counter-current manner to be used in preceding washing and fluming operations. The overall effect is that the product is moved forward after each washing or fluming operation water which is cleaner than that used in the preceding operations. A recent development for final purification of starch employs this principle. The starch milk is pumped into the first of several solid-liquid cyclones while clean water is pumped into the last cyclone, and the two work their way counter-currently through the batteries. The water emerges from the first unit carrying all the soluble impurities which had been in the starch milk while the purified starch emerges from the last unit ready for filtration and drying. (Douglass 1965) In any process line with successive washes and rinses, counter-current flow should be considered if water conservation by recirculation is unfeasible.

Process Control and In-Plant Treatment

Proper operation of the process equipment can reduce the waste load as well as the loss of product. It is therefore important that the different process steps are adjusted according to the operational variables so as to reduce the waste volume and/or amount of contaminants to a minimum under the prevailing conditions. This may involve reduced solids losses allowed in operations such as peeling, cutting, and screening. Reduction of water usage should of course be considered. In many cases such adjustments may require an evaluation of treatment cost versus trimming cost or product quality. Previous records are helpful in such situations. Examples of steps that may be taken to reduce peeling losses include better control of the caustic concentration in lye peeling and use of higher pressure water sprays in washing facilities. (Talburt and Smith 1967) Maintenance of the process equipment is another important factor. Efforts to reduce the volume or strength of a waste stream are easily offset by the effects of inadequate equipment.

Good house-keeping and in-plant treatment, such as screening, can result in significant waste load reductions. Potato peel and pulp contain 0.1 mg of BOD per mg of dry solids. (Carlson, 1967) Therefore, in-plant efforts to separate potato solids from the waste water as early as possible, or keeping the solids out of the liquid waste altogether, will markedly reduce the dissolved organic content of the waste stream. When potato solids are left in contact with water over a period of time, considerable leaching of organic materials take place. The following table shows the influence of contact time on soluble BOD. (Sproul, 1968)

TABLE XII
LEACHING OF ORGANIC MATERIALS
FROM SLICED POTATOES IN WATER

Mixing Time Minutes	Dissolved BOD mg/L
2	200
3.5	215
5	225
10	230
30	300

In this experiment Maine Russet potatoes were cut into 1/4-inch cubes and 150 grams were added to 1.5 liters of distilled water. The starch liberated during cutting was added also, which accounts for most of the BOD after 2 minutes of mixing. After 30 minutes the dissolved BOD had increased by 50 percent with respect to the 2 minute concentration, and additional mixing would have increased the BOD even more, since 10 percent of the dry weight would give about 2.6 grams of available BOD. Only 0.45 grams were measured after 30 minutes. Potato pieces with larger surface area, such as flakes or granules, would leach considerably larger amounts of organic material per unit weight, since the leaching rate is proportional to the surface area exposed. The temperature of the water also influences leaching. Warm water will extract more organics than will cold water.

Unnecessary spills must be avoided, since spills increase waste loads as well as product losses. Automatic controls may be used to reduce spills, and sumps substituted for floor drains will prevent the spilled material from entering, the waste water. Useable materials may be recovered in this manner. (Black and Porges 1965) Spills during the packing operation represent a direct loss of finished product as well as solid waste which often is washed away to the plant waste stream. Wreckel (1969) found a loss of 1 percent of finished product in the filling operation in a pea cannery. Similar losses in a plant processing corn were estimated to be 3 percent.

Very few of the persons working on the process line understand the magnitude of the waste problem and what contributes to it. Efforts to explain how they, through better house-keeping and consideration, can reduce this problem, seem well worthwhile.

Redesign and Modifications of the Process

Numerous possibilities exist for redesign and modifications of the process to reduce the waste load. New and improved equipment and methods are being developed, but for economical reasons the processor cannot always take full advantage of the improvements.

Much attention should be given to improving the peeling process, which contributes the major part of the waste load in potato processing. Change of peeling method can reduce the waste load considerably. Conversion from caustic to steam peeling at the Borden's Food Company processing plant at Grafton, North Dakota, resulted in a BOD reduction of the combined plant waste of almost 47 percent. The total suspended solids concentration was reduced by 79 percent and the volatile suspended solids by 83 percent. Fixed solids were reduced by almost 50 percent. (Olson et al. 1965)

Presently, two newly developed "dry" peelers are being tested. These peelers were developed independently by the Western Research Laboratories, USDA, at Albany, California, and by the Institute for Storage and Processing of Agricultural Produce, IBVL, at Wageningen, the Netherlands.

The peeler developed by the Western Research Laboratories is based on the application of infra-red radiation to caustic treated potatoes followed by abrasion treatment to remove the peel. The use of water to remove the peel, as in conventional caustic or steam peeling, is eliminated, and the peeling waste can be removed from the process as a concentrated residue.

A pilot plant operation of the process by the Potato Processors of Idaho Association has been described by Willard (1969). Potatoes were removed continuously and randomly from the flow to a conventional caustic peeling line and transported by conveyor to a small conventional ferris-wheel type caustic peeler. A woven wire mesh conveyor fitted with cleats transported the potatoes from the caustic peeler to the infra-red treatment unit. The holding time on the conveyor allowed the caustic solution to penetrate to the desired depth. The infra-red treatment unit consisted of a feeder, used to align the potatoes in rows and deliver them to a 48 inch roller conveyor, 10 feet long, which conveyed and turned the potatoes beneath the infra-red source. To provide infra-red radiation 8 rows of 6 porous ceramic burners were used, each rated at 20,000 BTU per hour, operating on natural gas. The burners provided a temperature of 1650°F with an output of approximately 50 percent infra-red radiation. Following the infra-red treatment the softened skin was removed in a scrubber. The scrubber contains twenty-three 3 inch diameter soft stud rubber rolls, 6 feet long, rotating in planetary action at adjustable speeds from 700 to 920 r.p.m. in a continuously rotating cylindrical cage. An adjustable speed inner screw conveyor controls the residence time in the scrubber. The peel removed by this vigorous action is thrown by centrifugal force and collected on the inner surface of a drum supported to rotate about the rolls. A drag conveyor installed in the drum continuously wipes the residue to one point for collection. After the scrubber the potatoes were given a final brush washing. This unit is similar to the scrubber except that the stud rubber rolls have been replaced by polypropylene cylinder brushes.

The test conditions used to obtain a "normal" peel were:

Feed rate - 5500 lbs of raw potatoes per hour.
Caustic treatment - 12.3% concentration, 0.8 minutes contact time, 185°F, holding belt time 9 minutes.
Infra-red treatment - 48 burners operating at 20,000 BTU's per hour, effective treatment time 1.2 minutes.
Scrubber - 1.32 minutes treatment time with rolls operating at 772 r.p.m.
Brusher - 1.23 minutes residence time with rolls operating at 778 r.p.m., water rate about 4.6 g.p.m.

The process was frequently compared with the conventional caustic peeling line. Trim loss was taken as an indication of the effectiveness of peel removal. Following are the results of two tests when the peel removal on the two lines were approximately equal, as indicated by the identical trim losses.

	Pilot Line	Conventional Line	Pilot Line	Conventional Line
Trim Loss	5.0%	5.0%	2.5%	2.5%
Peel Loss	12.9%	20.4%	13.1%	22.7%
Caustic Use*	0.18	0.63	0.18	0.63

*Lbs of NaOH used per cwt. of raw potatoes peeled.

These results indicate a substantial reduction in peeling losses and caustic usage with the infra-red peeler when compared to the conventional caustic peeler.

Three separate waste materials were produced in the infra-red process. These were debris brushed from the conveyor rollers in the radiation unit, the scrubber sludge, and the concentrated washer effluent. The scrubber sludge was a heavy viscous paste with a solids content of about 23 percent. Pump tests demonstrated that the sludge could be pumped, even at the original solids content. When combined with the brush washer effluent the solids content was reduced to about 12 to 14 percent, and this greatly reduced the handling problem.

Successful operation of the infra-red peeling process would reduce the total waste load significantly. An estimate of the reduction in waste load to a secondary treatment system using both conventional and infra-red peeling for two hypothetical operations is shown in Table XIII. From this table it appears that, based on solids content, infra-red peeling can reduce the waste load by 70 percent in a French fry plant. Similarly, in a granule plant the waste load is reduced by 50 percent.

The peeler developed in the Netherlands is quite similar to the infra-red peeler. The main difference is that no infra-red radiation is used. The potatoes, after treatment by lye or steam are conveyed directly into a brushing machine for peel removal. Sijbring (1968B) has reported operational results on the brush peeler. Two steam peeling lines were operated in parallel, one using a conventional washer for peel removal, the other using the brushing unit. The results are shown in Table XIV. Indications are that, with proper adjustment, water usage for brushing unit could be reduced to 1 m^3 per ton of potatoes.

TABLE XIV
BRUSH PEELING VS. CONVENTIONAL STEAM PEELING

	Peel Removal by	
	Washing	Brushing
Water consumption, m^3/ton	21.7	12.1
Pollution, pop. equiv./ton/day	190	48
Peel Loss, percent	17.3	19.0
Solids removable by sedimentation, m^3/ton	0.890	0.130

By-Product Recovery from Potato Waste

Any reduction of the amount of solids entering the waste stream will aid in the alleviation of the waste problem. Utilization of the recovered solids in a manner that results in income will reduce the total cost of waste treatment and eventually reduce the cost of the final product.

TABLE XIII
EFFECT OF PEELING METHOD ON WASTE DISPOSAL

Type of Plant	French Fry Manufacturer		Granule Manufacturer	
Method of Peeling	Lye Peel	Infra-Red Peel	Steam Peel	Infra-Red Peel
Input, lbs/hr	21,200	20,000	20,000	20,000
Peel Loss, percent	18 (a)	13 (a)	10 (b)	10 (b)
Peel Loss, lbs/hr	3,800	2,600	2,000	2,000
Peeled Potatoes, lbs/hr	17,400	17,400	18,000	18,000
Peel Waste Solids, lbs/hr	760	520	400	400
Non-Peel Waste Solids, lbs/hr	326 (c)	326 (c)	400 (d)	400 (d)
Total Plant Waste Solids, lbs/hr	1,086	846	800	800
Primary Waste Recovery, lbs/hr	543 (e)	163 (e)	400 (e)	200 (e)
Total Waste Solids Recovery, lbs/hr	543	683	400	600
Waste Solids to Secondary, lbs/hr	543	163	400	200

(a) Estimated year-round average, based on pilot plant observations.

(b) Recovery using IR peeling assumed equal until further data available.

(c) Assuming 70 percent total plant loss is peeling loss.

(d) Assuming 50 percent total plant loss is peeling loss.

(e) Assuming 50 percent solids recovery in primary clarifier.

(From Willard 1969)

All potato processing plants probably use screens to remove large solids before further treatment or disposal of their waste water. The degree of removal varies from plant to plant, as do the methods for handling the solids after removal. In some plants the solids are disposed of by one of several conventional solid waste disposal methods, while in others the solids are merely ground to a fine slurry for return to the waste streams. More and more attention is being directed, however, towards producing salable by-products from the recovered solids. The feasibility of by-product recovery depends to a great extent on the size of the plant and the amount of solids recovered.

The part of the potato which is wasted generally has about the same high food value as the part which is processed. Shaw (1965) has proposed utilization of solid waste like pulp and particulate materials for a number of snack items. Solid waste has been used extensively as feed for livestock. Depending upon the moisture content, the waste may be dried or mixed with other feedstuffs or fed directly. Experiments have shown that the nutritional value of dried potato pulp is equivalent to corn when fed to beef cattle. (Harp 1965) (Dickey et al. 1965)

Potatoes are a high energy carbohydrate feed with a low protein to carbohydrate ratio, generally on the order of 1:10 to 1:12. Thus, excessive use of potatoes for cattle feed results in over-fattening of the animals and unnecessary wastage of carbohydrate. In Poland, Janicki et al. (1965) have tried to overcome this problem by growing yeast on a potato medium to produce a feed material richer in protein. The resulting product can be fed to the animals directly or in dehydrated form.

A symbiotic yeast process has been developed and patented by the Swedish Sugar Corporation. (Wramstedt 1968) Process water is screened and passed through a desludger, and the supernatant, containing about 2 percent solids, is used to make a growth medium for the yeast, Torula. The finished product can be used as a feed additive or for human consumption. Pilot plant results have been very promising. Not only is a valuable by-product produced, but the BOD of the process water is reduced by 80 to 90 percent.

The protein water, or fruit water, from starch plants is difficult to treat because of the high concentration of dissolved organics. Recovery of proteins from this waste stream would result not only in BOD reduction but also in yield of a valuable by-product.

Protein may be precipitated from the waste stream either by heating or by acidification. At temperatures above 80°C the protein coagulates and settles out. At low pH values precipitation takes place as well. Theoretically, the pH should be adjusted to the iso-electric point, pH 4.7. Experiments at the University of Idaho showed that most efficient precipitation took place at pH 3.2. No coagulation took place above pH 5.8. (Jackson 1962) Heat treatment yields a more easily filterable deposit than chemical treatment but is more expensive. Acidification, on the other hand, preserves the valuable ascorbic acid present in the waste, gives a more desirable product on drying, and inhibits foaming during processing. Ascorbic acid and remaining protein can be recovered by acid and basic ion exchange, respectively. Protein water treated by coagulation and ion exchange has been found to contain less than 2 percent of the solids originally present, and would not present any pollution problem. (Jackson 1962) Presently, work is underway to develop methods for extensive recovery of by-products from starch waste at the Eastern Utilization Research and Development Division of the USDA. (Heisler et al. 1969) The proposed treatment process would consist of five steps: (1) concentration of dilute waste by reverse osmosis; (2) precipitation and recovery of protein by steam injection or other suitable method; (3) separation and recovery of potassium and other inorganic cations by ion exchange; (4) separation and recovery of amino compounds by ion exchange; and (5) recovery of organic acids and phosphates by ion exchange. Promising results have been obtained.

Deproteinized process water also can be used for yeast production or alcohol fermentation, and it is more suitable for disposal by spray irrigation than protein-rich water, since the protein tends to clog the pores of the soil.

The fuel value of potato wastes has been investigated by Hindin and Dunstan (1965). They considered anaerobic digestion and combustion and concluded that because of the capital investments for construction of such facilities, the use of potato solids as fuel does not appear feasible at this time. In the future, however, incineration and combustion units may bring financial return.

Waste Separation and Combination

Waste streams from different process steps in many cases should not be combined. Large savings in treatment costs may result from keeping dilute and concentrated waste streams separate. Dilute waste water can often be re-used or disposed of after little or no treatment. Also, since the size of treatment units generally is determined by the waste volume rather than the strength, concentrated wastes will require smaller treatment units at lower capital investments. Waste streams with extreme pH values should be carefully considered because of their effect on biological treatment. The combination of acid and basic waste streams may result in neutralization, and if possible, cooperation between adjacent industries may be very beneficial.

SECTION 6

CURRENT WASTE WATER TREATMENT PROCESSES

Preliminary Treatment

Wash Water Silt Removal

Removal of silt and sand resulting from washing the raw potatoes is important for several reasons. If the wash water is to be reused, the presence of sand and grit can seriously damage pumps and other equipment through which the water might pass. The presence of such inorganic solids in primary sludges is undesirable, since they are not biodegradeable. Where sludges are treated by anaerobic digestion, for example, inorganic solids can increase the total volume of solids significantly since considerable dirt may be present on raw potatoes. If sand and silt are not removed prior to disposal by spray irrigation, clogging of pipes and nozzles is likely to occur.

