EPA-600/2-77-135
July 1977

Environmental Protection Technology Series

MINIMIZATION OF WATER USE IN LEAFY VEGETABLE WASHERS

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-77-135
July 1977

MINIMIZATION OF WATER USE IN LEAFY VEGETABLE WASHERS

by

Malcolm E. Wright
Agricultural Engineering Department
and
Robert C. Hoehn
Civil Engineering Department
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

Grant No. S-802958

Project Officer

Harold W. Thompson
Industrial Pollution Control Division
Industrial Environmental Research Laboratory
Corvallis, Oregon 97330

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

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

This report covers the construction and evaluation of an improved leafy greens vegetable washing system. This system consisted of two series drum immersion washers, each with associated settling tanks and moving belt screens. Wash water was used in a counter-current flow regime. Results obtained when comparing the prototype process to current commercial washing systems were encouraging. Significant reductions in wash water requirements and wastewater generation were reported; as was an increase in cleaning efficiency.

It appears that this process modification will become a building block in the development of economically achievable waste management systems for the leafy greens processing industry. As a result this report should be of interest to processors of leafy greens, designers of processing facilities, equipment manufacturers and environmental regulatory agencies.

Further information on this project can be obtained by contacting the Food and Wood Products Branch of IERL-Ci.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This project was undertaken to construct and test an improved leafy greens washing system employing water recirculation, to characterize the quality of the wash water and waste stream, and to make comparisons to conventional washers. The prototype system produced a cleaner product while reducing water requirements and consolidating waste loads.

The prototype system consisted of two drum immersion washers in series, each with associated settling tanks, filters, and water recirculation systems. Construction was similar to conventional washers but with modifications to improve removal of floating trash and increase hydraulic agitation of product. Fresh water input was limited to that required to replace water carried off by the product plus a small, overflow, effluent stream from the system.

The prototype was tested in a commercial processing plant during the fall and spring harvesting seasons, 1975-76. Sixty-seven metric tons of collards, spinach, and turnip greens were processed through the prototype in 52 hours of actual operating time. Conventional washers were monitored for 27 hours (38 tons) for comparison. Insect and bacteria counts, COD, TSS, VSS, and several other water and product parameters were measured at predetermined times and locations. Data were obtained to predict expected waste loads from the products processed.

Economic considerations indicate that the annual fixed costs of owning the prototype system would be approximately $600 per year more than the costs of owning a conventional system, of comparable capacity. Operating costs, however, were $100/day less for the prototype than for the conventional system in an example problem using conditions similar to those at the test site. These results would, of course, vary considerably depending on local utility rates and other operating costs.

This report was submitted in fulfillment of Grant No. S802958 by the Virginia Polytechnic Institute and State University under the partial sponsorship of the Environmental Protection Agency. This report covers the period from May 1, 1974 to January 31, 1977, and work was completed as of January 31, 1977.

CONTENTS

FIGURES

TABLES

ABBREVIATIONS

BOD	-- biochemical oxygen demand
BOD_5	-- five-day biochemical oxygen demand
BOD_{20}	-- twenty-day biochemical oxygen demand
COD	-- chemical oxygen demand
TS	-- total solids
TSS	-- total suspended solids
VSS	-- volatile suspended solids
SS	-- suspended solids
O_2	-- oxygen
metric ton	-- 1000 kilograms
PVC	-- polyvinylchloride

ACKNOWLEDGMENTS

The most generous cooperation of the personnel of Exmore Foods, Exmore, Virginia is gratefully acknowledged. The open-handed willingness to allow the use of plant space, utilities, and personnel time in the conduct of this project was exemplary, indicating a far-sightedness that transcends immediate gain. The results of this work will carry much additional weight by virtue of the tests being performed in a practical, working environment.

Principals to be cited include Mr. Gaspar Battaglia, President of Exmore Foods, for his suggestion that his plant be used for the test site and his continued interest throughout the project; Mr. Charles Floyd, Plant Manager, for his cooperation in day-to-day arrangements; Mr. Stoakely Pearson, Plant Engineer, for the skill, care, and energy exerted in getting the equipment installed and making certain necessary modifications; and Mrs. Lucille Floyd, Mr. Woodrow Brawley, and Mr. James Morrison for allowing the unrestrained use of their laboratory. Many others should be cited, particularly the foremen and workers on the processing lines. Their patience, humor, and apparent pride in being associated with the project were a source of inspiration, especially during trying moments.

Special recognition is extended to the graduate students associated with the project, particularly Bill Robinson, Paige Geering, and Jim Coleman. Several others also made significant contributions. The kind and amount of work that they were subjected to and the inconveniences of the travel imposed were uncommon compared to usual graduate studies. Their response and enthusiasm were also uncommon -- well above the ordinary requirements implied by the receipt of stipends and degrees.

SECTION 1

INTRODUCTION

A 1971 estimate by the National Canners Associations indicated that the 1838 fruit and vegetable canning and freezing plants in the U. S. used 99 billion gallons of water and discharged 96 billion gallons of wastewater (14). Approximately 626 million pounds of leafy greens and broccoli were processed in 80 plants during that same year (6) (21) requiring an estimated 2.5 billion gallons of process water. Even though greens processing represents only a small percentage of the fruit and vegetable industry output, research in areas related to it can have general applicability in many instances.

Two major concerns of leafy greens processors are water use management and initial cleaning of freshly harvested product. Concerns in water management, particularly those related to effluents, have assumed added importance in recent years relative to the new emphases on environmental protection. Major problems have arisen in handling effluents from the lack of knowledge of waste stream characteristics. Design information on wastewater parameters for treating combined flows from fruit and vegetable processing is sketchy at best. Flow and concentrations of waste stream constituents from unit operations within plants are even less available.

A limited amount of information is available on combined waste stream loadings from leafy vegetable processing in reports by Mercer (12), Ramseier (16), Frey (8) (9), the NCA (14) and SCS Engineers (18). Carter (4), Bough (2), Frey and SCS Engineers have reported on certain unit operations. The data available, however, are still inadequate for proper design of in-plant or out-of-plant waste stream management. The parameters reported vary from study to study and might include any of the following: BOD, COD, TS, TSS, VSS, dissolved O_2, pH, alkalinity, or bacterial counts. Methods of reporting each parameter may also vary. For instance, COD may variously be given in terms of miligrams/liter of wastewater, pounds per ton of product processed or even pounds per 1000 cases of canned product. Other important information, such as flow rates of product and water, is often omitted or crudely estimated. Total water consumption has been reported to range from 3.2 to 5.4 gal/lb of greens processed. Estimates of total water consumption required for initial washing range from 68 to 88 percent. Obviously, the major volume of the total wastewater comes from this source. While the inconsistencies cited above do not necessarily invalidate reported results, they do limit their usefulness and/or credibility.

Virtually no information is available on the relative effectiveness of different devices used in the initial cleaning of various greens. Typical equipment used prior to blanching is described by Carter, Bough, Frey and Lopez (11). This usually includes, in order, a dry tumbler for removal of loose soil and small particles, hand inspection and picking belts, and from one to four wet washers.

The present study was initiated to address the two major problems of producing cleaner product in the initial processing of leafy greens and to characterize the waste streams from these processes. An experimental, two-washer, prototype system incorporating the principle of water recirculation was constructed and tested during two harvesting seasons at a commercial, frozen-vegetable processing plant. Design of the washers was based on modifications of conventional washers developed by Frey to increase their effectiveness. High recirculation rates within the system provided hydraulic agitation to supplement the mechanical agitation. Input water was limited to that required for makeup plus one small waste stream from the system. Water and product quality and flow rates were monitored at several points in the prototype during the fall of 1975 to determine washing effectiveness and characterize internal and external water flows. A similar testing program, conducted during the spring of 1976, included tests on conventional washers for comparison purposes.

SECTION 2

CONCLUSIONS

The experimental prototype leafy-greens washing system was more effective, though not dramatically so, in removing grit and insects from product than the conventional washers. It also showed a potential for better control of bacteria counts on product prior to blanching. The final rinse, with fresh chlorinated water, appeared to be quite effective for grit removal and bacteria control. There was no apparent increase in grit or insects on product as washing proceeded with recirculated water. A soap-like foam accumulated on the water surfaces of the prototype that may have had a significant effect on product cleaning.

Differences in water use between the two systems to obtain cleaning was dramatic, the prototype using only about 1/5 the amount of water used by the conventional washers. Waste water discharge from the prototype was approximately 1/12 that of the conventional washers. The average amount of water carried out on product from the prototype was 2.2 ℓ/kg (0.26 gal/lb) A fresh water input rate to the system of 3.5 ℓ/kg (0.42 gal/lb) is a recommended minimum.

The amount of each type of waste constituent (TSS, VSS, COD) discharged with the water from the prototype system per unit of product processed was less than that from the conventional washers though the concentrations were higher. For example, the average discharges, from each system respectively, while processing turnip greens were: TSS - 0.26 and 1.54, VSS - 0.04 and 0.26, COD - 0.16 and 2.31 kg per metric ton of product. Some of this difference, particularly for the non-volatile solids, was due to accumulations in the washers and settling tanks of the prototype that could be disposed of separately from the waste stream. VSS and COD production in the prototype was less than in the conventional washers, probably due to lower osmotic gradients between the recirculated water and the vegetables. Average concentrations in the discharge from the prototype and conventional washers, respectively, while processing turnip greens were: TSS - 273 and 85, VSS - 37 and 14, COD - 135 and 128 mg/ℓ of waste stream.

Approximately 75 percent of the cleaning took place in the first washer--settling tank sub-system of the prototype. Given steady inputs of product and water similar to the average conditions of this study (1278 kg/hr and 72 ℓ/min), the waste strength parameters in the washers and settling tanks will stabilize at some maximum value after approximately 5 hours of operation. This maximum value will be affected, of course, by the average "dirtiness" of the vegetables.

Waste production varies greatly between different varieties of vegetables and between different cuttings of the same vegetable. All parameters -- organic, inorganic, insects and bacteria -- are affected by age at harvest, growing conditions, method of harvest, etc. Of the three varieties tested, spinach consistently produced the most TSS per unit of product and could be used as a model for design information for this waste parameter. Other results, however, do not indicate that any of the three products tested - collards, spinach or turnip greens -- could be used as a general model for VSS and COD emissions. Wash waters were generally neutral in all trials indicating that pH would not be a problem in treatment of effluents.

The mechanical performance of the prototype washer was very satisfactory though it could be improved as outlined in the recommendations section. Of particular note are the product discharge conveyor belts and moving belt screens for the recirculated water. The discharge belts were made of plastic and appear to be a very effective and inexpensive substitute for stainless steel. The screen belts, also of a monofilament plastic, provided a relatively simple, inexpensive means of separating small leaf fragments and even insects from the wash water.

Processors of frozen vegetables use large quantities of water to cool blanched product prior to packaging. After the cooling water is separated from the product it is usually used in the raw product washers. Assuming that alternate means of economically cooling product (by chilled air, for example) can be found, then freezers, as well as canners, of leafy-vegetables would find considerable advantage in implementing low-water-use washing systems.

Recycling wash water in the initial processing of leafy vegetables is a viable means of consolidating wastes, reducing the amount of effluent and reducing the amount of total water required. Increased hydraulic agitation of product by high internal flow rates in the system coupled with a final rinse of controlled chlorine content can improve vegetable cleaning compared to conventional washers. These findings are significant in terms of environmental protection, resource conservation, and food quality. They indicate that the final efforts needed to encourage implementation by the food industry should be taken.

The intial cost of the prototype system developed in this study was estimated at $16,000 compared to $12,000 for a conventional system of equivalent capacity. Annual fixed costs of ownership were $2208 and $1656, respectively, for a difference of $552 per year. Assuming a product mix of 3/4 spinach and 1/4 turnip greens, operating conditions similar to those in this study, and using local labor and utility costs, the daily operating cost for the prototype was $158 and for the conventional washers $251 an advantage of $93 per day for the prototype. The difference in annual fixed costs, in this example then, were recovered in approximately six days of operation. If this is considered representative, then the economics of owning and operating the two systems strongly favor the low-water-use prototype washing system.

SECTION 3

RECOMMENDATIONS

The prototype, leafy-vegetable washing system is effective in cleaning leafy vegetables while using a minimum amount of water. No changes in its functional design are considered to be necessary at this time. This does not imply, however, that the effectiveness of the system could not be improved by study of additional components or techniques in operation. The relative effectiveness of the new system compared to similar conventional washers does seem to warrant its adoption by the food processing industry as soon as possible.

The present prototype has some limitations, unrelated to function, that need improvement prior to considering it for commercial use over an extended period. As now constructed, it requires too much space and is too complicated. These problems, however, can easily be overcome by a redesign that will not affect system performance and might possibly improve it. For example, overflow water from each washer is now collected in a sump and pumped over a moving-belt screen prior to discharge to a settling tank. From the settling tank it is returned to the washer via a high pressure spray system. The washer system could be greatly simplified by locating the settling tanks and moving-belt screens underneath the washers where they could receive the overflow by gravity. This would eliminate the sump pumps, reduce the floor space required and would probably increase the effectiveness of the settling tanks by equalizing the flow to them.

The redesign of the system should include construction of a second prototype, some limited laboratory testing to verify certain operating characteristics, and development of a complete set of plans and specifications. These plans could then be made available to interested food processors and equipment manufacturers. The food processing industry as a whole is very large and includes several giant corporations. Most food processing plants, however, tend to operate in an autonomous fashion, drawing little more than administrative support from their parent companies. Research and development of needed machinery are pursued rather haphazardly, usually on a "cut and try" basis. In order for a new system to achieve maximum and speedy acceptance by this industry, information on it should be presented in the most usable form. A processor given a complete set of plans and specifications for an apparatus is more likely to build it in his own shop or have it built than one who has to worry about design detail.

After the second prototype is built it should be installed in a commercial processing plant, somewhere in the U. S., and used under normal operating conditions for an extended period of two to three years. This would provide a reference demonstration for other processors and allow for refinements in design and operating technique.

Leafy vegetables go directly from the blancher to the cans in a canning process. In frozen food plants, however, they must be cooled before being packaged. This is usually done by fluming the product in large volumes of fresh, cool water. The water from this cooling process, or a portion of it, is then used in the washers after the cooled product is dewatered. Because the cooling water is usually in excess of that required by the washers little economic or environmental advantage would be gained by using low-water-use washers in vegetable freezing plants without using alternate means of product cooling. Some devices, such as air coolers, are available, but it appears that further studies in this area of vegetable processing are warranted.

A comprehensive review of literature on both combined- and unit-operation's effluents from fruit and vegetable processing should be initiated before this literature becomes voluminous. This review should be conducted with the object of accumulating known data in condensed form and "normalizing" it to a standard form of presentation. A corollary effort to this review would be the publication of guidelines for future studies to indicate what data should be taken and how it should be expressed. The review and guidelines should be developed with the view of providing designers of processing equipment and waste treatment facilities with the most useable data.

SECTION 4

PROTOTYPE WASHER SYSTEM

WASHER DESIGN

Lopez (11) described the three most common types of leafy vegetable washers as the 1) immersion, 2) rotary spray, and 3) spray belt. Of these the immersion (sometimes called immersion drum, drum, paddle wheel or dunker washer) is the most popular. Frey (8) (9), in response to industry concerns for cleaner product, made several modifications to a conventional immersion washer and demonstrated their effectiveness for removing insects and grit from spinach. He also measured BOD, COD, TS, SS and VSS of the waste stream. The water-use rate in this washer was approximately one gal/lb of product, well below the industry average. The low levels of the waste strength parameters indicated the feasibility of developing a washer prototype system incorporating the principle of water recirculation.

General Design of Washing System

A full scale prototype of an immersion washing and water recirculating system was constructed incorporating several of Frey's modifications to a conventional washer. It consisted of two, modified, leafy-vegetable immersion washers in series and their respective settling tanks and moving-belt screens for cleaning the water in the recirculation process. Figure 1 shows the arrangement of the system, as well as product- and water-flow patterns. Fresh makeup water was introduced into settling tank number 2 during trials in the fall of 1975. This arrangement was changed to apply the makeup water as a final spray on the product leaving washer number 2 during the spring trials of 1976. Excess water from settling tank number 2 overflowed into settling tank number 1. This was the only hydraulic link between the two washing units. Excess water in settling tank 1 flowed to waste. Figure 2 is an overhead view of the washing system as it was installed.

Description of a Washing Unit

Each washer and settling tank was constructed of 11 gage, type 304, stainless steel sheets, with a 2 x 2 x 1/4 inch angle-iron frame around the top. The washer was designed to wash approximately 4,000 pounds of product per hour based on similar conventional washers at a local processing plant. Each washer was 4 feet wide and 16 feet long with three "V" shaped sections forming the bottom of the tank (Figure 3). This configuration aided in the removal of grit when the tank was drained. The tank was three feet deep at the deepest point, 1 foot-10 inches at the shallowest point, and held 688 gallons of water when filled to the working depth of 2 feet, 7 inches.

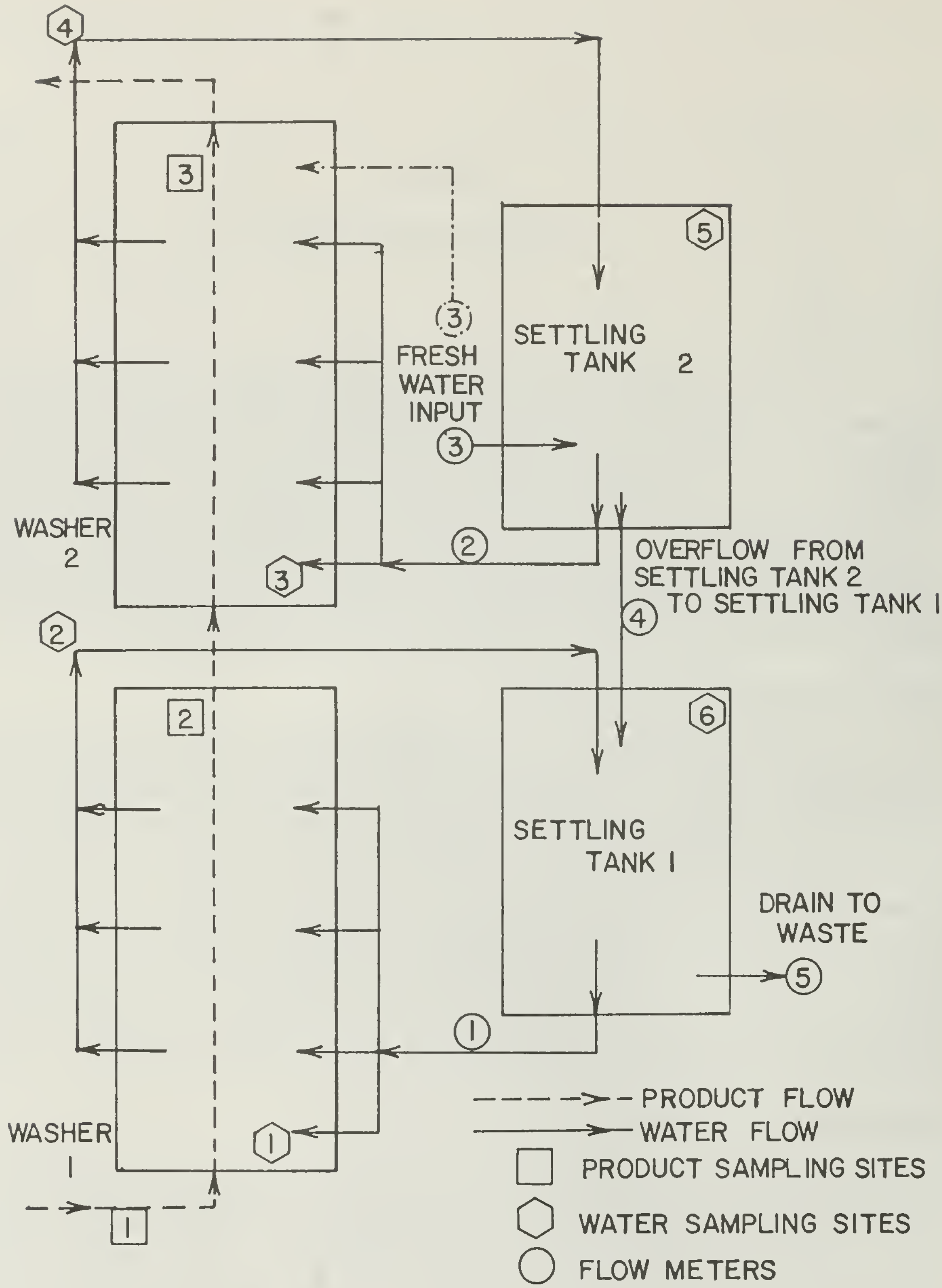


Figure 1: Diagram of washing system showing water and product flow patterns, sampling sites and water flow meter locations.

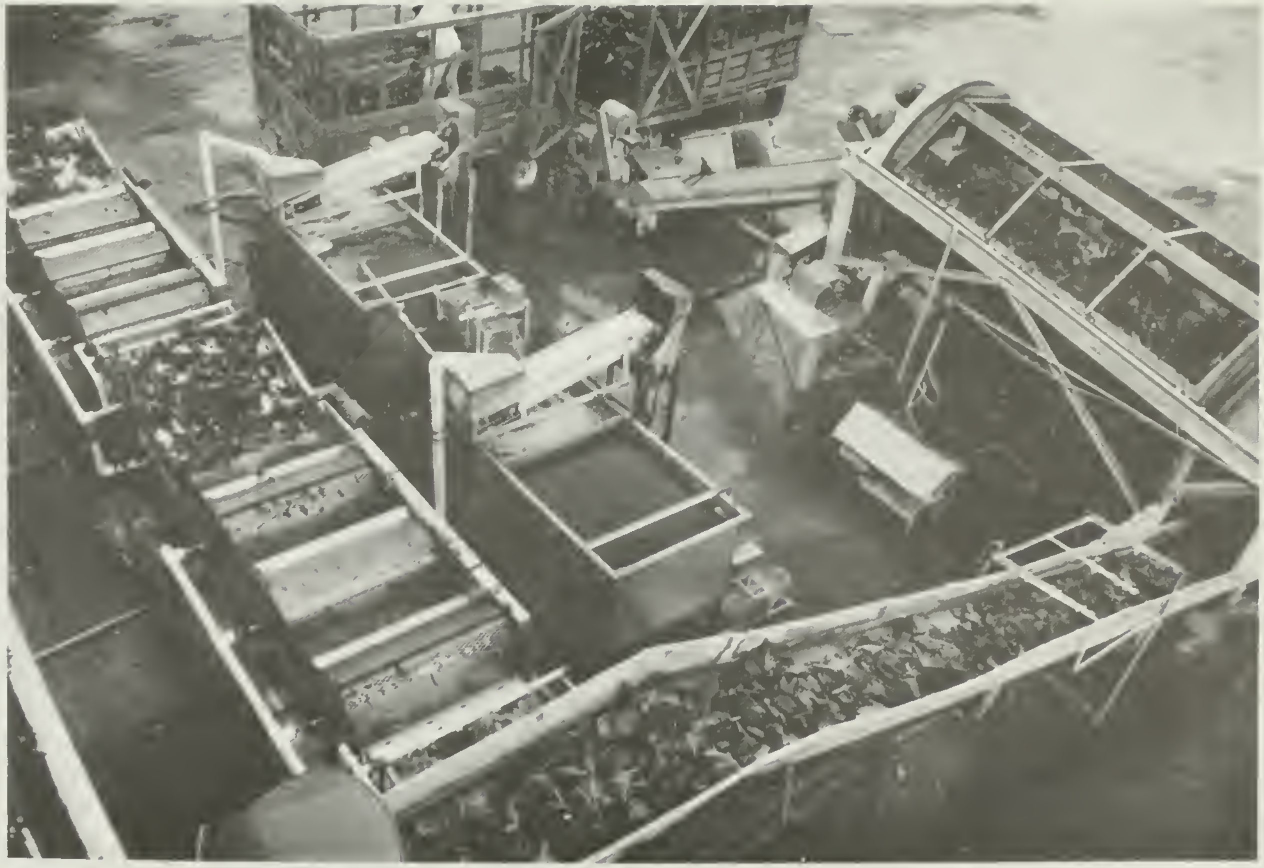
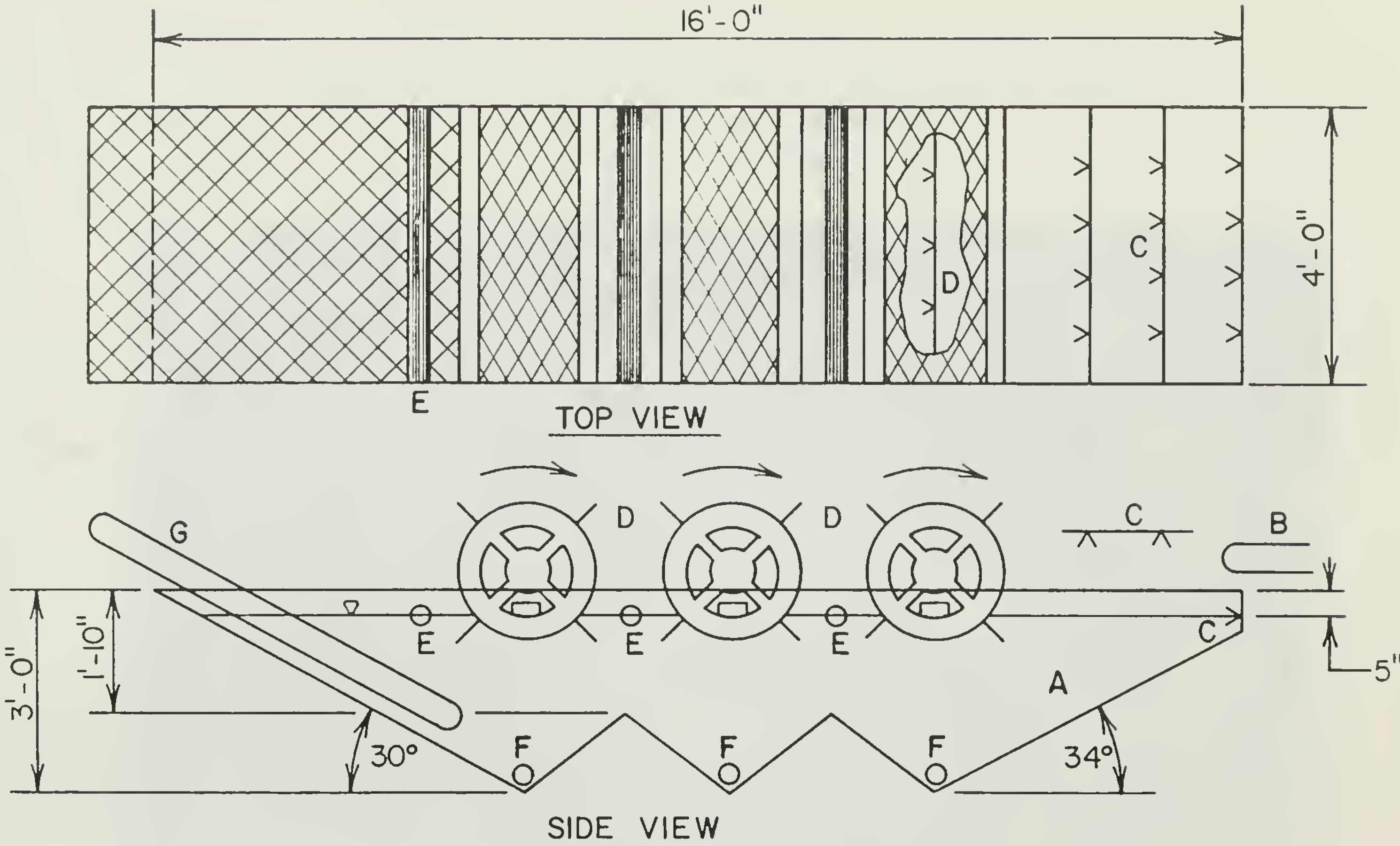


Figure 2. Overhead view of washing system adjacent to Exmore plant. Rotary sand tumbler and conveyor into plant are at right and foreground.



A. Washer tank
B. Input conveyor
C. Nozzle banks
D. Paddle wheels with side drains and interior nozzles
E. Skimmers (later removed)
F. Ports for draining tank
G. Exit conveyor
∇. Water level

Figure 3: Diagram of Prototype Washer.

Water was introduced from the settling tanks into the washer at several locations. There were three banks of nozzles at the input end of the tank, one located at the water level and two positioned above the incoming product (Figure 3). Each bank consisted of four, brass, Flat-Jet No. 1/2 P35100 nozzles, manufactured by Spraying Systems Company. They were mounted on 1-1/4-inch PVC pipe with split-eyelet connectors, Spraying Systems No. 8370A. These sprayers spread the incoming product, began the agitation process to remove grit and trash, and propelled the product toward the first agitation drum. The entire spraying system was designed for 200 gallons per minute (gpm) at a pressure of 35 pounds per square inch (psi).

Three agitation drums, or paddle wheels, on each washer served to agitate the product by alternately submerging and releasing it to remove grit and trash. They were driven with No. 60 roller chain at 11 revolutions per minute (rpm) by a 1-horsepower (hp), 3-phase electric motor coupled to a Winsmith M300T right angle, 60:1, speed reducer. The drums were 1 foot 11-3/4 inches in diameter and were covered with 16 gage, 3/4-inch mesh, flattened expanded stainless steel metal that allowed insects and leaf fragments to float to the surface inside the drum while the product was submerged (Figure 4). They each had four, 4-inch fins around their perimeter. A stationary bank of three, flat-fan, brass Vee Jet No. H 1/2 U80100 nozzles, manufactured by Spraying Systems Company was positioned inside each drum. The nozzles were mounted with split-eyelet connectors on a 1-1/4 inch, PVC pipe. This pipe was inserted through a hollow hub of the drum which located the bank along the axis of the drum and thus allowed it to remain stationary while the drum rotated. The nozzle bank was oriented so that the spray would strike the drum covering at the water surface where the product was released. This served to clean the drums during operation by preventing leaves from becoming entangled in the expanded metal covering. In addition the spray from these nozzles was another water input to the washer and an aid in the agitation process. The drums propelled the product through the washer and onto an exit conveyor (Figures 3, 5). This conveyor was constructed of an open-mesh belting made of plastic sections (manufactured by Intralox, Inc.). It had flights every 24 inches and was driven with No. 60 roller chain by a 1/4-hp, single-phase, gear motor at a speed of 33 feet per minute (fpm). The conveyor was inclined 30° from the horizontal.

The agitation drums had a spoked construction on one end (Figure 4) to allow water and trash collected inside the drum to flow out through side drains cut in the washer tank. The side drains were 4 1/2 inch diameter semicircles with their bottom edges located 5 inches below the top of the washer (at the working depth of the water). Skimmers made of 3-inch diameter stainless steel tubing with lengthwise slots 4 feet long by 2 inches wide were installed directly behind each drum. They were positioned to allow the product to flow beneath them before surfacing after it had been submerged by the paddle wheels. Their purpose was to skim floating trash from the water surface before it could recontaminate the product.

