This is to certify that the

thesis entitled

WATER CONSERVATION AND POLLUTION REDUCTION
DURING POTATO PROCESSING

presented by

Ahmad Shirazi

has been accepted towards fulfillment
of the requirements for

MS degree in Food Science & Human Nutrition

Theodore Wishnetsky
Major professor

Date October 31, 1979

O-7639

WATER CONSERVATION AND POLLUTION REDUCTION DURING POTATO PROCESSING

By

Ahmad Shirazi

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Food Science and Human Nutrition

1979

ABSTRACT

WATER CONSERVATION AND POLLUTION REDUCTION DURING POTATO PROCESSING

By

Ahmad Shirazi

This study was designed to examine water usage and waste production in a commercial, frozen French fry processing operation.

Existing plant layout and water/product flow patterns were studied, including measurement of water usage in virtually all of the plant's unit operations. Effluent measurements included in the study utilized Total Nonfiltrable Residue (Total Suspended Matter, TSM), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, and grease and oil content as the principal indices of pollution and included temperature measurement as well.

Based on data collected during the study, a number of possibilities for improved water conservation and waste reduction have been discussed. These suggested changes include by-product recovery, water reuse and recycling, as well as various process and equipment modifications.

Dedicated to

The Toiling People of Iran

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation and fondest regards to his advisor, Dr. T. Wishnetsky, whose help and guidance made the completion of this work possible.

Appreciation is also extended to Professors Alvin L. Rippen, P. Markakis and Steven L. Gyeszly for their critical evaluation of this Thesis. Thanks are also due to the management and other personnel of Mid-America Potato Company for their cooperation during the period of the plant survey.

Finally, the author is particularly grateful to his wife, Homa, for her patience, understanding and support throughout this study.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

LIST OF FIGURES

INTRODUCTION

Continued increase in demand for processed convenience potato products has led to rapid expansion of the potato processing industry. Consumption of frozen French fries has ranked above all other potato products. These increases in production resulted in more water usage. It also faced this industry with the problem of increasing waste that had to be either: (1) utilized; (2) treated and disposed of privately by the plant; or (3) transferred to a municipal system for treatment and disposal.

The increasing pollution problem prompted governmental bodies to promulgate and enforce stringent water quality standards and restrictive requirements for industry. Therefore, each industrial unit must attempt to minimize pollution, either through in-plant changes, end-of-pipe treatment or both.

Between the stated alternatives, in-plant changes as preventive measures have usually been less costly (27). They include process modification, use of special machinery which use a minimum amount of water, in-plant reuse/recycling of water, and waste segregation and utilization. On this basis, the present study was undertaken to investigate: (1) Pattern and quantity of water usage, (2) character and quantity of the plant waste, and (3) methods of water conservation and waste utilization/minimization in a frozen French fry plant, the Mid-America Potato Company plant in Grand Rapids, Michigan.

Cost analysis was considered beyond the scope of this investigation, though it is recognized that water-saving and waste-reducing changes would not normally be implemented in commercial situations without a thorough review of cost factors.

LITERATURE REVIEW

The frozen potato products industry is reported to have begun in 1945 with the commercial freezing of French fries (74). Since then, there has been a phenomenal increase in the consumption of such processed potato products as frozen French fries, hash brown, potato puffs, etc. in the United States. Based on data given by USDA (77), annual per capita consumption of frozen potato products was 0.1 pound in 1950. This was increased to 2.7, 5.7, 11.1, and 13.7 pounds in 1960, 1965, 1970, and 1975, respectively. To satisfy the demand for these items, more and more potatoes were grown and processed, as indicated by the data in Table 1.

Population growth and convenience in consumption of frozen foods are probably two major reasons for this increase. The frozen product is a decided convenience for both home and food service use because it needs only to be removed from the package and heated in an oven or briefly deep fat fried before serving.

Among the frozen potato products, frozen French fries are consumed the most. Amount of raw potatoes processed into frozen French fries increased from 3.8×10^7 cwt in 1968 to 6.9×10^7 cwt in 1974. These figures represent 84.62 percent and 88.25 percent of the potatoes used for

Table 1. Potato Production and Processing in the U.S.(1) 1968 - 1975

Item	1968	1969	1970	1971	1972	1973	1974	1975(2)
Production, 1000 cwt	295401	312418	325752	319354	295955	299410	342060	319834
Processed:								
1000 cwt	113151	125112	136574	138310	133719	143744	154157	153612
% of production	38.30	40.05	41.93	41.31	45.18	48.01	45.07	48.03
Frozen Products:								
1000 cwt	44662	51553	61859	63551	64027	69913	78424	79740
% of production	15.12	16.50	18.99	19.90	21.63	23.35	22.93	24.93
% of processed	39.47	41.21	45.29	45.95	47.88	48.64	50.87	51.91
Frozen French Fries:								
1000 cwt	37794	44654	54478	54667	56126	60349	69206	70406
% of production	12.79	14.29	16.72	17.12	18.96	20.16	20.23	22.01
% of processed	33.40	35.69	39.89	39.52	41.97	41.98	44.89	45.83
% of frozen prod.(3)	84.62	86.62	88.07	86.02	87.66	86.32	88.25	88.29

(1) Source: USDA Agricultural Statistics, 1977. (2) Preliminary. (3) Average value is 86.98. Coefficient of Variation = 1.51%.

production of frozen potato products in the stated years, respectively.

Increase in production of processed potatoes, like other segments of the food industry, has resulted in a corresponding increased volume of waste with potentially the same increase in water pollution (21). The fact that the food industry used 6.16×10^9 gallons in 1954 and 8.04×10^9 gallons of fresh water in 1963 shows this increasing trend (78).

Processing of fruits and vegetables necessitates the use of large quantities of water and generates enormous volumes of liquid wastes and solid residuals (42,56,83). In other words, the food industry is a major producer of "waste" with the usual intended product being the minor output. For example, the average cannery until recently used to produce ten times as much waste water as canned product (28). Root vegetables, in particular, require large volumes of water in processing operations, and substantial amounts of organic materials are introduced into processing plant waste water (48,49).

In the processing of potatoes, 20 to 50 percent of the processed raw potato is discharged as waste. Several values have been reported for waste water flow in potato processing. Most of the values fall within the range of 840 to 5,000 gallons per ton of raw potato processed, depending on the desired product (21,42). A wider range cited in the literature is 813 (22) to 12,000 (56) gallons per ton of raw potatoes. Average values of 3,420 - with standard deviation of 1,590-(30), 2,700 (24), and 3,600 (83) gallons of waste flow per ton of raw potatoes processed have also been reported.

Faced with a general rise in the potential solid and liquid waste load that ultimately must be treated, utilized, or transferred to the water environment and the realization that water supplies are not unlimited, governmental bodies at both state and federal levels have promulgated and enforced more stringent water quality standards (30,63, 91). Above all, it is Public Law 92-500, established by the U.S. Congress on October 18, 1972, which sets limitations on the quality of effluent. PL 92-500 necessitates the application of the "best practical control technology currently available" by July 1, 1977, the "best available technology economically achievable" by July 1, 1983 for the present sources, and the "best available demonstrated technology" for all the new sources (83). The industry should also meet the aim of "zero discharge" by 1985 (41). Due to this law, all waste water dischargers should obtain a permit known as the National Pollutant Discharge Elimination System (NPDES) which assures that effluent limitations are being met and that designated water quality standards are maintained. Furthermore, there are state and local requirements that are usually more restrictive than EPA guidelines (83) which industry must comply with. On the other hand, it is well realized that both water supply and waste disposal influence industrial growth, operation and product cost (91).

Based on the above, concern over water usage and pollution has touched the food processing industry at least as deeply as other sectors of the economy (43,48). Considerable effort has been made and extensive research is still going on to minimize pollution loads. These generally involve in-plant process changes and/or end-of-pipe waste water treatment (30,83).

Focussing on the end-of-pipe treatment alternatives for handling liquid waste from food processing operations are discussed in several references (42,59,79,83). Waste treatment is accomplished to reduce sewer user charges and to comply with effluent standards set federally, by state, or city. There are three possible options used for waste treatment (83):

1. Pretreatment of the waste and discharge to city sewer. This option includes common treatment like screening, neutralization, flow equalization or more extensive treatments such as gravity sedimentation or air flotation for soil and solids removal or neutralization. It is often required by city ordinance and is done to meet municipal ordinance requirements (63), reduce cost (37,83), and accommodate production increases. Efficiency of

pretreatment processes are reported in the literatures (21,42,81,91).

Processors discharging to municipal systems are subject to local sewer service charges varying from a flat rate to a charge proportional to the flow or floor area of the plant. Charges usually are higher when the industry uses a facility that has received federal funds for treatment plant construction. Such charges are called industry's "fair share" and are calculated in proportion to the amount of waste load discharged by the industry. Pretreatment is used in cyclic processes.

2. Complete treatment of waste and discharge to stream. Potato wastes are organic in nature (42,74) with an average BOD of about 10 to 30 times greater than domestic sewage (39,46). Waste water from the French fry industry and similar effluents can be treated quite successfully by conventional biological treatment plants which treat domestic sewage, providing there are suitable modifications to compensate for the waste water characteristic differences (15,30).

This option, preceded by in-plant management and pretreatment and followed by chlorination and filtration, can meet "zero discharge" requirements (79). Biological treatment systems for potato waste, as shown in the literature, are able to reduce BOD by 71 to 98 percent (21).

Installation and operation of complete treatment facilities is very expensive. A thorough study of costs of treatment to meet effluent requirements is found in EPA publication number 440/1-74-027-a (79).

3. Discharge to land. Land treatment systems such as spray or flood irrigation are effective and relatively economical alternatives for waste treatment. This option is one of the oldest methods of treatment which has been used successfully for the disposal of cannery wastes (15). When feasible, it is generally the most economical end-of-pipe treatment technique that will meet EPA standards scheduled to go into effect in 1983 as well as EPA standards for new source performance (55,79). Aside from unavailability of extensive areas of land, there are other factors which limit the use of land for disposal of wastes. Such factors are climatic conditions, soil texture, contamination of underground waters when operated improperly and runoff problem (15,59). Costs of using land as the ultimate disposal method have been estimated (79). The financial burden of such operations can be minimized by a modest revenue obtained from the sites, as when crops are grown on the irrigated land.

No doubt that high level technology exists for complete end-of-pipe waste treatment, but the application is very costly. This is obvious and can be fully understood by scanning several references (27,28,37,79).

Conversion of raw food materials into processed products inherently requires the use of water. Since water comes in direct contact with the raw materials during processing, significant amounts of organic and inorganic materials in the suitable colloidal, or particulate form are generated as "waste". Waste is normal, but allowing it to cause pollution - which is a resource out of place - is abnormal. It shows a serious lack of proper management of two major resources, namely food solids and water (26). Dumping the wastes requires setting up sludge plants, which are expensive bacterial cafeterias. One should develop other industries utilizing wastes from the first stage of industry for the production of by-products (27). As stated by Gallop et al. (1976), "In effect, the individual discharges from process units become the ingredients of a large, manufactured, inedible, almost irreversible, worthless "omelette" in drains." The processor is faced with a problem to solve promptly at great cost. The effluent must be treated to satisfy EPA with regard to protection of fish, the public, and the environment as a whole. The problem is that of separating the solutes and suspended matter from the carrier before discharging and then buying some more water to repeat this foolish exercise. Therefore, it would be wiser to prevent this problem from occurring because prevention is always preferable to an attempted cure later. In this connection, one can reduce the organic load in the discharge by minimizing product-waste contact whenever possible. In more specific terms, we must manage 100 percent of our minimal water input so as to minimize our wasteful output. Waste streams should be monitored at their source and kept concentrated and isolated prior to conditioning for re-use within or beyond the plant or for discharge under good control with negligible environmental damage.

Based on the above, reduction of product-water contact is the other way of pollution minimization as previously stated in contrast with end-of-pipe treatment of wastes. It can be achieved by varying operational practices and by use of improved food processing equipment (83). These together could generally be called in-plant modifications every effort of which somehow aims toward conservation of water.

Among the beneficial results stemming from water conservation are: (1) assurance that limited resources of fresh water will keep pace with the growing population and expanding industries (89); (2) savings in the purchase and disposal of water (34,38); (3) reductions in the volume and increases in the concentration of leached material in process water plus reduction in leaching because of the reduced concentration gradient all contribute to greater economy and efficiency of treatment (50,51,56); (4) enhanced potential for recovery and utilization of by-products

(83); and (5) conservation of heat energy when reused at the elevated temperatures of the discharging unit operations (29,47).

There has been much controversy concerning the safety of water reuse in the food industry in order to achieve the above-described benefits. The National Canners Association presented data supporting a continuation of those water conservation practices now in use which have been shown to have no adverse effect on the quality and wholesomeness of the finished product (83). Efforts toward water conservation have been tackled in several ways.

Employment of low-volume, high-pressure systems for washing the product and for clean up reduces water use and waste generation (45). It was reported that increasing nozzle pressure from 40 psi (2.7 atmospheres) to 250 psi (17 atmospheres) reduced water use by approximately 65 percent.

Other changes in operational practices such as elimination of excess running water, prevention of unnecessary overflows, spillages, and dumps, dry handling and disposal of solid wastes from floors, machines, and other work areas instead of fluming-to-waste will reduce water usage and waste generation (42,45). Conveying product and solid wastes in water instead of "dry" increases both the waste flow and BOD more often than not (56).

The handling of crops containing much soil may cause problems during processing, such as plugging of flows, conveyors, and sewer lines due to settling of soil. Precleaning of raw potatoes by dry method - agitating on screens or roller conveyors - removes adhering soil which may amount to 1.87 percent (53) and reduce water usage.

Being concerned primarily with the product quality improvement, food processing industries have been using too much water through the employment of the absurd, expensive, linear process "once-use" system (19,28). Such a practice has caused most of the industry's pollution problems and turned it into the world's largest effluent-producing industry (27). This has probably resulted from the historical belief that water is the cheapest commodity available in comparison with processing equipment and labor (30).

Among the approaches used to solve pollution and economic problems resulting from extravagant water usage is water reuse. This does not necessarily change the manner of use by industry, only the source. It deals only with the recovered water fraction of the waste water. Such a case is reported (5) for a potato processing plant in England where strict water pollution regulation and high cost of process water justified the reuse of the reclaimed waste water. The waste water, having a BOD of 1,918 mg/ℓ, was subjected to primary settling, biological treatment, sand filtration and chlorination before reuse.

Immediate reuse (before treatment) may also be practiced. In a case confirming such practices, an overall possible reduction in excess of 44 percent for the total daily water needs of a potato processing plant was reported (38). As stated in the report, 18.8 percent of total plant water intake per day - from the refrigeration compressors and condensors - could be reused with little or no further treatment in any processing operation. An additional 10 percent of reusable water (part of the 29.1 percent of total daily plant intake that is used by the Allen grader, the conveyor flume for by-products and the potato cutters) is suitable for immediate reuse in fluming of raw potatoes. The rest - 19.1 percent - could be reused after treatment to remove suspended solids and reduce bacteria to an acceptable level for other purposes.

Use of waste water from any process line as the make up water in the fluming of potatoes has also been suggested by Hindin (1970). He studied water use and waste water reuse at three processing plants whose major product was frozen French fried items and proposed a scheme for reuse of waste water in processing based on the in-plant investigations.

Reuse of water in processing may effect considerable reduction in overall usage, but waste separation - separation of low and high strength waste streams - which is an essential practice (15,30,60) must precede any effort toward water reuse. Kueneman (1965) reported that waste flow of 3,650 to 4,200 gallons per ton of raw potatoes could be reduced to 200 to 400 gallons per ton with considerable water reuse. Dornbush et al. (1975) showed that water usage dropped from 3,500 to 815 gallons per ton of raw potatoes processed through extensive in-plant water conservation along with utilization of a dry-caustic peeling process.

In the course of reuse, the quality of the water that comes in contact with the product is of extreme importance (30). On the other hand, water used in some unit operations need not necessarily be of the same sanitary quality (83). For example, the quality of water used to remove potato peels is the least critical in regard to quality of all the process operations (39). Therefore, from a practical standpoint, the same water can be used for a number of successive purposes, each less demanding of quality than the preceding, with or without purification (54,60). In such a "retrograde" manner of water reuse - which is called counterflow water system - most of the fresh water is used in the final operation. This water is then collected and reused in previous operations. Since the water always passes counter to the flow of the product, the product comes into contact with successively cleaner water (83,89) and is finally washed or rinsed with fresh water. Such water reuse reduces the (fresh) water usage and minimizes the volume of waste water discharges.

The amount of water saved by a counterflow system varies within each plant. Under average conditions this is estimated to be about 50 percent of the total water usage (83). A study (79) showed that one-third less water was used and there was less danger of bacterial growth in a once-through counterflow system than in the recirculation system with which it was compared. Bruce _et_ _al_. (1977) reported over 30 percent reduction in water usage in a few frozen potato plants through the use of a counterflow water system. They found the major problem in retrograde water reuse to be in controlling microbial growth within the water system and preventing product contamination to the next unit process. The problem was controlled by use of chlorine dioxide as the primary microbial control agent in the system.

Another approach toward water conservation and waste minimization is recycling of waste water which could be done in either limited or complete form. When a closed system is not practical, limited recycling - recirculation of waste water for a limited number of cycles - would save some water. For example, according to Hindin (1970), the trim table waste water can be recycled for at least seven hours before disposal.

Complete or continuous recycling of waste water (also called a closed loop system) eliminates most pollution problems through monitoring of wastes at their sources. In such a reliable, cheap and adaptable process, the effluents from each step of the line are used in a systematic counter flow pattern, with each one being cyclically used for one operation. This system requires only make-up volumes of water and permits solids accumulation to, and maintenance at, an acceptable "background" level and only excesses above these need be removed between each reuse by simple means like screening, flocculation, settling, filtration, cycloning, cooling, chlorination and other cited treatment methods (81). Most of the problems are also controlled this way. For example, color, foam, bacteria and the like problems during recirculation of wash water at the potato rinse stage can be solved by a combination treatment of pH and activated carbon (41). Such minor purifications by in-line "cartridge purifiers" is bound to be cheaper and more desirable than purifying similar volumes to a much greater degree in a large external treatment plant, discharging it out, then buying more fresh water. Furthermore, this "creaming-off" of the excess percentage of nuisance factors follows the fact that reuse of the pollutant fraction should be an integrated part of the water reuse planning (16). It brings about the potential for recovery or by-product utilization which not only saves water, minimizes pollution, and expands product usefulness (54), but can also sometimes be implemented at a profit (28,64,75). Therefore, waste treatment could turn into a money making proposition. For example, the starch in cutter water causes extremely high BOD and suspended solids concentration, the removal of which by centrifugal hydrocyclones reduces the total effluent BOD and makes a slight profit when it is sold (37). Taylor (1973) reported that use of hydrasieves and cyclones in potato processing reduce BOD and suspended solids by more than 50 percent, resulting in lower treatment costs and saving $439 per day on recovered products. In several European potato processing plants the suspended starch grains are separated by sedimentation followed by vacuum filtration. The recovered starch is washed, dried and sold, and the starch-free water is reused (15).

