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Characterization and Utilization Of Waste From Ocean Quahog And Surf Clam Processing Plants

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A REPORT

on

CHARACTERIZATION AND UTILIZATION OF WASTE FROM OCEAN QUAHOG AND SURF CLAM PROCESSING PLANT

Civil Engineering
Section

by

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INTRODUCTION

The first step in preparing surf clams (Spisula solidissima) and ocean quahog clams (Arctica islandica) for market is removing the organism from the shell and separating the usable portion of the meat from, inedible parts. Seven processing plants in Virginia employ a combination of manual and mechanical processes to accomplish this shucking and separation (Figure 1). These plants are classified under the U. S. Department of Commerce Standard Industry Classification code 9023, subcategory x, Mechanized Clam Processing.

The plants are located adjacent to salt water tidal creeks or the Chesapeake Bay. They are, in most cases, in fairly remote locations without access to municipal wastewater collection and treatment systems. Wastewater generated during the shucking process currently is disposed by discharging it directly into nearby salt water creeks after only minimal treatment. Severe deteriorations in water quality have been observed in the salt creeks near the discharge points (Lundsford, 1980 and Smithson, 1987 and 1988). Virginia's State Water Control Board is taking steps to limit future deterioration by imposing more stringent effluent limitations on the processing plants in new National Pollutant Discharge Elimination System (NPDES) permits. This will impose significant economic and technical hardship on the industry as meeting these new limitations will require changes in plant operations to reduce water use and wastewater generation and will mean implementing significantly greater amounts of wastewater treatment.

During the shucking process, large volumes of fresh water are used, and correspondingly, large volumes of wastewater are generated. The wastewater contains large amounts of dissolved and suspended organic m material and solids. The concentrations of organic material and solids vary greatly between plants and over time at each plant. These variations are not well understood, which creates problems when designing waste treatment facilities or when imposing realistic effluent discharge limitations.

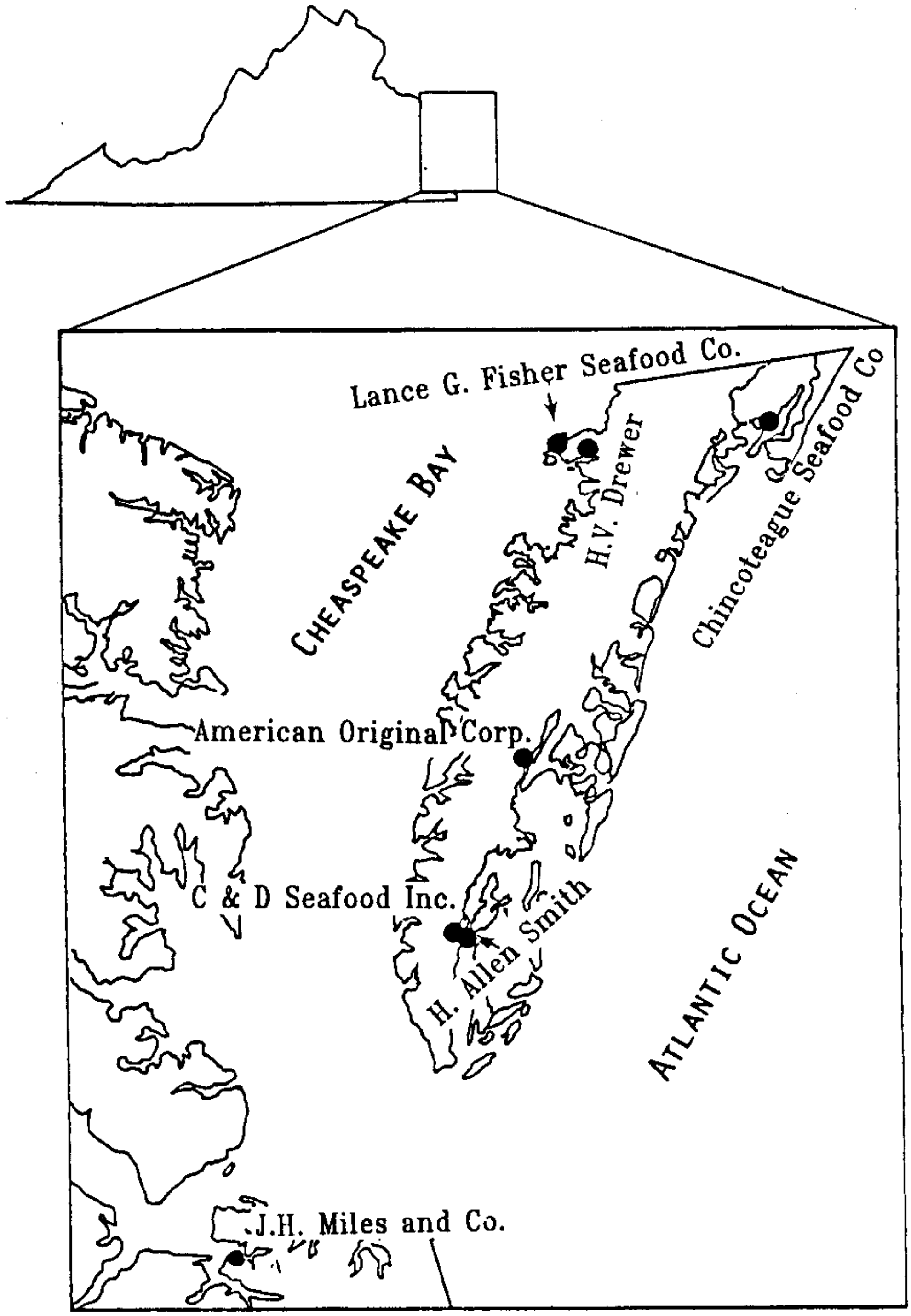


Figure 1: Map showing the location of Virginia clam processing plants

In addition to liquid wastewater, solid wastes such as discarded shell material and the unused portion of the organism are also generated and must be disposed. These wastes contain a large amount of organic material and are very putrescible. Solid wastes currently are disposed of at sea or in landfills. Increased hauling costs and landfill charges, along with limitations on disposal options, make these methods of disposal unacceptable. Stabilizing these solids and converting them into marketable products are of great interest to the industry.

The purpose of this study was to investigate the wastes generated during the shucking process and evaluate waste-reduction and resource-recovery options available to the industry. Specific objectives were: 1.) to study the water use patterns in the processing plants and to identify ways of reducing water-use; 2.) study the generation of wastewater and to measure the generation of organic and solids loadings from the different points in the process line; 3.) characterize the physical and chemical characteristics of liquid and solid wastes generated during the shucking process; 4.) evaluate available technologies for treating these wastes; 5.) evaluate the potential for converting wastes into usable products by resource recovery; and 6.) help evaluate the economic impact of stricter effluent limitations on the Virginia clam-processing industry by comparison with the effluent limitations imposed on similar plants in other East Coast states.

These objectives were met by: 1.) visiting three clam-processing plants to develop an understanding of the processes used by the industry and to identify the major points of waste generation within the process stream; 2.) sampling the waste at different locations in the plants and the final wastewater effluent; 3.) analyzing the physical and chemical characteristics of the different liquid and solid wastes; 4.) identifying the potential for resource recovery from the wastes; 5.) searching the literature for information on the feasibility of recovering such products; and, 6.) conducting bench-scale experiments to confirm that the waste could indeed be used as a resource.

LITERATURE REVIEW

Description of the Processing Scheme

A number of researchers have described the clam shucking process (Zall and Hood, 1979, Zall et al., 1976, Carawan et al., 1979, and Burnette et al., 1983). The process is similar in all mechanized shucking plants with minor differences in the actual layout. Understanding the process is important when trying to understand the generation of wastes.

The clams are collected by hydraulic dredging off the Atlantic coast of the North Central U.S. They are placed in steel 1.13 cubic meter (m^3) (32 bushel), steel cages after very minimal sorting. The cages are transported to shore by the dredging ships and unloaded at the processing plant, or if the plant is some distance away, onto refrigerated trucks for overland transport. At the plant, cages are stored in large refrigerated rooms until needed, generally less then 24 hours after dredging.

At the start of the processing line the cages are moved by forklift from the cold storage room and placed on a mechanical dumper. The clams are dumped onto a belt conveyer and carried to a heating step. In most plants there is some form of spray-washing as the clams move along the belt. This first washing removes sand and silt and other materials associated with the clams from the dredging process.

The clams are carried on belt conveyers to propane-fired, tunnel ovens or to steam retorts for heating. This step heats the shell to denature the proteins of the adductor muscle attachment causing it to separate and allow the shell to open. The heating step is designed to detach the muscle from the shell without cooking the organism. This is only partly successful, and some cooking of the meat occurs (Rukma Reddy, personal communication). Some in the industry believe the clam meats derived by this heating followed by mechanical shucking process are somewhat lower in quality then hand-shucked product (Carawan et al., 1979).

After heating, the clams are placed in rotating horizontal drums designed to break the shells and separate the meat. There is generally a spray washing system inside the drum or immediately after it.

The clams are then dumped into flotation tanks where density separation in a saturated, sodium chloride (NaCl) brine or forced-air flotation are used to separate the meat from the shells. The shells, along with other inorganic solids, are removed from the bottom of tank by belt conveyers or dumped during shut down periods. The shells are carried out of the plant on belts and loaded onto trucks or dumped in piles for later loading. The separation process is not entirely efficient, and the shell material is manually inspected and sorted as it leaves the plant so that additional meat, which is still attached, can be recovered.

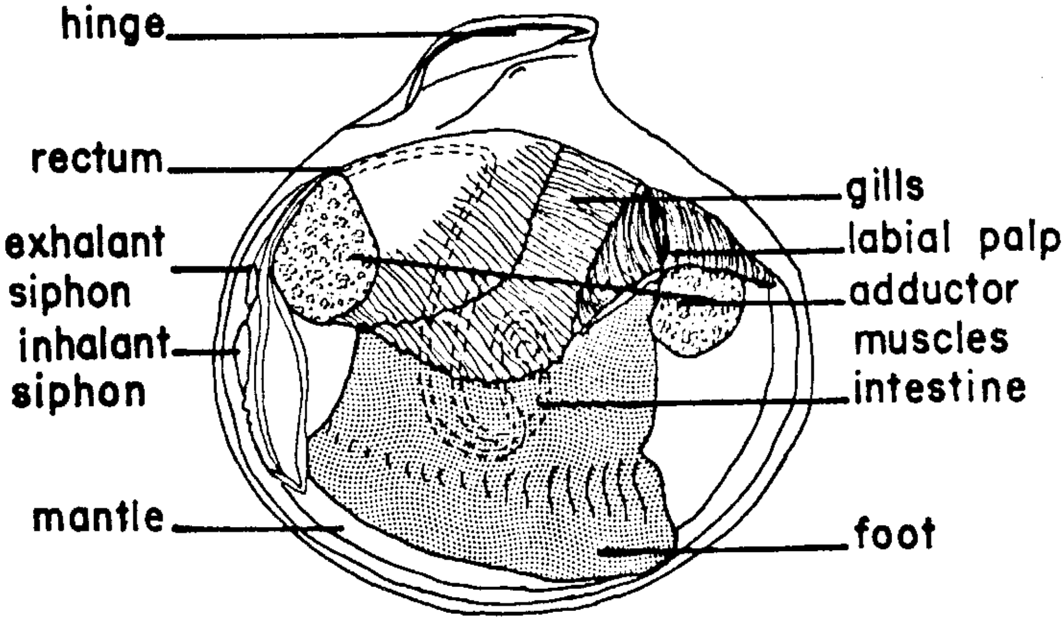
The clam meat is placed on either draining tables or vibrating belts to remove the brine for reuse and to dewater the meat. It is then carried on belts past a group of workers who sort the meat to remove any shells, burned meat or other impurities. These wastes are placed on belts and added to the shell-disposal system. The meat is placed in water flumes or on belts and carried on for further processing and separation into usable and waste portions (Figure 2). In less-mechanized plants, the meat is carried in large, stainless steel pails to sorting tables where it is sorted by hand to remove impurities.

In most plants, the meat is then sent to a hydraulic system, which detaches the intestinal tract from the rest of the clam. This viscera, or "belly" material, is placed on either dewatering screens or tables for draining and then is pumped out of the plant for disposal. In less-mechanized plants, the viscera is removed by hand at the sorting table and carried to collection points in the plant in stainless-steel pails. Depending on the final product desired, this debellying step may be skipped and the viscera left attached to the clam body.