Stones and gravel in flume water often are removed by sand traps. These are sections of increased depth in the flume where particles of high specific gravity settle out. The potatoes are kept from settling by agitating the water with compressed air or by other means. Stones also may be caught on riggles, while the potatoes are carried on by rapidly flowing water. (Talburt and Smith 1967) Regular grit chambers or constant velocity channels may also be used. Flow velocities of about one foot per second will allow the heavy inorganic solids to settle out, while the lighter organic matter is carried on. (Dickinson 1965)

Silt-laden wash water sometimes is treated separately in shallow settling ponds. Usually, the settled solids do not contain enough organic matter to cause serious odor problems, and can be removed mechanically during an off period, when the pond can be drained. (Haas 1968) (Talburt and Smith 1967) The organic content of the effluent from silt ponds is generally low (BOD of 200-300 mg/l) compared with overflow from other treatment processes. However, as secondary treatment plants are installed, the silt pond effluent may contain higher BOD concentrations than the secondary effluent. Additional treatment of the silt pond effluents will then probably be required. (Dostal 1968A)

A variety of grit removal and separation equipment is available from waste treatment equipment manufacturers. One type of degritter is essentially a centrifuge with no moving parts. This unit is very compact and requires a minimum of space. Another type combines grit removal, sedimentation, and surface skimming in a circular tank having an aerated grit chamber in the middle. Primary sludge and grit are discharged separately. Aerated grit chambers might prove beneficial when the water is to be reused.

Disposal of sand and silt presents no problems since the material is almost completely inert.

Main Waste Screening

Screening is an effective and extensively used method for removing larger solids and floating debris. Three types of screens are in use: fixed or stationary, rotary, and vibratory screens.

The simplest type of stationary screen consists of a number of bars evenly spaced across the waste channel. The bars usually are installed at an angle so that material retained on the screen tends to "ride up" on the bars and thus not restrict the flow of water through the screen. The simplest type of bar screen is cleaned by periodically raking off the accumulated material manually. A variety of automatically cleaned bar screens are available also. The cleaning mechanism consists of a set of rakes on a motor driven endless chain. Cleaning may be continuous or programmed to follow an operation schedule. More sophisticated control and reduced power cost are obtained by having the raking mechanism start when the head loss across the screen reaches some predetermined value. Cleaning by rakes limits the bar spacing to a minimum of 1/2 inch, although 3/4 inch is much more common. Bar spacing down to 1/2 inch is possible when the screen is cleaned by brushes.

Removal of solids smaller than those retained on number 7 mesh is not practical with fixed screens. Mesh screens with openings of such size plug easily. Nevertheless, fixed screens, and especially bar screens, have proven helpful in affecting further treatment by removing large solids. This is necessary to protect pumps and finer screens located downstream. (Ballance 1965)

Rotary screens also are used to a large extent, and a variety of types are available. The most common type is the drum screen which consists of a revolving mesh drum where waste water is fed into the middle of the drum, and solids are retained on the peripheral mesh as the water flows outward. The solids are removed by high-pressure water jets directed against the outside of the mesh at the top of the drum. The solids fall into a trough and are removed hydraulically. The smallest practical opening for screening waste water is about 120 mesh, but more commonly mesh sizes 20 and 40 are used. (Ballance 1965)

Another type of rotary screen is the disc screen which is a perforated plate or wire mesh disc set at right angles to the waste stream. The retained solids are removed at the top of the disc by brushes or water jets. Mesh sizes smaller than 20 are impractical because of the large diameter disc necessary to provide enough openings for water passage.

A common disadvantage of rotary screens is the high moisture content of the screenings. When water jets are used to remove the retained materials, the moisture content of the screenings may be as high as 99 percent. (Ballance 1965)

Vibratory screens may have reciprocating, orbital or rocking motion, or a combination of these. The waste water is fed onto the horizontal surface of the screen, and the water passes through while the retained solids are bounced across the screen to a discharge point. Vibratory screens finer than mesh 40 are uncommon in waste treatment. The main advantage of this type of screen is the relatively dry screenings produced. The moisture content is usually about 80 percent.

Removal efficiencies by screening will naturally vary greatly with the type and number of screens employed and the bar spacing or mesh sizes of the screens. Ballance (1965) stated that the solids removal by a 20 mesh screen should not be expected to exceed 35 percent.

The Engineering Committee of the Idaho Potato Processors Association made a thorough investigation of the standard methods of preliminary treatment of potato wastes. They concluded that self-cleaning rotary or vibratory screens were effective in removing larger solids which may cause plugging of pipes and pumps. To prevent plugging and extremely wet screenings it was recommended that the minimum screen opening should be 20 mesh. If the screen was to be followed by clarification, it was felt that it would be better to use larger openings - from 6 mesh to 1/2 inch. Such screens would reduce the BOD by 10 to 15 percent and the suspended solids by about 25 percent. (Grames and Kueneman 1968)

Talburt and Smith (1967) have summarized waste characteristics from several operations prior to and after screening. Their data indicate the following removal efficiencies:

Description of Waste Stream	Screening Removal Efficiency, %			
	Total Solids	Suspended Solids	Settleable Solids	BOD
Chip Plant Waste		44	53	26
French Fries and Starch Waste	31	34		23
Caustic Peeling Waste	59			18

Primary Treatment

Although secondary treatment will be required by many authorities in the near future, primary treatment will become no less important. Secondary treatment is more expensive, and the maximum degree of primary treatment should be obtained to reduce the load on the secondary system. Primary treatment is used extensively with good results, but much can be done to improve its performance.

Plain Sedimentation

Because of the high concentration of settleable suspended solids in potato wastes, sedimentation has been an effective treatment method. Treatment facilities range from simple settling ponds to rather sophisticated clarifiers specifically designed for potato waste.

Settling ponds provide good removal of suspended solids until they become filled with solids and must be drained and dredged. Dredging is an expensive and odorous operation which makes the use of clarifiers seem more desirable.

Conventional clarifiers are either rectangular or circular. The circular type is available from a number of equipment manufacturers and is the most common. Many workers have presented design recommendations and expected removal efficiencies.

Talburt and Smith (1967) report that most clarifiers are designed for an overflow rate of 800 to 1000 gallons per day per square foot of surface area and a depth of 10 to 12 feet. Most of the settleable solids will be removed from the effluent, and COD removals of 50 to 70 percent may be expected if the plant effluent has been properly screened. Filbert (1968) recommends similar design parameters. Pilot plant studies by the Engineering Committee of the Idaho Processors Association indicated that detention times of 2 to 4 hours with overflow rates of 800 gal/day/sq ft would give BOD removals of 50 percent. (Kueneman 1965) A deep sludge blanket gave the highest solids concentration in the underflow. With caustic peel waste, the underflow would be about 3.5 percent solids, and by additional conditioning and lowering of the pH, the solids content could be 5.0 to 8.0 percent. With steam peeling waste the underflow could be expected to contain 5.0 to 6.0 percent solids.

The results from further pilot plant studies and experience from early clarifier installations have been reported by Grames and Kueneman (1968). The maximum desirable overflow rate was found to be 600 gal/day/sq ft with detention times of 2 1/2 to 3 hours. A deep clarifier with a deep feed well gave best settling of the fluffy potato solids. Side water depths of 9 to 12 feet were used successfully, and better solids removal was obtained when the feed well was provided with anti-turbulence baffles near the lower lip. Rake mechanisms with sludge-thickening pickets provided a combined clarifier and thickener and produced an underflow of maximum solids concentration. This is important for proper sludge dewatering.

Corrosion protection was found to be another very important consideration. Bacterial decomposition of the settled sludge will lower the pH, and sometimes it is impossible to prevent the pH from dropping to 4 or even 3, a problem especially for plants using steam peeling, and sometimes with wastes from caustic peel plants. Two or three heavy coats of epoxy-tar paint were found effective in protecting both steel and concrete structures submerged in the clarifier.

Many investigators have reported on the actual performance of primary clarifiers. Kueneman (1965) reported suspended solids and BOD reductions of 93 and 70 percent, respectively in an Idaho plant with steam peeling. A plant with lye peeling was reported to obtain 66 percent COD removal. Pailthorp and Filbert (1965) reported 58 percent removal of suspended solids and 44 percent removal of BOD in another lye peeling plant. Olsen et al. (1965) studied the performance of a clarifier treating waste from a chip plant in North Dakota. Suspended solids removal was 92 percent and BOD removal was 63 percent. Primary clarification of potato flour processing waste gave 83 percent suspended solids removal and 51 percent BOD removal. Wastes from the J. R. Simplot Company's plants at Heyburn and Burley, Idaho, are treated in a 100 ft diameter clarifier with an overflow rate of about 800 gal/day/sq ft. Dostal (1968B)reported 37 percent BOD reduction for this unit. Both plants are using lye peeling. Performance data from Simplot's plant at Caldwell, Idaho, has been presented by Grames and Kueneman (1968). The primary treatment plant consists of grease removal facilities, three rotary screens with 4-mesh cloth, and a clarifier 100 ft. in diameter with 12 ft. side water depth. Based on the reported flow rate the overflow rate is about 730 gal/day/sq ft. Average removal efficiencies for the 1967-68 operating season were: COD - 62.2%; suspended solids - 93.5%; and settleable solids - 95.2%.

Flocculation and Sedimentation

Little has been reported on flocculation of potato wastes prior to sedimentation. Flocculation has been found to increase the removal efficiency of clarifiers markedly when treating domestic waste as well as industrial waste.

Mechanical flocculation is accomplished by gently stirring the waste with rotating paddles, thus causing the finely divided particles to coalesce into larger flocs with improved settling characteristics. Flocs so produced are easily broken up by too rapid stirring, and the most efficient peripheral speed of the flocculator has been reported to be 1.4 ft/sec (Klein 1966). Hurley and Lester (1949) obtained 20 percent increase in clarifier removal efficiency by mechanical flocculation prior to sedimentation. It has been indicated that return of some of the settled sludge may be beneficial in some cases (Klein 1966).

Chemical flocculation or coagulation is used more extensively in waste treatment. The addition of certain chemicals to the waste followed by gentle stirring, results in the formation of an insoluble flocculent precipitate, which adsorbs and carries down suspended and colloidal matter. Chemicals commonly used include lime, aluminum sulphate, copperas, and various ferric salts. The cost of the chemicals makes this method considerably more expensive than mechanical flocculation, but higher removal efficiencies are obtained.

In potato processing, coagulation is used to recover protein from the fruit water of the starch process, as discussed earlier. Heating of the protein water is also used to coagulate and precipitate protein.

Flocculation prior to sedimentation deserves more attention as a treatment method for potato wastes than it has received thus far. Experiments with oxidized lignite and other coagulants have been performed in North Dakota with some success (Fossum 1965).

Flotation

Flotation is another solids removal method which has not been used to any extent in potato waste treatment.

The waste or a portion of the clarified effluent is pressurized to 40 to 60 psi in the presence of sufficient air to approach saturation. When this air-liquid mixture is released at atmospheric pressure, minute air bubbles are released from solution. The rising bubbles adhere to or are trapped by the suspended solids and sludge flocs and float them to the surface where they are skimmed off.

The process is used by a potato processing plant in Presque Isle, Maine, and the removal efficiency of settleable solids has been reported to be as high as 86%. However, since the calculations are based on a volume per unit volume measurement (ml/l) it is difficult to compare this result with removal efficiencies based on weight per unit volume measurements. (mg/l) (Ballance 1965)

A pilot plant study was carried out by the Potato Products Waste Disposal Executive Committee for the Red River Valley area of North Dakota and Minnesota. The flotation unit was a standard Permutit colloidair unit with a capacity of 80 gallons per minute. Reductions in suspended solids of from 86 to 94 percent and BOD of from 66 to 75 percent were obtained. Lye peeling wastes were used. (Francis 1962)

The primary treatment investigations in Idaho considered flotation as a possible method, but it was concluded that because of the expense and operational results obtained this method was not feasible. (Grames and Kueneman 1968)

Centrifugation

Dickinson (1965) pointed out the advantages of treating potato waste, particularly flume and wash water, by centrifugation. A centrifuge conserves space and delivers the solids in a relatively dry state. Furthermore, any risk of anaerobic decomposition in settling tanks is avoided.

The investigation carried out in Idaho did not find centrifugation a feasible replacement for conventional clarification. (Grames and Kueneman 1968)

Secondary Treatment

Secondary treatment at the present is not being used to any extent by the potato processing industry. Stricter water quality criteria in the future will, however, require higher degrees of treatment. Thus, the Idaho Department of Health has asked that processors now using primary treatment plants be prepared to supplement these with secondary treatment in the future. (Cornell, Howland, Hayes and Merryfield 1966)

Biological Treatment

Since biological treatment depends on the activity of microorganisms, such treatment can be effective only when the environmental conditions are favorable to growth. Potato processing wastes do not always provide a suitable environment for microorganisms. Most organisms are sensitive to extreme pH values, and wastes from a lye-peeling plant thus may present problems. Potato wastes also are generally deficient in two essential nutrients, nitrogen and phosphorous. These factors must be considered carefully in the design of any biological treatment facility.

Activated Sludge

No reports on large scale installations of activated sludge treatment of potato wastes could be found in the technical literature, but several workers have reported on pilot plant studies.

Anderson (1961) has reported on early activated sludge treatment of wastes from a plant using lye peeling. The system, which provided for about 4 days aeration time, settling, and sludge return, could not remove more than 50 to 60 percent COD without nutrient addition. Batch treatment by aeration and settling with detention times of 2 and 4 days gave COD reductions of 49 and 82 percent, respectively, when pH was adjusted to 7.0 and nutrients were added. The conclusions from the study were that pH adjustment of lye peel wastes prior to activated sludge treatment is not necessary, but addition of nitrogen and phosphorous will increase the treatment efficiency.

Atkins and Sproul (1964) studied the feasibility of treating the combined wastes from a processing plant using lye peeling by the complete mix activated sludge process. The plant produced several types of French fried products as well as prepeeled uncooked potatoes.

Straight potato processing waste as well as waste adjusted to pH 8 were treated in bench scale units. Treatment of the pH adjusted waste at a detention time of 8 hours and mixed liquor suspended solids (MLSS) concentration of 4000 mg/l gave BOD removals ranging from 85 to 99 percent. Most of the time the efficiency was above 97 percent. Suspended solids removal was approximately 90 percent. The organic loading varied from 234 to 413 lb BOD/1000 cu ft/day. The straight potato waste (no pH adjustment) was treated at detention times of 6 and 12 hours at a MLSS concentration of 4000 mg/l. With organic loadings from 191 to 358 lb BOD/100 cu ft/day and 6 hours detention time, BOD removals from 96 to 99 percent were obtained. The COD removals ranged from 71 to 94 percent. The suspended solids concentration was generally reduced by more than 90 percent. For the 12 hour detention time, organic loading ranged from 65 to 276 lb BOD/1000 cu ft/day. No improvements in removal efficiency over the runs at 6 hours detention time were observed. It was concluded that pH adjustment of potato wastes prior to activated sludge treatment is unnecessary, since the production of carbon dioxide with subsequent formation of carbonic acid is sufficient to offset the high alkalinity and thus reduce the pH of the mixed activated sludge to a tolerable level. The unadjusted influent waste had a pH of 11.5, while the effluent pH had been reduced to about 9.0.