Another complete recycling is in the closed system for fluming of raw potatoes, the required in-line treatment for which is sedimentation. In one case (37), fluming used 50 percent recycled water and discharged 75 gallons per minute of effluent having an average suspended solids (silt) of 7,000 mg/ℓ and a BOD of 110 mg/ℓ. Addition of one mg/ℓ of anionic polymer caused quick gravity settling of silt which was dewatered and used as topsoil replenisher.

The recovery of potato protein, which is a remarkably nutritive protein and contains all the essential aminoacids (57), can be achieved directly from the waste stream or indirectly by fermentation (75). In the direct method (25), reverse osmosis and ultrafiltration membrane processes are employed. With the indirect method, waste starch and other carbohydrates may be converted into yeast cells (protein). The first commercial Symba-yeast plant to purify potato waste was built in Sweden. It was able to achieve 90 percent purification of input material (68). Preparation of an organic cleaning compound from potato processing waste has also been reported (8).

Conservation of water and reduction of wastes through equipment and/or process modification is of paramount importance in potato processing. This is because 20 to 50 percent of raw potatoes become waste during processing. To utilize slivers and nubbins, that part of the waste resulting from cutting, by-products such as patties, puffs, hash-brown and mashed potatoes may be produced. This reduction in waste represents about 10 percent (74) of the raw potatoes processed. A considerable amount of loss still remains; namely that which occurs during other processing operations.

Peeling of potatoes is one of the major waste-producing processes. It represents 20 percent of the water flow, over 50 percent of BOD, and over 60 percent of suspended solids of the total processing effluents (79). This considerable waste stems from the large quantities of water usage along with the high losses from the raw potatoes which (when trimming is included) usually falls within the range of 15 to 40 percent of raw product weight (74). This is because the amount of loss varies with size and shape of potatoes, depth of eyes, length of storage time of the tubers, and type of peeling. Use of large potatoes, which have less peeling losses (74), or certain tuber varieties the deep eyes of which are bred out, can reduce wastage (26) during peeling. Newly harvested potatoes have less loss than older potatoes from storage. Burton (1963) stated that, over long periods of storage, potatoes become increasingly unacceptable until, at 10 percent weight loss (based on original weight going into storage), the potatoes are wrinkled, spongy and very difficult to peel.

Caustic and steam peel treatment are the generally accepted methods (79) of peeling in the potato processing industry - except for potato chip manufacture, which usually utilizes abrasion peeling. Table 2 provides a summary of estimated quantities of peel in waste in potato generated by different methods of peeling.

The dry caustic or infrared caustic process which was developed by the USDA Western Regional Laboratory as a modification of the conventional or wet caustic peeling process has proved to be very efficient from a pollution-control point of view. This process reduces water usage by 75 percent, BOD by 67 to 78 percent and solids by 73 percent. Improvements in the dry peeling process such as double-dip caustic peeling (40) or recirculation of water from the washer to the scrubber (18) can save more caustic or water, respectively.

Change of equipment can also serve the purpose of pollution control. For example, by installation of dry brushing equipment such as the Dutch I.B.V.L. brushing machine (85) right after the lye or steam peeler, the treated potato skin will be brushed off clean without the use of water. By keeping the dry peel waste generated by the dry process out of the plant waste water, a reduction

Table 2. Effect of Peeling Methods on Quantity of Waste.

Peeling Method	Peel Wastes % of Raw Wt.	BOD lb/ton of Raw Potatoes	Ref.(1)
Abrasion	3-12	---	32
Abrasion	25	---	33
Abrasion	14-25	---	23
Infrared	13	260	87
Infrared	10	200	87
Lye (Wet Caustic)	18	---	87
Lye (Wet Caustic)	12-30	---	52
Lye (Wet Caustic)	22	---	33
Lye (Wet Caustic)	11-23	---	23
Lye (Wet Caustic)	--	186	86
Dry Caustic	--	26	31
Mechanical(2)	7-31	---	90
Lye/steam	15	---	2
Steam	10	260	87
Steam	11-19	---	23
Steam	18	---	33

(1) Numbers correspond to listing in Literature Cited.

(2) The author did not specify type of mechanical system used. The term may have signified abrasion peeling.

of approximately 75 percent (69) can be achieved in the amount of solids in the effluent of a French fry plant.

Production of a uniformly-colored final product is of notable importance in French fry processing. Hot water blanching, in addition to its other functions (as detailed under Experimental), is the process which deals with this purpose. The process has a leaching effect on reducing sugars which, when coupled with amino acids, cause brown color in potato cuts during heat treatment (74). Meanwhile gelatinized starch is released and other desirable low molecular weight compounds (15), e.g., flavor constituents (74), are also leached out into the blanching liquor. A considerable amount of liquid waste is generated during water blanching, which contributes significantly to overall plant effluent. It is reported (79) that blanching of potatoes may contribute over 20 percent of the BOD in the plant waste load and, in the case of frozen products, the rate of water usage is 250 gallons per ton of raw potatoes processed. It has been reported (86) that blanching, when coupled with peeling, will account for about 44 percent of the total plant effluent, 89 percent of the total BOD, 86 percent of the total COD, and 37 percent of the total suspended solids generated during processing of potatoes. Tables 3 and 4 present blanching data.

The alternate low-waste producing blanch processes

Table 3. Suspended Solids and Total Solids in Potato Blanching Effluent.

Process Step	Effluent gal/min	% of Total	SS(1) mg/ℓ	TS(2) mg/ℓ	Ref.(5)
"Hot Blanch" (steam)	30	--	3300	----	6
"Wet Blanch" (water)	90	--	195	----	6
Blancher and Peeler	153.5	44	----	3330	86

Source: EPA Report 12060 EDK 08/71.

(1) Suspended Solids. (2) Total Solids. (3) Numbers correspond to listing in Literature cited.

Table 4. Pollution Load in Effluent from Water Blanching of Potatoes.

Effluent Flow		BOD		COD		SS[1]		
Gal/hr	Gal/min	lb/ton	% of Total	lb/ton	% of Total	lb/Ton	% of Total	Ref.[2]
2520	42.0	52	--	58	--	37	--	6
2310	38.0	22	--	32	--	25	--	6
9210	153.5	186	89	279	86	181	37	86

Source: EPA Report 12060 EDK 08/71.

Note: Figures on the bottom line include both blanching and peeling loads.

(1) Suspended solids.

(2) Numbers correspond to listing in literature cited.

like hot gas, microwave, steam, and individual quick blanch (IQB) methods which are discussed in several references (10,12,17,49,61,62) are not applicable (15) to French fry processing at the present time. This is because there are normally large amounts of the leachables which must be removed during this process step in order to prevent development of brown color on the surface of the cuts in later heat treatments.

The effluent, generated in the blanching process, is separable from the total waste stream and can be treated to reduce pollution loads significantly in the total process waste flow (63). As a preventive measure, use of potato varieties which are poor sugar formers and processing of stored tubers at periods during which they are at the desired sugar level plus the use of reconditioning (1,74) may leave no necessity for the use of water blanching to leach unwanted reducing sugars. This will enable processors to substitute low-waste producing methods (such as those referred to above) to conserve water. It is also possible to minimize pollution from blanching by recirculating the blanch water to build up the concentration of extracted soluble constituents so as to restore some of the soluble material extracted by passage of the potatoes through the blancher (74). It is said (79) that this procedure will decrease the product loss, but it can also adversely affect the removal of undesirable leachables from the product.

In the defatting operation, surplus oil is removed from the French fries by passing the product over vibrating screens (15,74). Oil recovery can be enhanced by a variety of methods. Hot water may be sprayed on the fried cuts during the vibrating process. It is also possible to use specially designed equipment (74) in which the French fries are shaken and subjected to a high velocity stream of hot air to aid the removal of excess fat.

The most ideal solution (3) to water and waste management in the food industry - and naturally, potato processing - is a total system approach such as that proposed by Gallop et al. (1976). In such a system, one must view the entire plant as a "total system" with the waste element being as important as (or in some cases, more important than) the product being put out for commercial sale.

Waste Characterization

The reduction of pollution in the processing of fruits and vegetables depends on the identification of sources and characteristics of the waste water (30). This enables a researcher to find large water-use, waste-producing areas in the processing operation and to determine methods of reducing their effect on total pollution load. Therefore, the first step of a pollution control program is to characterize the waste water so as to determine (4,83,91) the quantity and the treatability of organic compounds involved. This also provides information (91) relating to possible in-plant separation of the most significant waste streams for separate handling at the processing plant.

After initial studies (80,91), including the establishment of a complete picture of the entire production process, showing of all raw materials, additives, and products, by-products, and liquid and solid wastes and also locating the process piping and waste drains, one can proceed with flow measurement and determine points of sample collection.

Collection of flow data is an essential part of the waste water survey on which any pollution control measure is dependent. Selection of the proper measuring method or device should be done with consideration given to such factors as cost, type and accessibility of the conduit, hydraulic head available and type and character of the waste. A thorough description of flow measurement methods is given in the EPA Handbook for Monitoring Industrial Waste Water (80).

Sampling is of paramount importance in waste survey programs. The information obtained by sampling provides the basis for any plant pollution abatement program. The type of information desired will dictate the method utilized for obtaining waste water samples (83). The choice between grab and composite samples should be made on the basis of the stability of the constituent to be measured, and the degree of accuracy desired in the results. Although composite samples have the advantage of being less sensitive to fluctuations in waste characteristics which occur during the sampling period (83), a grab sample may be preferred over a composite sample when the waste characteristics are relatively constant (80). For wastes in the latter category a complex sampling is not necessary since an occasional grab sample may be entirely adequate to establish waste characteristics. In other words, the data collected by grab samples, while not as precise, would still be exceptionally valuable in terms of defining the process from a waste-generating standpoint. For in-plant surveys, grab samples should be taken several times per shift (83) but, in deciding on the frequency of sampling, one must always strike a balance between reliability and cost (66).

In situations where analysis of waste water samples will be unavoidably delayed, the samples may be preserved. In the case of freezing, samples should be placed in flexible containers with sufficient space left in the containers to allow ice expansion (83). The subject of sample collection and care of sample is treated adequately in references (7) and (80).

Selecting Indices of Pollution

Determination of the volume and composition of the wastes permits the assessment of locations at which the greatest pollution load problems occur in the course of processing (63). For this purpose, significant indices of waste water composition should be evaluated.

For potato processing, a thorough analysis of the literature (15) shows that Biochemical Oxygen Demand (5-day, 20°C, BOD_5), Total Suspended Solids (TSM), and pH are the measures having major pollutional significance.

Determination of Chemical Oxygen Demand (COD) of the waste is also useful from any of the following standpoints: (1) serving as a quick check or guide for BOD (83); (2) measuring the oxygen equivalent of the portion of the organic matter in the effluent that is susceptible to oxidation by a strong chemical oxidant (but not necessarily biodegradable) and, last but not least; (3) being the only method for determining the organic load in certain wastes containing toxic substances (7).

Settleable solids is another major waste water index (83) which would be included in the determination of total nonfilterable residue - previously referred to as Total Suspended Solids or Total Suspended Matter (7).

Analytical Procedures

Many researches (38,71,91) follow the methods described in "Standard Methods for the Examination of Water and Waste Water" (7). The test procedures described in the Standard Methods are approved by the U.S. Environmental Protection Agency (83). Other EPA approved test procedures (82) are basically the same as those given in the Standard Methods.

The BOD test can be done on either prepared dilutions of the sample or the undiluted sample. The Standard Dilution Method, though long used, has never been completely satisfactory. The Hach Manometric BOD Apparatus, using undiluted sample and producing equivalent results in terms of both accuracy and precision, has several advantages over the Standard Dilution method (35).

Interpretation of Data

The Q-Test (20) can be used as the criterion for rejection of an observation in the measurement of desired waste water indices.

Once the data are obtained, a proper statistical technique should be used to interpret the results. The four recommended techniques (91) are: (1) Testing the difference between means, (2) Analysis of runs, (3) Regression, and (4) Chi-square test.

EXPERIMENTAL

Process Description

Raw product quality and uniformity are the predominant factors which determine the rate of water usage and waste generation. Ideally, potatoes received at the processing plant should have high solids content, low reducing sugars content, thin peels and uniform size and shape. The processing steps are as follows:

Receiving/Cleaning: Potatoes purchased and used during the period of these tests were of the Kennebec variety. Delivery was by truck and rail car. Potatoes received at the plant may have soil loads of 3-5% of their weight (Lutz et al. 1967). Soil removal and elimination of some foreign materials are achieved by passing the raw product on roller conveyors and upward-inclined belt conveyors. The potatoes are then stored in piles for processing.

Fluming/Transportation: The potatoes are washed away from the leading edge of selected storage piles into a flume by recycled water and conducted to a settling basin for gravel and silt removal. Intermittent discharge of silt calls for making up the water of the closed fluming system. Fluming acts as a dual purpose step, transporting and washing the raw product. Potatoes are pumped from the settling basin to the elevated dewatering screens from which they are dropped down into successive hoppers and conveyors for better cleaning and foreign matter removal. The relatively clean product is next taken to the peeling operation by a vertical pump-referred to as a pump/flume.

Lye Peeling/Trimming: The tubers are dipped in a 20 percent lye bath at 160°F for a few minutes (depending on the thickness of the peel) to loosen their skins and then conveyed to the scrubber. The conveyor is sprayed with fresh water through a perforated pipe. In the scrubber, abrasive rolls, revolving in opposite directions, and fresh water spray remove most of the peel from the potatoes as they roll along the unit down to the washer. This unit is identical to the scrubber and is employed for better peel and caustic removal.

The trimming operation completes the peel removal. In this operation the eyes, blemishes, and remaining peel are removed manually. A spray of chlorinated water at the end of trimming conveyor improves sanitation.

Surface Darkening Control: A pump, similar to that before the lye peeler, takes the trimmed potatoes into an elevated surge tank containing SO_2 solution to prevent brown color development.

Cutting: The peeled-trimmed potatoes are cut into smaller pieces having the desired shape. During cutting, a number of potato cells are ruptured and a considerable amount of starch is released. Some water is used to remove this starch and facilitate the operation in the cutters. The starch-rich-effluent is then discharged into the waste stream.

Sizing: Potato cuts are directed onto a multiple-layer vibrating screen with water sprays on the top to eliminate remaining starch and the undersized cuts called slivers and nubbins.

Blanching: A two-step, hot water blanch (160°F, 8-20 min.) is employed to achieve the following:

1. Inactivation of enzymes to prevent color and flavor changes.
2. Partial cooking to reduce frying time and also fat absorption through gelatinization of the surface layer of starch.
3. Reduction of bacterial count.
4. Elimination of excessive reducing sugars to obtain the desired color in the final product.
5. Improvement of the texture of final product.

This step is one of the biggest water users in the plant.

Coloring/Sugar Dip: Since virtually all of the sugar has been removed from the potato cut during blanching, a small, controlled amount must be added back during the coloring/sugar dip stage. This is done by fluming of the blanched cuts in a solution containing dextrose, sodium acid pyrophosphate, and food color to establish the desired color in the finished product.

Surface Drying: Surface moisture is removed by hot air blast to prevent high oil pick up during frying.

Frying and Defatting: The cuts are par-fried to facilitate later preparation by the consumer or the institutional user. Some heat inactivation of microorganisms is also accomplished during this step.

Surface oil of the fries is washed off by hot water spray on a vibratory screen conveyor. The waste water, containing considerable oil, goes to an oil recovery system, then to a grease trap, and finally to the sewer.

Precooling and Freezing: After cooling by a cold air blast, the cuts are quickly frozen in a tunnel freezer, which is the bottleneck unit operation in the plant. The coils of the cooler and the freezer should be defrosted at intervals during the operation. Fresh water is used for this purpose.

Packaging and Storing: The frozen cuts are packed in the desired size containers and stored at freezing temperatures.

Water Use in the Plant

Water is used in different processing steps and achieves the following purposes:

1. Transportation: Fluming of raw potatoes, water conveying of the colored cuts.
2. Washing/Cleaning: Washer, trimming belt, cutter, sizer, and fluming of raw potatoes.
3. Removal or Separation of Unwanted Materials: Scrubber, cutter, sizer, defatter, liquid/solid waste separator, and blanchers.
4. Heating or Cooling: Ammonia or air compressors, boilers, blanchers, and defrosting of freezer and cooler coils.

Solvents and Chemicals

All solvents, chemicals and reagents were of analytical grade. Distilled, deionized water was used for laboratory analyses throughout the study.

Sampling

Selection of unit processes for which the effluent would be surveyed, was based on several factors, namely: volume and/or pollutional strength of effluent, possibility of by-product recovery, possibility of effluent being re-used or recycled with little or no treatment, and feasibility of sample collection.

Based on the above mentioned factors, the chosen unit processes were the washer, cutter, sizer, and each of the two blanchers. The final plant effluent and the mixture prior to addition of defatting and sanitary effluent were also sampled.

Samples were collected for determination of Biochemical Oxygen Demand (BOD), Total Nonfiltrable Residue (Total Suspended Matter, TSM), Chemical Oxygen Demand (COD), Grease and Oil (for final plant effluent), pH, and temperature from the selected unit processes.

Grab sampling was chosen over composite sampling for the following reasons:

1. Remote location of the plant necessitated longer time between taking and freezing of the samples.
2. Composite sampling needs costly equipment, especially when there are more sampling points.
3. Continuous operation of the plant with a relatively stable production rate (114 hours per week and

about 9,000 lb of processed potatoes per hour) gave reasonable assurance that the strength of the waste waters should be relatively constant.

However, for improved accuracy, the samples were manually composited. That is, several (three) grab samples taken from the same point at different times, were combined to form representative samples of each unit operation. Samples taken for grease and oil determination, however, were not composited before testing.

Plastic containers were used for all samples to withstand freezing. Approximately 1,500 ml samples were collected in half-gallon milk bottles for BOD and TSM tests, 500 ml samples were collected in freezer boxes for COD measurement at each discharge point, and 1,000 ml samples were obtained for grease and oil determination from the final plant effluent for each sampling date.

<u>Sample Handling and Preservation</u> - The samples were kept in styrofoam chests over ice soon after they were taken and during transportation. Samples taken for COD and grease and oil analysis were acidified at the sampling site. Acidification was done by gradual addition of concentrated H_2SO_4 to the sample under continued stirring until a pH of ≤ 2 was attained.

Representative portions (each of about 300 ml) were taken from the larger samples and kept at +4°C for at most a few days before TSM determination. All other samples were placed in the freezer (-15°F or -26°C) where they were held until time of analysis - a time lapse of about two months. There is no indication in the literature that the freezing/thawing process has any effect on test results.

Analytical Methods

Sample Preparation - The frozen samples were placed in warm water until completely thawed. In the case of BOD and COD samples, the containers were shaken occasionally for rapid thawing. Tests were run on the thawed samples (BOD, COD, and Grease and Oil) immediately.

pH Determination - The pH was measured immediately after taking the sample at the sampling site, using a Corning pH Meter, Model 7.

Temperature Measurement - A portable digital readout thermocouple and a bimetallic strip thermometer were used alternately to measure the temperature of the effluent at each discharge point.

Total Nonfiltrable Residue (Total Suspended Matter, TSM) - Method number 208D, page 94, of the Standard Methods for the Examination of Water and Waste water, 14th edition, 1976 (7) was used to determine TSM of the effluents. The sample was kept well mixed by a magnetic stirrer. An aliquot (at least 10 ml) was transferred slowly by pipet to a pre-washed, dried, and tared glass fiber disk filter set on a Gelman 47 mm magnetic filter funnel and vacuum filtered. The interior of the funnel was then washed with three successive 10 ml portions of distilled water. After breaking the vacuum, the filter and its contents were transferred into a tared aluminum planchette, dried for at least one hour at 103° to 105°C, cooled in a desiccator and weighed. The drying cycle was repeated until weight loss was less than 5.0 mg. Total Suspended Matter was calculated as shown in Footnote (1), Appendix Table V.