Water and trash from the skimmers and side drains (Figure 6) were collected in a sump box, 2 feet by 2 feet by 1 foot 4 inches. A sump pump (2-hp, 230 volt, single phase, Kenco No. 34N2 submersible), with a capacity

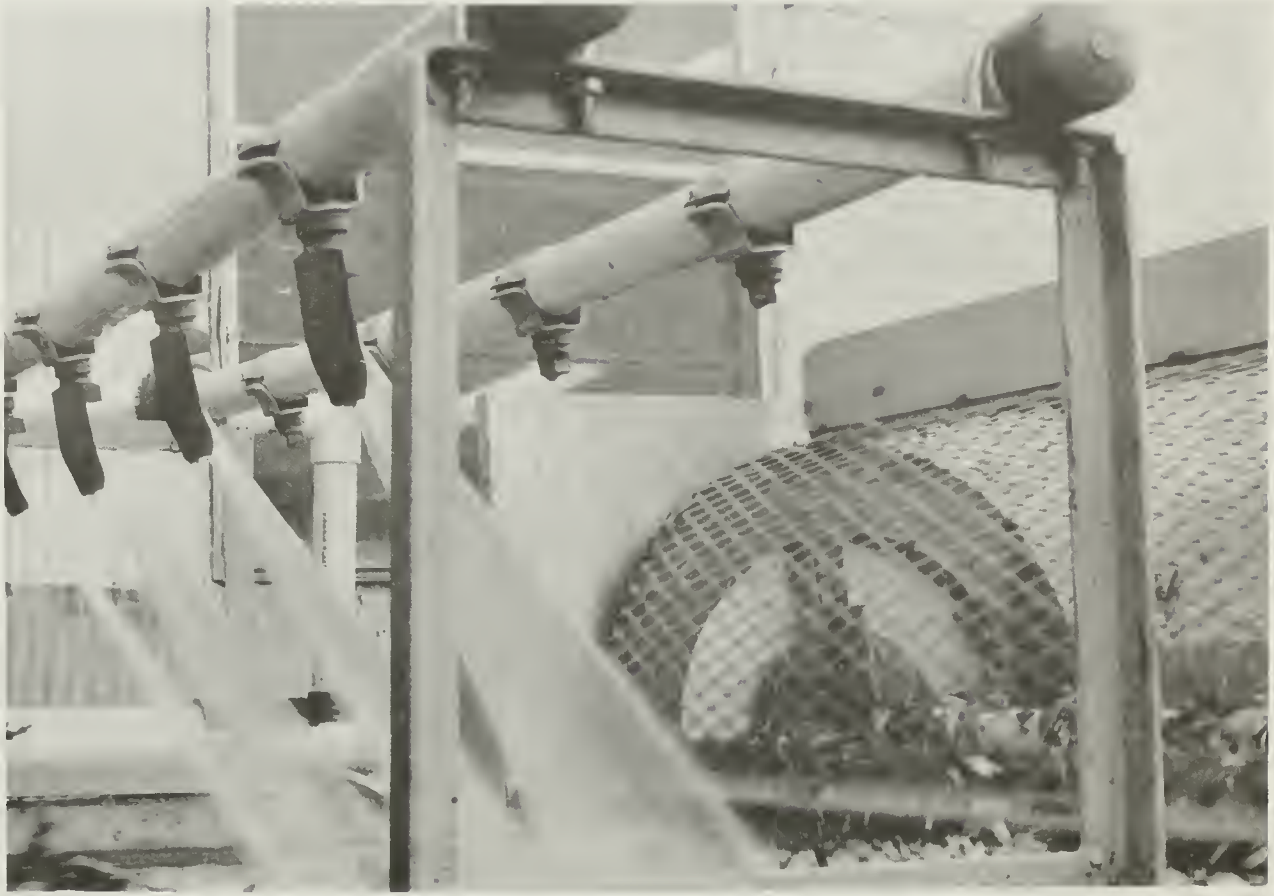


Figure 4. Paddle wheel showing expanded metal covering and spoked end construction. Elevated nozzle banks are shown in foreground.

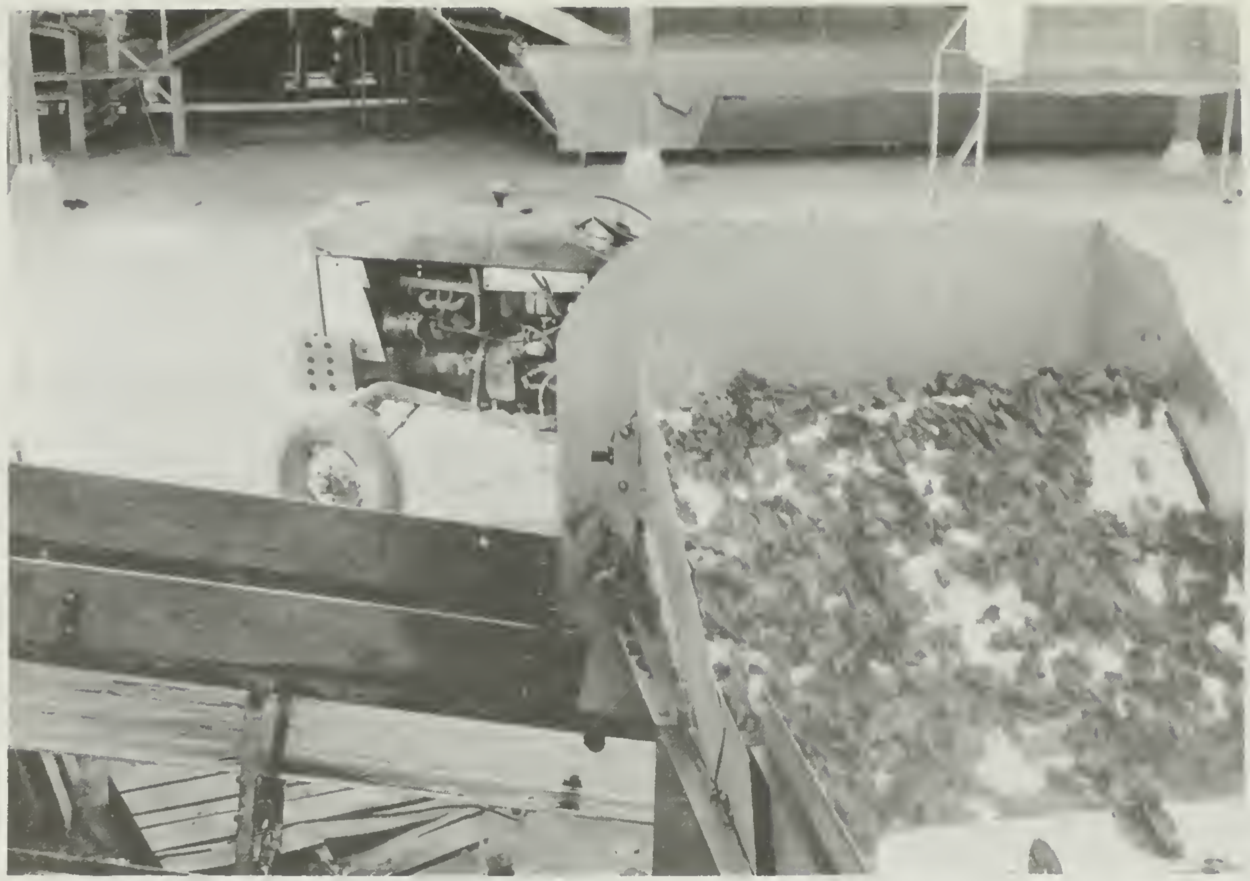


Figure 5. Exit conveyor of washer number 2.

Figure 6. View of washer side drains in operation.

of 14,000 gallons per hour at 15 feet of head, was used to pump trash and water from the sump box to a moving-belt screen that was mounted on top of the settling tank. This pump was controlled by a Kenco Series 112-C12 Liquid Level Control.

A gate valve was used to regulate the flow from the sump pump through a 3-inch, PVC pipe to the filter. The moving-belt screen was a conveyor (5 feet long by 1 foot wide) inclined at an angle of 16° from the horizontal to prevent water from flowing off the exit end. The belt was made of No. 410 Monofilament Polyester Screen manufactured by the Globe Albany Company and had a permeability of 600 cubic feet per minute (cfm) per square foot under a 1/4-inch head (Figure 7). The belt was chain-driven at 47 fpm by a 1/4 hp electric gear motor. Trash was carried away on the belt while the water flowed through it. A 3/4-inch galvanized pipe, which had forty-eight 1/16-inch holes spaced 1/4-inch apart along its length, was positioned under the exit end of the moving-belt screen. Compressed air was directed through this pipe and against the belt to remove the trash. This trash was collected in boxes placed at the end of the moving-belt screen (Figure 8).

Water flowed through the moving-belt screen and into a settling tank where grit could settle out. The tank was 8-feet long by 4-feet wide with a 4-foot-6 inch maximum depth and a 3-foot minimum depth. Figure 9 shows the settling tank construction as well as the direction of water flow through it. The baffles prevented floating material from getting to the pump. The tank held approximately 700 gallons of water and had an overflow rate of 2.81 gpm/ft^2 based on an assumed particle size of 50 microns and a particle density of 2.65 g/cc [Metcalf and Eddy (13)].

An Aurora Model 344 centrifugal pump, with a 3-inch inlet and a 2 1/2-inch outlet, was used to pump the water from the settling tank to the washer spray nozzles. The pump capacity was 200 gpm against 35 psi. It was driven by a 3-phase, 1800 rpm, 7-1/2 hp, electric motor with a V-belt drive.

A gate valve was used to regulate the flow from the settling tank through a 2-1/2-inch PVC pipe to the washer tank. The flow was divided at the washer and carried to the nozzle banks by 1-1/4-inch PVC pipe.

Motor starters for the 10 electric motors in the system were assembled on a control panel, making it possible for one person to control the entire washing system from one location.

WATER FLOW INSTRUMENTATION

Five meters were installed in the washing system to monitor fresh water input, recirculation rates, and overflow rates (Figure 1). Meters 1 and 2 measured the recirculation rates within washing units 1 and 2, respectively. The meters used were Badger Model MLFT, 3-inch totalizing propeller meters with a normal operating range of 35 to 200 gpm.

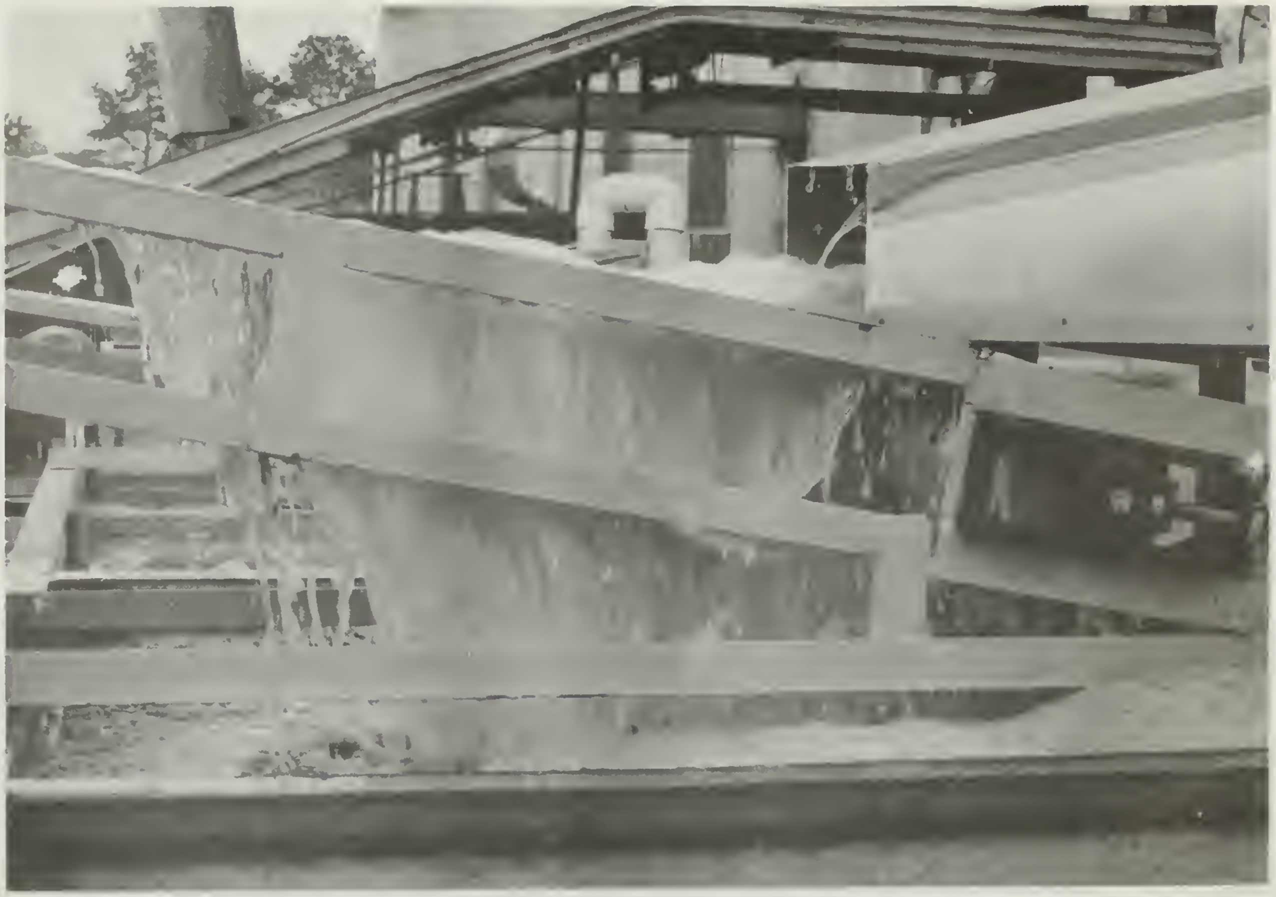


Figure 7. Moving Belt Screen in Operation

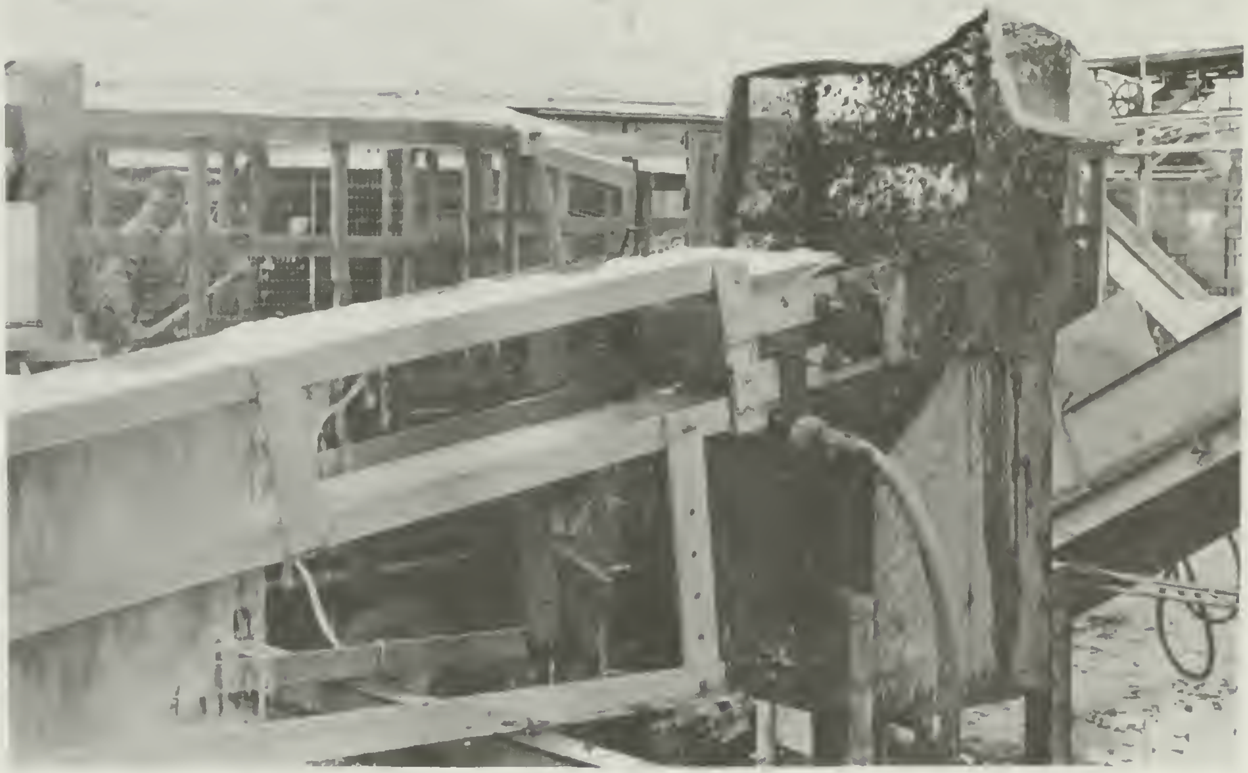
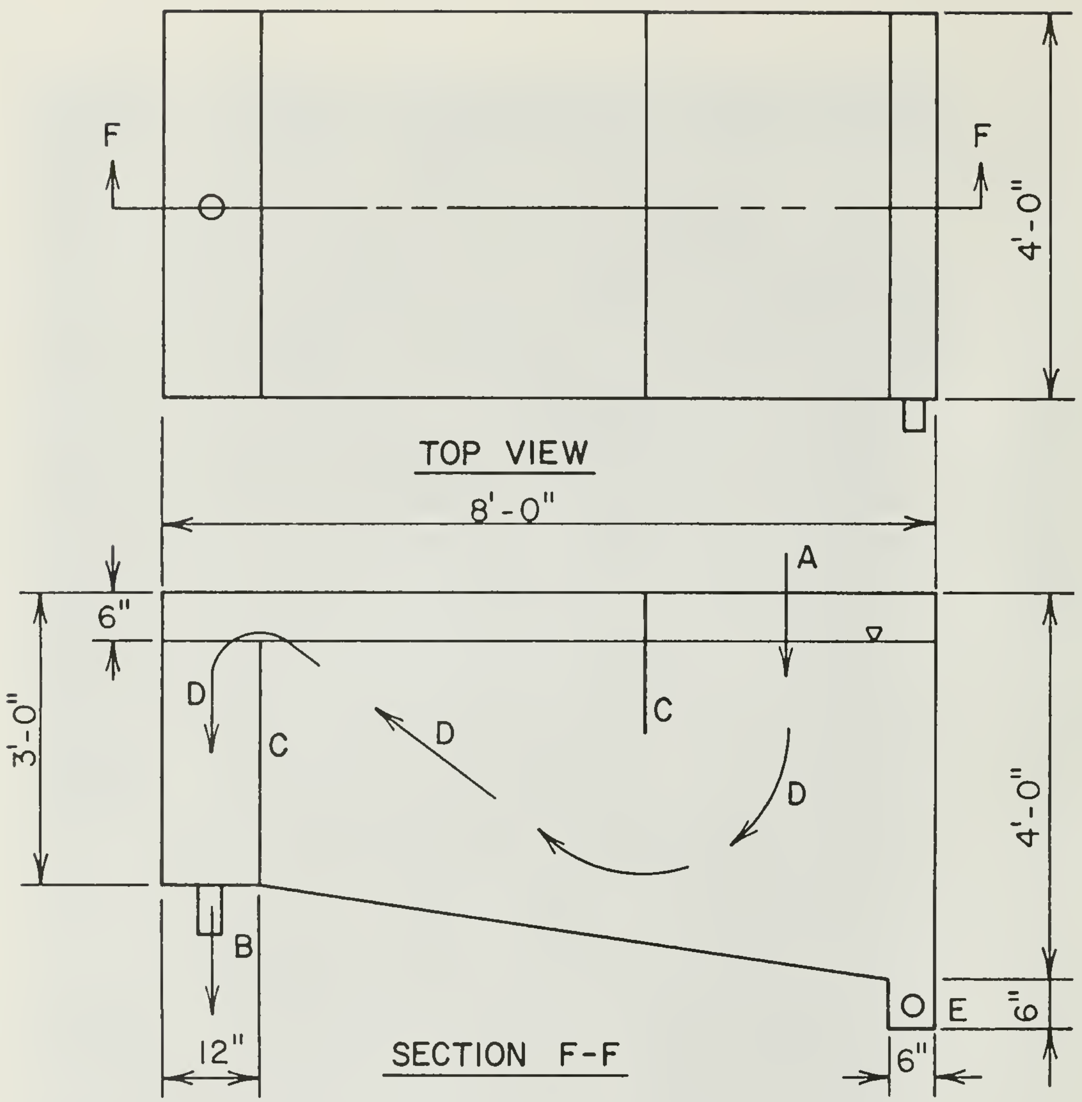


Figure 8. Moving belt screen and trash collector. Compressed air hose for removing trash from belt is shown in foreground.



A. Water input
B. Water outlet to pump
C. Baffles
D. Direction of flow
E. Port for draining tank

Figure 9: Prototype settling tank

Flow meter 3 measured the flow of fresh makeup water into the system. A 1-1/2-inch Badger Model SC-ER totalizing, disc-type meter, with a normal operating range between 5 and 80 gpm, was used to monitor this flow which was regulated by a gate valve. The makeup water was piped directly into the second settling tank from the meter during the test trials made in the fall of 1975. During the spring trials of 1976, the makeup water was introduced as a spray through five nozzles (Spraying Systems Co. Flat-Jet No. 1/2 P35100) onto the exit belt of washer 2 to provide a final product rinse. This was the only modification made to the experimental prototype between the two seasons.

The overflow from settling tank 2 to settling tank 1 was measured by meter number 4. This meter was an 0.8-foot deep, Plexiglas, HS flume constructed according to specifications in the Field Manual for Research in Agricultural Hydrology (10). A Friez FW-2, water stage recorder was used to continuously monitor the depth of water in the flume (Figure 10). For details of the construction and calibration of Plexiglas HS flumes, see Robinson and Wright (17).

Meter number 5 measured the water flow from settling tank No. 1 to the drain. An 0.8-foot, HS flume and Friez recorder were also used to monitor this flow (Figure 11).

INSTALLATION AND MODIFICATIONS

The washing system was built in the Agricultural Engineering Department Laboratory on the campus of Virginia Polytechnic Institute and State University (VPI&SU). It was determined to be operational and then disassembled and transported to the Exmore Foods, Inc., plant in Exmore, Virginia. The washing apparatus was reassembled adjacent to the Exmore plant for testing at that site (Figure 2). Leafy greens were conveyed out of the plant to the washers after having passed over a series of dry inspection belts. After passing through the experimental washers, the product was carried back into the plant and allowed to pass through the plant's conventional washers. A reversible-feed belt was used to carry the product from the dry inspection belts directly into the conventional washers when the experimental washers were not in use.

Initial testing of the washer system with turnip greens revealed that the skimmers did not function as anticipated. The product did not pass under the skimmers, but collected on top of them. A skimmer had been used successfully by Frey (8), but with a considerably lower product flow rate. The skimmers were removed and their drains sealed off. The remaining side drains, located at the ends of the paddle wheels, were not large enough to carry off the flow introduced by the nozzle banks, so two modifications were made to overcome this problem. Larger rectangular side-drains (4 inches high by 7 inches wide) were cut at these locations with the bottom of each drain 2 inches below the designed water surface level of the washer. In addition, the bank of nozzles closest to the first drum was sealed off. This latter modification was made in order to maintain high nozzle pressure while reducing the water recirculation rate.

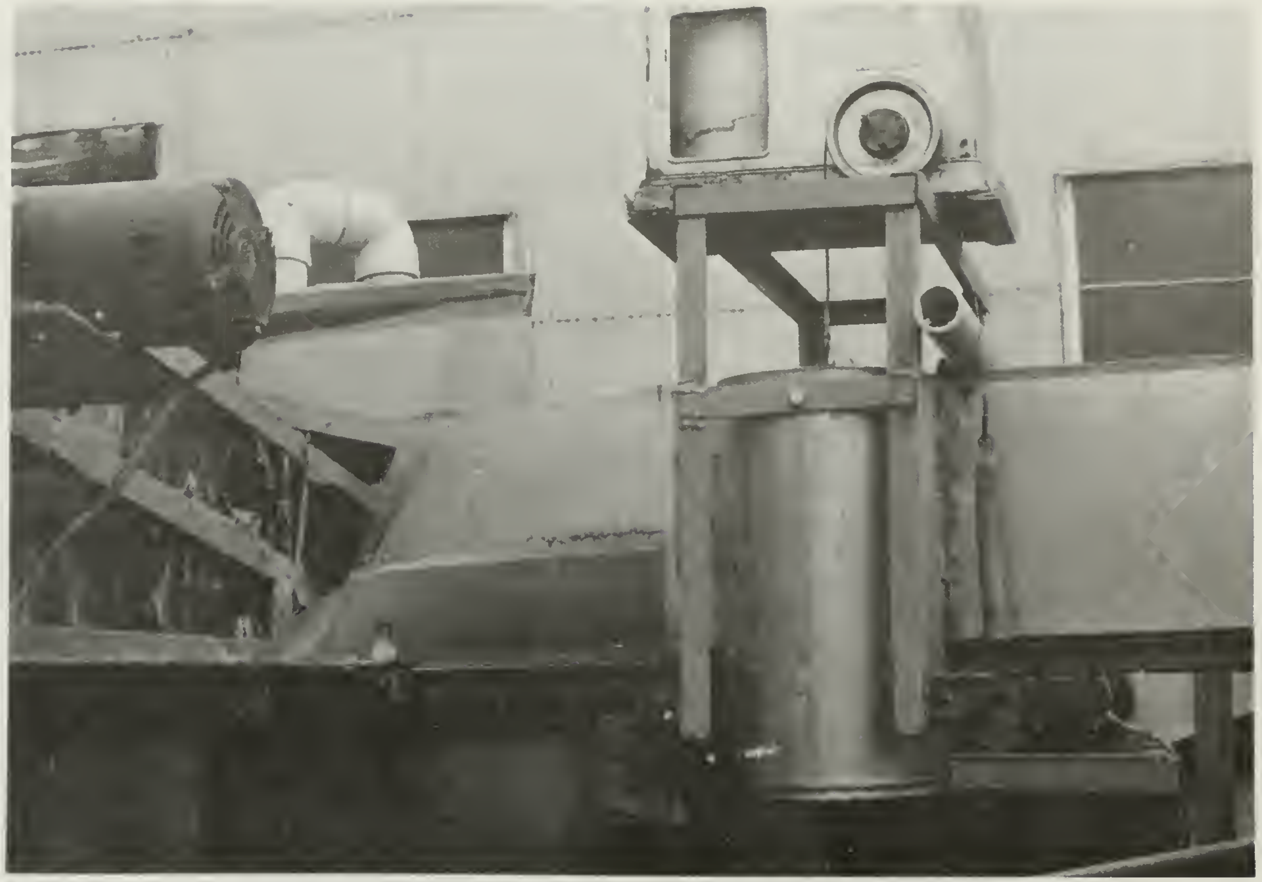


Figure 10. HS flume meter number 4 with water level recorder (Refer to Figure 1).

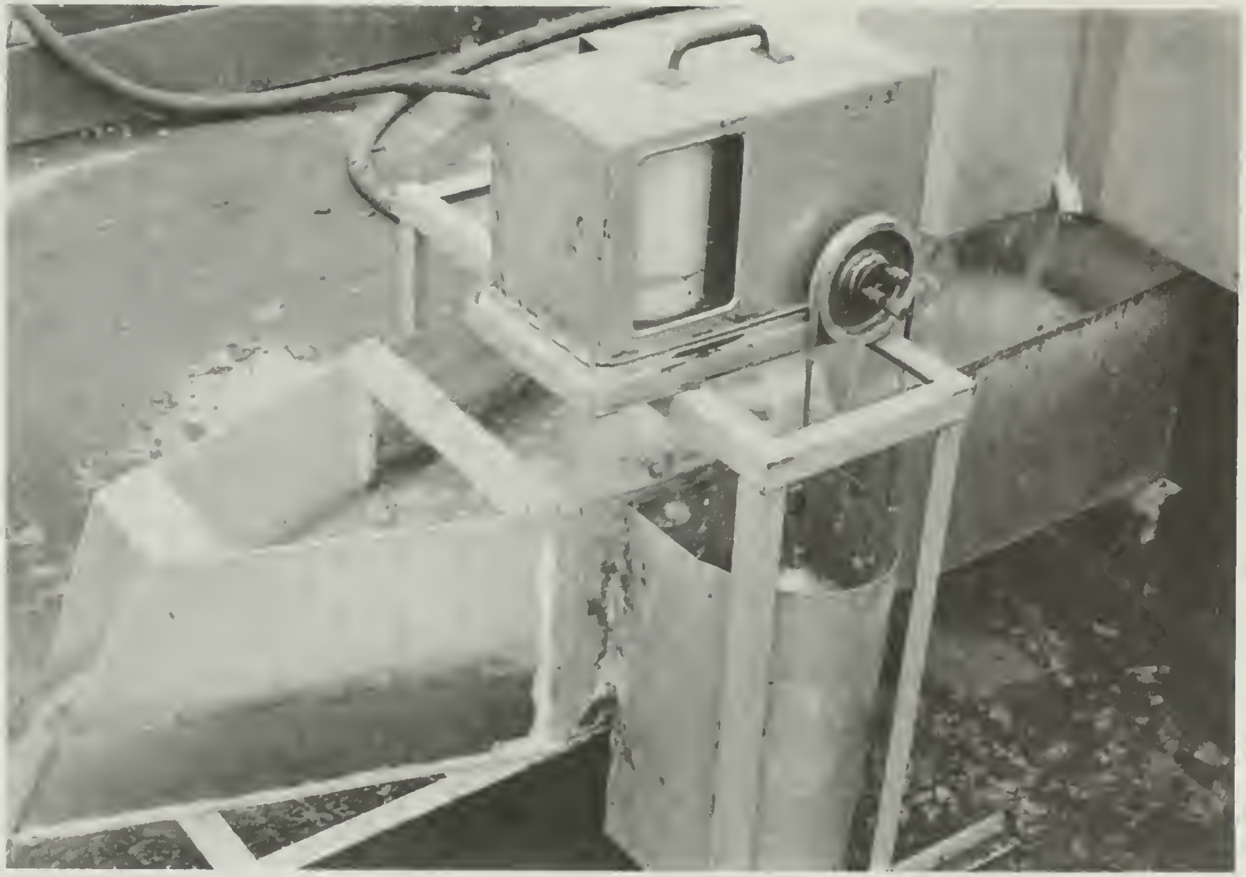


Figure 11. HS flume meter number 5 with water level recorder (Refer to Figure 1).

SECTION 5

PROCEDURES

OVERVIEW

Construction of the prototype leafy green's washer was completed on June 20, 1975, and attempts were made to purchase leafy vegetables in bulk quantities for laboratory tests. Very dry weather in the local area, however, had shortened the spring harvest season considerably. Packers, who would normally have excess leafy greens, were importing product from other regions to meet their obligations. Hence, testing was postponed until the fall season of 1975. Arrangements were made in the interim to test the prototype on site at the Exmore Foods Plant in Exmore, Virginia.

Testing the washer in a commercial food plant had several advantages. Tests were more realistic because the experimental equipment was subjected to the same conditions under which conventional washers operate. The minimum material needed for a reasonable test was estimated to be 25 tons. Arranging for delivery of this amount of material to the laboratory without spoilage, devising means to correctly meter it into the washers and disposing of it as waste after testing would have been a formidable task. Pre-washing treatments of product, such as dry tumbling and hand inspection, could also be performed more easily in-plant than in the laboratory. A final advantage was that the experimental equipment could be tested in comparison with conventional washers. These comparison tests were subsequently arranged for the spring season of 1976 under an extension of the original project.

Several difficulties were encountered as a result of working under commercial conditions. Principal among these was the distance to the test site, 350 miles. Each trip to collect data required a minimum of three days, two for travel and one for tests. A large volume of samples was taken during each trial, and it required special packing to avoid deterioration during transport from the plant back to the laboratory at Virginia Tech. For each trial, a considerable number of small instruments and a variety of glassware had to be transported to the plant and set up in a temporary lab on the processing floor to supplement the company's laboratory facilities. Finally, there was considerable difficulty in arranging travel schedules to coincide with the plant's processing schedule, which was very unpredictable. Decisions to process a certain vegetable, dependent on weather and several other factors, were often made only a few hours in advance of actual processing. Decisions to terminate processing were often more precipitous, usually depending on some factor that affected quality.

