DEVELOPMENT OF ALTERNATIVE CRAB CLAW PROCESSING SYSTEMS TO MINIMIZE ENVIRONMENTAL IMPACT

by

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CHAPTER 1. INTRODUCTION

1.1 Background

The crab industry is currently the nation's fourth largest fish industry. The blue crab, "Callinectes sapidus" or the "beautiful swimmer," comprises approximately half of the total annual crab harvest (Warner, 1977). Nearly fifty percent of these, 50 to 80 million pounds of crabs each year, are harvested from the Chesapeake Bay area (Murray, 1981).

The crab processing industries are very seasonal operationally and highly localized geographically. In Virginia, over 55% of the annual production occurs in the five months between June and October. In Maryland, the seasonality of the processing is more pronounced, with 88% of the production occurring within the same period. The localization of crab processors is noted particularly in Maryland, where approximately 66% of the crab processing occurs in a 350 square miles area located west of a line from Cambridge to Stockton. (Murray, 1981) This seasonality and localization is of particular concern, because it means that the waste discharges from processing will be likely to have a heavy impact a small range of receiving waters.

The problems posed by a short time span of processing waste production and a small region for waste discharge are augmented for the blue crab industries because the processing yields very high quantities of solid waste products and high pollutant concentrations in its wastewater. After crab processing, only an approximate 14% of the total weight of the live crab harvest will be used for human consumption. The remaining 86% of the weight becomes by-products or waste (Diz, 1994). This became noted as a problem in the 1970's when complaints about the condition of the waters, including visible floating debris, odor problems, and increased turbidity, began to surface (Kramer, 1983).

Concurrent with these complaints was a trend by the federal and state regulating agencies to limit water pollution. The seafood processing companies, along with other

industries which discharged wastewaters to receiving waters, were regulated under the 1972 Federal Water Pollution Control Amendments (FWPCA). Since then, citizen and environmental groups have continually pressured government agencies to adopt more stringent standards regarding pollutants in order to restore water quality and prevent further degradation.

The trend of the past two decades towards increasingly stringent environmental legislation has resulted in federal and state regulations which have new standards. These have resulted in: the loss of public landfills, highly regulated waste transportation regulations, the inability of municipal systems to accept industrial wastes, waste disposal surcharges, and new liquid effluent standards for discharge into receiving waters. The new standards have become so stringent that many new blue crab processors may have difficulty in complying with the discharge limits. The problem with meeting the current standards is less defined for older companies, whose discharges may be "grandfathered" and thus less stringent. However, both new and existing companies face the possibility of further regulations on discharges, such as more stringent standards or ammonia limits, which many processors would be unable to comply with (Diz, 1994). Wheaton (1984) was concerned with Maryland processors, and presented that many of the state's industries would not be able to meet the treatment guidelines and remain in business. These waste problems have resulted in the need for many of the processors to investigate alternatives, such as water conservation and recovery processes, improved by-product recovery systems, and the development of industrial products from wastes (Harrison, 1993).

1.2 Scope of the Research

Many of the waste streams resulting from blue crab processing have high pollutant strengths and are thus of concern to environmental quality. However, this

research will concentrate on the waste streams resulting from the mechanized processing of the crab claws.

Currently, the processors use a mechanized system called the Harris Claw Machine to separate crab claw meat from shells. The machine employs a brine bath to accomplish this separation. The claws are washed in a tumble spray, pulverized in a hammer mill, and then conveyed to a 70% saturated brine bath. In the bath, the shell pieces sink and the meat floats. The brine bath in the tank is dumped about once a day. The waste stream from this is of particular concern because it is contains a high five day biochemical oxygen demand (BOD_5), ranging from 7,000 to 15,000 mg/L, and a chloride ion concentration of 135,000 to 150,000 mg/L (Harrison, 1993). For new plants, this stream typically surpasses the biological oxygen demand effluent limitations, but is released to the ocean, virtually without treatment, because the chloride ion concentration is so high that it renders biological treatment ineffective. If the standards for existing plants is increased in future regulations and the processors no longer meet the effluent standards without treatment, then the need to find a more treatable waste stream will become increasingly important.

1.3 Research Objectives

The objectives of this project were to develop feasible alternatives to the Harris Claw brine bath for the separation of crab claw meat and shell. The alternative methods were devised to improve the environmental quality of the wastewater by eliminating the problem of chloride ion toxicity and improve meat product quality by eliminating the unappealing salt flavor characteristic of mechanically processed crab claw meat. The feasibility of the alternatives was investigated through the impacts of the new processes in terms of: product yield; meat product quality, including shelf-life and appearance and taste; and environmental impacts through wastewater characterization.

Two new methods for claw meat and shell separation were investigated. In the first method, the possibility of using hydraulic principles, as applied in a typical channel-type grit removal system for wastewater treatment, to separate shell from meat was investigated. Recycling the water would reduce water use, and eliminating the salt additions would improve wastewater treatability. The second method investigated involved the use of alternative dense solutions for processing with the Harris Claw Machine. The use of corn syrup or corn syrup/salt solutions in place of the standard brine bath would potentially improve wastewater treatability and improve the meat product taste.

CHAPTER 2. LITERATURE REVIEW

The following review includes the federal and Virginia state effluent regulations to which crab processors are subject, an overview of the crab processing procedure, specifically concentrating on mechanical processing of crab claws, and previous studies on the characterization of wastewater from the mechanical processing of crab claws. The review also includes an overview of the hydraulic principles from grit chamber design for the application to a claw meat separator system, an explanation of the use of a laser-Doppler system for measuring water velocity within a channel, and an overview of the use of alternative dense media solutions for the separation of crab claw meat and shell.

2.1 Federal (EPA) Regulations

Blue crab (*Callinectes sapidus*) processing industries, as effluent dischargers, are subject to federal, state, and sometimes local regulations. Historically, federal regulations have classified the blue crab processing industries under a "canned and preserved seafood processing" industry category, and thus the processors have been subject to regulation under the Federal Water Pollution Control Act Amendments (FWPCA) of 1972. Section 304(b) of the act designated a national goal of eliminating the discharge of all pollutants to navigable waters, or a "zero discharge" goal, by 1985. The act established a permitting system and interim guidelines in order to achieve this goal (40 CFR 403).

FWPCA requires that all dischargers obtain a National Pollutant Discharge Elimination System (NPDES) permit which indicates the maximum levels allowable of certain pollutants. The permits for the blue crab processing industry allow for different effluent qualities based on a number of criteria. These include standards for conventional (manual) blue crab processors versus mechanical processors, existing versus new sources, and direct offsite discharges versus "indirect" discharges to publicly owned treatment works (POTW) (40 CFR 403).

The first interim guideline established in FWPCA required that dischargers achieve effluent qualities based on the best practicable control technologies (BPT) by July 1, 1977. The second interim guideline required that by July 1, 1983 dischargers achieve effluent qualities based on the best achievable control technologies (BAT). The BAT requirements were much more stringent than the BPT requirements. It was later determined that the BPT guideline was too stringent for industries discharging conventional pollutants to be achievable. The requirements for the second interim guideline were then changed so that the dischargers would be responsible only for meeting effluent qualities based on the best conventional control technologies (BCT). The BCT levels were less stringent than the BAT, and for the blue crab processing industries resulted in required effluent pollutant levels which were equal to the original levels required by BPT (Virginia Polytechnic Institute and State University, 1995).

The under the most current regulations under FWPCA, the EPA regulates only four parameters for the blue crab processing industries. These include five day biochemical oxygen demand (BOD_5), pH, total suspended solids (TSS), and oil and grease (O&G). Table 1 enumerates the maximum allowable effluent limits for conventional treatment processors and Table 2 includes the limits for mechanical treatment processors as of 1993. The tables are adopted from Harrison, 1993 (Virginia Polytechnic Institute and State University, 1995).

The processing industries may discharge their wastes directly to surface waters or "indirectly" to POTWs. Sections 307 (b) and (c) of FWPCA require that new and existing sources must achieve pretreatment standards for the introduction of pollutants into POTWs, because the POTWs may not be able reduce certain pollutants or certain pollutants might interfere with the treatment processes. These pretreatment standards are set by the National Pretreatment Program (40 CFR 403). The industries must achieve wastewater quantities and qualities determined by the affected treatment plants. The treatment plants also have the authority to apply surcharges for wastewater volumes, rates, and pollutant concentrations (Diz, 1994).

Table 1. Conventional blue crab processing[1] federal effluent limitations
40 CFR 408-Subpart B. Adopted from Virginia Polytechnic
Institute and State University, 1995.

	EXISTING SOURCE			NEW SOURCE		
	Direct Discharge		Indirect Discharge	Direct Discharge		Indirect Discharge
	Max [2]	Avg [3]		Max [2]	Avg [3]	CFR 403
BOD_5	no limit	no limit	no limit	0.30	0.15	(5)
TSS	2.2	0.74	no limit	0.90	0.45	(5)
O&G	0.60	0.20	no limit	0.13	0.065	(5)
pH	(2)	(2)	no limit	(2)	(2)	(5)

Note: All units, except pH, are in lb/1,000 lb raw seafood processed.
(1) Applies to existing facilities manually processing more than 3000 lbs of raw seafood on any day during the calendar year and all new sources.
(2) Maximum for any one day.
(3) Average of daily values for 30 consecutive days.
(4) Within the range of 6.0-9.0.
(5) Set by POTW with an approved pretreatment program.

Table 2. Mechanized blue crab processing[1] federal effluent limitations
40 CFR 408-Subpart C. Adopted from Virginia Polytechnic
Institute and State University, 1995.

	EXISTING SOURCE			NEW SOURCE		
	Direct Discharge		Indirect Discharge	Direct Discharge		Indirect Discharge
	Max [2]	Avg [3]		Max [2]	Avg [3]	CFR 403
BOD_5	no limit	no limit	no limit	5.0	2.5	(5)
TSS	36	12.0	no limit	13	6.3	(5)
O&G	12	4.2	no limit	2.6	1.3	(5)
pH	(2)	(2)	no limit	(2)	(2)	(5)

Note: All units, except pH, are in lb/1,000 lb raw seafood processed.
(1) Applies to existing facilities manually processing more than 3000 lbs of raw seafood on any day during the calendar year and all new sources.
(2) Maximum for any one day.
(3) Average of daily values for 30 consecutive days.
(4) Within the range of 6.0-9.0.
(5) Set by POTW with an approved pretreatment program.

2.2 State Regulations

Federal law requires that states adopt and maintain water quality standards for state waters and allows the states to include effluent limits which are at least as stringent, or more so, than the federal limits. Virginia maintains an effluent permit program, the Virginia Pollutant Discharge Elimination System (VPDES) which is enforced by the Virginia Department of Environmental Quality (DEQ). The permit limits are based on federal requirements, Best Professional Judgment (BPJ), water quality standards, water quality models, water quality management plans, etc.

The permits under VPDES place limits on the same four effluent quality parameters as the federal laws, including BOD_5, suspended solids, pH, and oil and grease. In the past, permits within the state have varied on a case by case basis, with variations dependent on such plant criteria as new versus existing sources, conventional versus mechanical processors, and the location and production rates of plants. The permits have been valid for five years, but the state maintained the authority to make the requirements more stringent at any time within the duration of the permit (VR-680-14-10, Draft 1996; Virginia Polytechnic Institute and State University, 1995).

Recent changes to the permitting system have been proposed. A draft for a General NPDES Permit Regulation System for Seafood Processing Facilities was prepared for April 1996 (Virginia State Water Control Board, VSWCB, 1996). Under the general permit system, all facilities with the same or similar types of operations and facilities that discharge with the same or similar types of wastes would be required to meet the same standardized effluent limitations, conditions, and monitoring requirements, and additionally would be required to develop a site-specific storm water pollution prevention program. The recent system provides limitations for twenty-six (subject to change) different seafood processes in Virginia. The limits proposed by the general permit system for conventional and mechanized blue crab processors are listed in Table 3 and Table 4, respectively. The limits are essentially the same as the limits under the

federal guidelines, and are representative of the degree of effluent reduction attainable by the application of both BPT and BCT. Again, the General NPDES permits would also be effective for five years (VR 680-14-10, Draft, 1996).

Table 3. Conventional blue crab processing State Water Control Board General VPDES, VR 680-14-10 for Seafood Processing Facilities.

	EXISTING SOURCE (1) Direct Discharge		NEW SOURCE Direct Discharge	
	Max (2)	Avg (3)	Max (2)	Avg (3)
BOD_5	no limit	no limit	0.30	0.15
TSS	2.2	0.74	0.90	0.45
O&G	0.60	0.20	0.13	0.065
pH	(2)	(2)	(2)	(2)

Note: All units, except pH, are in kg/1,000 kg raw seafood processed.
(1) Applies to existing facilities manually processing more than 3000 lbs of raw seafood on any day during the calendar year and all new sources.
(2) Maximum for any one day.
(3) Average of daily values for 30 consecutive days.
(4) Within the range of 6.0-9.0.
(5) Set by POTW with an approved pretreatment program.

Table 4. Mechanized blue crab processing State Water Control Board General VPDES, VR 680-14-10 for Seafood Processing Facilities.

	EXISTING SOURCE Direct Discharge		NEW SOURCE Direct Discharge	
	Max (2)	Avg (3)	Max (2)	Avg (3)
BOD_5	no limit	no limit	5.0	2.5
TSS	36.0	12.0	13	6.3
O&G	13.0	4.2	2.6	1.3
pH	(2)	(2)	(2)	(2)

Note: All units, except pH, are in kg/1,000 kg raw seafood processed.
(2) Maximum for any one day.
(3) Average of daily values for 30 consecutive days.
(4) Within the range of 6.0-9.0.
(5) Set by POTW with an approved pretreatment program.

2.3 Blue Crab Processing

Blue crabs are delivered live and unrefrigerated to the processing plants by boat or truck. The crabs are weighed and then dumped into large stainless steel baskets. During the winter, the crabs burrow and dredging is necessary in order to harvest the crabs. These crabs are covered with sand and grit, and are thus directed through a tumble spray washer before being put into the steel baskets. The steel baskets are then placed in horizontal or vertical retorts and cooked by steaming for 7-12 minutes at 121°C and 15 psig (Phillips and Peeler, 1972). The goals of the cooking step are to facilitate the removal of the meat from the shell, to give the product a characteristic crab meat odor and flavor, and to reduce the microbial populations in the crab meat.

After cooking, the crabs are allowed to cool to room temperature in a cooling room equipped with blowing fans for approximately 30 minutes, and then are placed in a cooler at 33 - 40°F (0.6 - 4.4°C). The precooling to room temperature is essential because if steaming crabs were placed into the cooler, the steam would form condensate on the cooler ceiling, which could drip back down onto the crabs and potentially contaminate them (Ulmer et al., 1964; Wentz et al., 1985).

Crabs are prepared for meat removal by either a wet or dry process. In the wet process, the crabs are backed and declawed first. The crab bodies are then washed by hand or machine and the meat is removed immediately, or the bodies may be refrigerated overnight for later meat removal. In the dry process, the crab body washing procedure is not included. Each picker backs, declaws, and removes all of the meat from each crab. (Cockey, 1980)

Hand picking is a very labor intensive practice, and therefore mechanized crab meat picking is practiced in many industries. The Quik-Pik machine uses high speed vibration to remove the body meat from the shell. The Harris Claw machine uses a saturated brine (salt) solution to separate crab claw meat from shells. The Harris Claw machine process is the focus of this report, and thus is described in the following.

The claws are first washed in a tumble spray process, and produces an effluent stream known as the "claw wash reel" effluent. The claws are carried by a conveyor to a hammer mill which pulverizes the crab claws. The fragments produced from the hammer mill are then dropped into a tank which contains an approximately 70% saturated brine solution (Harrison, 1993; Hong, 1990).

Within the brine bath, the shells will sink to the bottom of the tank and the meat will float due to the density differences and the density of the salt solution. The settled shells are removed by a screw conveyor which empties into a perforated receptacle. The liquid runs through this receptacle, and produces a waste stream identified as the "shell liquid" effluent. The meat in the brine tank floats out of the top of the tank and is caught on a conveyor. The meat is washed by spray nozzles in order to reduce the salt content of the meat. The effluent from this step is referred to as the "claw meat wash water." Excess water which has been absorbed by the meat is removed by a metal squeezer. The brine tank water is changed at least once during each day of operation producing the "Harris Claw brine bath" effluent (Virginia Polytechnic and State University, 1995).

The Harris Claw machine produces a crab meat product with a high salinity. This has very low sensory acceptability, and thus, the meat product is only used as a base meat for the manufacture of crab cakes or other processed crab products (Hong, 1990).

2.4 Characterization of Wastewater from Crab Processing

The wastewater characteristics generated by processors of blue crab have been evaluated in a few different studies. In most studies, the characteristics of the overall effluent of selected processing plants were published. Only one study was available which provided the characteristics of the effluent streams of the Harris Claw machine (Virginia Polytechnic Institute and State Universtiy, 1995).

In the early 1970's the first significant study of the wastewater characteristics from the crab processing industries was made in an attempt to determine the effluent

limitations achievable through BPT/BCT under the FWPCA. The results of the study are presented in the 1974 EPA *Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Catfish, Crab, Shrimp, and Tuna Segment of the Canned and Preserved Seafood Processing Point Source Category.* The study included documentation based on two conventional and two mechanized processing plants in the Chesapeake Bay. General conclusions drawn from these studies resulted in the derivation of separate categories and standards for the conventional and mechanized blue crab processing industries. The separation was based on two main conclusions: that the conventional blue crab processing industries use only 1/10th the wastewater of the mechanized processing industries and that the effluent BOD_5 concentration of the mechanized industries was significantly higher than the effluent concentration of the conventional industries.

The studies revealed that the mechanized processing industries consumed 30% more water to produce the same amount of raw crab meat product as the conventional processing industries. The wastewater pollutant concentrations of the mechanized industries were lower, however, the increased water consumption resulted in an overall higher pollutant loading than the conventional processors. The mechanized processes were also found to be more subject to large wastewater flow variations.

The evaluations of the conventional processing industries yielded the following breakdown of average wastewater characteristics: an average effluent flow of 660 gal/day was produced from approximately 60% ice making cooling water, 23% cleanup water, and 17% cooker effluent. An average water consumption of 142 gallons per 1,000 pounds of raw crab processed was observed. According to Riley of the EPA (1980), an approximate 264 gallons of wastewater was produced per 1,000 pounds of live crab processed. The overall wastewater had and average concentration of 4,400 mg/L BOD_5, 620 mg/L TSS, 220 mg/L O&G, 760 mg/L total Kjeldahl nitrogen (TKN-N), and 50 mg/L ammonia-nitrogen (NH_3-N).

The mechanized processing industry studies yielded significantly different average wastewater characteristics. An average effluent flow of 46,500 gal/day was produced from approximately 90.5% machine picking water, 7.7% washdown water, 1.1% ice making cooling water, 0.5% brine tank and 0.2% cooker effluent. An average of 4,415 gallons of water per 1,000 pounds of raw crab processed was consumed. Riley estimated that (1980) an approximate 7,530 gallons of wastewater was produced per 1,000 pounds of live crab processed. The overall wastewater concentrations were 600 mg/L BOD_5, 330 mg/L TSS, 150 mg/L O&G, 760 mg/L TKN-N, and 5.4 mg/L NH_3-N. In the brine separation tanks, average chloride concentrations ranged from 100,000 to 200,000 mg/L. The tanks contained approximately 275 gallons of water and were dumped at the end of each shift. The EPA data are summarized in Table 5.

Published literature by Brinsfield et al. (1977), Rubin (1983), and Overcash et al. (1980) characterized the wastewater of conventional blue crab treatment plants. Brinsfield et al. studied six plants and noted that some used a brine solution to separate meat from shell during operation. The chloride concentration of this step ranged from 100,000 mg/L to 200,000 mg/L. Rubin noted a typical flow rate of 3,000 gal/day. In plant changes reduced this to 600 gpd, but no characterization of the changes in effluent pollutant concentrations was noted. The results of these studies are summarized in Table 5.

Table 5. Conventional and mechanized blue crab wastewater characterization found in published literature. Adopted from Virginia Polytechnic Institute and State University, 1995.