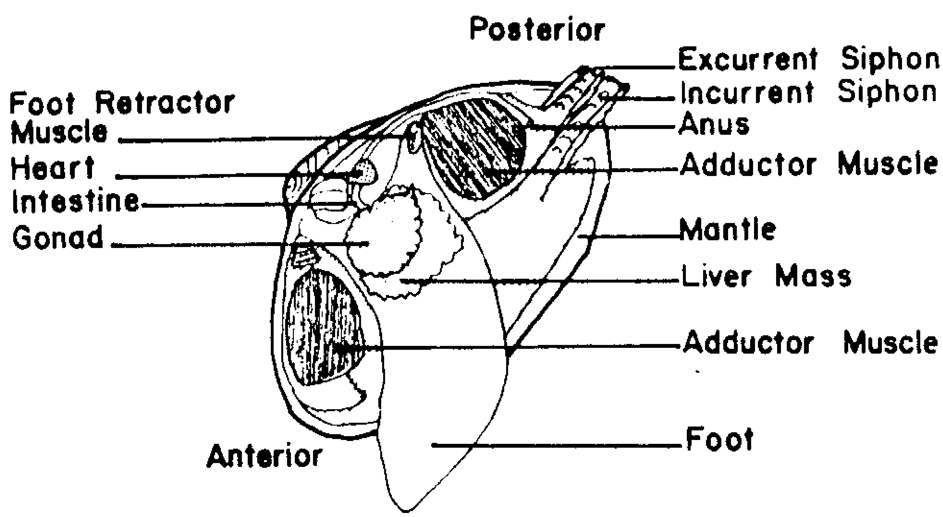
After debellying, the clam is separated into "tongue" and "salvage" portions. The tongue portion consist of the foot muscle and is used to prepare clam strips. Salvage consists of all other edible portions of the organism. The salvage portion is used to prepare soup and chowder products. In some plants, the clam is minced without separation, and the whole organism is used in soups and chowders. After separation, the different products are sorted and inspected, washed, chilled, and packed in ice or frozen for shipment to other facilities for further processing.

Water Use in Clam Shucking Plants

Zall et al. (1976) described the water usage at a manual shucking plant on Long Island. This plant used 30,000 - 40,000 gallons of water per day. The largest use of water was at three washing stations in the processing line.



QUAHOG CLAM



SURF CLAM

Figure 2: Anatomy of Quahog and Surf Clams

These washing operations accounted for about 30% of the total water use. Another 30% apparently was used to fill tanks and other systems during startup. The remainder was used throughout the day to replenish losses and for cleanup operations.

The EPA (1975) studied four mechanized shucking plants, and reported similar patterns of water use. They found that the first washing step accounted for 35% of total water use with second washing accounting for another 16%. Cleanup operations accounted for 22 to 45%.

Total water use has been reported for mechanized plants in Virginia and elsewhere. These range between about 50,000 and 400,000 at Virginia plants (Mashaw, 1988), and are similar to plants in other areas (EPA, 1988, and Rhode Island Department on Environmental Management, 1988)

Potential for Reducing Water Use

The EPA (1975) estimated that the amount of water used could be reduced by 12% through better "housekeeping" or modifications in the process line to reduce splashing, overflow, and other discharges. Brinsfield et al., (1978) estimated that turning off hoses when not in use, using spring-loaded hose nozzles, and encouraging plant personnel to conserve can reduce water use by 20%. Carawan et al. (1979) estimated that reductions of as much as 50% can be realized through better water management.

Waste Characterization

Wastewater

While a number of researchers have studied the physical and chemical characteristics of wastewater generated by manual clam shucking plants (Zall et al., 1976; Guida and Kugelman, 1986), published data describing the wastewater characteristics from mechanized shucking plants is somewhat limited.

In preparing effluent-limitation guidelines, the EPA studied four plants in the mid-Atlantic region (EPA, 1975). They reported the wastewater characteristics for two plants based on a total of nine samples, four from one plant and five from the other. From this limited survey they reported variations in five-day biochemical oxygen demand (BOD_5) of the effluent from 993 to 1590 milligrams per liter (mg/L) at one plant and 341 to 980 mg/L at the other. Chemical oxygen demand (COD) varied from 1050 to 2100 mg/L and from 633 to 2740 mg/L, respectively. While suspended solids ranged from 157 to 549 mg/L and from 179 to 534 mg/L respectively. Large variations in wastewater characteristics between plants and within each plant over time were reported.

Solid Wastes

Shell-waste material consists of the discarded shell along with a portion of meat that has not been removed during the shucking process (Zall et al., 1976) The shell are about 98 percent calcite and aragonite. The shell represents about 50-55% of the total weight of the clam, while usable meat represents about 30 percent. The rest is made up of water and belly material (table 4). In typical processing plants only about 80 percent of the meat is removed from the shell. The other 20 percent is discarded along with the shell solids. This discarded meat along with non-clam organic material, such as starfish and crab parts, make up about 10 percent of the shell weight (Zall et al., 1976).

Belly Waste

The solid waste referred to as the "belly" consists of the digestive system of the clam along with its contents. The bellies are 75 to 90% water and represent 3 to 8% of the total weight of the clam. They were slimy and difficult to handle and quickly become mephitic. Belly wastes reach high microbiological counts within a few hours of removal (Zall and Hood, 1979).

Waste Treatment

Physicochemical Treatment

Zall et al. (1976) have shown that centrifugation and coagulation/sedimentation are ineffective in reducing the organic load much further then plain settling. They reported reductions in organic load using coagulation followed by sedimentation ranging from 2.8% with alum and $FeCl_3$ to 15.7% with chitosan. They concluded that "opportunities for chemical-physical treatment do not appear promising".

Biological Treatment

Several studies have indicated that this waste is amenable to biological treatment (Creter and Lewandowski, 1975; Kugelman and Guida, 1986; Zall et al., 1976). The results of these studies suggest that it is technically feasible to achieve large reductions in organic material and suspended solids. Other factors, such as the availability of land to build treatment facilities, must be considered in evaluating the economic feasibility of such treatment systems.

Aerobic Treatment

Aerated lagoons are commonly used to treat wastewaters with high organic and solids loadings (Eckenfelder, 1980). Lagoons are not practical for the Virginia clam industry because they require large areas.

Activated sludge has been shown to be practical for the treatment of clam wastewater (Zall *et al*., 1976, and Kugelman and Guida, 1986). These studies confirmed that the BOD of clam wastewaters can be reduced by 95 to 98% in activated sludge systems at sludge ages of three to five days.

Creter and Lewandowski (1975) described the use of a portable activated sludge system for the treatment of wastewater from a small, oyster-processing plant. Because the waste from oyster processing is similar in composition to clam wastewater, this system may provide an indication of the treatment efficiency which can be achieved with similar treatment systems for clam wastewater. They observed BOD reductions of 80 to 90% at hydraulic retention times in the area of several hours for wastes with BOD levels of 400 to 1,200 mg/L.

Anaerobic Treatment

Anaerobic digestion is commonly used in the treatment of concentrated organic wastes. It can have the additional benefit of converting wastes with high organic content into intermediate- and high BTU gas for use as fuels (Klass, 1984). Anaerobic digestion has been used to treat a variety of food-processing wastes, including meat and poultry, vegetable, and beverage wastes (Totzke, 1987); however, it has not been applied to clam-processing wastes.

Wetlands

Kugelman and Guida (1986) have studied the use of wetlands to polish the effluent from aerobic treatment. They reported BOD, nutrient and solids removal efficiencies approaching 100 percent. Since the clam plants are located near salt marshes, it may be possible to use the marsh ecosystem to polish wastewaters from the clam-processing plants. State and federal regulatory agencies may not permit natural wetlands to be used for this purpose, but it may be possible to create artificial wetlands for waste treatment.

Compost

Solid wastes and sludges containing high organic contents can be stabilized and converted into usable products by composting under aerobic conditions (Haug, 1980). Composting is commonly used to reduce odor problems and to destroy pathogenic organisms in municipal and agricultural wastes. It has been used to treat a variety of food processing wastes (Kuter, 1987), but the potential for treating clam processing wastes has not been explored.

Resource Recovery

Products for Human Consumption

A number of researchers have studied converting clam wastes into edible products such as flavor extracts and clam juice. Burnette *et al.* (1983) converted liquids from processing of ocean quahog clams (*Arctica islandica*) into an acceptable flavor product and clam juice. Joh and Hood (1979) found that juices from hand shucking of surf clams (*Spisula solidissima*) could be dehydrated to yield a clam flavoring product. Hood *et al.* (1976) converted clam wash water into an acceptable juice product which is currently being marketed (Zall and Hood, 1979). Zall and Cho (1977) developed similar products from recovery of meat normally discarded with the solid wastes.

Studies have shown that it is possible to recover proteins (Hang, *et al.*, 1980) and a variety of bioactive compounds (Chen and Zall, 1985 and 1986, and Jacober *et al.*, 1980,) from wastewater and from viscera wastes.

Animal Feed

Solid wastes from clam processing have been evaluated as animal feeds. The EPA (1975) suggested using belly wastes as a feed source as a way of eliminating a disposal problem. Clam bellies have been used as additions to porcine feed somewhat unsuccessfully (Richard Meyers, personal communication). Problems with putrefaction, variability, and intermittent supply due to the variable nature of the industry combine to make it unattractive to farmers.

Zall and Hood (1979) reported that clam-belly wastes can be ensiled with formic acid and sodium chloride to stabilize the material and allow longer storage and reduce

Operation	Typical Wastewater Loading	
	Organic Load (mg/L COD)	Total Suspended Solids (mg/L)
Unloading		
↓ Wash	2000	10,000
↓ Retort or Tunnel Oven	30,600	5,000
↓ Flotation Separation	17,000	8,000
↓ Debellying	18,600	7,000
↓ Wash	6,200	3,000
↓ Sorting and Packaging	16,700	7,300

Figure 3: Typical organic and suspended solid loading in wastewater from different plant operations

spoilage. They also developed a process for using a gelling agent to stabilize the wastes for use as bait for lobster fishing. Marvin and Anderson (1962) patented a process for thickening belly material for canning and use as a pet food.

Meyers, et al. (1987) have studied the utilization of scallop viscera as a feed supplement for porcine feeds. They found that the wastes could be ensiled with formic acid with minimal nutrient deterioration after 28 days. The resulting silage could be stored until needed, eliminating the problem of putrefaction. They also evaluated the effect inclusion of the silage as a feed supplement would have on pigs and found that the quality of meat produced was not affected by the inclusion of up to 12 percent silage in the animals' diet. Clam viscera is very similar to scallop wastes, so these results suggest that it could be possible to convert clam viscera into a marketable feed product by ensiling.

Clam waste solids also have been used as food for eel aquaculture. The clam solids do not provide complete nutrition but may be used as feed supplements (Meyers, 1987).

METHODS AND MATERIALS

To understand the mechanized clam shucking process, three clam processing plants were studied: J. H. Miles Seafood in Norfolk, Virginia; C & D Seafood in Oyster, Virginia; and, American Original Corporation in Willis Wharf, Virginia. Figure 1 shows the location of these plants and of other processing plants in Virginia. Table 1 lists the current NPDES wastewater effluent discharge limitations. The three plants selected for this study illustrate how the sophistication of clam processing varies, ranging from just slightly more advanced than hand shucking to a highly mechanized process.

Each of the three plants was visited on several occasions so that the clam-shucking process could be observed. Each plant was studied with a technical representative from the company present to become familiar with the different processing operations and to gain an understanding of the uses of water in the plants and of the sources of waste materials.

Once the process stream in each plant was well understood, several visits were made to observe the plants under operating conditions. These visits were spread over a year period to ensure a representative sampling of the operations. During these visits measurements were made of the water flow at different points in the process and the total water usage was determined. Wastewater flow also was measured at different points in the process stream. From these measurements, it was possible to identify points of maximum water waste and sources of maximum wastewater generation.

During the plant visits, wastewater samples were collected at the points in the process that were identified as major sources of waste. These samples were transported to the Virginia Tech Environmental Engineering laboratories in Blacksburg, Va., and analyzed for organic content and solids.

Samples of the solid waste materials generated during the shucking process were collected, including viscera and belly material, shell waste, and dewatered sludges. These samples were analyzed to determine their elemental and biochemical composition, their potential uses or products which may be derived from them, and their suitability for disposal by various methods such as land application or burial in landfills.

Additional plant visits were made to monitor water usage and wastewater generation over an entire working day, from

Table 1: Current NPDES Wastewater Effluent Discharge Limits for Virginia Clam Processing Plants

Plant	Parameter			
	BOD_5 kg/day		TSS kg/day	
	Monthly Avg.	Daily Max.	Monthly Avg.	Daily Max.
The American Original Corp.	1687.4	3374.8	2309.6	13,857.6
Lance G. Fisher Seafood, Co., Inc.	no limit	no limit	58.79	192.69
C & D Seafood	no limit	no limit	408	2,449
J. H. Miles & Co. Inc.	no limit	no limit	3061.8	18,370.8
H. V. Drewer	77.6	238	60	413
Chincoteague Seafood Co., Inc.	no limit	no limit	2,034.6	12,207.7
H. Allen Smith	746.7	1965.0	576.0	3,406.0

morning start-up, usually between 4 and 6 a.m., to the end of the cleanup procedures in the late afternoon or evening. Water-meter readings and flow measurements were taken to measure the use of water over time within the process cycle. Wastewater samples also were collected for analysis throughout the day so that variations in organic and solid loadings with time could be determined.

Measurement of Water and Wastewater Flow

Water usage at the plants was determined by water meter readings to determine total usage and by measuring the flow at specific locations throughout the plants to determine the water used at different stages of the process line. Flow measurements were made by allowing the flow to fill a 12-L, plastic bucket during a timed interval. Wastewater flow was measured in the same way. This method has large potential for error, so all measurements were repeated at least three times and the data were averaged. Because the flows varied greatly, they were measured at several different times during the day.