Chemical Oxygen Demand (COD) - Method number 508, page 550, of the Standard Methods for the Examination of Water and Waste Water, 14th edition, 1976 (7), was employed to determine chemically oxidizable matter in the effluents. The strong effluent was diluted with distilled deionized water, using a dilution factor of 1/20. A combination of reagents was selected, as detailed in Table 508.1, page 553, of the "Standard Methods . . ." in which 0.4 g of crystalline

$HgSO_4$ was added to 20.0 ml of diluted sample to complex chlorides that would otherwise interfere with the results. After addition of 5 ml of H_2SO_4 reagent and cooling of the flask content, 10.0 ml of the standard $K_2Cr_2O_7$ solution was added. The glass was attached to a condenser, cooling water started, and the remaining H_2SO_4 (25 ml) added through the open end of the condenser. At the same time, flask contents were mixed well to prevent localized overheating. The mixture was refluxed for at least 2 hours. Then the condenser was washed down, the mixture was cooled and diluted to about twice its volume and, using 2-3 drops of ferrion indicator, the excess dichromate was titrated with standard ferrous ammonium sulfate to a sharp color change from blue-green to reddish brown.

A blank sample consisting of reagents and distilled water equal in volume to that of the sample was refluxed and titrated in the same way.

The reactions involved in chemical oxidation and titration may be represented, respectively, in a general way as follows (66):

$$C_nH_aO_b + cCr_2O_7^{=} + 8cH^+ \xrightarrow{\Delta} nCO_2 + \frac{a+8c}{2} H_2O + 2cCr^{3+}$$

Where $C = \frac{2}{3} n + \frac{a}{6} - \frac{b}{3}$

$$6Fe^{++} + Cr_2O_7^{=} + 14H^+ \rightarrow 6Fe^{3+} + 2Cr^{3+} + 7H_2O$$

To evaluate the technique and quality of reagents, a standard solution was made by dissolving 425.1 mg of potassium acid phthalate in distilled water and diluting to 1,000 ml. This solution has a theoretical COD of 500 mg/ℓ. The analysis of this solution showed 98.44 percent recovery of the theoretical oxygen demand which fell within the range given by the "Standard Methods . . .".

Normality of the standard ferrous ammonium sulfate was checked daily and the COD of samples were calculated as shown in Footnote (1), Appendix Table VI.

Biochemical Oxygen Demand (BOD) - Hach Manometric BOD apparatus (Model 2173A; Hach Chemical Co., Ames, Iowa) was used to determine the quantity of oxygen required during stabilization of decomposable organic matter by aerobic biochemical action. Aside from the simplicity of BOD measurement by Manometric Method, the results have been proven to be equivalent in terms of both accuracy and precision to those obtained by the Standard Dilution Method (35).

Preparation of Dilution Water: The desired volume of distilled water was placed in plastic milk bottles and then 1 ml of each BOD reagent listed in the "Standard Methods . . ." namely, $MgSO_4$, $CaCl_2$, and $FeCl_3$ solutions was added per liter of water. The bottles were cotton-plugged and kept in an incubator at 20±1°C until needed (maximum of 36 hours). One ml of phosphate buffer was added per liter of dilution water just prior to using it to dilute the effluent sample, as described below under Procedure.

Preparation of Seed: The supernatant liquor from raw domestic sewage - primary effluent - was taken from the East Lansing Waste Water Treatment Plant in plastic milk bottles, settled for 24-36 hours at 20°C - in an incubator - and was used as the standard seed material.

Procedure: To determine the BOD of the effluents, a representative portion - 100 ml - was taken from each sample. After adjusting its pH with 1 N H_2SO_4 or NaOH to bring it within the range of pH 6.5-7.5, the volume was increased to 1,000 ml by dilution water (dilution factor of 1/10) to bring the final BOD within the working range of the apparatus (maximum of 700 mg/ℓ). For the cutters and sizer effluents a different dilution factor (1/20) was used. Consulting the Table of Volume-Scale Relations (35), 95 ml of the prepared sample was placed in the bottle of the apparatus. One ml of seed material was added to each BOD sample and a magnetic stirring bar was placed in each bottle.

300 ml of the diluted seeding (dilution factor of 1/2) was also prepared to be used both as a control and a correction basis for the results. Seal cups, each containing 3 pellets of KOH and with seal lips greased with mineral

oil, were placed in the necks of the sample bottles. When putting the sample bottles on the apparatus and starting the motor, the bottle caps were screwed in place loosely while the manometer caps were open. After running the apparatus for 30 minutes to reach the thermal equilibrium in the incubator, the previously greased manometer and bottle caps were tightened, the scales were adjusted to zero, and the time was recorded.

Manometer readings were obtained each 12 or 24 hours for any possible later use of the data. The BOD of the samples was calculated as indicated in Footnote (1), Appendix Table VII.

Preparation of BOD Standard Samples: Standard samples were run periodically to check the accuracy of the data obtained. For this purpose, a solution was prepared containing 150 mg/ℓ glucose and 150 mg/ℓ glutamic acid, each of which had been previously dried in an oven at 103°C for one hour. One hundred eighty ml of this standard solution was seeded with 20 ml of the seed. Then 160 ml of this seeded standard was used for determination of the BOD. The corrected BOD of the standard solution fell within the recommended range of 220±11 mg/ℓ which indicated that the apparatus was performing properly.

Grease and Oil Determination - Method number 502A, page 515 of 14th edition of the "Standard Methods . . ." (7) was used for measurement of grease and oil content of the final plant effluent. A deviation from the method was necessary to evaporate liquids other than oil. For this purpose, in addition to the use of recommended evaporating technique, the extract was vacuum dried at 70°C until its weight loss became less than 5.0 mg per one hour.

The level of the thawed sample in the container was marked for later sample volume determination. The whole sample then was transferred into a 2,000 ml separatory funnel. The sample container was carefully rinsed with 30 ml of Freon-113 (1,1,2-trichloro-1,2,2-trifluoroethane). The rinse liquid was added to the separatory funnel, the contents of which were then shaken vigorously for 2 minutes. After separation of layers, the Freon layer was drained through a funnel containing solvent-moistened filter paper (Whatman No. 40) into a clean, tared distilling flask. The extraction was repeated two more times and then the filter paper was washed with 10 ml of Freon. The flask containing the combined extracts was placed in a water bath at 70°C to remove most of the Freon by evaporation and then on a steam bath for 15 minutes to remove the last traces of Freon. During the final one minute, air was drawn through the flask by means of an applied vacuum.

Since the standard procedure did not remove the non-oil liquids, the mixture was vacuum dried as stated previously. Scorching occurred during vacuum drying which indicated that scorchable, non-oil organic materials were extracted by Freon along with the desired grease and oil, during the extraction process. It is felt that the scorching and accompanying weight loss minimized the possible error from non-oil nutrients in the Freon extract.

To determine the solvent residue, 50 ml of Freon was placed in a tared clean distilling flask and underwent the same drying procedures. The gain in weight of the flask, which corresponded to the residue weight from 50 ml of solvent, was converted to that of 110 ml of Freon and used as weight of solvent residue in the calculation of grease and oil content of the sample, as shown in Footnote (1), Appendix Table VIII.

Standard Sample Preparation: Standard sample was made by mixing one gram of the frying oil used in the processing plant with water to a total volume of one liter. The container used for this purpose was the same as those used for the final plant effluent samples taken for grease and oil determination. The standard sample was handled and analyzed the same way as the effluent samples. The results of the standard sample analysis was used as a correction basis for reporting the data (See Footnote (1), Appendix Table VIII).

Flow Measurement and Water Usage Determination

A total water usage of 300,000 gallons per day by the plant was used as a basis for calculations in these studies. This value had previously been determined from water usage data by the plant personnel.

The flow rates for specific operations in the plant were determined in several ways. The method(s) in each instance, being chosen on the basis of reliability and practicability under plant conditions, are cited in Appendix Table II along with the flow rate data. The methods used were: 1) Meter readings on specific water lines; 2) Measurement of water quantities in measured periods of time, representing influents or effluents of various unit processes at average operating pressure. During periods of water collection, operating pressures were adjusted to the average operating pressures given in Table 5. These, in turn, had been determined previously by installation and monitoring for a two-week period of pressure gauges on the water pipes leading to each of the listed unit operations. In a few of the operations listed in the Appendix Table II, pressure readings could not be obtained but flow rates in each of these unit operations were insensitive to variations in line pressure (based on previous determinations by plant personnel); and 3) Calculation of water usage by formula, using manufacturer's specifications for nozzle output as

Table 5. Pressure Gauge Readings (Water Pressure) for Unit Operations.

Unit Operation	Replication	Operating Pressure, psi						
		Date						
		6/14/77	6/16/77	6/20/77	6/23/77	6/27/77	6/29/77	Av.
Post-Peeler Conveyor	1	36	28	22	10	13	30	23
	2	37	26	22	11	13	31	
	3	36	28	22	10	13	30	
Scrubber	1	43	46	44	46	52	50	47
	2	44	44	44	46	52	49	
	3	46	46	44	46	52	50	
Washer	1	41	44	44	44	42	42	43
	2	42	42	44	44	42	42	
	3	44	44	44	44	42	42	
Sizer	1	17	7	10	6	9	30	13
	2	17	6	10	6	9	30	
	3	17	7	10	6	9	30	
Liquid/Solid Waste Separator	1	22	22	22	20	20	20	21
	2	21	22	22	18	20	20	
	3	22	22	22	20	20	20	

a function of line pressure. Appendix Table I provides information relating to the spray nozzles used in each unit operation. Footnote (3-b) to Appendix Table II indicates the method used to calculate nozzle flow rate.

RESULTS AND DISCUSSION

Plant Layout and Water Flow Pattern

The general sketch of the plant at the time of these studies (1976-77) is shown in Figure 1 and a scaled-up sketch of the processing area is displayed in Figure 2. Preparation of these figures resulted in better assessment of the drains and water flow in the plant.

The water flow pattern is shown in Figure 3. The product flow plus both solid and liquid waste flows are also shown in this figure. It is evident that water conservation in terms of water reuse or recycling is being practiced just in three unit operations. The first area of conservation involves fluming of raw potatoes in which water is recycled continuously with occasional discharge of mud. Some of the water is lost during each mud discharge. The make up for this loss comes from the fresh water which is used to lubricate the pumps or to obtain the required level in the pumping and destoning unit through an automatic level controller. The second area of water conservation is the first blanching unit which reuses cooling water from the water-cooled ammonia compressors. The third area is the sugar dip or coloring operation in which the coloring solution is used for fluming of the treated potato cuts to the vibratory screen

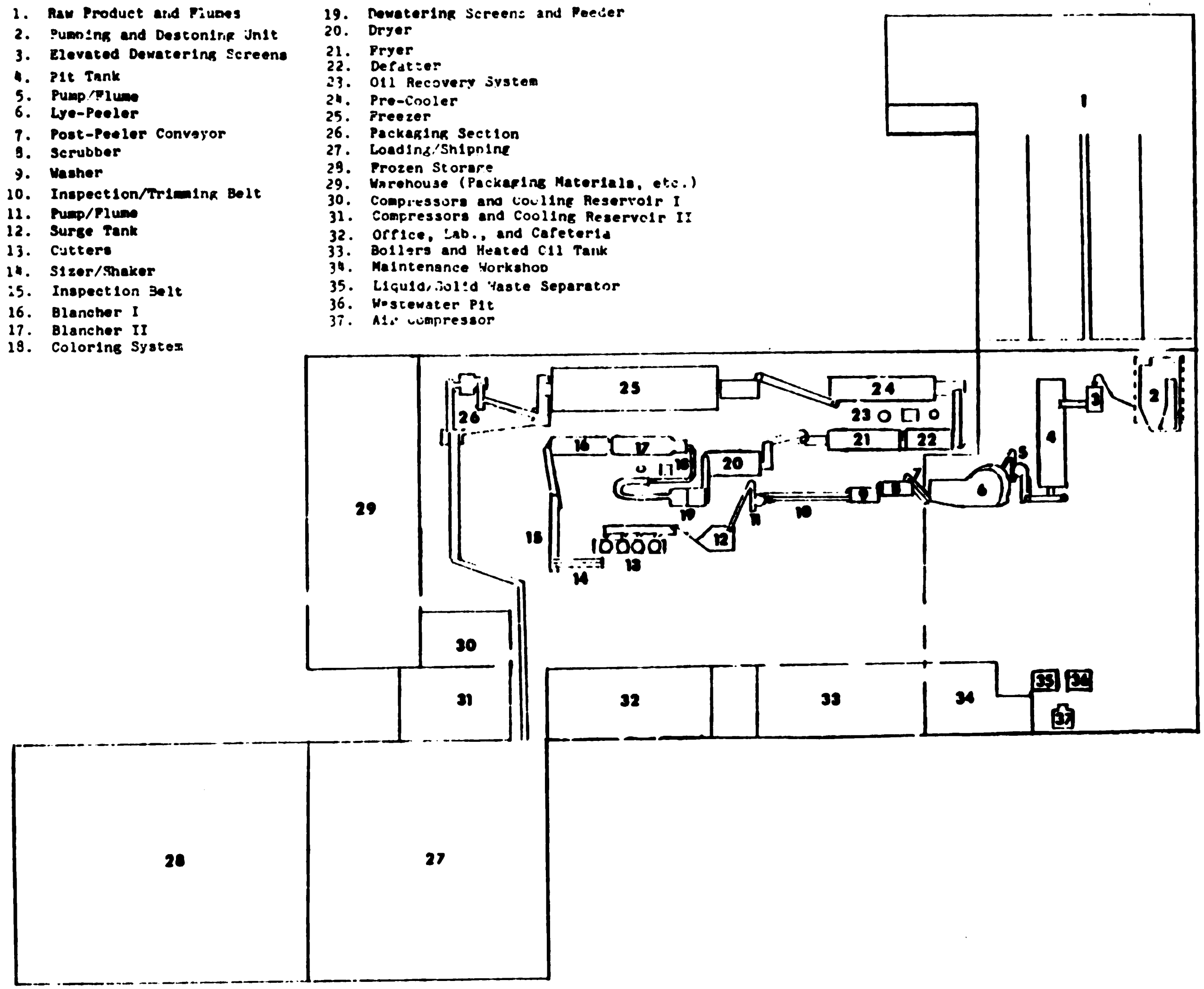

Figure 1. General Sketch of the Plant.

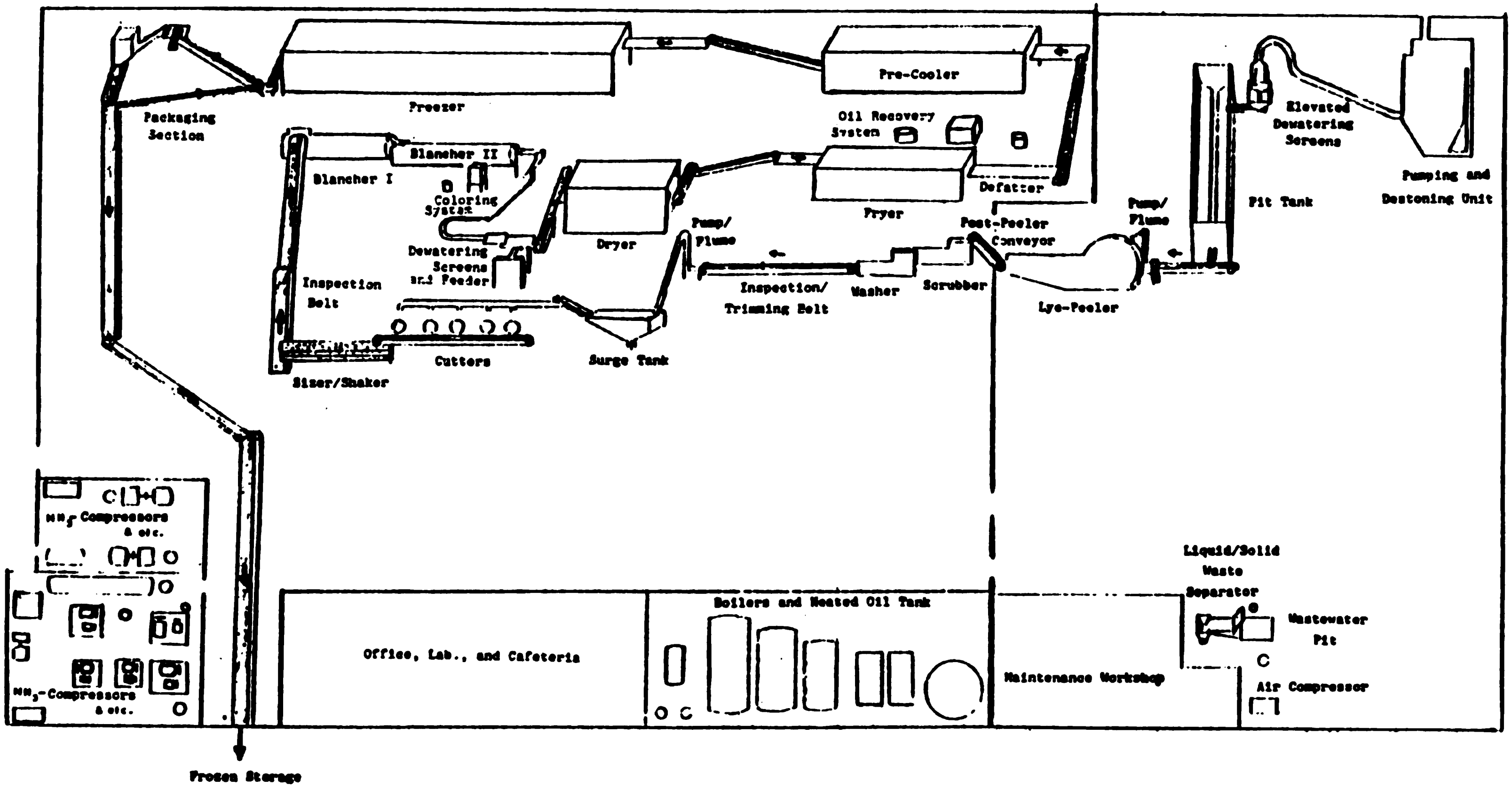

Figure 2. Scaled-up Sketch of the Processing Area.