Type	CONVENTIONAL PROCESSES					MECHANICAL PROCESSES	
	EPA Development Document, 1974		Brinsfield et al., 1977	Overcash et al., 1980	Rubin 1983	EPA Development Document, 1974	
	Average	Range	Average	Average	Average	Average	Average
No. samples	18	18	74	-	6	7	7
No. plants studied	2	2	6	-	1	2	2
Production (lb/day)	5700	-	4400 ± 1500	-	-	-	-
Flow (gal/day)	665	630-700	-	-	3000	46500	20000-73000
Flow (gal/1000 lb)	142	128-158	765± 69	-	-	4415	3480-5350
BOD-5 (mg/L)	4400	-	-	-	-	600	-
BOD-5 (lb/1000 lb)	5.2	4.8-5.5	2.67± 7.81	-	-	22	22-23
COD (mg/L)	6300	-	-	1100	968± 119	980	-
COD (lb/1000 lb)	7.5	7.2-7.8	-	-	-	36	29-42
TSS (mg/L)	620	-	-	-	-	330	-
TSS (lb/1000 lb)	0.74	0.70-0.78	1.92± 4.26	-	-	12	-
O&G (mg/L)	220	-	-	-	-	150	-
O&G (lb/1000 lb)	0.26	0.21-0.30	0.04± 0.07	-	-	5.6	4.3-6.9
TKN-N (mg/L)	760	-	-	55	1330± 113	98	-
TKN-N (lb/1000 lb)	0.90	0.80-1.0	0.27± 0.66	-	-	3.6	2.7-4.4
NH3-N (mg/L)	50	-	-	-	119± 11	5.4	-
NH3-N (lb/1000 lb)	0.06	-	0.04± 0.13	-	-	0.02	0.016-0.024
Phosphorus (mg/L)	-	-	-	10	69± 9	-	-
Phosph. (lb/1000 lb)	-	-	0.04± 0.08	-	-	-	-
pH	7.5	7.2-7.9	-	-	-	7.0	6.9-7.2

Three mechanized blue crab processing plants, two of which used the Harris Claw machine, were characterized over the course of one year by Virginia Polytechnic Institute and State University (1995). In this study, the characteristics of the wastewaters emanating from different processes in the industry were reported. Of particular concern is the waste streams which result from the processing of crab claws in the Harris Claw machine, because they tend to contain relatively concentrated wastewaters and possess potential toxicological effects due to the high concentration of chloride ion used in the brine bath.

The plants exhibited maximum flows of 20,00 gpd and 10,000 gpd for plants #1 and #2, respectively, during normal operation. The flows averaged only 2,000 gpd when the mechanical processes, including the Quik-Pik and Harris Claw, were not in use. Overall, Harrison found that the Harris Claw machine processing and clean up waste streams of plant #1 contributed 79-95% of the total wastewater volume from the plant, 13-52% of the total COD loading, and 70-91% of the total TSS. In plant #2, the Harris

Claw waste streams contributed 70-79% of the plant wastewater volume, 43-61% of the COD loading, and 70-88% of the TSS loading. The temperatures of the effluent streams from the Harris Claw machine were found to be in an acceptable range of 16°-30°C, and the pH also was found to be consistently within the range of 6.0-9.0.

The Harris Claw machine effluents were found to display large variability in terms of the effluent quality both between and within the studied plants. The variability was found to be related to such parameters as the time of year and the location of the particular batch of crabs harvested and differences between processing, such as whether or not the crabs were processed through the tumble spray or the particular operation of conveyors and washes in plants.

The Harris Claw Wash Reel effluent was found to contain a high percentage of organic matter. The VSS was 85-88% of the TSS, and is therefore assumed to be degradable. This stream, also, does not contribute the problem of a high chloride content which is found in the other waste streams associated with the Harris Claw machine, because the washing takes place prior to the addition of any salt. Plant #1 did not operate the wash reel during the study.

The shell waste effluent and the brine bath were found to have the highest TSS level of any waste stream in the processing plants, due to the large amount of meat and shell particles which remain suspended in the brine solution. The VSS concentration was also high due to the remaining meat particles. However, the VSS was only 19-30% of the TSS, indicating a relatively large proportion of inorganics in suspension. The inorganic concentration was due to the presence of inert shell components, which are comprised of 40-50% calcium carbonate, and precipitated salt. These two waste streams also contain 100,00-144,00 mg/L chloride ion, and thus are relatively difficult to treat. The chloride ion concentration is so high that on one visit, it was noted that 3,440 pounds of salt were used to produce 2,250 pounds of claw meat.

The volume and COD loading of the shell waste effluent in one plant was found to be 4-5 times that of the other plant. This was due to the utilization of different

conveyor types at each plant. At the plant which had a larger volume of wastewater, the shell conveyor pulled out a much larger volume of water from the tank, but the COD concentration of the bath was relatively similar. Thus, the COD loading increased as the wastewater volume increased.

The claw meat conveyor wash effluent was also found to be highly variable. One plant used 4-5 times the amount of water to wash an equal amount of crab meat. In this case, the larger volume of water also had a lower COD concentration, so the total COD loadings from each processor were approximately the same. The chloride ion concentration in this waste stream was also found to be a problem; the waste stream contained 3,100-15,275 mg/L chloride ion. Table 6 indicates the process flows and production information found from the waste streams associated with the Harris Claw machine process and cleanup. Table 7 summarizes the characterization of the wastewater in terms of the concentrations, and Table 8 summarizes the wastewater characterization in terms of pounds per 1,000 pounds finished meat product.

Table 6. Characterization of blue crab processing wastewater associated with the Harris Claw machine. Adopted from VPI&SU, 1995.

Process Type	Plant	Product (lbs)	Flow Rate (gpm)	Volume (gal)	Temperature °C	pH
Harris Claw	2	2,380	1.8	650	30	7.5
Reel Wash	2	1,535	2.3	540	-	8.4
	2	760	-	390	-	-
Shell Waste	1	-	0.3	-	22	8.4
Effluent	1	1,550	0.5	135	16	8.2
	2	2,380	1.1	400	30	8.1
	2	1,535	2.2	520	-	7.9
	2	760	-	370	-	-
Harris Claw	1	-	-	230	20	8.3
Brine Bath	1	1,550	-	230	19	8.2
	2	2,380	-	220	30	-
	2	1,535	-	220	-	7.9
	2	760	-	220	-	-
Claw Meat	1	-	25.4	-	22	8.6
Conveyor	1	1,550	33.5	9,715	19	8.3
Wash	2	2,380	8.2	2,950	30	8.2
	2	1,535	8.8	2,070	-	8.2
	2	760	-	1,800	-	-
Claw Room	1	-	7.8	-	22	8.6
Cleanup	1	1,550	-	420	18	8.5
	2	2,380	-	-	-	-
	2	1,535	1.3	120	-	8.5
	2	760	-	360	-	-

Table 7. Characterization of blue crab processing wastewater associated with the Harris Claw machine. Adopted from VPI&SU, 1995.

Process Type	Plant	(mg/L)								
		COD	BOD-5	TSS	VSS	Cl	O&G	TKN-N	NH3-N	TP
Harris Claw	2	9,145	>3,740	3,970	3,400	620	-	-	-	-
Reel Wash	2	2,940	2,770	1,270	1,100	-	-	400	14	42
	2	15,410	>7,800	10,880	9,500	-	-	2,400	100	135
Shell Waste	1	15,690	15,350	18,340	5,160	112,170	10	-	-	-
Effluent	1	23,280	15,120	25,100	5,420	-	-	2,260	330	190
	2	13,005	>9,250	-	-	100,160	-	-	-	-
	2	17,260	13,500	13,740	2,660	-	-	2,240	225	170
	2	39,680	16,240	33,415	16,390	-	-	3,390	115	280
Harris Claw	1	14,980	7,000	17,460	4,390	143,990	6	-	-	-
Brine Bath	1	21,510	15,000	31,540	8,320	-	-	3,060	190	270
	2	-	7,805	-	-	135,020	-	-	-	-
	2	17,460	14,000	14,970	4,270	-	-	2,330	110	230
	2	15,870	8,925	12,670	3,740	-	-	1,775	80	160
Claw Meat	1	570	265	445	410	3,100	-	-	-	-
Conveyor	1	650	640	660	540	-	-	150	<10	7
Wash	2	1,790	1,020	585	355	15,275	-	-	-	-
	2	2,520	2,040	930	480	-	-	370	22	25
	2	2,625	1,790	1,170	775	-	-	390	17	27
Claw Room	1	3,920	1,260	1,375	630	26,770	-	-	-	-
Cleanup	1	900	-	3.050	2,790	-	-	210	<10	20
	2	-	-	-	-	-	-	-	-	-
	2	550	420	590	500	-	-	160	<10	8
	2	-	-	-	-	-	-	-	-	-

Table 8. Characterization of blue crab processing wastewater associated with the Harris Claw machine. Adopted from VPI&SU, 1995.

Process Type	Plant	(lbs/1,000 lb product)								
		COD	BOD-5	TSS	VSS	Cl	O&G	TKN-N	NH3-N	TP
Harris Claw	2	20.8	>9	9.0	7.7	1.4	-	-	-	
Reel Wash	2	8.6	8.1	3.7	3.2	-	-	1.2	0.04	
	2	66.0	>33	46.6	40.7	-	-	10.3	0.43	
Shell Waste	1	16.9	11.0	18.2	3.9	-	-	1.6	0.24	
Effluent	2	18.2	>13	-	-	140	-	-	-	
	2	48.8	38.1	38.8	7.5	-	-	6.3	0.35	
	2	161.1	65.9	135.7	66.5	-	-	13.8	0.47	
Harris Claw	1	26.6	18.6	39.0	10.3	-	-	3.8	0.24	
Brine Bath	2	-	6.0	-	-	104	-	-	-	
	2	20.9	16.7	17.9	5.1	-	-	2.8	0.13	
	2	38.3	21.5	30.6	9.0	-	-	4.3	0.19	
Claw Meat	1	34.0	33.5	34.5	28.2	-	-	7.8	<0.52	
Conveyor	2	18.5	10.5	6.0	3.7	158	-	-	-	
Wash	2	28.3	22.9	10.5	5.4	-	-	4.2	0.25	
	2	51.9	35.4	23.1	15.3	-	-	7.7	0.34	
Claw Room	1	2.5	-	8.5	7.8	-	-	0.6	0.03	
Cleanup	2	0.4	0.3	0.4	0.3	-	-	0.1	0.01	

2.5 Use of Principles from Grit Chamber Design for Claw Meat Separation

In wastewater treatment processes, the grit chamber is designed to handle the portion of suspended solids contained in municipal sewage which consists of inert inorganic particles, such as sand, metal fragments, eggshells, etc. These particles are termed “grit”, and their treatment in a preliminary treatment process is necessary since grit can block conduits and promote excessive wear of mechanical equipment. Grit removal devices primarily operate based on the significant difference between the specific gravity of organic and inorganic particles (McGhee, 1991).

In a typical open channel, the horizontal velocity in the center and just below the water surface will be the highest, and a differential horizontal velocity will be established within the channel. The velocity will be lowest at the boundaries of the channel due to frictional forces between the fluid and walls. For this reason, typical channel-type grit chambers will be designed as constant flow channels in order to effectively separate particles. The flow in constant velocity channels is controlled by an orifice, weir, or downstream flume. There are two primary categories of constant velocity channels used in grit chamber construction. One is a channel of parabolic cross-section, or the approximate equivalent of this, in which flow is controlled by a rectangular standing-wave flume (control section). A more complete description of the hydraulics principles involved in this design is presented by McGhee (1991). The second is a channel of approximately rectangular cross-section, in which flow is typically controlled by a special shaped weir plate (Escritt, 1984).

The particles in grit chamber design are assumed to settle as “discrete” types, with particle settling velocities, v_s, controlled by Newton’s law. The law applies to the terminal settling velocity of a spherical particle.

$$v_s = \left[\frac{4g(\rho_s - \rho)d}{3C_D\rho}\right]^{1/2} \qquad [2.1]$$

where ρ is the fluid density, ρ_s is the particle density, and C_D is the dimensionless drag coefficient. C_D is found from:

$$C_D = \frac{24}{} + \frac{3}{\sqrt{}} + 0.34 \qquad [2.2]$$

where is the Reynold's number. In hindered settling, the high density of particles produce particle interactions, and as individual particles displace water during settling, the relative velocities of neighboring particles are affected. The hindered settling velocity, v_h, is found from:

$$v_h = v_s (1 - C_v)^{465} \qquad [2.3]$$

where C_v is the ratio of the volume of the particles to the total volume of the suspension. This equation is appropriate when the Reynold's number is less than 0.2. Hindered velocity settling is typically observed in sludge thickening processes, however, is not typically found in grit chamber processes (McGhee, 1991).

An important parameter in the design of a grit chamber is the horizontal, or flow through, velocity in the channel. The velocity must be high enough so that the organic particles are not allowed to settle, but lower than the velocity which causes scour of the settled grit particles. Thus, in order to permit the organic particles which may settle in the channel to be resuspended by scour, and still effectively remove grit, the horizontal velocity must be designed to be close to, but less than, the scour velocity of the grit. The horizontal velocity, V, which will just produce scour is:

$$V = \left[\frac{8\beta(s-1)gd}{f}\right]^{1/2} \qquad [2.4]$$

where β is a dimensionless constant ranging from 0.04 to 0.06, s is the specific gravity of the (grit) particle, and f is the Darcy-Weisbach friction factor, ranging from 0.02 to 0.03 (McGhee, 1991).

In the design of a typical grit chamber, the flow-through velocity is generally set at 1.0 fps. This velocity will allow the removal of 65 mesh grit (grit particles retained on a 65 mesh screen). Some variation is allowed, but recommendations by the EPA indicate

that the velocity should range between 0.75 fps and 1.25 fps at all flow rates in order to accomplish removal (EPA, 1978). Escritt (1984) recommends that design should be for a horizontal velocity of 300 mm/s (1.0 fps), with variations between 225 mm/s (0.74 fps) and slightly above 300 mm/s. A horizontal velocity below 200 mm/s (0.66 fps) will permit organics to settle, and above 375 mm/s (1.2 fps) will cause detritus (grit) to be swept away. Because the range of horizontal velocities permissible in the channel is so narrow, the width of the control section, or controlling weir, must be very precise (Escritt, 1984).

The design approach for a parabolic channel-type grit chamber is outlined by Metcalf and Eddy (1972). The grit chamber assumes a parabolic cross section in order to establish a uniform flow velocity throughout the cross section of the channel. The cross-sectional area of the channel, A, is given by:

$$A = \frac{2}{3} HT, \qquad [2.5]$$

where H is the depth of water within the cross section and T is the width of the top of the parabola (at water level). If the channel depth and width are chosen as reasonably constructable parameters and the flow through (horizontal) velocity, V, is chosen based on the above description, then the flow rate, Q, can be calculated from:

$$Q = AV = \left(\frac{2}{3}\right) HTV. \qquad [2.6]$$

The rectangular control section, which maintains the horizontal velocity as a constant, is constructed in the form of an abrupt channel contraction. The dimensions of the required control section can be found by application of energy conservation (Bernoulli's equation) between the channel and the control section according to the following:

$$H + \frac{V^2}{2g} = d_c + \frac{v_c^{\,2}}{2g} + 0.1\frac{v_c^{\,2}}{2g} \qquad [2.7]$$

where d_c is the depth of water in the control section, v_c is the critical velocity, and g is the acceleration due to gravity. The above equation assumes a 10 % head (energy) loss as

the water flows into the sudden contraction (Metcalf and Eddy, 1972). The acceptability of this assumption is by a study on the head losses in channel contractions by Formica (1955). The head loss in a square edged channel contraction (abrupt) is approximately 23 percent of the velocity head $\left(0.23\frac{v_c^2}{2g}\right)$ and is 11 percent of the velocity head in a rounded edged contraction. These coefficients vary with the ratio of the water depth in the control section to the width of the water right at the contraction. When the ratio is less than one, the coefficients reduce to 0.10 and 0.04 for square edged and rounded edged contractions, respectively (Henderson, 1966).

The energy conservation equation, equation [2.7] can be solved by using the relationships for critical flow. The flow within the control section will be critical (McGhee, 1991). Therefore, the following derivation applies:

$$\frac{dE}{dy} = 1 + \frac{q^2}{gy^3} \qquad [2.8]$$

The above equation is the definition of critical flow, where E is energy, y is depth, and q is the flow rate per unit width. From equation [2.8]:

$$q^2 = gd_c^3 \qquad [2.9]$$

$$v_c^2 d_c^2 = gd_c^3 \qquad [2.10]$$

where $q=v_c d_c$. Then:

$$\frac{v_c^2}{2g} = \frac{1}{2}d_c \qquad [2.11]$$

$$d_c = 2\frac{v_c^2}{2g} \qquad [2.12]$$

(Henderson, 1966).

If equation [2.12] is substituted in equation [2.8], the following results:

$$H + \frac{V^2}{2g} = 2\frac{v_c^2}{2g} + \frac{v_c^2}{2g} + 0.1\frac{v_c^2}{2g} = 3.1\frac{v_c^2}{2g} \qquad [2.13]$$

Since, H and V are knowns, the velocity head in the control section can be calculated as:

$$\frac{v_c^2}{2g} = \frac{1}{3.1}\left(H + \frac{V^2}{2g}\right) \qquad [2.14]$$

The depth of the control section is then calculated as twice the velocity head in the control section, from equation [2.12]. The width of the control section is found from:

$$v_c = \sqrt{2g\left(\frac{v_c^2}{2g}\right)} \qquad [2.15]$$

The cross sectional area of the control section, a, is used to find the width of the control section, w:

$$a = \frac{Q}{V} \qquad [2.16]$$

$$w = \frac{a}{d_c} \qquad [2.17]$$

The required length for settling within the channel, L, is calculated from:

$$L = \frac{HV}{V_S} \qquad [2.18]$$

where V_S is the settling velocity of a typical particle within the system (Metcalf and Eddy, 1972). The length of the channel must be sufficient so that the smallest particle will settle from the top water level of the channel, to the bottom of the channel during the detention time of the channel, accounting for the unavoidable turbulence in the channel which tends to prevent settling (Escritt, 1984).

2.6 Dense Media Separation

In 1990, Gi-Pyo Hong presented the results of an examination of alternative dense solutions to replace the 70% saturated brine bath used in the Harris Claw machine. In preliminary trials, a number of different solutions of corn syrups, high fructose corn syrups, and salt were adjusted to achieve physical properties that would achieve a similar separation as the brine solution. The corn syrups and high fructose corn syrups were purchased from the A. E. Staley Manufacturing Company (Decatur, IL). Ten solutions

were chosen for further study, and a 19.0% (w/v) solution, similar to the brine (salt) solution used by the processing industry, was prepared as a standard for comparison. The physical properties, including specific gravity and viscosity, and the sensory properties of the meat product were used as a basis of comparison for initial trials.

The solutions were adjusted to have a specific gravity between 1.130 and 1.140 at 60°F, which is the approximate density of the salt solution. The viscosities of the solutions were measured, and it was found that the viscosities of the alternative media solutions were higher than that of the salt solution, and the corn syrup solutions (Sweetose 4300 and Staley 1300) tended to have higher viscosities than the high fructose corn syrups (Isosweet 5500 and 100). The salt solution had a viscosity of approximately 1.222 cst. The corn syrup solutions had viscosities ranging from 1.733 cst to 3.811 cst, and the high fructose corn syrups had viscosities ranging from 1.619 cst to 1.944 cst. The composition of the alternative media, the specific gravities, and viscosities found are presented in
Table 9.

In the study, canned, pasteurized flake crabmeat was submerged in each solution for 40 seconds, which is the approximate residence time of a meat particle in the Harris Claw machine. The meat was drained and packaged for sensory and shelf life analyses. The sensory evaluations were performed by 20 panelists, each rating appearance, odor, flavor, texture, and overall acceptability. With a 5% significance level, no difference was found between the alternative solutions in appearance, odor, and texture, except one solution, the 30% (v/v) Sweetose 4300 corn syrup scored significantly lower in appearance. In the flavor category, all of the alternative solutions were found to be significantly superior to the salt solution standard, which was extremely unacceptable in flavor and overall acceptability. Solutions C, G, I, and K (refer to Table 9) were acceptable in flavor (scored above 6), and solutions B, C, F, G, I, and K were rated well in overall acceptability (above 6). Solution I received the highest scoring in flavor and overall acceptability. It was found that very sweet solutions or solutions with over 5%

(w/v) salt produced meat that was unacceptable in flavor. The sensory evaluation, including only taste and overall acceptability since these categories yielded significant differences in the results, are presented in Table 9.

Table 9. Alternative separation solution compositions, physical properties, and sensory ratings of meat products. Adopted from Hong, 1990.

Solution	Composition[1]	Specific Gravity	Viscosity (cst)	Flavor[2]	Acceptability[2]
A	19.0% salt	1.130	1.222	2.07	2.95
B	16.1% Isosweet 5500 HF CS + 10.0% salt	1.135	1.619	5.71	6.43
C	24.6% Isosweet 5500 HF CS + 5.0% salt	1.130	1.811	6.36	6.45
D	30.0% Sweetose 4300 CS	1.136	2.719	5.36	5.64
E	14.6% Sweetose 4300 CS + 10.0% salt	1.130	1.733	3.36	4.34
F	22.5% Sweetose 4300 CS _5.0% salt	1.135	2.163	5.99	6.21
G	30.0% Staley 1300 CS	1.139	3.811	6.50	6.33
H	14.6% Staley 1300 CS + 10.0% salt	1.130	1.907	4.00	4.21
I	22.5% Staley 1300 CS + 5.0% salt	1.135	2.685	6.92	6.67
J	18.0% Isosweet 100 HF CS + 10.0% salt	1.133	1.648	3.50	4.02
K	28.0% Isosweet 100 HF CS + 5.0% salt	1.130	1.944	6.08	6.35

(1) CS = Corn Syrup, HF = High Fructose. % corn syrup and % high fructose corn syrup are expressed as volume/volume percentages. % salt is expressed as weight/volume percentage.
(2) Rating Scale used is: 9 = excellent, 8 = very good, 7 = good, 6 = slightly good, 5 = neither good nor poor, 4 = slightly poor, 3 = poor, 2 = very poor, 1 = extremely poor.