The flow of final effluent was measured at locations where the wastewater discharged into receiving waters. In situations where there was more then one effluent pipe, an effort was made to measure each, and the flows were combined to provide a total effluent flow.

Sample Collection

Samples were collected at each location of major waste generation in the three plants. Effluent wastewaters were collected from each outflow. As there were large variations in the organic and solids loadings of the effluent, samples were collected throughout the day to obtain a representative sample. At least one trip was made to each plant for the specific purpose of collecting final effluent samples over an entire work day. This generally involved sampling over a 24-hour period.

All liquid samples were collected in collapsible polypropylene jugs which were previously washed with detergent. Once the jugs were filled, they were sealed with as little trapped air as possible. The samples were then packed in ice and transported to Virginia Tech where they were stored at 4° C until use.

Shell material from all three plants was collected from conveyer systems outside the plants and from shell dump piles. The amount of organic material attached to the shells and interspersed throughout the dump piles decreases with time so an attempt was made to collect shell material representative of a range of decomposition times. Shell material was also collected from an old dump pile in Oyster, Virginia that had been abandoned for several years.

Semi-solid viscera or belly material was collected at the Oyster and Willis Wharf plants. In Oyster, the bellies were collected from large, plastic cans where the wastes were dumped after being separated manually from the rest of the clam. At Willis Wharf, viscera material was collected at the belly dewatering screen.

Dewatered clam sludge was collected at the Miles plant from the screw press.

All solid samples were collected in new plastic bags and packed on ice for transport to Virginia Tech. At Virginia Tech the samples were either stored at 4° C if they were to be used immediately.

Organic Analysis of Wastewater Samples

A number of techniques were evaluated for determining the organic content of wastewater samples collected at the three plants. Total Organic Carbon (TOC), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) analyses were performed according to standard procedures (Standard Methods, 1984) to evaluate their usefulness in quantifying the organic content of clam wastewater. It was decided that the COD test provided the best indication of the organic content of wastewater samples. TOC proved to be impractical because the level of solids in the wastes interfered with the analysis. The presence of organic particulates in BOD-test bottles also made the results of the BOD determination questionable. This uncertainty, the large number of dilutions required to achieve usable test results given the possible variation in organic load, the large number of samples collected, and the requirement that the BOD test be set up within 24 hours combined to make BOD analysis of all samples impractical.

The relationship between COD and BOD varied a great deal. BOD/COD ratios varied from as low as 0.20 to as much as 1.1. This variation in the relationship between the two parameters has been observed by other researchers (Zall et al., 1976). While effluent permits are written in terms of BOD, it was felt that for the purpose of this study COD analysis provided the best method for evaluating the organic content of the wastewater.

Before samples were diluted for COD analysis they were blended for approximately 3 minutes. Care was taken to keep the samples mixed during pipetting. If analyses was not performed within 24 hours of collection, the samples were acidified with sulfuric acid to a pH of less than 2 and then stored at 4° C.

Solids Analysis of Wastewater Samples

Total and volatile dissolved solids and suspended solids were determined according to standard procedures (Standard Methods, 1984). This involved placing well-mixed samples of wastewater in aluminum pans and drying at 105° C to determine total solids. To determine dissolved solids a well-mixed sample of wastewater was vacuum filtered and the solids content was determined gravimetrically. The volatile portion of the total and dissolved solids was determined by ashing at 550° C and reweighing the ashed sample. The suspended fraction was determined by subtracting the amount of dissolved solids from the total solids.

Organic Analysis of Whole Clams

Large pieces of clam meat and whole clams were often found in the wastewater, so the organic load contributed by large pieces was determined. This was done by blending whole clams in distilled water and then analyzing the COD of the mixture.

Chemical Analysis of Viscera

Clam viscera material was collected at the Willis Wharf and Oyster plants and analyzed by inductively coupled plasma emission spectroscopy (ICP) to determine calcium, magnesium, potassium, sodium, phosphorus, iron, copper, and zinc concentrations. These samples were prepared for analysis by ashing at 400° C and dissolving the ash in 1.2 N HCL. The ICP analyses were performed by the Soil Testing and Plant Analysis Laboratory at Virginia Tech with a Atomscan 2400 Sequential Spectrometer according to standard Association of Official Analytical Chemists (AOAC) procedures (AOAC, 1984).

Chemical Analysis of Settled Sludge

Settled sludges from the Norfolk plant were analyzed for elemental composition, moisture content, and organic content in terms of COD per gram of dry solids. Elemental analysis by ICP spectroscopy was performed by Virginia Tech's Soil Testing and Plant Analysis Laboratory. Moisture content was determined by weighing samples that had been dried at 105^{o} C for 24 hours. COD was determined by blending weighed portions of sludge with distilled water for 5 to 10 minutes to break up the sludge and then determining the COD of the suspension.

Settleable Solids and Removal of Organic Material By Plain Sedimentation

Settleable solids were determined by pouring a well-mixed wastewater sample into a 1-L Imhoff cone and allowing the sample to settle for one hour (Standard Methods, 1984). The samples were allowed to settle for another hour and aliquots were collected 5 cm below the liquid surface, taking care not to stir the settled material. These aliquots, analyzed for suspended solids and COD, were compared to the suspended solids and COD of the sample prior to settling.

Analysis of Shell Solid Waste

The shell wastes moisture content was determined by weighing samples that had been dried 24 hours at 105°C.

Fresh, shell-waste material from the Norfolk plant and from an old shell pile at Oyster were collected for elemental analysis. These materials were ground in an corundum mortar to pass through a 200-mesh screen. The powder was fused with lanthanum hexaborate at 900° C for one hour and analyzed using a Diano WDXRF wavelength dispersion X-Ray fluorescence instrument with a copper X-Ray source with a nickel filter. Trace element analysis was performed by taking a sample of the ground shell material and pressing it into a pellet with a cellulose binder. The pellet was analyzed on a KEVEX X-Ray fluorescence unit with copper radiation and nickel filter.

The suitability of shell solid wastes as a source of fine aggregate for use in cement was evaluated by standard methods (ASTM, 1984) These samples were crushed in a hammermill to pass through a standard #4 sieve (openings less then 4.75 mm). The crushed shell was tested to determine if the organic content was high enough to be of the material as a fine aggregate in Portland cement by standard colorimetric techniques (ASTM, 1979).

Composting Experiment

Samples of viscera collected at the Willis Wharf plant were composted with saw dust to evaluate composting as a way of stabilizing the waste materials prior to disposal in a landfill or use as a soil amendment.

Three bench-scale compost piles were created by mixing viscera material with fresh, white pine sawdust from the Sardo Pallet Laboratory at Virginia Tech. In one pile clam belly waste was used as collected. In the second pile, the belly material was blended in a kitchen blender for several minutes before being mixed with the sawdust. In the third, the bellies were blended and mixed with sawdust and fresh shell waste crushed to less than 3 cm. Table 2 shows the proportions of belly material, sawdust and shell waste in each pile. The compost mixtures were placed in 18.5-L plastic buckets and covered with nylon, insect netting. The buckets were placed in a fume hood and maintained at room temperature for the duration of the study.

The compost mixtures were mixed by hand once a day. Measurements of pile weight and temperature were taken just prior to mixing. After mixing, samples were placed in a freezer for later analysis. A decrease in pile temperature and in the odor were used to determine when the composting process was complete and the material stabilized (Parr et al., 1978).

The pH of the compost mixtures was determined according to the procedure described by McKinley et al. (1985). A 5.0 g sample of compost was mixed with 10 ml distilled water and the pH of the mixture determined with a pH meter. The compost's moisture content was determined by weighing fresh samples, drying overnight at 105° C to drive off the water and reweighing.

Anaerobic Experiment

Batch reactors were used to evaluate the response of dewatered sludges to anaerobic decomposition. Sludge from the Miles plant was diluted with deionized water to achieve a mixture with COD of about 30,000 mg/L. The mixture was blended for several minutes then placed in 1-L, glass

Table 2 Composition of Compost Pile Mixtures

Waste	Weight Percent
Pile A	
Belly Waste (as collected)	50
Saw Dust	50
Pile B	
Belly Waste (blended)	50
Saw Dust	50
Pile C	
Belly Waste (as collected)	30.3
Saw Dust	33.3
Shell Waste	33.3

reactor bottles and seeded with sludge from anaerobic digesters at the Roanoke, Virginia wastewater treatment plant. The reactors were placed in a 35^{o} C water bath on a shaker table. After about 12 hours of operation the temperature controller on the water bath malfunctioned and was shut offf. The reactors were maintained at room temperature, between 25 and 29^{o} C, for the rest of the experiment.

Gases generated in the reactors were collected in 2-L, graduated plastic containers inverted in a tank of water, and the volume of gas produced was measured daily.

At 24-hour intervals, individual reactors were sacrificed and the contents were analyzed for COD, suspended and volatile solids, and pH (Standard Methods, 1984).

RESULTS AND DISCUSSION

Sources of Wastes

Three main types of waste generated by Virginia clam processing plants are: 1. liquid waste consisting of fresh and salt water with suspended and dissolved material; 2. solid waste consisting of the clam viscera and a small portion of meat; and, 3. and solid shell material which contains some organic material. The sources, amount, and characteristics of each of the wastes were determined and are described in this section.

Wastewater

Liquid wastes were generated in most of the operations used in clam processing plant. Water is used to wash the clams, to separate clam meat from shell material, to transport meat throughout the plant, and to clean the equipment and plantfloor after operations were shut down. All processes which use water were sources of wastewater.

The first step in processing clams was their delivery in 32 bushel baskets by truck or boat. There were large amounts of silicate sand associated with the clams from dredging operations. This sand was delivered along with the clams and had to be removed in the processing scheme.

The cages were dumped onto a belt conveyer which carried the clams into the plant and to steam retorts or tunnel ovens. As the clams moved along the belt, they passed under a spray washer, which removed much of the sand and silt from the outside of the shell. The wash water picked up a load of inorganic solids, which consisted mostly of silicate minerals and a smaller portion of carbonates. These solids were mostly sand and silt-sized particles. Suspended solid concentrations were on the order of 10,000 mg/L. The specific gravity of the solids were in range of 2.7 to 4.0. These materials settled out of the wash water fairly quickly. Settling tests indicated that simple sedimentation will remove greater than 98% of the suspended solid load in the wash water. These solids were often deposited in mounds of sand under the belt. The materials also were deposited in wastewater-collection channels and clogged the channels. Blockages were removed by hand or washed away with high pressure hoses.

The clams were delivered to steam retorts or to a tunnel oven where heat caused denaturation of the proteins associated with the adductor muscle. This detached the clam from the shell.

Steam-retort processing generated wastewater with volatile solids levels of about 10,000 mg/L. The industry has evaluated producing a clam concentrate from the wastewater and has determined that it is economically possible to use this waste as a product source instead of treating it as a wastewater. The tunnel-oven method of clam shucking produced a large amount of steam and waste heat which was vented to the environment and, consequently, did not create a wastewater problem.

After heating, the clams were tumbled in a rotating, horizontal tub to break up the shells and separate the meat. A spray washer was generally directed at the clams just before they entered the tub or inside the tub itself. This wash water removed sand and shell fragments, both of which added to the wastewater loading. The water also carried out suspended and dissolved organic material. This wash water, along with the water from the first washing prior to retorting, was the major source of inorganic solids in the wastewater stream.

After tumbling, the clams were delivered to a flotation bath where either sodium chloride brine or diffused air flotation was used to separate the meat from the shell material. The meat was passed on in the plant for further processing while the shell material was transported out of the plant on belt conveyers. This step was another major source of solids and organic loading in the wastewater due to splashing of tank contents out onto the floor and emptying the tank during cleanup procedures. Fresh water was constantly being added to the flotation tank to replace that which was lost with the shells and meat and onto the floor. This not only contributing to the wastewater but also required constant replenishment of the salt.

The shell material was removed from the plant by belt conveyers and either deposited in nearby dump piles or placed on trucks and transported to dump sites. Water associated with the shells ran off the belt and onto the floor and ground. Water also was used to frequently wash down the shell transport system. Once the shells were outside the plant, the water associated with them was generally allowed to drain into the receiving water with little or no treatment. At one plant water dripping from the conveyance system was collected for a distance of about 3 m until the shells were deposited onto trucks for transport to nearby dump sites. Wastewater was observed flowing off the trucks. The wastewater had a COD of 12,000 mg/L and flow volume equal to about 1% of the plant's total water usage.

At the Norfolk and the Willis Wharf plants, small sedimentation basins were used to remove suspended solids from water which flows overland. However, since both plants used shell material and sand as a fill material to build up areas to park trucks and to build shell piles, most of the water associated with the shells was discharged to receiving waters by subsurface flow. Water discarded with the shell wastes, along with precipitation, was allowed to percolate through several feet of shell and sand waste before it was discharged by subsurface flow. This flow contained dissolved and suspended material from the processing operations and picked up material as it percolated through. It was difficult to estimate the total volume and loading of this subsurface flow, but one sample was collected which had a COD concentration of 1700 mg/L and suspended solids concentration of 833 mg/L.