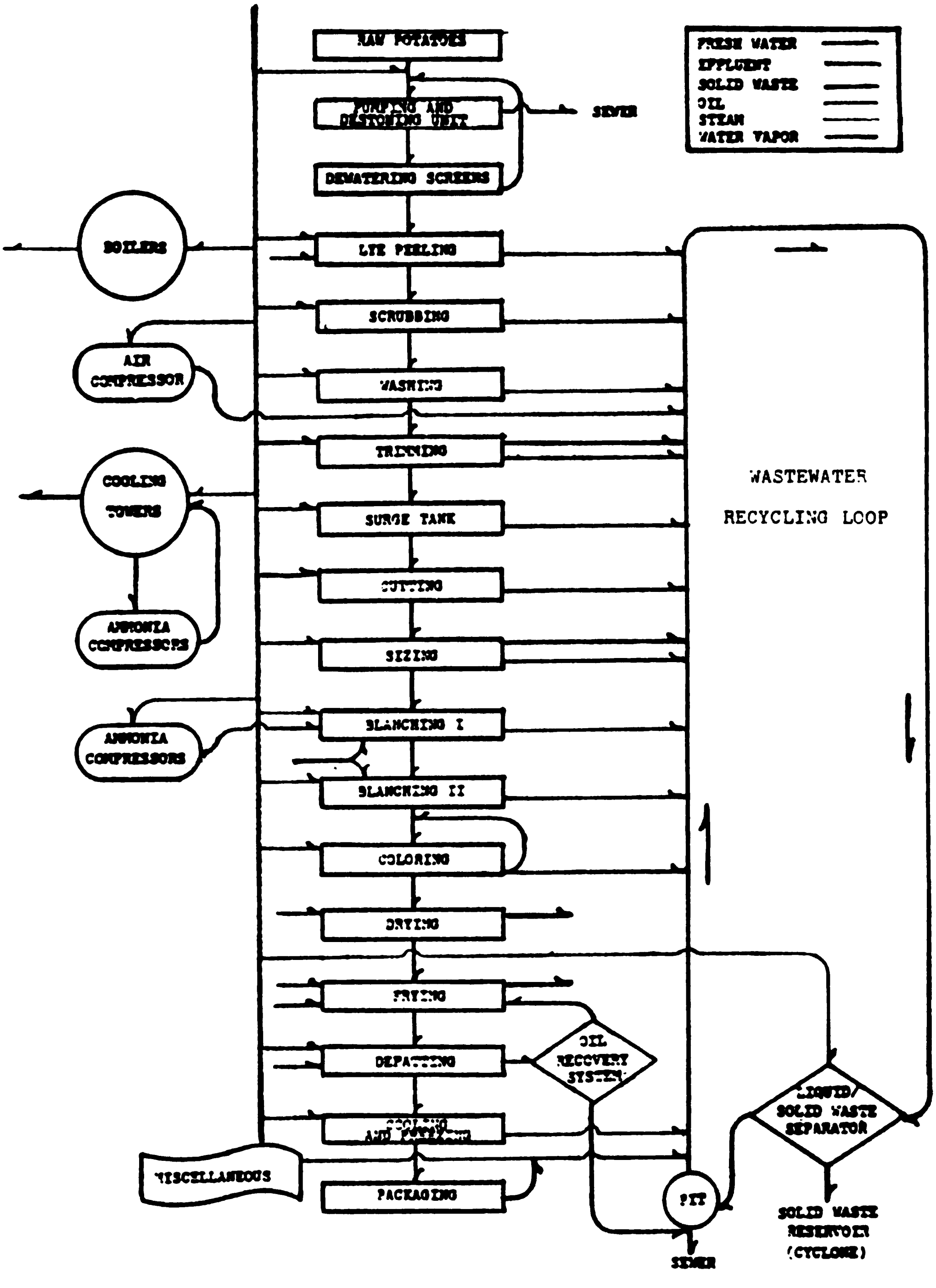

Figure 3. Water/Product Flow Pattern.

(also called shaker) located just before the dryer. Thereby, the solution is recycled continuously and only a small portion of it is lost during each cycle. This small loss is made up from a reservoir containing fresh coloring solution. Another thing shown in Figure 3 is that, other than the pumping, defatting and sanitary waste waters, all the effluents from different processing steps enter into the gutters which, being continuously flushed with recycled waste water, constitute a part of a waste water recycling loop within the plant. The solids, washed off the floor or directly dumped into the gutters, are separated from the recyclable liquid portion by a screen/shaker-type separator and then passed on to the solid waste reservoir (referred to by plant personnel as a "cyclone").

The three practices described above, along with the use of cooling towers, constitute the total water conservation effort in the plant.

Water Usage

The total flow rates for all streams in the plant are listed in Table 6. (Table II in the Appendix gives the original weight per time measurements and other details as well as sample calculations.)

The Miscellaneous category in Table 6 includes daily

Table 6. Gallons of Water Used by Specific Operations.(1)

		Water Usage			
No.[2]	Water Using Operation	Gal/ Min.	Gal/ Day[3]	Gal/ Ton[4]	%[5]
-	Fluming of Raw Potatoes	6.5	9360	34.7	3.1
5	Pump/Flume	2.9	4176	15.5	1.4
7	Post-Peeler Conveyor	17.3	24912	92.3	8.3
8	Scrubber	16.5	23760	88.0	7.9
9	Washer	22.6	32544	120.5	10.8
10	Trimming Belt	1.9	2736	10.1	0.9
11	Pump/Flume	3.0	4320	16.0	1.4
13	Cutter	8.7	12528	45.9	4.2
14	Sizer	8.8	12672	47.4	4.2
16	Blancher I	22.2	31968	118.4	10.7
17	Blancher II	31.6	45504	168.5	15.2
18	Coloring System	0.1	144	0.5	0.0
22	Defatter	22.7	32688	121.1	10.9
--	Defrosting	2.8	4032	14.9	1.3
35	Liquid/Solid Waste Separater	8.2	11808	43.7	3.9
37	Air Compressor	5.3	7632	28.3	2.5
33	Boilers	1.1	1584	5.9	0.5
--	Cooling Towers	0.5	720	2.7	0.2
--	Ammonia Compressors[6]	2.7	3888	14.4	1.3
--	Weekly Clean-up	13.2	19008	70.4	6.3
	Subtotal	195.9	282096	1044.8	94.0
	Miscellaneous[7]	12.4	17856	66.1	6.0
	Total[8]	208.3	299952	1110.9	100.0

(1) Data were taken all from Appendix Table II.

Table 6. Continued.

Footnotes:

(2) Numbers correspond to those in Figure 2.

(3) Based on 24 hours per day.

(4) Based on 270 tons of raw potatoes processed per day.

(5) Based on the average daily water usage of 300,000 gallons which had been calculated from water bill data by the plant personnel.

(6) Included in Blancher I.

(7) Includes daily housekeeping, sanitary, laboratory, and other non-processing uses.

(8) See Footnote (5) of this Table.

housekeeping, sanitary, laboratory, and other non-processing uses. One minor usage of water during processing is also included in this Miscellaneous category because of its negligible nature, namely water to fill the surge tank between trimming belt and cutters. The Miscellaneous category may be somewhat larger or smaller than the true total value for the various miscellaneous water uses that are listed since it reflects the unavoidable errors involved in measuring water usage in each of the other categories.

The conversion of gallons per minute into gallons per day has been done by a factor of 1440 (minutes per 24 hours). For example, in the case of fluming of raw potatoes, it is done as follows:

$$\frac{(6.5 \text{ gallons})(1{,}440 \text{ minutes})}{(\text{minute}) \qquad (\text{day})} = 9{,}360 \text{ gallons per day}$$

Although the most meaningful unit of water flow is in terms of volume per time (89), most researchers have chosen the unit of volume (of water) per ton of raw product processed. On this basis and for ease of comparison, at an average hourly production rate of 9,000 pounds of finished French fries (see Appendix Table IV) and an average yield of 40 percent(15,74,84), the daily tonnage of raw potatoes processed was calculated. Flow rates were then converted into gallons of water per ton of raw potatoes processed. The calculation of raw product tonnage is shown below:

$$\text{Raw Potatoes Used} = \frac{9{,}000\ \frac{\text{lb finished fries}}{\text{hour}}\ (24\ \frac{\text{hours}}{\text{day}})}{\frac{\text{40 lb finished fries}}{\text{100 lb raw potatoes}}\ (2{,}000\ \frac{\text{lb}}{\text{ton}})}$$

$$= 270\ \text{Tons/Day}$$

As in the case of fluming of raw potatoes, a sample calculation of flow rates in terms of gallons per ton of raw potatoes processed would be as follows:

$$\frac{9{,}360\ \text{gallons/day}}{270\ \text{tons/day}} = 34.7\ \text{gallons/ton of raw potatoes}$$

Considering the fact that a negligible amount of water is consumed through evaporation in the plant, it seems reasonable - for the purpose of simplified calculation - to assume that all influent water turns into waste water. Thereby, comparison of total water used in the plant per ton of raw potatoes processed (1,111 gal/ton) with the reported range (21,22,24,30,42,56,83) of waste water flow in potato processing (813 to 12,000 gallons per ton) reveals that this plant could be classified as an efficient water conserving establishment. (A more detailed comparison of literature values with those obtained in these studies of water usage for specific stages of processing is shown in Appendix Table III.)

A more careful examination of Table 6 reveals that lye-peeling (comprised of post-peeler conveyor, scrubber and washer), blanching (including both blanchers), defatting, sizing, and cutting are the major water users in the plant using 27.0, 25.9, 10.9, 4.2, and 4.2 percent of total water intake, respectively.

Waste Generation

Values for Total Nonfiltrable Residue (Total Suspended Matter, TSM), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of the measured effluent streams, including the final plant effluent plus grease and oil content of the final plant effluent are shown in Tables 7, 8, 9, and 10, respectively. (More detailed data may be found in Appendix Tables V, VI, VII, and VIII, respectively. Relevant sample calculations are included with the respective tables.)

As indicated in the above-mentioned tables, the same seven sampling points were used throughout the study,

Table 7. Total Nonfiltrable Residue Dried at 103-105°C (Total Suspended Matter).

Effluent Source	Milligram Per Liter, Based on 9,000 lbs/hr Production Rate							6/14/77-6/27/77 (5)	
	6/9/77 K(1)	6/14/77 SS(2)	6/16/77 STK(3)	6/20/77 STK	6/23/77 SS	6/27/77 SS	6/29/77 CTG(4)	Mean mg/ℓ	C.V.(6) %
Washer	5674	1740	2891	1739	2963	2386	6536	2344	25.4
Cutter	----	----	19186	14197	19850	18877	4320	18028	14.3
Sizer	----	4700	5665	7952	8213	4505	7065	6207	28.5
Blancher I	137	655	318	351	368	305	253	399	36.3
Blancher II	----	185	244	262	106	97	101	179	42.6
Plant Eff. I(7)	3561	2340	3166	2274	3875	4029	5844	3137	26.3
Plant Eff. II(8)	4304	2740	4024	2829	4404	4404	6952	3680	22.6

(1) K : Krinkle cut.

(2) SS : Shoestring cut.

(3) STK: Steak fries.

(4) CTG: Cottage fries

(5) Discussion of reasons for exclusion of 6/9/77 and 6/29/77 data from calculated mean can be found under Results and Discussion.

(6) C.V.: Coefficient of variation which is equal to $\frac{\text{Standard Deviation}}{\text{Mean}}$ x 100.

(7) Plant effluent excluding the sanitary and the defatter effluent.

(8) Total plant effluent.

Table 8. Biochemical Oxygen Demand, BOD.[1] (5 days, 20°C)

Effluent Source	Milligram Per Liter, Based on 9,000 lbs/hr Production Rate							6/14/77-6/27/77	
	6/9/77 K	6/14/77 SS	6/16/77 STK	6/20/77 STK	6/23/77 SS	6/27/77 SS	6/29/77 CTG	Mean mg/ℓ	C.V. %
Washer	5854	1388	2211	1404	1831	1512	4759	1669	21.0
Cutter	----	----	15329	8780	12125	11978	2768	12053	22.2
Sizer	----	7277	5379	6475	5867	4224	6705	5844	19.7
Blancher I	4387	4850	5704	5752	5833	4458	3690	5319	11.7
Blancher II	----	2382	2898	2976	1967	905	371	2226	37.9
Plant Eff. I	4729	3632	3692	3237	5740	4182	6676	4097	23.9
Plant Eff. II	5022	4082	5545	4128	5925	4689	7744	4874	17.1

(1) Footnotes of Table 7 are applicable here.

Table 9. Chemical Oxygen Demand, COD.(1)

Effluent Source	Milligram Per Liter, Based on 9,000 lbs/hr Production Rate							6/14/77-6/27/77	
	6/9/77 K	6/14/77 SS	6/16/77 STK	6/20/77 STK	6/23/77 SS	6/27/77 SS	6/29/77 CTG	Mean mg/ℓ	C.V. %
Washer	7146	2313	3729	2638	3631	2560	7944	2974	22.1
Cutter	----	----	26186	19050	26619	25324	4574	24295	14.6
Sizer	----	8173	7624	11076	10170	5956	9323	8600	23.8
Blancher I	4893	6071	6277	6663	6372	5538	4795	6184	6.8
Blancher II	----	2829	3563	3894	2097	1140	595	2705	41.3
Plant Eff. I	5029	4112	4722	4135	6355	5083	7635	4881	18.8
Plant Eff. II	5360	4547	6067	4596	7193	5846	9216	5650	19.6

(1) Footnotes of Table 7 are applicable here.

Table 10. Grease and Oil Content of the Total Plant Effluent.

Sample	Grease and Oil Content mg per liter of Sample
6/9/77	571.8
6/14/77	557.8
6/16/77	582.9
6/20/77	440.9
6/23/77	569.7
6/27/77	581.4
6/29/77	808.3
Average(1)	546.5
C.V., Percent(2)	11.0

(1) Average amount (mg) of grease and oil per liter of sample calculated for the samples dated 6/14/77 to 6/27/77. Discussion of reasons for exclusion of 6/9/77 and 6/29/77 data from calculated mean can be found under Results and Discussion.

(2) See Footnote (6), Table 7.

thereby providing sets of seven samples for each of the times and dates on which measurements were made. Since a trial sampling was conducted on 6/9/77 to find any obstacle associated with the sample handling, results obtained on that date will not be discussed here. Likewise, data from 6/29/79 have not been averaged with the other results because of the dissimilarity between cottage fries (which were processed on that date) and the types of cuts normally produced by the plant. In addition, these potatoes were atypical with respect to quality (small, somewhat dehydrated, and shriveled). Data from both of these dates are, however, included in the tables for reasons of general interest and completeness of data.

Therefore, attention will be focussed on the mean values calculated for the period of 6/14/77 to 6/27/77. Although the magnitude of the coefficients of variation associated with the mean values for unit operations shown in Tables 7 through 10 for this period indicates a highly variable effluent discharge, the mean values for the period (based on both steak cut and shoestring French fries) are believed to be valid. The justification for combining the data for the steak- and shoestring-cut potatoes in Tables 7 through 10 has been detailed in Appendix Table IX.

Factors contributing to variation of the results presented in Tables 7 through 10 may include raw product composition (e.g., sugar content), process variations (e.g., water usage), sampling errors, and the inherent error of the method of analysis.

The results of the grease and oil content of the final plant effluent (Table 10) may be higher than the true values. This stems from the fact that Freon, like other solvents, has the ability to dissolve not only grease and oil, but also other organic substances. Such a theoretical consideration was supported by the scorching of unknown organic materials which occurred on the inside surface of the sample containers during the vacuum drying that followed extraction.

Temperature and pH values of the effluents are listed in Table 11. These values remained fairly stable over a long period of time, hence the average of two separate measurements was chosen to provide a reliable estimate of those in the plant. Monitoring of the pH of an effluent that is to be reused or recycled can be useful in preventing adverse effects on equipment or product. pH measurements are also of value in determining the degree of neutralization required by plant effluent. Temperature is important both from the standpoint of product quality and heat recovery (or thermal pollution which is the other side of the coin).

To draw any inference from the obtained data or to use it for comparison with those reported in the literature

Table 11. Temperature and pH of the Effluents.

Source	Temperature °C	°F	pH
Post-Peeler Conveyor	24	75	11.3
Washer	22	71	9.7
Cutter	18	64	6.8
Sizer	19	66	6.8
Blancher I	69	156	6.2
Blancher II	69	156	6.4
Defatter	56	134	7.6
Recycled Waste Water	28	82	12.3
Air Compressor	38	100	7.4
Plant Effluent I(1)	28	82	12.2
Plant Effluent II(1)	30	85	12.2
City Water	15	59	7.4

(1) See Table 7 for descriptions.

it should be arranged in a more expressive way through which the totality of each waste stream could be regarded. Such an arrangement can be found in Table 12. To construct this table, the following equation was used:

$$\text{Daily Pollutant, lb/day} =$$

$$\frac{(\text{Water Usage, } \frac{\text{gal}}{\text{day}})(3.785\ \frac{\ell}{\text{gal}})(\text{Waste Produced, } \frac{\text{mg}}{\ell})}{(4.536 \times 10^5\ \frac{\text{mg}}{\text{lb}})}$$

For example, total suspended matter for the washer was calculated as follows:

$$\text{Washer, TSM} = \frac{(32{,}400\ \frac{\text{gal}}{\text{day}})(3.785\ \frac{\ell}{\text{gal}})(2{,}344\ \frac{\text{mg}}{\ell})}{4.536 \times 10^5\ \frac{\text{mg}}{\text{lb}}} =$$

$$634 \text{ lb/day}$$

Percentage of total pollutant attributable to each source is also shown in Table 12, as calculated from the lb/day figures.

Table 12. Total Pollutants Discharged(1) Per Operating Day.

Effluent Source	Waste Volume		TSM		BOD		COD		Grease & Oil	
	gpm	% of Total	% of lb/day	% of Total	lb/day	% of Total	lb/day	% of Total	lb/day	% of Total
Washer	22.6	10.8	637	6.9	453	3.7	808	5.7	----	----
Cutter	8.7	4.2	1885	20.5	1260	10.3	2540	18.0	----	----
Sizer	8.8	4.2	656	7.1	618	5.1	909	6.4	----	----
Blancher I	22.1	10.6	106	1.2	1419	11.6	1650	11.6	----	----
Blancher II	31.6	15.2	68	0.7	845	6.9	1027	7.3	----	----
Defatter	22.7	10.9	---	---	---	---	----	---	(1368)[2]	(100)[2]
Plant Eff. I[3]	185.6[4]	89.1	6996	76.0	9137	74.9	10885	77.0	----	----
Plant Eff. II[3]	208.3[5]	100.0	9211	100.0	12199	100.0	14141	100.0	1368	100
Miscellaneous[6]	91.8	44.1	5859	63.8	7604	62.4	7207	51.0	----	----

(1) Based on the average value of indices for the period of 6/14/77-6/27/77.

(2) Virtually all grease and oil comes from the defatter.

(3) See Table 7 for descriptions.

(4) Assuming the sanitary effluent volume to be negligible, this is obtained by subtracting defatter's waste volume from total plant effluent.

(5) As very negligible amount of water is consumed in the plant, it is assumed that all the incoming water is discharged as effluent.

Table 12. Continued.

(6) Miscellaneous figures are obtained - in each column - by subtracting the sum of the figures for washer, cutter, sizer, blanchers I and II, and defatter from that of plant effluent II. In other words, it includes all items listed in Table 6 except for items numbered 9, 12, 13, 16, 17, and 22, and in the case of waste volume, the defatter also is excluded from the Miscellaneous value.

Based on the Table 12 results, the cutter effluent, though relatively low in volume, holds a large share of the total daily waste production (10 to 20 percent, depending on which index of pollution is used). The sizer, using almost the same amount of water as the cutter, produces only 5 to 7 percent of the daily waste. Blanchers are large water users, but small TSM producers. However, blanching effluents are very strong both from BOD and COD standpoints.