Six solutions which obtained the highest ratings in the sensory evaluations were further studied for shelf life. Mesophilic aerobic plate counts were measured for meat products stored at 32°F (0°C) and 36°F (2.2°C) for 28 days. The results indicated that the meat product from solution G showed a dramatic increase in the aerobic plate count within two weeks, and had the shortest shelf life among the solutions. The shelf life of solution G product was estimated at 10-12 days at 32°F and 8-9 days at 36°F. Crab meat which was not treated with any solution had a shelf life of 10-12 days at 32°F and one week at 36°F. The shelf life of the salt solution was determined to be 42 days at 32°F

and 19-20 days at 36°F. The shelf life of meat product from solution K was 28 days at 32°F and for B, C, F, and I was 16-18 days at 32°F. The results of the aerobic plate counts at 32° F are presented in Table 10.

Table 10. Shelf life of crabmeat treated with alternative separation solutions at 32°F. Adopted from Hong, 1990.

Solution	Composition[1]	7th day	14th day	21st day	28th day
A	19.0% salt	1.7×10^3	2.2×10^3	1.9×10^3	2.1×10^3
B	16.1% Isosweet 5500 HF CS + 10.0% salt	5.8×10^3	9.2×10^3	1.3×10^7	TNTC
C	24.6% Isosweet 5500 HF CS + 5.0% salt	6.4×10^3	1.0×10^4	3.5×10^5	6.9×10^7
F	22.5% Sweetose 4300 CS _5.0% salt	6.9×10^3	5.5×10^3	1.3×10^6	TNTC
G	30.0% Staley 1300 CS	4.1×10^3	1.8×10^6	TNTC	
I	22.5% Staley 1300 CS + 5.0% salt	1.2×10^3	2.3×10^3	1.2×10^7	TNTC
K	28.0% Isosweet 100 HF CS + 5.0% salt	4.0×10^3	4.9×10^3	4.5×10^3	1.1×10^5
None		<10	8.6×10^5	TNTC	

Note: TNTC = too numerous to count
(1) CS = Corn Syrup, HF = High Fructose. % corn syrup and % high fructose corn syrup are expressed as volume/volume percentages. % salt is expressed as weight/volume percentage.

The carbohydrate content, in terms of percent reducing sugar, was determined for the meat products of five of the alternative separation media, the brine solution, and untreated crab meat. The meat from solution G was not included due to its short shelf life. The general trends indicated that the percent of reducing sugar in the meat product was proportional to the concentration of corn syrup or high fructose corn syrup in the separation solution, with solutions K and C having the highest amounts of reducing sugars. The reducing sugar percent results are shown in Table 11 in the following.

Table 11. Reducing sugar percent of crabmeat treated with alternative separation solutions. Adopted from Hong, 1990.

Solution	Untreated	B	C	F	I	K
Composition (1)		16.1% Isosweet 5500 + 10.0% salt	24.6% Isosweet 5500 + 5.0% salt	22.5% Sweetose 4300 + 5.0% salt	22.5% Staley 1300 + 5.0% salt	28.0% Isosweet 100 + 5.0% salt
% reducing sugar	0.41	2.40	5.02	3.89	3.02	5.16

(1) CS = Corn Syrup, HF = High Fructose. % corn syrup and % high fructose corn syrup are expressed as volume/volume percentages. % salt is expressed as weight/volume percentage.

The salt content of the meat products from the different separation media was also determined for comparison. The untreated crabmeat contained 0.67 % salt (NaCl), and the meat treated with the commercial Harris Claw brine solution (19.0% salt) contained 9.43 % salt. The samples treated with the different sugar-salt solutions all contained 3.0 to 3.5 percent salt. It was observed that the salt content of the crabmeat was not depended on the salt content of the solution, except in the case of the high salt content solution. The salt content of the final products was found to be primarily affected by the concentration and viscosity of the corn syrup used in the solutions.

2.7 Laser-Doppler Velocimetry (LDV) Theory

The use of laser-Doppler velocimeters (LDV), or laser-Doppler anemometers (LDA), as a reliable method for measuring fluid velocities in complex flow conditions began in 1964. It has been widely used since then because of its many advantages. LDV systems allow for non-invasive measurements to be made in intrusive-sensitive flow conditions. Measurements with LDV can be made under hostile conditions, including chemically reactive flows, combustion, flames, and flows with radiation. The technique is compatible with a wide range of velocities, densities, and temperatures. The small measurement volume allows for essentially point measurements, and the rapid response time allows for accurate measurements during high frequency fluctuations. (Hoang, 1991).

The Dantec FlowLite system is one of many commercially available LDV systems. In this system, a laser light beam is split with a Bragg cell. The beams cross in an intersection volume, and as a particle passes through this volume, light is scattered. The scattered light is collected by the front lens of a probe, and then focused on the end of a fibre optical cable. The cable carries the light to a photomultiplier at the other end, where the light is converted to electrical signals. A signal processor sends these signals to a computer, where they are analyzed and velocity results are presented (Dantec).

The LDV system operates by focusing two laser beams so that they cross each other at a given angle such that they are coherent to each other within their intersection volume. As a particle travels through this volume, the light scattered light caused by the particle motion contains information about the Doppler frequency. A photodetector receives the light, with two components from each of the two beams. The photodetector allows the intensity of the two light sources mixing on its surface to be obtained. The intensity consists of two terms. One term is a constant term which is equal to the sum of the intensities of each of the light sources. The second term is a heterodyne term, which oscillates at a certain frequency, and is the Doppler shift of the scattered light (Dantec; Hoang, 1991).

The intersection volume caused by the crossing of the two light sources at a point is ellipsoidal and contains light and dark fringes. As the particle passes through the fringes, it scatters light which contains the Doppler frequency. The relationship between the incident and scattered light, referred to as the differential Doppler, can be used to derive the velocity of the particle. A second approach to determining the particle velocity uses the inverse of the Doppler frequency, or the inverse of the fringe crossing frequency. This inverse frequency is equal to the time for a particle to travel from one fringe to another. The distance between the fringes can be determined using the theory of optical interference, and from this information, the particle velocity can be obtained. This second approach is known as the “fringe model” (Hoang, 1991). The differential Doppler method will be used to derive the velocity equations in the following.

The relationship between the incident and scattered light from a single light beam is given by:

$$f_s = f_i + \frac{\vec{u}}{\lambda}\left(\hat{s} - \hat{i}\right) \qquad [2.19]$$

where f_s and f_i are the scattered and incident light frequencies, respectively, $\vec{u}$ is the particle velocity, λ is the wavelength of the light, and $\hat{s}$ and $\hat{i}$ are the unit vectors in the directions of the scattered and incident light, respectively. Equation 2.19 can be written in the form:

$$f_{s_1} = f_{i_1} + \frac{\vec{u}}{\lambda}\left(\hat{s}_1 - \hat{i}_1\right) \qquad \text{and} \qquad f_{s_2} = f_{i_2} + \frac{\vec{u}}{\lambda}\left(\hat{s}_2 - \hat{i}_2\right) \qquad [2.20]$$

The subscripts 1 and 2 indicate the light two light beams. The Doppler frequency, f_D, received by the photodetector is equal to the difference between the Doppler shift of the scattered light beams,

$$f_D = f_{s_1} - f_{s_2} \qquad [2.21]$$

From substitution of Equation 2.20 into Equation 2.21, the Doppler frequency can be expressed as:

$$f_D = \left(f_{i_1} - f_{i_2}\right) + \frac{\vec{u}}{\lambda}\left(\hat{s}_1 - \hat{i}_1 - \hat{s}_2 + \hat{i}_2\right) \qquad [2.22]$$

The unit vectors, $\hat{s}_1$ and $\hat{s}_2$, are in the same direction. Thus, Equation 2.22 can be written as:

$$f_D = \left(f_{i_1} - f_{i_2}\right) + \frac{\vec{u}}{\lambda}\left(\hat{i}_2 - \hat{i}_1\right) \qquad [2.23]$$

In order to obtain the velocity component perpendicular to the bisector of the two incident beams, $\vec{u}_x$, this can be expressed as:

$$f_D = \left(f_{i_1} - f_{i_2}\right) + \frac{u_x}{\lambda}\left|\hat{i}_2 - \hat{i}_1\right| \qquad [2.24]$$

If κ is the half-angle between the two incident beams, then

$$\left|\hat{i}_2 - \hat{i}_1\right| = 2\sin\kappa \qquad [2.25]$$

By combining the last two equations, the velocity can be expressed as:

$$u_x = \left[f_D - \left(f_{i_1} - f_{i_2} \right) \right] \frac{\lambda}{2 \sin \kappa} \qquad [2.26]$$

The term $\left(f_{i_1} - f_{i_2} \right)$ is obtained by shifting one of the incident beams by a certain frequency with respect to the other with the Bragg cell (Hoang, 1991).

If no shift in the incident beam frequencies is made, then the Doppler frequency would be expressed, using Equation 2.26, as:

$$f_D = u_x \left(\frac{2 \sin \kappa}{\lambda} \right) \qquad [2.27]$$

This would mean that the frequency would not be dependent on the sign of the direction of the velocity. Thus, a velocity in either direction with the same magnitude would give an equal Doppler shift. Thus, in order to determine the velocity direction, it is necessary to shift the frequency of one of the incident beams using the Bragg cell. If this is done, the Doppler frequency would be expressed as:

$$f_D = u_x \left(\frac{2 \sin \kappa}{\lambda} \right) + \left(f_{i_1} - f_{i_2} \right) \qquad [2.28]$$

Thus, from Equation 2.28, it can be seen that a particle traveling against the fringes will produce a Doppler burst of higher frequency than the shift, and similarly, a particle traveling in the same direction as the fringes will produce a burst of lower frequency. (Dantec)

The “fringe model” to derive the particle velocity produces the same resultant equation (Equation 2.28). The application of this model depends on the observation of an interference pattern. This is possible if the following conditions are met: the light must be coherent (constant phase difference) in time, the frequencies of the light sources must be equal and their planes of polarity must be the same, and the amplitudes must be equal. The use of laser light satisfies these conditions, and thus, the model is applicable and yields the same results as the differential Doppler method (Hoang, 1991).

CHAPTER 3. MATERIALS AND METHODS

3.1 Investigation of Crab Claw Meat and Shell Properties

All of the blue crab claw meat and shell samples for these analyses were obtained from a commercial mechanized crab processing plant located in Hampton, Virginia. The crabs were processed as typically done in the processing plant. The separated crab claws were washed and then crushed in the hammer mill. Samples were taken prior to submersion in the Harris Claw machine brine bath. Samples were transported from Hampton, VA in ice packing and frozen in Blacksburg, VA. Prior to analysis, the samples were allowed to thaw to room temperature.

3.1.1 Densities of Crab Claw Meat and Shell

Densities of crab claw meat and crab claw shell were determined using standard pycnometers. The pycnometers used were either 30 cm^3 glass or 12 cm^3 aluminum pycnometers. Measurements were made with six shell samples and six meat samples. The weight of water to fill the pycnometer was measured, and the volume of the pycnometer was calculated from this and the density at the measured water temperature. A known weight of material was added, and then the remaining pycnometer volume was filled with a measured weight of water. The volume of water added was calculated from the weight and density. The volume of material was then calculated as the difference between the total pycnometer volume and the volume of the added water. The measured material weight and calculated material volume were then used to calculate the material density.

3.1.2 Settling Velocities of Crab Claw Meat and Shell

Settling velocities of crab claw meat and crab claw shell were determined by releasing approximately 3 grams of material at the surface of a 1 liter graduated cylinder, with a measured height of fall, equal to the height of the 1 liter water level in the graduated cylinder (13 1/16 in, 33.2 cm). The approximate density of the material dropped was 0.1 g/cm^2 (0.2 lb/ft^2). Five samples of shell and five samples of meat were measured. The time for the first and the last of the particles to settle was measured in order to report the range of settling velocities observed.

3.2 Design and Construction of the Hydraulic Separator System (HSS)

The HSS was designed as a typical grit chamber with a parabolic cross-section in a wastewater treatment facility, according to Metcalf and Eddy's Wastewater Engineering (1972, pp. 437-439). The flow rate, Q, was calculated from:

$$Q = \left(\frac{2}{3}\right) HVT \,, \qquad [2.6]$$

as previously outlined in Section 2.5 of the literature review. For the design of the HSS, H and T were chosen to be 8 inches and 5 inches, respectively, in order to maintain a relatively small scale system with an achievable flow rate. The flow-through velocity was set at 0.5 fps in order to accommodate for the organic nature of the particles in the HSS system. A typical grit chamber design uses a standard flow-through velocity of 1 fps, and assumes that particles of concern in the chamber are inorganic in nature. The choice of a lower flow-through velocity for the HSS would allow the inorganic particles to settle, while keeping the organic particles in suspension.

The settling tests indicated that the approximate range of velocities for the meat particles was 4 fpm to 13 fpm and was 11 fpm to 33 fpm for the shell particles. The settling velocity for the HSS was chosen to be 15 fpm. This choice would allow all of the

meat particles to be carried through the system since the meat particles had lower settling velocities than the design value. The velocity would also allow most of the shell particles to be settled, since most shell particles had settling velocities higher than the design. Thus, the 15 fpm settling velocity was chosen to maximize both the yield and the separation of meat and shell particles. The required length, L, was then calculated from:

$$L = \frac{HV}{V_S} \qquad [2.18]$$

The control section of the system was constructed as an abrupt width contraction, as shown in Figure 1. The depth of water in the control section, d_c, was calculated from the following equations:

$$H + \frac{V^2}{2g} = d_c + \frac{v_c^2}{2g} + 0.1\frac{v_c^2}{2g} \qquad [2.7]$$

$$d_c = 2\frac{v_c^2}{2g} \qquad [2.12]$$

The width of the control section, w, was found from:

$$a = \frac{Q}{V} \qquad [2.16]$$

$$w = \frac{a}{d_c} \qquad [2.17]$$

Thus, for the overall design the following assumptions were made:

horizontal (flow through) velocity = 0.5 fps (0.15 m/s)
top width, T = 5 inches (12.7 cm)
water height, H = 8 inches (20.3 cm)

The resulting design calculations (included in Appendix 1) yielded the following:

flow rate, Q = 40 gpm (151 L/min)
settling length = 16 inches (40.6 cm)
control section width = 0.67 inches (0.170 cm).

The design is illustrated in Figure 1.

The HSS was built from 0.5 inch thick Plexiglas, with straight side walls to approximate a parabolic cross-section. The total length of the system is 8.25 feet (2.51 m). This includes length for flow stabilization at the inlet and outlet ends of the channel as well as extra length to provide for variations in the operation of the system.

The system was built so that the channel height, 13 inches (33.0 cm), allowed for freeboard and variability in the operation of the system, and 1 inch (2.54 cm) for collection of settled material. A 4 inch (10.2 cm) deep by 12 inch (30.5 cm) long basin at the effluent end was provided to allow for the collection of settled material. The basin was equipped with two ball valves (one 0.5 inch valve on the bottom and one 1.25 inch valve on the side) which can be opened to flush collected material out during cleanings. Figure 1 illustrates three views of the channel. There is some discrepancy between the design dimensions and the actual dimensions. Specifically, the width varied along the length of the channel. This variance resulted from the difficulty in maintaining the angle at which the seam was glued over the entire length of the channel. However, the discrepancy was small; the top width ranged between 4.698 inches and 4.783 inches.

A baffle wall with fifty-six 3/8 inch holes was placed 30 inches from the influent end of the channel in order to create an even dispersion of water throughout the channel. Water from the control section (effluent) was allowed to free fall into a basin. A 0.5 horsepower submersible sump pump (Water Ace Pump Co., Ashland, Ohio) in the basin provided the influent water flow to the system. PVC pipes of 1.5 inch and 2 inch diameters carried the water to the influent end. An effluent pipeline, labeled as the recirculation line in Figure 2, of 2 inch and 1.5 inch pipes diverted some of the pumped water from re-entering the channel, and a ball valve located near the inlet on this line allowed control over the water flow rate in the channel. Figure 2 illustrates the system with the pump and water lines. A wooden frame support was constructed to hold the channel and the pipes in place.

A meat recovery system was constructed from a fine mesh cider press bag from Cumberland General Store, Tennessee (item number 001902). The bag was attached to a metal cylinder. When placed at the effluent end of the HSS, the bag recovered solid meat and shell particles which flowed out of the system while water passed through the filter and was returned to circulation.