Based on the results reported above, Sproul (1965) recommended the following design criteria:

Organic loading: 200-400 lb BOD/1000 cu ft/day

Mixed liquor suspended solids concentration: 3000-4000 mg/l

Detention time: 8 hours

No pH adjustment is necessary

Cornell, Howland, Hayes and Merryfield, Consulting Engineers, (1966) have reported results of a pilot plant study for the Potato Processors of Idaho Association. It was found that the complete mix activated sludge system performed best at loadings below 150 lb BOD/1000 cu ft/day. At a temperature of 60°F BOD removals above 90 percent were obtained. At lower temperatures the treatment was less efficient. This is in agreement with Eckenfelder (1966) who has presented an equation by which a temperature correction factor can be estimated. Foaming was a problem with loadings in excess of 150 lbs BOD/1000 cu ft/day. When operating at this loading, excess sludge production is high. About one pound of biological solids will be produced per pound of BOD removed. Because it is difficult to concentrate activated sludge in a clarifier beyond one percent, a large volume of excess sludge would result, and present another disposal problem. Treatment of one million gallons of waste with a BOD concentration of 2000 mg/l would result in approximately 180,000 gallons of 1 percent solids excess sludge. This sludge can be concentrated to about 4 percent solids in a flotation type thickener and, after chemical conditioning, further concentrated to about 18 percent solids by centrifugation or vacuum filtration. This would reduce the volume of excess sludge to 10,000 gallons. It was further pointed out in the report that nutrient addition and chlorination would probably be necessary in a full scale activated sludge plant.

Bench scale studies on completely mixed continuous flow activated sludge systems for French fry processing waste and French fry waste in combination with starch processing waste has been made by the Edward C. Jordan Company, Engineers and Planners, Maine. (Hunter 1969) With a mixed liquor concentration of 3000 mg/l and a detention time of 7 hours, BOD removals of 90 percent were obtained. The growth rate constant, K_s, was found to be 0.000425. A limited sludge production study indicated a range of from 0.65 to 1.0 lbs of volatile solids produced per lb of BOD removed. The lower figure was found for the French fry waste, while the higher value was for the combination of French fry and starch wastes. The waste from the French fry plant, which used steam peeling, had been settled for removal of suspended solids and about 40 percent of the BOD.

Buzzel et al (1964) studied the treatment of protein water from a potato starch plant by the complete mix activated sludge process. It was found that protein water contains sufficient nitrogen and phosphorous for biological treatment. The data collected indicated that whenever the loading intensity was less than 80 lbs of BOD/day/ 1000 lbs of suspended solids/hour of aeration, the BOD removal would exceed 90 percent. The loading in terms of BOD/1000 cu ft of aeration capacity/day would be 420. At higher loadings the removal efficiency decreased rapidly. Foaming was a problem and was found to increase with decreased detention time.

Weaver et al. (1953) have reported high removal of COD from protein water. The waste was aerated vigorously at 30°C with 12 hours detention time. With an initial COD of 4050 mg/L the removal efficiency was 79 percent.

At the time this report was prepared a full-scale complete mix activated sludge plant was started up at the Pillsbury Company's processing plant at Grafton, North Dakota. (Michaelson 1969) The design loading was 400 lbs BOD/1000 cu ft/day with a detention time of 5 hours. A sludge thickener designed for a solids loading of 8 lbs/sq ft/day was included. The effluent from the treatment facilities, which was expected to have a BOD concentration of 200-400 mg/L, was to be discharged to the Grand Forks municipal sewer for final lagoon treatment before discharge into the Red River of the North.

Atkins and Sproul (1964) also investigated the possibility of using the contact stabilization process. With a contact time of one hour and reaeration time of 6 to 8 hours, 80 percent of the BOD was removed. The results were obtained in a batch unit at a mixed liquor suspended solids concentration of 4000 mg/L and with the pH of the waste adjusted to 8.0.

Based on these experiments Sproul (1965) presented the following tentative design recommendations:

Contact time = 60 min.

Reaeration time = 6-8 hours

Mixed liquor suspended solids = 3000-4000 mg/L

Some pH adjustment by acid may be necessary, but wastes with pH values of 9.0 to 9.5 could probably be handled successfully.

The pilot plant study by Cornell, Howland, Hayes and Merryfield (1966) also included contact stabilization. It was found that the process was capable of about 60 percent BOD removal at loadings up to 480 lbs BOD/1000 cu ft/day, when operated at a contact time of one hour and a reaeration time of 10 hours. Reducing the reaeration time to 6 hours caused a decrease in removal efficiency to about 50 percent. The results were obtained at a temperature of 70°F. Foaming in the contact basin was a problem. It was stated that nutrient addition probably would be required in a full scale plant. Excess biological solids produced by contact stabilization treatment amounted to about 1.3 pounds per pound of BOD removed, and possessed the same characteristics as sludge produced in the complete mix process.

Kintzel (1964) has reported on laboratory treatment of potato starch waste water by contact stabilization. Seventy percent BOD removal was obtained after a contact time of 5 minutes. The removal increased to 90 percent after 30 minutes. The whole process had a combined detention time of 2.5 hours.

Pasveer (1965) has found the oxidation ditch effective for treating domestic waste as well as industrial wastes. The oxidation ditch is a modification of the activated sludge process, similar to the extended aeration process. The ditch is simple to construct, and the most common form is a ring-shaped circuit or ditch. Aeration and circulation in the ditch are provided by one or more partially submerged rotors. The ditch can be loaded at up to 34 lbs BOD/1000 cu ft/day and still provide essentially complete oxidation of the waste.

Biological Filtration

A considerable amount of pilot plant work has been done on the application of trickling filters for secondary treatment of potato wastes. The most recent investigations have employed artificial filter media, which have proven superior to the stone media used earlier.

Buzzel et al. (1964) studied the treatment of protein water by standard and high rate biological filters using rock media. The standard filter gave BOD reductions of 90 percent and above at loadings up to 1300 lbs BOD/acre ft/day (30 lbs BOD/1000 cu ft/day). The hydraulic loading rate was rather low because of the high BOD of the protein water. Large reductions in acidity were obtained at all loadings. The effluent alkalinity was reduced over the influent but generally increased in response to the organic loading to values on the order of 200 to 300 mg/l. The pH of the effluent was generally between 7 and 8.

With the high rate filter, BOD reductions of 90 percent and above were obtained at organic loadings up to 3000 lbs BOD/acre ft/day (69 lbs BOD/1000 cu ft/day). The recirculation rate was 10. At higher loadings the filter became clogged with sloughed biological solids. Since the filter media consisted of rather small rocks, of 3/4 inch diameter, it was felt that the practical upper limit of organic loading was not reached in the study. A full scale filter with larger rocks, and thus larger interstices, would permit the passage of a greater amount of sloughed material without clogging.

Pailthorp and Filbert (1965) reported results of a pilot plant study for the Potato Processors of Idaho. The pilot unit used a synthetic media, Surfpac, which is a polystyrene plastic media made by the Dow Chemical Company. The unit was classified as a super-rate filter, and was operated with a recycle ratio of 6. At an organic loading of 132 lbs BOD/1000 cu ft/day the BOD reductions were 71 percent with no settling and 85 percent with settling. No nutrients were added to the waste before treatment. The influent pH was about 9.0.

Cornell, Howland, Hayes and Merryfield (1966) have reported on further studies with the same pilot plant. It was found that the Surfpac unit operated most satisfactorily at a BOD loading of about 400 lbs/1000 cu ft/day; the filter appeared capable of removing 300 lbs. Although the recycle ratio was varied during the course of the study, no valid relationship could be established between percent BOD removal and recycle rate. It was recommended that full scale installations be designed for a minimum recycle ratio of 3 with provisions to permit increasing the ratio to 7. Addition of nutrients was found to be advantageous. It was not found necessary to adjust the pH of lye peel process water. Treatment of steam peel wastes may require addition of an alkaline substance when the loading exceeds 400 lbs BOD/1000 cu ft/day, to prevent the pH of the system from dropping below 6.3 to 6.5. Excess solids production was found to be on the order of 0.6 to 0.8 lbs per pound of BOD removed when operating at loadings around 400 lbs BOD/1000 cu ft/day. This sludge could be concentrated to about 3 percent solids by gravity and further concentrated by flotation. One million gallons of waste with a BOD of 2000 mg/l would yield 5000 gallons of 18 percent solids excess sludge. It was further stated that chlorination of the effluent would most likely be required to meet state requirements on coliform counts.

Mercer et al. (1964) used a Surfpac pilot plant for secondary treatment of peach and pear canning waste. The influent and effluent samples were settled for 15 minutes to simulate primary and secondary clarification. The raw waste had a pH of 10.5, and the effluent pH was 6.2. The results of the study is presented in the following table:

TABLE XV

TRICKLING FILTRATION OF PEACH AND PEAR CANNING WASTE

Flow, gpm/ft^2		BOD, mg/l		BOD, lbs/1000ft^3/day		Percent
Raw	Recycle	Influent	Effluent	Loading	Removal	BOD Removal
0.14	2.0	4033	580	316	273	86
0.42	2.0	3200	1395	730	410	56
0.72	2.0	2700	1800	1060	350	33
1.0	1.0	3210	2040	1760	630	36
1.0	1.0	2750	1515	1510	680	45[1]

[1]Nutrients added (20 lbs diammonium phosphate per 24 hours)

Norman et al. (1965) compared the use of the activated sludge process and the plastic media trickling filter as roughing treatment for beet sugar waste. Overloading the activated sludge unit to obtain only 50 percent BOD removal caused the formation of bulking sludge, and it was concluded that this process was not feasible for such treatment. The trickling filter gave BOD removals of between 33 and 50 percent on once through passes at loadings of 400 to 230 lbs BOD/1000 cu ft/day.

Sak (1967) has reported operating results from full scale installations as well as pilot plants employing Surfpac media to treat a variety of industrial wastes.

Hatfield et al. (1956) treated corn processing waste by super rate biofiltration in a two stage filter system. An artificial filter media, "Aero Block," consisting of clay blocks with vertical openings of 1 inch diameter and made by the Red Wing Sewer Pipe Corporation was used in the filter. The BOD of the waste ranged from 500 to 2000 mg/l with an average of about 900 mg/l. The pH of the waste, which was predominately acid, was adjusted to between 6.5 and 8.5 with soda ash. Nitrogen and phosphorous were added to the waste prior to treatment to give ratios to BOD of 1 to 20 and 1 to 75, respectively. At BOD loadings up to 150 lbs/1000 cu ft/day and a recycle ratio of 10, BOD removals above 94 percent were obtained. Similar removals were obtained with BOD loads up to 110 lbs/1000 cu ft/day when the recycle ratio was 5.

The Anaerobic Filter

The anaerobic filter offers promise as a prospective treatment facility for certain potato processing wastes. While conventional anaerobic digestion is limited to wastes of high strength and solids content at relatively high temperatures, the anaerobic filter has performed well at nominal temperatures with relatively dilute, soluble wastes.

The anaerobic filter, which is similar to the aerobic trickling filter in appearance, has upward flow so that the rock media is completely submerged. The anaerobic organisms are attached to the stones as well as suspended as discrete particles in the interstitial spaces. High solids retention time (SRT), which is an important operational parameter in anaerobic treatment, is easily obtained in the anaerobic filter, and is on the order of hundreds of days (Carlson 1968B). A gradual accumulation of solids may take place to the point where solids wasting may be required.

Recent studies have indicated the feasibility of the anaerobic filter. Young and McCarty (1968) obtained BOD removals ranging from 60 to 99 percent when treating either simple volatile acids or complex protein - carbohydrate wastes. The BOD concentration of the wastes ranged from 500 to 8000 mg/l, and the filter was loaded up to 150 lbs BOD/1000 cu ft/day at a temperature of 25°C. The treatment efficiency was found to be inversely proportional to the hydraulic detention time, which was varied from 4.5 to 72 hours. The filter could be operated from several months to years without requiring solids wasting, and the effluent suspended solids concentration was sufficiently low so that subsequent settling was not required. Shock loadings did not appear to have adverse effects, as the filter recovered very rapidly. Some possible limitations mentioned were:

(a) The filter is best suited for treating completely soluble wastes, (b) a significant fraction of carbohydrates in the waste may require solids wasting, and (c) hydrogen sulfide produced from sulfate reduction may cause odor nuisances, corrosion problems, and may be toxic to anaerobic treatment.

Caudill (1968) studied the treatment of dilute wastes by the anaerobic filter. Soluble, synthetic sewage with a COD of 300 mg/l was treated at 26 and 37°C, and removal efficiencies of 67 and 80 percent were obtained, respectively. Potato starch waste with a COD of 300 mg/l was treated at 37°C. Removal efficiencies of 76 percent was obtained with this waste. The theoretical hydraulic detention time for these wastes was 1.64 days and the loading was 5.1 lbs COD/1000 cu ft/day. Treatment of a more concentrated starch waste (COD of 1000 mg/l) gave COD reductions of 78 percent at 30°C. It was found that most of the COD removal took place in the first 10 inches of the 6 inch diameter column used in the study. Also, most of the microorganisms were found suspended in the liquid rather than attached to the rock media.

Webster and Carlson (1968) used the anaerobic filter for treatment of pulp mill sulfite waste liquors. The temperature was held at 110°F and the initial BOD was about 30,000 mg/l. At detention times of about 4 days and recycle rates of 8:1, BOD reductions up to 90 percent were obtained. The COD removal was about 25 percent. High gas production was experienced. The gas consisted mainly of methane and hydrogen sulfide. Odor control by soil columns was suggested.

Extensive pilot plant studies for the Potato Processors of Idaho Association on the application of anaerobic filters to potato processing waste were completed recently by Cornell, Howland, Hayes and Merryfield (1969). Two 5-foot diameter filter units were tested, one with a 4-foot rock media depth and the other with an 8-foot depth. The pilot plant feed consisted of primary treated process water from the J. R. Simplot Company's Heyburn and Burley plants. This is a combined waste from lye peeling operations, potato processing, and potato starch production. The pH of the primary treated waste varied with the operation of the clarifier from about 7.5 to about 11.0 with a median value of 10.2. Average organic removals of almost 70 percent were obtained at loadings of 100 lbs COD/1000 cu ft/day. This corresponds to a BOD loading of 57 lbs/1000 cu ft/day, according to the average COD/BOD ratio determined. Average total suspended solids removal at this loading was about 60 percent. Almost identical treatment efficiencies were obtained in both filters. The average temperature of the filter influent was 25°C, while the effluent was at a slightly lower temperature. It was estimated that a full-scale installation would operate at approximately 20°C. Only occasional additions of alkalinity in the form of sodium bicarbonate were necessary to adjust the pH in the feed to the filters. It was expected that alkalinity addition would not be required when operating the filter under stable conditions on potato processing waste, including wet lye peeler discharge. The gas produced in the filter had a methane content of more than 70 percent. This gas is combustible, and, in a full-scale plant, could be used for energy production.

The organic removal efficiencies of both filters were found to increase over the test period without regard to loading, temperature, or detention time, indicating that the anaerobic bacteria were continuing to build and becoming further acclimated as the test progressed. It was expected that the acclimation period, from start-up until efficient operation is experienced might take two to three weeks. During start-up, alkalinity should be added to act as a buffer against pH drop from volatile acids production, and fresh anaerobic seed should be added to provide the system with methane bacteria. The effluent from an anaerobic filter should be passed through a short-term, flow-through aeration basin to provide additional organic removal and render the effluent suitable for discharge to a receiving stream. With primary treatment, this system appears capable of 90 percent BOD removal.

Ponds

Pond treatment of domestic sewage as well as industrial wastes is common around the world, and there are several reports of application of this treatment method to potato processing wastes on a pilot plant basis and in full scale ponds. Ponds are often designated by various names, such as lagoons, oxidation ponds, stabilization ponds, and waste conversion ponds. Dugan and Oswald (1968) classified the different types of ponds as follows:

Aerobic ponds - Those ponds in which only the reactions above the point where dissolved oxygen becomes zero (termed the oxypause) occur, which provide aerobic oxidation and photosynthetic oxygenation.