The main contribution of the defatter to the total waste production is the grease and oil found in the final plant effluent. The washer, as a part of the peeling operation, generates higher TSM than BOD or COD. This might be ascribed to the incorporation of parts of the skin into the effluent which includes a layer of corky periderm. Other phases of the overall peeling operation are included as part of the Miscellaneous category in Table 12. This Miscellaneous category is made up of all effluent sources not specifically listed in the table, namely: flume for raw potatoes, lye-peeler, post-peeler conveyor, scrubber, trimming belt, surge tank, and water handling of solid wastes generated all over the plant plus other minor waste producing sources.

Among the above sources contributing to the Miscellaneous category in Table 12, the scrubber is the major source of pollution, but meaningful measurements could not be made because of the extremely wide variation in rate of solid discharge from this unit. Hosing of solid wastes into the gutters brings about more contact time between solids and water both within the gutters and during passage through the liquid/solid waste separator, resulting in increased leaching of pollutants. Fluming of raw potatoes is another significant source of pollution, consisting primarily of insoluble solids such as silt from the potato surface. Some indication of the quantity of pollutants derived from the other Miscellaneous sources mentioned above can be found in the literature (38,39).

BOD-to-COD Ratio

The BOD-to-COD ratio for each of the effluent streams under consideration was calculated. These ratios, which are listed in Table 13, provide an indication of the probable effectiveness of biological treatment. The higher the ratio, the more effective the biological treatment would be. Thus, the final (or total) plant effluent, having the highest ratio, would be the most responsive and the cutter effluent, with the lowest ratio, would be the most refractory waste water with regard to biological treatment.

Table 13. BOD-to-COD Ratio.

Effluent Source	BOD-to-COD Ratio			
	Exp. Value(1)	Literature Values(2)		
		Plant A	Plant B	Plant C
Washer	.561	----	----	----
Cutter	.496	.132	.157	----
Sizer	.679	----	----	----
Blancher I	.860	.458	.761(3)	.500
Blancher II	.823	.474	----	----
Plant Effluent I(4)	.839	----	----	----
Plant Effluent II(4)	.863	.627	----	.596

(1) Based on experimentally-obtained (mean) values in Tables 8 and 9.

(2) Calculated from the BOD and COD values reported by Hindin (1970) in his studies on three potato processing plants.

(3) Values for both Blanchers (I and II) are included.

(4) See Table 7 for description.

Comparison of the Obtained Results with Those From Other Studies

The comparison of test results obtained in these studies with those of other studies taken from the literature is shown in Appendix Table III. Focussing on total plant effluent, one can see that the plants reported upon in the literature used substantially more water per ton of potatoes than the one under study here. As might logically be expected, the high water-using plants exhibited lower concentration of pollutants in the effluent. This dilution effect is apparent in the comparative figures for TSM, BOD and COD of total plant effluent as well as in the TSM, BOD and COD values for those process steps for which comparative values are given. Based on data shown in Appendix Table III, less water is being used in just about every process step mentioned in the table with the exception of blanching and defatting. The biggest water saving processes are primary wash flume (fluming of raw potatoes), cutting and trimming.

The slightly higher pH of the total plant effluent in these studies might be attributable to lower water usage or possibly to higher initial alkalinity of the water supply. The higher pH of both blanching effluent and cutting effluent in these studies, as compared with Table III literature values may likewise have resulted from higher pH of the fresh water supply. Other factors such as potato variety and condition, size and type of cut, and time and temperature of contact between water and potato cuts may have also contributed to the pH variations shown in Table III, but there appears to be no direct evidence to support this belief.

Although the quantity of waste generated by the peeling operation in the plant under study is not fully reflected in the Appendix Table III, data for peeling and washing (since they do not include waste emanating from the scrubber), earlier reports (79) indicate that peeling is invariably one of the major waste-producing operations in the overall manufacturing process. This has been discussed in more detail in the Literature Review.

According to Table 13, the BOD-to-COD ratios obtained in these studies are higher than those calculated from the studies done by Hindin (1970). This difference may be ascribed to storage time and variety of potatoes and/or to processing conditions.

Potential for Improved Water Conservation and Waste Reduction

The results of these studies indicate possible practices the implementation of which will culminate in conservation of water and/or reduction of waste. Each of these possibilities, discussed hereunder, has certain advantages and drawbacks the balancing of which determines its feasibility.

The most feasible practice deals with the reuse of air compressor cooling water. This warm water has a normal pH (as it is shown in Table 11) and is, at least, as clean as the cooling water from the ammonia compressors, but is being discharged directly as waste water. Some piping may make its reuse possible in any unit operation - preferably those using heated water such as blanching - without further purification and, thereby, a saving of 2.5 percent could be achieved in the total plant daily water use. Added to this, is the recovery of heat energy of this effluent.

As it was discussed in Literature Review, slivers and nubbins constitute about 10 percent of the raw potatoes (74). Processing of these cuts into some sort of by-products seems to be promising from several standpoints. As a water saving technique, it eliminates the practices of hosing these potato cuts into gutters and rinsing them at the liquid/solid separator later. This can, at least, save 3.9 percent of total plant water use which is applied in the separator. However, the elimination of the abovementioned rinsing may necessitate the dry handling of other solid wastes (namely, potato cuts spilled on the floor or tubers rejected by trimming operation). As a waste reducing measure, it avoids leaching of solubles off the usable pieces of potatoes (slivers and nubbins) during fluming. Finally, it not only prevents a noticeable portion of raw product from ending up as waste, but also brings about more marketable by-products. On the other hand, its accomplishment requires more new equipment and manpower.

Other possible practices involve water reuse or recycling and/or process modification. In defatting operations hot water is sprayed upon the fried cuts at a rate of 22.7 gpm. The effluent goes through a partial oil recovery system and discharged still hot (134°F) and containing some oil (see Table 11 and Footnote 10, Appendix Table II). If a more efficient oil recovery system is maintained, the hot and relatively oil free effluent can be recycled with some make-up water. This can save a considerable percentage of total plant water use that is now being utilized for this purpose (Table 6). It also can save the considerable energy being used to heat this water. In contrast with the stated advantages, the implementation of this practice requires new equipment and may cause less oil recovery from the cuts. In another development, a completely mechanical defatting process requiring no water can be used. Oil recovery in this operation can be improved by employment of hot air stream. Conservation of water (10.9 percent of the total plant water use) and reduction of oil content of final plant effluent are the advantages of this system. However, cost of new equipment is expected to be the main drawback. Product weight loss might occur due to the drying effect of the hot air though it might be negligible because the oil layer around the cuts may work as a barrier to moisture loss. Operating cost may range above that of the present system.

Blanching was shown to be one of the biggest water using operations in the plant. The major reason for using water blanching in French fries processing has been discussed to be the undesirable leachables, mainly reducing sugars (15,74). Hot water serves to even out variations of sugar concentration at or near the surfaces of French-fry strips. Therefore, use of potatoes that are "reconditioned" to reduce sugar level and/or varieties resistant to sugar build up during storage can reduce water use and waste generation in the blanching operation.

Another way of water conservation and waste minimization in blanching involves a counterflow water system. An experiment was performed on 5/5/77, in which the effluent from blancher II was reused in blancher I. Focussing on the amount of fresh water used in blancher I, unlike the usual average usage rate of 20 gpm, the counterflow system reduced the fresh water use to 7.3 gpm (see Appendix Table II). This reduction corresponds to 6.1 percent of the total plant water use.

The above counterflow water system could be extended to the upstream unit operations namely, peeling operation units on one hand and all pump flumes on the other hand. To do so, the blanching effluent may undergo a purification process started with a heat exchange step to yield its heat energy. The effluent, depending on the reuse requirements, can go through further purification, which may involve fine-screening to leave its large floating or suspended particles, an air flotation step to give up its fine suspended matter, and a disinfection step for sanitary purposes.

Twelve gpm of the treated blanching effluent, corresponding to 5.8 percent of the total plant water use, can satisfy the requirement of the four pump flumes, two of which operate in the Pumping and Destoning section and the other two are numbered 3 and 7 in Figure 2 or Table 6. The remainder (about 28 gpm) can be reused in a retrograde manner in washer, scrubber, and post-peeler conveyor. Reuse of washer effluent in the scrubber and that of scrubber on post-peeler conveyor have to be preceded by screening and/or settling. Such a counterflow use of water starting from blanching can save 38.9 percent of the total plant water use. This saving includes 6.1, 5.8, 10.8, 7.9 and 8.3 percent of total plant water use which corresponds to blanching and pump flumes (as mentioned in the above), washer, scrubber, and post-peeler conveyor, respectively. However, cost of the equipment and the effort needed for practicing this water use pattern (including operation supervision and maintenance) may discourage its complete implementation.

In connection with peeling, the desirable practice might be the Dry-Caustic or Infrared peeling proved to reduce water usage and waste generation to 25 percent or less of that normally associated with the wet caustic process. This can result in a saving of more than 20 percent of the total daily water usage shown in Table 6. Another aspect of it is the potential advantage of separate (dry) handling of peeling waste. Nevertheless, the investment required and the increasing cost of energy (which escalates the operating costs) are the two major disadvantages associated with this practice.

Partial modification of present peeling system is also worthy to note. Installation of a dry brushing equipment (85) directly after the lye-peeler will brush clean the lye-treated potatoes without use of water. In order to remove the adhering starch, however, the potatoes are said (85) to require after-washing with about one cubic meter of water per ton of potatoes. If true, the 270 tons of potato processed per day would use 49.5 gpm of water rather than the 56.4 gpm used presently in the washer, scrubber and post-peeler conveyor (see Table 6). Therefore, a saving of at least 3.3 percent in total plant water use can be achieved. Another advantage is the separate (dry) handling of peeling wastes. In contrast with these advantages, the equipment and operating costs should be considered for further evaluation.

Starch recovery in cutting and sizing operations is another promising practice. As it is shown in Table 12, the rough daily discharge of total suspended matter (TSM) from cutting and sizing is 2,500 pounds. This conforms to 27.6 percent of the daily TSM discharged by the plant and most of it is the starch washed off the surface of potato cuts in these two operations. Therefore, if the effluent from sizer is reused in cutters, almost all the washed starch can then be recovered from cutters effluent by means of hydrasieve cyclones or settling. Such a system can reduce 27.6 percent of total TSM, 15.4 percent of total BOD, and 24.4 percent of total COD discharged from the plant each day. A marketable product can be made from the starch and saving of at least 4.2 percent can be achieved in the total daily water usage in the plant. In addition, the clean effluent from the starch recovery system is reusable in any upstream unit operation. This practice calls for new investment and would change the operating cost, but would probably result in increased earnings (15,37,76) for the company.

The suggested water conservation and waste reduction plans in these studies do not change the pattern, source and/or amount of water use in other unit operations. These are, namely; boilers, cooling towers, ammonia and air compressors, defrosting, trimming belt, surge tank, coloring, weekly clean up, and sanitary and laboratory uses.

SUMMARY AND CONCLUSIONS

The studies reported herein were designed to ascertain the water usage, waste generation and ways of pollution reduction in a potato processing plant through water conservation and waste utilization.

The study of plant as well as water and waste flow patterns reveal possibilities for water conservation and waste reduction. Water usage measurement and calculated values show that the major water using operations are lye peeling (including the units immediately following lye immersion - the post-peeler conveyor, scrubber, and washer), blanching, defatting, sizing, and cutting with 27.0. 25.8, 10.8, 4.2 and 4.2 percent of the total daily plant water use, respectively.

Results of the present studies, when considered in conjunction with previously-reported findings, suggest some process and/or equipment modifications as well as conservation practices to minimize water use and waste generation. These possibilities, discussed in Results and Discussion, are briefly stated in the following.

The most easily implementable change, representing a saving of about 2.5 percent of total water usage, would involve the reuse of air compressor cooling water without treatment in the blanching operation.

Production of by-products from slivers and nubbins coupled with dry handling of solid wastes will minimize pollution and curtail total water usage at least 3.9 percent. A new product would also be offered for sale.

Use of modified defatting systems which employ either recycled water or a mechanical method can reduce the amount of oil in the final plant effluent and save up to 10.9 percent of the total water usage.

Using low sugar varieties or reconditioned potatoes helps in waste reduction and water conservation in blanching. Reuse of second blancher effluent in the first blancher achieves a 6.1 percent reduction in total water usage. An additional 32.8 percent saving can be achieved through the reuse of blanching effluent in pump flumes and, in a retrograde manner, the peeling operation.

Setting up a dry caustic peeling process can be expected to save about 20 percent or more of the plant's present total water usage. This will also take most of the peeling waste out of the plant effluent stream. The installation of dry brushing equipment can reduce water consumption by at least 3.3 percent.

Finally, a starch recovery system can reduce total plant waste 15.4 to 27.6 percent and water usage by 4.2 percent, at the same time yielding a considerable amount of marketable starch. Other operations requiring water would not be affected.

Despite the stated benefits of the changes suggested above, a thorough cost analysis would be required before commercial implementation of each such change. Cost analyses, however, were considered to be beyond the scope of this investigation.

LITERATURE CITED

LITERATURE CITED

1. Abbott, M. T., Heldman, D. R., and Bedford, C. L., 1974. Influence of temperature on reconditioning of potatoes for maximum chip quality. ASAE Transactions. 17(1):42.

2. Adams, H. W., Hickey, F. D., and Willard, M. J., Jr., 1960. Lye-Pressure steam peeling of potatoes and other products. Food Tech. 14(1):1.

3. Agardy, F. J., 1973. Evaluation of research and development needs for the food processing industry. Proceedings of the 4th Nat'l Symposium on Food Processing Wastes. Syracuse, N.Y.

4. Agardy, F. J., et al., 1967. Cannery waste treatment part II: Treatability. Proceedings of the 22nd Industrial Waste Conference, Purdue Univ., Lafayette, IN.

5. Allen, T. S. 1972. Water reuse in the food processing industry. Paper presented at ASME-EPA Water Quality Control and Food Industry Process Waste Conf., New Orleans, LA.

6. Atkins, P. F., and Sproul, O. J. 1964. Feasibility of biological treatment of potato processing wastes. 19th Ind. Waste Conf., Purdue Univ., Lafayette, IN.

7. APHA. 1976. Standard methods for the examination of water and waste water, 14th ed., American Public Health Association, New York, NY.

8. Bhagat, S. K., Ongerth, J. E., and Etting, B. V. 1974. Organic cleaner prepared from potato processing plant waste. Engineering bulletin No. 145, Purdue University, Lafayette, IN.

9. Bhattacharyya, G. K. and Johnson, R. A. 1977. Statistical concepts and methods. John Wiley and Sons, Inc., Toronto, Canada.

10. Bomben, J. L. 1976. Vibratory blancher-cooler saves water, heat and waste. Food Engineering, 48(7):55.

11. Bomben, J. L., Dietrich, W. C., Hudson, J. S., Hamilton, H. K., and Farkas, D. F., 1975. Yields and solids loss in steam blanching cooling and freezing vegetables. J. Food Sci., 40(4):660.

12. Brown, G. E., Bomben, J. L., Dietrich, W. C., Hudson, J. S., and Farkas, D. F. 1974. A reduced effluent blanch-cooling method using a vibratory conveyor. J. Food Sci., 39(4):696.

13. Bruce, D. J. and Stevens, P. B. 1977. Chlorine dioxide key to successful retrograde water system. Food Eng. 49(4):154.

14. Burton, W. G. 1963. The basic principles of potato storage as practiced in Great Britain. European Potato Journal, 6:77-92.

15. Cansfield, P. E. and Gallop, R. A. 1970. Conservation, reclamation and reuse of solids and water in potato processing. Proceedings of the 17th Ontario Industrial Waste Conf., Niagra Falls, Ontario.

16. Cecil, L. K. 1977. Water reuse in industry. Water renovation and reuse. Academic Press, New York, NY, Chapter 4.

17. Chen, S. C., Collins, J. L., McCarty, I. E., and Johnson, M. R. 1971. Blanching of white potatoes by microwave energy followed by boiling water. J. Food Sci. 36(5):742.

18. Cyr, J. W. 1971. Progress report: Study of dry caustic versus conventional caustic peeling and the effect on waste disposal. Proceedings of the 2nd Nat'l Symp. on Food Processing Wastes, Denver, CO.

19. Danek, L. R. 1975. Conserve industrial water: cool, treat, recirculate. Water Supply and Conservation, Plant Engineering Magazine, Plant Eng., Barrington, IL.

20. Day, R. A., Jr., and Underwood, A. L. 1974. Quantitative Analysis. 3rd ed., Prentice-Hall, Inc., Englewood Cliffs, NJ.

21. Demonstration of a full-scale waste treatment system for a cannery. 1971. Stilwell Canning, Stilwell, Oklahoma, Water Pollution Control Research Series Contract No. 12060DSB.

22. Dornbush, J. N., Rollag, D. A., and Trygstad, W. J. 1975. Investigation of an anaerobic-aerobic lagoon system treating potato processing wastes. Proceedings of the 6th Nat'l Symp. on Food Processing Wastes, Madison, WI.

23. Douglass, I. B. 1960. By-products and waste in potato processing. Proceedings of the 15th Industrial Waste Conf., Purdue Univ., Lafayette, IN.

24. Formo, H. G. 1961. Problems and approaches in the treatment of wastes from potato processing plants. Proceedings of the 10th Pacific Northwest Industrial Waste Conference.

25. Furukawa, D. H. 1971. Recent developments in treatment of food processing wastes. Proceedings, Food Engineering Forum Environment and the Food Processor, published by the Food Engineering Forum Sponsors: Dairy and Food Industries Supply Association, Washington, D.C. and ASAE, St. Joseph, MI.

26. Gallop, R. A. 1969. The latest in water and waste disposal. Contribution to a panel discussion at the Annual Convention of the Canadian Food Processors Association, April 26-29.

27. Gallop, R. A. 1973. Pollutionless cyclic process systems. Complete Water Reuse, 'Industry's Opportunity'. Based on papers presented at the Nat'l Conf. on Complete Water Reuse. Sponsored by American Institute of Chemical Engineers. New York, NY.

28. Gallop, R. A., Hydamaka, A. W., Stephen, P. W., and Rastogi, R. K. 1976. Total, symbiotic, pollutionless systems for efficiently managing water, effluents, solid organic wastes, and odors in food processing and similar industries. Proceedings of the 3rd Nat'l Conference on Water Reuse, Cincinnati, OH.

29. Gibbons, G. F., Jr. 1975. Are you using too much water? Here's how conservation program saved 40 million gallons annually. Water supply and Conservation, Plant Engineering Magazine, Plant Eng., Barrington, IL.

30. Gilde, L. G. and Aly, O. M. 1976. Water pollution-control in the food industry. Industrial Waste Water Management Handbook, McGraw-Hill Book Co., Inc., New York, NY (Chapter 5).

31. Graham, R. P., Huxsoll, C. C., Hart, M. R., Weaver, M. L. and Morgan, A. I., Jr. 1969. "Dry" caustic peeling of potatoes. Food Technology, 23(2)195.

32. Gray, H. F. and Ludwig, J. F., 1943. Characteristics and Treatment of potato dehydration wastes. Sewage Works Journal, 15(1)71.

33. Grieg, W. S. and Manchester, A. C., 1958. Cost of peeling potatoes by lye and abrasive methods. U.S. Dept. of Agriculture, Marketing Research, Report No. 225.

34. Guy, D. B. 1975. New Technique for purifying water: Reverse osmosis process. Water Supply and Conservation, Plant Engineering Magazine, Plant Eng., Barrington, IL.