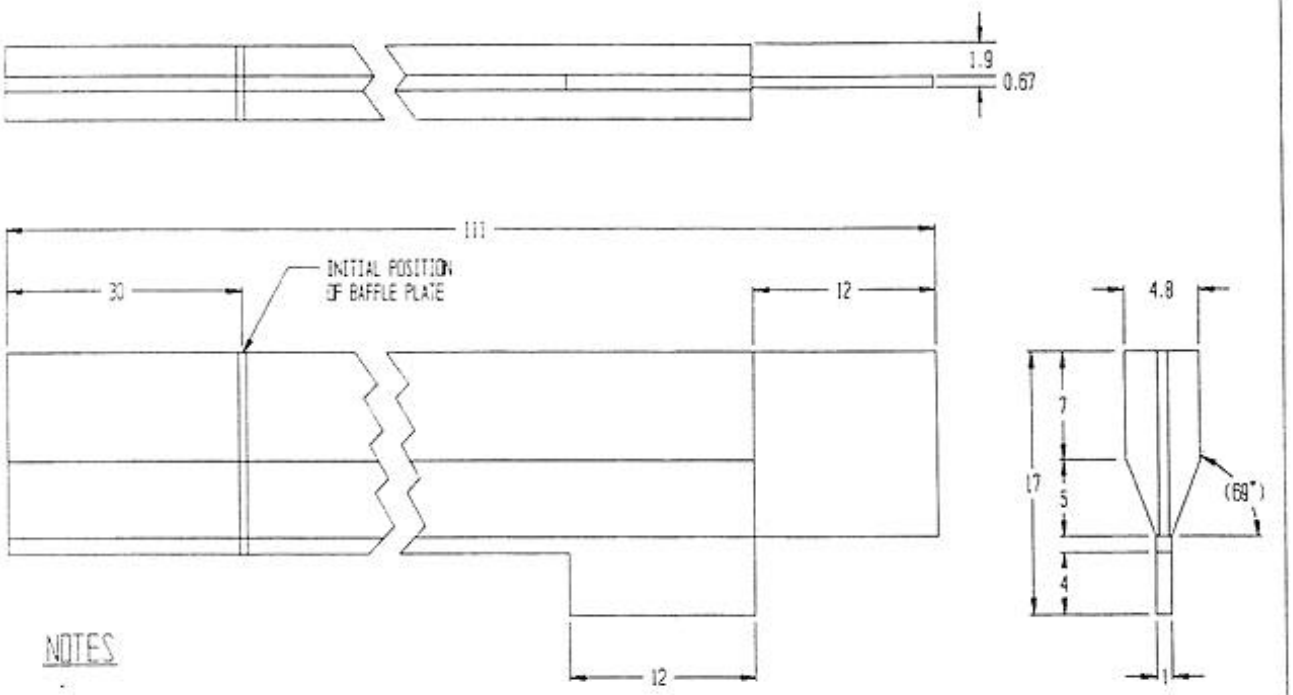


Figure 1. Hydraulic Separator System

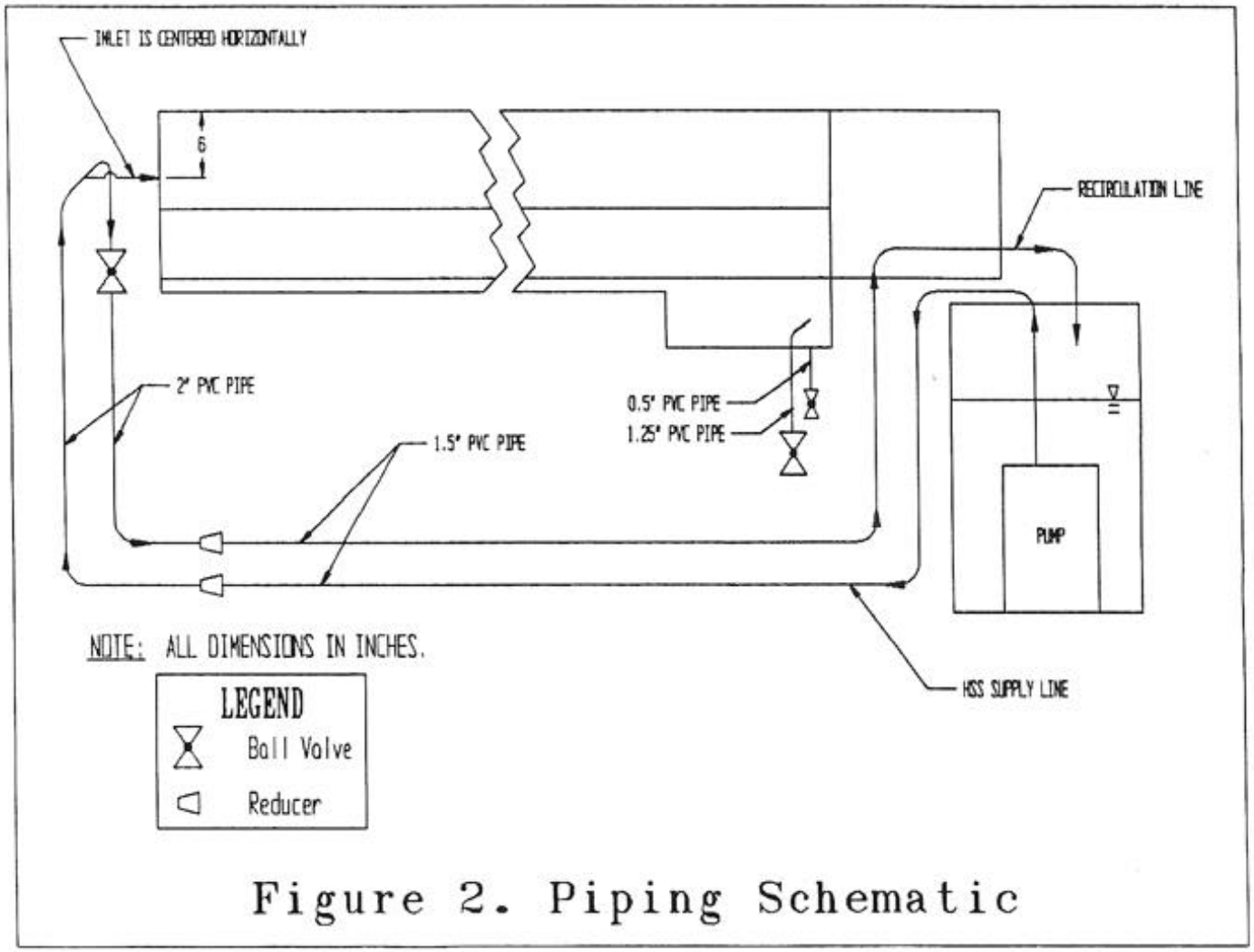


Figure 2. Piping Schematic

3.3 Characterization of HSS

3.3.1 Flow Rates

As mentioned above, flow rates in the HSS were varied by adjusting the ball valve on the diversion pipeline. Final flow rates were measured at a local swimming pool. The HSS was operated next to the pool. A duplicate 0.5 horsepower submersible sump pump (Water Ace Pump Co., Ashland, Ohio) was placed in the pool, with 1.5 inch PVC piping extending from the pump to the water supply basin of the HSS. This second pump provided a continuous supply of water to the HSS. Flow from the effluent (control section) of the HSS was diverted through 4 inch flexible drainage pipe attached to the control section to a 55 gallon drum located below the water surface to avoid any back water effects. The time required to reach a 50 gallon level in the drum was measured. When desired flow rates of 30, 35, 40, 45, and 50 gpm were reached (each measured in triplicate), the location of the ball valve was marked with etching and pen. The ball valve setting was then moved and returned etched markings. Duplicate flow rates were similarly measured at each of the flow rates in order to determine the repeatability of the marked flow rates. Flow rates were again measured after unplugging and replugging the pump.

3.3.2 Cross-Sectional Velocity Profiles

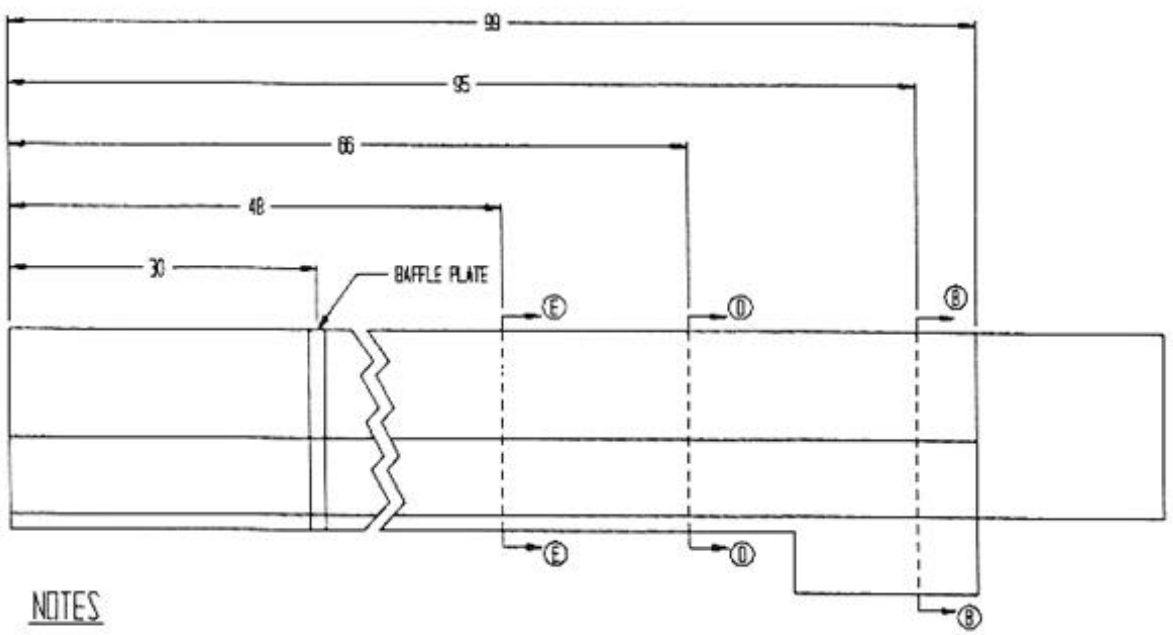
A measurement grid was established within a cross-section of the HSS. Velocity measurements at each location of the grid were measured in order to establish a velocity profile. The grid consisted of 37 points for measurements. Velocity measurements were taken at 0.25, 0.5, and 1 inch from each wall of the HSS, at depths of 0.5, 1.5, and 3.0 inches below the water surface (as measured from the water level at a flow rate of 40 gpm). Additional measurements were taken at 2 inches from each wall, at depths of 0.5,

1.5, 3.0, 4.5, and 6.0 inches below the water surface. A set of center line measurements was taken at depths of 0.5, 1.5, 3.0, 4.5, 6.0, 7.5, and 9.0 inches. Since measurements were made with regard to the depth from the water level at 40 gpm, the depths from the water level at the different flow rates were different. However, the vertical distances of the grid points from the bottom of the channel remained the same as the flow rates changed.

The velocity profiles were measured at different cross sections within the channel. Figure 3 shows the locations of the cross sections used for velocity measurements. At a flow rate of 40 gpm, measurements were taken at cross sections B, D, and E. At flow rates of 45 gpm and 50 gpm, measurements were taken at cross sections D and E.

Initial attempts to establish water velocity profiles of the HSS were made through the use of a TSI Model 1210-20W hot wire probe and anemometer. The instrument was calibrated, however, the hot wire was damaged before measurements could be made in the system.

Velocity measurements were taken using FlowLite (Dantec Measurement Technology), a laser-Doppler system. The HSS water was "seeded" with iriodine 100 silver pearl particles, 10-15 μm. Two laser beams (10 mW, helium-neon, 632.8 nm) were adjusted so that they crossed at the precise points at which the velocity was to be read, i.e., locations within the described grid. The laser beam system was first positioned at the appropriate cross section. Horizontal movements of the laser beams were made by manually turning a screw-type crank with a motion of 20 turns per inch. Vertical movements of the laser were made with a similar crank which was controlled by a computer program, operated from DOS. Light scattered from the movement of the iriodine particles relayed information on the movement of the particles within the beams' intersection volume over time. This information was collected by a 60 mm 1D probe and



NOTES

1. ALL DIMENSIONS IN INCHES.

Figure 3. Locations of Cross-Sections

sent through a 5m fiber optic cable to a Flow Velocity Analyzer which converted the information to electric signals to be interpreted by a computer program, FLOware, operated from DOS. The program interpreted the data and calculated the velocity of water at the specified point.

3.4 Performance of the HSS

The HSS was operated using pulverized crab meat and shell obtained after processing in a hammer mill. A known weight of the mix was dropped into the system over a given time period for each trial. From these trials, the performance of the system, in terms of yield, processed meat quality, and wastewater characteristics were evaluated.

3.4.1 Yield

The yield was determined on the basis of the initial, known weight of the mixed pulverized crab meat and shell, and the meat product recovered in the filter bag. Samples of the pulverized crab meat and shell weighing 0.76 lb (345 g) were dropped into the system over 15 seconds and mixes weighing 1.52 lb (689 g) were dropped over 30 seconds. The filter bag weight was measured before each trial, and the weight with the meat, after excess water was squeezed out, was measured. Yield measurements were taken at varying flow rates and varying distances from the outlet.

The HSS allowed some meat to settle within the channel along with the shell. This tank residual was thoroughly mixed and a sample was taken. The sample was analyzed for protein content. Analysis for protein was performed through a Kjehldahl nitrogen analysis on a Caltech Auto 1030 Analyzer using sulfuric acid and a catalyst for digestion. The analysis was performed at the Virginia Tech Feed and Fertilizer Laboratory.

3.4.2 Meat Product Quality

The meat product quality was determined based on the following parameters: shelf-life, odor and appearance, and taste. The meat product recovered from the HSS was placed into plastic Whirl-Paks and stored on ice for further quality evaluations.

Microbial Analyses

The microbial quality of the meat product was measured on the basis of mesophilic aerobes, total coliforms, fecal coliforms, and *E. coli.* The analyses were performed using procedures described in the Bacterial Analytical Manual (BAM, 1995). The crab meat was stored on ice, and tested for the above parameters on 0, 3, 5, 7, 10, and 12 days from processing. The plate counts were performed at the Virginia Tech Seafood Research and Extension Center in Hampton, Virginia.

Sensory Evaluation: Appearance and Taste

The crabmeat samples were transported from Hampton, Virginia to Blacksburg, Virginia in ice packing. After transportation, samples were stored on ice until analysis. The samples were evaluated at 4, 7, and 13 days of storage.

The sensory evaluations were conducted using a 15 member panel (except on day 13 when 11 panel members participated). The panels consisted of faculty, staff, and students at Virginia Tech of varying age, sex, and ethnic background. A brief panel orientation informed the members of the method used to evaluate the crab meat samples. A reference sample, hand-picked crab claw meat, was chosen as a basis of comparison to the crab claw meat samples obtained from HSS processing. All sensory evaluation tests were performed in mid-morning or mid-afternoon in order to prevent the masking of taste by previous meals.

For the sensory analysis, a sample of hand picked claw meat and a sample of HSS claw meat was served. Panel members were asked to rate the samples by marking a line indicating the relative quality of the attributes on a standard score sheet which was provided (Appendix B1). The attributes analyzed were appearance and taste. Water was provided to panelists so they could rinse and refresh their mouths between samples. Evaluation was conducted through the use of the SAS, Version 5.18 computer program. The significance of the differences were determined using an ANOVA test with a two way factorial design (day by treatment) at a 0.05 significance level. A mean separation test using Duncan groupings was then applied once a significant difference was verified.

3.4.3 Wastewater Characterization

The HSS was tested with 0.76 lb (345 g) of pulverized crab claw meat and shell input per trial. The system was cleaned, and the water was changed between three successive trials. Wastewater samples were collected from each of three runs for analysis. An initial water sample was collected after the system was filled with clean water and water was pumped into circulation within the system.

Temperature, Color, pH

The temperature, color, and pH of the samples were measured immediately after taking the samples. The color of the samples was measured on a Hach Spectrophotometer at a wavelength of 455 nm. The “apparent color” of each sample was measured on untreated samples, diluting with distilled water as necessary. The “true color” of each sample was measured on samples which had been filtered through Whatman 934-AH filters.

Turbidity

The turbidity of each sample was measured after samples were transported from Hampton to Blacksburg. Turbidity was measured on a Monitek TA1 turbidimeter, in accordance with method 2130 B. Nephelometric Method (Standard Methods, 1996). Samples were diluted with distilled water as necessary.

Suspended Solids

The total suspended solids and volatile suspended solids were measured according to methods 2540 D. and 2540 E., respectively (Standard Methods, 1996). The solids measured were those retained on Whatman 934-AH filters.

Alkalinity

The alkalinity of samples was measured according to Method 2320 B. (Standard Methods, 1996). The endpoint pH was determined by creating a typical titration curve (pH versus volume of acid used) for one of the samples, and noting the approximate inflection point of the graph. This inflection point indicated a pH endpoint of 4.6. Approximately 30 to 50 mL of sample were used for each alkalinity titration, and titrations were performed using 0.02 N H_2SO_4.

Biochemical Oxygen Demand

The 5 day BOD of the wastewater samples was determined by method 5210 B. (Standard Methods, 1996). The water was not seeded, since it was assumed that the samples contained sufficient bacteria for measurements. Dilutions of the samples were made based on the expected oxygen demand. Dissolved oxygen concentrations were

measured using a Yellow Springs Instrument Co., Inc. (Yellow Springs, Ohio), model YSI57, oxygen probe.

Chemical Oxygen Demand

The COD was measured using method 5220 C. Closed Reflux, Titrimetric Method (Standard Methods, 1996). Samples were measured in 20 x 150 mm culture tubes, and titrations were performed using 0.05 N ferrous ammonium sulfate (FAS). Total COD measurements were obtained on samples which were collected at Hampton, acidified to a pH less than 2 with H_2SO_4 for preservation, and stored at 4°C (39°F) after transportation to Blacksburg. Soluble COD measurements were obtained on samples which were collected at Hampton, filtered through Whatman 934-AH filters, acidified, and stored at 4°C in Blacksburg.

Dissolved Organic Carbon

The dissolved organic carbon (DOC) was measured using a Dohrmann (Santa Clara, California) Total Organic Carbon Analyzer. Samples were diluted with distilled water as necessary. Samples collected at Hampton were filtered through Whatman 934-AH filters and acidified to pH less than 2 with H_2SO_4.

Ammonia and Organic Nitrogen

The ammonia concentrations in the samples was measured using methods 4500-NH_3 B, Preliminary Distillation Step and 4500-NH_3 E. Titrimetric Method. Organic nitrogen levels were determined by method 4500-N_{org} C. Semi-Micro-Kjeldahl Method (Standard Methods, 1996). Sample volumes were determined based on the anticipated ammonia or organic nitrogen levels in the samples. The ammonia samples tended to

foam when heated for distillation, and the organic nitrogen samples tended to foam when digested. In order to minimize sample loss through the apparatus, heat levels were lowered and adjusted such that samples could be heated without losses. Samples were collected at Hampton, acidified to pH less than 2 with H_2SO_4, and stored at 4°C in Blacksburg.

Phosphorus

Phosphorus concentrations were determined by method 4500-P B. Sample Preparation and 4500-P E. Ascorbic Acid Method (Standard Methods, 1996). Phosphorus digestions were performed using persulfate as a digestion reagent. Dilutions with distilled water were performed based on anticipated phosphorus levels in the samples.

Ions

The cations, Na, K, Ca, Mg, and NH_4, and the anions, Cl and SO_4 were measured on a Dionex (Sunnyvale, California) Ion Chromatograph. The procedure was in accordance with method 4110 B(4) (Standard Methods, 1996). Dilutions were made as necessary, and samples were filtered through a 0.45 μm filter. The ion chromatograph had a 50 μL sample volume and a pressure of 1200 psi. The cation analyses were performed at a flow rate of 1.0 mL/min., with 0.1 mM methanesulfonic acid eluent, and SRS controller. The anion analyses were performed at a flow rate of 2.0 mL/min., with 1.80 mM Na_2CO_3 eluent, and 0.05 H_2SO_4 regenerant. The samples were stored at 4°C after transportation from Hampton to Blacksburg.

3.5 Dense Media Separation

On September 13, 1996, a full scale test was performed using different separation solutions in the Harris Claw machine at Graham and Rollins, Inc. at Hampton, Virginia. From previous studies (Hong, 1990) and preliminary tests, two corn syrup solutions were chosen for the test. One was a 30% (v/v) Staley 1300 corn syrup solution, and the other was a 22.5% (v/v) Staley 1300 corn syrup plus 5.0% (w/v) salt. In each trial, approximately 7 barrels of blue crab claws (approximately 50 lb per barrel, for a total of approximately 350 lb) were processed. The Harris Claw machine equipment was cleaned between trials.

The first trial was performed with the 30% (v/v) corn syrup solution. The corn syrup was heated in a hot water bath at 190°F (88°C) in order to allow complete mixing of the corn syrup and water. The Harris Claw machine solution tank held 190 gallons. The solution was thus produced from approximately 57 gallons of corn syrup mixed with 133 gallons of water. The total trial time was approximately 30 minutes. During the course of the experiment, the solution was stirred to keep the corn syrup mix consistent, and the specific gravity was repeatedly measured in order to verify solution consistency. Some water loss occurred during processing, so approximately 10 gallons of water were added to the tank during the trial.

The second trial was performed with the 22.5% (v/v) corn syrup solution plus 5.0% salt. Again the corn syrup was first heated in a hot water bath. The solution was produced from approximately 42.75 gallons corn syrup and 9.5 lb salt, with water making up the remaining volume. The total time of the trial was approximately 45 minutes. At approximately 19 minutes, approximately 10 gallons of water, 0.75 gallons of corn syrup, and 0.5 pounds of salt were added, and at approximately 32 minutes, 1 gallon of corn syrup, 1/2 lb of salt, and water to fill the tank were added. The solution was stirred during the trial in order to keep the corn syrup mix consistent.

The third trial was performed using the 19.0% (w/v) salt solution (brine) typically used in the Harris Claw machine. The total trial time was approximately 5 minutes.

Samples of the separation media were collected from the Harris Claw machine for each of the three trials, one at the beginning of the experiment (initial sample), one after approximately 4 barrels or approximately 200 lbs of crab claw were processed (middle sample), and one at the end of the trial (final sample). These samples were analyzed for specific gravity and viscosity.

Specific Gravity

The specific gravity of solution samples was measured with a standard Fisherbrand Hydrometer (Model 11-320-4).

Viscosity

Viscosity measurements were made with a Brookfield Laboratories (Stoughton, MA) model DVLV-III Programmable Viscometer. The attachments used were the SC4-18 spindle and the SC4-13R cup. Measurements were made at a speed of 30 rpm, a shear rate of 264 sec^{-1}, and room temperature (between 20.0°C and 21.7°C). Measurements were performed at the Virginia Tech Biological Systems Engineering Laboratory.

3.5.1 Yield

The yield of each trial was determined by comparing the initial weight of the seven barrels to be processed by each of the three solutions with the weight of the crab claw meat which was recovered after processing. Prior to processing in each solution, the initial weight of seven barrels was measured and recorded. The seven barrels were processed as typically performed in the Harris Claw machine, and the recovered meat on

the conveyor was packed into one pound plastic snap-lock containers. The total number of containers of meat recovered on the conveyor was added to the number of containers of meat recovered from the fine-mesh filtering of the tank liquid overflow, referred to as "Swaco" claw meat because it consists of very small particles of meat. The total yield was calculated as the total pounds of meat from the conveyor plus Swaco meat divided by the total weight of crab claws in the seven barrels, expressed as a percentage.

The Harris Claw machine allows some meat to settle within the tank along with the shell. This tank residual was thoroughly mixed and a sample was taken. A sample of the waste claw from the machine was also taken after thorough mixing. These samples were analyzed for protein content. Analysis for protein was performed through a Kjehldahl nitrogen analysis on a Caltech Auto 1030 Analyzer using sulfuric acid and a catalyst for digestion. The analysis was performed at the Virginia Tech Feed and Fertilizer Laboratory.

3.5.2 Meat Product Quality

Microbial Analyses

The microbial analyses were performed for the meat product from each solution using the method described in Section 3.4.2. The microbial of the meat product was measured on the basis of mesophilic aerobes, total coliforms, and fecal coliforms. Testing for the above parameters was performed on 0, 4, 6, 8, 11, and 13 days post-processing.