After the clam meat was separated from the shell, it was transported to sorting tables where bits of shell material, non-clam organic matter, such as starfish pieces, burned meat and other impurities, were separated by hand. In highly mechanized plants, the clams were transported by belt conveyers, vibrating tables or water flumes. In less mechanized plants they were hand-carried in large, stainless steel pails.

While the clams were being transported to sorting tables there was often some form of dewatering system to remove brine from the clams and return the water to the flotation tank. This was a shaker table and screen arrangement or, in the less mechanized plants, simply a draining table. This dewatering step was a source of waste due to splashing and leaking of the system. Large pieces of shell and meat also dropped onto the floor and became part of the waste stream.

In less-mechanized plants, workers carrying the meat to the sorting tables sometimes dropped meat out of over-filled pails. Since the clam meat adds 150 mg of COD per g of meat, or about 15% by weight, every effort must be made to prevent whole clams or large pieces of meat from becoming part of the waste load.

In highly mechanized plants, vibrating tables, water flumes, and belt conveyers were used to move the clams and waste materials. The flumes contributed to the wastewater load through splashing of their contents and when their contents were dumped during cleanup. Waste materials sometimes fell off belts and formed piles on the floor. This material was generally shoveled up and placed on the shell belt, but any that remained at cleanup time was washed into the wastewater stream.

In plants with manual sorting, the clam viscera along with bits of shell and other waste material were removed at the first sorting step. The clam meat was separated into "tongue" and "salvage" portions. The tongue consisted of the foot muscle and was generally processed into clam strips. The salvage material was everything else, including the siphon, the mantle and other edible portions (Figure 2). Salvage was packed separately from tongue material for use in preparing clam flavoring and soups. The viscera was disposed as a waste product. The different portions were sorted and collected in stainless-steel pails and either hand carried to the next step in the processing line or dumped into large, plastic, waste cans.

Hand-sorting used less water and generated less wastewater then mechanized processes. Wastewater was created mostly from draining of the clams on the sorting table and from overflow and splashing from washing and chilling tanks. Dumping the tanks and washing the equipment during cleanup were the other major sources of wastewater at less mechanized plants.

In the more-mechanized plants, the clam meat was carried by water flumes from the first sorting tables to a mechanical debellying process where the viscera was removed and separated from the meat. The viscera was then dewatered and carried away for disposal. The meat was carried to another sorting table where wastes such as burned meat, any non-clam organic material, and any viscera material still attached was removed. Depending on the finished product, the meat was then either washed, inspected, and packed for shipment or was sent to another sorting table where the tongue and salvage portions were separated and the meat washed, inspected, and packed for shipment.

Wastewater was generated in a number of ways at the different steps in the process line. The major source of organic loading in the wastewater was the dewatering of the belly material. In one plant draining and overflow from the belly dewatering tank contributed approximately 4500 L wastewater pre hour with COD levels of about 33,000 mg/L. This COD consisted of a large amount of dissolved organic material along with pieces of the viscera and intestinal contents. This system was also the major source of foaming agents.

Water used to wash and move meat in flumes also appeared to contribute a significant amount of solids and organic load to the wastewater stream. Water sometimes splashed from the flumes and periodically, it was necessary to dump and clean these systems.

Wastewater Variation With Time

Wastewater flow and composition were monitored throughout the working day to characterize variations. Variations in the volume of water used at the three plants studied are shown in Figure 4. The total water used during the working day is shown in Figure 5. Organic matter and solids variations are illustrated in figures 6 and 7.

Wastewater loadings varied greatly during the working day, but a general pattern was observed in all three plants. The organic and solids loadings increased quickly at the start of processing and reached a plateau by midmorning. The loadings remained at about this level until the midday break and cleanup, when sharp increases were observed. Organic and solids loadings increased during the afternoon and reached a peak during the evening cleanup. These variations were due to the different operations in the plant. The highest loads were observed during and just after the morning and afternoon cleanup procedures. Most of this load was due to dumping of water from brine tanks, washing and cooling tanks, and flumes. The plateaus reached in the morning and afternoon were due to relatively constant overflow and splashing and other continuous discharges.

Solid Wastes

Solid waste associated with clam processing consisted of shell material, non-clam organic material such as crab and starfish parts, and sand. These wastes were separated from the clam meat by salt brine and forced air flotation. The materials were carried out of the plant on belt conveyers and deposited in nearby dump piles or loaded on trucks and transported to dump sites.

Some solid material was recovered from settling tanks. These materials were similar in composition to those from the flotation operations. The material was usually placed on a conveyor belt to be disposed of along with the shell material.

At one of the plants, settling and dewatering of solids generated a sludge with COD of about 15 percent by weight. As treatment facilities at all clam processing plants are improved, the plants will generate similar sludges.

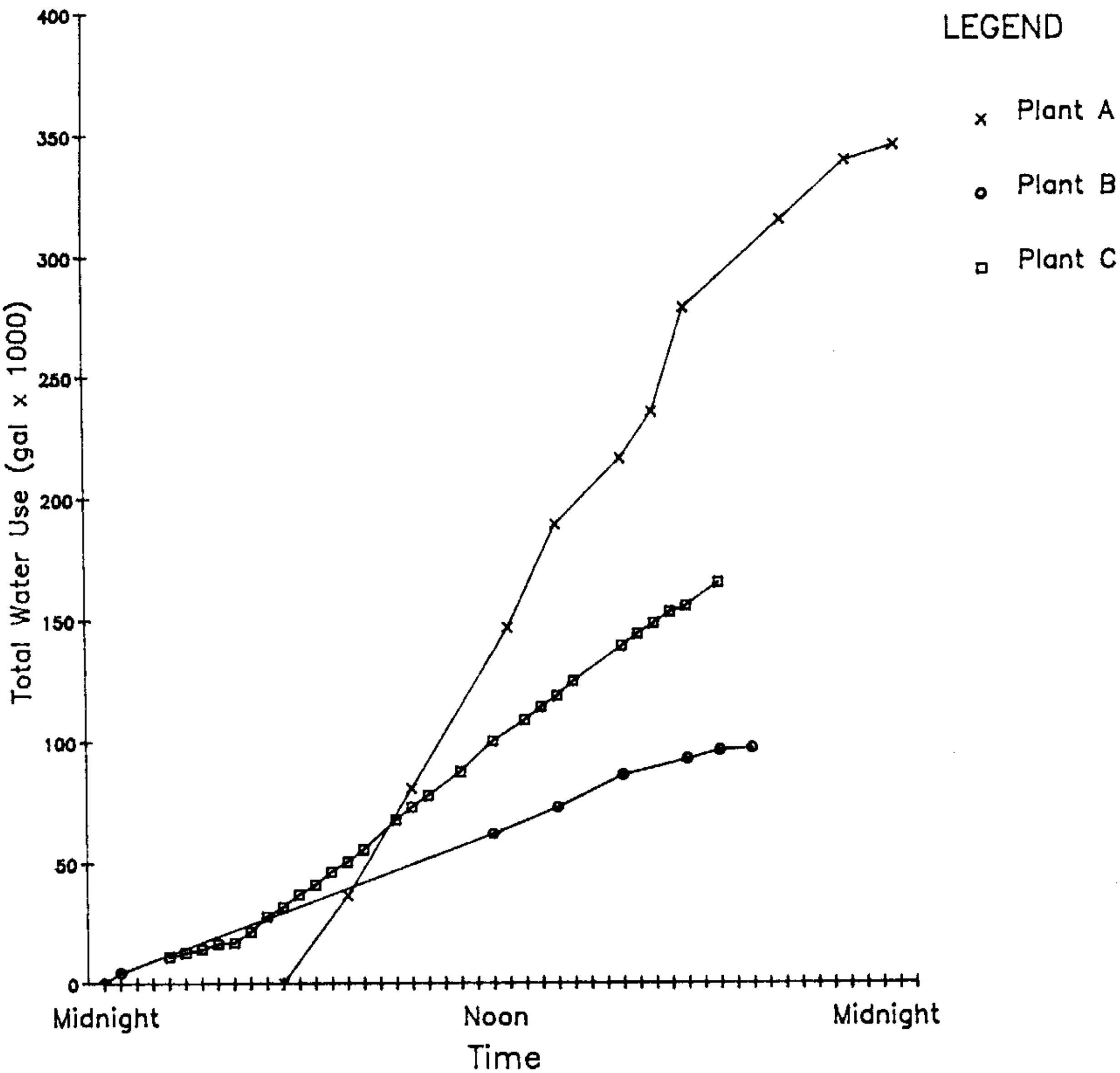


Figure 4: Total water use during working day

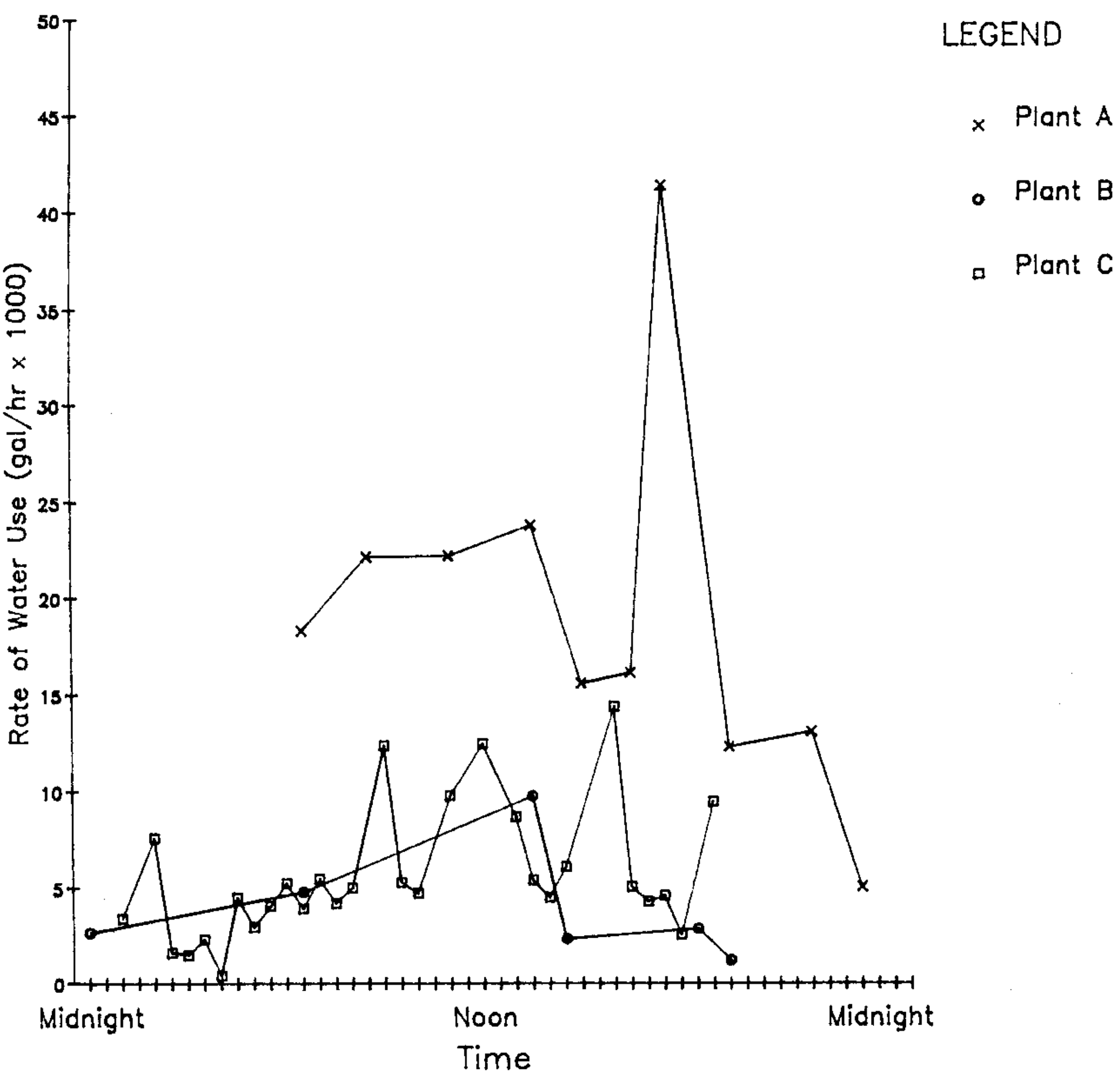


Figure 5: Variation in water use during the working day

Belly Waste

Viscera or belly material was generated at all plants. This material was about 50% water by weight and was often treated as a liquid waste. In plants with mechanical debellying this material was removed from the clam and either pumped to a storage tank or was dumped into the waste collection system along with the wastewater. At less-mechanized, plants the material was removed by hand, collected in small stainless steel pails and hand carried to collection points in the plant. In two of the plants the belly material was carried or pumped to trucks or boats for disposal. In one plant, the belly material was discharged with wastewater to a settling and dewatering system.

Characterization of Wastes

Wastewater

In general, clam processing wastewater consisted of fresh water which contained a large organic load. The organic material consisted of large and small suspended pieces of clam meat along with an appreciable amount of dissolved organic material. The wastewater also contained high concentrations of suspended and dissolved solid material, which were mostly organic particles and silicate sand in suspension.