Additional difficulties, if they can be called that, included the fact that the investigators had no control over the rate at which product was processed, its initial condition before washing, or down time during trials. Even input water flow rates fluctuated somewhat due to changes in operating pressures in the plant's water system. Developing equipment and procedures to control all of these variables in a laboratory experiment would, of course, have added a degree of precision to the results, plus considerable time and expense in obtaining them. This added precision, however, would not have offset the insight gained from working under more realistic conditions.

Prototype Installation, Plant Layout and Conventional Washers

The prototype washer system was installed adjacent to the Exmore Foods Plant in Exmore, Virginia during the week of August 4, 1975 as described in Section 4. Exmore Foods has two leafy vegetable processing lines, an east line and a west line. The prototype was located so that it could operate in series with the conventional washers of the west line or, when not in use, could be bypassed (Figure 12).

The east and west conventional processing lines had two paddle wheel washers each in series (Figure 12) followed by a combined paddle wheel washer/pre-blancher, and then a blancher. The washers were three and one-half feet wide, approximately eighteen feet long, and three feet deep at the deepest point. There were four paddle wheels in each washer for propelling the product through the washer. Product from the blancher was cooled and transported in a cooling flume fed by fresh water. Dewatering and recirculation of the cooling flume water provided all the input water for the washers on the west line. The water input was at the head of each washer through a perforated pipe. The dewatering of the cooling flume water on the east line provided only a portion of the input water. The majority of this water was fresh, piped into the bottom of the washers. All the overflow from the washers was wasted to an open channel floor drain.

Overflow from the conventional washers was measured with HS flumes and water stage recorders like those used in the prototype system. An attempt was made to measure input water, which was under pressure, with propeller-type totalizing water meters. These meters soon became inoperative because some large, vegetable particles were being pumped from the dewaterers to the washers. However, an accurate estimate of the input water, it was reasoned, could be made by measuring the amounts of effluent water from each unit and using the data in water carried off by the product available from the prototype trials.

Summary of Trials

Tables 1 and 2 summarize the trials that were made during the fall and spring processing seasons. A total of 35,200 kilograms of product was processed through the prototype in 27 hours of actual operation during the fall and 31,500 kilograms in 24.4 hours during the spring. A total of 16,500 kilograms was processed in 11.7 hours through the east conventional line and 21,200 kilograms in 15.3 hours through the west conventional line

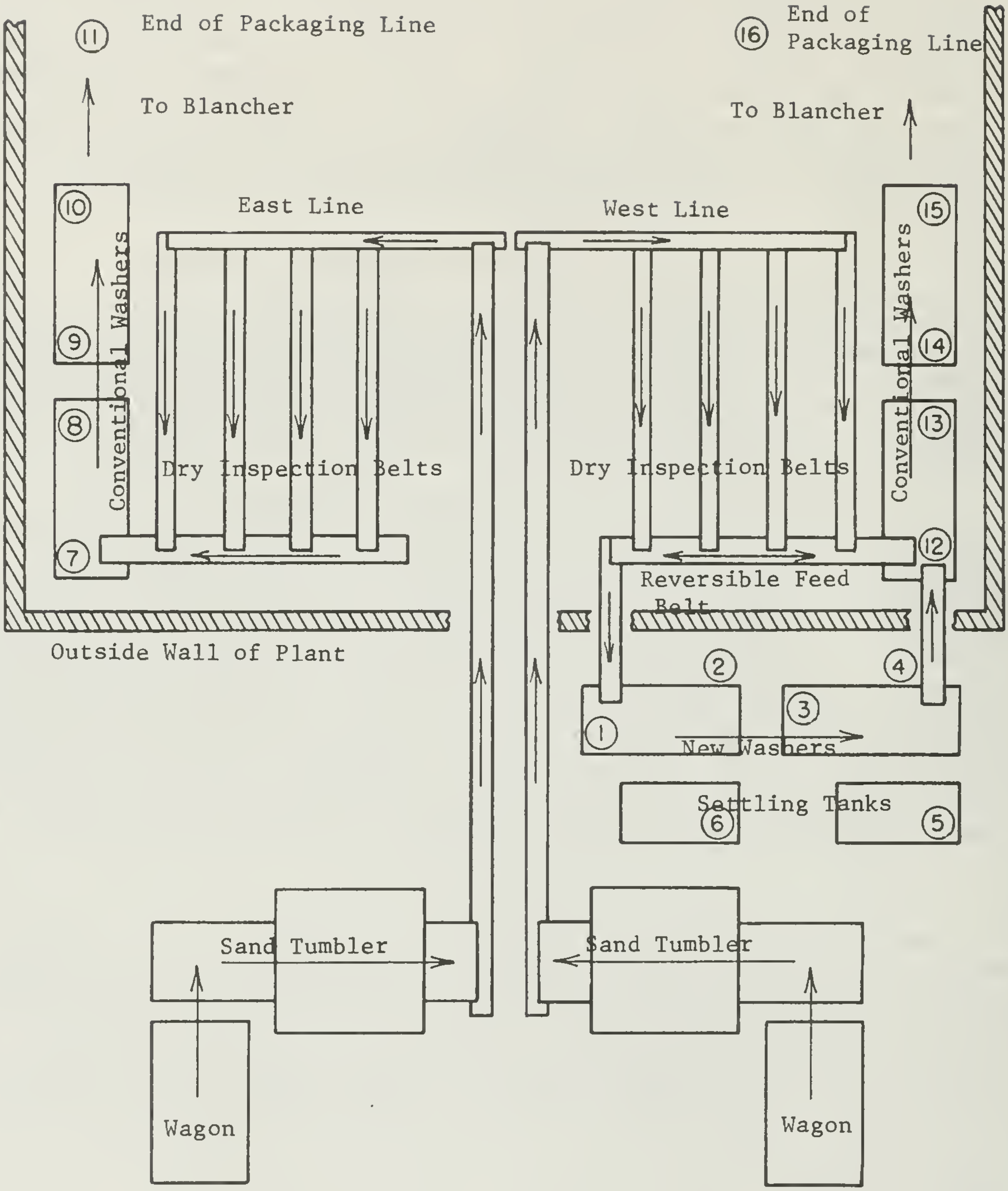


Figure 12: Schematic showing water and product sampling sites for comparative study of new vs. conventional leafy greens washing systems at Exmore Foods, Exmore, Va. Circled numbers refer to water and/or product sampling sites.

TABLE 1. SUMMARY OF INFORMATION FOR TRIALS OF PROTOTYPE WASHER SYSTEM DURING THE FALL SEASON OF 1975

Trial	Date	Product	Total Operating Time (hrs)	Total Fresh Weight of Product Washed (kg)*
1	10/24/75	Collards	3.80	4418**
2	11/4/75	Collards	5.78	9975
3	11/20/75	Collards	6.68	8866
4	12/1/75	Collards	6.68	7945
5	12/15/75	Spinach	4.05	3989

* Fresh weight through washer system obtained from weight of product packaged adjusted by determinations of relative moisture contents of incoming and packaged product. These figures approximate raw product entering first washer.

** Product samples for moisture content analysis were damaged in transport to laboratory. Estimate was made from data from other collard trials.

TABLE 2. SUMMARY OF INFORMATION FOR TRIALS OF PROTOTYPE AND CONVENTIONAL WASHING SYSTEM DURING THE SPRING SEASON OF 1976

Trial	Date	Product	Total Operating Time (hrs)		Total Fresh Weight* of Product Washed (kg)	
			Prototype	Conventional	Prototype	Conventional
1	4/22/76	Spinach	6.83	3.91 (E)	8764	4397
2	5/12/76	Spinach	-	7.83 (E)	-	12132
3	5/21/76	Spinach	-	3.17 (W)	-	5136
4	6/4/76	Turnip Greens	5.50	4.00 (W)	7999	5525
5	6/10/76	Turnip Greens	6.17	4.00 (W)	6781	5933
6	6/11/76	Turnip Greens	5.92	4.08 (W)	7974	4658

- No processing with prototype

* Fresh weight through washer systems obtained from weight of product packaged adjusted by determinations of relative moisture contents of incoming and packaged product. These figures approximate weight of raw product entering first washer.

(E) = East conventional washing line (see Figure 12).

(W) = West conventional washing line (see Figure 12).

during the spring. The amounts of product quoted here (and in the last columns of Tables 1 and 2) are fresh (i.e. raw) weights as delivered into the first washer from the dry inspection belts. Each trial consisted of a complete or partial eight or nine hour shift. Down time and breaks were substracted from total time.

The company packaged five different varieties of leafy greens during the fall season, the largest volume of which was collards. Consequently, travel schedules of the investigators coincided with collard processing four out of five trials. The leaves of this variety tended to be large, very mature, relatively clean, and easy to wash. Spinach was processed during the fifth trial. It was not as clean as the collards, and the leaves tended to be small and immature.

Initial plans for the spring season included dual trials with the prototype on the west line running simultaneously with the conventional east line. Unfortunately, there were only a few days early in the season when both lines were processing the same product, and travel to the plant could not be arranged at those times. As a best alternative, the prototype system was tested during the day shift (8:00 a.m. to 5:00 p.m.), and data were taken on one of the conventional lines the same night for the first half of the night shift (6:30 p.m. to 11:00 p.m.). Clean-up and sample preparation were usually complete by 12:30 a.m. Material processed during a given day usually came from the same field, so comparisons between the prototype and conventional lines could be made. Taking data on the conventional washers for complete shifts was not necessary because the water was not recirculated and, thence, effluent characteristics and product quality parameters were not time dependent. Four trials were made in this manner.

Data were taken on conventional lines alone during trials 2 and 3. The west line, where the prototype was located, was not operated on the day of trial 2. Plant operations were precipitously curtailed on the day of trial 3 by a deterioration in the quality of locally grown product. Only one large truck load of spinach, purchased in a neighboring state, was processed. Consequently, a decision was made to take data on the conventional washers of the west line because data for spinach washing with the prototype were already available. Quality of the spinach processed in the spring varied considerablly--from prime (trial 3) to overly mature (trials 1 and 2) and from very clean (trial 3) to very dirty because of sprinkler irrigation in the field (trial 2). The variation in quality of turnip greens, although great, was much less than spinach. Those in trial 4 were average in quality and cleanliness, in trial 5 overly mature and clean, and in trial 6 good quality and dirty.

SPECIFIC PROCEDURES

The following sections outline, in order, (1) water and product sampling sites, (2) typical procedures that were followed for a trial during the fall season, (3) modifications of those procedures for the spring trials and (4) analytical procedures.

Sampling Sites

Water and product sampling sites were selected so that the effect of each major component of the system could be evaluated for each parameter measured. Product samples were taken on the feed conveyor to the first washer, the exit conveyor for the first washer and the exit conveyor for the second washer in each case (product sampling sites 1, 2, 3, Figure 1 for the prototype; sites 7, 8, 10, for the east conventional line and 12, 13, 15 for the west conventional line, Figure 12). Packaged product samples were taken at the end of the respective line in each trial (sites 11, 16, Figure 12).

Water sampling sites for the prototype are depicted in Figure 1. Sites 1 and 3 were the spray nozzles at the head end of washers 1 and 2, respectively, sites 2 and 4 the sump boxes that collected the total flow from each washer, and sites 5 and 6 the input ends of the settling tanks. Hence, for example, difference in samples between sites 1 and 2 measured the effect of washer 1, between sites 2 and 6 the effect of the sump pump and filter belt, and between sites 6 and 1 the effect of the settling tank. Similarly, water samples from the conventional line were taken at entrance end of each washer and from the overflow at the exit end of each washer. (Sites 7, 8, 9, 10, 12, 13, 14, 15, Figure 12).

Typical Day - Fall Trials

The sequence of events for each trial, of course, varied. The following outlines a typical work day during the trials.

Time	Event
1) Night prior to trial	a) Laboratory set up on location.
	b) Water quality instruments and flow meters calibrated.
	c) BOD dilution water prepared and aerated.
	d) Prototype washers and settling tanks rinsed and filled.
2) Morning of trial, before processing	a) Washer and instruments turned on.
	b) Flow rates set on meters 1, 2, and 3. (See Figure 1).
	c) Recorders started on meters 4 and 5.
	d) Sodium sulfite prepared to neutralize chlorine in BOD and bacteriological samples.

Time	Event
3) Beginning of trial	a) Start-up time recorded.
4) After 15 minutes operation	a) Grab samples of product taken for moisture content, bacterial counts and insect counts.
	b) Grab samples of water taken for biochemical oxygen demand (BOD), chemical oxygen demand (COD), color, turbidity, chlorine residual, total suspended solids (TSS), volatile suspended solids (VSS), conductivity and pH.
	c) Grab samples of water collected in sterile bottles for total plate counts and coliform counts (repeated at middle and end of trial).
5) After each hour of operating time (exclusive of breaks and downtime).	a) Same as 4, a and b.
	b) Number of packages of product processed recorded.
	c) Flow meters 1, 2 and 3 checked with stop watch.
6) Between samplings	a) Chlorine residual determined.
	b) BOD's set up and placed in a low temperature, Precision Model 815 incubator.
	c) Conductivity, color, turbidity, and pH determined.
	d) Samples for TSS and VSS filtered, crucibles and filters prepared for shipment to Virginia Polytechnic Institute and State University laboratory in Blacksburg, Virginia.
	e) Remaining water preserved with acid for return to Blacksburg for COD determination.
	f) Water samples for bacteriological analysis plated and incubated at 35°C.
	g) Product samples weighed and frozen in plastic bags.

Time		Event
7) After trial	a)	Trash collected and weighed.
	b)	Tanks drained.
	c)	Grit collected.
8) Day after trial	a)	Product samples packed in ice.
	b)	BOD bottles placed in cartons to maintain approximate temperature of 20°C during transport.
	c)	Bateriological samples with sufficient growth were counted. Others were packed for transport.
	d)	Samples and equipment transported to Blacksburg.
9) Week following trial (in V.P.I. & S.U. laboratory)	a)	Moisture contents, grit particle sizes, COD's, TSS, VSS, BOD_5's, BOD_{20}'s, insect counts and bacterial counts determined.
	b)	Preparations made for next trial.

Variations Between Spring and Fall Trials

Procedures for the spring trials were essentially the same as those for the fall with the following exceptions:

(1) Product samples were taken for grit analysis in addition to samples taken for moisture content, bacterial counts, and insect counts. Samples for grit analysis were taken at two-hour intervals of operating time rather than every hour. Product samples for grit analyses were hand washed and the wash water filtered between sampling periods for later determination of suspended solids.

(2) Water samples were taken for analyses of COD, TSS, VSS, chlorine residual, pH, and pesticides both spring and fall, but BOD, color, turbidity, and conductivity were not measured in the spring trials. Samples for pesticide analysis were taken twice during each trial, mid-way and end, at the outlet of the first washer of the prototype only (site 2, Figure 1). During the fall trials water samples were taken at the input end of each settling tank (sites 5 and 6, Figure 1) by dipping the container into the surface of the water. Some rapidly settling solids may have been lost by this technique. In the spring trials these samples were taken by holding the container directly under the moving screen belt to catch the water before it entered the settling tank.

(3) Water and product sampling for the conventional washers were essentially the same as those for the prototype except for sampling associated with the settling tanks. An attempt was made to get a quantitative analysis of grit accumulated in the conventional washers, but this could not be accomplished without interfering with company personnel in their clean-up procedures. One set of soil samples, however, was obtained for particle size analysis.

Analytical Procedures

Following is a brief summary of the procedures used in analyzing samples for each type of data taken during the investigation.

Water Flow Rates --

Totalizing water meters on the prototype were read at the beginning of each trial and hourly thereafter to obtain flow rates as a function of time. Depth of water flow through the HS flumes was continuously recorded on strip chart recorders. Flow rates, as they varied with time, were later calculated using these recordings and the calibration curve of flow vs. depth that had been developed for the flumes (17).

Product Flow Rates - -

Product samples for moisture content determination were taken from input conveyors, weighed, sealed in plastic bags and frozen for transport. Sample packages of product from the end of the processing line were taken simultaneously and frozen for transport. At the lab, these samples were dried at 105°C for 24 hours in a forced convective oven, and moisture contents were calculated on a wet basis. The relative moisture contents of input and output product and the package counts of output product were then used to calculate the rate of fresh product input to the washers. This was a better measure of input product than total field weight because considerable material was lost from the dry tumbler and the dry inspection belts ahead of the washers and very little was removed by subsequent inspections between the blanchers and packaging.

Grit Accumulation - -

The washers and settling tanks of the prototype were drained after each trial and the volume of grit on the bottom of each tank was measured. Some grit was inevitably lost while the tanks were draining. An attempt to recover this loss was made by filtering the water as it flowed from the tank. These filters were effective in trapping the larger sand particles, but allowed some of the smaller silt and clay particles (those particles with a diameter of less than 50 microns) to be lost. Grit loss in the washer tanks was minimized by draining the tank through the port farthest from the incoming product, where the grit accumulation was lowest. At the end of trial 5 in the fall, a submersible sump pump was used to empty the two settling tanks. This technique was used to empty the washers and settling tanks in the spring trials.

After the volume of grit had been determined, samples were taken from each of the three bottom sections of the washers and from the settling tanks. At the laboratory, they were dried in a forced convective oven at 105°C for 24 hours. A soil particle size analysis was then performed using standard hydrometer methods (5) for particles in the range below 50 microns and standard sieve analysis (3) for larger particles.

Trash Accumulation - -

The trash collectors for the prototype were emptied at the end of each trial and their contents weighed. Samples from each moving-belt screen were taken, weighed, and frozen for transport to the laboratory. There, they were dried by the same procedure as used for the product, and moisture contents were calculated. These figures were compared with those for the incoming product to determine the weight of trash collected when corrected to the moisture content of the incoming product.

Water Sample Analyses - -

Following is a summary of methods used in analyzing water samples taken during the trials.

Chlorine residual -- The total chlorine residual was determined amperometrically as described in Standard Methods for the Examination of Water and Waste Water (Sec. 114B) (19) with a Fischer-Porter amperometric titrator.

pH -- The pH was determined as described in Standard Methods (Sec. 144A) (19) with a Corning Model F pH Meter in the fall, with a Fisher Accumet Model 230 in the spring.

BOD_5 -- The BOD_5 was determined as described in Standard Methods (Sec. 219) (19). Sodium sulfite was added stoichiometrically to neutralize the chlorine residual, which, if not treated, could kill the microorganisms present in the sample. Experiments were conducted to determine the difference between BOD_5 of a seeded and unseeded sample. No difference was detected, so the samples were not seeded.

Color -- True color was determined by filtering a portion of water sample through a Reeve Angel glass-fiber filter and determining the optical density on a Klett-Summerson Photometer, using a #42 (blue) filter.

Turbidity -- Turbidity was determined by measuring the optical density of a small portion of water sample with a Klett-Summerson Photometer, using a #42 (blue) filter.

Solids -- Total suspended and volatile suspended solids were determined according to Standard Methods (Sec. 148B and 244D, respectively) (19).

COD -- Water samples for COD were acid-fixed (ph $\sim$ 2.0) for preservation until analyzed. Determinations were made in the laboratory as described in Standard Methods (Sec. 220) (19).

Bacterial counts -- The total plate count was determined according to Standard Methods (Sec. 660) (19) except during trials 3, 4 and 5 during the fall and trials 1, 2 and 3 during the spring when the streak-plate technique was used instead of the pour-plate technique.

In addition to total plate counts, a non-specific coliform count was made in the fall trials using desoxycholase agar, a selective medium for coliforms. The pour-plate technique was used during trials 1 and 2 and the streak-plate technique was used during trials 3, 4 and 5. All colonies growing on the media were counted.

Pesticide Analyses -- Pesticide analyses were made on water samples taken from the first washer in the prototype during the spring trials. The samples were examined only for organophosphorus pesticides, as they were the only ones applied to the crops during the growing season. Phosdrin was the principal one in use at the time of the study. Methods of analyses were EPA-approved (Federal Register 38, No. 85, Part II, Nov. 28, 1973), gas chromatrographic analyses of solvent extracts of the samples. These were conducted in the Department of Biochemistry Pesticide Analysis laboratory.

Product Sample Analyses --

Following is a summary of methods used in analyzing product samples during the trials.

Bacterial counts -- The method used for determining the total plate count of the product was that used by technicians at Exmore Foods. Eleven grams of product were placed in a bottle containing ninety milliliters of sterile dilution water. From this bottle, a series of dilutions was made and plated out on Total Plate Count agar. The test proceeded as described in Standard Methods (Sec. 660) (19). Coliforms were determined on several occasions (but not routinely) by plating aliquots of the water on desoxycholate agar.

Insect counts -- Insect counts on product samples were made using the gasoline extraction method described by Townsend et al. (20).

Grit on product -- A simple hand washing test was devised to determine the amount of grit on the product at each product sampling site. Duplicate, 1000-gram samples of product from each site were agitated 1-2 minutes by hand in containers with 15 liters of water. Product was separated from the water with a large-mesh screen and an aliquot of 500 ml. from each water sample was filtered for solids determination.

SECTION 6

RESULTS AND DISCUSSION

OPERATING PARAMETERS

The following is concerned with those quantities measured during the trials that could be considered operating parameters, i.e., those things that were either under the control of or required action by personnel operating the systems. They include water and product flow rates for both the prototype and conventional systems, and grit and trash accumulations in the prototype system.

Water Flow Rates

Tables 3 and 4 summarize the water flow rates used in the prototype during the fall and spring trials, respectively. Figures 13 and 14 are examples of the water flows in the prototype for the fall and spring trials. Meters 1 and 2 in each graph represent the recirculation rates for washers 1 and 2, respectively. Meter 3 is the input of fresh water to the system; meter 4, the flow from settling tank 2 to settling tank 1; and meter 5, the overflow to waste from settling tank 1 (refer to Figure 1). All tables and graphs relate only to water flows during actual processing time. Meters 1, 2, and 3 were totalizing meters and the graphs were plotted from readings taken at timed intervals. Meters 4 and 5 were open channel HS flumes with water level strip chart recorders. Data for the graphs was taken from the strip charts at 15 minute intervals. Graphs for the spring trials were plotted by hand (Figures 13, A-1 through A-4). Graphs for the spring trials were taken from computer plots (Figures 14, A-5 through A-12).

Recirculation rates in the washers varied somewhat but were generally maintained near 404 ℓ/min (107 gal/min). A recirculation rate of 530 ℓ/min (140 gal/min) in washer 1 was tried for a few hours in one trial (trial 5, fall, Figure A-4), but it was discovered that the control system on the sump pump did not react fast enough to handle this flow.

Fresh water to the system was introduced into the second settling tank during the fall trials (meter 3, Figure 1). No attempt was purposely made to vary this flow, maintained as near the average of 66.8 ℓ/min (17.7 gal/min) as fluctuations in the plant water pressure would permit. Fresh water was introduced as a final rinse spray on the produce discharge belt of washer 2 during the spring trials. In trials 4, 5, and 6 (Figures A-5, A-6, A-7) this rate was increased with each trial [52.9, 71.3, 94.8 ℓ/min (respectively, 14.0, 18.8, 25.0 gal/min)]. During the fall trials, the input water was turned off during periods of down time. This technique was tried

TABLE 3. AVERAGE WATER USE DATA FOR PROTOTYPE LEAFY VEGETABLE WASHING SYSTEM DURING FALL TRIALS, 1975

Trial No.	Date	Product	Recirculation, Washer 1 (ℓ/min)	Recirculation, Washer 2 (ℓ/min)	Input to System (ℓ/min)	Output from System (ℓ/min)	Input Water/Product* (ℓ/kg)	Water Carried Out On Product* (ℓ/kg)
1	10/24/75	Collards	398.6	333.5	64.2	38.2	3.31	1.34
2	11/4/75	Collards	437.1	392.2	74.6	20.0	2.59	1.90
3	11/20/75	Collards	366.9	377.5	61.7	18.9	2.79	1.94
4	12/1/75	Collards	362.8	368.7	65.1	25.8	3.28	1.98
5	12/15/75	Spinach	483.1	479.2	68.6	25.5	4.18	2.63
Averages			410 (108 gal/min)	390 (103 gal/min)	66.8 (17.7 gal/min)	25.7 (6.8 gal/min)	3.23 (0.39 gal/lb)	1.96 (0.24 gal/lb)

*Fresh (raw) product entering first washer from dry insepction belts (Figure 12).

TABLE 4. AVERAGE WATER USE DATA FOR PROTOTYPE LEAFY VEGETABLE WASHING SYSTEM DURING SPRING TRIALS, 1976

Trial No.	Date	Product	Recirculation, Washer 1 (ℓ/min)	Recirculation, Washer 2 (ℓ/min)	Input to System (ℓ/min)	Output from System (ℓ/min)	Input Water/ Product* (ℓ/kg)	Water Carried Out On Product* (ℓ/kg)
1.	4/22/76	Spinach	376.8	448.3	92.0	29.5	4.30	2.92
4.	6/4/76	Turnip Greens	405.4	453.8	52.9	3.9	2.18	2.02
5.	6/10/76	Turnip Greens	360.7	377.1	71.3	24.1	3.99	2.64
6.	6/11/76	Turnip Greens	443.1	397.7	94.8	37.7	4.22	2.54
Averages			397 (105 gal/ min)	419 (111 gal/ min)	77.8 (20.5 gal/ min)	23.8 (6.3 gal/ min)	3.68 (0.44 gal/ lb)	2.53 (0.30 gal/ lb)

*Fresh (raw) product entering first washer from dry inspection belts (Figure 12).

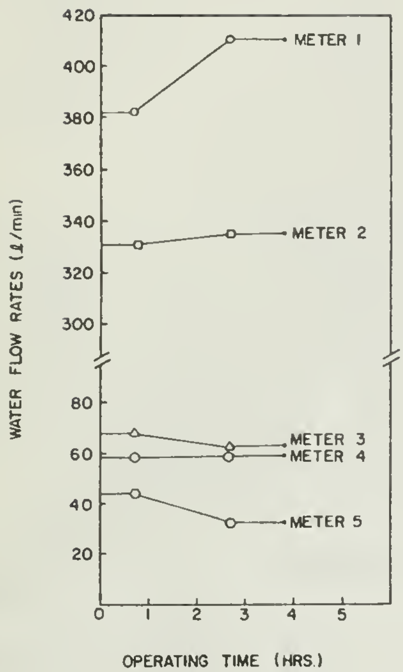


Figure 13: Water flow rates vs. operating time, trial 1, Fall, 1975, when processing collards with prototype system. Refer to Figure 1 for meter locations.

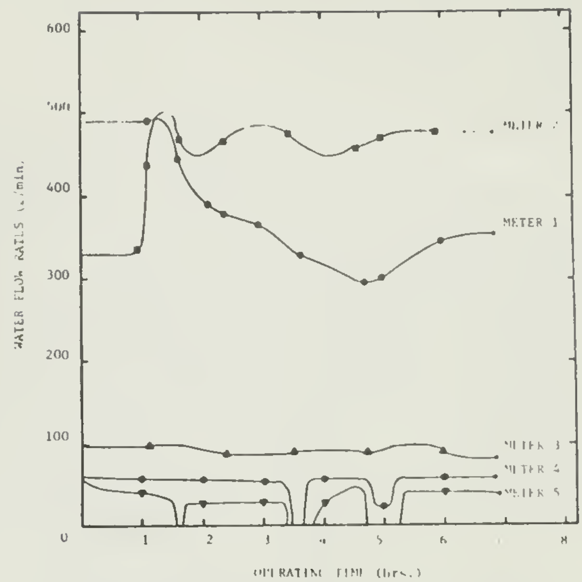


Figure 14: Water flow rates vs. operating time, trial 1, Spring, 1976, when processing spinanch with prototype system. Refer to Figure 1 for meter locations.

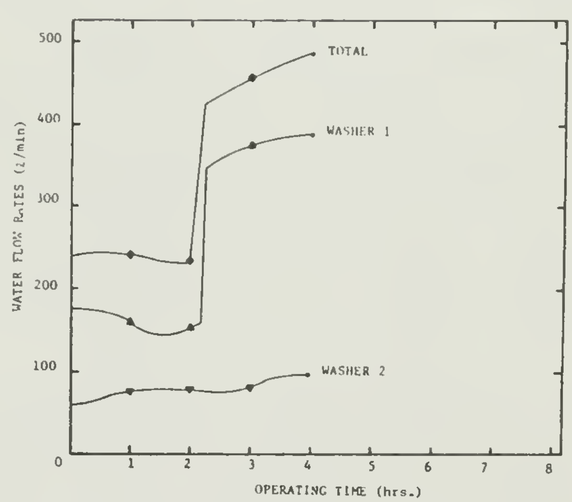


Figure 15. Water overflow rates from conventional washers vs. operating time, trial 1, spring, 1976, when processing spinach on the east line.

during trial 1 of the spring trials, but the amount of water carried off by the product was such that there were periods of time after breaks when the overflow to waste and the overflow between settling tanks was reduced to zero (Figure 14). In trial 4 (Figure A-5) the input was left partially open during breaks. Again, however, there were periods of no overflow to waste. This was due to water carried off by the product plus the low rate of fresh water input (52.9 ℓ/min). On subsequent trials the fresh water was left on during breaks which ultimately had the effect of reducing the concentration of the waste components used as measures of water quality.

Differences between the flow rates at meters 3 and 5 represent the water being carried from the system on the product. Differences between meters 4 and 5 represent water carried from washer 1 into washer 2 by the product, and differences between meters 3 and 4 represent additional wetting of the product in washer 2. As expected, the amount of additional wetting of the product in washer 2 was relatively slight in trials 1 and 2 during the fall (Figures 13 and A-1). However, this trend was not observed in the remainder of the fall and spring trials. This additional wetting may have been influenced by a number of factors including the age and variety of product. A particularly interesting phenomenon was the build-up of a soap-like foam on the surface of the water in the settling tanks and washers. It resulted, no doubt, from the surfactant action of organic matter leached from the greens.

Table 5 is a summary of the water flow data for the conventional washers, and Figure 15 is an example graph (trial 1, spring). Graphs of the flows in other trials are included in Figures A-8 through A-12, Appendix A.

The flow rate of water to the conventional washers was left entirely to the judgement of the line foreman during each shift. More or less water was used in each washer based on his judgement and experience. The graphs show considerable variations in flow that did not always appear to be related to initial product quality or product flow rate. One mechanical influence on the east line (trials 1 and 2, Figures 15 and A-8) was the inefficiency of the cooling flume dewaterer, requiring that most of the input water to these washers be fresh. Consequently, water use on this line tended to be minimized, especially in washer 2. Conversely, the dewaterer on the west line (trials 4 through 6, Figures A-9 through A-12) worked well, and all of the input to these washers was recirculated product cooling water, used unstintingly. In most, but not all, cases more water was used in the first conventional washer in a line than in the second. It seems obvious that some means of cooling blanched product other than with large quantities of fresh water would be necessary in order for a company to take maximum advantage of a water-conserving washing system.

Several other observations can be made from the water flow data. 1) Though the number of trials for each product are few, there is an indication that different varieties of greens tend to carry away different amounts of water from a washing process. Average values, in order, are: collards - 1.79 ℓ/kg (0.22 gal/lb), turnip greens - 2.40 ℓ/kg (0.29 gal/lb), and spinach - 2.78 ℓ/kg (0.33 gal/lb). These figures, on a relative basis, are consistent with expectations based on qualitative evaluations of leaf surfaces; i.e., collards have a waxy, smooth surface compared to spinach.