Facultative ponds - Ponds in which an aerobic zone exists in the surface strata and an anaerobic zone exists in the lower strata.

Anaerobic ponds - Ponds in which the anaerobic reactions below the oxypause are the predominant ones.

The aerated lagoon is a fourth type, where oxygen is supplied by diffused or mechanical aeration systems, which also cause sufficient mixing to induce a significant amount of surface aeration.

Aerobic and Facultative Ponds

Aerobic and facultative ponds depend upon the photosynthetic capabilities of algae to provide the oxygen required to satisfy the BOD applied. Some surface aeration from wind action also occurs. Since sunlight is essential for algae, the depth of the ponds is limited. In aerobic ponds the waste material is stabilized wholly through aerobic oxidation. The depth is therefore limited to that through which sunlight will penetrate. For most wastes this will not exceed 18 inches. (Eckenfelder 1966) Extremely large surface areas are therefore required. Most existing ponds are facultative. In facultative ponds, settled solids undergo anaerobic decomposition in the bottom layers, while aerobic oxidation takes place in the upper layers. Serious odor problems will not develop if adequate depth is maintained and an upper aerobic environment is predominant. The depth of facultative ponds is seldom greater than 5 feet.

Since both aerobic and facultative ponds are highly dependent upon algal photosynthesis, the environmental factors affecting the growth rate of algae must be considered carefully in pond design. Gloyna (1968) has presented design criteria for the various classifications of ponds.

Cornell, Howland, Hayes and Merryfield (1966) carried out studies on 3 foot deep pilot size ponds. It was found that the BOD loading to the ponds should be kept well below 80 lbs per acre per day. This is within the conventional loading range and it was concluded that aerobic ponds for potato waste be designed according to the criteria used for domestic sewage ponds.

Porges (1963) made a survey of industrial waste ponds in the United States in 1962. He reported three ponds treating potato processing waste. The median loading to these ponds was 111 lbs BOD/acre/day, and the median detention time was 105 days. The ponds had an average depth of 5 feet. No BOD removal efficiencies were reported, but one of the installations was reported effective while another caused odor nuisances.

Fossum et al. (1964) presented data collected over a 40-month period on the operating characteristics of two ponds for the municipalities of Park River and Grafton in northern North Dakota. Both ponds had been heavily overloaded by potato processing wastes during the processing season. The ponds were ice covered during the winter and acted merely as storage ponds during this period. The accumulated organic load had to be stabilized during the summer months. It was found that potato processing wastes combined with domestic sewage digest readily in these ponds, when the organic loading from potato wastes was 15 times or more the organic loading from domestic sewage. Digestion may be aerobic or anaerobic. Anaerobic digestion in these shallow ponds caused severe odors. During summer conditions, potato waste and domestic sewage could be applied at rates well above the conventional design loading for northern climates of 20 lbs BOD/acre/day. Although no specific loading recommendations could be made from the study because of the "diametrically opposed" operating season for the processing plant and the pond, it was indicated that loadings on the order of 50 to 60 lbs BOD/acre/day might be possible. The ponds remained aerobic until the BOD in the ponds exceeded 200 mg/l. Once anaerobic conditions were established, the ponds did not convert back to aerobic operation until the BOD fell below 100 mg/l.

One reason for the extended anaerobic period was found to be the wave damping effect of potato organics, reducing surface reaeration. Although the ponds have been subject to serious complaints because of the odors produced, they carried loadings far above what might have been expected possible, and certainly much higher than their design loading.

Olson et al. (1965) have commented further on the over loading of the Grafton ponds. The increased loading of the ponds presented the problem of growth of the purple sulphur bacterium, Chromatium. Due to the extended anaerobic period, the Chromatium was selected out by the pond. This photosynthetic organism utilizes the hydrogen sulfide released from anaerobic decomposition in the pond. It was observed that BOD removal from the pond was about the same during the growth of the sulphur bacteria as during the later period of algal growth, but the purple color from the photosynthetic pigments of the bacterium gives the lagoon a purple color. The pigmentation and anaerobic nature of the Chromatium prevent the growth of algae. It thus seems that the growth of purple sulphur bacteria could be a good indicator of an overloaded pond.

Voege and Stanley (1963) have reported on the use of industrial waste stabilization ponds in Canada. A cannery in Vancouver, B.C., processing peas and beans, used 4 ponds in series, with depths varying from 2 to 5 feet. The influent was passed over a 20-step aeration deck along with recycled effluent. The temperature of the waste varied between 57 and 72°F, and the pH was controlled between 6.5 and 8 by adding lime at the aeration deck. Assuming no substantial removal on the aeration deck, the BOD loading was about 1400 lbs/acre/day and the removal efficiency about 87 percent. The effluent had a bright green color and a BOD of about 100 mg/l. It was finally discharged to spray irrigation fields.

Anaerobic Ponds

Although anaerobic ponds have been used quite extensively for treatment of food processing waste, they have not been used with much success by the potato processors. Porges (1963) reported that, in 1962, 3 anaerobic ponds were used in the United States for treatment of potato wastes. No information was given on the efficiency of these ponds, but it was reported that odor nuisances were associated with one of them.

Other industrial wastes have been treated successfully with anaerobic ponds. Howe and Miller (1963) used an anaerobic pond to treat wastes from a chemical and fermentation products plant. With a BOD loading of 2.6 lbs/1000 cu ft/day a removal efficiency of 60 percent was obtained at a temperature of 5°C. At a temperature of 15°C the removal efficiency increased to 78 percent. To obtain this efficiency it was necessary to adjust the pH to 6.8 to 7.2. Nitrate was added to prevent formation of hydrogen sulfide.

McIntosh and McGeorge (1964) had some success with a full scale anaerobic pond receiving corn processing waste. The pond was loaded at about 40 lbs BOD/1000 cu ft/day with sludge recirculation from the end to the inlet of the pond. After about 40 percent of the surface area of the pond was covered with a Styrofoam raft, the BOD removal was found to increase from 32 percent to 40 percent. The pond influent was at a temperature of 91 to 114°F, and this high temperature undoubtedly improved the performance of the system. Nitrate was added for odor control, and the pH was adjusted to between 9 and 11 with caustic soda.

Research efforts on potato waste treatment indicate that anaerobic ponds can be used advantageously to condition the waste for further treatment by aerobic means.

Dostal (1968B) has reported results of pilot plant studies at Burley, Idaho. Two Styrofoam covered anaerobic ponds were first operated in parallel. Pond 1, with a detention time of 4 days, was loaded at 23 lbs BOD/1000 cu ft/day, and gave BOD removals of 17 percent. Pond 2 had a detention time of 20 days and was loaded at 4.6 lbs BOD/1000 cu ft/day. A BOD reduction of 22 percent was obtained. Suspended solids reductions were 56 and 62 percent for Pond 1 and 2, respectively. The ponds were not mixed, and the temperature ranged from 60° to 70°F.

During the second period of operation the ponds were operated in series. The first pond continued to operate as an anaerobic pond, and a pump was installed to mix the contents. A 5 hp floating surface aerator was installed in the second pond which consequently operated as a mechanically aerated pond. The performance of the system under different operating conditions has been summarized below.

	Detention Time, Days	BOD loading lbs/1000 cuft/day	Removal - % SS	COD	BOD
Anaerobic pond	8.8	11	82	33	25
Aerated pond	8.8	8	-230	49	88
Overall			74	73	95
Anaerobic pond	5	22	35	15	12
Aerated pond	5	20	-75	58	87
Overall			66	82	94
Anaerobic pond	2.4	46	52	15	12
Aerated pond	2.4	40	-226	28	64
Overall			51	68	81

These results indicate excellent removals by the combination anaerobic-aerated ponds. It should be pointed out that the removal efficiencies were based on effluents with all solids remaining.

Continuing studies on the same pilot plant for the Potato Processors of Idaho Association have been reported by Cornell, Howland, Hayes and Merryfield (1966). The results from the anaerobic ponds were not conclusive with respect to design criteria, but valuable information was obtained. The ponds appeared to take the waste through the first stage of anaerobic digestion, breaking down large molecules such as starch and protein into smaller molecules of organic acids, aldehydes, and alcohols. This results in a rather small BOD reduction, but yields an effluent which is more amenable to aerobic treatment. Nutrient addition did not appear necessary. It was indicated that it would not be advisable to design anaerobic ponds at detention times less than 4 days due to the high rate of solids buildup. A pond with a 4 day detention time may possibly be operated for four seasons before cleaning is necessary, while a pond operating at a one day detention time probably would have to be cleaned annually.

The effluent from one anaerobic pond was treated in a flow through aeration basin. When operated at a loading of 130 lbs BOD/1000 cu ft/day and a detention time of 22 hours, additional BOD removal of 57.5 percent was obtained. Limited data was collected at a detention time of 11 hours, which showed similar removal efficiency. Suspended solids in the effluent were measured in amounts up to 1.2 lbs per lb of BOD removed, and consisted of dispersed bacteria, which could not be settled out at normal detention times. Nutrient addition was not necessary, but foaming was a problem, and it was recommended that provisions for defoaming agent addition be included in full scale design.

Results from continued studies on the Burley pilot plant were reported recently (Cornell, Howland, Hayes and Merryfield, 1969). The two covered anaerobic ponds were operated in parallel, one as a straight flow-through pond, the other as a mixed pond. The effluent from the mixed pond was passed through the aerated pond. The flow-through pond obtained BOD removals of about 40 percent at a loading of approximately 7 lbs BOD/1000 cu ft/day. The effluent volatile acids concentration was much higher than the influent because of incomplete biological degradation in the pond. The continuously mixed pond performed much better than the flow-through pond. Average organic removal efficiencies of more than 70 percent were obtained at loadings of about 8 lbs BOD/1000 cu ft/day. The more complete biodegradation also resulted in much lower volatile acids and suspended solids concentrations in the effluent.

The aerated pond was effective in further reducing the organic content of the anaerobic process effluent. Organic removals of almost 40 percent were obtained at a loading of about 4 lbs BOD/1000 cu ft/day.

It was stated that alkalinity in the influent, such as that derived from the wet lye peel process, would be required in anaerobic pond applications. The problems associated with inefficient operation during start-up of the system, offensive odors from the pond unless covered, and the lack of operational control were emphasized.

Olson et al. (1965) conducted pilot plant studies on combined anaerobic - aerobic treatment. Two days of anaerobic fermentation gave solids and BOD reductions of 30 and 22 percent, respectively. When the effluent was aerated for 4 and 6 days, the combined system yielded BOD reductions of 85 and 90 percent, respectively. Total solids reductions through the system were 52 and 54 percent. Future work was proposed on a bi-level pond, where a suspended air-aqua tube separates the two zones.

Aerated Lagoons

Some information on aerated lagoons has already been presented in the review of the anaerobic - aerated pond systems. However, these aerated lagoons are treating waste which has already been "conditioned," and which appears to be more amenable to aerobic treatment.

Olson and Vennes (1963) reported the results of mechanical aeration of potato processing waste and domestic sewage at Park River, North Dakota. A one acre experimental aerated lagoon was constructed to pretreat the waste prior to treatment in primary and secondary facultative ponds. During the first 6 months of operation only domestic sewage was treated. The average BOD loading during this period was approximately 380 lbs/acre/day with a detention time of 14 days. This gave BOD removals of 85 percent or more even at temperatures close to 0°C. The average pH of the sewage was 7.8.

A later operation using equal volumes of potato waste waters and domestic sewage resulted in a waste mixture with a pH of 11.6. Under this loading the aerated lagoon pH gradually shifted to 11.3. Neutralization was not feasible because laboratory studies indicated at least 70 ml of concentrated sulfuric acid would be needed per 100 ml of waste. While BOD loadings were almost 3000 lb/acre/day at a 6 day detention time, the decrease of BOD removal efficiency to 25% was attributed to the high pH. It was evident that the aerated lagoon was limited in its ability to reduce the pH of the mixed waste, and some form of pH control would be required for this lagoon to be effective as a pretreatment unit. It was suggested that recirculation from the primary pond might provide the necessary buffering. In-plant pH control was also suggested. The use of steam peeling rather than lye peeling will provide a waste with a pH more suitable for biological treatment.

Olson et al. (1964) also have described the results of installing an aerator in one of the two ponds at Grafton, North Dakota. These ponds are ice covered in the winter, and stabilization of the organic matter takes place in the summer. Anaerobic conditions prevailed during a large part of the stabilization period, and odors have been a problem. Aeration was found to shorten the anaerobic period considerably, and although insufficient oxygen was supplied for complete stabilization of the organic matter, the purple sulfur bacteria were removed much easier and an active algal population was restored. It was indicated that by keeping the pond open during the winter months it might be possible to maintain the algal population throughout the year.

Other industrial wastes have been treated successfully in aerated lagoons. Dostal (1968C) reported results from the operation of a lagoon treating pea processing waste in Washington. The pond which had a surface area of 1.75 acres, an average depth of 10 feet, and a volume of about 5.6 million gallons, provided a detention time of 5.5 days. Oxygen was supplied by four 50 horsepower surface aerators. The effluent from the aeration basin flowed into a smaller polishing pond. Recirculation of settled solids from the polishing pond back to the aerated pond was intended, but this practice was never initiated. According to values reported the BOD loading to the aerated pond ranged from 3000-4400 lbs/acre/day (7.0 to 10.3 lbs/1000 cu ft/day). The influent temperature ranged from 17°C to 30°C with a pH range from 6.7 to 8.2. An average BOD removal of 76 percent was obtained, while total solids were reduced by 20 percent. Suspended solids were found to increase by 70 percent through the lagoon. The polishing pond had little effect on the degree of treatment as it readily filled with solids. Bulking sludge was a problem and was thought to be due to the seasonal operation of the processing plant. Improved operation of the lagoon prior to processing was expected to better the condition of the sludge. Recirculation of settled solids would improve the removal efficiencies of the system.

Butler and Burns (1968) presented operational data from a lagoon treating unbleached kraft pulp mill effluent in Pennsylvania. Two aeration basins in series, designed for a detention time of 1.5 days each, were followed by a settling basin with 9 hours detention time. The design loading was 5 lbs BOD/1000 cu ft/day. Three 20 horsepower surface aerators were installed in each aeration basin, and underflow from the settling pond was recirculated back to the inlet of the aeration basin. Average BOD removal during the first year of operation was 85 percent. This was obtained with a loading of 4.2 lbs BOD/1000 cu ft/day and a detention time of 3.72 days. The effect of seasonal temperature fluctuations was reported. During the summer, fall, and winter, when the average temperatures were 30°C, 25°C, and 18°C, respectively, the BOD removals were 88%, 83.7%, and 81 percent. Nutrients in the form of 30% aqua ammonia and 70% phosphoric acid were added to give BOD:N:P ratios of 240:3:1. These high ratios made the addition of a defoaming agent necessary.

Spray Irrigation

Spray irrigation has been used successfully by many processors as a method of final disposal of waste water from fruit and vegetable processing. Successful operation of spray irrigation fields is dependent on the capacity of the receiving site to absorb the waste water. Among the variables influencing soil receiving capacity are type of soil, stratification of soil profile, depth to ground water, initial moisture content, and cover crop. Waste water characteristics also are important.

General design criteria or recommendations cannot be stated for spray irrigation because of the variables involved, and most systems must be designed with considerable flexibility. Results and recommendations from some successful applications of spray irrigation will be presented.