35. Hach Chemical Co. 1977. Manometric BOD Apparatus, Model 2173A, Laboratory Instrumentation Manual. Hach Chemical Co., Ames, Iowa.

36. Hamza, A., Smallwood, C. Jr., and Jones, V. A. 1976. Conservation of water in food processing by use of low volume high pressure sprays. Proceedings of the 3rd Nat'l Conf. on Complete Water Reuse, Cincinnati, OH.

37. Hassett, A. F. and Klippel, R. W. 1973. Food processing waste water municipal discharge or separate treatment? Proceedings of the 4th Nat'l Symp. on Food Processing Wastes, Syracuse, NY.

38. Highland, M. E., Al-Hakim, S. and Hogan, J. M. 1967. Water conservation in potato processing. Bulletin No. 647. Maine Agricultural Experiment Station, University of Maine.

39. Hindin, E. 1970. Waste water utilization in the potato processing industry. Circular No. 34, Washington State Univ., Pullman, WA.

40. Huxsoll, C. C. Weaver, M. L., and Graham, R. P., 1976. Double dip caustic peeling of potatoes. Proceedings of the 6th Nat'l Symp. on Food Processing Wastes. Madison, WI.

41. Hydamaka, A., Stephen, P., Gallop, R. A., and Carvalho, L. 1976. Control of color problem during recycling of food process waters. Proceedings of the 7th Nat'l Symp. on Food Processing Wastes, Atlanta, GA.

42. Jones, H. R. 1973. Waste disposal control in the fruit and vegetable industry, Noyes Data Corporation, Park Ridge, NJ.

43. Krochta, J. M., Williams, G. S., Graham, R. P., and Farkas, D. F. 1973. Reduced-water cleaning of tomatoes. Proceedings of the 4th Nat'l Symp. on Food Processing Wastes. Syracuse, NY.

44. Kueneman, R. W., 1965. Performance of primary waste treatment plants in northwest U.S.A. Proceedings of the International Symposium on the utilization and disposal of potato wastes. New Brunswick Research and Productivity Council, Federieton, New Brunswick, Canada.

45. LaConde, K. V., and Schmidt, C. J. 1976. In-plant control technology for the fruit and vegetable processing industry. Proceedings of the 7th Nat'l Symp. on Food Processing Wastes. Atlanta, GA.

46. Lash, L. D., Martin, J., and Pude, B. 1973. Recycle of potato processing waste water. Complete Water Reuse, 'Industry's Opportunity' based on papers presented at the Nat'l Conf. on Complete WateReuse, Sponsored by American Institute of Chemical Engineers. New York, NY.

47. Leavitt, P., and Ziemba, J. V. 1969. At Gerber-water does triple duty. Food Engineering, 41(9):90.

48. Lee, C. Y., Downing, D. L., Hang, Y. D. and Russell, P. H., Jr. 1973. Waste reduction in table beet processing. Proceedings of the 4th Nat'l Symp. on Food Processing Wastes. Syracuse, NY.

49. Lund, D. B., 1973. Impact of the individual quick blanching (IQB) process on cannery waste generation. Proceedings of the 4th Nat'l Symp. on Food Processing Wastes. Syracuse, NY.

50. Mady, O. B. 1975. Coupled analysis of potato processing and waste water treatment, Thesis. Department of Chemical Engineering, the University of Rochester. Rochester, NY.

51. Mady, O. B., Osmer, H. R. and Friedly, J. C. 1976. Analysis of food processing and subsequent waste water treatment to evaluate water reuse opportunities. Proceedings of the 3rd Nat'l Conf. on Complete WateReuse, Cincinnati, OH.

52. Mazzola, C. L., 1943. New caustic peeling method reduces waste, saves labor. Food Industry, 15(1): 53.

53. Mercer, W. A. 1967. Handling, washing, and utilization of mechanically harvested tomatoes. Nat'l Canners Assoc., Information letter No. 1202, Washington, D.C.

54. N.A.M., and U.S.C.C. 1965. Water in industry. The National Assoc. of Manufacturers and United States Chamber of Commerce.

55. Norum, E. M. 1975. Land application of potato processing waste through spray irrigation. ASAE Transactions. Paper No. 75-2514.

56. Olson, N. A., Kalsuyama, A. M., and Rose, W. W. 1974. Economic effects of treating fruit and vegetable processing liquid waste. Proceedings of the 5th Nat'l Symp. on Food Processing Wastes. Monterey, CA.

57. Oosten, B. J. 1976. Protein from potato starch mill effluent. Food From Waste, Applied Science Publishers, Ltd, London.

58. Perkins, G. 1970. A case history in food plant waste water conservation and pretreatment experience. Proceeding of the 1st Nat'l Symp. on Food Processing Wastes, Portland, OR.

59. Petruska, J. A., and Perumpral, J. V. 1976. Potential use of magnetic separation for treating waste water from food processing units. ASAE Transactions. Paper No. 76-3510.

60. Potter, N. N. 1973. Food Science. 2nd ed. The AVI Publishing Co., Inc., Westport, CT, 602-620.

61. Ralls, J. W., Maagdenberg, H. J., Yacoub, N. L., and Mercer, W. A. 1972. Reduced waste generation by alternate vegetable blanching system. Proceedings of the 3rd Nat'l Symp. on Food Processing Wastes, New Orleans, Louisiana.

62. Ralls, J. W., Maagdenberg, H. J., Yacoub, N. L., Zinnecker, M. E., Reiman, J. M., Karnath, H. D., Homnick, D. N., and Mercer, W. A. 1973. In-plant hot-gas blanching of vegetables. Proceedings of the 4th Nat'l Symp. on Food Processing Wastes, Syracuse, NY.

63. Rose, W. W., Mercer, W. A., Katsuyama, A., Sternberg, R. W. Brauner, G. V., Olson, N. A., and Weckel, K. G. 1971. Production and disposal practices for liquid wastes from cannery and freezing fruits and vegetables. Proceedings of the 2nd Nat'l Symp. on Food Processing Wastes, Denver, CO.

64. Rosenau, J. R., Whitney, L. F., and Elizondo, R. A. 1976. Low waste water potato starch/protein production process-concept, status, and outlook. Proceedings of the 7th Nat'l Symp. on Food Processing Wastes. Atlanta, GA.

65. Rosenau, J. R., Whitney, L. F., and Haight, J. R. 1978. Upgrading potato starch manufacturing wastes. Food Tech., 32(6):37.

66. Sawyer, C. N. and McCarty, P. L. 1967. Chemistry for sanitary engineers. 2nd ed. McGraw-Hill Book Co., Inc., New York, NY.

67. Shaw, R. and Shuey, W. C. 1971. Production of potato starch without waste. Proceedings of the 2nd Nat'l. Symp. on Food Processing Wastes. Denver, CO.

68. Skogman, H. 1976. Production of symba-yeast from potato wastes. Food From Waste. Applied Science Publishers, Ltd, London.

69. Smith, T. J., 1970. Pilot plant experience of USDA-Magnuson dry caustic peeling process. Proceeding of the 1st Nat'l Symp. on Food Processing Wastes, Portland, OR.

70. Soderquist, M. R., Blanton, G. I., Jr. and Taylor, D. W. 1972. Characterization of fruit and vegetable processing waste water. Proceedings of the 3rd Nat'l Symp. on Food Processing Wastes, Cincinnati, OH.

71. Splittstoesser, D. F., and Downing, D. L. 1969. Analysis of effluents from fruit and vegetable processing factories. Research circular No. 17, New York State Agricultural Experiment Station, Geneva, NY.

72. S. S. C. 1963. Chemical and industrial spray nozzle manual, Spraying Systems Co., Bellwood, IL.

73. Stutz, C. N. 1972. Industrial waste manual. Brigham Young University, Provo, UT (chapter 10).

74. Talburt, W. F., and Smith, O. 1967. Potato processing. 2nd ed. The AVI Publishing Co., Inc., Westport, CT, 69-72, 270-276, and 341-359.

75. Tannebaun, S. R. and Pace, G. W. 1976. Food from waste: An overview. Food From Waste. Applied Science Publishers, Ltd, London.

76. Tylor, J. A., 1973. The C. E. Bauer hydrasieve and high efficiency liquid cyclone equipment. Canadian Potato Chip Assoc. Environmental Seminar, Toronto, Canada.

77. USDA, 1977. Agricultural statistics. United States Government Printing Office, Washington, D.C.

78. USDC, 1972. Water use in manufacturing. Census of Manufacturers, Bureau of the Census, U.S. Dept. of Commerce, MC72 (SR)-4.

79. U.S. Environmental Protection Agency, 1974. Development document for effluent limitations guidelines and new source performance standards for the apple, citrus, and potato processing segment of the canned and preserved fruits and vegetables point source category. EPA-440/1-74-027-a.

80. U.S. Environmental Protection Agency, 1973. Handbook for monitoring industrial waste water. EPA, Technology Transfer. Cincinnati, OH.

81. U.S. Environmental Protection Agency, 1971. Liquid wastes from canning and freezing fruits and vegetables. EPA 12060 EDK 08/71.

82. U.S. Environmental Protection Agency, 1974. Manual of methods for chemical analysis of water and waste water. EPA, Technology Transfer, Cincinnati, OH. EPA-625/6-74-003a.

83. U.S. Environmental Protection Agency, 1977. Pollution abatement in the fruit and vegetable industry. EPA 625/3-77-0007, volumes 1, 2, and 3.

84. Van De Velde, J., 1973. Industrial potato processing, A quantitative analysis. Publication No. 11, Institute for Storage and Processing of Agricultural Produce, Wageningen, The Netherlands.

85. Van Nielen, L. 1972. The brushing machine and peeling of potatoes without the use of water. Publication No. 3A, Institute for Storage and Processing of Agricultural Produce, Wageningen, The Netherlands.

86. Weckel, K. G., Rambo, R. S., Veloso, H., and Von Elbe, J. H., 1968. Vegetable canning process wastes. Research Report 38, College of Agriculture and Life Science, Univ. of Wisconsin. Madison, WI.

87. Willard, M. J., 1969. Pilot plant study of the USDA-Magnuson infrared peeling process. Proceedings of the 19th Potato Utilization Conf., Ferris State College, Big Rapids, MI.

88. Wilson, G. E., and Hang, J. Y., 1977. Water conservation; Dramatic changes taking place. Food Engineering 49(6):79.

89. Wixon, C. W., and Zeisler, K. F., 1966. Industrial uses of water in Michigan. Graduate School of Business Administration, University of Michigan, Ann Arbor, MI.

90. Wright, R. C., and Whiteman, T. M., 1949. Tests show which potatoes have least peeling loss. Food Ind., 21(12):69.

91. ____________, 1968. In-plant treatment of cannery wastes, A Guide for Cannery Waste Treatment, Utilization and Disposal. Publication No. 38. State Water Resources Control Board, Sacramento, CA.

APPENDIX

Table I. Manufacturers' Designation for Spray Nozzles in Unit Operations Under Study.

Unit Operation	Nozzles Number in Use	 Type and Number
Pumping and Destoning Unit	1	H 1/8 VV 4004 Spraying Systems Co.
Scrubber	4	81-3 SC 15 Delavan Co.
Washer	8	81-3 SC 15 Delavan Co.
Trimming Belt	6	H 1/8 VV 4003 Spraying Systems Co.
Sizer	12	1/4 GG Flat Jet 6.5 Pat. #3104829 Spraying Systems Co.
Liquid/Solid Waste Separator	4	1/4 P3520 Flat Jet Pat. #2530571 Spraying Systems Co.
Defatter	13	1/4 GG Flat Jet 6.5 Pat. #3104829 Spraying Systems Co.

Table II. Water Usage in Specific Unit Operation.*

No.(1)	Unit Operation	AOP(2) psi	Date	Weight of Water oz	Time Sec	Gallons Per Minute Indiv.	Gallons Per Minute Set	Gallons Per Minute Unit Oper.(15)
	Fluming of Raw Potatoes(3)							
	Level Controller		6/20/77 to 6/24/77			0.1	0.1	
	Nozzle					0.4	0.4	
	Pump Lubrication I					3.0	3.0	
	Pump Lubrication II					3.0	3.0	6.5
5	Pump/Flume(4)		5/5/77	98.0	15	2.9		
				64.5	10	2.9		
				129.5	20	2.9	2.9	
			6/20/77	96.0	15	2.9		
				64.5	10	2.9	2.9	2.9
7	Post-Peeler Conveyor	23	6/25/77	193.0	5	17.3		
				171.0	4.5	17.1		
				117.0	3	17.5	17.3	17.3
8	Scrubber	47	6/25/77					
	Nozzle #1			26.3	3	3.9		
				26.7	3	4.0	4.0	
	Nozzle #2			30.4	3	4.6		
				30.5	3	4.6	4.6	
	Nozzle #3			21.6	3	3.2		
				21.7	3	3.3	3.2	

Table II. Continued.

No.[1]	Unit Operation	AOP[2] psi	Date	Weight of Water oz	Time Sec	Gallons Per Minute Indiv.	Set	Unit Oper.[15]
	Nozzle #4			21.0	2	4.7		
				21.0	2	4.7	4.7	16.5
9	**Washer**	43	6/25/77					
	Nozzle #1			28.0	5	2.5		
				29.0	5	2.6	2.6	
	Nozzle #2			31.0	5	2.8		
				30.5	5	2.7	2.8	
	Nozzle #3			19.4	5	1.7		
				19.8	5	1.8	1.8	
	Nozzle #4			27.0	5	2.4		
				27.0	5	2.4	2.4	
	Nozzle #5			29.5	5	2.7		
				30.0	5	2.7	2.7	
	Nozzle #6			26.0	5	2.3		
				26.0	5	2.3	2.3	
	Nozzle #7			31.0	5	2.8		
				31.0	5	2.8	2.8	
	Nozzle #8			23.0	2	5.2		
				23.0	2	5.2	5.2	22.6
10	**Trimming belt[5]**					0.3	0.3	1.9

Table II. Continued.

No.(1)	Unit Operation	AOP(2) psi	Date	Weight of Water oz	Time Sec	Gallons Per Minute		
						Indiv.	Set	Unit Oper. (15)
11	Pump/Flume(4)		5/5/77	99.5	15	3.0		
				87.5	13	3.0	3.0	
			6/20/77	68.0	10	3.0		
				96.5	14	3.0	3.0	3.0
13	Cutter(4)		6/14/77					
	Unit #1			74.0	15	2.2		
				75.0	15	2.2	2.2	
	Unit #2			58.5	15	1.8		
				59.5	15	1.8	1.8	
	Unit #3			34.0	60	0.3		
				17.0	30	0.3	0.3	
	Unit #4			77.0	15	2.3		
				78.0	15	2.3	2.3	
	Unit #5			69.0	15	2.1		
				68.5	15	2.1	2.1	8.7
14	Sizer(6)	7	6/25/77					
	Nozzle #1			19.2	15	0.6		
				19.3	15	0.6	0.6	
	Nozzle #2			18.5	15	0.6		
				18.5	15	0.6	0.6	

Table II. Continued.

No.	Unit Operation	ΔOP(2) psi	Date	Weight of Water oz	Time Sec	Gallons Per Minute Indiv.	Set	Unit Oper. (15)
	Nozzle #3			18.3	15	0.5		
				18.2	15	0.5	0.5	
	Nozzle #4			19.1	15	0.6		
				19.0	15	0.6	0.6	
	Nozzle #5			18.5	15	0.6		
				18.5	15	0.6	0.6	
	Nozzle #6			18.2	15	0.5		
				18.2	15	0.5	0.5	
	Nozzle #7			18.3	15	0.6		
				18.3	15	0.6	0.6	
	Nozzle #8			18.7	15	0.6		
				18.7	15	0.6	0.6	
	Nozzle #9			17.9	15	0.5		
				18.0	15	0.5	0.5	
	Nozzle #10			18.4	15	0.6		
				18.4	15	0.6	0.6	
	Nozzle #11			17.5	15	0.5		
				17.5	15	0.5	0.5	
	Nozzle #12			18.0	15	0.5		
				17.9	15	0.5	0.5	(6.7)
		7				0.55	0.55	(6.6)
		13				0.73	0.73	8.8(6)

Table II. Continued.

No.	Unit Operation	AOP(2) psi	Date	Weight of Water oz	Time Sec	Gallons Per Minute Indiv.	Gallons Per Minute Set	Gallons Per Minute Unit Oper. (15)
16	Blancher I(4)(7)		5/5/77					
	Fresh Stream #1			47.0	10	2.1		
				71.0	15	2.1	2.1	
	Fresh Stream #2			100.5	15	3.0		
				103.0	15	3.1	3.0	
	Fresh Stream #3			71.5	15	2.1		
				96.0	20	2.2	2.2	
	Reused Stream #1			67.5	1.0	30.3		
	(blancher II effluent)			129.0	1.9	30.5	30.4	
	Reused Stream #2 (NH$_3$-Comp. effluent)					2.7	2.7	(40.4)
			6/16/77					
	Fresh Stream #1			74.0	5	6.7		
				75.0	5	6.7		
				75.0	5	6.7	6.7	
	Fresh Stream #2			66.0	5	5.9		
				66.5	5	6.0	6.0	
	Fresh Stream #3			72.5	5	6.5		
				74.0	5.1	6.5		
				72.0	5	6.5	6.5	
	Reused Stream (NH$_3$-comp. effluent)					2.7	2.7	(21.9)

Table II. Continued.

No.	Unit Operation	AOP(2) psi	Date	Weight of Water oz	Time Sec	Gallons Per Minute Indiv.	Gallons Per Minute Set	Gallons Per Minute Unit Oper.(15)
			6/27/77					
	Fresh Stream #1			82.0	2.6	14.2		
				88.0	2.9	13.9		
				65.5	2.1	14.0	14.0	
	Fresh Stream #2			49.5	10	2.2		
				50.0	10	2.2		
				49.5	10	2.2	2.2	
	Fresh Stream #3			97.5	15	2.9		
				97.2	15	2.9	2.9	
	Reused Stream (NH_3-Comp. Effluent)			84.5	15	3.3		
				85.0	15	3.3		
				86.0	15	3.3		
				85.5	15	3.3	3.3	(22.4)
								22.2(7)
	Blancher II(8)		5/5/77					
	One Stream			125	1.8	31.2		
				126	1.8	31.5	31.4	(31.4)
			6/14/77					
	Stream #1			145.0	2.5	26.1		
				150.0	2.5	27.0		
				173.0	3.2	24.3		
				112.5	1.9	26.6	26.0	

Table II. Continued.

No.	Unit Operation	AOP(2) psi	Date	Weight of Water oz	Time Sec	Gallons Per Minute Indiv.	Gallons Per Minute Set	Gallons Per Minute Unit Oper. (15)
	Stream #2			73.0	15	2.2		
				70.0	15	2.1		
				144.0	30	2.2	2.2	
	Stream #3			71.5	10.1	3.2		
				107.5	15.2	3.2	3.2	
	Stream #4			95.5	15	2.9		
				95.0	15	2.8	2.8	(34.2)
			6/27/77					
	Stream #1			112.0	2.4	21.0		
				99.0	2.1	21.2		
				131.3	2.8	21.1		
				156.5	3.2	22.0	21.3	
	Stream #2			88.5	10	4.0		
				88.5	10	4.0		
				87.0	10	4.0	4.0	
	Stream #3			46.5	10	2.1		
				47.5	10	2.1	2.1	
	Stream #4			42.3	6	1.9		
				43.2	6	1.9		
				42.6	6	1.9	1.9	(29.3)
								31.6(8)
18	Coloring(9)		6/27/77					0.1

Table II. Continued.