The composition of the solids and organic loadings varied greatly both from plant to plant and over time in the same plant. Figure 6 shows the variations of organic load observed at the three plants. COD values were as high as 27,800 mg/L, and generally ranged between 1,000 and 5,000 mg/L while the plant was in operation. The COD decreased to the level of the incoming fresh water by the end of the daily cleanup. The organic load of the effluent consisted of materials derived from the break-up of clam meat. This material tended to be easily biodegradable and, would therefore exert an oxygen demand when discharged into surface water.

About 50% of the organic load consisted of large pieces of clam meat. This material had a specific gravity close to that of water and, therefore, settled out of the wastewater slowly. Overloading of the plant's treatment facilities often created high flow velocities through the treatment systems. The resulting short detention times were not sufficient to allow the particles to settle out of the wastewater, so the particles were carried out in the effluent.

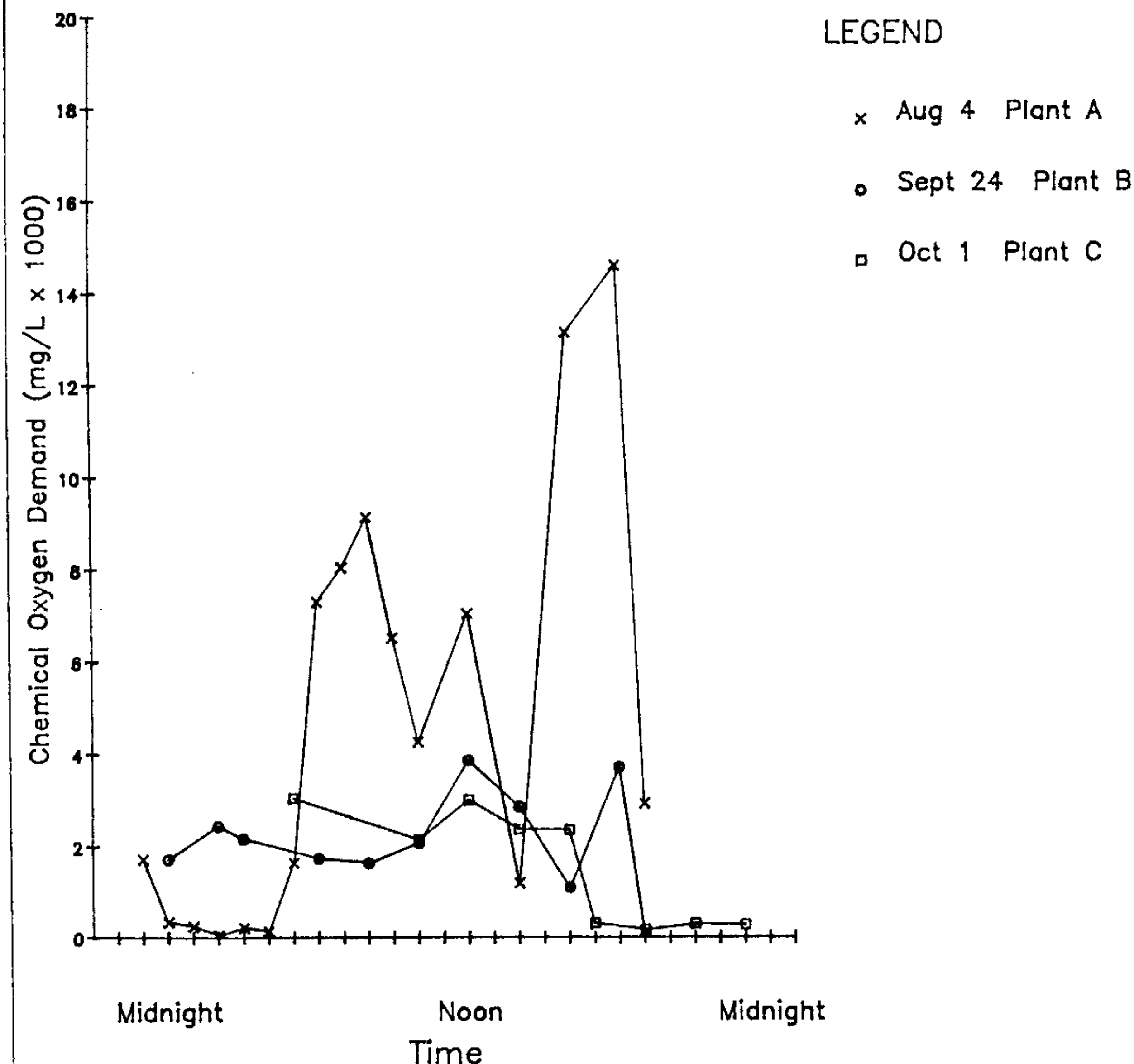


Figure 6: Variation in wastewater organic load (COD) over working day

Suspended solids in the wastewater consisted mainly of large clam pieces, sand and shell material. Most of the solids were silicate sand and silt with a lesser amount of carbonate shell material.

Composition of Solids

Shell Solids

The solids associated with shells consisted of calcium carbonate, silicate sand and silt, and some non-clam organic material. This waste also contained about 7% water by weight. Tables 3 and 4 show the composition of shell waste collected at the Norfolk plant and an old dump pile in Oyster, Virginia.

The shells were about 98% calcite and aragonite. The shells represented about 50 to 55% of the total weight of the clam, while the meat of the clam represented about 30% (table 5) (Zall and Cho, 1977). In the processing plants only about 80% of the meat was removed from the shell. The other 20% was discarded along with the shell solids. This discarded clam meat along with non-clam organic material, such as starfish and crab parts, made up about 10% of the shell waste.

Silicate sand and silts, associated with the shell wastes, represent less then ten percent of the solid waste by weight and consist mostly of quartz (SiO_2) along with a small amount of complex silicates.

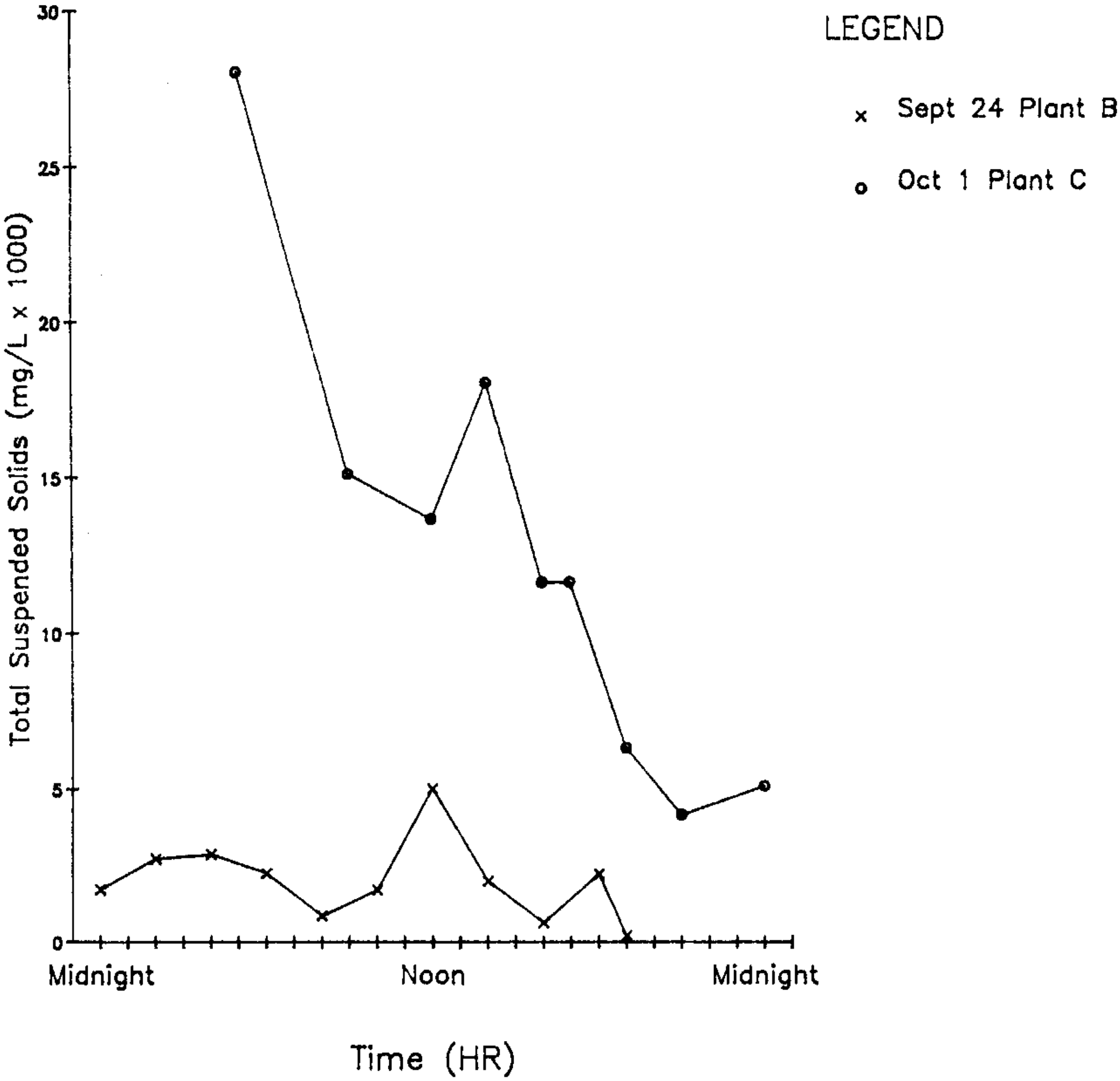
Viscera

The semisolid waste referred to as bellies consists of the digestive system of the clam along with its contents. The bellies were 75 to 90% water and represented 3 to 8% of the clam's total weight. They were slimy, difficult to handle, and quickly became odorous. Table 6 shows the chemical analysis of belly material from the Oyster and Willis Wharf plants.

Waste Treatment

Current Wastewater Treatment

All three clam-processing plants attempted to reduce wastewater solids and organic loadings with some form of physical treatment. Two plants had settling tanks with volumes of 1-2 cubic meters and hydraulic residence times of only a few minutes. These settling basins removed large



Variation in wastewater total suspended solids (TSS) load over woring day

Table 3. Analysis of Shell Wastes

Element as Oxide	Weight Percent	
	Fresh Shell Waste from Norfolk Plant	Old Shell Material from Dump Pile in Oyster, VA
SiO_2	3.58	6.16
Al_2O_3	1.81	1.96
Fe_2O_3	0.27	0.24
MgO	3.22	3.18
CaO	22.92	23.97
Na_2O	1.79	1.45
K_2O	0.04	0.08
TiO_2	0.01	0.07
P_2O_5	0.20	0.22
MnO	< 0.05[1]	< 0.05[1]
Loss on ignition	43.67	45.21
	77.56%[2]	82.59%[2]

[1] Below detection limit

[2] Believed to be due to incomplete combustion

Table 4. Trace Element Analysis of Shell Waste

Element	PPM	
	Fresh Shell Waste from Norfolk Plant	Old Shell Material from Dump Pile in Oyster, VA
Ba	10	9
Ce	15	11
Cr	< 20*	< 20*
Cu	< 2*	23
La	6	<2*
Nb	<10*	<10*
Ni	31	32
Rb	< 2*	<2*
Sr	1350	1370
Y	< 2*	35
Zn	< 2*	< 2*
Zr	23	82

*Below detection limit

Table 5. Weights of parts of the surf clam *Spisula solidissima* (Zall and Cho, 1977)

Body Part	Weight % of Total
Shell	50-55
Juice	10-15
Meat	
Foot	11
Abductor muscle	6
Neck	2-3
Mantle	7-9
Bellie	3-8

Table 6. Composition of Belly Waste from Oyster and Willis Wharf Plants

Component	Willis Wharf	Oyster
Moisture (%)	74 - 88	
Protein (%)	52.4	49.6
Nonvolatile Solids (%)	6.8	8.2
Phosphorus (mg/g)	9.7	7.8
Calcium (mg/g)	2.7	2.7
Magnesium (mg/g)	1.7	1.6
Potassium (mg/g)	10.1	7.6
Sodium (mg/g)	10.4	12.9
Iron (μg/g)	202.0	150.0
Copper (μg/g)	34.0	25.0
Zinc (μg/g)	69.0	72.5

pieces of clam meat when the flow was low, but during high wastewater flows, little material settled in the basins. Additionally, during periods of high flow the wastewater passing through the tanks resuspended pieces of meat which had settled earlier. Similar problems were observed with screens at the plants. At low flow the screens removed larger pieces of materials. At higher flows the screens clogged and little material was removed. Screens and settling basins also did not remove the smaller suspended particles or, of course, the dissolved material which represents a major portion of the total load.

In two plants the treatment systems removed only about 30% of the total organic load. At times of high flow, such as during cleanup and when the contents of tanks were dumped, treatment-system efficiency decreased greatly with little, if any, treatment of wastewater.

At the third plant the treatment system was similar, but it was sized more appropriately. Longer settling time and lower loading on the screens resulted in better treatment, but the system was still overloaded under high flow conditions, and fine suspended and dissolved material were not removed.