Szebiotko (1965) reported that agricultural use of the effluents from potato starch plants was found to be the most effective and economical method of disposal in Poland. It was calculated that one million gallons of effluent is sufficient to irrigate about 3.5 acres of grassland. The effluent, which has a very high fertilization value, is free of substances harmful to soil and plants. Spray irrigation was found most effective when used on grassland, and the optimum annual dose was reported to be from 200 to 500 mm (8 to 20 inches). With high doses (800 to 1000 mm per year) the grass plants disappeared after 2 to 3 years, and nettles, which tolerate higher doses of nitrogen, appeared.

Adler (1965) reported spray irrigation to be the best and most economical method for disposal of potato starch processing waste water in Germany. One plant was reported to produce from 90 to 130 million gallons of dilute potato "fruit" water during the 90 days of operation. The water was sprayed on an area of 620 acres, which corresponds to a loading of 145,000 to 210,000 gallons per acre. A three-year rotation program was used, so that a total area of 1860 acres was required. The importance of soil characteristics and fertilizer value of the waste stressed.

Successful spray irrigation of effluents from fruit and vegetable canneries in Britain has been reported by Dickinson (1965). A small producer of pre-peeled, packed potatoes sprayed a volume of 14,000 gallons per day on an area of 1 acre. The effluent had a BOD of 3600 mg/1, a suspended solids concentration of 1300 mg/1, and a pH of 11.8. A 7-day rotation program was used, requiring a total land area of 7 acres.

Rose (1965) presented recommendations regarding application rates and cover crops. For different soil types and drainage conditions the following application rates were recommended: (from Maryland Processors' Report, Vol. 11, No. 12, March 1965)

Soil Type	Drainage	Inches per Hour
Galestown S. L.	Excessive	1.0
Sassafrass L. S.	Well	0.6
Matapeake Silt	Well	0.4
Keyport Silt	Mod. Well	0.3
Elkton Silt	Poorly	0.2
Bayboro Silt	Very Poorly	0.2

Without adequate vegetation excessive soil erosion or surface run-off will occur. It has been reported that, without cover crop, the amount of liquid taken up by the soil will be only 10 to 15 percent of the amount which can be absorbed by a field with a cover crop. A cover crop mixture which has proven to be satisfactory over a wide range of soils and operating conditions is as follows:

Ladino clover - 1 lb/acre

Aisike clover - 4 to 6 lbs/acre

Reed canary - 6 to 8 lbs/acre

Haas (1968) reported on successful spray irrigation of potato processing wastes at Moses Lake, Washington. A spray field of about 120 acres covered with a mixture of grasses and alfalfa was used. The cover crop was cut, cured, and baled twice per year, but it was pointed out that this probably should be done more often. A preliminary survey showed the soil to be loam with 2 to 4 feet of top soil followed by a broken layer of caliche and gravel about one foot thick with sand below. A compacted clay mixture with sand was found 6 to 7 feet below the surface. The water table was, in one place, found to be 6 to 7 feet down. The waste consisted of fluming water and primary wash water as well as process water. Prior to disposal, larger solids were removed on a 20-mesh vibrating screen, and silt was removed in a settling basin. The total flow to the spray field was about 840 gpm. This corresponds to an application rate of 0.35 inches per day or 100 inches per year. A ten-day rotation program was used. The spray field received between 5 and 6 million pounds of organic solids per season.

Drake and Bieri (1951) reported on spray irrigation of vegetable canning wastes at several plants in Minnesota. One plant, processing peas and corn, reported successful disposal of an estimated 16 million gallons to a 72 acre annually cropped field. The waste was passed through a 20-mesh rotary screen before being pumped to the spray field. The soil was a silty loam underlain with clay.

Another cannery, also processing peas and corn, experimented with spray irrigation of lagooned waste mixed with fresh waste. The soil in this area was a heavy-black loam underlain with clay. The average application rate was one half inch per day and the rotation cycle took 8 days. When the lagooned wastes were sprayed, objectionable odors occurred. This was not noticeable when fresh wastes were sprayed. Similar problems occurred at another plant employing a storage lagoon during part of the processing season. The odors at this plant did not appear to be as serious, probably because of the more suitable sandy soil.

Luley (1963) reported results of an unusual application of spray irrigation for disposal of tomato, peach and apple processing wastes. The land area used had a slope varying from 2 to 12 percent. The soil was a silty clay mixed with shale, underlain with layers of shale at 1 to 2 feet below the surface, so that very little water infiltrated the ground. The waste which was sprayed on the field trickled slowly over and through the vegetation on the sloping terrain, which consisted of honeysuckle and reed canary grass, and flowed down to a creek. It was found, from average results over one year of operation, that the BOD of the run-off to the river had been reduced by 97 percent. To prevent soil erosion, the steepest slopes had been contour-plowed. The spray system provided at least 2 days rest for the ground between 24-hour spray applications. The land area used was about 52 acres, and the average BOD of the raw waste was 1095 mg/l or 2196 lbs/day. This corresponds to a loading of 4600 gallons/acre/day. The spray field was operated during the winter as well as during the summer. Some icing of the field occurred during the winter, but, although the BOD reductions were somewhat lower, they were quite acceptable.

It should be emphasized again that the results presented above are valid only under the respective local conditions. Such results may be helpful when designing new spray irrigation systems, but local conditions must be considered carefully, and flexibility should be provided.

Tertiary Treatment

As re-use of treated waste water becomes more essential, tertiary treatment of these waters will become increasingly important. The biological treatment methods, as presently used, leave significant residues in the effluents, and several physical and chemical treatment methods have therefore been investigated as a means for polishing effluents before re-use. These methods include adsorption, foam separation, electrodialysis, evaporation, reverse osmosis, coagulation, chemical oxidation, and freezing.

Adsorption - This process can effectively remove COD-bearing organic material. Activated carbon has been found to be the most effective adsorbent for many classes of organic substances. When activated sludge effluents are passed through beds of granular carbon, or when powdered carbon is slurried with the effluent and subsequently removed, from 70 to 95 percent of the remaining COD can be removed. The organics which are not removed are believed to be largely colloidal. Inorganic salts are not removed by carbon.

Foam separation - The foaming tendancy of secondary effluents is the basis for this process. Foam generated by deliberately blowing air through the effluent, at an appropriate rate, will contain 85 to 95 percent of the ABS and up to 35 percent of the remaining organics. The foam is collected and condensed to a small volume. Foam separation is especially effective in removing dissolved surface active contaminants like ABS. Inorganics are not removed unless they are surface active.

Electrodialysis - When a difference in potential is established across a solution of electrolytes, current will flow as a result of ion migration toward the electrodes of opposite charge. In electrodialysis, cation and anion permeable membranes are placed in alternate sequence across the electric field. The anion permeable membranes will obstruct the movement of cations toward the cathode, while the cation permeable membranes will obstruct the migration of anions toward the anode. As a result, cells are formed in alternate sequence in which the water becomes either more dilute or more concentrated with respect to the electrolytes. Electrodialysis reduces the inorganic ion concentration effectively, with exception of the ammonium ion. Some organics are also removed, but these will eventually foul the membrane, so that a rather difficult regeneration process is required. Power requirements are estimated to 6 - 10 kwh/1000 gallons of water treated for a removal of 300 to 500 mg/l of solids. Electrodialysis is already a commercially proven process.

Evaporation - Although evaporation or distillation of waste water effluents does not produce drinkable water, the process has attractive possibilities. The distillate generally contains less than 5 - 10 mg/l inorganics and 2 - 3 mg/l organic carbon. However, volatiles such as ammonia and low boiling organics are not removed. The effects of many of the operational variables are not well known, and further work is required to evaluate the feasibility of the process.

Reverse osmosis - This process has received less attention than the ones above, but nevertheless deserves to be mentioned. Relatively pure water has been produced by forcing water through semi-permeable membranes under a pressure of 750 psi. The membranes filter out organics, inorganics, and even bacteria and viruses. Water with 50 mg/l total dissolved solids and less than 5 mg/l organics can be produced.

Coagulation - Coagulation has already been described in connection with primary treatment. In tertiary treatment coagulation has proven beneficial as a pretreatment to the processes mentioned above.

Chemical oxidation - Oxidation of organics to carbon dioxide and water using chemical oxidants would be a very attractive treatment method. Short detention times and thus small waste treatment facilities would result. Also, the substances resistant to bacterial oxidation would be removed. Oxygen, ozone, chlorine, and chlorine dioxide have been tried as oxidation agents. Active oxygen in the form of free hydroxyl radicals is also a strong oxidant in aqueous systems and will oxidize organic compounds containing hydrogen and many other ions such as the halogens. This radical can be generated using iron salts and hydrogen peroxide. When this method was used to treat an effluent, refractory organics were reduced by 50 to 70 percent when the pH was controlled between 3 and 4. ABS removals of 98 percent also were achieved. However, this method of supplying free hydroxyl radicals is too expensive and further work is required to produce an economical oxidation agent.

Freezing - Freezing has received much attention as a means of converting saline water to fresh water. The process also has been investigated for treating waste water effluents. The ice crystals formed under proper conditions are relatively pure. The contaminants adhere to the crystals, and the success of the process depends on effective washing of the crystals.

Ammonia as a problem - The ammonium ion is difficult to remove from the effluent by the methods which are capable of removing inorganics. One solution to this problem is to convert the ammonia to nitrate by microbial nitrification. This is relatively easily achieved in the activated sludge process by extending the time of aeration or by operating at higher mixed liquor suspended solids concentrations. Ammonia also can be removed by air stripping at high pH.

SECTION 7

DISPOSAL OF SOLIDS

Solid waste from potato processing operations include sand and grit, peelings, trimmings, and potato pulp. Solids also are one of the end products of nearly all waste treatment processes. Effective solid waste disposal is essential for the waste treatment process to be successful. Depending upon the method used, solids disposal may result in economic return or additional treatment cost.

Complete utilization is the ideal solution to the solids disposal problem, and fortunately a large fraction of the solid waste from potato processing is suitable for use as animal fodder and even for processing into by-products of commercial value. (Shaw 1965) (Dickey et al. 1963) However, large amounts of solid waste are disposed of by other methods for economic as well as practical reasons. In some areas the demand for the solid waste products is not sufficient to warrant the capital investment. Furthermore, pesticide residues and high alkaline content may limit the usability of raw solid waste. Microbiological spoilage of food wastes presents another problem, since no economical method of preservation has been discovered. (Rose 1965)

Disposal to Sewer

Some processing plants discharge solid wastes as well as liquid wastes directly to a municipal sewer. Generally, larger solids are comminuted prior to discharge. From the processor's standpoint this is a most convenient solids disposal method. The obvious disadvantage is the greatly increased waste load to the receiving treatment facility or water way. In many instances solid waste discharge would not be permitted or would be economically unsound because of increased treatment cost.

Land Disposal

A widely used method for disposal of solids wastes is by land disposal. Strict control is essential to prevent ground water contamination, fly breeding, and odor nuisances. An important requirement is that the waste is covered with a soil layer within 24 hours. (The Cost of Clean Water 1967) Primary and secondary sludges have a very high water content and must generally be dewatered prior to disposal. The dewatering step can be omitted by applying the sludge to the land in a thin layer. Liquid sludges can easily be pumped and sprayed onto the land. The same method may be applied to the solid waste from the processing operations. This method provides low cost oxidation of organic matter, providing sufficient low cost land is available. In many instances agricultural and forest soils are improved. Odors and fly breeding may cause problems. (The Cost of Clean Water 1967)

Composting

Composting processes have long been used as a method of converting putrescible plant residues to more stable organic materials of value as fertilizers or soil conditioners. Composting also has had application as a method of solid waste disposal. Decomposition of the organic materials may proceed aerobically or anaerobically, depending upon the availability of oxygen. Anaerobic processes are slow, and offensive odor production is difficult to control. Aerobic composting is a much more rapid process and no offensive odors are produced. The process may be carried out in outdoor piles or in high-rate mechanical units. (Rich 1963)

Rose (1965) reported results of experiments on fruit waste composting by the National Canners Association. In early experiments it was found that efficient aerobic composting would proceed in a pile if the water content of the material was held below 70 percent by mixing with absorbent materials. At higher water content slow anaerobic decomposition with offensive odors was experienced. Grinding the solids greatly improved the rate of the process by exposing more surface area to microbiological attack. Fruit acids were found to have an inhibitory effect at pH levels below 4.5. By adding lime the acids were neutralized and the stabilization period was shortened. Since composting is a biological process, addition of urea to the nitrogen deficient waste proved beneficial. Rich (1963) states that the initial carbon to nitrogen ratio, C/N, should be from 30 to 35 (by weight) for aerobic composting. The C/N ratio of the completed compost will be within the range from 10 to 20. Further composting experiments by the NCA compared regular windrows with forced aeration windrows. Perforated copper pipes were imbedded in the base of the bins, which were 9 feet wide and 5 to 6 feet deep, containing about 30 cubic yards of solids. The material was mixed with a windrow turner. Although the complete results of this experiment were not compiled, all indications were that forced aeration increased the composting rate and helped preventing odorous conditions. It was found that raw waste could be added to the bins at rates up to 86 lbs/cubic yard/day without adversely affecting the process. Dried compost together with rice hulls was used as the absorbant. Automated methods of handling the waste material also were investigated. A two-sectioned reservoir was built on the site. The first section was used to hold the waste as received from the cannery. A bucket elevator was used to convey the solids to a grinder located over the second section. The pulpy slurry produced by the grinder was pumped from the second reservoir to the bins or windrows with a diaphragm type pump. This handling method was found satisfactory.

Composting of primary sludge requires dewatering of the sludge. Primary sludge is generally from 95 to 98 percent water, and unreasonable amounts of absorbing material would be required to lower the water content below 70 percent. Dewatering may be accomplished by air drying, vacuum filtration, pressure filtration, or centrifugation. (Ballance 1965)

Air drying on sludge drying beds is a method commonly used in municipal sewage treatment plants. The sludge is applied to a bed of sand and gravel and the water is drained off. Most of the removal takes place in one day, after which further removal is primarily by evaporation. A major disadvantage with sludge drying beds is the land requirement. Climate is an important factor, and some drying beds are covered with a glass building similar to a greenhouse.

Vacuum filtration has been found to be the most favorable method for dewatering primary sludge from potato processing plants. (Grames and Kueneman 1968) (Francis 1962, Red River Valley) Studies carried out by the Engineering Committee of the Potato Processors of Idaho Association showed that sludge from plants using steam peeling could be dewatered to a solids content of 12 to 16 percent. The filtrate has a suspended solids concentration of 1000 to 1200 mg/l, and most of these solids would settle again when the filtrate was returned to the clarifier. Dewatering of sludge from plants with caustic peeling at first appeared impossible. The water would not separate from the solids, and the gelatinous slurry blinded the filter cloth immediately. It was found that chemical conditioning of the sludge with ferric sulphate and lime released the water and flocculated the solids. The cost of chemicals was high, however. Later it was discovered that ageing of the sludge in the clarifier improved the filterability due to bacterial action. If the solids were held too long, the bacteria would decompose the solids and filterability was greatly reduced. Also, reduced clarifier efficiency was observed.

The optimum time of ageing has been found to vary from plant to plant. While 4 to 5 hours may be sufficient in one installation, 24 hours may be required in another.