TABLE 5. AVERAGE WATER USE DATA FOR CONVENTIONAL LEAFY VEGETABLE WASHERS DURING SPRING TRIALS, 1976

Trial No.	Date	Product and Line	Input to† Two Washers (ℓ/min)	Output From Two Washers (ℓ/min)	Input Water/ Product+ (ℓ/kg)	Water* Carried Out On Product+ (ℓ/kg)
1	4/22/76	Spinach(E)	380.3	328.3	20.3	2.78
2	5/12/76	Spinach(E)	179.0	107.2	6.9	2.78
3	5/21/76	Spinach(W)	341.5	266.3	12.6	2.78
4	6/4/76	Turnip Greens (W)	461.1	405.9	20.0	2.40
5	6/10/76	Turnip Greens (W)	455.9	396.6	18.4	2.40
6	6/11/76	Turnip Greens (W)	438.6	393.0	23.1	2.40
Averages			376 (99 gal/min)	316 (84 gal/min)	16.9 (2.02 gal/lb)	

* Estimated from average values determined in prototype trials.

† Calculated from output data and estimated values of water carried out on product.

(E) = East conventional line.

(W) = West conventional line.

\+ Fresh (raw) product entering first washer from dry inspection belts (Figure 12).

2) The water input to two conventional washers averaged 5.2 times that of the prototype system, the water output or waste stream 12.7 times that of the prototype. 3) Average fresh water input for the conventional washers was 16.9 ℓ/kg (2.02 gal/lb) vs. 3.43 ℓ/kg (0.41 gal/lb) for the prototype, a ratio of 5:1.

Product Flow Rates

Several different sizes of packages were used at the Exmore plant. Retail packages for collards and turnip greens were 283 g nominal net weight (10 oz) and those for spinach were 340 g (12 oz). In some cases diced turnip roots were included with the greens (8 oz of greens, 2 oz of roots). The weight of roots was accounted for when analyzing the moisture content of samples, and only the greens processed are reported here. These packages were counted with an electronic counter located immediately following the packaging machine. Some product was packed in 6.8 kg (15 lb) trays for institutional packs and some on open trays in lots of 181 kg (400 lb) for bulk freezing and storage. The number of these units was recorded as they were put into the freezer.

Figures 16 and 17 are examples of the instantaneous flow rate and cumulative flow of fresh product into the washers versus operating time. Figures A-13 through A-30 depict flows during other trials. Initially, it was assumed that the flow of material through the system would be rather uniform. Consequently, only the total product processed was recorded during trial 1 in the fall. During this trial it became obvious that input to the system was very erratic. Inputs to the prototype system ranged from 456 to 2251 kg/hr (1105 to 4963 lbs/hr); for the conventional washers 459 to 3330 kg/hr (1012 to 7341 lb/hr). These wide fluctuations in input rates undoubtedly affected the quality of the product. An obvious means of improving washing quality, and perhaps increasing the average processing rate, would be to devise a means of metering the product more evenly into the washers.

Tables 6, 7, and 8 are summaries of the product data. The average rate of fresh product input into the washers for all trials was 1324 kg/hr (2918 lb/hr), and the average rate of output from processing was 1808 kg/hr (3985 lb/hr), for an output/input ratio of 1.37. A limited number of tests during the fall trails indicated that very little water was absorbed in the washing process. It is assumed, therefore, that most of the water absorption took place during blanching. The average input/output ratios for the three varieties tested were: spinach - 1.54, collards - 1.34, and turnip greens - 1.25, indicating the relative abilities of each vegetable to absorb moisture during processing. The range of absorption within each variety, however, was considerable indicating that other factors--such as initial leaf condition (turgid or wilted), age, size, etc.--would have effects. Particularly noteworthy is the fact that variation in moisture content of the fresh product (8.8%) was much greater than that of the packaged product (3.2%). Plant records indicate that overall ratios for packaged product to product delivered from the field are approximately 0.75 for turnip greens, 0.90 for collards and 0.95 for spinach. These ratios include wastage such as the losses on the dry inspection belts and the gains due to water absorption. They vary considerably both within seasons and from year to year.

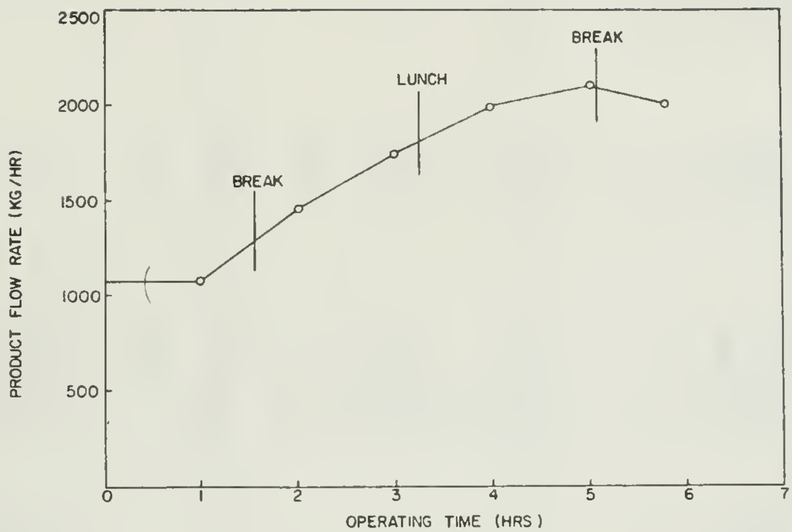


Figure 16: Product flow rate vs. operating time, trial 2, Fall, 1975, when processing collards with the prototype system. Fresh product into first washer.

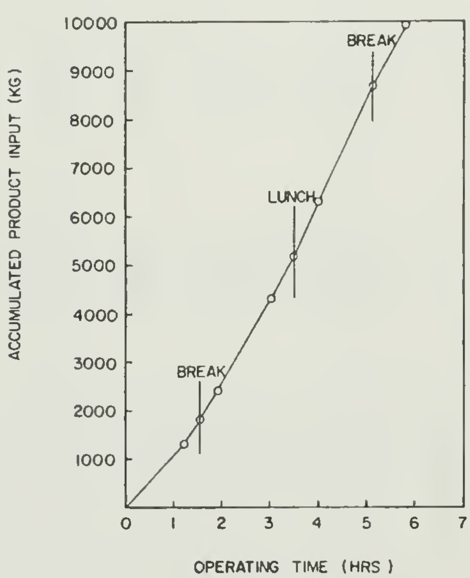


Figure 17: Accumulated product input vs. operating time, Trial 2, Fall, 1975, when processing collards with the prototype system. Fresh product into first washer.

TABLE 6. PRODUCT DATA FOR PROTOTYPE LEAFY VEGETABLE WASHING SYSTEM DURING FALL TRIALS, 1975

Trial No.	Date	Product	Avg. Fresh Product† Input (kg/hr)	Avg. Moisture Content of Fresh Product (% w.b.)*	Avg. Moisture Content of Packaged Product (% w.b.)*	Total Packaged Wt.‡ (kg)	Total Fresh Wt. (kg)	Ratio: Packaged Wt. / Fresh Wt.
1	10/24/75	Collards	1163	88.6**	91.3**	5891	4418	1.33
2	11/4/75	Collards	1726	90.3	91.3**	12315	9975	1.24
3	11/20/75	Collards	1327	88.6	91.2	11514	8866	1.30
4	12/1/75	Collards	1189	87.0	91.4	11858	7945	1.49
5	12/15/75	Spinach	985	85.4	90.3	6137	3989	1.54

* Percent wet basis.

** Estimate from other collard trials; samples lost in transit.

† Fresh (raw) product entering first washer from dry inspection belts, (Figure 12).

‡ Divide packaged weight by 0.90 for collards and 0.95 for spinach to estimate field weight of product delivered to plant.

TABLE 7. PRODUCT DATA FOR PROTOTYPE LEAFY VEGETABLE WASHING SYSTEM DURING SPRING TRIALS, 1976

Trial No.	Date	Product	Avg. Fresh Product† Input (kg/hr)	Avg. Moisture Content of Fresh Product (% w.b.)*	Avg. Moisture Content of Packaged Product (% w.b.)*	Total Packaged Wt.‡ (kg)	Total Fresh Wt. (kg)	Ratio: Packaged Wt./Fresh Wt.
1	4/22/76	Spinach	1283	84.6	90.0	13426**	8764	1.53
4	6/4/76	Turnip Greens	1454	90.3	93.1	11189	8000	1.40
5	6/10/76	Turnip Greens	1099	90.9	91.9**	7596**	6781	1.12
6	6/11/76	Turnip Greens	1348	91.2	92.1**	8916**	7974	1.12

* Percent wet basis.

** Calculated from nominal package weight and number of packages.

† Fresh (raw) product entering first washer from dry inspection belts (Figure 12).

‡ Divide packaged weight by 0.95 for spinach and 0.75 for turnip greens to estimate field weight of product delivered to plant.

TABLE 8. PRODUCT DATA FOR CONVENTIONAL LEAFY VEGETABLE WASHERS DURING SPRING TRIALS, 1976

Trial No.	Date	Product	Avg. Fresh Product Input† (kg/hr)	Avg. Moisture Content of Fresh Product (% w.b.)*	Avg. Moisture Content of Packaged Product (% w.b.)*	Total Packaged Wt.‡ (kg)	Total Fresh Wt. (kg)	Ratio: Packaged Wt. / Fresh Wt.
1	4/22/76	Spinach	1122	82.4	90.1	7802	4397	1.78
2	5/12/76	Spinach	1549	86.1	91.1	18754	12132	1.55
3	5/21/76	Spinach	1622	90.8	93.0	6713	5136	1.31
4	6/4/76	Turnip Greens	1381	89.4	93.2	8438	5525	1.53
5	6/10/76	Turnip Greens	1483	90.8	92.3**	7064**	5933	1.19
6	6/11/76	Turnip Greens	1141	89.7	92.7**	6525**	4658	1.12

* Percent wet basis.

** Calculated from nominal package weight and number of packages.

† Fresh (raw) product entering first washer from dry inspection belts (Figure 12).

‡ Divide packaged weight by 0.95 for spinach and 0.75 for turnip greens to estimate field weight of product delivered to plant.

Grit Accumulation

Removing accumulated grit from the washers is one of the clean-up tasks required at the end of a shift, or sooner if necessary. Mechanical or hydraulic means for continuous removal could have been incorporated into the experimental system at considerable expense. An expedient, but workable, alternative used in the operation of the conventional washers was to open the first drain valve on the first washer for a few seconds as necessary to "flush out" excess grit, because most grit tends to settle out immediately beneath the fresh product input. This technique was not often required, although it did increase the effort needed in clean-up when used.

The amount of grit on incoming product varies greatly depending on the particular type green being processed. Spinach is usually the "dirtiest" because the convolutions in the leaf surfaces tend to trap soil particles and because it grows close to the ground. Collards, on the other hand, have smooth, waxy surfaces and grow erect. Turnips greens are intermediate in these characteristics. Other factors include soil splashing from recent rains or sprinkler irrigation, age of the leaves (older leaves tend to be larger, smoother and cleaner), and the cutting (first cuttings are made closer to the ground than subsequent ones).

Table 9 summarizes the measurements of accumulated grit in the trials of the prototype washer. The collards processed during the fall trials 1 through 4 were very clean, leaving very little grit in the system. During these trials, several techniques were tried to capture or collect the grit as the water flowed out of the drains. In trial 5 (spinach) a measurable amount of grit accumulated in the system, and it was scooped out of each tank after the tank had been drained over the top with a sump pump. This technique was used in the spring trials with the prototype and required approximately an hour's work for each clean-up plus considerable agility on the part of the clean-up crew.

The majority of the grit collection took place in the first washer (38% avg.) and in the first settling tank (43% avg.). Only 4 percent was collected in the second washer and 15 percent in the second settling tank. Although the figures for the maximum amount in each trial vary between washer 1 and settling tank 1, the amount accumulated in washer 2 was always the lowest for all four units. In only one case (trial 6, spring) did settling tank 2 collect more grit than settling tank 1. These figures strongly indicate that the majority of grit removal took place in the first washer sub-system.

The washers each had three drains, located at the apex of the V-shaped bottom sections (Figure 3). Approximately 60 percent of the grit collected in each of the washers settled in the first V-section, 26 percent in the second and 13 percent in the third. Figures 18 and 19 show the summation percentages of the particle size analyses for grit from the various units of the prototype system for trial 5 in the fall. Figures A-31 through A-34, Appendix A, depict these results for the spring trials. These analyses indicate: (1) that most of the larger particles (>100 μ) settle out in the washers, (2) that the settling tanks were removing some particulate matter smaller than the design diameter of 50 μ, and (3) there was little or no

TABLE 9. DRY WEIGHT OF GRIT FROM VARIOUS UNITS OF THE PROTOTYPE LEAFY VEGETABLE WASHER AT END OF EACH TRIAL‡

Trial No.	Date	Product	Washer 1 (kg)	Washer 2 (kg)	Settling Tank 1 (kg)	Settling Tank 2 (kg)	System Total (kg)	Total/ Product† (g/kg)
5*	12/15/75	Spinach	8.5	0.4	38.3	12.7	59.9	15.0
1**	4/22/76	Spinach	16.9	3.9	19.1	6.9	46.8	5.3
4	6/4/76	Turnip Greens	10.4	0.7	4.7	1.3	17.1	2.1
5	6/10/76	Turnip Greens	4.4	0.3	2.4	0.6	7.7	1.1
6	6/11/76	Turnip Greens	17.9	1.3	1.1	2.4	22.7	2.9

* Grit settling in washing system during fall trials 1-4 (collards) was very slight.

** Spring trials.

‡ Does not include grit discharge from system during each trial.

† Fresh (raw) product entering first washer from dry inspection belts (Figure 12).

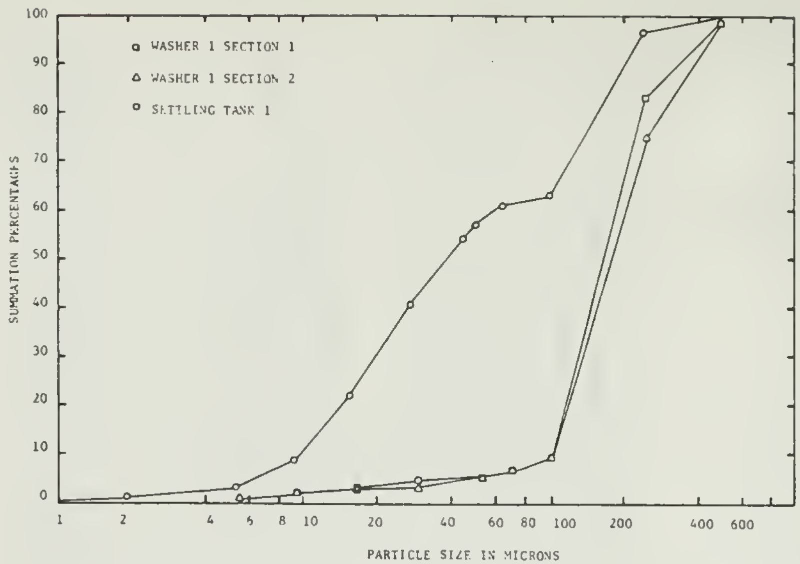


Figure 18. Summation percentages vs. particle size for grit (dry wt.) accumulated in the prototype system sub-unit 1; Trial 5, Fall, 1975, when processing spinach.

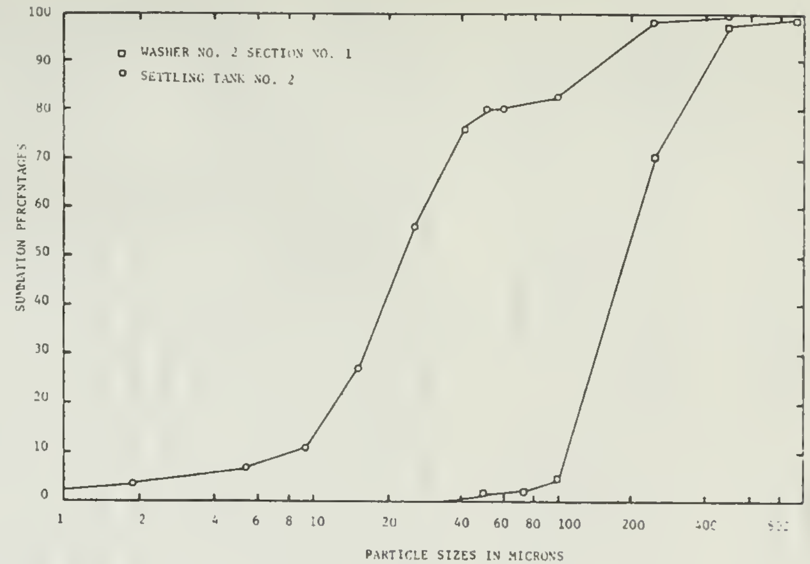


Figure 19: Summation percentages vs. particle size for grit (dry wt.) accumulated in the prototype system sub-unit 2, Trial 5, Fall, 1975, when processing spinach.

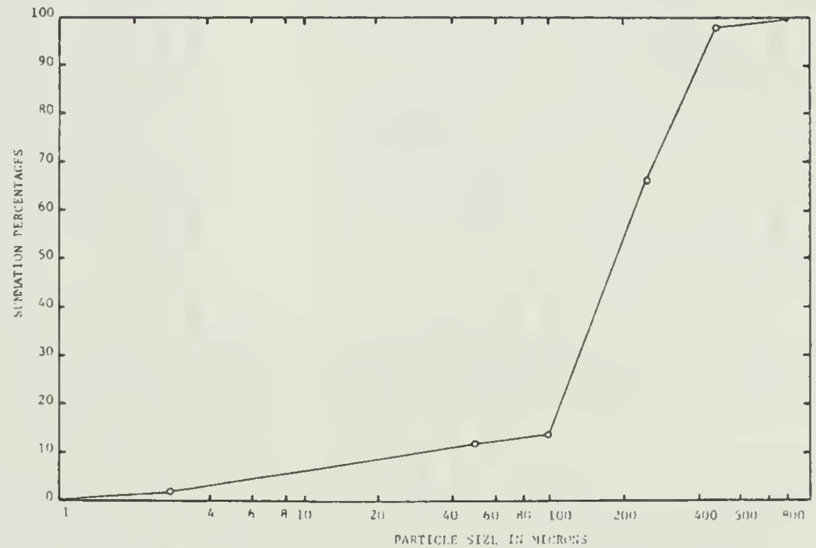


Figure 20: Summation percentages vs. particle size for grit (dry wt.) samples taken from conventional Washer 1, East Line, Trial 2, Spring, 1976 when processing spinach.

variation in the particle size distribution of grit from spinach, collards or turnip greens. These analyses should be useful for designers developing similar equipment for product grown on sandy and sandy-loam soils. For other soils, particle-size analyses would have to be developed.

The effectiveness of grit removal in the settling tanks could probably be improved by using a lower recirculation rate. Necessary hydraulic agitation could be provided by increasing the pressure on the spray nozzles in the washers. The surges in flow to the settling tanks produced by the sump pumps probably reduced effectiveness of the tanks. This problem could be eliminated by locating the settling tanks beneath the washers so that they would receive the overflow by gravity.

The amount of time required to remove accumulated grit, and the configuration of the conventional washers made it impossible to measure the grit collected in them during the trials. Only in trial 2 (spring) was the amount of grit on incoming product significantly different from that processed during the prototype runs. Accumulated grit had to be shoveled out of the first conventional washer during the lunch break--approximately 1700 kg. Visual observation of the conventional washers in the other trials indicated that the amount collected was of the same order of magnitude as that collected in the prototype washers. Again, most of this accumulation was in the front section of the first washer. Only limited amounts accumulated in the second washer. Samples for particle size analysis were taken during trial 2 (Figure 20). Because the accumulated soil had reached a level within a few inches of the water level in the washer where smaller particles could be deposited it is assumed that these results are representative of the total soil brought in on the product. If true then, 86 percent of the grit to be removed from the product was in the size range above 100 microns.

Trash Accumulation

Two operational characteristics can be derived from the trash collection data for the prototype system. They are: (1) the amount of waste product that would have to be disposed of and (2) the amount expected to be lost during washing. Table 10 summarizes these data and indicates that neither of the above would be a major concern. The data for equivalent weight of fresh product lost to trash was determined by adjusting the wet weight of the trash to the average moisture content of the incoming product during each trial.

The trash generated by the prototype consisted primarily of leaf particles. This type of material from the conventional washer flowed directly into the waste stream and had to be removed by vibrating screens before the plant effluent was released to treatment facilities.

PRODUCT QUALITY PARAMETERS

The product quality parameters measured were insect counts, bacterial contamination and grit on the leaves. Of these, only insect and bacterial

TABLE 10. ACCUMULATION OF FLOATING TRASH FROM SETTLING TANK MOVING BELT SCREENS FOR PROTOTYPE SYSTEM DURING FALL AND SPRING TRIALS

Trial No.	Date	Product	Moving Belt Screen	Total Wet Wt. (kg)	Wet Trash/ Product† (g/kg)	Equivalent Wt. of Fresh Product (kg)	Equivalent Product (g/kg)
2	11/4/75	Collards	1	14.1	0.2	*	*
			2	14.1			
3	11/20/75	Collards	1	18.5	4.8	11.9	3.1
			2	24.2		15.2	
4	12/1/75	Collards	1	14.2**	3.6	8.0	2.0
			2	14.0**		7.9	
5	12/15/75	Spinach	1	25.4	14.2	16.8	8.3
			2	31.3		16.4	
1	4/22/76	Spinach	1	29.9	8.3	24.7	6.2
			2	43.1		30.0	
4	6/4/76	Turnip Greens	1	5.1	2.3	4.9	2.1
			2	13.6		11.6	
5	6/10/76	Turnip Greens	1	3.4	2.1	4.3	2.0
			2	10.9		9.1	
6	6/11/76	Turnip Greens	1	10.9	3.7	11.3	3.1
			2	18.6		13.4	

* Moisture content samples damaged in transit.

** Trash collectors damaged by windstorm after 1.76 hours operation in a.m. Reinstalled in p.m. Trash collection for intervening time (1.70 hours) estimated from collection during rest of day.

† Fresh (raw) product entering first washer from dry inspection belts (Figure 12).

counts were made during the fall trials. The hand washing test for grit analysis was not devised until the start of the spring trials.

Insect Counts

Insect infestation of product was extremely low during the fall trials and not very severe during the spring trials. Though fortunate for Exmore Foods, this situation did not allow for a very rigorous test of the prototype for removing insects. Insect counts for trial 5 (fall) and trials 1-6 (spring) are included in Tables B-1 through B-7 in Appendix B. A total of only 10 insects were found on all the product samples taken during trials 1 through 4 in the fall with no more than 2 in any one sample.

Significant insect populations on the product appeared only during trial 2 (spring) when the prototype was not in operation. In this trial the two conventional washers removed 63% of the insects (aphids) from the spinach, and for all trials averaged 62%. Whether or not this could be considered representative is not known.

Several bits of evidence indicate that the prototype was effective in removing insects. First, the data show that it was consistent in lowering insect counts as the product was washed. Second, there was no evidence of build-up of insects or insect fragments on the product as time proceeded. This is significant in view of the fact that the wash water was being recirculated. Finally, counts on the trash collected from the washers during the fall averaged 124 whole insects and 81 fragments per 100 grams even though incoming product averaged only 4 whole and 1 fragment per 100 grams of sample taken. Over all trials the prototype removed 70% of all insects.

Grit on Product

Figures 21 through 24 depict some of the results of the hand washing tests of product samples for grit analysis in the spring trials. Complete data are included in Tables B-8 through B-13, Appendix B. The amount of grit on entering product varied greatly. The amount on product leaving the first washer varied less than initial readings and that leaving the second washer even less. In all four trials where both the prototype and conventional systems were operated the prototype removed a greater percentage of the grit - averages of 73 percent and 69 percent respectively.

Spinach harbored more grit than turnip greens. In trial 1 the prototype removed 80% of the grit and the conventional washers 73%. The conventional washers averaged 70% removal in trials 1, 2 and 3 (spinach). The maximum amount of grit observed on incoming spinach was 22,000 mg per 1000g product, 10 times greater than the maximum observation for turnip greens, 2070 mg per 1000g of product. In trials 4, 5, and 6 (turnip greens) the prototype averaged 64 percent removal and the conventional washers 59 percent. Removal percentages for turnip greens appeared to be lower in general than those for spinach. This probably relates more to the amount of grit on product than any other factor in these trials. Given several varieties of greens of "equal dirtiness" spinach would undoubtedly be the most difficult to clean.

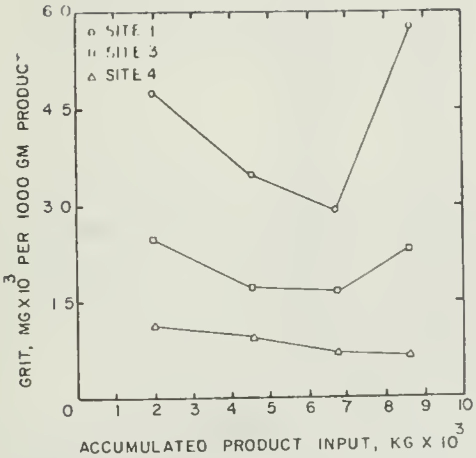


Figure 21: Grit (inorganic solids) on spinach vs. accumulated product at three sites in prototype system, Trial 1, Spring; unwashed product (Site 1), product exiting first washer (Site 3), product exiting second washer (Site 4).

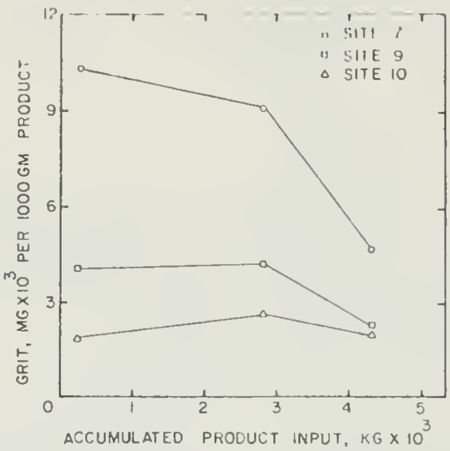


Figure 22 Grit (inorganic solids) on spinach vs. accumulated product at three sites in conventional system, Trial 1, Spring; unwashed product (Site 7), product exiting first washer (Site 8), product exiting second washer (Site 10).

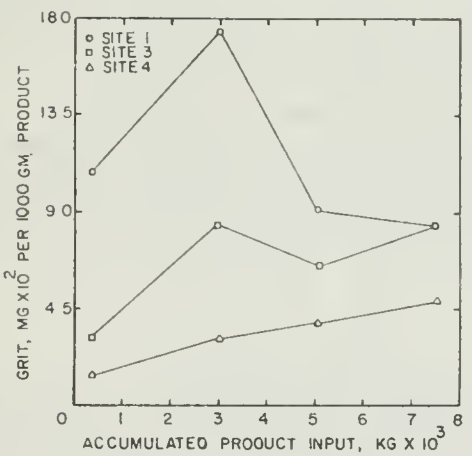


Figure 23: Grit (inorganic solids) on turnip greens vs. accumulated product at three sites in prototype system, Trial 6, Spring; unwashed product (Site 1), product exiting first washer (Site 3), product exiting second washer (Site 4).

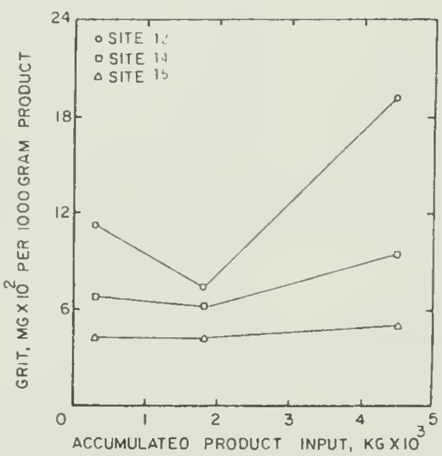


Figure 24: Grit (inorganic solids) on turnip greens vs. accumulated product at three sites in conventional system, Trial 6, Spring; unwashed product (Site 12), product exiting first washer (Site 14), product exiting second washer (Site 15).

The greater percentage removal of grit by the prototype over the conventional system may be attributed to the increased hydraulic agitation and the final fresh water rinse. However there was a decrease in the percent of grit removal with time in three of four trials, probably due to the use of recirculated water. Grit removal in the conventional washers varied randomly with time.

Bacteria Counts

Bacterial counts for both product and water samples are not as complete as originally planned for a variety of reasons -- including considerable variation in the amount of bacteria on input product, problems in transporting samples under controlled conditions and, in general, the rather primitive laboratory facilities on site. The data, however, are sufficient for certain inferences.

Bacteria counts on product samples are included in Tables B-14 through B-23, Appendix B. Table 11 is a summary of the principal effects on product and water bacteria. Over all trials, the prototype and the conventional systems each reduced the bacterial counts on product 74 percent of the time. Of special significance, however, are the prototype trials in the spring -- 1, 4, 5, 6. Unfortunately, a spreader-type organism present in the water overgrew the plates in trial 4, obscuring the colonies. In the other three trials, however, there was a very consistent and obvious lowering of bacterial counts (100% of the time) as the product passed through the system. Undoubtedly the addition of fresh chlorinated water as a final rinse on the product in these trials had an influence here.

Factors other than chlorine in the wash water appear to be operating in the reduction of bacteria on product. It may be that something from the product itself, which accumulates in the water, has a bacteriacidal action. Again, the results of the spring trials with the prototype showed a consistent reduction in counts in the first washer which received no fresh water (Figures 25 and 26). Counts for the conventional washers did not exhibit this consistency (Figures 27 and 28). Two other observations can be made from the data on bacteria counts. 1) There does not seem to be a clear relationship, if any at all, between counts in the wash water (data presented below) and on the product. 2) Though not obvious, it appears that higher initial bacteria counts may be expected on spinach than on collards or turnip greens. There are many uncontrolled influences here, however.

WATER QUALITY PARAMETERS

A total of 10 different water quality parameters were measured during the trials. In the fall these included bacteria counts (including total coliforms), chlorine residual, BOD_5, BOD_{20}, COD, TSS, VSS, turbidity, color and pH. In the spring bacteria counts, chlorine residual, COD, TSS, VSS and pesticide analyses were made.

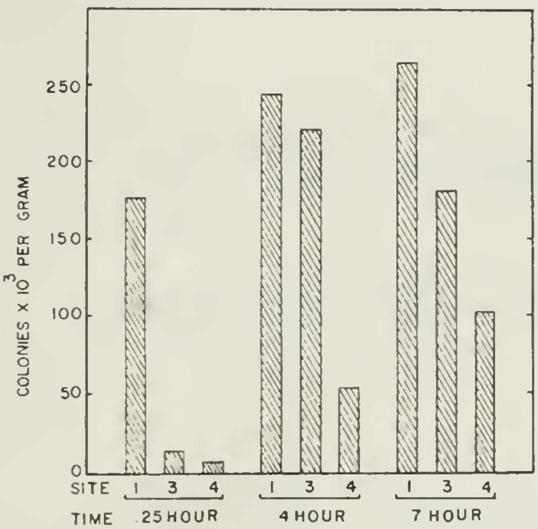


Figure 25: Total bacterial plate counts per gram of spinach at three sampling points, Trial 1, Spring; prototype system. Before washing (Site 1), exiting the first washer (Site 3), exiting the second washer (Site 4).

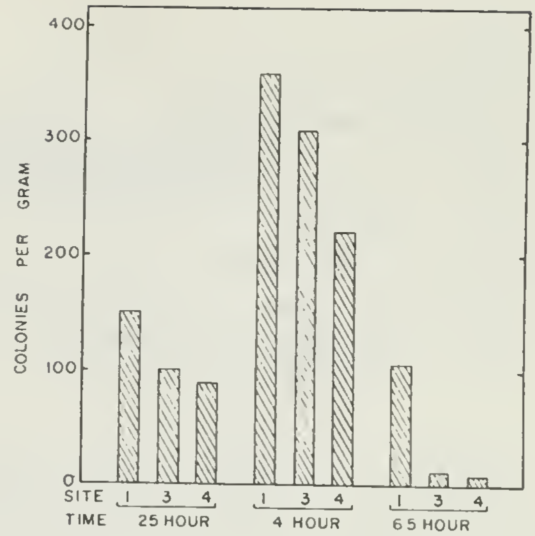


Figure 26: Total bacterial plate counts per gram of turnip greens at three sampling points, Trial 6, Spring; prototype system. Before washing (Site 1), exiting the first washer (Site 3), exiting the second washer (Site 4).