Sensory Evaluation: Appearance and Taste

The appearance and taste ratings for the meat products from each solution were evaluated as described in Section 3.4.2. The sensory evaluations were performed on 5, 8, and 13 days after processing, and each taste panel consisted of 15 panelists.

An additional test was performed in which the meats were mixed with hand-picked crab claw meat to determine if a significant difference between the mixed samples and the hand-picked samples existed. Three mixes were prepared from hand-picked claw meat and machined claw meat from the 30% corn syrup solution, the 22.5% corn syrup plus 5% salt solution, and the standard salt solution, each at a 4 to 1 ratio (hand-picked to machine-treated). For this evaluation, a 16 member panel consisting of faculty, staff, and students at Virginia Tech of varying age, sex, and ethnic background was used.

The sensory analysis was conducted as a "triangle" taste panel. Each panelist was given 3 plates, each plate representing a different solution of machine-treated meat product. Each plate consisted of three samples of hand-picked crab claw meat and a mix of hand-picked and machine-treated meat, with varying plates containing 1 or 2 samples of hand-picked and 1 or 2 samples of mixed meat. On the basis of appearance and taste, each panelist was asked to select the one sample that was different from the other two and record the selection on standard score sheet (Appendix B2). The results were evaluated by counting the number of correctly identified "different" samples. These results, based on appearance and taste, were statistically analyzed according to Sensory Evaluation Techniques, 1991, using a 0.05 significance level.

Water Phase Salt

The salt content of the crab claw meat recovered from the separation media which contained salt were compared to the salt content of hand-picked crab claw meat. The meat was frozen, and allowed to thaw. Moisture content measurements were made on a Denver Instrument Company Moisture Analyzer. The salt content of the meat was measured with Quantab Chloride Titrators (Miles Laboratories, Elkhart, IL). The dilution/extraction procedure for solid or semi-solid samples was followed. The percent water phase salt was calculated as equal to the percent salt divided by the sum of the percent moisture and percent salt.

Reducing Sugars

The reducing sugar content of the meat recovered from the separation medias which contained corn syrup were measured and compared to the reducing sugar content of hand-picked meat. Crab claw meat samples were frozen, and allowed to thaw for testing.

A reagent was prepared with 1% dinitrosalicylic acid, 0.2% phenol, 0.05% sodium sulfite, and 1% sodium hydroxide. The reagents were mixed together one at a time. A standard curve was prepared by measuring glucose standards. Standards were made by adding 0, 2, 3, 4, 5, 6, and 7 g of glucose to a 25 mL volumetric flask. Three (3) mL of reagent were added to 3 mL of sugar solution. The mixture was heated for 15 minutes in a boiling water bath and cooled to room temperature. The absorbence was measured at 575 nm.

One hundred (100) grams of crab meat sample were blended in a Wharing blender. One gram of the blended meat was refluxed using 50 mL of 80% ethyl alcohol for 15 minutes. The liquid was then filtered through a Whatman 541 filter paper, and nitrogen gas was bubbled through the solution for 3 to 5 hours. The liquid was transferred to a 25 mL volumetric flask and the volume was filled with hot deionized distilled water. Three (3) mL of solution was added to 3 mL of reagent and heated in a boiling water bath for 15 minutes. The sample was then cooled to ambient temperature, and the absorbence was measured at 575 nm (Hong, 1990; Miller, 1959; Sumner, 1921; Sumner, 1924; Sumner, 1925).

3.5.3 Wastewater Characterization

Wastewater was collected from the Harris Claw Machine for each of the three trial solutions; once at the beginning of the experiment (initial sample), once after approximately four barrels, 200 pounds, of crab claw were processed (middle sample), and once at the end of the trial (final sample). Wastewater characterization was based on the same parameters as analyzed for the HSS, again analyzed in duplicate. Temperature, color, pH, turbidity, solids, alkalinity, chemical oxygen demand, dissolved organic carbon, organic nitrogen, and ions were analyzed for the initial, middle, and final values, while biochemical oxygen demand, ammonia, and phosphorus were analyzed for the initial and final values only. The same procedures for analysis were used as described in Section 3.4.3, except for the procedures outlined in the following.

Alkalinity

The alkalinity of samples was measured as described in Section 3.4.3. The endpoint pH was determined from a titration curve constructed for the final samples from each separation solution. An endpoint pH of 4.8 was used for all of the samples. Approximately 50 mL of sample were used for each alkalinity titration.

Chemical Oxygen Demand

The COD was measured using the methods described in Section 3.4.3 for the corn syrup solutions. The brine solutions were analyzed using the same procedure, except a digestion reagent with 5 times the mercury of that in the standard reagent was used in order to accommodate for the high concentration of chloride ion. This digestion reagent was capable of analyzing a solution with up to 500 mg/L chloride ion. Dilutions of samples were performed based the dilution required to lower the chloride ion

concentration to less than 500 mg/L, using the results from ion chromatograph analysis. Observationally, no precipitation characteristic of a high chloride ion concentration was noted during the analysis. Due to the hazardous nature of the waste generated from this test, only the initial and final brine wastewater samples were tested.

Precipitate Analysis of Acidified Brine Solutions

After acidification for preservation of the middle and final samples of the brine solution, a precipitate formed in the sample. The percent by volume of the precipitate in the sample was measured by thoroughly mixing the sample, and then pouring 25 mL into a 25 mL graduated cylinder. The precipitate was allowed to settle, and the volume occupied by the precipitate after settling was measured. The solids concentration was measured by pouring the precipitate into a crucible and drying the sample at 105°C for two hours. The solids weight was measured and recorded as mg per volume of precipitate. The volatile solids portion of the precipitate was measured by heating the sample at 550°C for 20 minutes, and weighing the residual solids. The volatile solids was recorded as mg per volume of precipitate.

Organic Nitrogen

Organic nitrogen levels in the corn syrup solutions could not be determined by method 4500-N_{org} C. Semi-Micro-Kjeldahl Method (Standard Methods, 1996) because the digestion procedure created a hard, dense black solid mass on the bottom of the digestion flasks. This mass heated and caused cracking of digestion flasks during the procedure. Thus, Kjehldahl nitrogen analysis was performed on a Caltech Auto 1030 Analyzer using sulfuric acid and a catalyst for digestion. This analysis was performed at the Virginia Tech Feed and Fertilizer Laboratory. Results were reported as percent protein. This was converted to percent nitrogen by dividing by 6.25 (from a typical

assumption that 15% of nitrogen is in protein). Percent nitrogen was then converted to mg/L nitrogen by multiplying by 10^4.

Phosphorus:

Phosphorus concentrations were determined as described in Section 3.4.3. The corn syrup solutions yielded highly colored (yellowed) samples after the digestion procedure. This was corrected by the method outlined in Method 4500-P E.4(b). A blank for each corn syrup sample analyzed was prepared by adding all of the reagents except ascorbic acid and potassium antimonyl tartrate to the sample. The absorbence of the blank was subtracted from the absorbence of the sample to determine the phosphorus concentration.

3.6 Comparison of Final Product from Processed Crab Claws

The crab claw meat samples which were obtained from the two corn syrup solutions, the standard brine solution, and the HSS were used to prepare crab cakes and compared with crab cakes made from hand-picked crab claw meat. All meats had been frozen. The following standard recipe was used:

1 lb crab meat
1 tbsp Old Bayä seasoning
3/4 tsp salt
1 tbsp mayonnaise
1 tbsp Worcestershire sauce
1 tbsp chopped parsley
1 egg, beaten
2 slices bread, crusts removed, soaked in milk

The crab cakes were fried. Sensory panels consisted of 28 members, faculty, staff, and students at Virginia Tech of varying age and sex. A reference sample, crab cake made from hand-picked crab claw meat, was chosen as a basis of comparison to the crab claw

meat samples obtained from the 30% corn syrup media, the 22.5% corn syrup media, the Harris Claw brine media, and the HSS. Samples were evaluated based on appearance and taste. The procedure and analysis method followed was the same as that outlined in Section 3.4.2. The data was unbalanced, so analyses were performed on SAS using a General Linear Model (GLM) rather than an ANOVA, and a Least Means Difference test rather than a Duncan grouping.

CHAPTER 4. RESULTS AND DISCUSSION

4.1 Investigation of Crab Claw Meat and Shell Properties

4.1.1 Densities of Crab Claw Meat and Shell

The densities of the pulverized crab claw meat and shell particles from the hammer mill were determined as a preliminary test to determine the feasibility of separating crab meat and shell in a hydraulic system. The principles of grit chamber design, as explained in the literature review, Section 2.5, depend upon the existence of a significant difference in the densities of the particles to be separated. In the case of a typical grit chamber, the intention is to allow inorganic particles to settle, and organic particles to remain in suspension. Similarly, the design of a channel-type grit chamber to separate crab claw meat and shell would also depend on the existence of a significant difference in the densities of the crab claw meat and shell.

The results of the study indicated that a significance difference in the densities existed, and that the design of the hydraulic system to separate meat and shell would be theoretically feasible. The pulverized crab claw meat was found to have a density of 1.1044 $g/cm^3 \pm 0.1385$ g/cm^3, and the crab claw shell had a density of 1.4370 $g/cm^3 \pm$ 0.1839 g/cm^3. Because the density of water at 20°C is approximately 1.0 g/cm^3, these values with units would also be equal to the specific gravities. The results of these tests are presented in Table 12.

Table 12. Densities of Pulverized Crab Claw Meat and Shell Particles.

MEAT		**SHELL**	
Sample No.	ρ (g/cm^3)	Sample No.	ρ (g/cm^3)
1	1.2487	1	1.5200
2	0.8513	2	1.5156
3	1.1019	3	1.4333
4	1.0773	4	1.2970
5	1.1930	5	1.6890
6	1.1542	6	1.1671
Average =	1.1044	Average =	1.4370
Stnd. Dev. =	0.1385	Stnd. Dev. =	0.1839

4.1.2 Settling Velocities of Crab Claw Meat and Shell

The settling velocities of the crushed crab claw meat and shell cannot be determined from the knowledge of the specific gravities of the particles and the use of Newton's law for the terminal settling velocities of particles, because the particles are not spherical in nature and the particle sizes are not consistent or easily measurable. Thus, it was necessary to determine the settling velocities of the particles by an independent experiment. Due to the fact that the individual meat and shell particles were highly variable in terms of size, shape, composition, and specific gravity, the settling velocities of meat and shell particles were also highly variable. Thus, the velocities are reported as ranges. Table 13 below summarizes the settling velocity results.

Table 13. Settling Velocities of Pulverized Crab Claw Meat and Shell for Particles Released at the Water Surface of a 13.063 inch Fall.

MEAT			**SHELL**		
Sample No.	Settling Times (sec)		Sample No.	Settling Times (sec)	
	Minimum	Maximum		Minimum	Maximum
1	6	20	1	4	14
2	---	18	2	3	6
3	5	14	3	2	8
4	4	15	4	2	4
5	5	15	5	1	4
Average =	5	16	Average =	2	7
velocity (fpm) =	13	4	velocity (fpm) =	27	9

The settling velocities of the pulverized meat particles ranged from 4 fpm to 13 fpm, while the shell particles ranged from 9 fpm to 27 fpm. These results were used to choose the design settling velocity for the hydraulic separator system (HSS). The HSS design settling velocity was set at 15 fpm (0.25 fps). This velocity would theoretically allow all of the meat to remain suspended within the system, while a large percentage of the shell settle.

4.2 Design and Construction of the Hydraulic Separator System (HSS)

The construction of the HSS was difficult due to the use of Plexiglas as a building material and the shape of the channel cross-section. This resulted in a channel widths which were slightly different from the design dimensions, and some variation through the length of the channel of these widths. The widths at the top of the channel, at the middle seam (7 inches below the top of the channel), and at the lower seam (12 inches below the top of the channel) were measured with calipers at 5 cross sections along the length of the HSS. Table 14 shows the variations, averages, and standard deviations of these channel widths (refer to Figure 1). The ranges were from 4.698 to 4.773 inches for the top width, from 4.565 to 4.754 inches for the middle joint width, and from 0.909 to 0.986 inches for

the lower joint width. These variations were relatively small, and thus, could be neglected in further evaluations.

Table 14. Variations of the cross-sectional width dimensions of the HSS.

Cross Section	Distance of Section from Influent Channel End (inches)	Width at Top (inches) *	Width at Middle Joint (inches) *	Width at Lower Joint (inches) *
A	0	4.761	4.737	0.986
C	33	4.783	4.754	0.979
E	48	4.718	4.681	0.961
D	66	4.698	4.710	0.909
B	99	4.773	4.565	0.920
	AVERAGE =	4.747	4.689	0.951
	Standard Deviation =	0.037	0.075	0.035

* Note: Refer to Figure 1.

4.3 Characterization of HSS

4.3.1 Flow Rates

The control valve for the HSS flow rate was marked at approximately 30 gpm, 35 gpm, 40 gpm, 45 gpm, and 50 gpm based on the tests described in Section 3.3.1. This allowed the HSS flows to be varied in further testing. The actual measured averages and standard deviations for each flow rate settings are listed in Table 15 below.

Table 15. Average flow rates at various settings on the control valve of the HSS.

Valve Setting	Reference Flow Rate(gpm)	Average Flow Rate (gpm)	Stnd. Dev. (gpm)
1	30	31.6	1.2
1.5	35	36.3	0.3
2	40	40.3	0.3
2.5	45	46.9	0.7
3	50	50.8	0

The flow rates were measured again after the pump plug was unplugged and replugged and after changing the valve setting and resetting. The flow rates measured after these changes were all within the standard deviation of the average flow rate for the appropriate valve setting. Thus, these results indicated that the flow rates were reproducible. The reference flow rates are be used to describe the HSS flow in future references, despite the fact that the actual flow rates are slightly different from these. The actual average values were used in calculations.

4.3.2 Cross-Sectional Velocity Profiles

As described earlier, the cross-sectional velocity profiles were determined through the use of a laser Doppler system. The profiles were performed at cross-sections E, D, and B (See Figure 3) at a flow rate of 40 gpm and at sections E and D at 45 and 50 gpm. The FLOware system gives the standard deviations of the measured velocity at each point. In order to reduce overall variations, the velocity measurements were repeated at a single setting until a sufficiently low variation was achieved. At some settings within the measurement grid, the FLOware system displayed an error message instead of velocity results. If repeated trials could not result in a velocity reading, then the velocity at that point in the grid was shown as unmeasured. Typically, this occurred at measurements close to the sidewalls and within the sloping sidewalls. The measurement error is likely to have resulted from complications due to insufficient seeding along the walls.

Figures 4 and 5 illustrate the velocity profiles at cross-section E at 40 gpm. These figures show that the velocity for this cross-section range from 0.28 fps to 0.62 fps. The velocity appears to be higher at the highest measured water level (0.54, 0.55, 0.49 fps), decreasing with depth (0.45, 0.49, 0.39 fps) and then increasing at the lowest point measured above the lower seam (0.41 fps). The velocity also appears to be higher at the