The filtration rate is dependent upon sludge concentration and conditioning and may vary considerably. Experience indicates that it is safe to size filters on the basis of 5 lbs of dry solids per square foot per hour, although rates as high as 15 lbs/sq ft/hr have been obtained when the sludge characteristics were favorable. (Grames and Kueneman 1968)

Pressure filtration is a batch process and does not find much application, since it has the major disadvantage of requiring hand labor to remove the sludge cake. (Ballance 1965)

Continuous centrifugation of primary sludge can be used successfully. The solids content of the dewatered sludge is in the range of 16 to 20 percent. (Kueneman 1965) A problem associated with centrifugation is removal of the finer solids discharged with the centrate. The solid particles are broken down by the centrifugal force so that they exibit poor settling characteristics when returned to the clarifier. (Grames and Kueneman 1968)

Incineration and Wet-Oxidation

Incinerators currently are used in municipal treatment plants to burn solid organic wastes. (Hindin and Dunstan 1965) (Cost of Clean Water 1967) To avoid objectionable odors from the volatile organic acids, temperatures of about 1400°F must be maintained. Two basic types of open-air sludge incinerators are in use. These are the flash drier-incinerator and the multiple hearth incinerator.

By incinerating solid waste the fuel value of the solids can be utilized. The recovered heat energy may be used to generate steam for general plant use. Hindin and Dunstan (1965) found that screenable potato waste solids had a fuel value of about 6650 BTU per pound of dry solids. The heat energy obtained from a wet waste depends on the amount of organic matter present in terms of COD or volatile solids content and the degree of completion of the combustion.

In recent years, wet oxidation or pressure burning of industrial waste as well as municipal waste has been practiced. The Zimpro process has been used to oxidize various kinds of sewage sludges and waste pulp liquors. The waterborne organic matter is oxidized, under pressure, with air. Operational results of the process have been reported by Hurwitz et al. (1959). A sewage sludge containing 5.24 percent total solids, 3.47 percent volatile solids, and 64400 mg/l COD was fed to the reactor at a rate of 229 gallons per hour. With an average reactor temperature of 506°F and an average pressure of 1200 psi, 7058 BTU were produced per pound of dry solids when 2.34 lbs of air were added per gallon of sludge. The effluent contained 13700 mg/l COD, 1.74 percent total solids, and 0.4 percent volatile solids. The steam produced was used to heat the incoming sludge.

A more recent development is the Dorr-Oliver FS-System. In this process a preheated fluidized bed is used to dry and incinerate the wet organic waste. Thermal oxidation occurs at a pressure of about 2 psi and a temperature of 1500 - 1700°F. The process has been found self-sustaining if the water content of the wet waste does not exceed 65 percent. If the water content is higher or the waste has a low organic content, fuel as propane or fuel oil is added directly to the fluidized bed. (Hindin and Dunstan 1965)

It is important to note that dewatering of solid wastes with high water content is necessary for efficient use of any of the combustion methods described above.

Anaerobic Digestion

Anaerobic digestion of solid waste decomposes the organic liquids and solids to inorganic matter and organic gases. Methane is the principle organic gas formed.

Hindin and Dunstan (1963) studied digestion of varying mixtures of potato waste solids and sewage sludge. The potato waste solids are deficient in nitrogen and phosphorous, essential nutrients for bacteria, and the sewage served as a source of these nutrients. Also the sludge provided the mixture with an inocculum of methanogenic microorganisms, responsible for the methane fermentation process. Using conventional rate sewage sludge digestion, satisfactory digester performance was obtained with a mixture containing equal amounts of potato waste solids and sewage sludge. Signs of digester distress were observed when the mixture contained 75 percent potato waste solids. It was recommended that in actual large scale operation the digester feed should not contain more than 25 percent potato waste solids. Although it was found that the digester destroyed the solid organic matter efficiently, the supernatant had a BOD in excess of 1000 mg/l. Disposal of this highly organic liquid may present problems.

Much research is needed towards efficient utilization of the fuel value of potato waste solids through anaerobic digestion. Other areas which require further research are supernatant disposal, nutrient supplementation, and application of the high rate and contact digestion processes.

Animal Feeding

Utilization of potato pulp and peelings for cattle feed already has been discussed. Sludge from primary clarification of potato processing waste water also has been used successfully for cattle feed. All the sludge recovered from the clarifiers of the J. R. Simplot Company is fed to cattle. The sludge is dewatered to about 14 percent solids content by vacuum filtration. Caustic peel sludge is stored until the pH falls to neutral or below through fermentation. At the beginning of the feeding period, the mixture contains about 45 percent potato solids (by weight). The rest of the feed is mainly chopped hay with some grain. After 14 days the potato solids content is increased to about 70 percent, and this mixture is used for the remainder of the feeding period. The potato solids have been found to be at least equivalent to barley in nutritional value, and reports indicate that there has been an accelerated weight gain of about 1/2 lb/animal/day after the potato solids were included in the diet of the cattle. At the present the total weight gain of the Simplot cattle ranges from 2.6 to 4.1 lbs/animal/day with an average of about 3.0 lbs. Livestock feeders were long reluctant to use filtered sludge. Since its value was proven through experience, the filtered sludge has been in demand, and many processors are selling the sludge along with their screened solids at a price of about $3.00 per ton of waste at about 14 percent solids content. This price is sufficient to recover capital costs of primary treatment in two to four years. (Grames and Kueneman 1968)

SECTION 8

CURRENT RESEARCH AND DEVELOPMENT EFFORTS

At the present time a considerable amount of research and developmental work is under way on potato processing waste treatment in this country. The Pacific Northwest Water Laboratory of the Federal Water Pollution Control Administration in Corvallis, Oregon, has been assigned national responsibility for food processing wastes. In each of the major food processing areas, such as potato, the waste treatment research needs will be developed and these needs will be assigned priorities. The total problem will be attacked systematically from three directions. First, the FWPCA will do some in-house research. Second, research grants, contracts, and demonstration grants will be awarded to various universities, industries, and other groups to work on designated problems. Third, and not least, work will be done by industries and groups such as the Potato Processors of Idaho Association.

Research grants directly involved with potato processing wastes are described in Appendix B. The projects are those given in the Water Resources Research Catalog (1967, 1968). These projects cover aspects of biological waste treatment processes, by-product recovery, in-plant modifications, chemical process application, peeling processes, odor control and other process and treatment modifications. In addition to the projects described in Appendix B, many smaller projects are conducted by industry and other institutions.

Many studies on process waste water disposal for other related industries are under way and constitute a large potential source of research information which may be applicable to the potato processing industry. The concern for environmental quality control is international and is focused on preventing further deterioration of the environment. The effects of this growing concern, no doubt, will be to provide further stimulus for research and further requirements for waste water control.

SECTION 9

RESEARCH NEEDS

With the existing waste treatment technology any reasonable effluent quality requirement imposed on the potato processing industry can be met. In England, where effluent requirements are considerably more restrictive than in the United States, potato waste treatment facilities capable of producing effluents with BOD and suspended solids concentrations below 20 mg/l are in operation. In one such plant, primary sedimentation is followed by two stages of biofiltration and activated sludge treatment. Final polishing on sand filters enables re-use of a large fraction of the effluent in the processing operations without detrimental effects on the quality of the final product. Up to 75 percent of the effluent may be re-used. A treatment scheme such as this is of course costly, and cost is the main treatment problem facing most potato processors. Capital as well as operating costs are high, with little or no possibility for return on the investments. This is true now for conventional secondary treatment and will be a continuing problem as federal and state requirements on effluent quality become more restrictive, and a higher degree of treatment becomes necessary.

Cornell, Howland, Hayes and Merryfield (1969) have presented average capital and operating costs for potato waste treatment and compared these with similar costs for municipal waste treatment presented by Smith (1968). The costs for primary potato waste treatment were based on facilities constructed in the Pacific Northwest, while the costs for secondary treatment were based on engineering estimates from demonstration projects and from pilot plant systems studied by the Potato Processors of Idaho Association. The curves presented are shown in Appendix C. Because of the rapid change in construction costs, all figures were adjusted to a common base of June 1967 by using the Engineering News-Record building cost index. The history of the building cost index and a projection of the index into the future also is shown in Appendix C.

A survey of many potato processing plants was made in connection with this report. Limited treatment cost information was obtained. Primary treatment was reported to cost from $0.02 to $0.064 per pound of BOD removed. In terms of raw product input a treatment cost of $0.50 per ton of potatoes was given. A starch plant reported operation and maintenance cost of $0.04 per pound of BOD removed. Protein water was treated by anaerobic fermentation and diffused aeration and combined with flume water for sedimentation and disposal to a municipal sewerage system.

The survey showed that a large percentage of the potato processors do not know the cost of treating their own waste. Capital cost of the facilities is of course known, but operational cost is not determined. For efficient operation and control of the waste treatment facilities and to evaluate the effects of in-plant changes and procedures, cost information is essential in most cases. Large sums of money may be wasted unnecessarily unless consideration is given to cost of treatment versus the operational variables in the processing plant as well as in the treatment plant.

Proper considerations on the part of the processor also will result in considerable savings in capital costs. Efforts to reduce waste production must start with the operations prior to processing, i.e., harvesting, handling and storage. The in-plant efforts have been discussed earlier. Finally, good engineering knowledge must be used in designing and constructing the waste treatment facilities.

Although much can be done to reduce the cost of waste treatment with the knowledge and means available today, the future will bring more restrictive waste treatment requirements, and we must prepare to meet these requirements with economically feasible methods.

Specific Research and/or Demonstration Needs

Many possibilities exist for reducing the amount of waste from potato processing and improving the waste treatment technology; a great deal of work has already been done to alleviate the potato waste problem. However, with all due respect to previous and present efforts, there is always room for further improvements.

Harvesting, Handling, and Storage

Improvements in the operations prior to processing may reduce the total waste load significantly.

Harvesting. Mechanical injury to the tubers during harvesting greatly increases the chance of tuber disease and discoloration during storage. Rejection of injured tubers during processing increases the amount of solid waste and represents a direct loss to the processor. Improved mechanical harvesting equipment therefore should be developed.

Dirt Removal. Removal of dirt from the potatoes in the field would reduce the amount of water used for washing in the processing plant. Although wash and flume water does not require a high degree of treatment at the present time, secondary treatment will undoubtedly be required in the future. Therefore, reduction of wash water volume is important.

Transportation. Potato quality is affected by temperature during transit, and improvements in the environmental control systems in railroad cars and trucks would reduce the amount of potatoes wasted due to high reducing sugar content.

Storage. Temperature control is equally important during storage. Research also is needed in the field of sprout inhibition and in preventing diseases like rotting. Mechanically injured tubers should be sorted out before the crop is placed in storage.

Processing Operations

In-plant changes and modifications are considered by many to be the most important for waste reduction and prevention. In general, processing equipment and techniques need be improved to reduce the amount of waste water produced and the amount of solids entering the waste streams. Several possibilities and practices have been discussed earlier.

Peeling. The peeling operation, which contributes from 50 to 75 percent of the total plant waste load must be improved in order to reduce the waste load significantly. Very promising results have been obtained with the dry caustic peeler previously described. However, more work is required to perfect this process. Handling, disposal and utilization of the slurry produced from the peel and waste water must be investigated. The economics of the process compared to other peeling methods also must be demonstrated.

Other possible methods of peeling with minimal water usage should be investigated.

Other Processing Operations. The rest of the processing operations should be considered as well. Solids losses and water usage must be reduced, since these increase the waste load as well as the total loss from the process. Improved equipment and methods for slicing, blanching, cooking, etc. should be developed. In the same respect, firm guide lines for good housekeeping should be established, and process line personnel should be educated in waste prevention.

Solids Removal. A certain loss of solids will always occur. Preferably these solids should not be allowed to enter the waste stream. If they do enter the waste water, then as much as possible of these solids should be removed from the waste water immediately in the processing plant before considerable leaching of organics take place. Removal may be achieved by screening, filtration, or centrifugation. In this respect, research is needed on suspended solids particle size in relation to screening. Fragmentation of the particles on the screen may increase the apparent BOD. A similar phenomenon may take place in the centrifuge. The solid particles may be broken down by the centrifugal force and thus remain in the centrate. It has been reported that this indeed happens when primary potato sludge is dewatered by centrifugation. The small particles discharged with the centrate have poor settling characteristics and thus are not removed easily by sedimentation.

Re-use of Process Water. Re-use of process water has been discussed earlier. Besides removal of suspended solids, quality control of the water must be investigated. Various methods of microbial control should be evaluated to control deterioration of the recirculated water. The tolerance limits for different pollutants should be established for various steps in the process on a health hazard basis as well as on a product quality basis.

Separation and Concentration. As mentioned earlier, separation of various waste streams may be advantageous for subsequent treatment in different systems. Waste concentration also may prove very advantageous, since concentrated waste can be treated more efficiently than dilute waste. Concentration and separation would be necessary for efficient by-product recovery in many cases. Concentration and separation by reverse osmosis is one possibility which presently is being investigated. The concentrated portion of the waste stream may be subjected to recovery of various valuable constituents while the separated dilute portion may be re-used in the processing operations. The present research efforts are directed towards potato starch plant waste. Feasible application of this or similar processes to other types of potato waste water should be investigated.

By-Product Recovery. A variety of salable by-products can be recovered from the various waste streams, and considerable research has been conducted in this field. Few large scale economically feasible processes have been developed, however.

Some of the compounds which may be recovered from potato waste include amino acids, protein, organic acids, potassium, phosphates and other inorganic ions. All these compounds have been recovered by physical or chemical processes.

Potato pulp and waste water may also be used as growth media for yeasts and molds for production of protein and antibiotics. Promising results have been obtained with the yeast Torula.

A number of edible products for human consumption have been proposed from larger potato solids. Utilization of potato solids for livestock feed has found wide acceptance.

In order to take advantage of these possible by-products from potato wastes, feasible processes and a market must be developed. The present efforts on by-product recovery are concentrated mainly on starch plant waste, since the potato starch industry is a rather marginal industry. More emphasis should be directed towards recovery of salable products from other types of potato processing waste.

Waste Treatment

The ultimate solution to the waste treatment problem would be to produce an effluent which could be completely re-used in the processing operations. Although such a goal is rather impractical at the present time, the possibility of effluent re-use nevertheless should be kept in mind. In order to solve the more contemporary problems facing the potato processors, existing and proposed technology must be improved and modified to give more efficient, less costly waste treatment. The most pressing problem at present is secondary treatment, a requirement which is facing most of the processors across the nation. However, continued efforts to improve primary treatment methods should not be ignored since primary treatment can reduce the load on the secondary treatment facilities significantly.

Primary Treatment. Primary treatment has been adopted by a large part of the potato processing industry, and design criteria have been established through experience from pilot plants and full scale operations.

Methods for improving the removal of colloidal and dissolved matter should be improved.

Flotation. Solids removal by flotation has been tried to some extent in potato waste treatment. Promising results have been obtained, but high costs also have been reported. Further research on the applicability of the process to potato waste is needed.

Coagulation. Some research has been conducted on chemical coagulation of primary treated potato waste. Although the results obtained did not show appreciable improvement in the overall removal efficiencies, work in this area should be continued. The large variety of coagulants, coagulant-aids, and polyelectrolytes available should be tested at various points in the waste treatment process and for different types of potato waste.

Flocculation by pH Control. Recent investigations have shown that additional removal of solids from primary effluent can be accomplished by holding the effluent for a period of time until the pH is lowered by microbiological action. When the pH was lowered, the solids tended to flocculate and settle or float to the surface. Up to 50 percent additional removal was obtained. (Oates 1969) The feasibility of pH control for additional solids removal should be further investigated. The effects of coagulant aids, temperature and density should be established.