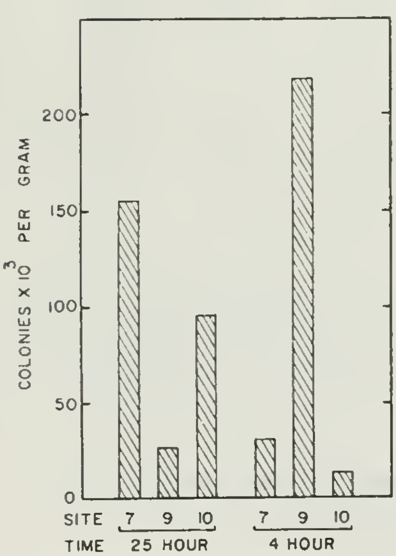


Figure 27: Total bacterial plate counts per gram of spinach at three sampling points, Trial 1, Spring; conventional system. Before washing (Site 7), exiting the first washer (Site 9), exiting the second washer (Site 10).

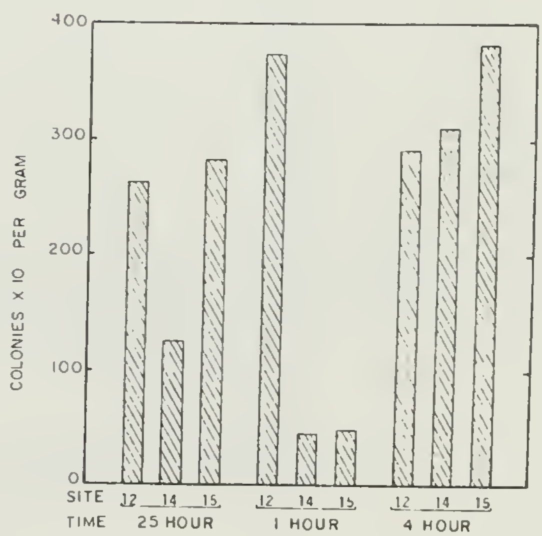


Figure 28: Total bacterial plate counts per gram of turnip greens of three sampling points, Trial 6, Spring; conventional system. Before washing (Site 12), exiting the first washer (Site 14), exiting the second washer (Site 15).

TABLE 11. COMPARISONS OF BACTERIAL POPULATION DENSITIES (TOTAL PLATE COUNTS) FOR PRODUCT LEAVING TO PRODUCT ENTERING A TWO-WASHER SYSTEM AND FOR WATER LEAVING THE SECOND WASHER TO WATER ENTERING THE FIRST DURING GREENS - WASHING TRIALS.

Trial	Product	Water		Product		Total Chlorine, mg/L***		
		A*	B**	A*	B**	Beginning	End	Average
Fall trials, prototype washer								
1	Collards	3/3	0.15	-	-	2.16	0.65	1.10
2	Collards	3/3	0.02	1/4	2.17	2.58	0.0	1.39
3	Collards	3/3	0.23	3/4	0.46	0.4	2.03	1.35
4	Collards	2/2	0.09	6/8	0.64	1.16	2.30	2.06
5	Spinach	2/3	0.98	3/5	0.50	1.30	1.50	1.52
Spring trials, prototype washer								
1	Spinach	3/3	0.11	3/3	0.72	1.30	0.57	0.61
5	Turnip Greens	2/3	0.73	3/3	0.33	1.79	0.68	1.02
6	Turnip Greens	2/2	0.28	3/3	0.07	1.32	0.62	0.91
Spring trials, conventional washers								
1	Spinach	2/3	2.57	2/2	0.59	1.23	1.15	1.07
2	Spinach	-	-	2/3	0.04	0.28	0	0.47
3	Spinach	1/3	1.49	3/3	0.03	0.23	0	0.08
4	Turnip Greens	1/2	1.15	4/5	6.26	0.55	0	0.18
5	Turnip Greens	1/3	1.22	3/5	0.38	1.56	0	0.52
6	Turnip Greens	1/3	0.92	3/5	0.85	0.54	0	0.18

*A = ratio of number of observations during a trial that the bacterial count was lowered (input of first washer to output of second washer) to total number of observations.

**B = ratio of average bacteria counts during trial, output of second washer to input of first.

*** = Residuals measured amperometrically and represent concentrations at the back of the second washer at the beginning and end of each trial, and the average for the entire trial. (3 to 8 observations per trial).

Bacteria Counts and Chlorine Residual

Total plate count data are recorded in tables C-1 through C-10, Appendix C. These counts ranged over 5 orders of magnitude during the fall trials and 4 orders of magnitude in the spring. The relative counts for water where the product entered compared to those where it was discharged in the prototype system exhibited some consistency as shown in the first two columns of Table 11. The bacteria count was lower for the output of the second washer compared to the input of the first washer in 20 of 22 observations. The opposite was true in the conventional washers where the output counts were lower only for 6 of 14 observations. These last results seem to indicate that the last water the product is exposed to does not necessarily have a direct effect on the product bacteria counts which were consistently lowered by the conventional washers.

The response to chlorine was not always consistent either as indicated in Figures 29 and 30. Total chlorine was measured and recorded each time a water sample was taken. Chlorine input to the fresh water in the plant was manually regulated and varied considerably. A high value of 3.8 mg/ℓ was recorded in the fall trials and a high of 1.79 mg/ℓ in the spring. Concentrations usually but not always decreased toward the end of the trials (Table 11), often falling to zero. This correlates with the fact that 73 percent of the counts on water samples taken at the end of the trials (all sites) were greater than those taken at the beginning. Fewer (54 percent) of the product samples at those times showed higher counts, and the magnitude of these changes was not as great as for the water samples.

The data in Table 12 re-enforce the lack of correlation between bacteria in water and on product. There appeared to be a consistent increase in bacteria counts in the water in both systems as time proceeded. The build-up in the conventional system may indicate a trend to higher levels because these trials were usually shorter than those with the prototype. The differences in counts on the product for the fall and spring prototype trials may be attributed to the generally higher levels of chlorine in the water during the fall. Warmer weather in the spring may have also been a factor. The differences between the build-up of counts on product for the prototype and conventional washers in the spring may merely be the influence of exposing the product to more chlorine treated water in the conventional washers.
In summary the influences on bacteria counts, both product and water, are not clear. A system similar to the prototype using a final product rinse with closely controlled chlorine content would appear, however, to have an advantage over conventional washers in bacteria control.

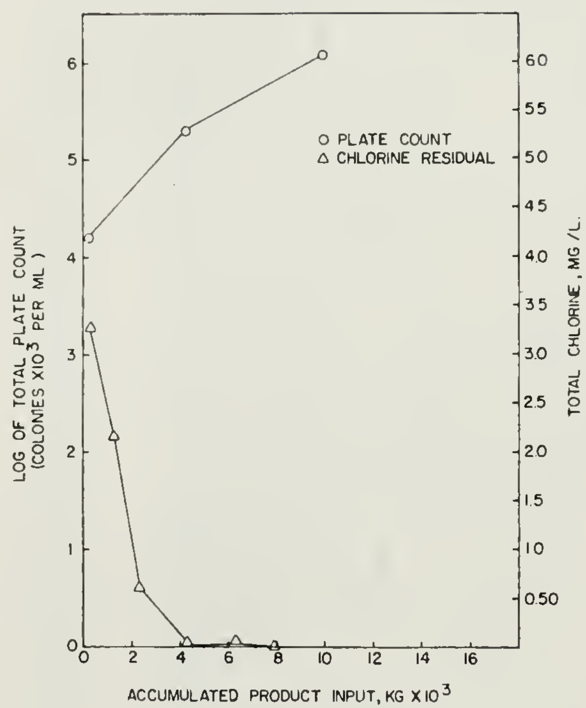


Figure 29: Bacterial populations and chlorine residual in wash water at Site 1 of prototype, trial 2, Fall, when processing collards.

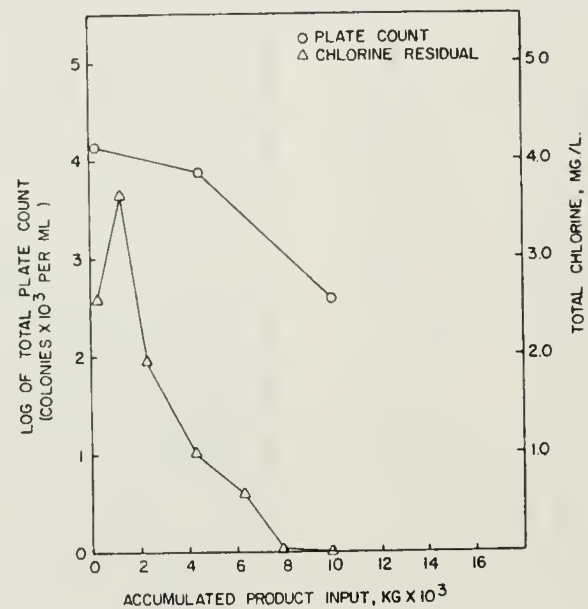


Figure 30: Bacterial populations and chlorine residual in wash water at Site 4 of prototype, trial 2, Fall, when processing collards.

TABLE 12. MAGNITUDE OF AVERAGE CHANGES IN TOTAL PLATE COUNTS FROM BEGINNING TO END OF TRIALS AT ALL SAMPLING SITES RECORDED.

Trials	Water*	Product**
Prototype (Fall)	+169.0	-110.3
Prototype (Spring)	+ 78.3	+ 41.7
Conventional	+356.0	- 4.6

* Colonies X 10^3 per milliliter

** Colonies X 10^3 per gram

Tables C-11 through C-15, Appendix C record data from the fall trials on total coliforms in the wash water. These organisms indicate the presence of fecal material on the incoming product. Their effect on final product, however, is not known.

TSS, VSS, COD and BOD

Figures 31 and 32 are two examples of water quality parameters at strategic points and times during the fall and spring trials of the prototype. In both cases the waste strength parameter is plotted vs. accumulated fresh product input to the washers during the trial. All parameters in all trials tended to follow similar patterns. Data on all trials are contained in Tables C-16 through C-57, Appendix C.

The six sites in the figures represent sampling locations (refer to Figures 1 or 12) and differences between adjacent sites in the flow pattern represent the effect of a certain component of the system on the quality of the wash water. Values at site 2 minus those at site 1, for instance, represent the amount of a waste component added to the wash water in washer 1; similarly for sites 3 and 4 in washer 2. Sites 2 and 6 bracket the effects of the sump pump and moving-screen belts in sub-system 1; sites 4 and 5 in sub-system 2. Sites 6 and 1 bracket the effects of the settling tank in the first sub-system; sites 5 and 3 in the second. Site 1 also represents the overflow to waste for the entire system.

The most obvious fact from these graphs is the considerable difference in waste strength in the first sub-system (sites 1, 2, and 6) compared to the second (sites 3, 4, 5). Approximately 75 percent of the product cleaning took place in the first washer and settling tank based on analysis of grit accumulated in the bottom of the tanks and remaining in the water at the end of each trial. These graphs also indicate the general effectiveness of the moving-belt screens and settling tanks. The effectiveness of the settling tanks, as noted earlier, could be improved by lowering the recirculation rate and eliminating the surges in flow caused by the intermittant operation of the sump pumps. Also, the settling tanks apparently performed better in

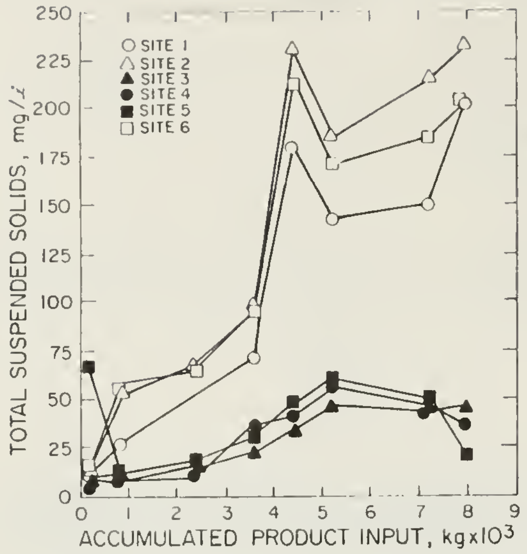


Figure 31: Total suspended solids vs. accumulated product input at all six sampling sites, Trial 4, Fall, when processing collards with prototype system.

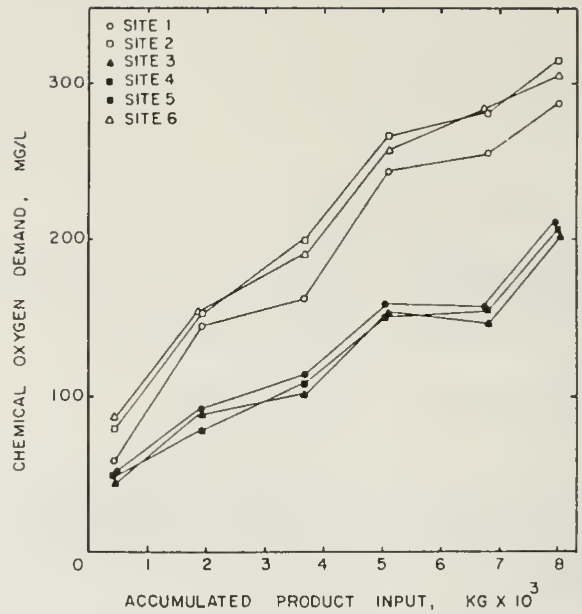


Figure 32. Chemical oxygen demand vs. accumulated product at all six sampling sites, Trial 4, Spring, when processing turnip greens with prototype system.

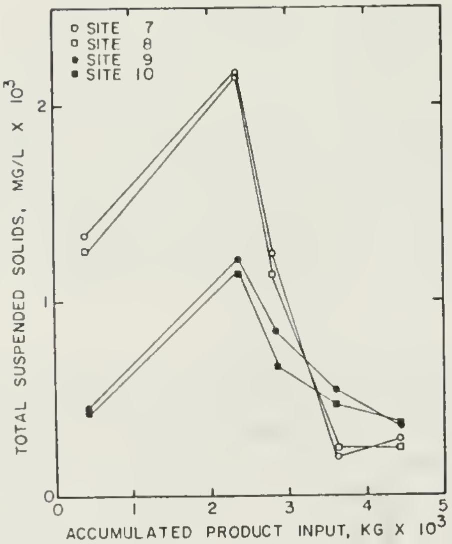


Figure 33. Total suspended solids vs. accumulated product at all four sampling sites, Trial 1, Spring, spinach processed with conventional washer.

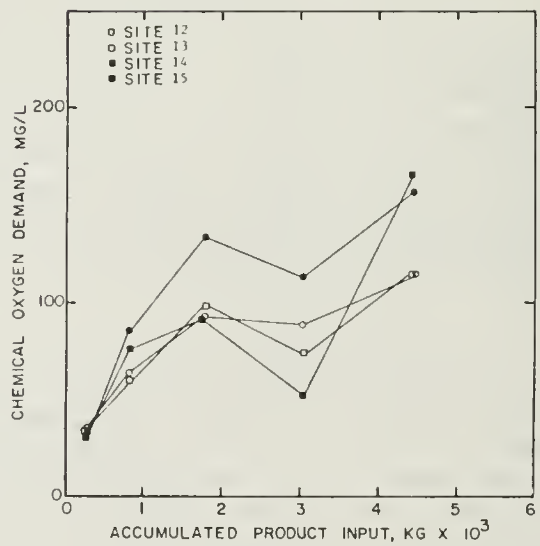


Figure 34. Chemical oxygen demand vs. accumulated product at all four sites, Trial 6, Spring, turnip greens processed with conventional system.

the fall trials than the data indicates due to the method of taking samples at sites 5 and 6 (input ends of the tanks). In the fall trials, water samples were taken at these points by dipping the container into the surface of the water. Some rapidly settling solids may have been missed by this technique. In the spring trials, these samples were taken by holding the container under the moving-screen belts to catch the samples before the water entered the tanks.

Ideally, a waste strength parameter in any one of the washers or settling tanks in a recirculating system should increase by some relationship such as:

$$x = A(1 - e^{-Bq})$$

where:

x = concentration of the particular parameter at any time, t.
q = total material processed to time, t.
A and B = constants.

In other words, given constant inputs - i.e., constant rate of material input of constant "dirtiness" and a constant fresh water input rate -- the waste strength parameter should approach the asymptotic value A with time. Material input rates, the amount of soil on the vegetables, and even the range in volatiles produced varied too much to be able to make precise predictions of concentrations. In general, however, it appears that the water quality parameters in the prototype system, operated as in these trials, could be expected to stablize in approximately 5 hours. Leaving the fresh water on during breaks in processing would, of course, tend to dilute the waste strength parameters, (note dip in values of TSS for first sub-system in Figure 31). Very low fresh water input rates as in trial 4 in the spring (Figure 32) would tend to increase the time until stability is reached. Accumulations of dissolved organics may also have the effect of lowering the emission rates of COD and BOD. The decrease in osmotic gradients between the product and the wash water could reduce the leaching of these materials as washing proceeds with recirculated water.

Twenty-day BOD values were taken on some of the water samples during the fall trials. These are tabulated in Tables C-54 through C-57, Appendix C.

Figures 33 and 34 show examples of water quality parameters vs. accumulated product for the sampling sites on the conventional washers. The waste strength parameters are again plotted vs. accumulated fresh product input to the washers. Generally the concentrations in the first washer (sites 7 and 8 or 12 and 13) were higher than those in the second (sites 9 and 10 or 14 and 15). This was not always consistent, strongly affected by the amount of water used in each washer. Waste strength also varied considerably from beginning to end of the trials and inconsistently with the amount of product processed. This inconsistency was the result of, not only variations in incoming product quality, but also in water flow rates.

pH

pH was measured and recorded every time water samples were taken. The range in the fall trials was 6.5 to 7.6 and in the spring trials 7.6 to 8.5. These ranges do not indicate any problems for waste treatment due to pH.

Color, Turbidity and Conductivity

Readings on color, turbidity and conductivity were taken and recorded during the fall trials with the prototype. These parameters generally followed the trends of the other waste strength parameters. These measurements are easy to make and any or all of them may provide simple means for controlling the operation of recirculating systems in the future. For example, Figures 35, 36 and 37 present simple regressions for BOD vs. color for trials 2, 3, and 4 (fall) with collards. Further study on these general relationships for each commodity appears warranted.

Pesticides

Water samples for pesticide analysis were taken midway and at the end of each trial of the prototype at the overflow of washer 1 (site 2) during the spring trials. These samples were analyzed for Phosdrin, the insecticide used by Exmore Foods. The results are listed in Table 13 below.

TABLE 13. CONCENTRATION OF PHOSDRIN IN WATER OF FIRST WASHER OF PROTOTYPE SYSTEM, SPRING TRIALS

Trial	Water/Product ℓ/kg	Hours of Operation	Concentration ppb*
4	2.18	3	1.45
		5	0.81
5	3.99	4	0.17
		7	non-detectable
6	4.22	4	Trace (< 0.01)
		6.5	non-detectable

*Parts per billion.

Samples from Trial 1, the first of the four trials with the prototype in the spring became overheated in transit, began to decompose anerobically, and consequently could not be analyzed. Samples from the other trials indicate that 1) concentrations of pesticide were very low, 2) they tended to decrease with time rather than build up in the recirculated water and 3) they tended to decrease with increased water/product ratios.

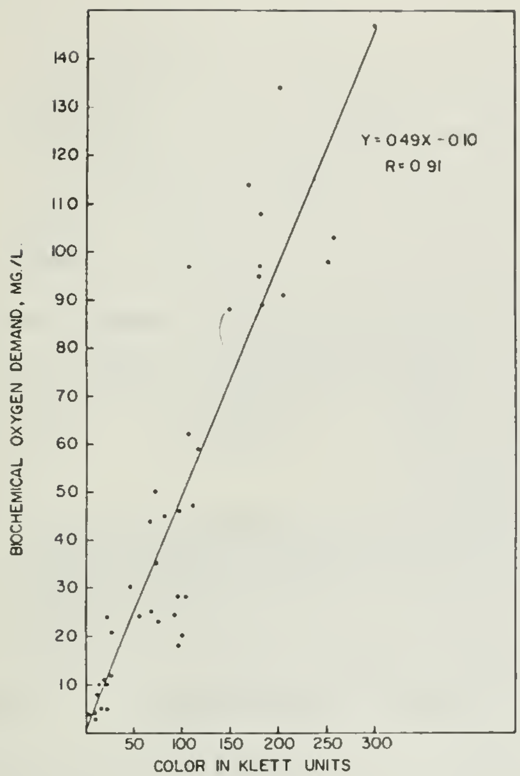


Figure 35. Five-day biochemical oxygen demand vs. color, Trial 2, Fall, when processing collards with prototype system.

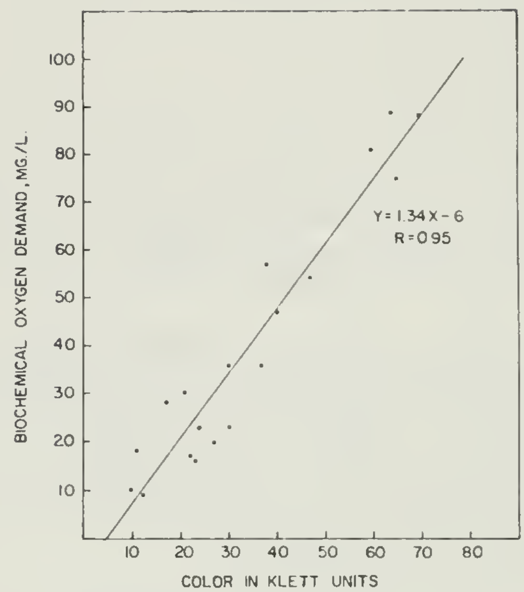


Figure 36. Five-day biochemical oxygen demand vs. color, Trial 3, Fall, when processing collards with prototype system.

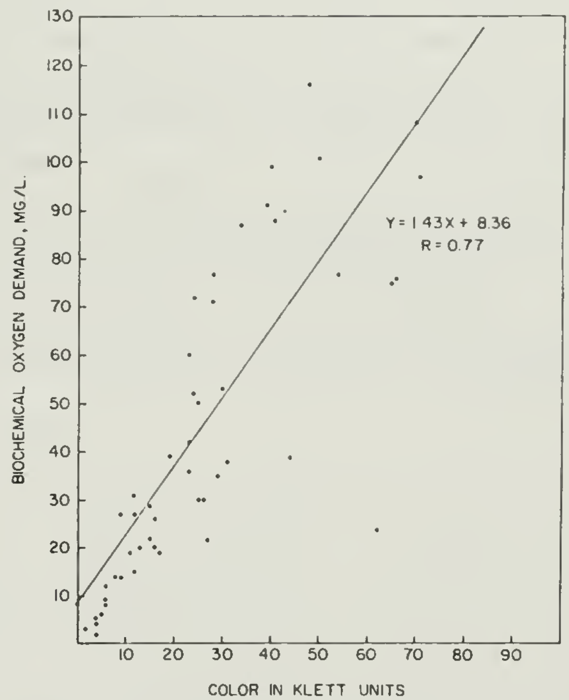


Figure 37. Five-day biochemical oxygen demand vs. color, Trial 4, Fall, when processing collards with prototype system.

SUMMARY OF WASTE PRODUCTION FROM WASHERS

Waste is carried from the washers by the water in three different ways: 1) with the effluent during processing, 2) with the water carried out of the system on the product and 3) with the water dumped from the washers (and settling tanks for the prototype) at the end of a processing shift. Tables 14, 15 and 16 show the amounts of each waste parameter measured in these trials per metric ton of product processed. Concentrations for each time period multiplied by average water flow during the period were summed for an entire trial to obtain the total waste leaving in the effluent. Similarly, the concentrations in the last washer multiplied by average product flow and amount of water leaving per unit of product were also summed. The amounts of waste in the washers and settling tanks at the end of processing was determined by multiplying the final concentrations by the volume of the tanks in which they were measured.

Tables 15 and 16 (spring trials) show the amounts of waste leaving the washers by each route. The percentages in each case varied considerably. The waste leaving the prototype (Table 15) on the product may be slightly less than estimated here because of the final rinse on the discharge belt of the second washer. One consistency to be noted for the three trials when turnip greens were processed (4, 5, 6) is that the percentage of waste removed by the system overflow increased very rapidly as the amount of fresh water input increased.

There are at least three things that affect total waste production and waste stream concentrations. They are: 1) the variety of vegetable being processed, 2) the amount of water per unit of product processed, and 3) the condition of the vegetables. Potter (15) shows that collards are high in nutritive value -- 7.5 vs. 4.3 grams of carbohydrates and 40 vs. 26 calories per 100 grams compared to spinach. This implies that there should be considerable difference in VSS and COD production from different varieties. On the other hand, Bough (2) found that spinach produced significantly higher waste loads during washing when compared to collards, turnip greens, mustard and kale. The results of this study however, do not indicate that any one of the three products tested could be used as a model for maximum VSS and COD emission. Emission rates for TSS were consistently higher for spinach. The combination of savoy leaf surfaces and low growth profile undoubtedly increases grit accumulation compared to other leafy vegetables.

The amount of water used to wash a unit of product appears to have considerable influence on waste production. VSS and COD mass emission rates were consistently lower for the prototype than for the conventional system. There are at least four possible reasons for this: 1) The concentrations of these waste components in the recirculated water of the prototype were considerably higher than those in the conventional washer. The more dilute and larger amounts of water used in the conventional washers may have affected the surface of the leaves and induced more leaching of organics, a possibility noted by EPA (7). 2) The water used in the conventional washers was, for the most part, taken from the product cooling flumes and did contain some soluble material. 3) A significant amount of these components may have left the system with the leaf fragments separated out by the moving belt

TABLE 14. WASTE LOADS DISCHARGED WITH WATER* FROM PROTOTYPE SYSTEM DURING FALL TRIALS, 1975

Trial	Product	Waste Stream/ Product (ℓ/kg)	Waste Load, kg/metric ton+			
			TSS	VSS	COD	BOD_5
1	Collards	1.97	0.38	0.19	0.92	0.25
2	Collards	0.69	0.27	0.21	0.77	0.16
4	Collards	1.30	0.43	0.24	0.88	0.22
5	Spinach	1.55	2.44 (15.0)**	0.21	0.91	0.17

*Sum of wastes carried out overflow of system during trials, plus waste in water carried out on product, plus waste in water remaining in system at end of processing.

**Grit collected from bottom of washers and settling tanks at end of trial. Amount of grit from this source was negligible in other trials.

+Waste loads given in kg/metric ton of fresh (raw) product entering washing system. See Table 6 for factors to convert these readings to field weight or packaged weight.

TABLE 15. WASTE LOADS DISCHARGED WITH WATER FROM PROTOTYPE SYSTEM DURING SPRING TRIALS, 1976

Trial	Product	Waste stream/ Product ℓ/kg	Waste* Source	Waste Load, kg/metric ton+ and percent of total TSS	VSS	COD
1	Spinach	1.38	A	0.65(25.4%)	0.11(26.6%)	0.37(32.4%)
			B	0.97(38.2%)	0.15(38.0%)	0.39(34.7%)
			C	0.93(36.4%)	0.14(35.4%)	0.37(32.9%)
			TOTAL	2.54(100%)	0.40(100%)	1.13(100%)
			D	5.30		
4	Turnip Greens	0.16	A	0.43(38.1%)	0.07(44.8%)	0.20(35.2%)
			B	0.06(4.9%)	0.01(6.9%)	0.02(3.6%)
			C	0.64(57.0%)	0.07(48.3%)	0.34(61.2%)
			TOTAL	1.13(100%)	0.15(100%)	0.56(100%)
			D	2.10		
5	Turnip Greens	1.35	A	0.19(32.5%)	0.04(38.1%)	0.13(27.7%)
			B	0.20(34.2%)	0.03(28.6%)	0.15(31.9%)
			C	0.20(33.3%)	0.04(33.3%)	0.19(40.4%)
			TOTAL	0.59(100%)	0.11(100%)	0.47(100%)
			D	1.10		
6	Turnip Greens	1.68	A	0.06(6.9%)	0.01(8.3%)	0.04(8.2%)
			B	0.53(65.6%)	0.08(66.7%)	0.32(64.3%)
			C	0.22(27.5%)	0.03(25.0%)	0.13(27.5%)
			TOTAL	0.81(100%)	0.12(100%)	0.49(100%)
			D	2.90		

*A - Carried out with water on product.

B - Discharged from settling tank #1.

C - Remaining in water in system at end of processing.

TOTAL - Total of wastes from water in system

D - Total grit collected in the bottom of the washers and settling tanks at the end of each trial.

\+ - Waste loads given in kg/metric ton of fresh (raw) product entering washing system. See Table 7 for factors to convert these readings to field weight or packaged weight.

TABLE 16. WASTE LOADS DISCHARGED WITH WATER FROM CONVENTIONAL WASHERS DURING SPRING TRIALS, 1976

Trial	Product	Waste stream/ Product ℓ/kg	Waste* Source	Waste Load, kg/metric ton+ and percent of total: TSS	VSS	COD
1	Spinach	17.5	A	1.74(12.2%)	0.22(13.0%)	0.39(8.7%)
			B	12.10(85.1%)	1.37(82.5%)	3.93(87.1%)
			C	0.39(2.7%)	0.07(4.5%)	0.19(4.2%)
			TOTAL	14.23(100%)	1.66(100%)	4.51(100%)
2	Spinach	4.1	A	4.30(46.5%)	0.40(42.0%)	0.65(46.8%)
			B	4.52(48.9%)	0.51(54.3%)	0.65(46.8%)
			C	0.43(4.6%)	0.04(3.7%)	0.09(6.4%)
			TOTAL	9.25(100%)	0.95(100%)	1.37(100%)
3	Spinach	9.8	A	0.81(16.8%)	0.15(17.2%)	0.56(15.9%)
			B	3.55(74.2%)	0.62(73.4%)	2.59(74.1%)
			C	0.43(9.0%)	0.08(9.5%)	0.35(10.0%)
			TOTAL	4.79(100%)	0.85(100%)	3.50(100%)
4	Turnip Greens	17.6	A	0.24(9.3%)	0.04(10.3%)	0.45(13.5%)
			B	2.26(87.4%)	0.29(85.3%)	2.74(81.9%)
			C	0.09(3.3%)	0.02(4.4%)	0.15(4.6%)
			TOTAL	2.59(100%)	0.35(100%)	3.34(100%)
5	Turnip Greens	16.0	A	0.12(8.1%)	0.04(10.4%)	0.49(15.1%)
			B	1.24(87.3%)	0.29(85.1%)	2.57(79.3%)
			C	0.07(4.6%)	0.02(4.5%)	0.18(5.6%)
			TOTAL	1.43(100%)	0.35(100%)	3.24(100%)
6	Turnip Greens	20.7	A	0.21(14.6%)	0.03(13.0%)	0.42(18.9%)
			B	1.14(79.2%)	0.19(82.6%)	1.62(73.6%)
			C	0.09(6.2%)	0.01(4.4%)	0.16(7.5%)
			TOTAL	1.44(100%)	0.23(100%)	2.20(100%)

*A - Carried out with water on product.

B - Discharged from washers 1 and 2

C - Remaining in water in system at end of processing.

TOTAL - Total of wastes from water in system. Grit remaining in bottom of washers at end of each trial could not be collected without interferring with plant operations.