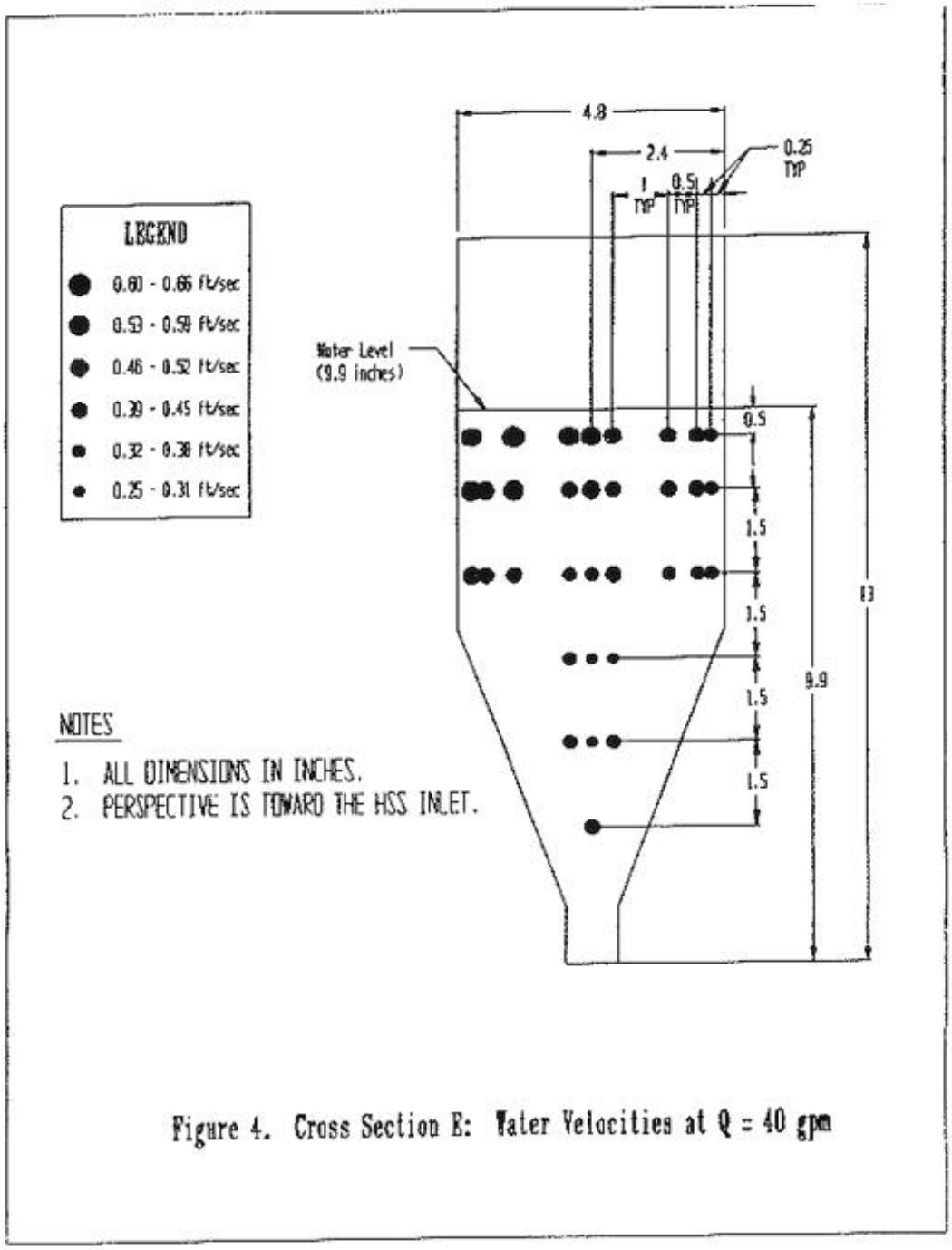


Figure 4. Cross Section E: Water Velocities at Q = 40 gpm

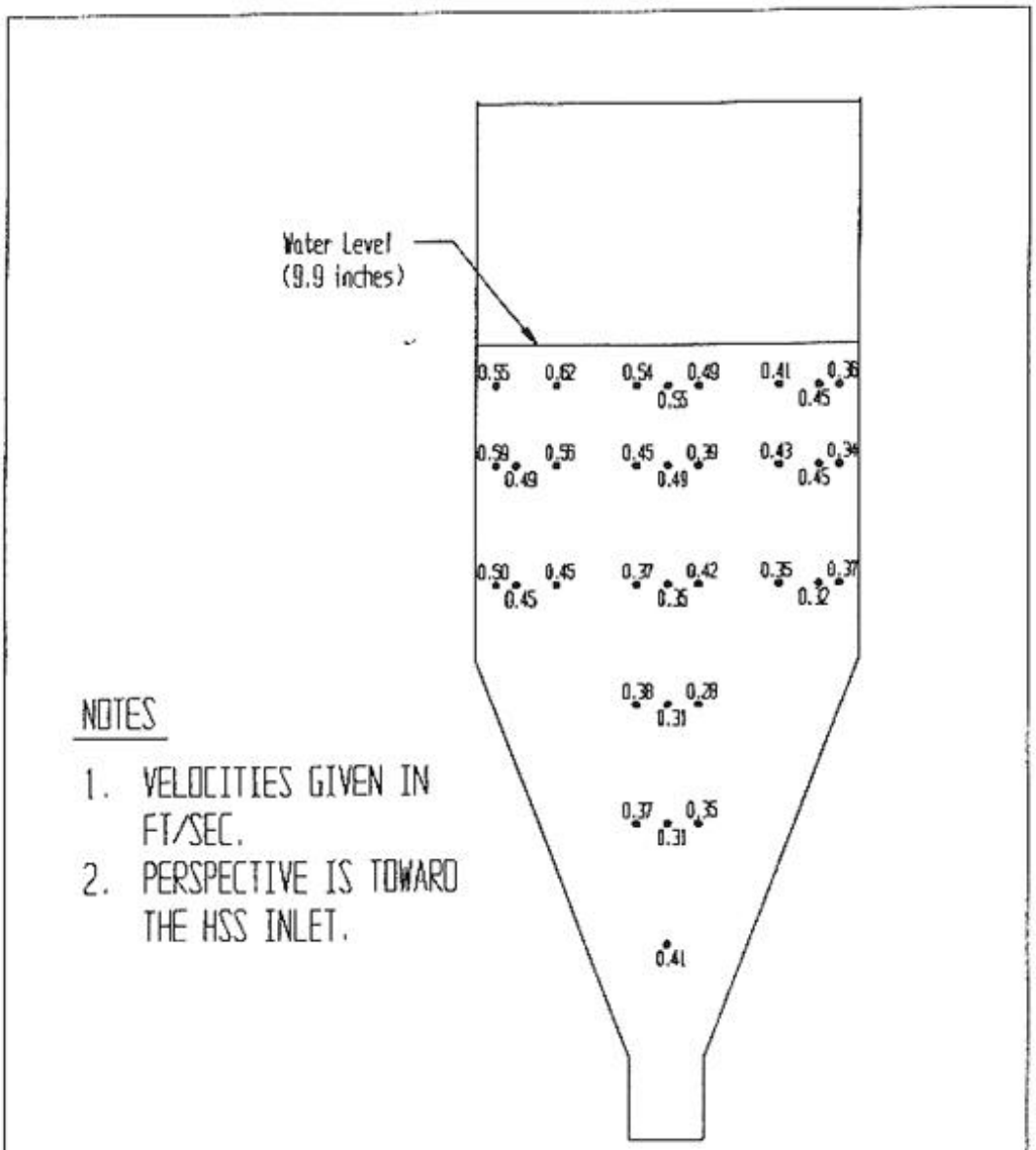


Figure 5. Cross Section E: Water Velocities at Q = 40 gpm

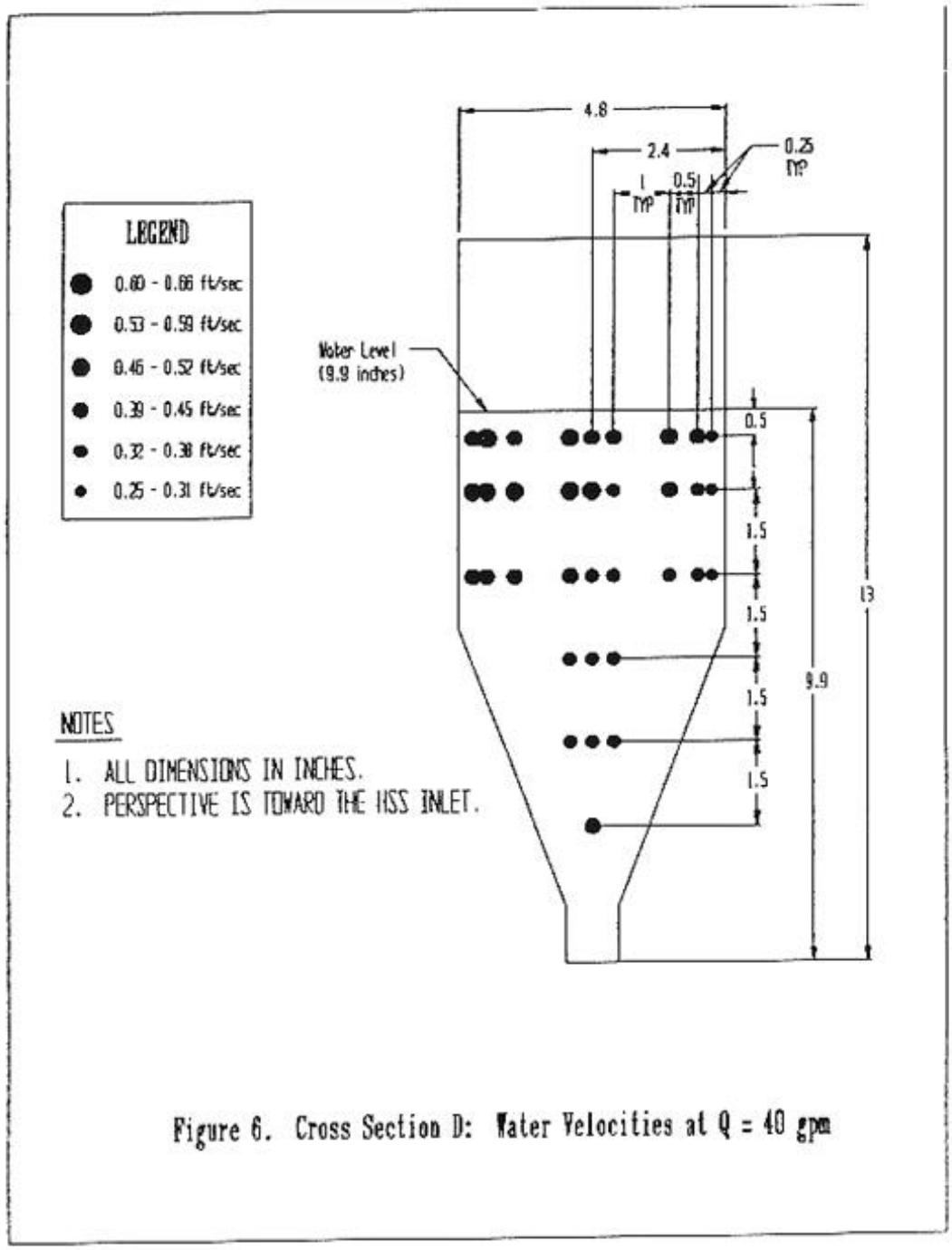


Figure 6. Cross Section D: Water Velocities at Q = 40 gpm

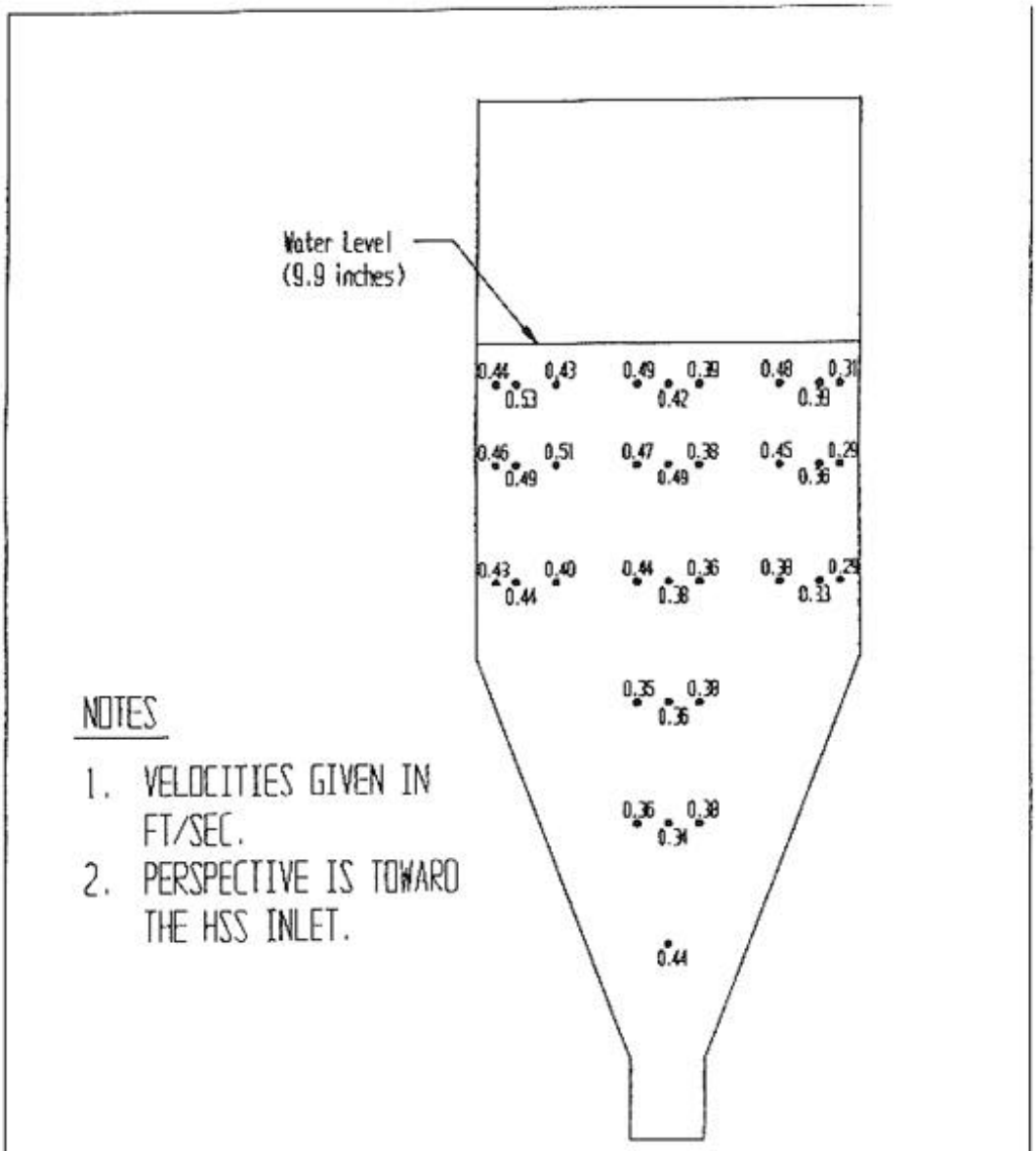


Figure 7. Cross Section D: Water Velocities at Q = 40 gpm

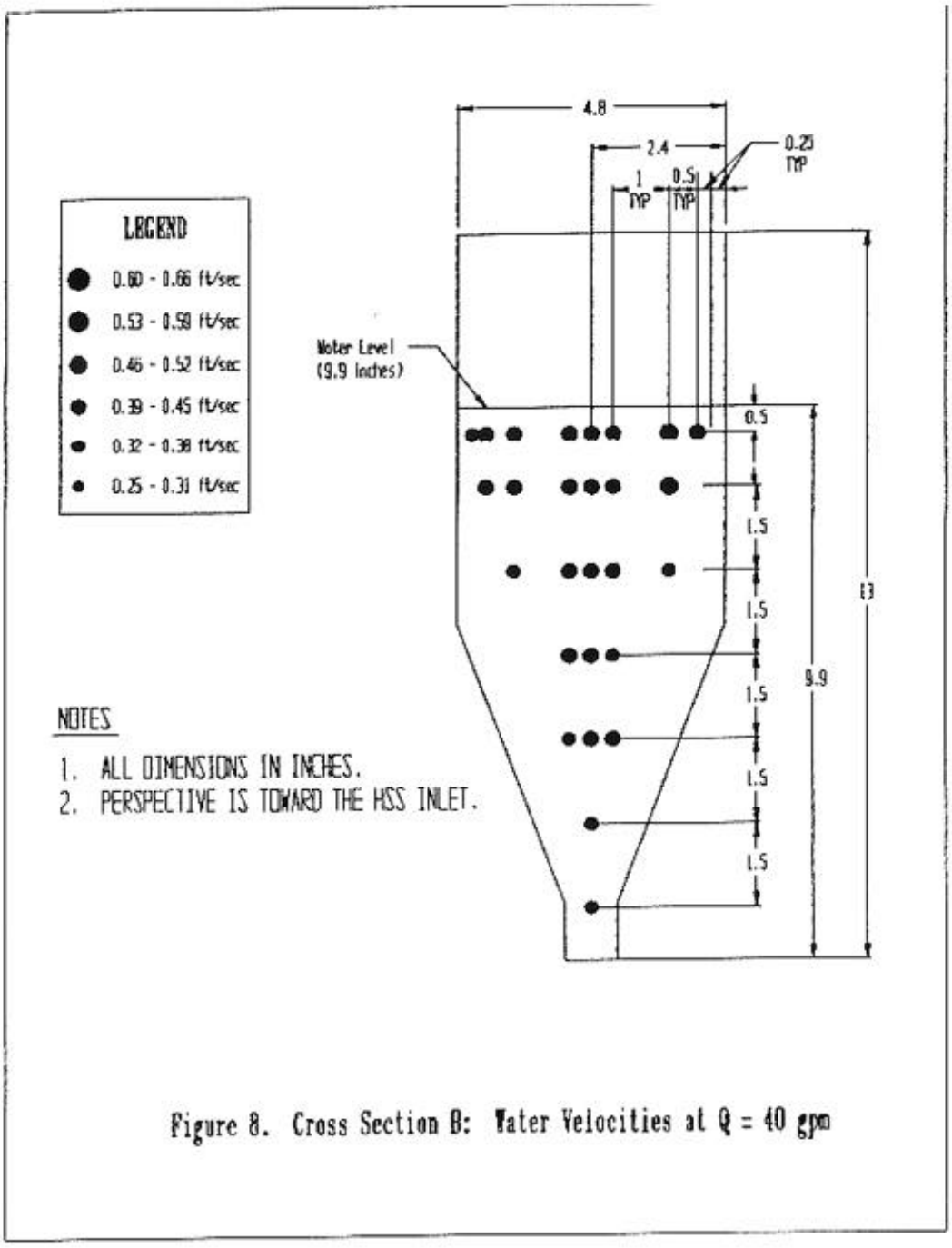


Figure 8. Cross Section B: Water Velocities at Q = 40 gpm

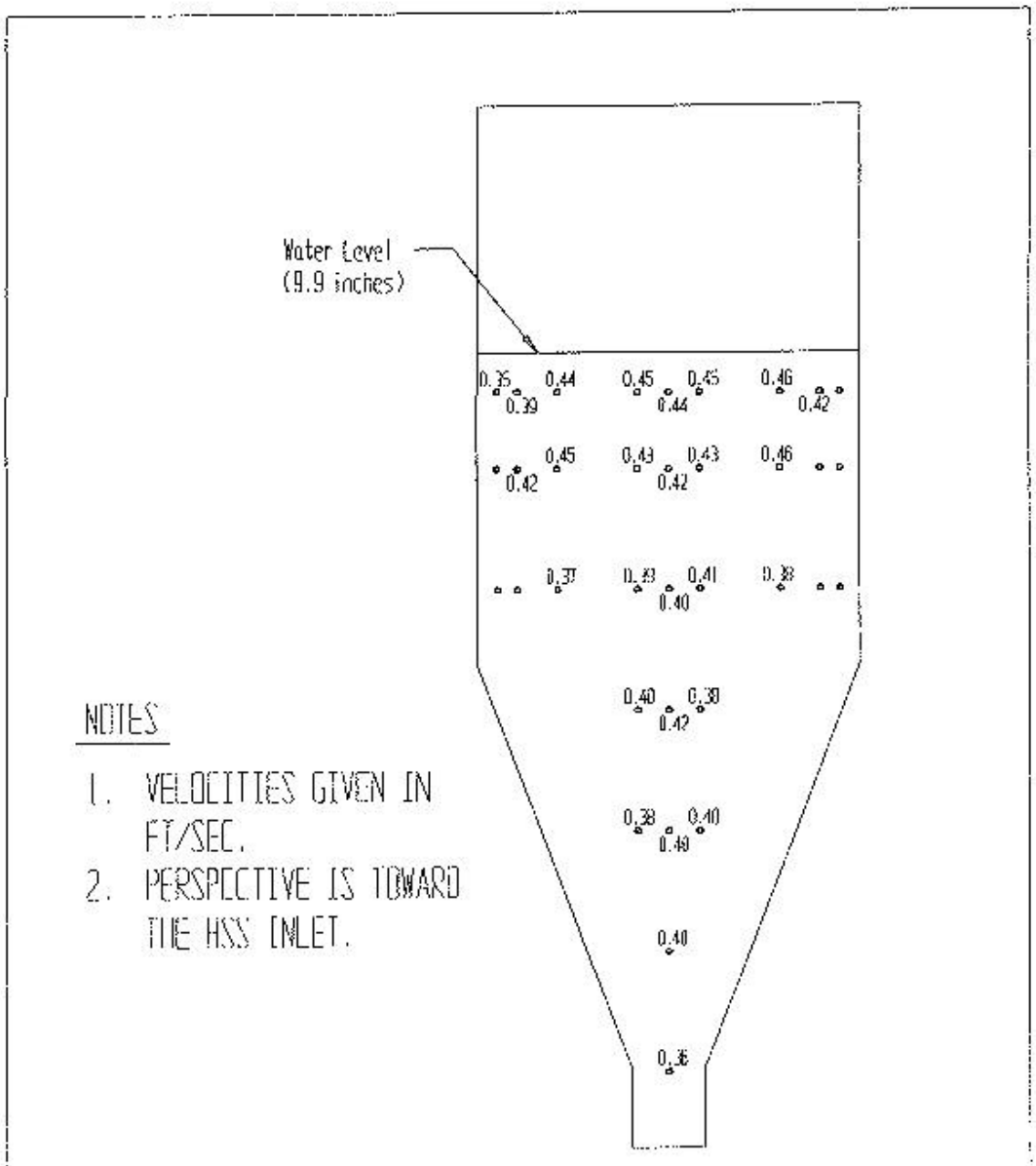


Figure 9. Cross Section B: Water Velocities at Q = 40 gpm

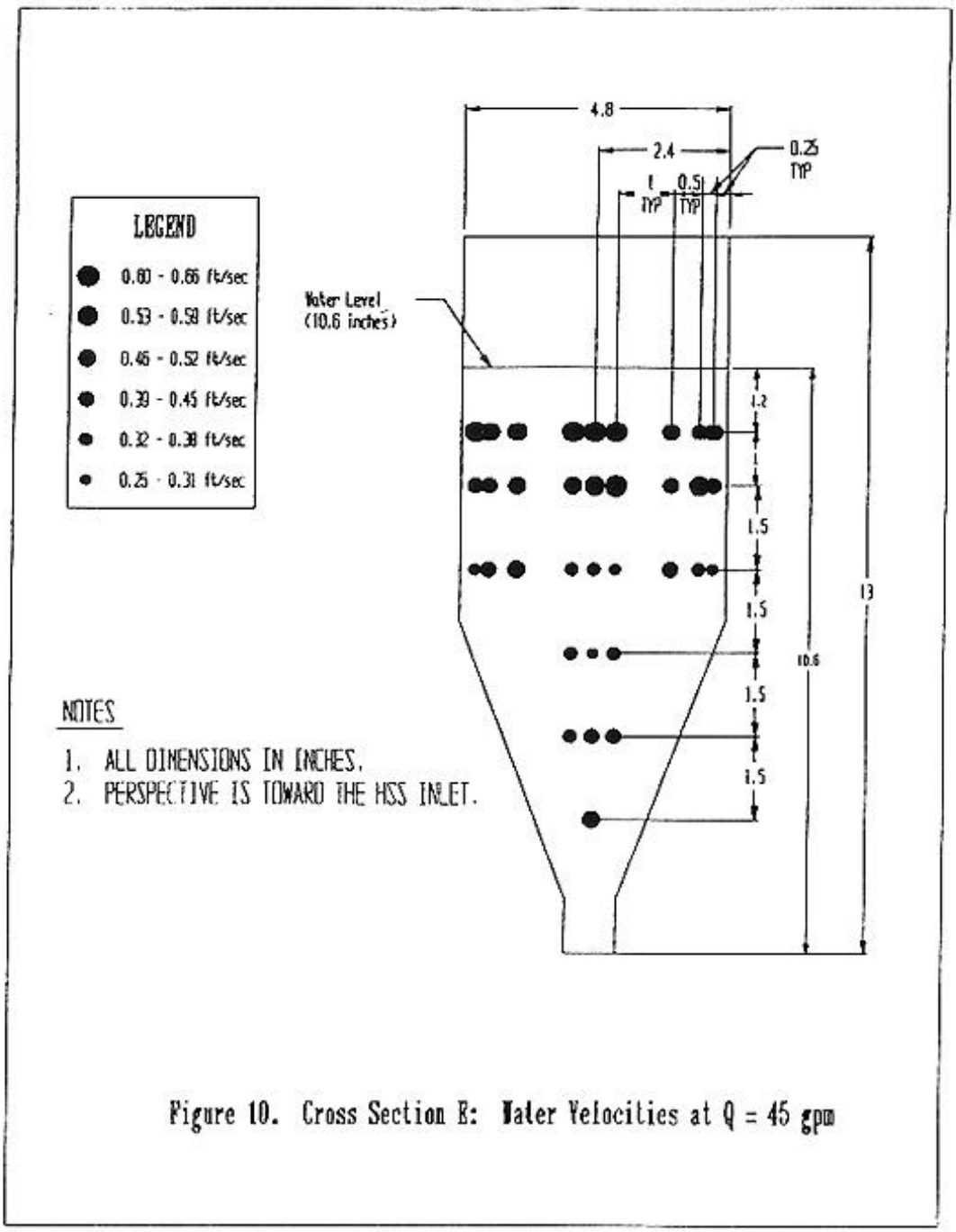


Figure 10. Cross Section E: Water Velocities at Q = 45 gpm

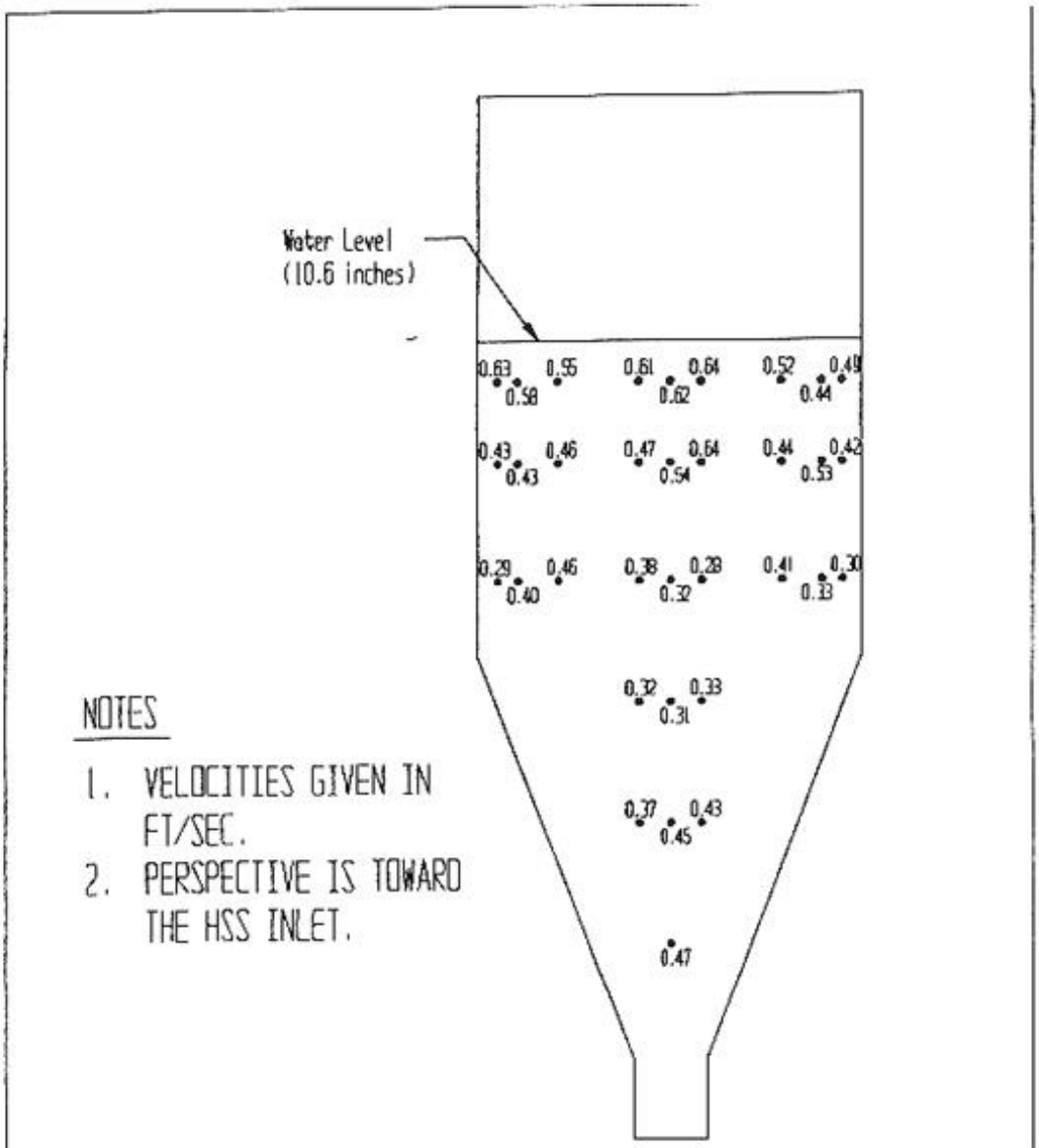


Figure 11. Cross Section E: Water Velocities at Q = 45 gpm

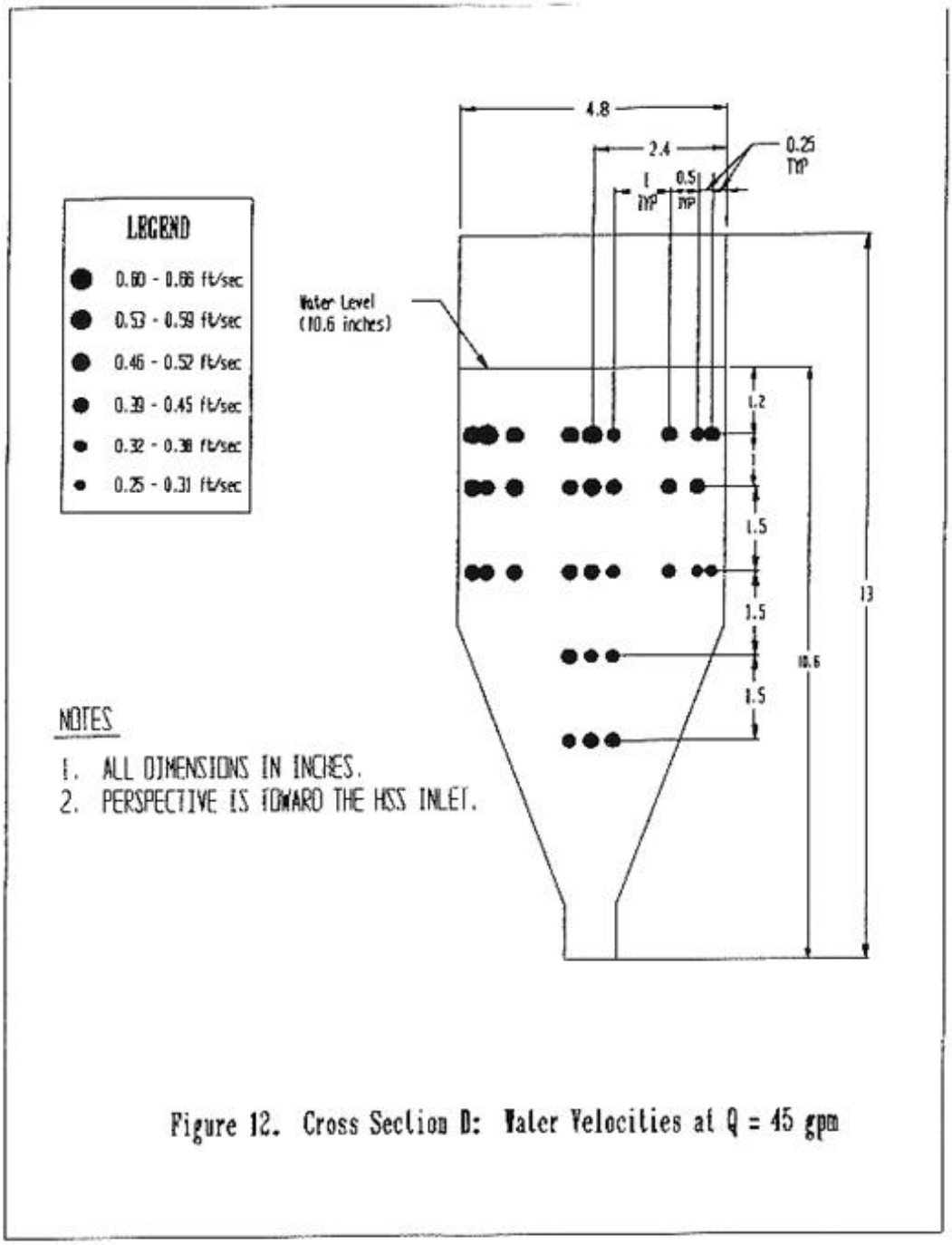


Figure 12. Cross Section D: Water Velocities at Q = 45 gpm

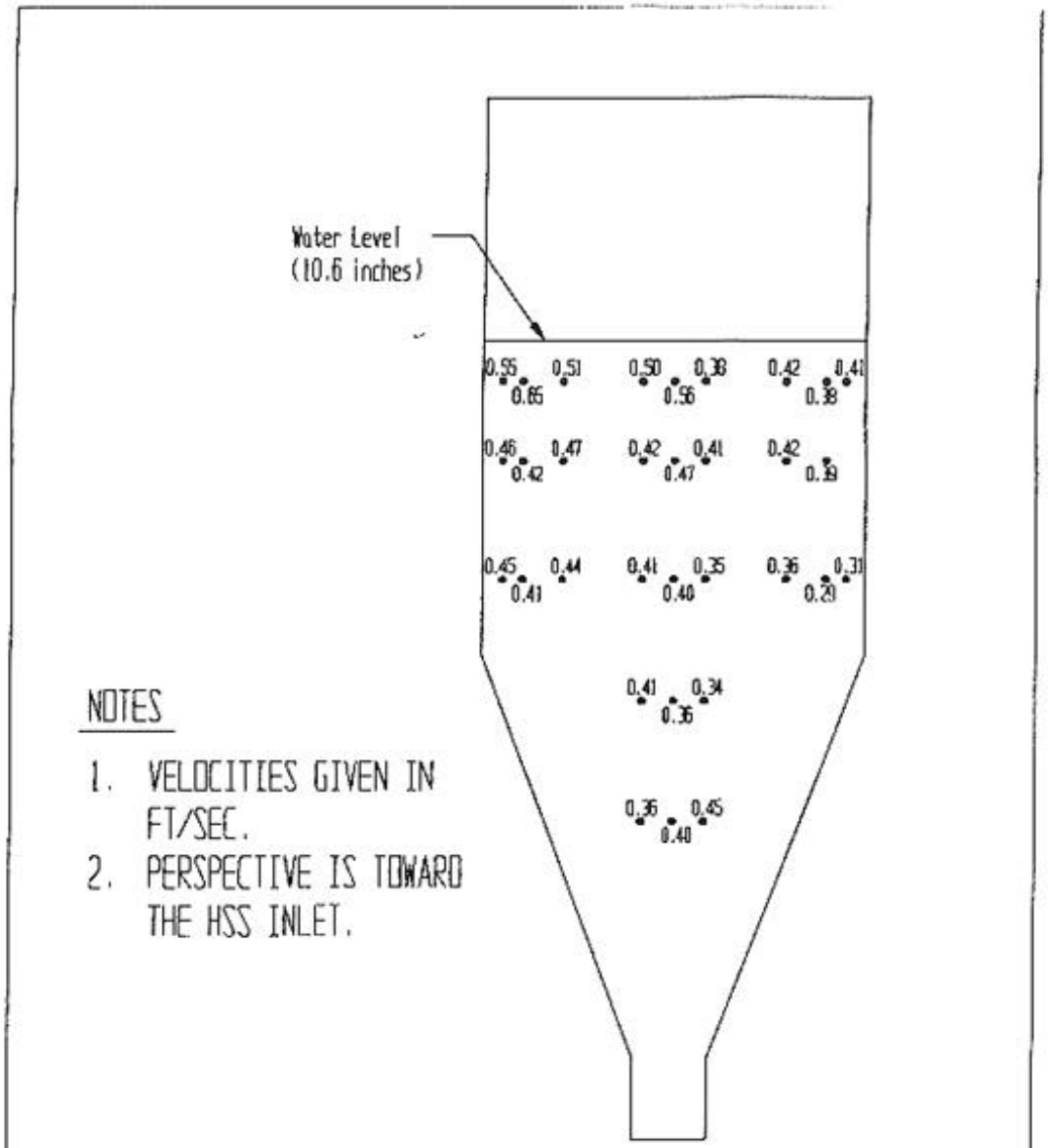


Figure 13. Cross Section D: Water Velocities at Q = 45 gpm

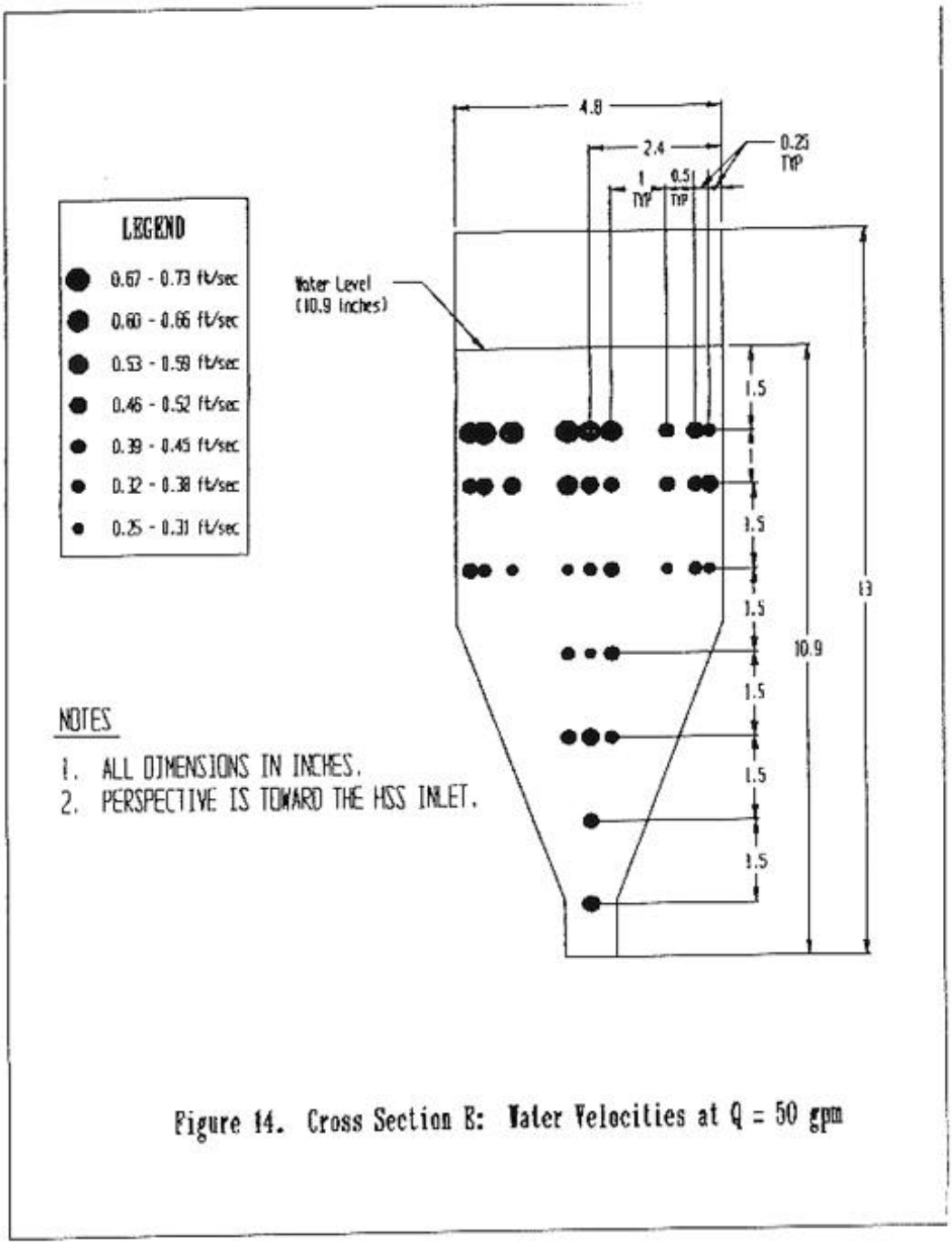


Figure 14. Cross Section B: Water Velocities at Q = 50 gpm

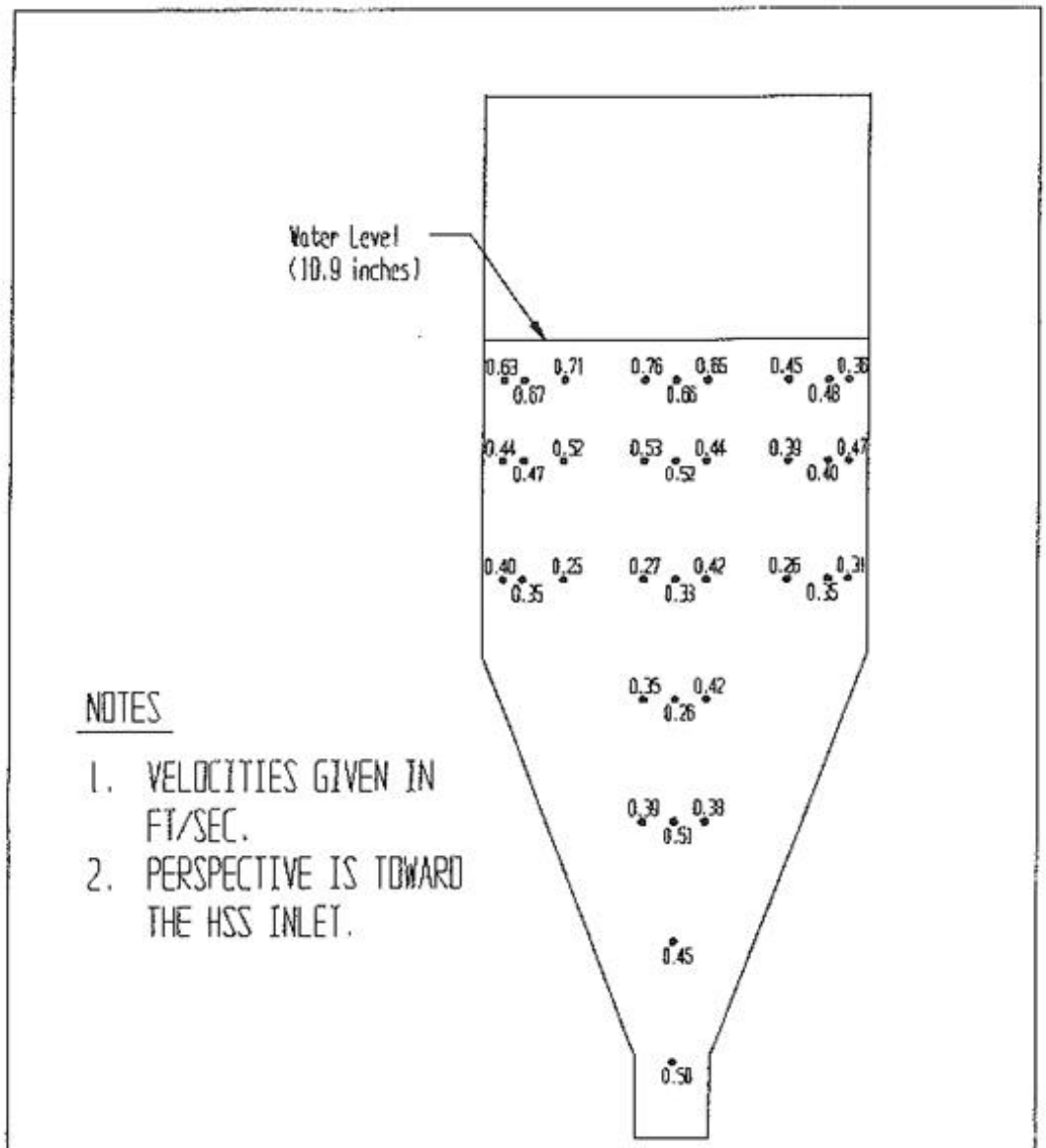


Figure 15. Cross Section E: Water Velocities at Q = 50 gpm

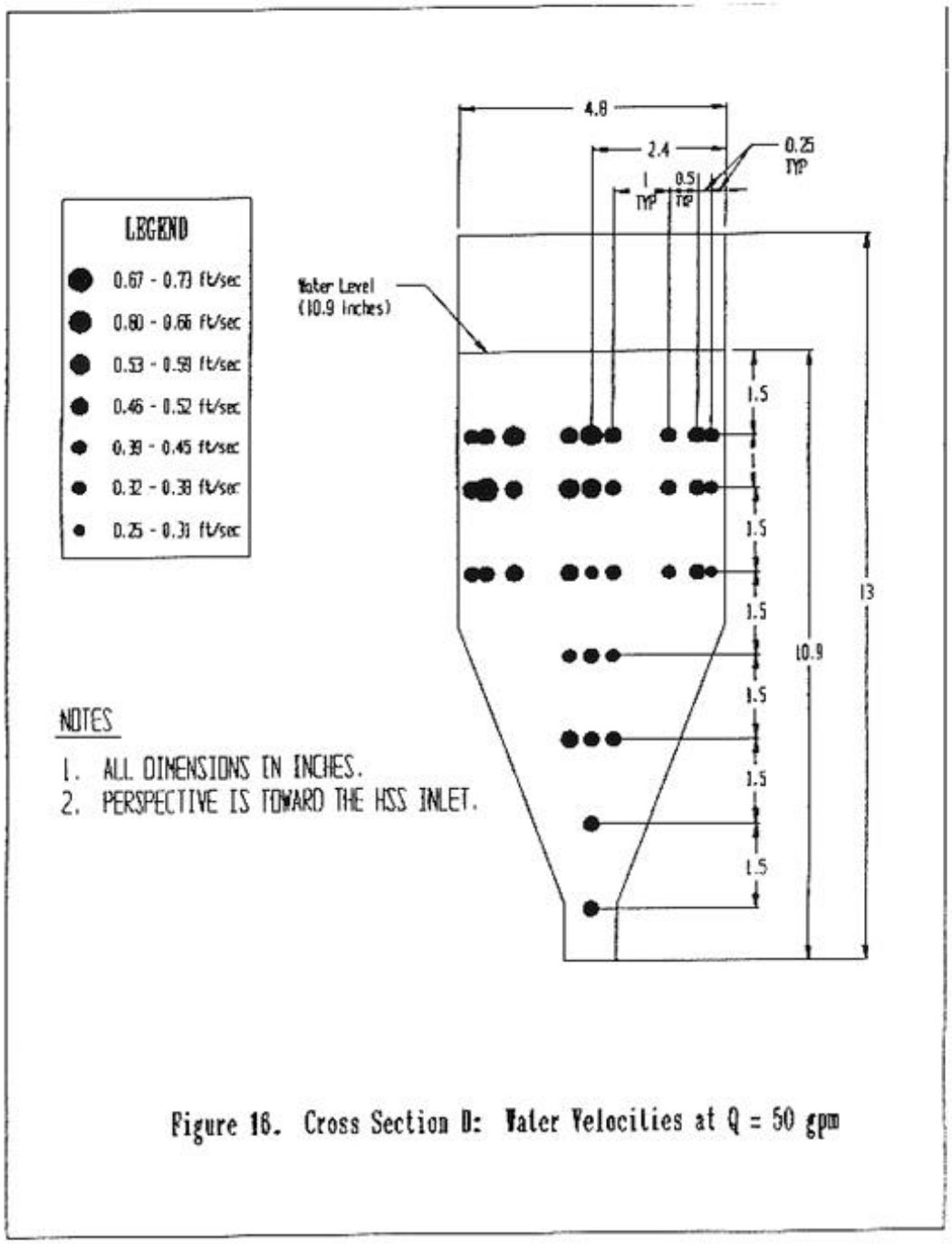


Figure 16. Cross Section D: Water Velocities at Q = 50 gpm

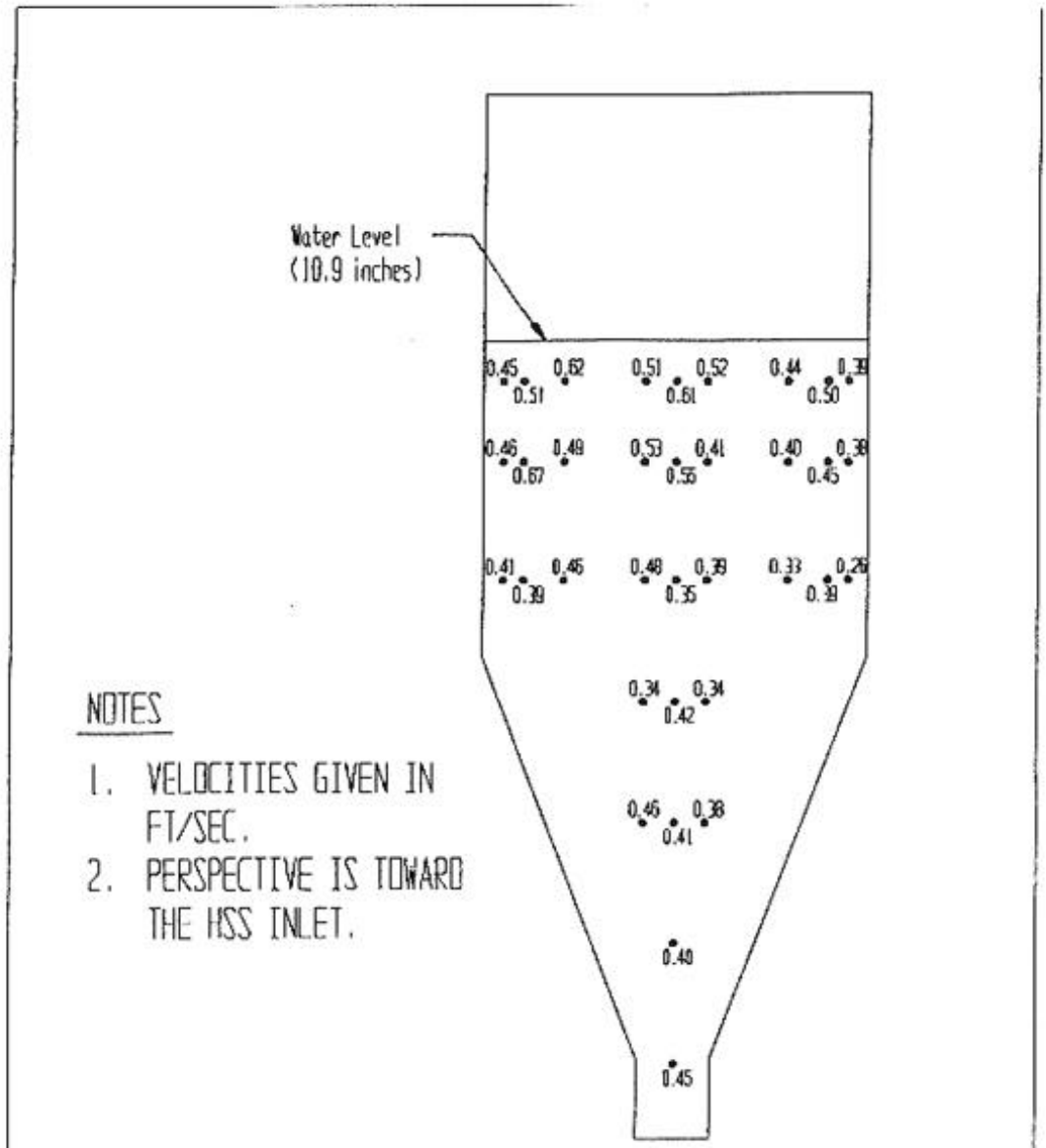


Figure 17. Cross Section D: Water Velocities at Q = 50 gpm

left side, facing the influent (0.62, 0.56, 0.45 fps) of the section than the right side (0.41, 0.43, 0.35 fps).

Figures 6 and 7 show the profiles at cross-section D at 40 gpm. The velocity ranges from 0.29 fps to 0.53 fps. The velocity appears highest at the highest measured level, with a decrease with depth until the point above the lower seam. The velocity distribution (Figure 6) appears relatively constant, although there appears to be a velocity "surge" on the left side, with velocities of 0.44, 0.46, and 0.43 fps on the left side and 0.31 and 0.29 fps on the right.

Figures 8 and 9 show the profiles at cross-section B (near the effluent) at 40 gpm. The velocity ranges from 0.29 fps to 0.48 fps. The velocity distribution (Figure 8) appears to be relatively constant, and the velocity surge on the left side appears to have dissipated. Velocity profiles at section B were not taken again, because it was expected that the majority of the particles will settle before this section. Also, the standard deviation (Table 16) of the velocities at this section was relatively lower than at the other sections (± 0.03 fps compared to ± 0.08 fps in cross-section E and ± 0.06 fps in section D), and it is anticipated that there will be less turbulence at this section because it is furthest from the influent and baffle plate, so the flow has been given sufficient time to reach a steady state.

The velocity profile at cross-section E at 45 gpm is illustrated in Figures 10 and 11. These figures show that the velocity ranges from 0.28 fps to 0.64 fps. The trend is again for an increased velocity at the upper level (0.62 fps in the center), decreasing as the depth increases (0.31 fps in the center) until the point above the lower seam (0.47 fps), and a surge of velocity on the left side of the channel, with velocities of 0.62 to 0.29 fps on the left and 0.49 to 0.30 fps on the right.

The velocity profiles at cross-section D at 45 gpm shows a velocity range of 0.29 fps to 0.65 fps in Figure 12. In Figure 13, it is noted that the overall trends are for a higher velocity at the highest measured level (0.56 to 0.36 fps), a slight surge on the left

side (0.55 down to 0.45 fps on the left and 0.41 to 0.31 fps on the right), and a relatively constant velocity distribution.

Figures 14 and 15 illustrate the profiles at section E at 50 gpm. The velocity ranged from 0.25 fps to 0.76 fps, and was again higher at the highest measured level (0.66 fps down to 0.26 fps along the centerline). The left side, at the top of the section appeared to show a velocity surge on the left (0.63 to 0.40 fps on the left and 0.36 to 0.31 fps on the right).

Figures 16 and 17 show the profiles at section D at 50 gpm. The velocity ranged from 0.26 fps to 0.67 fps, was higher at the highest measured level (0.61 fps down to 0.35 fps along the centerline), and showed no noticeable surge of velocity. The overall velocity distribution was relatively constant.

In all of the cross-sections measured, the velocities at the "core" of the section, where most of the settling is expected to occur, were relatively constant. For example, in Figure 17, cross-section D at 50 gpm, at the three centerline measurements from 2.6 inches to 7 inches from the water level ranged from 0.34 fps to 0.53 fps, which was a smaller range than the overall range of 0.26 fps to 0.67 fps.

Note that in Figures 4, 6, 8, 10, 12, 14, and 16 the areas of the circles representing velocities are not proportional to the velocity measurements. The figures are meant to show variations, ranges, and trends within each cross section. The overall trends are listed in Table 16. It can be seen that cross-section E shows greater variation than cross-section D. The standard deviations of the averages for E are higher or approximately equal to those of D. However, in the figures, it can be seen that the profiles of cross-section D tend to show a more constant distribution of velocities. This is as expected, since the turbulence should decrease as water flows away from the influent and baffle plate and achieves a more constant flow. Table 16 shows the results for all of the cross sections and flow rates.

Table 16. Velocity characterization of the HSS at various flow rates and cross-sections.

Flow Rate (gpm)	Cross-Section	Velocity Range (fps)	Average Velocity (fps)	Stnd. Dev. (fps)
40	E	0.28 - 0.62	0.42	0.08
	D	0.29 - 0.53	0.41	0.06
	B	0.35 - 0.46	0.41	0.03
45	E	0.28 - 0.64	0.42	0.11
	D	0.29 - 0.65	0.42	0.07
50	E	0.25 - 0.76	0.45	0.13
	D	0.26 - 0.67	0.44	0.08

4.3.3 Comparison of Results to Theoretical