Secondary Treatment. Potato processing wastes have been found easily degradable by biological treatment processes, and considerable progress has been made in the application of different processes to potato waste treatment. A significant amount of pilot plant work has been done, but operational results and experience from full scale installations are limited.

Biological Processes. Research needs for biological treatment processes are not unique to potato processing wastes but apply to most industrial wastes. In general, better prediction models for the different processes must be developed. The values of the model factors, i.e., removal rate constants, growth rate constants, etc., and their variations with waste quality parameters, should be determined more precisely. More specifically, the availability of the essential nutrients, such as nitrogen and phosphorous, for adequate treatment should be investigated. The amount of nutrients in potato waste is generally sufficient for effective biological treatment, but the nutrients may not be readily available for cell incorporation. The effects of conditions or compounds directly inhibitory to biological treatment, such as high pH, antifoaming agents and cleaning compounds, should be studied further.

Anaerobic Processes. Promising results have been obtained with the anaerobic filter and the anaerobic contact process in potato waste treatment, and work on these processes should be continued. Special attention should be given to start-up characteristics, duration of start-up period, optimum operating conditions, and solids-liquid separation. Solids disposal also should be considered.

Spray Irrigation. Successful applications of spray irrigation have been reported. Research is needed to determine the effect of sodium on the soil used for spray irrigation, and on proper soil conditions and operating conditions for maintaining adequate growth and soil drainage.

Chemical-Physical Processes. High-rate chemical oxidation processes have not been found economically feasible at the present. Further research on these and other chemical and physical processes should be conducted, especially with regard to more complete re-use of treated effluents.

Solids Handling and Disposal. Conventional primary treatment and biological secondary treatment produce excessive solids. Primary sludge has been used successfully for cattle feed. The possibility of utilizing secondary sludge in a similar way should be investigated. The economics of other solids disposal methods should be evaluated, since little is known about the feasibility of secondary sludge for cattle feed, and since there may not be a market for this product. Efficient and economical methods for dewatering dilute sludges should be developed, along with methods for handling sludge with high solids content.

Tertiary Treatment Processes. Although enforcement of tertiary treatment may be some years in the future, several of the processes developed for polishing effluents may soon be applicable in potato waste treatment for extensive effluent re-use and by-product recovery. The feasibility of these advanced treatment processes for potato waste should therefore be investigated.

Suggested Approach to the Problem

Current research in the specific area of potato processing waste waters involves about two million dollars per year. This expenditure includes demonstration grants. The research thus far has made in-roads on the pressing problems of applying secondary treatment and more satisfactory peeling methods to field installations. Further development is yet needed on anaerobic and non-conventional treatment.

Major emphasis needs to be given to reuse, recycle, recovery and good housekeeping as techniques to reduce waste loads. Research in these aspects of process modification may provide mechanisms which will offset much of the research investment. The salvage, saving and use of waste soil, potato material, and process chemicals involved in utilization of the potato can represent monetary gain to the producer as well as relieve some of the waste burden on the environment. The use of pollution control awareness programs for employees helps spread the appreciation for waste control and its beneficial aspects throughout the operation and will, if properly handled, produce significant waste load reductions.

With proper direction toward evaluation of newer experimental process control techniques and with a proportional investment in good research aimed toward applying new and imaginative processes to potato processing and potato processing wastes, the present dollar research expenditure and more could be well spent in the future in developing the production and waste control processes toward the continued further alleviation of waste load insults to the environment. At least 10% of the total monies spent on research and development should be reserved for innovative laboratory research. Of the remaining monies, care should be taken to avoid spending major fractions of the available research dollars on construction and maintenance of conventional facilities which have already been investigated in some detail. The research supported should be able to provide meaningful results which can be of significant value in solving the waste control problems of the industry. Enthusiastic monetary support is difficult to sustain when applicable fruitful results are not forthcoming for the projects supported. However, the problems in potato processing are real and require attention. With imagination, persistence, diligence and adequate support, competent researchers can provide the information needed to maintain the quality of the environment.

Environmental Impact

The impact of the potato processing industry on the total environment will be an area of vital concern in the seventies. It is not sufficient to consider only the growth and production of the product and the treatment of emanating waste streams. Concern must be directed as well to the chemicals, materials, energy and ecological balances involved in the production system and perhaps the most important research will deal with the effect of production on these balances. While the problems are not unique to the potato processing industry they are part of the total responsibility of mankind in maintaining the quality of the environment.

The loads of salts, pesticides, and herbicides dumped into the environment should be carefully evaluated in terms of their insult capacity to the environment and alternative methods should be considered for growing and processing where the method used is not compatible with maintaining the quality of the environment. Other methods of growing, harvesting and processing should be under study to explore mechanisms for providing greater amenability with the use of preservation of resources. Increases in receiving water temperature resulting from waste discharges can disrupt biospheres and create system imbalances which may have perturbations in other industries and water uses.

Cultivation and processing of food products encumber the growers and processors with the responsibility for proper management of the unused and wasted portions of the materials applied in the process as well as with the sale of satisfactory products. The use of the environment and its growing potential entails with that use the care and preservation of the environmental components which make life possible. Thus conservation of energy and material as well as proper use of those commodities and proper stabilization of components returned to the environment are all part of the total production process. Future research should deal effectively with the individual processing industry not only as an entity but also as part of the total environmental picture. While every productive consumptive use of material involves the destruction and wastage of some environmental component, it is necessary, for the future, to consider resources in terms of their highest and best use.

It is incumbent on workers in this field to be cogniant of their societal impact and research may well be involved with the legal and regulatory aspects of the process including incentive systems, planning and agricultural basin development. The future for research in potato processing involves technological assessment and improvement. Future research should expand also into the role of the industry in relationship to man's needs and the maintenance of a quality environment.

APPENDIX A
BIBLIOGRAPHY

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APPENDIX B
RESEARCH GRANTS ON POTATO PROCESSING WASTES

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The following is a list of research work directly involved with potato processing wastes, as described in the Water Resources Research Catalog (1967, 1968).

Treatment of Protein Water Waste from the Manufacture of Potato Starch by Anaerobic Fermentation - Aerobic Stabilization Process
W. Van Heuvelen
North Dakota Department of Health
State Capitol Building
Bismark, North Dakota 58501

The microbiological treatment of protein water waste from the manufacture of potato starch will be evaluated. A treatment of anaerobic fermentation and aerobic stabilization will be used.
Supporting Agency: Federal Water Pollution Control Administration

Treatment of Alkaline Wastes from Potato Processing
C. Bruce
Vahlsing, Inc.
Easton, Maine 04740

The objectives of this project are to demonstrate the feasibility of: Treating potato processing waste using the activated sludge system; combining potato processing waste with sugar beet refining waste; and the feasibility of three in-plant closed waste water systems in the sugar beet plant. The project will provide extremely valuable data to both the potato processing and beet sugar industry. The aim is also to determine if a $30 million industrial complex, composed of potato and sugar beet processing and a residential community, can exist on a small stream, as is proposed, and have clean waters.
Supporting Agency: Federal Water Pollution Control Administration

Aerobic Secondary Treatment of Potato Processing Wastes with Mechanical Aeration
W. M. Swanson
R. T. French Company
Drawer AA
Shelly, Idaho

The objective of this project is to demonstrate the aerobic biological treatment for potato processing wastes, to establish design criteria and to develop construction and operating costs. The following systems will be studied: 1) Extended aeration with sludge return; 2) Flow through aeration with sludge return; 3) Intermittant aeration with intermittant effluent withdrawal.
Supporting Agency: Federal Water Pollution Control Administration

Operation of Potato Processing Plants to Reduce Waste and Stream Pollution

M. L. Weaver
U. S. Department of Agriculture
Albany, California

Object: To help alleviate the growing problem of disposing of wastes from plants processing potatoes into food products, without polluting streams or the air, through the development of new or modified in-plant operations to reduce the quantity of wastes discharged and/or to convert them to a form more readily adaptable to available methods of waste treatment.

Plan of Work: Investigations will be made to determine the basic nature of the waste material, i.e., amount and kind of both mineral and organic solid particles, amount and kinds of soluble materials, pH, biochemical oxygen demand, chemical oxygen demand, etc., associated with different types of processed potato food products. The most economical and efficient means of removing suspended solids from aqueous plant wastes will be sought. Also, how to separate the mineral matter from insoluble organic solids. Possible uses for the suspended organic solids will be explored. Investigations will be made of ways to reduce the total quantity of soluble solids to be disposed of and to concentrate these for more efficient secondary treatment. Special attention will be given to the peeling operation in order to reduce the disposable waste.

Supporting Agency: U. S. Department of Agriculture

Pilot Plant Development of the Ion-Exchange Process for Recovery of Amino Compounds from Potato Starch Factory Effluents

W. L. Porter
U. S. Department of Agriculture
Chesnut Hill
Philadelphia, Pennsylvania 19118

Object: To alleviate the problem of disposal of secondary wastes from potato starch factory effluents and reduce stream and air pollution; to obtain a cost estimate for the process; and to produce crude amino acid mixtures.

Plan of Work: An evaluation will be made by pilot plant scale of the methods of recovery of free amino acids from potato starch plant effluent by ion-exchange treatment. The investigation will include: Effect on process of variation in concentration of in-put solids from 0.5-3.0% solution; applicability of Dutch process for recovery of protein before ion-exchange treatment of effluent liquor; degree of clarification required before ion-exchange processing; disposal of solutions from regeneration of columns and selection of regeneration acid from this viewpoint; methods for stabilizing the amino acid product; and determination of composition, BOD and COD of effluent stream before and after processing. Cost estimates will be provided based on the data and final process lay-out, for a full-

scale plant to recover nitrogen-containing materials from the 'protein water' effluent of a 10 ton per day and a 30 ton per day potato starch factory. A minimum of 500 pounds of dry crude amino acids will be delivered representing the typical product of the process for use in utilization studies and market development.
Supporting Agency: U. S. Department of Agriculture

Two grants have been awarded recently by the Federal Water Pollution Control Administration.

Western Potato Service, Inc., at Presque Isle, Maine, and Grand Forks, North Dakota, has been awarded a grant for "Full Scale Demonstration and Evaluation of Potato Dry and Wet Caustic Peeling Processes." It is proposed to install three dry caustic peeling lines in the Grand Forks processing plant. Conventional wet caustic peeling, existing in the Presque Isle plant, will be studied as a control. At both facilities will be installed equivalent primary waste treatment equipment for the purpose of comparative analysis.

The project objectives are as follows:

1. To determine total capital expenditures and operational and maintenance costs of dry caustic process and the conventional caustic process.

2. To compare the quantity and quality of the waste generated by the two systems.

3. To compare the treatment efficiency of silt removal systems and final clarifier and primary treatment systems at both plant locations.

4. To determine whether the dry caustic sludge would be accepted or rejected during cattle feeding operations.

The City of Grand Forks, North Dakota, was awarded a grant to study "Controlled Treatment of Combined Potato Processing - Municipal Wastes by Anaerobic Fermentation, Aerobic Stabilization Process." Project Objectives: Demonstrate, develop, and evaluate joint treatment of potato processing - municipal wastes by use of stabilization pond pretreatment methods consisting of (1) anaerobic - aerated combination, (2) anaerobic, or (3) aeration treatment. Study the effects of the treatment methods on the stabilization ponds. Determine any special procedures related to most efficient operation of the anaerobic and aerated units, factors most responsible for waste removal, and development, and control of odors.

APPENDIX C
POTATO PROCESSING WASTE TREATMENT COSTS

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POTATO PROCESSING WASTE TREATMENT COSTS

The cost curves presented in the following figures are taken from a report to the Potato Processors of Idaho Association by Cornell, Howland Hayes, and Merryfield (1969). The costs for domestic systems were presented by Smith (1968).

The costs for primary treatment of potato waste are based on systems which have been designed and constructed in the Pacific Northwest. The costs for secondary treatment of potato waste are based on engineering estimates which have been made for demonstration projects and preliminary estimates based on pilot plant systems studied by the Potato Processors of Idaho Association. All costs have been adjusted to a common base of June 1967 by using the Engineering News-Record building index. (See Figure 7) The costs, which include the contractor's overhead and profit and engineering, are averages, and should be used only for general guidance and comparison.

Silt Removal. Figure 8 is a presentation of the capital cost for silt removal. The costs are based on a mechanically-cleaned clarifier, and include solids pumps, electrical, piping and a building to house pumps and electrical gear. It is assumed that the unit would be adjacent to and integral with either primary or secondary treatment units.

Primary Treatment. The capital costs for primary treatment are shown in Figure 9. The costs include screen, clarifier, solids pumps, vacuum filter, solids bin, flow measurement, and a building to house pumps, screen, vacuum filter, and electrical gear.

Secondary Treatment. Figure 10 shows the capital costs for secondary treatment. The costs include primary treatment and solids handling equipment. It is assumed that the cost of land for stabilization ponds would be $500 per acre, that the cost for construction would be $2000 per acre, and that stabilization ponds would be loaded at about 50 pounds of BOD per acre per day.

Irrigation. The costs for irrigation systems are shown in Figure 11. The costs include a pump station, a self-cleaning screen, and a solids grinder. An allowance of $500 per acre of land has been made. The costs do not include primary treatment which would precede irrigation. An application rate of 1/2-inch per day has been assumed.

Operation and Maintenance Costs. The operation and maintenance costs for primary and secondary treatment systems are presented in Figure 12. The costs for potato waste treatment are based on very limited field information and are, for the most part, estimates. No allowance has been made for return from sale of the reclaimed solids.

Stabilization Ponds. The capital costs for stabilization ponds are shown in Figure 13. The costs are based on construction costs for municipal ponds and do not include allowance for land.

Clarifiers. Figure 14 shows the costs for clarifiers. The costs include the clarifier mechanism, concrete structure, piping, and foundation gravel. Normal excavation for a unit which sits 4 feet into the ground is included. No unusual foundation problems are included.