\+ - Waste loads given in kg/metric ton of fresh (raw) product entering washing system. See Table 8 for factors to convert these readings to field weight or packaged weight.

screens. 4) Some of these components may have settled out with the finer soil particles in the prototype settling tanks. Soil samples taken from these tanks were observed to be high in organic matter.

The amount of grit removed by the water from the conventional system (TSS minus VSS) appears to be greater than that for the prototype system. No direct comparisons, however, can be made because the grit collected in the bottom of the conventional washers could not be measured in these trials. The prototype showed a consistent advantage over the conventional washers in reducing the amount of grit on product samples that were hand washed as described earlier. Assuming that this is a correct representation of the relative effectiveness of the two systems, then the prototype has the added advantage of consolidating more of the wastes in its washers and particularly in the settling tanks for disposal separate from washer effluents.

Emission rates of the various waste components are also strongly influenced by the conditions of incoming product within a variety. This condition is influenced by many things including maturity of plants, growing conditions, whether wilted or turgid, rain or irrigation prior to harvest, etc. These effects are demonstrated by the data for each variety presented in Tables 14, 15, 16 and in Table 17 (described below). Even if these data were "normalized" to constant amounts of water per unit of product processed there would still be considerable differences in TSS, VSS and COD per kg of product within each variety.

Table 17 is a summary of average waste stream size and average waste component concentrations for each of the trials, fall and spring. These data do not reflect the changing concentration of waste components in the prototype system with time. They should, however, be useful in planning for design of a waste treatment system that uses either conventional or recirculating washers.

Overall average operating conditions for the prototype washing system during these trials included a product input rate of 1278 kg/hr and fresh water input of 72 ℓ/min. Under these conditions 2.20 ℓ/kg left the system with the product, 1.18 left via the waste stream and the waste concentrations (TSS, VSS, COD) in the various units of the system could be expected to stabilize in approximately five hours of continuous operation. The number of trials run were insufficient to indicate whether or not these were "optimum" conditions. Nevertheless, they appear to be "good" or minimum conditions for producing suitably clean product. For all product flow rates a minimum fresh water input of 3.5 ℓ/kg (0.42 gal /lb) is recommended.

ECONOMIC COMPARISONS

The following is an example problem to demonstrate the comparative economics of owning and operating a two-washer prototype system vs. a two-washer conventional system of equal output. Many variables will, of course, affect this type of comparison. The basis here is an assumed "reasonable" set of operating and economic conditions.

TABLE 17. WASTE STREAM CHARACTERISTICS FROM PROTOTYPE AND CONVENTIONAL SYSTEMS

Trial	Product	Average Waste Stream ± ℓ/min	Avg. Waste Conc.± , mg/ℓ			
			TSS	VSS	COD	BOD_5
1-F*-P+	Collards	38.2	80.8	30.6	137.6	46.8
2-F-P	Collards	20.0	91.7	68.6	264.1	62.6
3-F-P	Collards	18.9	158.0	95.0	346.3	62.5
4-F-P	Collards	25.8	121.4	65.9	127.7	57.0
5-F-P	Spinach	25.5	516.8	45.6	144.0	42.3
1-S-P	Spinach	29.5	818.5	126.9	331.1	---
4-S-P	Turnip Greens	3.9	414.5	48.0	191.7	---
5-S-P	Turnip Greens	24.1	194.4	28.0	131.7	----
6-S-P	Turnip Greens	37.7	230.0	35.6	139.9	---
1-S-C	Spinach	328.3	1157.1	103.1	216.2	---
2-S-C	Spinach	107.2	3618.0	168.9	255.1	---
3-S-C	Spinach	266.3	336.7	60.1	228.9	---
4-S-C	Turnip Greens	405.9	129.3	17.2	156.2	---
5-S-C	Turnip Greens	396.3	70.6	16.4	147.8	---
6-S-C	Turnip Greens	393.0	54.9	9.1	78.6	---

*F = fall trial, S = spring trial

+P = prototype, C = conventional

± = Values are averages for the single waste stream from the prototype system and are weighted averages for the total waste flow from the two conventional washers.

Annual Fixed Costs

The assumptions here are: 1) The two conventional washers will cost \$12,000 (\$6,000 each. Estimate from A. K. Robins Co., Baltimore, Md.) and the prototype will cost \$16,000. The prototype cost is based on an estimate of 1.33 times that of the conventional washers and assumes that it will be constructed to include the simplifications cited in the recommendations (section 3 of this report). 2) Useful life of the equipment is 12 years and salvage value at the end of usefulness will be 10% of initial cost. Straight line depreciation will be used. 3) Interest on investment will be equal to 8% of the average value of the equipment over its useful life, per year; and 4) cummulative over ownership costs (taxes, housing, insurance) are equal to 2% of the initial cost per year. The following annual costs are derived using these assumptions.

Item	Washer Line	
	Conventional	Prototype
Depreciation	\$ 900	\$1200
Interest on investment	516	688
Taxes, housing, insurance	240	320
Totals	\$1656	\$2208

Yearly difference: \$2208 - 1656 = \$552.00

Operating Costs

Operating costs and variables are taken from local information (Blacksburg, Va.) and conditions comparable to those reported in this study. Only the waste stream from the washers is considered in computing sewer charges. Assumptions include:

Item	Washer Line	
	Conventional	Prototype
Hours of operation	16	16
Man-hours labor/day	18	20
Labor cost, \$/hr	3.5	3.5
Product throughput, lb/hr	3000	3000
Input water rate, gal/min	100	20
Water for filling system, gal.	1500	3000
Waste stream, gal/min	85	6.5
Waste production, into waste stream, lbs/ton of product, (Assumes that 3/4 of the product processed is spinach, 1/4 turnip greens):		
TSS	11.53	3.16
VSS	1.49	0.48
COD	5.14	1.33

Power to operate washers, kw	3.0	14.6
Electricity costs, ¢/kwh	3.4	3.4
Fresh water cost, $/1000 gal	0.5	0.5
Sewer charge for water, $/1000 gal	1.0	1.0
High strength surcharge rates, ¢/lb		
TSS above 200 mg/ℓ	10	10
COD above 120 mg/ℓ	7	7
Repairs and maintenance, (0.02% of initial cost/hr.) $/hr.	2.40	3.20

Using the above assumptions the following daily operating costs were calculated:

Item	Washer Line	
	Conventional	Prototype
Electric Power	$ 1.62	$ 7.96
Water (including two fill-ups/day)	49.50	12.60
Sewer Charges	84.60	12.24
Sewer Surcharges	14.03	4.38
Repairs	28.40	51.20
Labor	63.00	70.00
TOTAL	$251.15	$158.38

Daily difference $251.15-158.38 = $92.77

Under the assumed conditions for this problem, then, the average annual difference in owning the two types of systems could be recovered in slightly less than 6 days of operating time.

REFERENCES

1. Agricultural Research Service, 1963. "Composition of Foods." Agriculture Handbook No. 8, USDA, Washington, D. C.

2. Bough, W. A. 1973. "Composition and Waste Load of Unit Effluents from a Commercial Leafy Greens Canning Operation." Journal of Milk and Food Technology, Vol. 36, No. 11, pp. 544-553.

3. Buckman, H. O., and N. C. Brady. 1969. The Nature and Properties of Soils, 7th Edition, The MacMillan Co., Printed in U.S.A.

4. Carter, L. W. 1970. "A Study of Water Conservation and Reuse at the Stillwell Canning Co. in Stillwell, Oklahoma." Report prepared for the Ozarks Regional Commission.

5. Day, P. R. 1965. "Hydrometer Method of Particle-Size Analysis." Methods of Soil Analysis, Part 1, Amer. Soc. Agron., Madison, Wis.

6. Directory of the Canning, Freezing and Preserving Industries. 1971. E. E. Judge, and Sons Publishers. Westminister, Maryland.

7. E.P.A. 1976. "Final Effluent Guidelines and Standards for Phase II of the Canned and Preserved Fruits and Vegetables Processing Industry Point Source Category." Federal Register. Chapter I. Subchapter N, Part 407.

8. Frey, B. C. 1973. "Modification of a Leafy Vegetable Immersion Washer." Unpublished Master's Thesis, Virginia Polytechnic Institute and State University.

9. Frey, B. C., M. E. Wright, and R. C. Hoehn. 1974. "Modification of a Leafy Vegetable Immersion Washer." Transactions of the A.S.A.E., Vol. 17, No. 6, pp. 1057, 1058, 1059 and 1063, St. Joseph, Mich.

10. Holtan, H. N., N. E. Minshall, and L. L. Harrold. 1962. Field Manual for Research in Agricultural Hydrology. Agricultural Research Service. Agricultural Handbook No. 224, Washington, D. C.

11. Lopez, A. 1969. A Complete Course in Canning, 9th Edition. The Canning Trade, Baltimore, Maryland.

12. Mercer, W. H. 1956. "Canner Foods." Industrial Waste Water Control. Edited by C. F. Guinham, Academic Press, New York, n. Y., pp. 65-71.

13. Metcalf & Eddy, Inc. 1972. Wastewater Engineering, McGraw-Hill Book Co., New York, N. Y.

14. National Canners Association. 1971. "Liquid Wastes from Canning and Freezing Fruits and Vegetables." Water Pollution Control Research Series, 12060 EDK-08/71. U.S. Government Printing Office, Washington, D. C.

15. Potter, N. N. 1968. "Food and Waste." Food Science, The AVI Publishing Co., Inc., Westport, Conn., pp. 471-587.

16. Ramseier, R. E. 1942. "The Evaluation of Industrial Wastes in the East Bay." California Sewage Works Journal, XIV, No. 1, pp. 26-37.

17. Robinson, W. H., Jr., and M. E. Wright. "A Note on Plexiglass H S Flumes." Water Resources Research. In press.

18. S.C.S. Engineers. 1971. Industrial Waste Study on Canned and Frozen Vegetables, Interim Report, Contract No. 68-01-0021 for the U.S. E.P.A., Long Beach, California.

19. Standard Methods for the Examination of Water and Wastewater. 1971. Edited by AWWA, APHA, and WPCF, 13th Edition.

20. Townsend, C. T., I. I. Somers, F. C. Lamb, and N. A. Olsen. 1956. A Laboratory Manual for the Canning Industry, 2nd Edition, National Canners Association Research Laboratories, Washington, D. C.

21. U.S. Department of Agriculture. 1971. Agricultural Statistics. Government Printing Office, Washington, D. C.

APPENDIX A

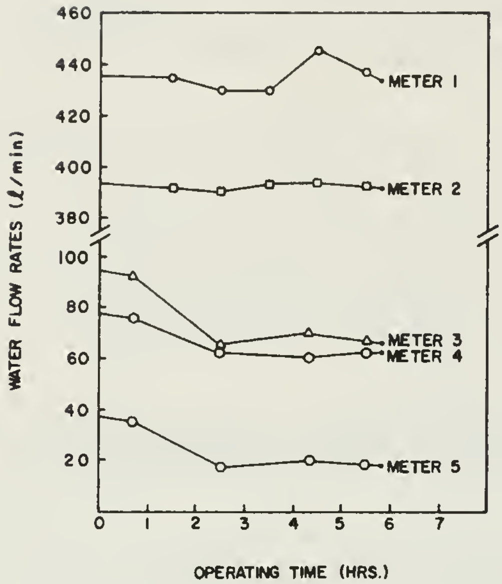


Figure A-1: Water flow rates vs. operating time, trial 2, Fall, 1975, when processiog collards with prototype washer.

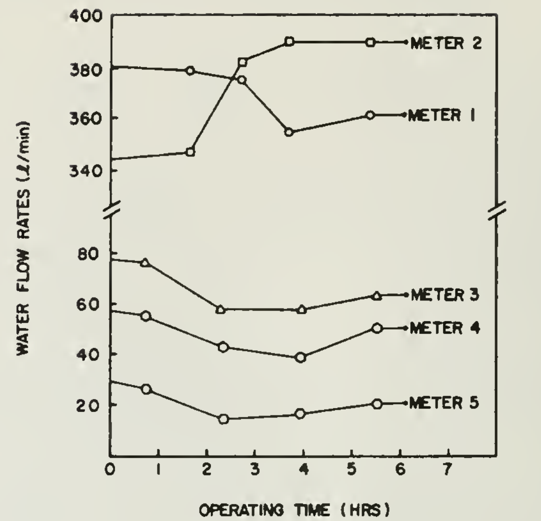


Figure A-2: Water flow rates vs. operating time, trial 3, Fall, 1975, when processing collards with prototype washer.

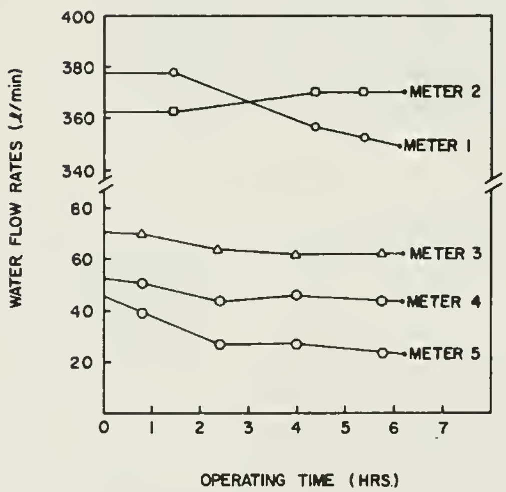


Figure A-3: Water flow rates vs. operating time, trial 4, Fall, 1975, when processing collards with prototype system.

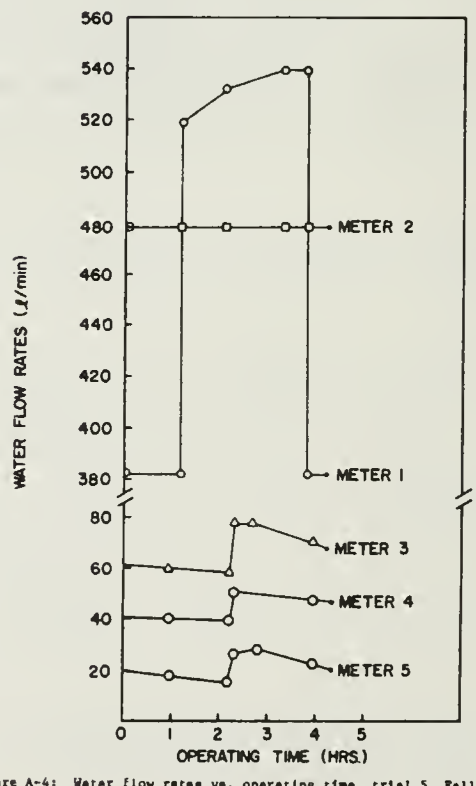


Figure A-4: Water flow rates vs. operating time, trial 5, Fall, 1875, when processing spinach with prototype system.

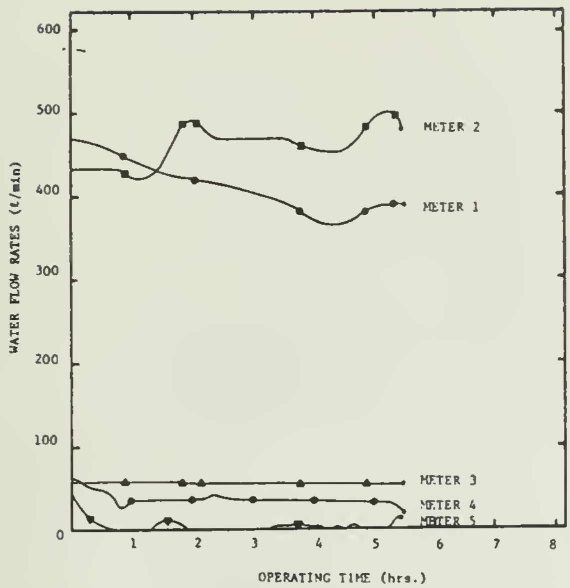


Figure A-5: Water flow rates vs. operating time, Trial 4, Spring, 1976, when processing turnip greens with prototype system.

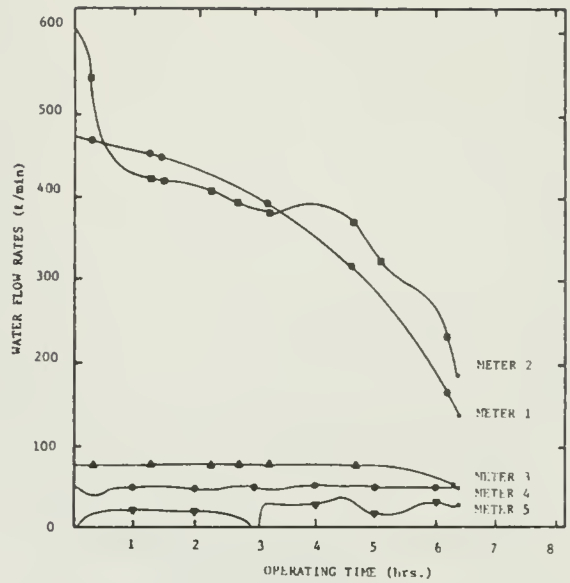


Figure A-6: Water flow rates vs. operating time, Trial 5, Spring, 1976, when processing turnip greens with prototype washer.

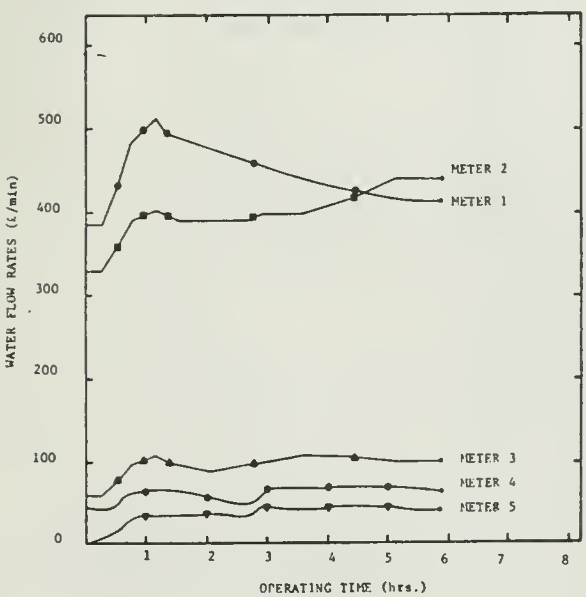


Figure A-7: Water flow rates vs. operating time, Trial 6, Spring, 1976, when processing turnip greens with prototype washer.

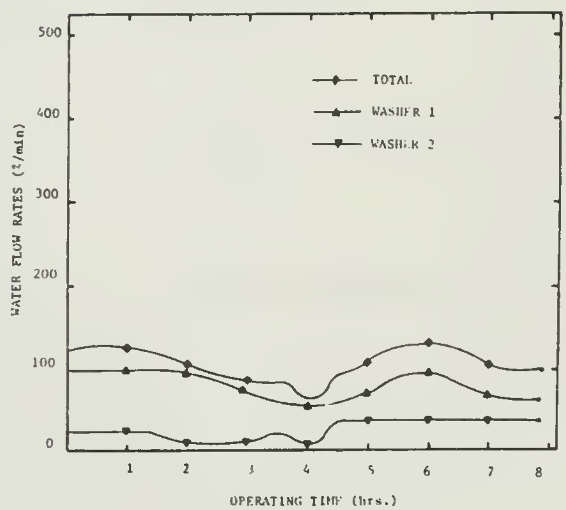


Figure A-8: Water overflow rates from conventional washers vs. operating time, Trial 2, Spring, 1976, when processing spinach on the east line.

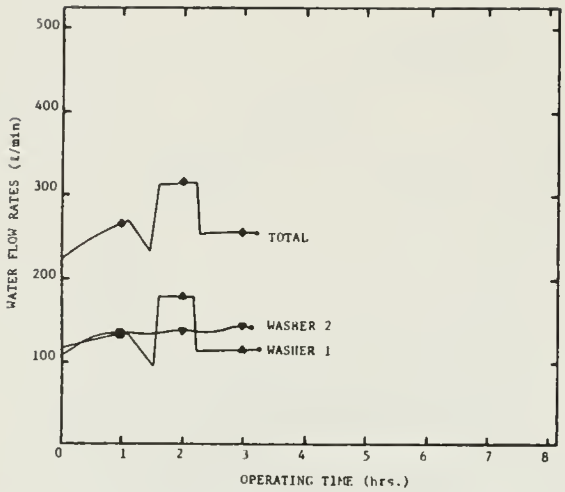


Figure A-9: Water overflow rates from conventional washers vs. operating time, Trial 3, Spring, 1976, when processing spinach on the west line.

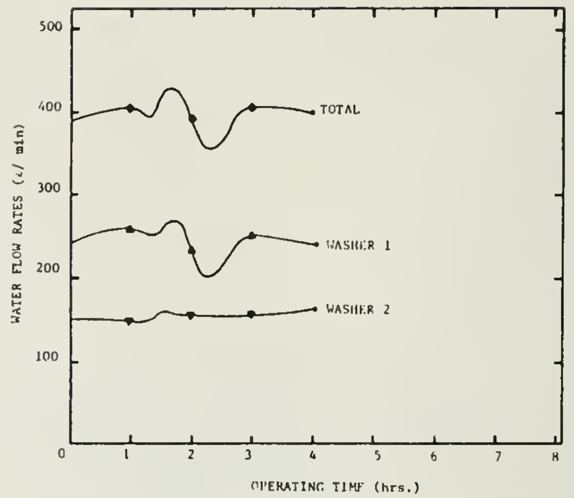


Figure A-10: Water over flow rates from conventional washers vs. operating time, Trial 4, Spring, 1976, when processing turnip greens on west line.

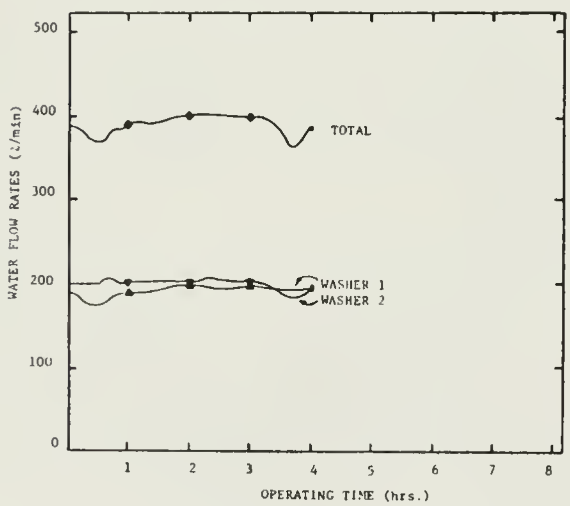


Figure A-11. Water overflow rates from conventional washers vs. operating time. Trial 5, Spring, 1976, when processing turnip greens on west line.

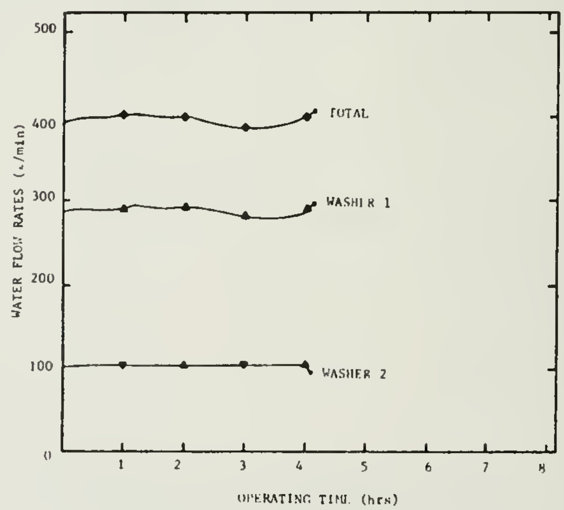


Figure A-12: Water overflow rates from conventional washers vs. operating time, Trial 6, Spring, 1976, when processing turnip greens on west line.

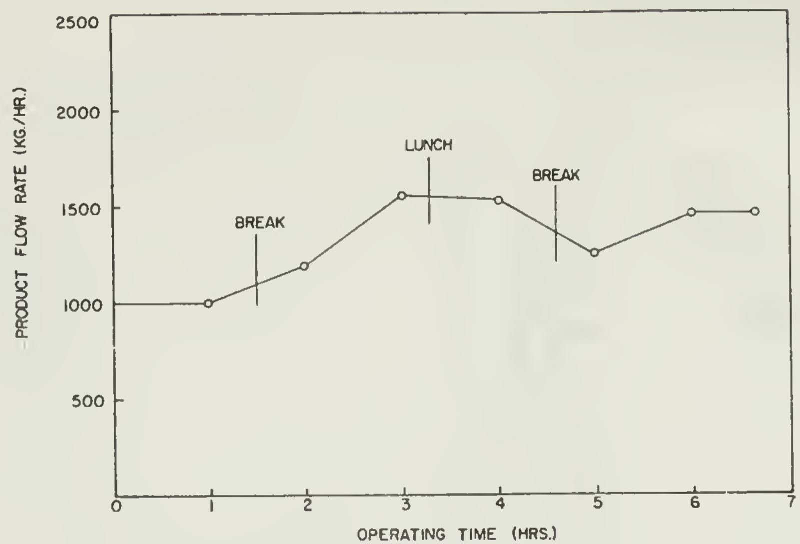


Figure A-13: Product flow rate vs. operating time, Trial 3, Fall, 1975, when processing collards with the prototype system.

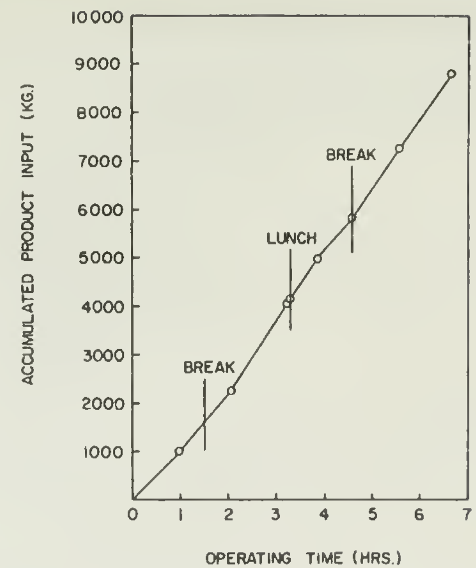


Figure A-14: Accumulated product input vs. operating time, Trial 3, Fall, 1975, when processing collards with prototype system.

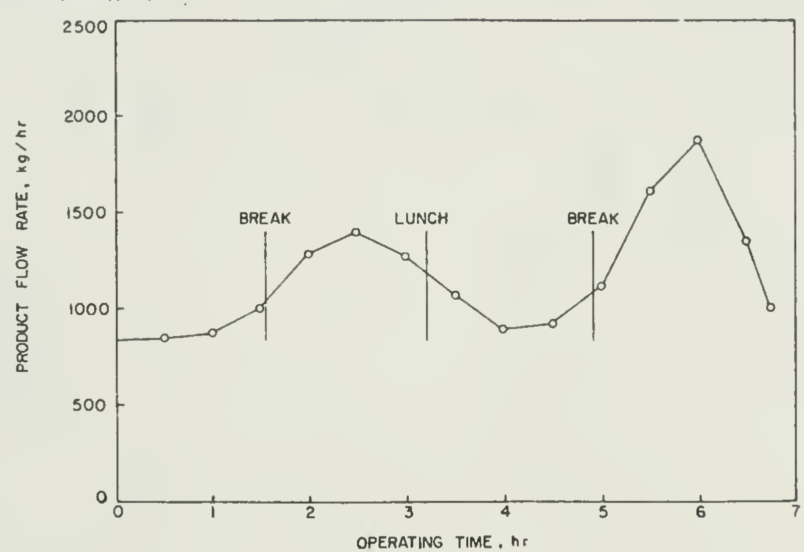


Figure A-15: Product flow rate vs. operating time, Trial 4, Fall, 1975, when processing collards with the prototype system.

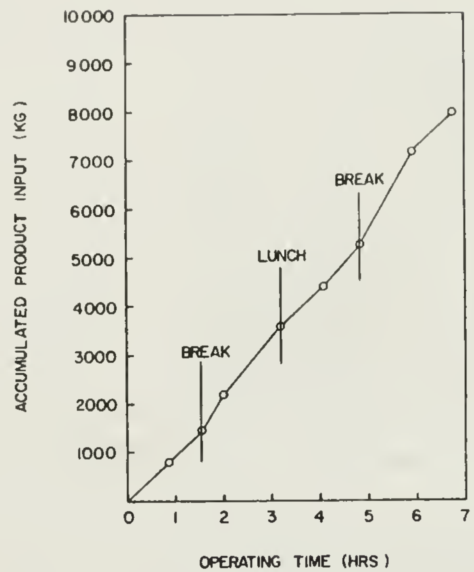


Figure A-16: Accumulated product input vs. operating time, Trial 4, Fall, 1975, when processing collards with the prototype system.

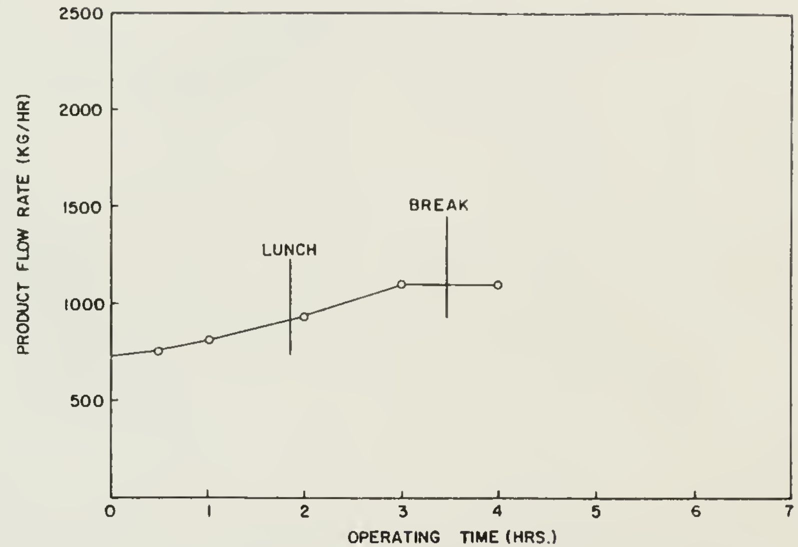


Figure A-17: Product flow rate vs. operating time, Trial 5, Fall, 1975, when processing spinach with prototype system.

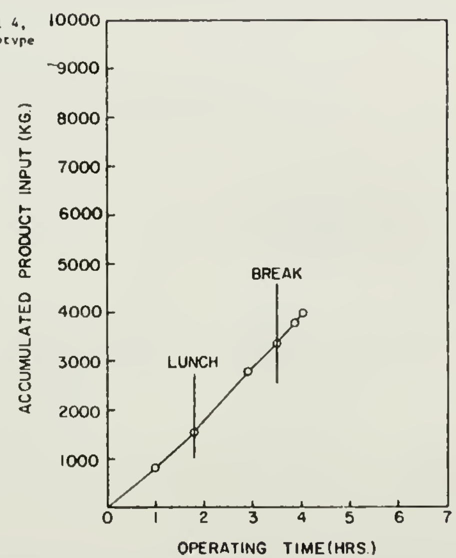


Figure A-18: Accumulated product input vs. operating time, Trial 5, Fall, 1975, when processing spinach with the prototype system.

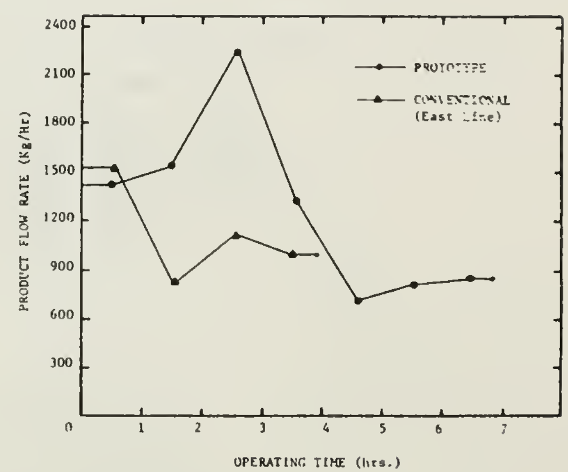


Figure A-19: Product flow rate vs. operating time, Trial 1, Spring, 1976, when processing spinach.