The results of the velocity profiles, as tabulated in Table 16 can be used to compare the average velocities of the HSS to the theoretical, or design velocities. The theoretical velocity can be calculated from Equation 2 as presented in Section 2.5 of the literature review: $Q = (2/3)HVT$. The top width, T, is the width at the water level. This was taken to be 4.718 inches, which is the approximate width at the water level. The value was derived from interpolation to the approximate water level from the average widths at the top of the channel and at the middle joint. The flow rate used in calculations was the measured average flow rate at the specific control valve setting, and the water level depth was measured at each flow rate with a ruler as the depth of the water in the channel minus the 1 inch catch basin. The theoretical velocities and the range of percent differences (from the low measurement to the high measurement) at each flow rate and cross section are summarized in Table 17.

Table 17. Theoretical velocity and percent differences of measured velocities of the HSS.

Reference Flow Rate (gpm)	Cross-Section	Depth of Water (inches)	Theoretical Velocity (fps)	% Difference of Measured Velocities
40	E D B	8.938	0.46	-39% - + 35% -37% - +15% -23% - +0%
45	E D	9.625	0.50	-44% - + 28% -42% - + 30%
50	E D	9.938	0.52	-52% - + 37% -50% - +46%

The measured velocities indicated a large variation, between -52% to +46%, from the theoretical "constant velocity" intended in the approximately parabolic channel. The large variations are likely due to the fact that the channel is relatively small and has high flow rates. This causes turbulence which is difficult to dissipate in the small channel. Also, the channel cross-section is only an approximation of a parabola. The difference seems to be large enough to lead to variations, especially in a channel of small size.

Generally, the variations from the theoretical velocity appeared to increase at higher flow rates. This is as anticipated, since the higher flow rates exhibit more turbulence in flow. Also, as the depth of the water in the channel increases, the channel becomes further from an approximation of a parabola, and thus it is less likely to exhibit constant velocity conditions. The velocities at the 40 gpm and 50 gpm showed less variation at cross-section D than at section E. This is expected since section D is further from the baffle plate, and thus the flow had more time to stabilize. Cross-section B had the least variation in velocities from the theoretical since it is furthest from the influent, where turbulence results from the high flow rate entering a relatively small area. At 45 gpm, the variations at cross-section D and E are too similar to draw conclusions.

The "new" expected required minimum settling lengths (which are different from the initial calculated settling lengths) can be calculated from Equation 2.18 from Section 2.5 of the Literature Review: $L = HV/V_s$. The velocity used in this equation was the

theoretical velocity at the appropriate flow rate, and the settling velocity used was 0.25 fps. The results are summarized in Table 18.

Table 18. Minimum settling length of the HSS for measured flow rates, heights, and calculated velocities.

Reference Flow Rate (gpm)	Water Depth (inches)	Theoretical Velocity (fps)	Required Settling Length (inches)
40	8.938	0.46	16.4
45	9.625	0.50	19.3
50	9.938	0.52	20.7

The results shown in Table 18 indicate that the "ideal" minimum settling lengths at these three flow rate settings are between 1 and 2 feet. The minimum lengths, however, do not take into account any additional length required due to unstable flow conditions.

4.4 Performance of the HSS

The HSS was operated using pulverized crab meat and shell obtained after processing in the hammer mill. A known weight of the mix was dropped into the system over a given time period for each trial. From these trials, the performance of the system, in terms of yield, meat quality, and wastewater characteristics were evaluated.

4.4.1 Yield

The HSS was operated with input quantities of pulverized crab claw meat and shell obtained after processing in the hammer mill step. The use of Plexiglas as a building material for the HSS allowed for visual observations to be made as the meat and shell particles settled within the channel length. As the crab claws were input, the shell particles sank almost immediately, or within a few inches of the point of input in the channel. The shell particles created a "pile" of approximately 4 or 5 inches in length

along the length of the channel. The large, heavy meat particles, or meat particles with shell still attached, settled further down in the channel, approximately 8 to 12 inches from the input location. The piles hindered flow and caused increased quantities of particles to settle. Some very small meat particles remained in suspension, and due to turbulence in the HSS channel, were trapped in circulating patterns within the channel.

The yield of the HSS was measured at various flow rates, settling lengths, and quantities of input meat (0.76 lb quantities were introduced over 15 seconds and 1.52 lb quantities were introduced over 30 seconds). The 50 gpm flow rate was not tested because the input of crab claws tended to cause excessive foaming problems in the channel, and at this flow rate, water splattered over the walls of the channel. The purposes of these tests were to determine the optimum operating conditions for the HSS and to compare these results to the results from the standard industrial system, the Harris Claw machine. The results are tabulated in Table 19.

Table 19. Meat product yield of the HSS at various operating conditions.

Flow Rate (gpm)	Distance from output (ft)	Input meat and shell (lb)	Recovered meat (lb)	Yield %	Visual Observations of Recovered Meat--Shell
40	1.5	0.76	0.24	32	more shell
40	1.5	0.76	0.20	26	more shell
40	2.0	0.76	0.14	18	very small amount of shell
40	2.5	0.76	0.20	26	very small amount of shell
40	3.0	0.76	0.12	16	no shell
45	1.5	0.76	0.20	26	more shell
45	1.5	0.76	0.20	26	more shell
45	2.0	0.76	0.14	18	very small amount of shell
45	2.5	0.76	0.14	18	very small amount of shell