Potential Treatment Technologies

Wastewater Reduction

Reducing water use could result in better treatment efficiency due to lower hydraulic loadings on the treatment systems. Significant reduction is possible without changes in the process stream. For example, in all the plants there were instances when water hoses were left running unattended. Spring-loaded, automatic-cutoff nozzles on the end of hoses would save water and decrease the volume of wastewater requiring treatment.

In several instances, better attention to the setup and maintenance of the process line would result in water savings. During start-up and operation, inflow lines for filling tanks for wash water, cooling water and flotation brines were often left running after the tank was filled to overflowing. Splashing and overflow from flumes, shaker tables and other equipment contributed to the volume of wastewater and to the level of organic matter and solids in the wastewater. Placing splash guards over such equipment would decrease this waste. Other sources of leaks included improperly connected water lines and pumps.

It is not unreasonable to expect a decrease in the total water use of 20% or more through better "housekeeping".

It's important to note that since this study began these plants have made adjustments that have significantly decreased water usage and wastewater generation.

Wastewater Treatment Technologies

Physicochemical Treatment: this study demonstrated that it was possible to remove between 30 and 60% of the organic matter and 75 to 95% of the suspended solids through plain sedimentation (Table 7). Typical reductions in COD achieved with a detention time of two hours were from 17,248 mg/L to 3920 mg/L. Typical suspended solid reductions were from 667 mg/L to 90 mg/L. While this represents a major reduction in the waste load, it will not be enough to meet the 90 mg/L BOD and 90 mg/L TSS limits proposed by the Virginia State Water Control Board.

Much of the organic load consisted of suspended pieces of clam meat. As this material had a specific gravity close to that of water, it tended to remain in suspension. This suggested that flotation or upflow-sludge blanket clarifiers might be used to achieve large reductions in organic load.

The results of experiments conducted during this study and the results described in the literature suggest that it is technically feasible to treat the wastewater generated during clam processing to the degree required to meet the proposed effluent limits using a combination of physicochemical and biological treatment technologies (Table 7).

Anaerobic Treatment: the batch anaerobic reactor study indicated that clam wastes are easily degraded under anaerobic conditions. The results of this experiment suggested that the waste material is amenable to anaerobic treatment. Reductions in COD of 75% were observed in 7 days with about 1.0 L of methane produced per L of waste (Figure 8). This corresponded to decreases in COD concentration from about 21,400 to about 5500 mg/L.

Aerobic processes such as sequencing batch activated sludge systems and wetlands polishing can be designed to treat these wastewater to reduce organic and solids loading sufficiently to meet the proposed limits.

While an in-depth analysis of the economics of treating these wastes was beyond the scope of this project, some

Table 7. Efficiencies of Treatment Technologies

Treatment	Percent Removal Possible			
	Organic Load	Suspended Solids	TKN	Turbidity
	Physicochemical Treatment			
Sedimentation[1]	30-60	75-95		
Centrifugation[2]	0.0		13.3	58.3
Coagulation[2]				
Alum	2.8		6.6	50.0
$FeCl_3$	2.8		6.6	76.6
Chitosan	15.7		14.6	80.0
Coagulation - Centrifugation[2]				
Alum	2.8		14.6	63.3
$FeCl_3$	25.7		14.6	80.0
Chitosan	37.1		16.0	86.6
	Biological Treatment			
Activated Sludge[2]				
θ_c[3] (days)				
2.5	93.0			
5.0	94.1			
10	94.1			
15	97.0			
Activated Sludge[2]				
θ_c (days)				
3	91	89		
5	92			
10	90	89		
15		89		
20	91			
Activated Sludge[4]				
θ_c (days)				
3	91	89		
5	92			
10	90	89		
15		89		
20	91			
Activated Sludge Followed by Salt Marsh Polishing	99+	99+		99+

[1] This study
[2] Zall et al, 1976
[3] θ_c = cell residence time or sludge age
[4] Kugelman and Guida, 1986

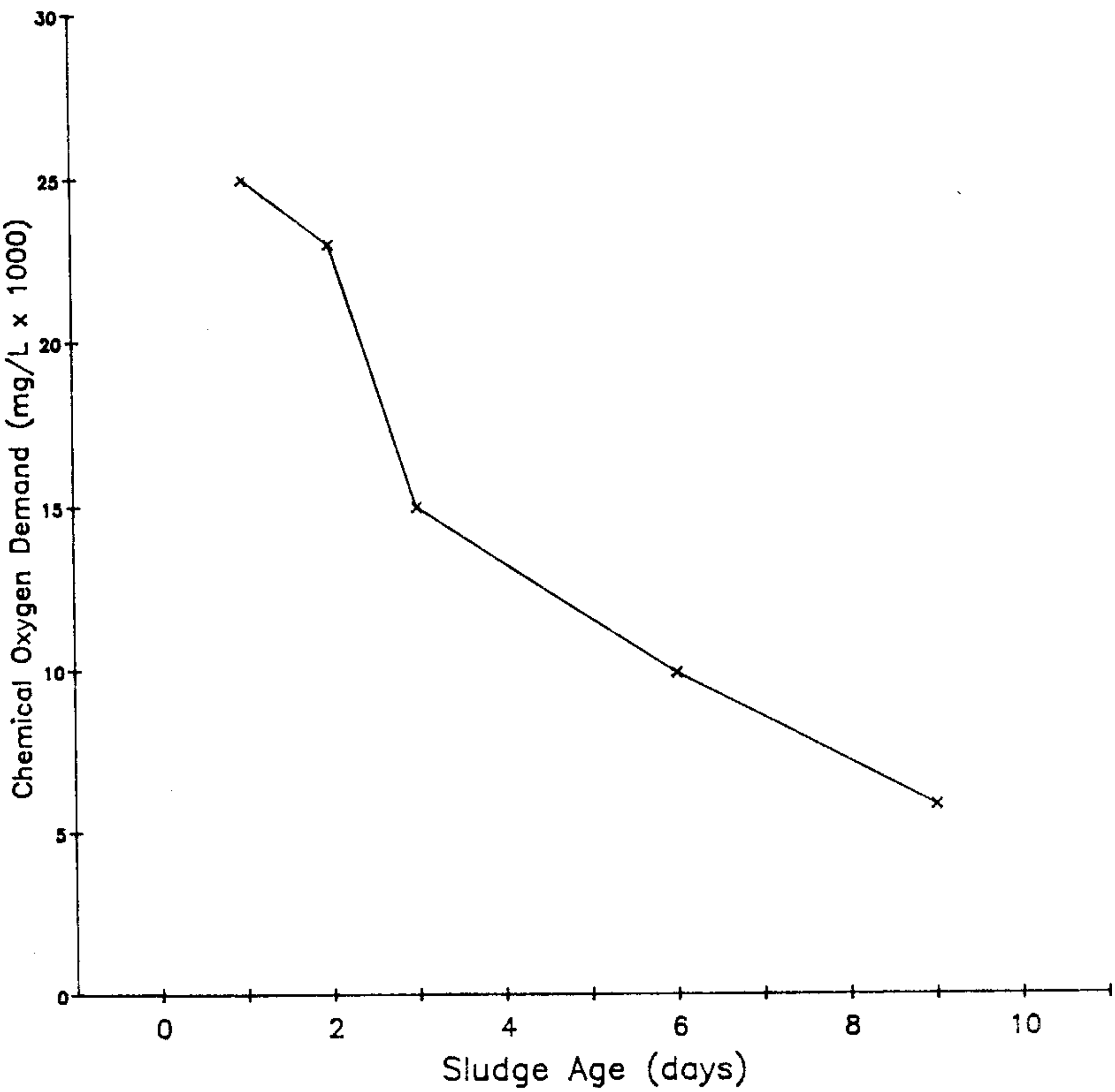


Figure 8: Reduction in COD by anaerobic digestion

information on the cost of treatment was obtained and is presented below.

Recent calculations by CH_2M Hill Engineers indicated that construction costs for a 90,000 gpd treatment system would be approximately $1.2 million (Lisa Sullivan, personal communication). In addition to the initial cost, operation and maintenance costs were estimated to be about $200,000 annually. Woodard and Curran Inc. estimated that the construction cost for a 200,000 gpd treatment system would be $1.2 million and operation and maintenance costs would be about $120,900 annually (Clayton Richardson, personal communication). The Hampton Roads Sanitation District estimated that surcharges of $600,000 annually would be levied for disposing of wastewater generated at the Norfolk Plant to municipal sewers.

<u>Sludges</u> generated during waste treatment must be considered in the design of treatment systems. The costs associated with sludge disposal represent a significant portion of the total treatment system expenses. The current practice of landfilling sludges will become more expensive as the amount of sludge generated increases with increased treatment efficiency. Composting and anaerobic digestion have been shown to be effective ways of reducing and stabilizing these wastes.

<u>Composting of Belly Wastes</u>: the results of the compost experiments indicate that belly wastes can be stabilized and converted into soil amendments by composting. The three compost piles all resulted in the degradation of the organic portion of the belly material. The temperature of the piles increased to above 40° C and remained elevated for seven days (Figure 9). After seven days, the pile temperatures decreased to room temperature indicating that microbial degradation was complete. This was also indicated by the decreasing "rotting marine life" odor generated by the piles. After seven days, the odor was not detectable.

Moisture content of the piles decreased slightly over the seven-day degradation period but remained within acceptable limits for microbial growth (Figure 10). The total weight of each pile decreased about 10% as a result of the organic material converting to water vapor and carbon dioxide, and losses through volatilization (Figure 11).

Including shell waste in the pile did not have a significant affect on the composting process. The shell material was not affected by the process, except that the attached organic material, left attached to the shell during the shucking process, was degraded. This left the