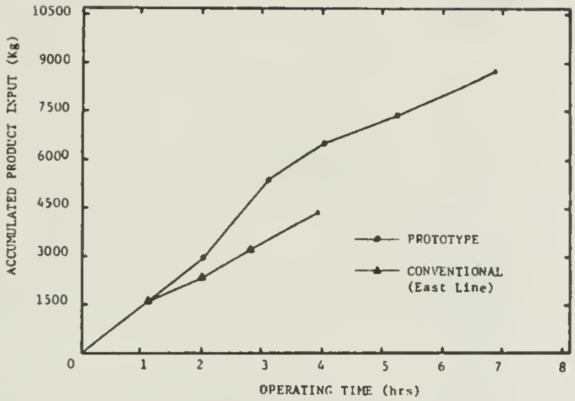


Figure A-20: Accumulated product input vs. operating time, Trial 1, Spring, 1976, when processing spinach.

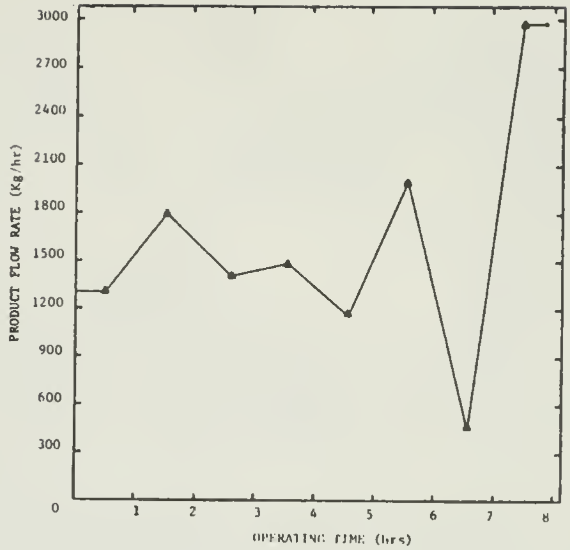


Figure A-21: Product flow rate vs. operating time, Trial 2, Spring, 1976 when processing spinach with the conventional washers, east line.

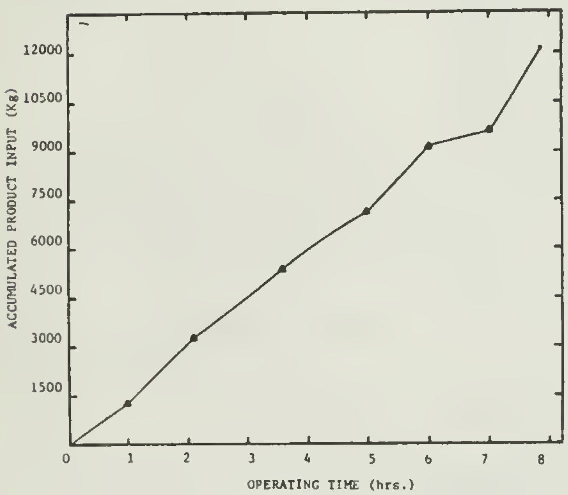


Figure A-22: Accumulated product input vs. operating time, Trial 2, Spring, 1976, when processing spinach with the conventional washers, east line.

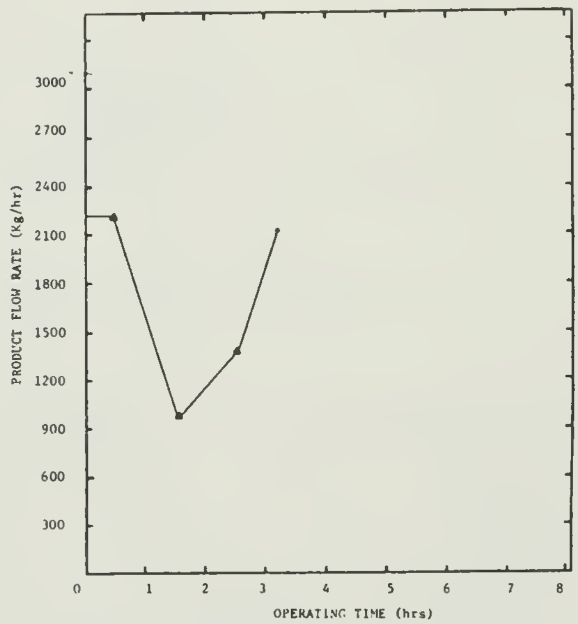


Figure A-23: Product flow rate vs. operating time, Trial 3, Spring, 1976, when processing spinach with the conventional washers, west line.

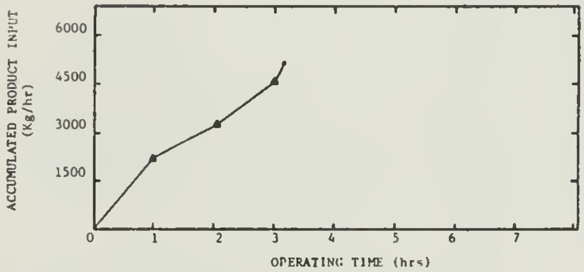


Figure A-24: Accumulated product input vs. operating time, Trial 3, Spring 1976, when processing spinach with conventional washers, west line.

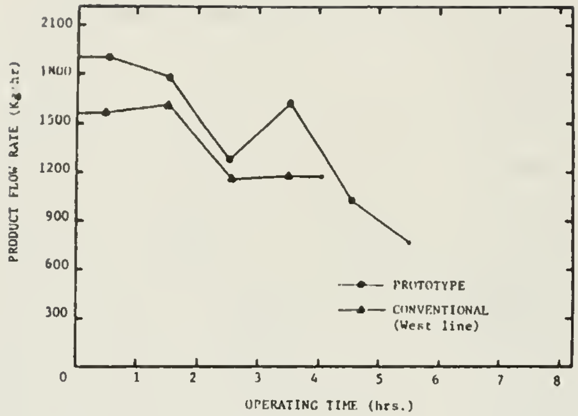


Figure A-25: Product flow rate vs. operating time, Trial 4, Spring, 1976, when processing turnip greens.

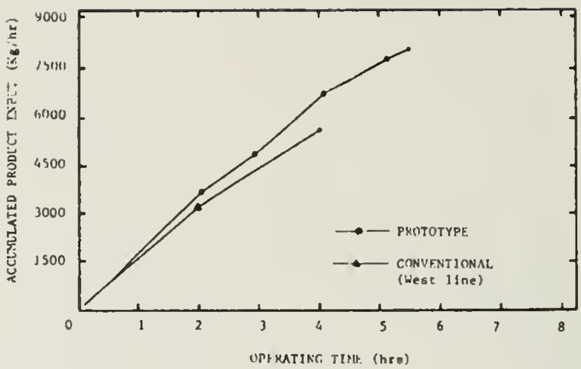


Figure A-26: Accumulated product input vs. operating time, Trial 4, Spring, 1976, when processing turnip greens.

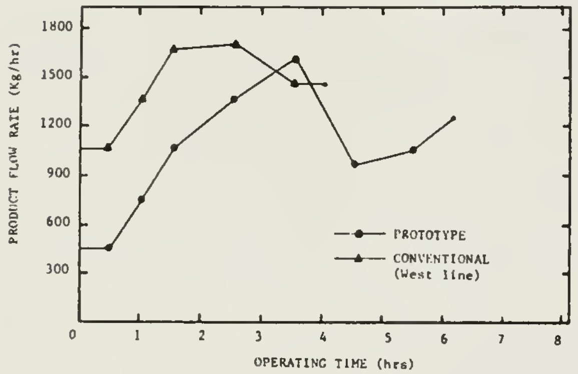


Figure A-27: Product flow rate vs. operating time, Trial 5, Spring, 1976, when processing turnip greens.

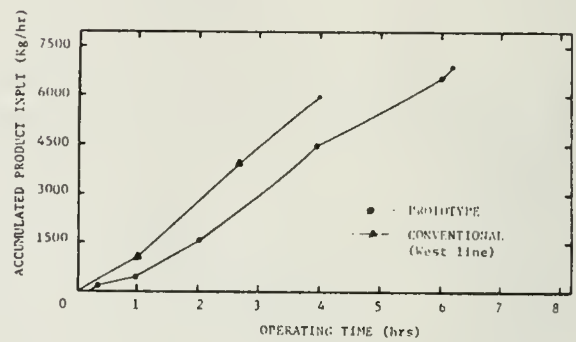


Figure A-28: Accumulated product input vs. operating time, Trial 5, Spring, 1976, when processing turnip greens.

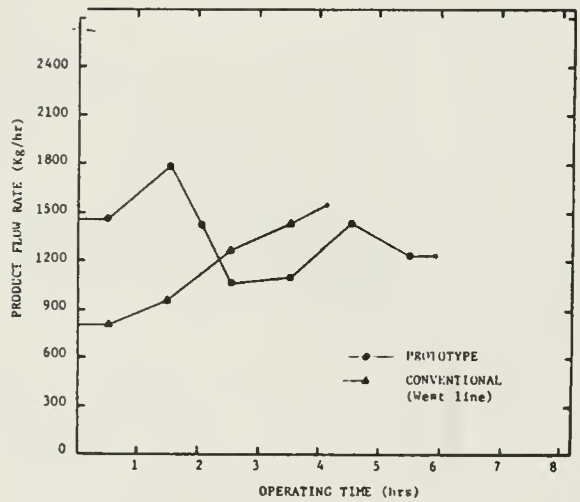


Figure A-29: Product flow rate vs. operating time, Trial 6, Spring, 1976, when processing turnip greens.

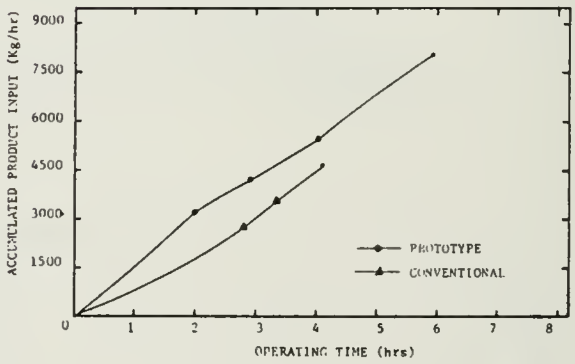


Figure A-30: Accumulated product input vs. operating time, Trial 6, Spring, 1976, when processing turnip greens.

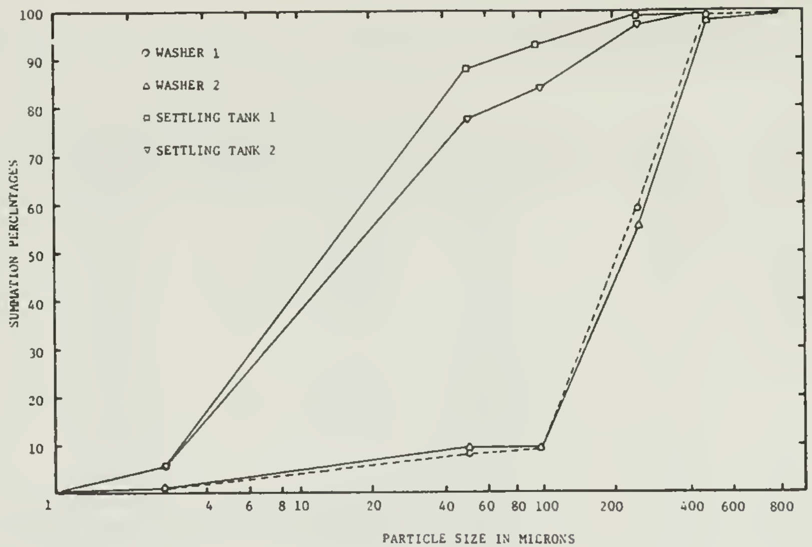


Figure A-31: Summation percentages vs. particle size for grit accumulated in prototype system, Trial 1, Spring, 1975 when processing spinach.

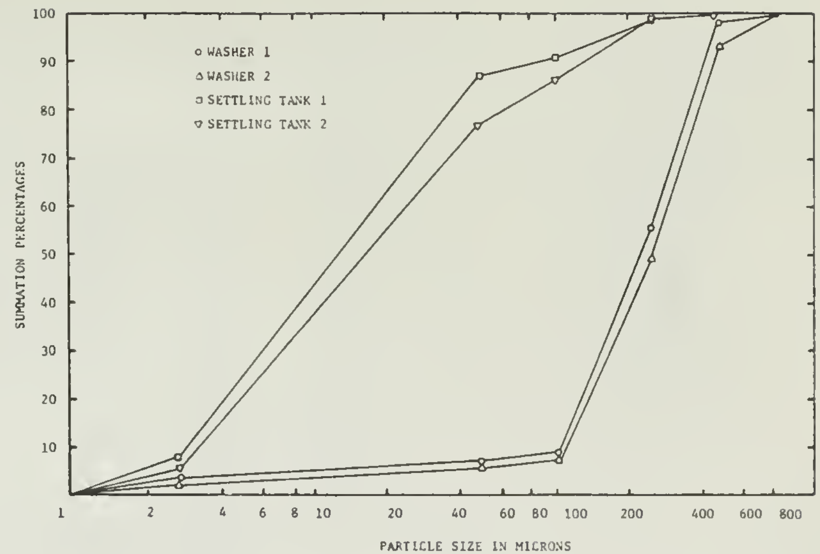


Figure A-32: Summation percentages vs. particle size for grit accumulated in the prototype system, Trial 4, Spring, 1976, when processing turnip greens.

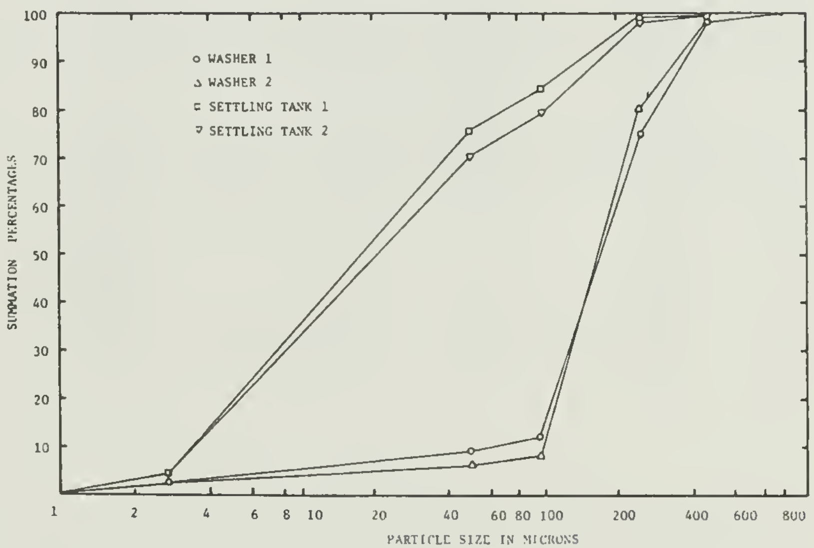


Figure A-33: Summation percentages vs. particle size for grit accumulated in the prototype system, Trial 5, Spring, 1976, when processing turnip greens.

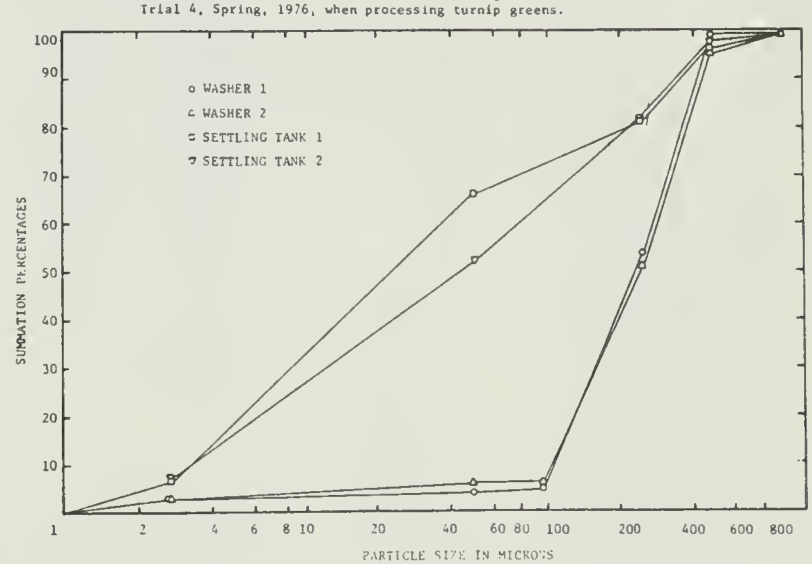


Figure A-34: Summation percentages vs. particles for grit accumulated in the prototype system, Trial 6, Spring, 1976, when processing turnip greens.

APPENDIX B

TABLE B-1. TOTAL INSECTS ON PRODUCT SAMPLES[a] OF SPINACH GREENS, TRIAL 5, FALL, DECEMBER 15, 1975

Site	Hours of Operation 1.0	2.0	3.0	4.0
1	1	12	7	0
3	1	0	6	1
4	0	10	4	0

[a]100 gram samples, replicated values.

TABLE B-2. TOTAL INSECTS ON SAMPLES[a] OF SPINACH GREENS, TRIAL 1, SPRING, APRIL 22, 1976.

Site	Hours of Operation .25	1	2	3	4	5	6	7
1	0	-	-	0	2	1	0	0
3	0	-	-	0	0	1	0	0
4	0	-	-	1	0	1	0	0
7	0	0	0	0	1	-	-	-
9	0	0	0	0	0	-	-	-
10	1	3	2	0	0	-	-	-

[a]100 gram samples

TABLE B-3. TOTAL INSECTS AND FRAGMENT COUNTS ON PRODUCT SAMPLES[a] OF SPINACH GREENS, TRIAL 2, SPRING, MAY 12, 1976

	Hours of Operation													
Site	2		3		4		5		6		7		7.5	
	Ins.[d]	Frag.[c]	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.
7	12	2	18[b]	5[b]	71[b]	14[b]	91	23	3	3	10	4	7	0
9	8	2	0	1	50[b]	5[b]	86	27	5	9	4	2	5	1
10	11	9	4	5	8	2	42	18	8[b]	2[b]	4	4	3	1

[a]100 gram samples [b]Average of Two Values [c]Fragments [d]Insects

TABLE B-4. TOTAL INSECTS AND FRAGMENT COUNTS ON PRODUCT SAMPLES[a] OF SPINACH GREENS, TRIAL 3, SPRING. MAY 21, 1976

	Hours of Operation									
Site	.25		1		2		3		3.25	
	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.
12	8	3	5	5	3	1	4	3	3	0
14	1	0	3	4	5	4	2	3	1	1
15	2	0	1	0	0	2	1	0	0	0

[a]100 gram samples

TABLE B-5. TOTAL INSECTS AND FRAGMENT COUNTS ON PRODUCT SAMPLES[a] OF TURNIP GREENS, TRAIL 4, SPRING, JUNE 4, 1976

Site	Hours of Operation											
	.25		1		2		3		4		5.5	
	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.
1	0	1	1	7	5	2	4	4	1	1	3	2
3	1	1	0	1	0	0	2	3	2	1	2	1
4	3	0	1	0	1	0	0	0	0	1	1	3
12	7	0	10	1	0	0	2	0	1	1	-	-
14	0	0	0	0	2	1	0	0	1	0	-	-
15	1	0	2	1	2	0	1	0	1	0	-	-

[a]100 gram samples

TABLE B-6. TOTAL INSECTS AND FRAGMENT COUNTS ON PRODUCT SAMPLES[a] OF TURNIP GREENS, TRIAL 5, SPRING, JUNE 10, 1976

Site	Hours of Operation													
	.25		1		2		3		4		5		6.5	
	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.
1	5	5	2	3	6	6	8	2	0	5	4	5	3	0
3	0	1	0	0	2	1	0	1	0	2	1	0	1	2
4	0	0	0	0	1	1	1	0	0	1	2	7	0	2
12	2	0	0	1	0	2	2	2	2	1	-	-	-	-
14	0	1	0	2	2	0	4	1	2	2	-	-	-	-
15	0	1	0	0	3	3	1	0	0	1	-	-	-	-

[a]100 gram samples

TABLE B-7. TOTAL INSECTS AND FRAGMENT COUNTS ON PRODUCT SAMPLES[a] OF TURNIP GREENS, TRIAL 6, SPRING JUNE 11, 1976

Site	Hours of Operation													
	.25		1		2		3		4		5		6	
	Ins.[c]	Frag.[b]	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.	Ins.	Frag.
1	7	6	12	5	8	3	0	0	0	0	4	3	0	0
3	4	0	3	1	0	1	2	0	0	0	0	0	0	0
4	0	0	0	1	0	1	1	0	0	0	0	0	2	0
12	1	0	0	0	0	0	0	0	-	-	-	-	-	-
14	0	1	0	0	0	0	1	0	-	-	-	-	-	-
15	1	0	0	0	0	0	0	1	-	-	-	-	-	-

[a]100 gram samples [b]Fragments [c]Insects

TABLE B-8. MILLIGRAMS OF GRIT PER KILOGRAM OF PRODUCT FOR TRIAL 1, SPRING, WASHING OF SPINACH GREENS, APRIL 22, 1976

Site	Hours of Operation						
	.25	1.5	2	3	4	5	7
1	-	4770	-	3510	-	2925	5775
3	-	2475	-	1710	-	1665	2280
4	-	1125	-	930	-	675	645
7	10350	-	9195	-	4740	-	-
9	4050	-	4215	-	2355	-	-
10	1845	-	2595	-	2085	-	-

TABLE B-9. MILLIGRAMS OF GRIT PER KILOGRAM OF PRODUCT FOR TRIAL 2, SPRING, WASHING OF SPINACH GREENS, MAY 12, 1976

	Hours of Operation			
Site	.83	3	5	7
7	6255	22275	4245	3510
9	1845	6525	1920	1920
10	1275	3765	1215	1080

TABLE B-10. MILLIGRAMS OF GRIT PER KILOGRAM OF PRODUCT FOR TRIAL 3, SPRING, WASHING OF SPINACH GREENS, MAY 21, 1976

	Hours of Operation	
Site	.25	2
12	1740	1890
14	1230	1230
15	660	900

TABLE B-11. MILLIGRAMS OF GRIT PER KILOGRAM OF PRODUCT FOR TRIAL 4, SPRING, WASHING OF TURNIP GREENS, JUNE 4, 1976

	Hours of Operation			
Site	.25	2	4	5
1	2070	1560	1530	690
3	1080	855	1035	675
4	675	765	660	480
12	855	1185	750	-
14	615	750	285	-
15	375	630	270	-

TABLE B-12. MILLIGRAMS OF GRIT PER KILOGRAM OF PRODUCT FOR TRIAL 5, SPRING, WASHING OF TURNIP GREENS, JUNE 10, 1976

	Hours of Operation			
Site	.25	2	4	6.5
1	1005	945	1230	615
3	300	352	1410	451
4	195	300	345	242
12	615	1395	1005	-
14	300	720	570	-
15	345	510	465	-

TABLE B-13. MILLIGRAMS OF GRIT PER KILOGRAM OF PRODUCT FOR TRIAL 6, SPRING, WASHING OF TURNIP GREENS, JUNE 11, 1976

	Hours of Operation			
Site	.25	2	4	6.5
1	1080	1740	915	840
3	345	840	660	840
4	150	330	375	480
12	1125	750	1935	-
14	675	630	945	-
15	435	435	510	-

TABLE B-14. TOTAL PLATE COUNT[a] (COLONIES X10^3 PER GRAM) ON PRODUCT FROM PROTOTYPE FOR TRIAL 2, FALL, WASHING OF COLLARD GREENS, NOVEMBER 4, 1975

	Hours of Operation			
Site	0.25	2	4	6
1	1.7	7.3	3.5	1.7
3	4.1	11.6	54.5	2.7
4	6.0	5.3	11.2	8.3

[a]Each value is average of two readings.

TABLE B-15. TOTAL PLATE COUNT (COLONIES X10^3 PER GRAM) ON PRODUCT FROM PROTOTYPE FOR TRIAL 3, FALL, WASHING OF COLLARD GREENS, NOVEMBER 20, 1975

	Hours of Operation			
Site	1	3	5	7
1	682.0	1227.0	350.0	359.0
3	509.0	473.0	109.0	682.0
4	250.0	163.0	1418.0[a]	80.0

[a]Single value, other values are average of two readings.

TABLE B-16. TOTAL PLATE COUNT (COLONIES[a] X10^3 PER GRAM) ON PRODUCT FROM PROTOTYPE FOR TRIAL 4, FALL, WASHING OF COLLARD GREENS, DECEMBER 1, 1975

	Hours of Operation							
Site	0.25	1	2	3	4	5	6	7
1	160.0[b]	140.0	290.0	420.0	150.0	430.0	630.0	180.0
3	180.0	20.0	-	100.0	350.0	30.0	4.0	120.0
4	80.0	520.0	40.0	100.0	650.0	50.0	4.0	70.0

[a]Gram positive rods.

[b]Single value, other values are average of two readings.

TABLE B-17. TOTAL PLATE COUNT (COLONIES X10^3 PER GRAM) ON PRODUCT FROM PROTOTYPE FOR TRIAL 5, FALL, WASHING OF SPINACH GREENS, DECEMBER 15, 1975

	Hours of Operation				
Site	0	1	2	3	4
1	600.0[b]	2090.0[c]	210.0[c]	820.0[c]	170.0[c]
3	710.0[a]	100.0[a]	230.0[c]	-	140.0[a]
4	255.0[c]	150.0[c]	1090.0[c]	110.0[c]	300.0[c]

[a]Average of two values. [b]Average of three values [c]Average of four or more values.

TABLE B-18. TOTAL PLATE COUNT (COLONIES X10^3 PER GRAM) FOR PRODUCT FROM PROTOTYPE AND CONVENTIONAL SYSTEMS FOR TRIAL 1, SPRING, WASHING OF SPINACH GREENS, APRIL 22, 1976

	Hours of Operation		
Site	.25	4	7
1	164.0	245.0	265.0
3	14.7	222.0	182.0
4	6.0	52.7	104.0
7	155.0	31.6	-
9	27.3	218.0	-
10	96.4	14.2	-

TABLE B-19. TOTAL PLATE COUNT (COLONIES X10^3 PER GRAM) FOR PRODUCT FROM CONVENTIONAL SYSTEM FOR TRIAL 2, SPRING, WASHING OF SPINACH GREENS, MAY 12, 1976

	Hours of Operation		
Site	2	4	7.5
7	35.5	95.5	0.6
9	2.1	1.2	0.4
10	1.6	0.9	2.9

TABLE B-20. TOTAL PLATE COUNT (COLONIES X10^3 PER GRAM) FOR PRODUCT FROM CONVENTIONAL SYSTEM FOR TRIAL 3, SPRING, WASHING OF SPINACH GREENS, MAY 21, 1976

	Hours of Operation		
Site	.25	2	3
12	3.3[a]	4.1[a]	136.0[a]
14	0.2[a]	2.6	1.8[a]
15	0.3	0.7	2.0[a]

[a]Average of two values.

TABLE B-21. TOTAL PLATE COUNT (COLONIES X10^3 PER GRAM) FOR PRODUCT FROM CONVENTIONAL SYSTEM FOR TRIAL 4, SPRING, WASHING OF TURNIP GREENS, JUNE 4, 1976

	Hours of Operation				
Site	.25	1	2	3	5.5
12	4.1	4.6	5.6	8.7	3.5
14	0.7	4.3	5.6	2.1	2.3
15	157.0	1.7	3.0	2.4	1.5

TABLE B-22. TOTAL PLATE COUNT (COLONIES X10^3 PER GRAM) FOR PRODUCT FROM PROTOTYPE AND CONVENTIONAL SYSTEMS FOR TRIAL 5, SPRING, WASHING OF TURNIP GREENS, JUNE 10, 1976

	Hours of Operation					
Site	.25	1	2	3	4	6.5
1	0.2	-	-	-	0.4	1.1
3	0.1	-	-	-	0.3	0.1
4	0.1	-	-	-	0.2	0.2
12	2.6	3.7	61.8	10.1	2.9	-
14	1.2	0.5	0.8	11.9	3.1	-
15	2.8	0.5	19.5	4.8	3.8	-

TABLE B-23. TOTAL PLATE COUNT[a] (COLONIES X10^3 PER GRAM) FOR PRODUCT FROM PROTOTYPE AND CONVENTIONAL SYSTEMS FOR TRIAL 6, SPRING, WASHING OF TURNIP GREENS, JUNE 11, 1976

	Hours of Operation					
Site	.25	1	2	3	4	6
1	2.32	-	-	-	0.9	10.7
3	0.7	-	-	-	0.6	0.6
4	0.3	-	-	-	0.4	0.3
12	20.5	2.3	15.7	8.1	1.4	-
14	0.4	9.1	2.8	1.7	1.9	-
15	1.5	29.3	2.4	6.2	1.6	-

[a]Average of two values.

APPENDIX C

TABLE C-1. TOTAL PLATE COUNT (COLONIES[a] X 10^3 PER MILLILITER) IN WASH WATER FROM PROTOTYPE FOR TRIAL 1, FALL, WASHING OF COLLARD GREENS, OCTOBER 24, 1975

	Hours of Operation		
Site	1	3	4
1	198.0	10.2	232.0
2	0.2	15.0	>30.0[b]
3	0.2	33.0	3.3
4	24.6	6.0	3.9
5	13.3	0.5	110.0
6	10.2	5.8	210.0

[a]Average of more than one value. [b]Insufficient dilutions before plating.

TABLE C-2. TOTAL PLATE COUNT (COLONIES X 10^3 PER MILLILITER) IN WASH WATER FROM PROTOTYPE FOR TRIAL 2, FALL, WASHING OF COLLARD GREENS, NOVEMBER 4, 1975

	Hours of Operation		
Site	0.25	1	4
1	15.8[c]	345.0[b]	1177.5[c]
2	24.7[c]	561.0[a]	1065.0[c]
3	11.0[c]	2.7[b]	9.2[b]
4	14.0[c]	7.6[c]	3.8[a]
5	13.7[c]	3.2[a]	12.7[b]
6	18.0[c]	1573.0[b]	1270.0[b]

[a]Average of two values. [b]Average of three values. [c]Average of four values.

TABLE C-3. TOTAL PLATE COUNT (COLONIES X 10^3 PER MILLILITER) IN WASH WATER FROM PROTOTYPE FOR TRIAL 3, FALL, WASHING OF COLLARD GREENS, NOVEMBER 20, 1975

	Hours of Operation		
Site	1	5	7
1	16.0	100.0	100.0
4	0.1	18.0	32.0

All values replicated. Colonies were 99% *Bacillus subtilis*.

TABLE C-4. TOTAL PLATE COUNT (COLONIES X 10^3 PER MILLILITER) IN WASH WATER FROM PROTOTYPE FOR TRIAL 4, FALL WASHING OF COLLARD GREENS, DECEMBER 1, 1975

	Hours of Operation		
Site	1	3	7
1	36.0[a]	3.9	9.2[a]
2	18.0[a]	7.8[a]	9.4[a]
3	-	-	2.8[a]
4	0.2[a]	-	2.9[a]
5	0.2	-	6.6[a]
6	16.1	5.3[a]	14.0

[a]Average of two values.