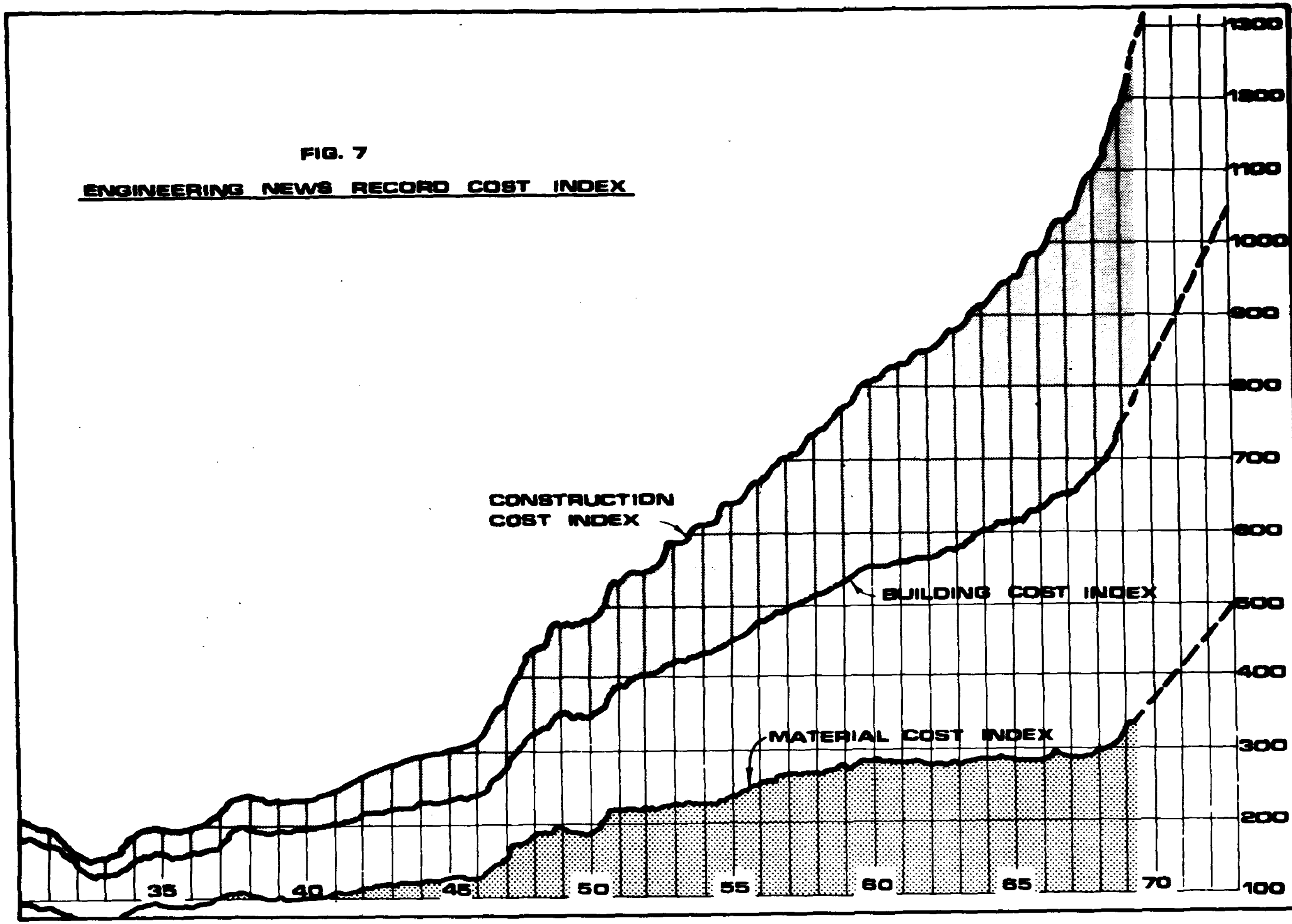
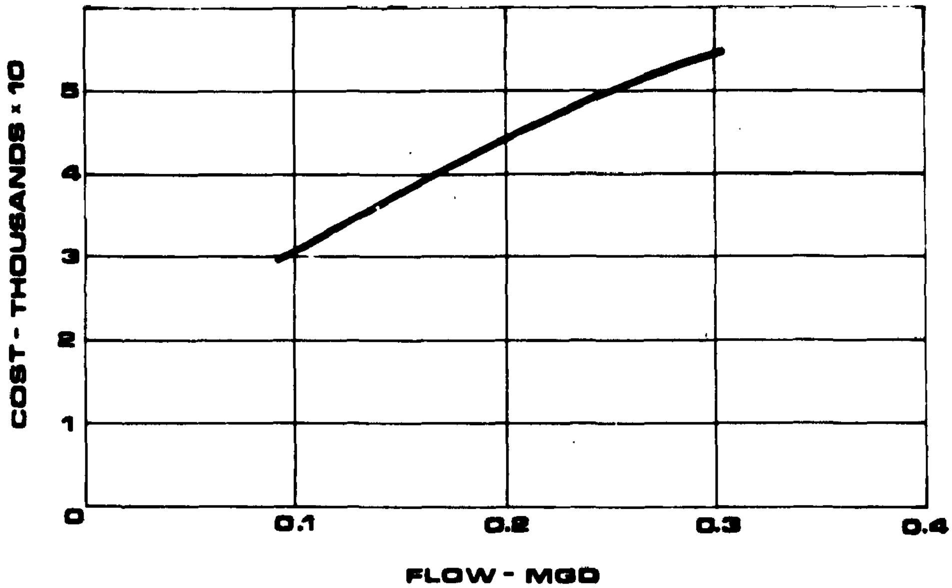


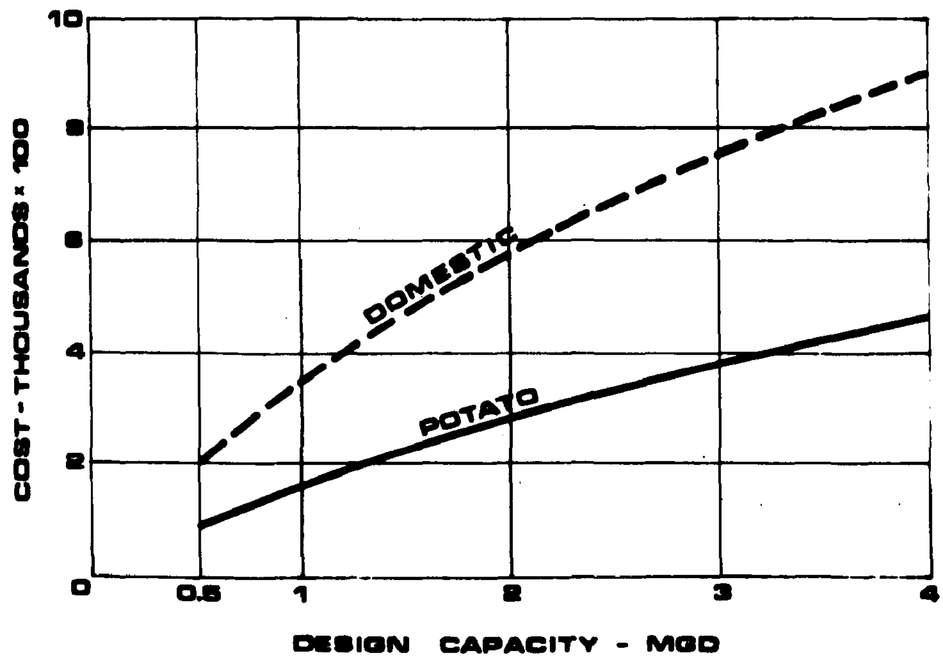
FIG. 7

ENGINEERING NEWS RECORD COST INDEX



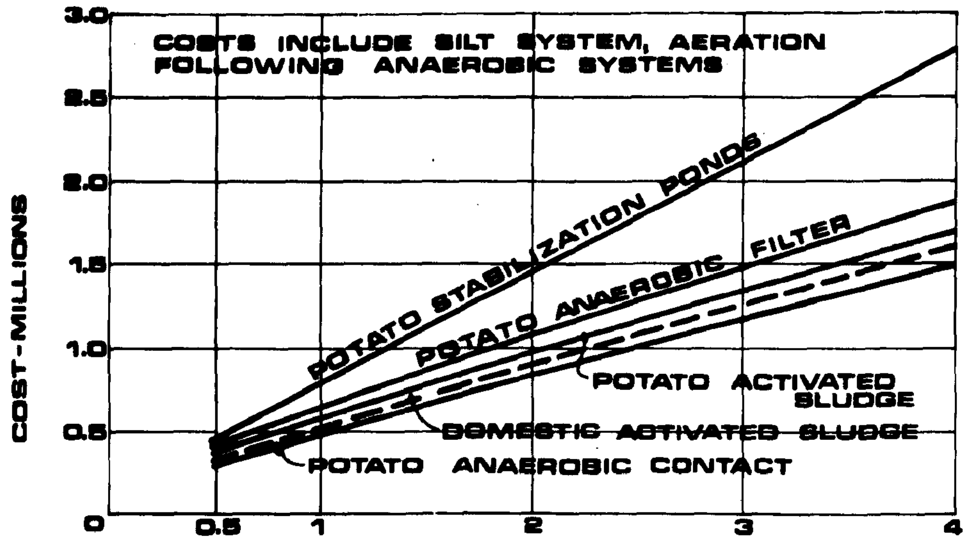
MECHANICAL SILT REMOVAL - CAPITAL COST

FIG. 8



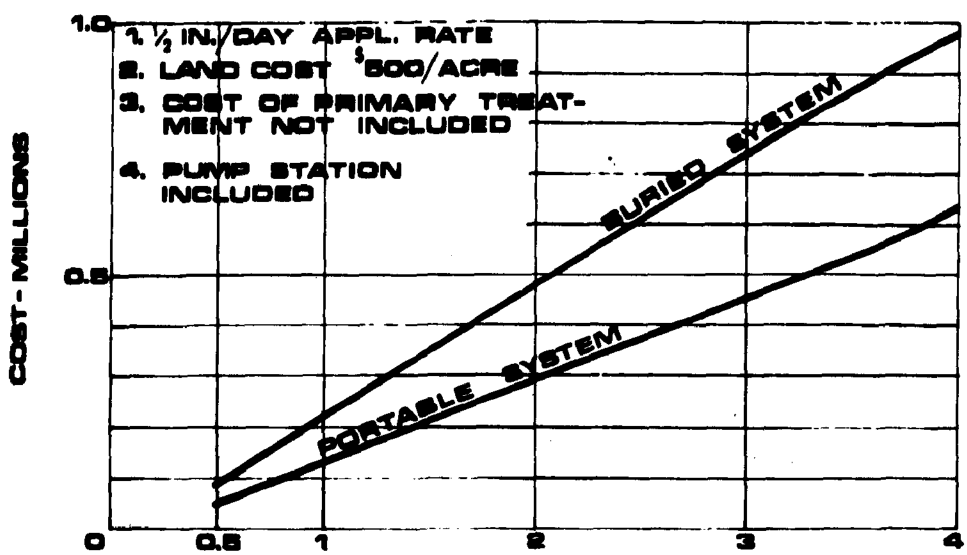
PRIMARY TREATMENT CAPITAL COST

FIG. 9



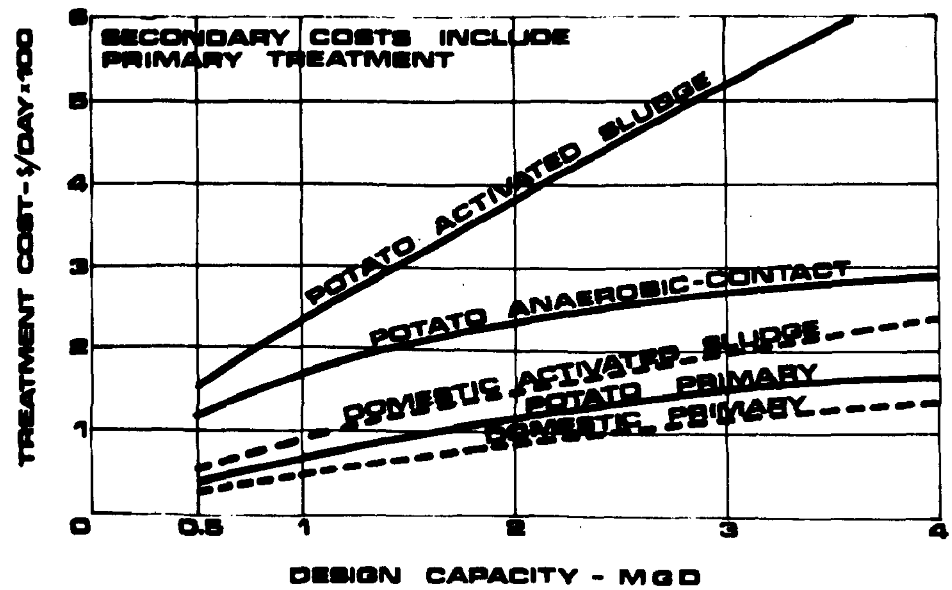
SECONDARY TREATMENT CAPITAL COST

FIG. 10



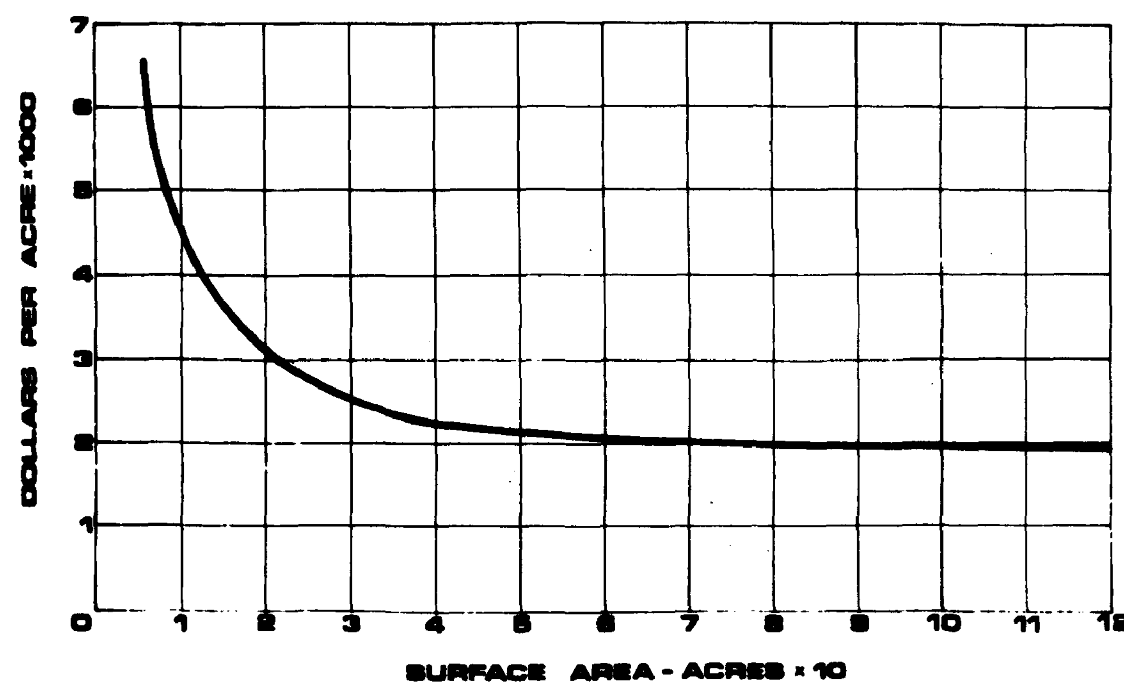
DISPOSAL BY SPRAY IRRIGATION CAPITAL COST

FIG. 11



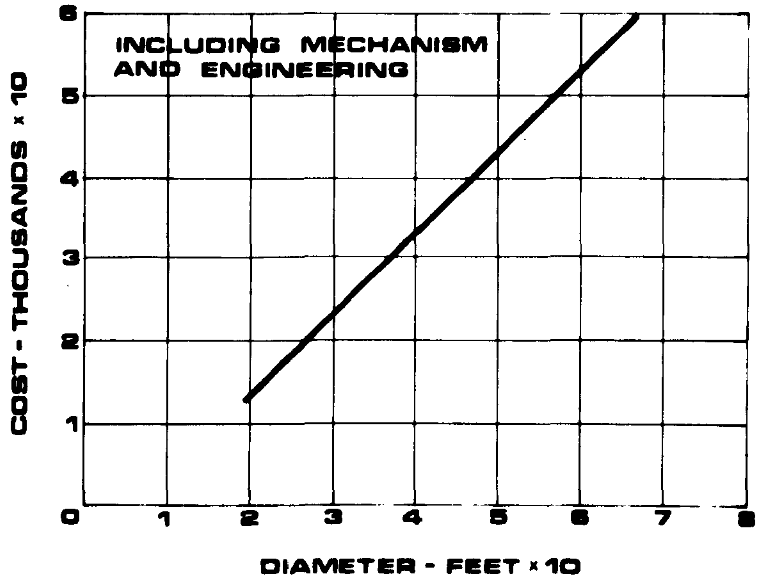
OPERATING & MAINTENANCE COSTS

FIG. 12



STABILIZATION POND CAPITAL COST

FIG. 13



CLARIFIERS CAPITAL COST

FIG. 14