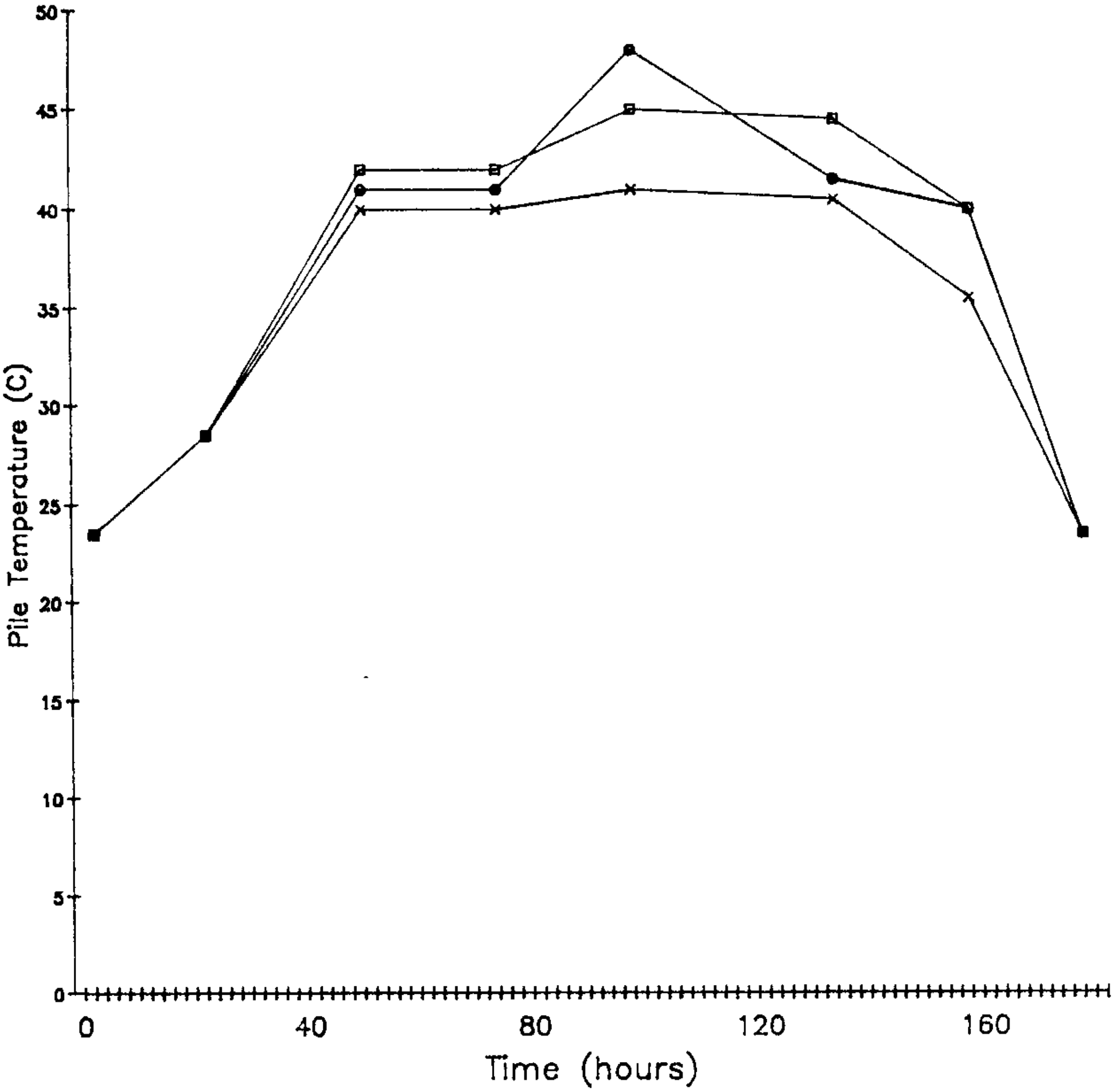


Figure 9: Compost pile temperature

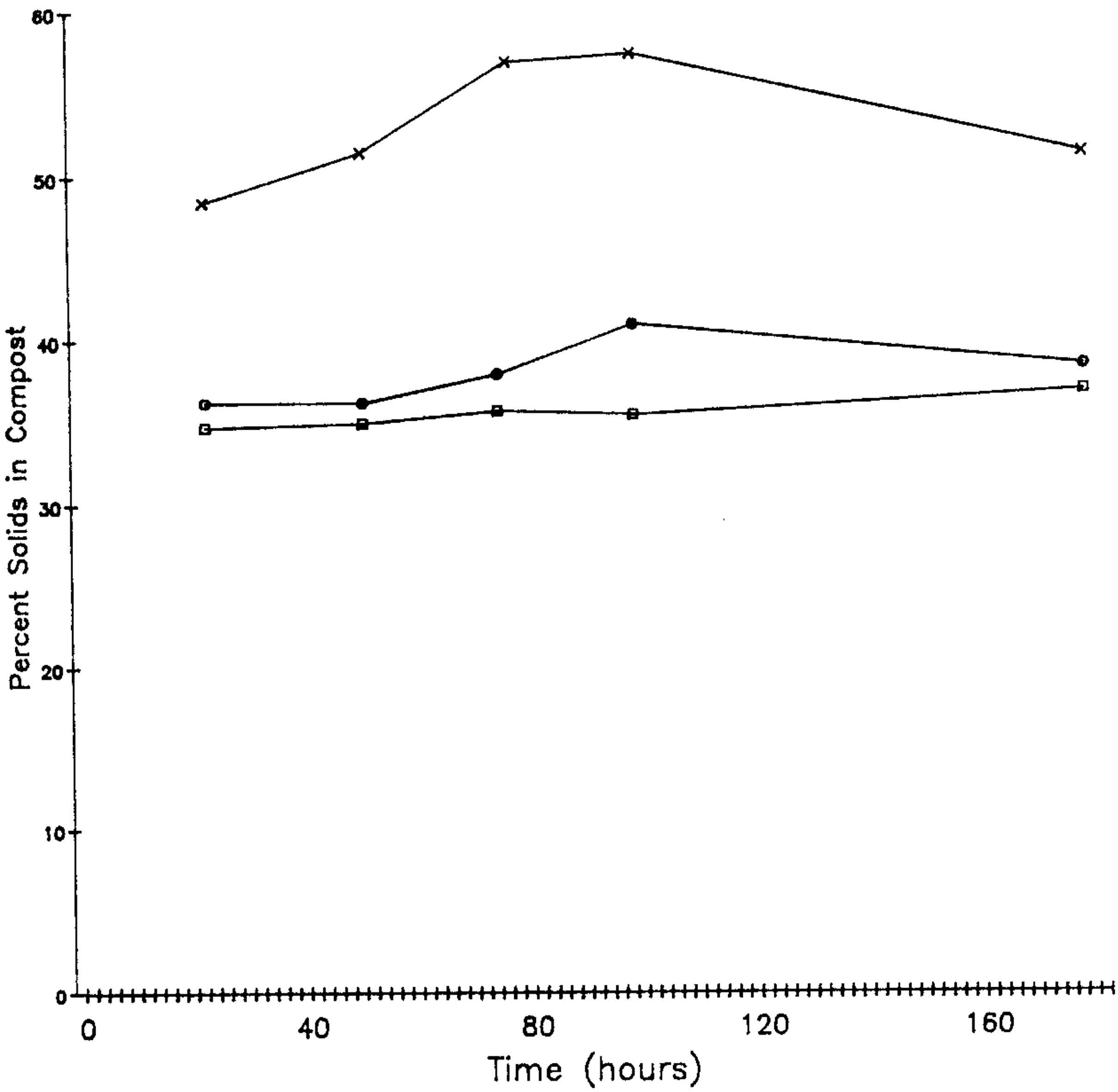


Figure 10: Moisture content (% solids) of compost piles

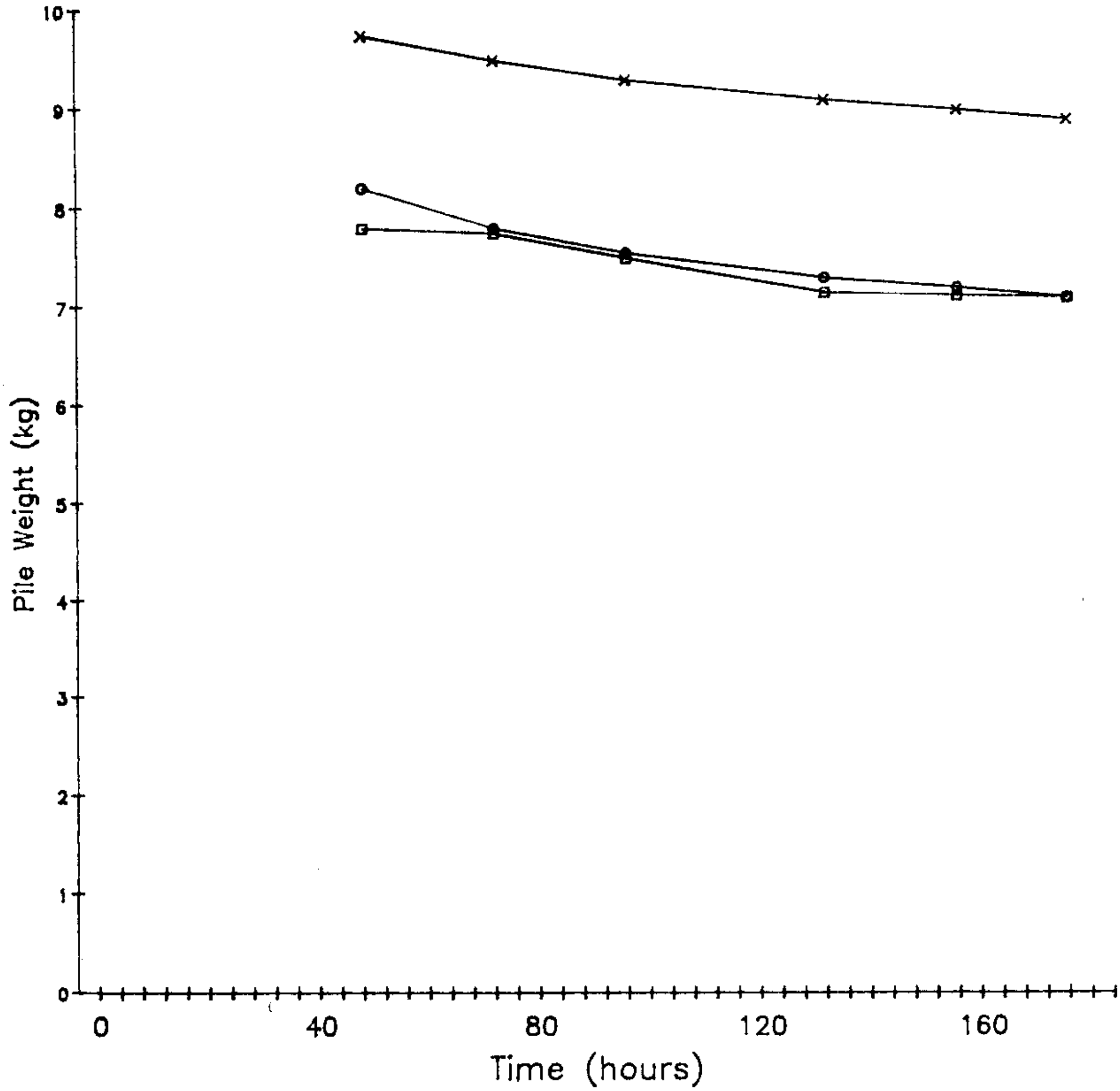


Figure 11: Weight of compost piles

shells quite clean and free of organic matter. Composting of the shells, therefore, is an inexpensive way of removing the associated organic matter to enhance their value for paving material or as a source aggregate. The shell waste can act as a bulking agent in the compost.

Survey of Effluent Limitations Imposed on Similar Plants in Other Areas

The Virginia State Water Control Board has proposed effluent limits of 90 mg/L BOD and 90 mg/L suspended solids. These limits are much more stringent then current limits (Table 1). The proposed limits are generally more stringent than those imposed on similar plants in other areas of the Eastern United States. A telephone survey of regulatory agencies in other areas was conducted to determine the limitations in those areas. Where this information was not readily available, Freedom of Information Act requests were made to obtain copies of the NPDES permits issued to all mechanized clam processors from the state regulatory agencies and the U. S. Environmental Protection Agency. Table 8 lists the results of this survey.

At the time the survey was taken, only New Jersey has effluent limitations equal or more restrictive than those proposed by the Virginia State Water Control Board (Steven Kim, personal communication). Permits issued by the New Jersey Department of Environmental Protection are based on water quality concerns and, in some cases were stringent enough to force the processing operations out of business (Zelnik, 1985). Other jurisdictions have generally followed the federal guidelines, as described in the Development Document for Effluent Limitations Guidelines and New Source Performance Standards (EPA, 1975), in establishing discharge limits.

Table 8. Wastewater Effluent Limitations Imposed on Mechanized Clam Processing Plants in Other States

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Delaware:

No permits issued under the Standard Industrial Classification codes for Mechanized Clam Processors

Maryland:

One major plant in operation. This plant uses spray irrigation to dispose of wastewater. Smaller plants are required to screen their wastes to below 20 mesh and to disinfect. They have no BOD or TSS limits.

Maine, Massachusetts, and New Hampshire:

The industry in these states are under control of the EPA region 1. Their effluent limitations follow the 1975 EPA guidelines (EPA, 1975).

New Jersey:

Effluent limitations in New Jersey are based on the federal guidelines modified to include water quality standards. The state has become very strict in controlling effluent to protect water quality and has forced the industry out of certain areas. They have issued permits with BOD_5 limits of 15 mg/L and TSS reductions of 85%.

New York:

Effluent limitations are based on the federal guidelines modified for water quality protection. In general they are fairly lenient but in select cases they have included limits of as low as 30 mg/L TSS>

Rhode Island:

The one major plant in Rhode Island has effluent limitations of Daily Maximum TSS 5,400 mg/L but no limit on BOD_5.

CONCLUSIONS

1. The concentrations of organic matter and suspended solids in wastewater from the different plants varied widely. Typical variations in wastewater COD concentrations ranged from less than 10 mg/L to more than 15,000 mg/L over the working day. Suspended solids levels in the wastewater were as high as 30,000 mg/L but were more commonly in the area of 1,000 to 10,000 mg/L. These variations in wastewater character must be taken into account in designing waste treatment facilities. The intermittent nature of plant operation, resulting from the effects of weather and availability of clams, must also be considered.

2. Plain sedimentation may provide significant reductions in wastewater organic and solids loadings, but sedimentation alone will not achieve sufficient reductions in organic and suspended solid concentrations to meet the limit of 90 mg/L proposed by the State Water Control Board of Virginia.

   At a minimum, secondary treatment will be required. The organic matter in clam wastewater is readily biodegradable under both aerobic and anaerobic conditions. Anaerobic treatment of sludges and/or wastewater can provide reductions in organic levels, reduce sludge volumes and produce methane.

3. To reduce the size of the treatment systems required and to ensure proper loading of the systems, water use and wastewater generation must be reduced as much as possible. There is ample opportunity for reduction in water use and wastewater generation by simple changes in operational procedures, such as installing automatic cutoff nozzles on hoses and timers on spray washers. In addition plant personnel should be encouraged to pay closer attention to efficient water use. These simple changes can be expected to reduce water use and wastewater generation by 20%. Other changes, such as substituting belt conveyers in place of flumes, may achieve additional reductions.

4. There is significant potential for reducing waste and increasing profits by recovering materials from the waste (Figure 12). Products for human consumption, such as juices and flavorings, can be recovered from liquid wastes. Feed additives for

SHELLS	.Loose Road Construction .Oyster Spat Substrate .Lime .Aggregate .Compost Bulking Agent
WASTEWATER	.Flavor Products .Juice and Other Food Products .Animal and Fish Food Products .Bioactive Compounds
BELLY WASTES AND SLUDGES	.Flavor Products .Bioactive Compounds .Animal and Fish Food Products .Biogas .Soil Amendments

Figure 12: Potential resource recovery products available from clam processing wastes

animals and for aquaculture can be recovered from sludges and from belly wastes.

Shell waste can be used as a source of carbonate and aggregate. As clam plants are located in areas with few limestone deposits, there are potentially large local markets for the shells. The use of shell material for loose paving and substrate for oyster spat should be increased. The potential for construction of lime roasting facilities, perhaps using waste heat from shucking ovens, should be studied.