TABLE C-5. TOTAL PLATE COUNT (COLONIES X 10^3 PER MILLILITER) IN WASH WATER FROM PROTOTYPE FOR TRIAL 5, FALL, WASHING OF SPINACH GREENS, DECEMBER 15, 1975

	Hours of Operation		
Site	0	3	4
1	>3.0[b]	8.4[a]	15.5[a]
2	>3.0[b]	13.9[a]	10.1[a]
3	2.7	5.8[a]	3.2[a]
4	0.04[a]	24.9[a]	4.9[a]
5	0.04[a]	3.0[a]	5.0[a]
6	>3.0[b]	16.5[a]	12.9[a]

[a]Average of two values. [b]Insufficient dilutions before plating.

TABLE C-6. TOTAL PLATE COUNT (COLONIES X 10^3 PER MILLILITER) IN PROTOTYPE AND CONVENTIONAL WASH WATER, TRIAL 1, SPRING, WASHING OF SPINACH GREENS, APRIL 22, 1976

	Hours of Operation				
Site	.25	2	3	4	7
1	0.3	-	90.0	-	25.4
4	0.2	-	7.0	-	5.3
8	12.0	14.6	-	700.0	-
10	3.6	4.4	-	1860.0	-

TABLE C-7. TOTAL PLATE COUNT (COLONIES X 10^3 PER MILLILITER) IN WASH WATER OF CONVENTIONAL SYSTEM FOR TRIAL 3, SPRING, WASHING OF SPINACH GREENS, MAY 21, 1976

	Hours of Operation		
Site	.25	2	3.25
13	104.0[a]	34.0[a]	480.0[a]
15	142.0[a]	280.0	460.0

[a]Average of two values.

TABLE C-8. TOTAL PLATE COUNT (COLONIES X 10^3 PER MILLILITER) IN PROTOTYPE AND CONVENTIONAL WATER FOR TRIAL 4, SPRING, WASHING OF TURNIP GREENS, JUNE 4, 1976

	Hours of Operation			
Site	.25	2	3	5.5
1	>30.0[a]	-	200.0	30.0[a]
2	>30.0[a]	-	450.0	300.0[a]
4	>30.0[a]	-	390.0	600.0
13	>30.0[a]	63.0	-	38.0
15	>30.0[a]	85.0	-	31.0

[a]Insufficient Dilution.

TABLE C-9. TOTAL PLATE COUNT (COLONIES X 10^3 PER MILLILITER) IN PROTOTYPE AND CONVENTIONAL WATER FOR TRIAL 5, SPRING, WASHING OF TURNIP GREENS, JUNE 10, 1976

	Hours of Operation			
Site	.25	2	4	6.5
1	9.2	-	26.0	24.0
2	9.7	-	29.0	38.0
4	2.5	-	1.2	40.0
13	38.0	220.0	55.0	-
15	44.0	300.0	39.0	-

TABLE C-10. TOTAL PLATE COUNT (COLONIES X 10^3 PER MILLILITER) IN PROTOTYPE AND CONVENTIONAL WATER FOR TRIAL 6, SPRING, WASHING OF TURNIP GREENS, JUNE 11, 1976

	Hours of Operation			
Site	.25	2	4	6
1	19.5	-	25.0	23.0
2	106.0	-	51.5	31.0
4	-	-	7.5	6.0
13	49.0	290.0	160.0	-
15	70.0	130.0	260.0	-

TABLE C-11. TOTAL COLIFORM COUNT (COLONIES X 10^2 PER MILLILITER) IN WASH WATER FROM PROTOTYPE FOR TRIAL 1, FALL, WASHING OF COLLARD GREENS, OCTOBER 24, 1975

	Hours of Operation	
Site	3	4
1	1.00	>3.00[a]
2	0.32	0.02
4	0	0
6	0.06	54.0

[a]Insufficient dilution before plating.

TABLE C-12. TOTAL COLIFORM COUNT (COLONIES X 10^2 PER MILLILITER) IN WASH WATER FROM PROTOTYPE FOR TRIAL 2, FALL, WASHING OF COLLARD GREENS, NOVEMBER 4, 1975

	Hours of Operation		
Site	0.25	3	6
1	0.01	15.60	90.00
2	0.31[a]	11.75[a]	6.15[a]
4	0.11[a]	-	1.00
6	7.13[b]	39.00	5.10[b]

[a]Average of two values. [b]Average of three values.

TABLE C-13. TOTAL COLIFORM COUNT (COLONIES X 10^2 PER MILLILITER) IN WASH WATER FROM PROTOTYPE FOR TRIAL 3, FALL, WASHING OF COLLARD GREENS, NOVEMBER 20, 1975

	Hours of Operation		
Site	1	5	7
1	0.10	14.00[a]	4.00
4	-	0.05	22.00

[a]Average of three values.

TABLE C-14. TOTAL COLIFORM COUNT (COLONIES X 10^2 PER MILLILITER) IN WASH WATER FROM PROTOTYPE FOR TRIAL 4, FALL, WASHING OF COLLARD GREENS, DECEMBER 1, 1975

	Hours of Operation		
Site	1	3	7
1	336.0[b]	39.0[a]	91.4[b]
2	174.0[b]	78.0[b]	93.6[b]
3	-	-	28.0[b]
4	1.8[b]	-	29.0[b]
5	2.0[a]	-	18.0[a]
6	134.0	78.0[c]	127.0[b]

[a]Average of two values. [b]Average of four values. [c]Average of five values.

TABLE C-15. TOTAL COLIFORM COUNT (COLONIES X 10^2 PER MILLILITER) IN WASH WATER FROM PROTOTYPE FOR TRIAL 5, FALL, WASHING OF SPINACH GREENS, DECEMBER 15, 1975

	Hours of Operation		
Site	0	3	4
1	>10.00[b]	>10.00[b]	3.20
2	>10.00[b]	>10.00[b]	2.40[a]
4	-	>10.00[b]	-
5	-	-	14.00
6	>10.00[b]	>10.00[b]	21.60[a]

[a]Average of two values. [b]Insufficient dilutions before plating.

TABLE C-16. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 1, FALL, WASHING OF COLLARD GREENS, OCTOBER 24, 1975

	Hours of Operation				
Site	0.25	1	2	3	4
1	10[a]	79[a]	108[a]	98	109[a]
2	36	132	120	100	152[a]
3	8[a]	9[a]	17[a]	41[a]	20
4	2	6	2	12	34
5	8[a]	12[a]	10	33[a]	40
6	2	64	112	115[a]	124

[a]Average of two values.

TABLE C-17. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 2, FALL, WASHING OF COLLARD GREENS, NOVEMBER 4, 1975

Site	Hours of Operation 0.25	1	2	3	4	5	6
1	24[a]	37	58[a]	92	92[a]	119[a]	220[a]
2	32	47[a]	76	120[a]	128	155[a]	180[a]
3	20	11	15[a]	24	29[a]	22	64
4	10	16[a]	18	44[a]	36	58	72
5	18[a]	22	24[a]	12	44[a]	60	76
6	25	43[a]	76	134[a]	116	145[a]	210[a]

[a]Average of two values.

TABLE C-18. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 3, FALL, WASHING OF COLLARD GREENS, NOVEMBER 30, 1975

Site	Hours of Operation 1	3	5	7
1	52[a]	184	240	156
4	26[a]	44	68	225
6	-	188	-	-

[a]Average of two values.

TABLE C-19. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 4, FALL, WASHING OF COLLARD GREENS, DECEMBER 1, 1975

Site	Hours of Operation 0.25	1	2	3	4	5	6	7
1	15[a]	27[a]	162	69[a]	184	166	148[a]	200[a]
2	16[a]	53[a]	68[a]	94	230[a]	184	214[a]	232[a]
3	11	7	15	22	33	47	42	44
4	12[a]	10	10	37[a]	41	56[a]	46[a]	36[a]
5	67	10	18	31	48	60	48	20
6	16[a]	58	63[a]	96	211[a]	196	184[a]	200

[a]Average of two values.

TABLE C-20. ANALYTICAL CONCENTRATIONS[a] (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 5, FALL, WASHING OF SPINACH GREENS, DECEMBER 15, 1975

Site	Hours of Operation 0	1	2	3	4
1	39	384	720	752	689
2	32	491	802	902	632
3	16	112	199	224	227
4	29	137	217	274	280
5	18	121	207	274	274
6	41	456	766	902	712

[a]Average of two values in each case.

TABLE C-21. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 1, SPRING, WASHING OF SPINACH GREENS, APRIL 22, 1976

Site	Hours of Operation 0.25	1	2	3	4	5	6	7
1	243	637	1057	1213	913	797	750	938
2	314	1069	1537	1673	533	1130	690	1280
3	69	98	351	514	475	337	277	318
4	78	100	371	559	158	369	333	397
5	80	112	361	543	480	358	289	320
6	347	960	1485	1680	910	1101	827	1104
7	1321	2188	1252[a]	199	295	-	-	-
8	1277	2175	1145[a]	265	239	-	-	-
9	449	1219	849[a]	544	366	-	-	-
10	445	1156[a]	680[a]	471	379	-	-	-

[a]Average of two values.

TABLE C-22. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 2, SPRING, WASHING OF SPINACH GREENS, MAY 12, 1976

Site	Hours of Operation 2	3	4	5	6	7	7.5
7	2596[a]	6830[a]	1354	1047[a]	465[a]	953[a]	950
8	2464[a]	8306[a]	1386	996[a]	455[a]	1022[a]	929
9	1760[a]	3780[a]	2424[a]	1077[a]	515[a]	951[a]	1026
10	1612[a]	3716[a]	2195[a]	1041[a]	436[a]	851[a]	985

[a]Average of two values.

TABLE C-23. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 3, SPRING, WASHING OF SPINACH GREENS, MAY 21, 1976

Site	Hours of Operation 0.25	1	2	3	3.25
12	162	343	469[a]	523	446[a]
13	158	423	304[a]	490	419[a]
14	128	356	321	446[a]	376[a]
15	121	311	280	449[a]	416[a]

[a]Average of two values.

TABLE C-24. ANALYTICAL CONCENTRATION (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 4, SPRING, WASHING OF TURNIP GREENS, JUNE 4, 1976

	Hours of Operation					
Site	0.25	1	2	3	4	5.5
1	115	367	399	440[a]	588[a]	578[a]
2	324[a]	541	530[a]	476[a]	608[a]	635[a]
3	67	144	221	212[a]	275[a]	326[a]
4	117	228	200	258[a]	280[a]	329[a]
5	103	212	238	230[a]	316[a]	339[a]
6	323	513	494[a]	494[a]	603[a]	635[a]
12	53	128	230	119	81	-
13	62	155	227	166	125	-
14	53	115	185	115	79	-
15	54	93	164	119	72	-

[a]Average of two values.

TABLE C-25. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 5, SPRING, WASHING OF TURNIP GREENS, JUNE 10, 1976

	Hours of Operation						
Site	0.25	1	2	3	4	5	6.5
1	68	166	153	410[a]	274	158	132
2	94[a]	210	200	530[a]	333	187	155
3	27	75	40	160	149	101	68
4	27	85	40	168	110	69	72
5	23	77	90	120	158	65	157
6	87	152	229	471[a]	324	184	154
12	31	82	133	94	88	-	-
13	39	76	148	106	89	-	-
14	21	52	76	74	54	-	-
15	26	40	79	59	48	-	-

[a]Average of two values.

TABLE C-26. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF TOTAL SUSPENDED SOLIDS, TRIAL 6, SPRING, WASHING OF TURNIP GREENS, JUNE 11, 1976

	Hours of Operation						
Site	0.25	1	2	3	4	5	6
1	138	204	376[a]	365[a]	179	166	182
2	216	290	461[a]	430[a]	224	213	232
3	45	68	129[a]	134	79	71	89
4	62	91[a]	141	142	91	80	92
5	50	70	139	137	84	82	88
6	214[a]	278	476[a]	414	226	198	220
12	41	43	45	79	77	-	-
13	37	50	52	71	75	-	-
14	22	32	47	46	59	-	-
15	23	40	40	59	84	-	-

[a]Average of two values.

TABLE C-27. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 1, FALL, WASHING OF COLLARD GREENS, OCTOBER 24, 1975.

	Hours of Operation				
Site	0.25	1	2	3	4
1	1[a]	17[a]	36[a]	38	61[a]
2	2	44	46	50	70[a]
3	-	15[a]	13[a]	15[a]	14
4	2	2	4	18	34
5	5[a]	12[a]	18	20[a]	34
6	-	28	33[a]	53[a]	80

[a]Average of two values.

TABLE C-28. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 2, FALL, WASHING OF COLLARD GREENS, NOVEMBER 4, 1975.

	Hours of Operation						
Site	0.25	1	2	3	4	5	6
1	13[a]	27	41[a]	68	80[a]	96[a]	155[a]
2	20	36[a]	56	82[a]	108	125[a]	145[a]
3	7	9	15[a]	26	25[a]	-	40
4	9	15[a]	14	29[a]	32	42	56
5	10[a]	13	22[a]	10	39[a]	46	64
6	14	30[a]	58	94[a]	84	115[a]	135[a]

[a]Average of two values

TABLE C-29. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 3, FALL, WASHING OF COLLARD GREENS, NOVEMBER 20, 1975

	Hours of Operation			
Site	1	3	5	7
1	46[a]	106	120	108
4	29[a]	44	50	150
6	-	120	-	-

[a]Average of two values.

TABLE C-30. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 4, FALL, WASHING OF COLLARD GREENS, DECEMBER 1, 1975

	Hours of Operation							
Site	0.25	1	2	3	4	5	6	7
1	8	17[a]	124	36[a]	70	76	82[a]	114[a]
2	6[a]	27[a]	37[a]	48	84[a]	100	94[a]	100[a]
3	-	6	12	8	24	27	32	20
4	1[a]	-	10	33[a]	26	38[a]	37[a]	14[a]
5	2	10	15	21	27	36	44	-
6	6[a]	20	36[a]	64	71[a]	80	116[a]	72

[a]Average of two values.

TABLE C-31. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 5, FALL, WASHING OF SPINACH GREENS, DECEMBER 15, 1975

	Hours of Operation				
Site	0	1	2	3	4
1	5	39	66	61	57
2	4	52	69	66	32
3	2[a]	13	19	17	20
4	4	14	31	25	27
5	5	18	23	29	29
6	6[a]	45	68	54	40

[a]Single values, all others are average of two readings.

TABLE C-32. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 1, SPRING, WASHING OF SPINACH GREENS, APRIL 22, 1976.

	Hours of Operation							
Site	0.25	1	2	3	4	5	6	7
1	26	68	112	182	180	144	153	150
2	36	103	164	257	92	188	131	188
3	8	14	41	74	91	70	55	55
4	9	17	44	88	31	72	61	58
5	11	26	44	82	93	72	60	54
6	40	90	160	259	183	206	156	163
7	134	241	123[a]	22	62	-	-	-
8	136	228	114[a]	25	54	-	-	-
9	50	144	106[a]	58	71	-	-	-
10	47	137[a]	77[a]	52	71	-	-	-

[a]Average of two values.

TABLE C-33. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 2, SPRING, WASHING OF SPINACH GREENS, MAY 12, 1976

	Hours of Operation						
Site	2	3	4	5	6	7	7.5
7	190[a]	306[a]	138	156[a]	55	81[a]	77
8	177[a]	521[a]	160	152[a]	65	84[a]	77
9	161[a]	278[a]	200[a]	165[a]	72	90[a]	85
10	145[a]	267[a]	184[a]	164[a]	70	86[a]	86

[a]Average of two values.

TABLE C-34. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 3, SPRING, WASHING OF SPINACH GREENS, MAY 21, 1976

	Hours of Operation				
Site	0.25	1	2	3	3.25
12	20	60	64[a]	95	79[a]
13	21	67	50[a]	83	75[a]
14	20	67	57	93[a]	77[a]
15	15	62	55	85[a]	88[a]

[a]Average of two values.

TABLE C-35. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 4, SPRING, WASHING OF TURNIP GREENS, JUNE 4, 1976

	Hours of Operation					
Site	0.25	1	2	3	4	5.5
1	18	41	45	54	65	65
2	36[a]	58	63[a]	61[a]	68[a]	67[a]
3	10	20	29	32[a]	34[a]	41[a]
4	19	32	30	38[a]	36[a]	41[a]
5	15	28	35[a]	35[a]	59[a]	42[a]
6	34	51	61[a]	63[a]	71[a]	71[a]
12	12	15	21	15	12	-
13	12	20	21	18	15	-
14	16	21	22	1	15	-
15	15	17	21	20	13	-

[a]Average of two values.

TABLE C-36. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 5, SPRING, WASHING OF TURNIP GREENS, JUNE 10, 1976

	Hours of Operation						
Site	0.25	1	2	3	4	5	6.5
1	7	18	17	64[a]	42	26	22
2	12[a]	28	26	77[a]	45	30	25
3	4	8	-	40	15	12	12
4	8	12	-	38	11	13	13
5	1	11	11	35	16	12	27
6	6	14	34	76[a]	52	28	25
12	13	20	21	17	16	-	-
13	15	15	19	19	16	-	-
14	13	25	21	17	16	-	-
15	12	17	20	16	15	-	-

[a]Average of two values.

TABLE C-37. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF VOLATILE SUSPENDED SOLIDS, TRIAL 6, SPRING, WASHING OF TURNIP GREENS, JUNE 11, 1976

	Hours of Operation						
Site	0.25	1	2	3	4	5	6
1	25	49	56[a]	46[a]	28	23	22
2	39	73	102[a]	55[a]	29	25	28
3	9	17	23[a]	22	15	10	14
4	14	21[a]	23	24	15	14	15
5	11	17	22	23	15	16	15
6	41[a]	85	64[a]	54[a]	26	25	25
12	8	7	9	10	9	-	-
13	8	8	8	11	10	-	-
14	10	11	9	11	9	-	-
15	9	10	8	8	11	-	-

[a]Average of two values.

TABLE C-38. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF CHEMICAL OXYGEN DEMAND, TRIAL 1, FALL, WASHING OF COLLARD GREENS, OCTOBER 24, 1975

	Hours of Operation				
Site	0.25	1	2	3	4
1	26	91	136	173	262
2	33	132	169	207	346
3	10	33	45	69	103
4	8	47	57	96	144
5	8[a]	45	47	93	132
6	20	110	132	206	303

[a]Single value, all others are average of two values.

TABLE C-39. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF CHEMICAL OXYGEN DEMAND, TRIAL 2, FALL, WASHING OF COLLARD GREENS, NOVEMBER 4, 1975

	Hours of Operation						
Site	0.25	1	2	3	4	5	6
1	45	92	184	304	355	430	439
2	49	129	214	349	453	492	428
3	25	35	59	98	131	172	103
4	33	41	76	123	123	209	219
5	31	41	75	117	148	201	232
6	47	102	192	355	394	414	557

[a]Average of two values in each case.

TABLE C-40. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF CHEMICAL OXYGEN DEMAND, TRIAL 3, FALL, WASHING OF COLLARD GREENS, NOVEMBER 20, 1975

	Hours of Operation			
Site	1	3	5	7
1	149	378	458	400
4	93	186	194	264
6	-	409	-	-

[a]Average of two values in each case.

TABLE C-41. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF CHEMICAL OXYGEN DEMAND, TRIAL 4, FALL, WASHING OF COLLARD GREENS, DECEMBER 1, 1975

	Hours of Operation								
Site	0	0.25	1	2	3	4	5	6	7
1	12	24	86	96	204	244	275	292	321
2	-	26	140	158	234	290	315	359	367
3	16	20	36	192	67	81	87	106	112
4	-	28	58	68	89	108	110	131	230
5	2	24	40	66	91	87	117	127	127
6	-	29	42	238	220	265	290	330	341

[a]Average of two values in each case.

TABLE C-42. ANALYTICAL CONCENTRATIONS[a] (mg/l) OF CHEMICAL OXYGEN DEMAND, TRIAL 5, FALL, WASHING OF SPINACH GREENS, DECEMBER 15, 1975

	Hours of Operation				
Site	0	1	2	3	4
1	25	113	171	200	211
2	25	115	194	240	246
3	25	62	79	98	95
4	16	63	112	129	113
5	31	59	88	130	115
6	35	129	183	240	214

[a]Average of two values in each case.

TABLE C-43. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF CHEMICAL OXYGEN DEMAND, TRIAL 1, SPRING, WASHING OF SPINACH GREENS, APRIL 22, 1976

	Hours of Operation							
Site	0.25	1	2	3	4	5	6	7
1	82[a]	161[a]	313	433[a]	463[a]	431[a]	388[a]	378[a]
2	89[a]	194[a]	354	579	765[a]	538[a]	509[a]	464
3	47[a]	106	76	173	220	170[a]	132	136
4	63	124	136[a]	203[a]	347[a]	185[a]	164[a]	168[a]
5	109	72[a]	105	183	229	181	145	152
6	114	318[a]	343[a]	563[a]	641[a]	414[a]	492[a]	492[a]
7	274	506	271[a]	49	164[a]	-	-	-
8	261[a]	514	204	53	168[a]	-	-	-
9	117	247	97[a]	69	155	-	-	-
10	113[a]	277[a]	96	84[a]	134	-	-	-

[a]Average of two values.

TABLE C-46. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF CHEMICAL OXYGEN DEMAND, TRIAL 4, SPRING, WASHING OF TURNIP GREENS, JUNE 4, 1976

	Hours of Operation					
Site	0.25	1	2	3	4	5.5
1	60	141	163	243	255	288
2	77[a]	152[a]	200[a]	269[a]	282[a]	316[a]
3	43	90	102	157	149	204
4	45[a]	82[a]	108[a]	151[a]	159[a]	205[a]
5	47	94	114	157	157	208
6	87[a]	141[a]	190[a]	256[a]	283[a]	306[a]
12	60[a]	141	185[a]	167[a]	137[a]	-
13	63	145	188	161	125	-
14	67[a]	192	263[a]	233[a]	190[a]	-
15	61	196	259	237	190	-

[a]Average of two values.

TABLE C-44. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF CHEMICAL OXYGEN DEMAND, TRIAL 2, SPRING, WASHING OF SPINACH GREENS, MAY 12, 1976

	Hours of Operation						
Site	2	3	4	5	6	7	7.5
7	280[a]	557[a]	154[a]	279[a]	113[a]	221[a]	210[a]
8	222	224	139	249	87	208	202
9	277[a]	386[a]	267[a]	247[a]	128	192[a]	205[a]
10	236	385	301	274[a]	111	149	190[a]

[a]Average of two values.

TABLE C-45. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF CHEMICAL OXYGEN DEMAND, TRIAL 3, SPRING, WASHING OF SPINACH GREENS, MAY 21, 1976

	Hours of Operation				
Site	.25	1	2	3	3.25
12	80[a]	237[a]	252[a]	309[a]	304[a]
13	85	236	190[a]	321	349
14	82[a]	219[a]	213[a]	308[a]	375[a]
15	71	222	186[a]	301	329

[a]Average of two values.

TABLE C-47. ANALYTICAL CONCENTRATION (mg/ℓ) OF CHEMICAL OXYGEN DEMAND, TRIAL 5, SPRING, WASHING OF TURNIP GREENS, JUNE 10, 1976

	Hours of Operation						
Site	0.25	1	2	3	4	5	6.5
1	32	78[a]	155[a]	216[a]	151[a]	155	135[a]
2	28	102	157	220	178	149	153[a]
3	19[a]	45[a]	106[a]	122[a]	72[a]	61[a]	67
4	16	18	63	118	82	67	63
5	16[a]	38[a]	60[a]	119[a]	87[a]	55[a]	159[a]
6	44	98	149	243	169	145	141
12	65[a]	88[a]	199[a]	193[a]	186[a]	-	-
13	49[a]	69	200	184	180[a]	-	-
14	40[a]	133[a]	295[a]	225[a]	228[a]	-	-
15	41	92	235	222	204	-	-

[a]Average of two values.

TABLE C-48. ANALYTICAL CONCENTRATION (mg/ℓ) OF CHEMICAL OXYGEN DEMAND, TRIAL 6, SPRING, WASHING OF TURNIP GREENS, JUNE 11, 1976

	Hours of Operation						
Site	0.25	1	2	3	4	5	6
1	92[a]	185[a]	194[a]	178[a]	114[a]	104[a]	112[a]
2	144	240	228[a]	200	138[a]	120	124
3	38[a]	68[a]	92	98[a]	61[a]	56[a]	65[a]
4	44	80	104	98[a]	66	57[a]	70
5	47[a]	79[a]	122[a]	90[a]	66[a]	55[a]	72[a]
6	136	240	228	200	124	116[a]	130[a]
12	36[a]	64[a]	93[a]	89[a]	115[a]	-	-
13	36[a]	60	99[a]	74	115[a]	-	-
14	35[a]	86[a]	133[a]	112[a]	157[a]	-	-
15	32	76	92[a]	52	166[a]	-	-

[a]Average of two values.

TABLE C-50. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF FIVE-DAY BIOCHEMICAL OXYGEN DEMAND, TRIAL 2, FALL, WASHING OF COLLARD GREENS NOVEMBER 4, 1975

	Hours of Operation						
Site	0.25	1	2	3	4	5	6
1	8	24[a]	44	62	95[a]	108	97
2	11	30	45	88	89[a]	134	103[a]
3	4	8	11[a]	24[a]	28	35	20[a]
4	3	5	12	25	18	35	59
5	4	6	8	21[a]	27[a]	47	46
6	10	21	50	87	114	98	91[a]

[a]Average of two values, other values are average of three.

TABLE C-53. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF FIVE-DAY BIOCHEMICAL OXYGEN DEMAND, TRIAL 5, FALL, WASHING OF SPINACH GREENS, DECEMBER 15, 1975

	Hours of Operation			
Site	1	2	3	4
1	30[b]	49[b]	44[b]	46[b]
2	30[b]	52[c]	57[b]	39[a]
3	5[a]	24[b]	25[c]	22[a]
4	8[a]	21[b]	32[c]	22[a]
5	8[a]	22[b]	32[b]	19[b]
6	21[b]	47[b]	51[c]	32[c]

[a]Average of two values. [b]Average of three values. [c]Average of four values.

TABLE C-49. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF FIVE-DAY BIOCHEMICAL OXYGEN DEMAND, TRIAL 1, FALL, WASHING OF COLLARD GREENS, OCTOBER 24, 1975

	Hours of Operation			
Site	1	2	3	4
1	28	31	47[b]	81[a]
2	17	34[b]	54[b]	89
3	9	8	16[b]	20[b]
4	10	15[a]	23[a]	36[a]
5	18[b]	10	23[b]	36[a]
6	30[a]	17	57[a]	75[a]

[a]Average of two values. [b]Average of three values.

TABLE C-51. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF FIVE-DAY BIOCHEMICAL OXYGEN DEMAND, TRIAL 3, FALL, WASHING OF COLLARD GREENS, NOVEMBER 20, 1975

	Hours of Operation		
Site	1	5	7
1	-	48[a]	77[a]
4	22	38	41

[a]Average of two values.

TABLE C-52. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF FIVE-DAY BIOCHEMICAL OXYGEN DEMAND, TRIAL 4, FALL, WASHING OF COLLARD GREENS, DECEMBER 1, 1975

	Hours of Operation							
Site	0.25	1	2	3	4	5	6	7
1	3	27[b]	50[b]	60[b]	77[a]	75[a]	88[c]	76[b]
2	4[a]	31[c]	52[b]	71[c]	87[b]	91[c]	116[c]	97[b]
3	5	12[a]	14[a]	19[a]	20[a]	22[a]	30[a]	35[a]
4	2	14[a]	15[a]	22[a]	19[a]	30[a]	36[a]	39[a]
5	6[a]	9[a]	20[a]	27	26	39	42	38[a]
6	8[a]	29[b]	53[c]	72[b]	77[c]	99[c]	101[c]	24

[a]Average of two values. [b]Average of three values. [c]Average of four values.

TABLE C-54. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF 20-DAY BIOCHEMICAL OXYGEN DEMAND, TRIAL 1, FALL, WASHING OF COLLARD GREENS, OCTOBER 24, 1975

	Hours of Operation
Site	4.0
1	99
2	105
3	10
4	21
5	38
6	93

TABLE G-55. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF 20-DAY BIOCHEMICAL OXYGEN DEMAND, TRIAL 2, FALL, WASHING OF COLLARD GREENS, NOVEMBER 4, 1975

	Hours of Operation				
Site	1	2	3	5	6
6	45[a]	107	169	242[a]	247[a]

[a]Average of two values.

TABLE C-56. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF 20-DAY BIOCHEMICAL OXYGEN DEMAND TRIAL 4, FALL, WASHING OF COLLARD GREENS, DECEMBER 1, 1975

	Hours of Operation	
Site	0.25	1.0
1		35[b]
2	12	50[c]
3	18	10[a]
4	-	13[a]
5	-	6[a]
6	0	37[b]

[a]Average of two values. [b]Average of three values. [c]Average of four values.

TABLE C-57. ANALYTICAL CONCENTRATIONS (mg/ℓ) OF 20-DAY BIOCHEMICAL OXYGEN DEMAND, TRIAL 5, FALL, WASHING OF SPINACH GREENS, DEC., 15, 1975

	Hours of Operation				
Site	0	1	2	3	4
1	14[a]	35[c]	41[b]	69[b]	58[c]
2	15[a]	37[c]	60[c]	84[b]	23[b]
3	12[a]	6[a]	28[b]	30[c]	21[a]
4	17[a]	13[a]	30[b]	43[c]	34[a]
5	17[a]	12[a]	27[a]	43[c]	34[a]
6	13[a]	31[b]	62[c]	37[c]	62[c]

[a]Average of two values. [b]Average of three values. [c]Average of four values.

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

1. REPORT NO. EPA-600/2-77-135	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Minimization of Water Use in Leafy Vegetable Washers		5. REPORT DATE July 1977 issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Malcolm E. Wright Robert C. Hoehn (Civil Engr. Dept. - VPI & SU)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Agricultural Engineering Department Virginia Polytechnic Institute & State University Blacksburg, VA 24061		10. PROGRAM ELEMENT NO. 1BB610 11. CONTRACT/GRANT NO. S-802958
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Lab - Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 5/1/74 - 1/31/77 14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This project was undertaken to construct and test an improved leafy greens washing system employing water recirculation, to characterize the quality of the wash water and waste stream and to make comparisons to conventional washers. The prototype system produced a cleaner product while reducing water requirements and consolidating waste loads. The prototype system consisted of two drum immersion washers in series, each with associated moving belt screens, settling tanks and water recirculation systems. Construction was similar to conventional washers but with modifications to improve removal of floating trash and increase hydraulic agitation of product. The prototype was tested in a commercial processing plant during the fall and spring harvesting seasons, 1975-76. Sixty-seven metric tons of collards, spinach, and turnip greens were processed through the prototype in 52 hours of actual operating time. Conventional washers were monitored for 27 hours (38 tons) for comparison. Insect and bacteria counts, COD, TSS, VSS, and several other water and product parameters were measured at predetermined times and locations. Data were obtained to predict expected waste loads from the products processed. Wastewater discharge from the prototype was approximately 1/12 that of the conventional washers.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Food Processing, Circulation, Canneries, Freezers, Water Quality	Leafy-vegetable processing, Process modification, Washing systems, Water reuse	13/B

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* UNCLASSIFIED 20. SECURITY CLASS *(This page)* UNCLASSIFIED	21. NO. OF PAGES 105 22. PRICE

EPA Form 2220-1 (9-73)

U. S. GOVERNMENT PRINTING OFFICE 1977-757-056/6499 Region No. 5-11

TX 601 .Un3 2816

United States. Environmental
Protection Agency.

Minimization of Water Use in
Leafy Vegetable Washers.

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Technical Information Staff
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U.S. ENVIRONMENTAL PROTECTION AGENCY
EPA-335

Special Fourth-Class Rate
Book

If your address is incorrect, please change on the above label; tear off; and return to the above address.
If you do not desire to continue receiving this technical report series, CHECK HERE ☐*; tear off label, and return it to the above address.*