No.	Unit Operation	AOP(2) psi	Date	Weight of Water oz	Time Sec	Gallons Per Minute Indiv.	Set	Unit Oper. (15)
22	Defatter(4)(10)		5/5/77				22.7	22.7
	Defrosting(11)		9/7/76 to 4/29/77			2.8	2.8	2.8
35	Liquid/Solid Waste Separator	21	6/25/77					
	Nozzle #1			22.0	5	2.0		
				22.0	5	2.0		
				22.0	5	2.0	2.0	
	Nozzle #2			26.5	5	2.4		
				27.0	5	2.4		
				27.0	5	2.4	2.4	
	Nozzle #3			21.5	5	1.9		
				21.5	5	1.9		
				21.5	5	1.9	1.9	
	Nozzle #4			21.0	5	1.9		
				21.0	5	1.9		
				21.0	5	1.9	1.9	8.2
37	Air Compressor(4)		5/5/77	120.0	10	5.4		
				115.0	10	5.2		
				120.0	10	5.4		
				112.0	10	5.0		
				118.5	10	5.3		

Table II. Continued.

No.	Unit Operation	AOP(2) psi	Date	Weight of Water oz	Time Sec	Gallons Per Minute		
						Indiv.	Set	Unit Oper. (15)
	Air Compressor(4)			118.5	10	5.3		
				119.0	10	5.3		
				118.5	10	5.3		
				118.5	10	5.3	5.3	
			6/14/77	117.0	10	5.3		
				114.0	10	5.1		
				116.0	10	5.2		
				117.0	10	5.3	5.2	5.3
33	Boilers(12)		10/8/76			1.2		
			10/15/76			1.4		
			5/5/77			1.3		
			6/9/77			1.2		
			6/14/77			1.2		
			6/16/77			1.2		
			6/20/77			1.0		
			6/23/77			1.0		
			6/27/77			0.6		
			6/29/77			1.0	1.1	1.1
	Cooling Towers(12)		10/8/76			0.4		
			10/15/76			0.4		
			5/5/77			0.7		
			6/9/77			0.3		
			6/14/77			0.4		
			6/16/77			1.4		

Table II. Continued.

No.	Unit Operation	AOP(2) psi	Date	Weight of Water oz	Time Sec	Gallons Per Minute Indiv.	Gallons Per Minute Set	Gallons Per Minute Unit Oper.(15)
			6/20/77			0.2		
			6/23/77			0.3		
			6/27/77			0.6		
			6/29/77			0.3	0.5	0.5
	Ammonia Compressor(4)(13)		6/16/77	124.0	20.2	2.8		
				117.0	20.0	2.6		
				118.0	20.0	2.7		
				124.0	20.2	2.8		
				123.5	20.1	2.8		
				121.0	20.0	2.7	2.7	
			6/23/77	86.0	15.0	2.6		
				87.0	15.0	2.6	2.6	
			6/25/77	95.0	15	2.8		
				94.3	15	2.8		
				95.0	15	2.8		
				95.0	15	2.8	2.8	(2.7)(13)
	Weekly Clean Up(14)		5/14/77			101.2		
			5/18/77			102.5		
			6/25/77			104.7	102.8	(102.8)
								13.2(14)
Subtotal								195.9(15)
Total								208.3(16)
Miscellaneous								12.4(17)

Table II. Continued.

*Calculation of water usage: In these calculations, general assumption was that one $m\ell$ of water weighed one gram. Taking the scrubber as an example, the net amount of water collected from one of the nozzles over a period of three seconds in 2 successive samplings was 26.3 and 26.7 oz, respectively. Thus,

$$\frac{26.3 \text{ oz} \times 60 \frac{\text{seconds}}{\text{min}}}{3 \text{ seconds} \times 133.51 \frac{\text{oz}}{\text{gal}}} = 3.9 \text{ gpm}$$

and

$$\frac{26.7 \text{ oz} \times 60 \frac{\text{sec}}{\text{min}}}{3 \text{ sec} \times 133.51 \frac{\text{oz}}{\text{gal}}} = 4.0 \text{ gpm}$$

Taking the Average:

$$\frac{3.9 + 4.0}{2} \cong 4.0 \text{ gpm}$$

Doing exactly the same thing for the other three nozzles, we get the following average values: 4.6, 3.2, and 4.7 gpm. Summing these averages, we get the total water usage (overall average): 40 + 4.6 + 3.2 + 4.7 = 16.5 gpm which appears in the column headed as Overall Average. One may find either the sum of averages or the average of the averages in the last column.

(1) Numbers correspond to those in Figure 2.

(2) Average Operating Pressures (AOP) are shown in Table 5 under Experimental.

(3) Water usage in pumping or fluming of raw potatoes was calculated as follows:

(a) The level controlling system was metered:

Difference between meter readings: 991 gallons
Time between the readings: 6841 minutes
Therefore, rate of water usage was: $\frac{991 \text{ gal}}{6841 \text{ min}} \approx 0.1$ gpm

(b) Water use through the nozzle: The AOP in this case could not be measured but was assumed to be equal to that of the main line ($\sim$45 psi). To calculate water use at this pressure, interpolation was done on the data extracted from spray nozzle manuals (72) as follows:

Nozzle No.	Equivalent Orifice Diameter, inch	Capacity, gpm						
		Pounds Per Square Inch						
		7	10	15	20	30	40	60
1/4 VV4004	0.052	.17	.20	.25	.28	.35	.40	.49

By interpolation: flow capacity at 45 psi line pressure will be equal to 0.42 gpm.

(c) Pump lubrication I and II: The two lubricating streams of water are exactly the same size as in the pumps before the lye-peeler or the surge tank. Therefore, the average of measured values for those two pumps was assumed to apply to each of the fluming pumps as well:

(2.9 + 3.0)/2 = 3.0 gpm
2 streams x 3.0 gpm/stream = 6.0 gpm

Thus, total water usage will be equal to (a + b + c) or: 0.1 + 0.4 + 6.0 = 6.5 gpm.

(4) Although pressure readings could not be obtained for these unit operations, plant personnel had previously determined that water flow rates were insensitive to normal variations in line pressure.

(5) Following the same procedure as in Footnote (3-b), the rate of water use at 45 psi (main line pressure) was calculated to be 0.32 gpm for each nozzle, numbered H 1/8 VV4003 (equivalent orifice diameter of 0.043 in.). Thus, the total rate of water use (through six nozzles) will be 1.9 gpm.

(6) Water usage by the sizer was measured at 7 psi but the average operating pressure was later determined to be 13 psi. Since the calculated water usage at 7 psi (6.6 gpm) closely matched the measured water usage at this pressure (6.7 gpm), the calculated value at 13 psi (8.8 gpm) was considered to provide a reliable value for average water usage under normal operating conditions.

(7) The value of 40.4 gpm is not representative of normal plant operation because of the reuse of second blancher effluent in the first blancher. Therefore the average of the values obtained on other days, when there was no reuse of blancher II water in blancher I, was chosen as typical of water usage in the first blancher: (21.9 + 22.4)/2 = 22.2 gpm.

(8) The average value was taken as the typical water use in the second blancher, which represented the total inflow from the several inflow points itemized in the Table: (31.4 + 34.2 + 29.3)/3 = 31.6 gpm.

(9) Water use in this system was metered: Water used to fill the system at the start of the weekly operation = 104 gallons water used during operation:

Date	Time	Meter Reading, gal
6/27/77	14:30	1097
6/29/77	12:45	1335
	2775 min	238 gal

238 gal/2775 min = 0.086 gpm

$$\text{Total usage} = \frac{114 \text{ operating hours}}{\text{week}} \times \frac{60 \text{ min}}{\text{hr}} \times 0.086 \,\frac{\text{gal}}{\text{min}}) + 104 \text{ gal} = 692 \text{ gal/week}$$

In terms of gpm:

$$\frac{692 \text{ gal}}{\text{week}} \times \frac{\text{week}}{114 \text{ operating hrs}} \times \frac{\text{hr}}{60 \text{ min}} = 0.1 \text{ gpm}$$

(10) The approximate calculation of the water use in defatter was based on the effluent flow measurement done on 5/5/77 corrected for its oil content: Effluent flow measurement:

Weight of Water, oz	Time Sec	gpm	Liter/min
261.0	5	23.5	88.9
178.5	3.5	22.9	86.7

Oil content, gram/liter of effluent:

Sample		Weight of Flask, g		Weight of oil, g	g of oil per liter of effluent
Date	Volume, ml	Tare	Final		
6/23/77	965	116.1612	133.0742	18.9130	19.5990
6/27/77	1026	115.8840	134.7820	18.8980	18.4731
6/29/77	845	116.6165	136.2121	19.5956	23.1901
				Average	20.4207

Assuming a specific gravity of 1.0 for water and 0.92 for oil, the net water use was calculated as follows:

Volume of oil per liter of effluent = 20.4 g x $\frac{\text{ml}}{0.92\text{ g}}$ = 22.2 ml. Volume of oil in the average measured effluent:

(88.9 + 86.7)/2 = 87.8 liter/min.

$$87.8\ \frac{\text{liter of effluent}}{\text{min}} \times 22.2\ \frac{\text{ml oil}}{\text{liter of eff.}} \times \frac{\ell}{1000\text{ ml}} = 1.9\ \frac{\ell}{\text{min}}$$

$$\text{Volume of water} = (87.8 - 1.9)\ \frac{\ell}{\text{min}} \times \frac{\text{gal}}{3.785\ \ell}$$

(11) Based on 1976-1977 records from the maintenance of the processing plant, a total of 880 defrosts had been done during a period of 114 work days. Thus, 880 defrosts/114 days = 8 defrosts per day.

For each defrost of the freezer or the cooler coils, about half of the volume of a reservoir (3' x 6' x 8' = 144 cu. ft) - already filled with water - is used. Regarding 5 inches as the headspace, the volume of water hold by the reservoir would be:

$$(3)\left(\frac{(6 \times 12) - 5}{12}\right)(8) = 134\text{ cu. ft.}$$

$$134\text{ cu ft} \times 7.481\ \frac{\text{gal}}{\text{cu. ft.}} = 1002\text{ gal}$$

Total amount of water used for defrosting coils each day would be as follows:

$$\frac{8 \text{ defrosts}}{\text{day}} \times \frac{1000}{2} \text{ gal/defrost} = 4000 \text{ gal/day}$$

or, in terms of gpm: $4000 \text{ gal/day} \times \frac{\text{day}}{1440 \text{ min}} = 2.8 \text{ gpm}$

(12) Calculations are all based on meter readings.

(13) Included in blancher I.

(14) Weekly clean ups are done every Saturday for an average time of 15 hours. The values are calculated based on meter readings from the main pipeline entering the plant:

Date	Difference Between Meter Readings cu. ft x 10^2	gallons	Time Between the Readings min.	gpm
5/14/77	34.5	25,809	255	101.2
6/18/77	37.0	27,680	270	102.5
6/25/77	52.5	39,275	375	104.8
			Average	102.8

Subtracting water usage by ammonia compressors which work continuously, the net water usage for weekly clean up would be: $102.8 - 2.7 \cong 100$ gpm.

Thus, the weekly clean up converted into equivalent units of daily water usage would be:

$$\frac{100 \frac{\text{gal}}{\text{min}} \times 15 \frac{\text{hours}}{\text{week}}}{114 \frac{\text{hours}}{\text{week}}} = 13.2 \text{ gpm}$$

(15) Subtotal was obtained by adding up the underlined figures each of which represents the typical rate of water usage in the corresponding unit operation.

(16) This was derived from the average daily water usage of 300,000 gallons which had been calculated from water-bill data by the plant personnel:

$$\text{Total water usage} = \frac{300{,}000\ \frac{\text{gallons}}{\text{day}}}{24\ \frac{\text{hrs}}{\text{day}} \times 60\ \frac{\text{min}}{\text{hr}}} = 208.3\ \text{gpm}$$

(17) Includes daily housekeeping, sanitary, laboratory, and other non-processing uses. Calculated by difference: Miscellaneous = 208.3 - 195.9 = 12.4 gpm.

Table III. Water Usage and Waste Generation in Specific Process Steps.

Process Step	Water Usage				TSM				BOD				COD				pH		Temp, °C		
	Exp. Value[1]		Lit. Value[2]		Exp. Value		Lit. Value		Exp. Value		Lit. Value		Exp. Value		Lit. Value		Exp. Value	Lit. Value	Exp. Value	Lit. Value	Ref.
	gpm[3]	gpt[4]	gpm	gpt	mg/ℓ	ppt[5]	mg/ℓ	ppt	mg/ℓ	ppt	mg/ℓ	ppt	mg/ℓ	ppt	mg/ℓ	ppt					
Initial	6.5	34.7																			
Wash				70				2.0				0.5									
Flume			46.7	361.2			789	2.4													81
							3450				200										38
			56.0				11400				94				240			7.15		17	39
							4722				2580				1081			6.71			39
															4092			11.35		21	39
Peeling[6]	56.3	300.3			2344	2.4			1669	1.7											
and				468				2.2				2.2	2974	3.0							
Washing			35.0				41538				24690										81
															41008			12.80		33	39
	1.9	10.1																			
Trimming			111.0				93				90										
			9.0				2512				516				139			7.24		[illegible]	39
				190				0.5				1.6			2460			6.23		22	39
																					39
	8.7	45.9			18028	7.0			12053	4.7											
			24.6	190.3			1462	2.3					24295	9.4			6.8		18		
Cutting							5402				1040										38
			30.0				17205				1894				7862			5.93		27	39
				364				2.6				5.2			11840			5.59		22	39
																					79
Sizing	8.8	46.9			6207	2.4			5844	2.3											
			56.4	436.3			320	1.2					8600	3.4			6.8		19		
																					38
Blanching[7]	53.7	286.4			270	0.6			3502	8.4											
			51.0				1998				10000		4141	9.9			6.3		69		
			55.9												13141			4.61		58	39
				250				4.2				10.9									39
																					79
Defatting	22.7	121.1																			
			5.6				28				25						7.6		56		
				100											48			7.77		40	39
Final	208.3	1111			3680	34.1			4874	45.2			5650	52.4			12.2		30		79
Plant			644.9	4316.5				27.3													38
Effluent							2365				2850				4548			11.7	11.7		39
							2878				2255				4959			11.65		25	39

(1) Based on experimentally-obtained values in Tables 6, 7, 8, 9, 10, 11, and 12.

(2) Values extracted from the corresponding references (last column).

(3) Gallons Per Minute, taken from Table 6.

(4) Gallons Per Ton of raw potatoes processed.

(5) Pounds Per Ton of raw potatoes processed.

(6) The Experimental values in this row are the summation of water usage by post-peeler conveyor, scrubber and washer, but wastes from unit operations other than washer contributing to peeling process are not included in the "Exp. Values" for TSM, BOD, or COD.

(7) The values under columns headed "Exp. Value" represent the combined waste indices for both blanchers. Data needed for calculation of the combined indices were extracted from Tables 6, 7, 8, and 9. As an example, the combined TSM generated by both blanchers was calculated as follows:

$$\frac{(22.2\ \frac{gal}{min} \times 399\ \frac{mg}{\ell}) + (31.6\ \frac{gal}{min} \times 179\ \frac{mg}{\ell})}{(22.2 + 31.6)\ gal/min} = 270\ \frac{mg}{\ell}$$

Following the same method of calculation, the combined BOD and COD for blanching were calculated to be 3502 and 4141 milligram per liter, respectively. The pounds per ton values were obtained by adding pounds per day values for both blanchers (Table 12) and dividing the result by 270 tons per day. pH and temperature for both blanchers were similar (see Table 11). Therefore, their average values were used in this Table (III).

Table IV. Finished French Fries Hourly Production Rate.

Date	Production Rate(1) lbs/hr
6/9/77	9200
6/14/77	9000
6/16/77	8500
6/20/77	8590
6/23/77	9780
6/27/77	9750
6/29/77	8000
Mean	8974(2)

(1) Data obtained from plant production records.

(2) Rounded out to 9000 lbs/hr.

Table V. TSM Values(1) for Different Sources, mg/ℓ.

Sample Date	Sample No.	Washer	Cutter	Sizer	Blancher I	Blancher II	Plant Effluent I	Plant Effluent II
	1	5210	----	----	160	----	3920	4530
	2	5980	----	----	130	----	3350	4370
6/9/77	3	6250	----	----	120	----	3700	4600
	4	5760	----	----	150	----	3590	4100
	mean	5800			140		3640	4400
	v[2]	7.61			10.71		6.51	5.04
	Adjusted mean[3]	5674			137		3561	4304
	1	1640	----	4810	730	170	2760	3020
	2	1560	----	4490	900	190	1980	2610
6/14/77	3	1940	----	4930	1040	140	2150	2400
	4	1820	----	4570	690	240	2470	3130
	mean	1740		4700	840[4]	185	2340	2740
	v	9.88		5.19	19.23	22.72	14.78	12.29
	Adjusted mean	1740		4700	840	185	2340	2740
	1	3210	15240	2114[5]	295	60	3980	3720
	2	2100	21050	5270	310	275	2850	3980
6/16/77	3	2710	22440	4990	335	215	3010	4390
	4	2900	13750	5790	260	200	2120	3160
	mean	2730	18120	5350	300	230	2990	3800
	v	17.14	23.55	7.59	10.45	17.25	25.59	13.07
	Adjusted mean	2891	19186	5665	318	244	3166	4024
	1	1720	9630	6900	350	290	1620	3230
	2	1290	16420	7010	375	265	2600	2330
6/20/77	3	2090	270[6]	8550	320	215	2290	2750
	4	1540	14600	7900	295	230	350[6]	2490
	mean	1660	13550	7590	335	250	2170	2700
	v	20.27	25.94	10.29	10.41	13.65	23.08	14.57
	Adjusted mean	1739	14197	7952	351	262	2274	2829
	1	3520	19900	9240	380	105	4770	6720[5]
	2	2660	26930	8490	465	120	4130	4640
6/23/77	3	3010	24120	8230	450	100	5190	5120
	4	3690	15330	9740	305	135	3990	4730
	mean	3220	21570	8925	400	115	4520	4830
	v	14.66	23.48	7.78	18.34	13.75	12.41	5.28
	Adjusted mean	2963	19850	8213	368	106	4160	4445

Table V. Continued.

Sample Date	Sample No.	Source Washer	Cutter	Sizer	Blancher I	Blancher II	Plant Effluent I	Plant Effluent II
6/27/77	1	2700	18310	5310	295	110	4260	5360
	2	2420	23540	5040	370	100	4730	5300
	3	2330	15080	4670	350	90	4010	4090
	4	2890	24870	4500	305	120	4040	4530
	mean	2585	20450	4880	330	105	4410	4820
	v	9.95	22.32	7.47	10.86	12.29	7.61	12.78
	Adjusted mean	2386	18877	4505	305	97	4071	4449
6/29/77	1	2310[6]	4130	6120	210	100	4370	6800
	2	6450	3700	7060	235	80	6030	5070
	3	5640	4050	7810	230	95	5480	5740
	4	5340	3480	5330	45[6]	85	4900	7110
	mean	5810	3840	6280	225	90	5195	6180
	v	9.88	7.92	16.46	5.88	10.14	13.82	15.28
	Adjusted mean	6536	4320	7065	253	101	5844	6952

(1) a) Calculation of total suspended matters (TSM):

$$\text{TSM, mg/liter of effluent} = \frac{(B\text{-}A)\ 1000\ \frac{\text{mg}}{\text{g}}}{\text{m}\ell\ \text{sample}\ \frac{\ell}{1000\ \text{m}\ell}}$$

$$= \frac{B\text{-}A}{\text{m}\ell\ \text{sample}} \times 10^6$$

where: A = weight of filter and planchette, g;

B = weight of filter and planchette after filtration and drying the sample, g.