5. With regard to effluent regulations, Maine and New York are currently more lenient, but New Jersey is more restrictive. Maryland and Delaware currently do not have any plants located in their states but are likely to issue restrictive limits should plants locate there. Moving operations to avoid discharge limitations doesn't appear to be an answer to the current problems faced by the Virginia industry.

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Appendix 1.

Appendix 1a: Field data collected on visits to plant A on October 1, 1987

Time	Notes
05:30	Starting reading on well head meter 79691000 Water comes from well. Small portion comes from city water for sanitary facilities.
07:35	Well head meter reading 79727650. Sample 1 collected at effluent pipe. Wastewater temperature 38° C., D.O. 6.2, pH 8.5.
09:30	Well head meter reading 79772000. Sample 2 collected at effluent pipe. Temperature 28° C, D.O. 7.4, pH 7.7
12:15	Sample 3 collected at effluent pipe. Temp. 30° C, D.O. 6.0, pH 7.7. Sample taken during lunch break.
12:25	Well head meter reading 79838000
14:15	Well head meter reading 79880400. Sample 4 collected at effluent pipe. Temp. 31°C, D.O. 7.0, pH 7.6. Total of 84 cages processed by end of shift, 25500 lb meat.
16:00	Well head meter reading 79907700. Sample 5 collected at effluent pipe. Temp. 31° C, D.O. 5.0, pH 7.8.
16:15	Cleanup begins
17:09	Sample 6 collected at end of effluent pipe. Temp 26 °C, D.O. 7.2, pH 7.8. Wellhead meter reading 79926600
19:13	Sample 7 collected at effluent pipe. Temp. 25° C, D.O. 7.8, pH 8.7. Well head meter reading 79970100
21:08	Sample 8 collected at effluent pipe. Temp. 32° C, D.O. 7.0, pH 10.4. Well head meter reading 80006200. Lots of detergent in use. Too much? High pH.
23:01	Sample 9 collected at effluent pipe. Temp. 22°

	C, D.O. 7.3, pH 9.1. Well head meter reading 80030850
00:15	Shut down. Well head meter reading at end of day 80037000

Appendix 1b Field Notes From Visit To Plant A on July 8, 1987

Time	Notes
07:00	Processing started.
10:10	Receiving water temperature 3 m outside of settling pit 27° C.
10:15	Sample 1 collected at end of effluent pipe. Sample temp. 27 ° C. Sample 2 collected at settling pit effluent.
	Sample 3 collected from final rinse overflow. Sample temp. 25° C. Flow rate measured at 1.06L/sec.
	Sample 4 collected from overflow tank next to final wash. Overflow varies greatly. Flow rate at about 10:20 was 0.7 L/sec
11:30	Plant processing quahogs. Meat reaches 180°C. Takes 2-3 minutes to reach temperature. Shells being collected for use by Co. in Conn. to package process clam products.
	Sample collected for analysis by R. Reddy.
11:45	Sample 6 collected at drain under debellying area. Flow - 1.69 L/sec.
12:13	Sample 8 collected at drain # 5. Flow 0.12 L/sec.
12:14	Sample 9 collected at drain # 2. Flow 0.39 L/sec.
12:16	Sample 7 collected from floor drain # 3. Flow 3 L/sec.
12:18	Sample 10 collected at drain # 4. Flow 1.9 L/sec
12:26	Sample 11 collected at drain # 8. Flow 9.3

	L/sec.
12:37	Sample 12 collected from washwater under first wash on belt just after dumper. Flow 1.1 L/sec
12:41	Sample 13 collected at end of effluent pipe. Flow about 30 L/sec.
13:55	Sample 14 collected at end of effluent pipe.
	D.O. in receiving water: 3.8 at end of dock (80 m from discharge) 1.0 just outside settling pit 1.8 in pit
14:35	Sample 15 collected from effluent discharge
14:40	Sample 16 collected from underflow from first wash

Appendix 1c: Field Notes From Visit To Plant B on September 23 and 24, 1987

Time	Notes
23:00	Plant shut down about 5:30 this afternoon. Truck with clams arrived about 8 pm. Plant started up again at 10:30 pm. Some flow out of effluent - appears to be fresh water. No workers yet. Water meter reading 17028355 gal. Flow rate about 20 gal/ min. Most is waste due to overflow and leaks.
23:40	Sample 1 collected at downstream effluent pipe. Temp. 19° C, D. O. 8.1. Flow 0.5 L/sec. Flow from furnace floor drain 7491 L/hr.
00:01	Operations started. Flow 1.2 L/sec.
00:04	Sample 2 collected from upstream and center drains. Upstream flow 5.3 L/sec. Center flow 1.7 L/sec.
00:23	Sample 3 collected from drain on dock which collects water running off trucks and shell belt. Flow 0.11 L/sec. Lots of floating foam. There is a plume of floating solids and foam extending out about 40 m from plant.
00:40	4 cages emptied
02:00	Break time in plant. Sample 4 collected from downstream and center drains. Flow downstream drain 1.0 L/sec. Temp. 19° C. Center drain flow 1.8 L/sec. Temp. 19° C. Sample 5 collected from upstream drain. Flow 1.1 L/sec. Temp 18° C.
02:15	Second truck of clams started.
04:00	Sample 6 collected. Composite from all drains. Flow downstream drain 1.1 L/sec, center drain 2.2 L/sec, upstream drain 5.1 L/sec
06:05	Sample 7 collected. Composite of all three drains.

Appendix 1c (Con't.)

Time	Notes
	Flow downstream 1.1 L/sec. center 2.1 L/sec upstream 1.3 L/sec.
06:05	Third truck unloading
08:05	End of first shift (12 am-8 am) lots of birds around outfalls. Sample 8 collected. Composite of all three drains. Downstream flow 2.7 L/sec. Due to cleanup operations mostly. Center flow 0.85 L/sec. Upstream flow at trickle.
10:00	Second truck of shell waste starting to fill. Sample 9 collected. Composite of three drains. Downstream flow 1.6 L/sec. Center flow 2.2 L/sec. Upstream flow 5.1 L/sec.
12:02	Water meter reading 17090560. Third shell waste truck filling. Sample 10 collected. Composite of three drains. Flow downstream 5.2, center 2.1 L/sec., downstream 1.7 L/sec.
13:50	Water meter reading 17101610. Sample 11 collected. Composite of three drains. Flow upstream 1.5 L/sec., center 2.8 L/sec., downstream 5.0 L/sec.
16:00	Sample 12 collected. Composite of three drains. Flow upstream 1.3 L/sec., center 5.9 L/sec., downstream 1.1 L/sec. Fourth shell truck filling. Average about 1 truck per hour or 9 per shift. 46 cages processed since midnight by two shifts.
16:10	Water meter reading 17114790.
18:00	Water meter reading 17121370. Shell conveyer plugged up, water flowing over. Screen at upstream drain plugged up. Flow at center and downstream drains greatly reduced at 5:20 pm. Sample 13 collected. Composite of upstream and center drains. Flow downstream 3.2 L/sec, center 9.3 L/sec., upstream trickle.

Appendix 1c (Con't.)

Time	Notes
18:26	In clean up operations. Sample 14 collected. Composite of upstream and center. Flow upstream 0.4 L/sec, center 3.7 L/sec., downstream trickle.
19:15	Water meter reading 17124930. Flow rate about 1.26 L/sec.
20:00	Shutdown. Water meter reading 17125830. 36,975 lbs meat produced by two shifts.

Appendix 1d: Field Notes From Visit To Plant C on April 24, 1987

Time	Note
11:00	Sample 1 taken at drain of brine tank during cleanup. Temperature of wastewater effluent 9° C.
11:10	Leakage from pumps and connections at large cooling tank 0.018 L/sec.
11:20	Sample 2 taken from large settling tank. Temp 18° C. Sample 3 taken at small tank inlet pipe. Sample 4 taken at small tank outlet pipe. Flow into small tank 1.6 L/sec.
11:45	Sample 5 taken at brine recycle pipe about 0.5 hr after start of break.
11:50	Sample 6 collected at belly washing tank. Overflow rate 1.3 L/sec.
	Samples collected for R. Reddy 1. Belly wash overflow pipe 2. Tongue cooling water 3. Salvage cooling water 4. Salt brine tank
12:35	Sample 7 collected at effluent pipe
12:45	Sample 8 collected at small tank inflow pipe. Temp. 19° C. Flow 3.3 L/sec.
12:50	Sample 9 collected at small tank effluent.
13:05	Slack tide

location	D.O.	Temp.	pH
Upstream of plant	6.1 mg/L	16°C	7.2
In waste plume	6.1	19	-
In small tank	6.4	20	6.9
In large tank	5.9	22	7.3

Time	Note
13:50	Sample 10 collected from effluent
13:51	Sample 11 collected from large tank

Appendix 1e: Field Notes From Visit to Plant C on August 4 and 5, 1987

Time	Note
23:00	Wastewater flow and treatment has been changed since last visit. Net result appears to be no change in treatment efficiency. Sample 1 collected from effluent. Wastewater is dark, full of organics. Appears to be mostly from large tank and from cleanup of quahog line. Sample 2 collected from small tank. Fairly clean water with large bits of meat.
00:00	Sample 3 collected from small tank. Looks clear. Most wastewater is coming from clean water flowing over from large tank next to ice room. Some soap suds. Sample 4 collected from effluent. Temp 21° C.
00:20	High pressure hose left running at full flow for over an hour
00:30	Water meter reading 385155540
01:00	Water meter reading 385158800 gal. Sample 5 collected from effluent.
01:05	Sample 6 collected from small tank. All effluent is coming from small tank.
01:07	Sample 7 taken from large tank influent. Difference between 6 and 7 represents the effectiveness of the small tank and shaker table. Difference between 5 and 7 represents overall treatment efficiency.
02:00	Sample 8 collected from effluent. Water meter reading 385166400
02:25	Shift appears to be over. Water turned down
02:30	Water meter reading 385166800
03:00	Sample 9 taken from effluent. Water meter reading 385169480.
03:30	Water meter reading 385171800. Nobody working in plant. Water leaking from hoses and overflow from tanks.

Appendix 1e (Con't.)

Time	Notes
04:00	Sample 10 collected from effluent. Water meter reading 385172200
04:15	Water meter reading 385183100
04:30	Water meter reading 385176700
05:00	Sample 11 collected from effluent. Waste meter reading 385183100. Shift starts.
05:30	Water meter reading 385187160. Belly waste collected.
06:00	Sample 12 collected from final effluent. Water meter reading 385192400.
06:00	Water meter reading 385196330.
07:00	Sample 13 collected from final effluent. Water meter reading 385201800.
07:30	Water meter reading 385206000.
08:00	Sample 14 collected from final effluent. Waste meter reading 385211000. Shell wastes being used to fill in new dock area. Shells are also being loaded onto trucks from Sea-Shells, Inc., Craddockvills, Va. 442-7130.
09:00	Sample 15 collected from final effluent. Water meter reading 385223400.
09:30	Water meter reading 385228680.
10:00	Sample 17 collected from final effluent. Sample 18 collected from large tank effluent. Water meter reading 385233400.
11:00	Water meter reading 385243200.

Appendix 1e (Con't.)

Time	Notes
12:00	Sample 19 taken from small tank. Sample 20 collected from large tank. Water meter reading 385255700.
12:10	Sample 21 collected from final effluent.
13:00	Water meter reading 385264400.
13:33	Water meter reading 385269800.
14:00	Sample 22 collected from final effluent. Water meter reading 385274300.
14:30	Water meter reading 385280400.
16:00	Sample 23 collected from small tank. Sample 24 collected from large tank. Sample 25 collected from final effluent. 25-24 = screen efficiency. 23-24 = shaker efficiency. All flow coming from small tank. Water meter reading 385294800.
16:10	Tanks inside dumped.
16:30	Water meter reading 385299850.
17:00	Water meter reading 385304120.
17:15	Shift ended.
18:00	Sample 26 collected from small tank. Sample 27 collected from final effluent. All flow from small tank. Water meter reading 385311230.
18:40	Water meter reading 385308700
16:50	Sample 28 collected from final effluent. Water meter reading 385320700. Total production 163 cages quahogs, 107 cages surf clams.

Appendix 2

Appendix 2: Data from compost experiment

Time (hours)	Pile Temperature (°C)		
	A	B	C
0	23	23	23
23	29	29	29
49	40	42	41
73	40	42	41
98	41	45	48
133	40	44	41
158	36	40	40
179	23	23	23

Time (hours)	Pile Weight (kg)		
	A	B	C
0			
23			
49	9.75	8.10	7.80
73	9.52	7.86	7.75
98	9.32	7.61	7.51
133	9.08	7.24	7.21
158	8.97	7.12	7.09
179	8.90	7.01	7.00

Time (hours)	Percent Solids		
	A	B	C
0	23	23	23
23	29	29	29
49	40	42	41
73	40	42	41
98	41	45	48
133	40	44	41
158	36	40	40
179	23	23	23

Appendix 3

Appendix 3: Data From Anaerobic Batch Reactor Experiment

Sludge Age (hour)	COD (mg/L)	pH	Volume Gas Produced (ml)
12	25,067	6.6	90
48	23,000	6.8	500
72	15,593	7.1	850
120	9,535	7.6	1,250
168	5,527	7.3	1,550