For example, calculating the TSM of the sizer on 6/16/77:

For sample No. 1, 14 mℓ was filtered, A and B turned out to be 1.5285 and 1.5581, respectively. Thus, TSM would be:

$$\frac{(1.5581-1.5285)}{14} \times 10^6 = 2114 \text{ mg}/\ell.$$

Table V. Continued.

(1) a). Continued.

Doing the same thing for the other samples, we get:

Sample No.	A, g	B, g	(B-A), g	Sample Filtered, mℓ	TSM, mg/ℓ
1	1.5285	1.5581	.0296	14	2114
2	1.5137	1.5664	.0527	10	5270
3	1.5014	1.6012	.0998	20	4990
4	1.5080	1.5659	.0579	10	5790

b) Rejection of suspected results:

One of the calculated TSM values (2114) seems to be out of line with the others. Using the Q-Test (20) for rejection:

$$\frac{4990-2114}{5790-2114} \cong .78 \quad \text{vs.} \quad Q_{0.90} = .76$$

Since Q > .76, this observation is discarded.

c) Mean ($\overline{x}$) and coefficient of variation (v) is calculated as follows:

$$\overline{x} = \frac{4990 + 5270 + 5790}{3} = 5350 \text{ mg}/\ell$$

and the standard deviation is calculated to be 406 mg/ℓ Thus,

$$v = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100$$

$$= \frac{406 \times 100}{5350} = 7.59\%$$

d) Adjusting the Mean:

The mean value is adjusted on the basis of 9000 pounds per hour for ease of comparison:

$$\frac{5350 \text{ mg}/\ell \times 9000 \text{ lbs/hr}}{\text{Respective Production Rate, } 8500 \text{ lbs/hr}} = 5665 \text{ mg}/\ell$$

The value of 9000 lbs/hr was chosen because it represents the average production rate over the period of 6/9/77 to 6/29/77 (See Appendix Table IV).

Table V. Continued.

(2) For calculation of coefficient of variation (v) see Footnote (1-c).

(3) Adjustment of the mean is shown in Footnote (1-d).

(4) The mean value of 840 is actually the summation of Blancher I and Blancher II mean TSM values. This is because the effluent from Blancher II was being reused in Blancher I. Therefore, the actual mean TSM value for Blancher I is:

840-(mean TSM value of Blancher II) = 840 - 185 = 655 mg/ℓ.

(5) Rejected by Q-Test (see Footnote (1-b), this table) and therefore not used in calculation of mean.

(6) Considered as determinate error. That is, the error which can, at least in principle, be ascribed to definite causes and is generally unidirectional with respect to the true value, in contrast to indeterminate errors which lead to both high and low results with equal probability.

Table VI. COD Values(1) for Different Sources.

Sample		Source						
					Blancher		Plant Effluent	
Date	No.	Washer	Cutter	Sizer	I	II	I	II
6/9/77	1	7305	----	----	5042	----	5121	5439
	2	7305	----	----	4962	----	5161	5518
	mean	7305			5002		5141	5479
	Adjusted mean	7146			4893		5029	5360
6/14/77	1	2293	----	8094	8880	2829	4112	4586
	2	2333	----	8252	8920	2829	4112	4507
	mean	2313	----	8173	8900[2]	2829	4112	4547
	Adjusted mean	2313		8173	8900	2829	4112	4547
6/16/77	1	3542	24809	7357	5948	3326	4480	5691
	2	3502	24653	7043	5909	3404	4441	5770
	mean	3522	24731	7200	5928	3365	4460	5730
	Adjusted mean	3729	26186	7624	6277	3563	4722	6067
6/20/77	1	2499	18220	10532	6378	3717	3947	4330
	2	2537	18144	10609	6340	3717	3947	4445
	mean	2518	18182	10571	6359	3717	3947	4387
	Adjusted mean	2638	19050	11076	6663	3894	4135	4596
6/23/77	1	3986	28888	11089	6884	2279	6886	7876
	2	3906	28964	11013	6963	2279	6926	7757
	mean	3946	28926	11051	6924	2279	6906	7816
	Adjusted mean	3631	26619	10170	6372	2097	6355	7193
6/27/77	1	2832	27316	6413	6039	1216	5467	6293
	2	2714	27552	6491	5960	1255	5546	6372
	mean	2773	27434	6452	6000	1235	5507	6333
	Adjusted mean	2560	25324	5956	5538	1140	5083	5846
6/29/77	1	7022	4144	8209	4340	568	6826	8153
	2	7100	3987	8365	4184	490	6748	8231
	mean	7061	4066	8287	4262	529	6787	8192
	Adjusted mean	7944	4574	9323	4795	595	7635	9216

Table VI. Continued.

(1) Calculation of Chemical Oxygen Demand (COD):

$$\text{COD, mg/liter of effluent} = \frac{(a-b)\ N \times 8000}{(\text{m}\ell\ \text{sample})(\text{dilution factor})}$$

where,

a = mℓ of ferrous ammonium sulfate titrant, $Fe(NH_4)_2\ (SO_4)_2$, used for blank.

b = mℓ titrant used for sample.

N = Normality of the titrant determined by daily standardization and calculated as follows:

$$N = \frac{\text{m}\ell\ \text{dichromate} \times 0.25}{\text{m}\ell\ \text{titrant}}$$

For example, calculating the COD values on 6/9/77:

Standardization of the titrant: Using two 10-mℓ-portions of the standard dichromate solution (0.25 N), each of which took 25.6 mℓ of the titrant to complete reduction. The average volume of titrant required for the reduction of 10.0 mℓ of 0.25 N dichromate solution is:

$$\frac{25.6 + 25.6}{2} = 25.6\ \text{m}\ell$$

Therefore, the normality of the titrant would be:

$$N = \frac{(10.0)(0.250)}{25.6} = 9.77 \times 10^{-2}$$

Taking the Blancher I, two 20-mℓ-portions of the 20-fold diluted original effluent were reduced by 18.45 and 18.55 mℓ of the titrant after digestion. On the other hand, the average volume of the titrant used for two blank samples (control samples) turned out to be 24.80 mℓ. Thus, the corresponding CODs are calculated as follows:

$$\frac{(24.80-18.45)\ \text{m}\ell\ (9.77 \times 10^{-2})\ (8000)}{20\ \text{m}\ell\ (1/20)} = 4963\ \text{mg}/\ell$$

$$\frac{(24.80-18.55)\ \text{m}\ell\ (9.77 \times 10^{-2})\ (8000)}{20\ \text{m}\ell\ (1/20)} = 4885\ \text{mg}/\ell$$

Table VI. Continued.

As the standard solution of potassium acid phthalate, having a theoretical COD of 500 mg/ℓ, showed an average COD of 492.2 mg/ℓ, the percent recovery is:

$$\frac{492.2}{500} \times 100 = 98.44\%$$

Correcting for the percent recovery:

$$4963/0.9844 = 5042 \text{ mg/}\ell$$
$$4885/0.9844 = 4982 \text{ mg/}\ell$$

Taking the average:

$$\frac{5042 + 4962}{2} = 5002 \text{ mg/}\ell.$$

The calculated value (5002 mg/ℓ) was finally adjusted to 4893 mg/ℓ. Description of the method of adjustment is given in Footnote (1-d), Table V.

(2) The value of 8900 is the summation of COD values for both blanchers. This refers to the reuse of the effluent from Blancher II in the first blancher. The actual COD of Blancher I is calculated as follows:

8900 - (COD value of Blancher II) = 8900 - 2829 = 6071 mg/ℓ.

Table VII. BOD Values(1) for Different Sources.

		Source						
Sample					Blancher		Plant Effluent	
Date	No.	Washer	Cutter	Sizer	I	II	I	II
6/9/77	Measured	5984	----	----	4484	----	4834	5134
	Adjusted(2)	5854	----	----	4387	----	4729	5022
6/14/77	Measured	1388	----	7277	7232[3]	2382	3632	4082
	Adjusted	1388	----	7277	7232	2382	3632	4082
6/16/77	Measured	2088	14477	5080	5387	2737	3487	5237
	Adjusted	2211	15329	5379	5704	2898	3692	5545
6/20/77	Measured	1340	8380	6180	5490	2840	3090	3940
	Adjusted	1404	8780	6475	5752	2976	3237	4128
6/23/77	Measured	1990	13176	6376	6338	2138	6238	6438
	Adjusted	1831	12125	5867	5833	1967	5740	5925
6/27/77	Measured	1638	12976	4576	4830	980	4530	5080
	Adjusted	1512	11978	4224	4458	905	4182	4689
6/29/77	Measured	4230	2460	5960	3280	330	5934	6884
	Adjusted	4759	2768	6705	3690	371	6676	7744

(1) Calculation of BOD values:

The BOD values can, unlike the Standard Dilution Method, be read directly from the scale when the Manometric Method is used. Only very simple calculations are needed to correct the reading for the seeding or the dilutions (if any). A standard sample, containing glucose and glutamic acid and having a theoretical BOD of 220 mg/ℓ, was used periodically to see if the apparatus was functioning properly. An apparatus is said to be performing properly if the corrected BOD of the standard solution is within the range of 220±11 mg/ℓ. As an example, results for some of the samples from 6/9/77 and a standard solution are shown below:

Table VII. Continued.

Source	Dilu. Factor	Seeding, Percent	Readings						BOD5, mg/ℓ	
			Days							
			0	1	2	3	4	5	Cor.	Adj.
Washer	1/10	1	0	160	490	600	600	600	5984	5854
Blancher I	1/10	1	0	240	450	450	450	450	4484	4387
Plant Effluent II	1/10	1	0	235	445	510	515	515	5134	5022
Standard soln.	-	10	0	175	235	235	235	235	219	----
Seeding	1/2	-	0	60	80	80	80	80	160[a]	----

(a) No correction needed. To get the BOD_5, the 5th day's reading is divided by the respective dilution factor.

To calculate the BOD_5, the 5th day reading was taken, corrected for seeding and then divided by the dilution factor. For example, the calculations for the washer would be as follows:

$$BOD_x = \frac{\text{X'th day's Reading} - (\text{seeding percent})(BOD_x \text{ of the seeding})}{\text{Dilution Factor}}$$

Thus,

$$BOD_5 = \frac{600 - (1/100)\,(160)}{1/10} = 5984 \text{ mg/}\ell$$

Finally, this calculated value was adjusted to 5854 mg/ℓ (see Footnote (2)).

(2) Method of adjustment of the data is shown in Footnote (1-d), Table V.

(3) Due to the reuse of the effluent of Blancher II in blancher I, the BOD of the Blancher II should be subtracted from the value of 7232, to get that of blancher I:

$$7232 - 2382 = 4850 \text{ mg/}\ell.$$

Table VIII. Grease and Oil Content(1) of the Total Plant Effluent.

Sample	Volume mℓ	Tare Weight g	Final Gross Weight, g	Weight Difference g	Grease and Oil, mg per liter of sample
6/9/77	952	115.1058	115.5327	0.4269	571.8
6/14/77	1017	116.2840	116.7332	0.4492	557.8
6/16/77	1085	117.6510	118.1470	0.4960	582.9
6/20/77	1080	114.6020	114.9755	0.3735	440.9
6/23/77	1083	115.0415	115.5254	0.4839	569.7
6/27/77	918	115.4173	115.8359	0.4186	581.4
6/29/77	970	116.1612	116.7761	0.6149	808.3
Standard(2)	1000	116.6165	117.4153	0.7988	784.3
Solvent(3)	50	115.8840	115.8906	0.0066	-----
Average(4)					546.5
Total Average(5)					587.5

(1) Calculation method:

a) Solvent Residue, SR:

$$SR = \frac{\text{weight of residue, g}}{\text{m}\ell\text{ solvent used for residue test}} \times \begin{array}{c}\text{m}\ell\text{ solvent used to}\\ \text{extract grease}\end{array}$$

$$= \frac{0.0066\text{ g}}{50\text{ m}\ell} \times 110\text{ m}\ell$$

$$= 0.0145\text{ g}$$

Table VIII. Continued.

(1) b) Percent Recovery, PR:

$$PR = \frac{\text{(Weight Difference of the Standard Sample) - SR}}{\text{Weight of Grease Used to Make the Standard}} \times 100$$

$$= \frac{(0.7988 - 0.0145)\ g}{1\ g} \times 100$$

$$= 78.43\%$$

c) To calculate grease and oil (G&O) content of each sample, the following formula was used:

$$G\ \&\ O,\ mg/\ell = \frac{(\text{Weight Difference of the Sample, } g)(10^3\ \frac{mg}{g})(10^3\ \frac{m\ell}{\ell})}{(m\ell \text{ of sample})(\frac{\text{Percent Recovery}}{100})}$$

Taking the sample dated 6/9/77 as an example:

$$G\ \&\ O = \frac{0.4269 \times 10^6}{952 \times \frac{78.43}{100}} = 571.8 \text{ mg G \& O per liter of effluent sample.}$$

(2) Preparation, handling and analysis of the standard sample is discussed under Experimental.

(3) See Experimental and Footnote (1-a) of this Table.

(4) Average amount (mg) of grease and oil per liter of sample calculated for the samples dated 6/14/79 to 6/27/77.

(5) Average amount (mg) of grease and oil per liter of sample calculated for all the samples.

Table IX. Statistical Comparison of the Calculated Means of the Waste Indices[1].

Waste Index	Effluent Source	$\overline{X}$	$\overline{Y}$	n_1	n_2	S_{pooled}	Obs. $\|t\|$	$t_{0.005}$	Remarks(2)
TSM	Washer	2363	2315	3	2	686.1	.077	5.841	NR
	Cutter	19364	16692	2	2	2541.5	1.051	9.925	NR
	Sizer	5806	6808	3	2	1209.5	0.755	5.841	NR
	Blancher I	443	334	3	2	152.9	0.787	5.841	NR
	Blancher II	129	253	3	2	40.2	3.385	5.841	NR
	Plant Eff. I	3415	2720	3	2	845.0	0.903	5.841	NR
	Plant Eff. II	3849	3426	3	2	923.8	0.503	5.841	NR
BOD	Washer	1577	1808	3	2	378.6	0.670	5.841	NR
	Cutter	12052	12054	2	2	3275.3	0.001	9.925	NR
	Sizer	5789	5927	3	2	1325.4	0.114	5.841	NR
	Blancher I	5047	5728	3	2	578.7	1.292	5.841	NR
	Blancher II	1751	2937	3	2	622.8	2.090	5.841	NR
	Plant Eff. I	4518	3464	3	2	894.7	1.293	5.841	NR
	Plant Eff. II	4881	4836	3	2	976.1	0.051	5.841	NR

Table IX. Continued.

Waste Index	Effluent Source	$\overline{X}$	$\overline{Y}$	n_1	n_2	S_{pooled}	Obs. $\lvert t \rvert$	$t_{0.005}$	Remarks(2)
COD	Washer	2835	3184	3	2	725.0	0.528	5.841	NR
	Cutter	25972	22618	2	2	3626.3	1.015	9.925	NR
	Sizer	8100	9350	3	2	2224.5	0.617	5.841	NR
	Blancher I	5994	6470	3	2	379.1	1.378	5.841	NR
	Blancher II	2022	3728	3	2	704.6	2.658	5.841	NR
	Plant Eff. I	5183	4428	3	2	949.2	0.873	5.841	NR
	Plant Eff. II	5862	5332	3	2	1236.0	0.471	5.841	NR
Grease and Oil	Plant Eff. II	570	512	3	2	58.8	1.083	5.841	NR

(1) Statistical Analysis: The purpose of this analysis was to test the significance of the difference between the means (of waste indices) for effluents from shoestring and steak fry processing operations. In order to do the analysis, the results of the steak fries and shoestring cuts were considered as random samples from two independent populations (two treatments) whose distributions were normal and variances (σ_1^2 and σ_2^2) were equal. The statistical analysis conducted was testing the null hypothesis (H_0: $\mu_1 = \mu_2$ vs. H_1: $\mu_1 \neq \mu_2$) which employs the test statistic

$$T = \frac{\overline{X} - \overline{Y}}{\text{Spooled}\sqrt{1/n_1 + 1/n_2}}\text{, where:}$$

Table IX. Continued.

$\overline{X}$ = Unbiased estimator of the mean of shoestring cuts (μ_1);

$\overline{Y}$ = Unbiased estimator of the mean of steak fries (μ_2);

n_1 = Sample size corresponding to $\overline{X}$;

n_2 = Sample size corresponding to $\overline{Y}$; and

S^2_{pooled} = Square root of the pooled estimator of the common σ^2.

The pooled estimator of the common σ^2 is calculated by the following formula:

$$S^2_{pooled} = \frac{\sum_{i=1}^{n_1} (X_i - \overline{X})^2 + \sum_{i=1}^{n_2} (Y_i - \overline{Y})^2}{n_1 + n_2 - 2}$$

$$= \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}$$

A confidence level of $\alpha = 0.01$ was chosen, thereby, the two-sided rejection region was R: $|t| > t_{0.005}$.

Considering TSM values for the washer, sample calculations, (for the stated period) would be as follows:

Sample (results) from population 1 (shoestring cuts): 1740, 2963, 2386
Sample (results)from population 2 (steak fries): 2891, 1739
Sample means are:

$$\overline{X} = \frac{1740 + 2963 + 2386}{3} = 2363$$

$$\overline{Y} = \frac{2891 + 1739}{2} = 2315$$

Table IX. Continued.

Further

$$(3-1)S_1^2 = \Sigma(X_i - \overline{X})^2$$

$$= (1740 - 2363)^2 + (2963 - 2363)^2 + (2386 - 2363)^2 = 748658$$

$$(2-1)S_2^2 = \Sigma(Y_i - \overline{Y})^2$$

$$= (2891 - 2315)^2 + (1739 - 2315)^2 = 663552$$

Thus,

$$S^2_{pooled} = \frac{748658 + 663552}{3 + 2 - 2} = 470736.7$$

And

$$S_{pooled} = \sqrt{470736.7} = 686.1$$

The observed t value is then

$$t = \frac{2363 - 2315}{686.1\sqrt{\frac{1}{3} + \frac{1}{2}}} = 0.077$$

For degrees of freedom, $d_f = 3$, the tabled value is $t_{0.005} = 5.841$ which is larger than the observed $|t|$ value of 0.077. Hence, the null hypothesis is not rejected with $\alpha = 0.01$. This means that the analysis has not shown the means to be significantly different. Considering the four waste indices, the same calculations were performed for all other sources.

(2) As it is seen, none of the observed $|t|$ values is bigger than its corresponding $t_{0.005}$ value. That is why NR, standing for No Rejection of Null Hypothesis, appears all through the column.