40	1.5	1.52	0.30	20	more shell
40	2.5	1.52	0.24	16	very small amount of shell
40	2.5	1.52	0.26	17	very small amount of shell
45	1.5	1.52	0.34	22	more shell
45	2.5	1.52	0.18	12	very small amount of shell

The results in Table 19 show that the yield decreased as the quantity of crab claws input into the HSS increased. This was due to the “piling” effect of the settled particles, the size of which increased as the input quantity increased. The piles blocked the flow

and caused additional particles to settle which may have otherwise been carried through the control section.

Since the quantity of sample placed in the HSS was necessarily very small in order to achieve an acceptable yield, the samples displayed large variability, ranging from 12% to 32%. This made a general optimization of system operation parameters very difficult, since the variability in the samples lead to variabilities in the yield results. However, a few general observations can still be made.

At 40 gpm the yield, averaging 26% when the input sample quantity was 0.76 lbs, was generally slightly better than at 45 gpm , averaging 22% for 0.76 lbs, for most of the operating conditions (same input quantity and settling length). Also, the yield decreased as the length increased. This is as expected, since the lower settling length allows the larger particles to be carried out through the control section. However, the accuracy of this observation is somewhat questionable, since at the lower settling lengths, more shell particles were also carried through, and their addition was not accounted for in the yield measurements. Generally, however, at smaller settling lengths, the yield could be increased at the cost of an increased quantity of shell in the meat product. At longer settling lengths, the yield may decrease, but the amount of shell in the product will also decrease. This would allow some flexibility in the operation of a full-scale system, since the operating parameters could be varied to suit the individual processor's daily needs.

In the Harris Claw machine, the same batch of crab claw was estimated as having a yield of approximately 15% (C. Graham, 1996). Overall, the yields varied from 16% to 32% (isolating the 12% obtained at 45 gpm, 1.52 lbs input, and 2.5 ft distance as an outlier). This is comparable, or even better, than the estimated yield from the same batch of crab claws processed in the Harris Claw machine.

A further measure of the yield, or efficiency, of the HSS system used was the protein content of the HSS "scrap," a thorough mix of the meat and shell settled within the channel. The HSS scrap was found to have a protein content of an average of

19.34%. This indicates the quality of the scrap, and can be used to determine further treatment and uses of the "waste" material.

4.4.2 Meat Product Quality

The crab claw meat product quality was measured in terms of the microbial analyses and taste and appearance.

Microbial Analyses

The recovered crab meat from the HSS was tested for mesophilic aerobic plate count at 35°C, total coliform, fecal coliform, and *E. coli* at 0, 3, 5, 7, 10, and 12 days from processing. The results are presented in Table 20.

Table 20. Microbial composition of crab claw meat processed in the HSS.
(All results are expressed on a count per gram of meat product basis.)

Day	APC @ 35°C	Total Coliform	Fecal Coliform	*E. coli*
0	2.7×10^4	0.9	<0.3	<0.3
3	2.4×10^6	6.8	<0.3	<0.3
5	4.2×10^6	15.0	<0.3	<0.3
7	1.9×10^7	24.0	<0.3	<0.3
10	4.0×10^8	24.0	<0.3	<0.3
12	8.9×10^8	35.0	<0.3	<0.3

Note: APC= aerobic plate count

Fecal coliforms and *E. coli* were wither not present occurred in quantities too low for detection. This low population of both microorgamisms indicates that the claws and meat were produced under sanitary conditions.

An initial APC of 100,000/g is the regulatory guideline used by many state health control agencies. While the initial counts did not exceed this guideline, they are still relatively high. Either an improved claw handling procedure should be initiated by the crab firms or the water in the HSS needs to be either changed or given a chemical or

physical treatment to prevent microbial accumulation. Crab meat is normally considered spoiled or unfit for consumption when the population reaches 10^7. Consequently, the shelf-life of the product in this study is approximately one week. This time could be easily extended through implementation of a quality assurance program. Another alternative would be to pasteurize or freeze the meat thereby extending shelf-life.

Sensory Evaluation: Appearance and Taste

The appearance and taste ratings were evaluated for the HSS meat product and for hand-picked crab claw meat, both stored on ice. The evaluations were made on days 4, 7, and 13. The results are summarized in Table 21.

Table 21. Sensory preference ratings for crab claw meat processed in the HSS.

SAMPLE	APPEARANCE SCORE *			TASTE SCORE *		
	Day 4	Day 7	Day 13	Day 4	Day 7	Day 13
Hand-Picked Claw	13.27	12.41	11.28	14.32	13.88	11.69
HSS	6.29	4.56	4.34	3.12	3.68	3.23

* Score is the average score, based on a preference line location, with a maximum of 16.0 cm.

The statistical analysis of the taste panel results summarized in Table 21 indicate that for both taste and appearance the HSS meat product received a significantly lower score (based on a 0.5% significance level) than the hand-picked claw meat on each trial day.

The reduced acceptability of the HSS product was primarily caused by the water removing the small molecular compounds that are characteristic of blue crab meat flavor. However, the meat could be successfully incorporated into a further processed product which would be the meat's primary market.

4.4.3 Wastewater Characterization

Wastewater samples were collected after running the HSS at a flow rate of 40 gpm, a settling length of 2.5 ft, and an input quantity of 1.52 lb crab claw meat and shell. Samples were analyzed for temperature, pH, color (true and apparent), turbidity, alkalinity, BOD_5, COD (total and soluble), dissolved organic carbon, suspended solids (total and volatile), ammonia, TKN, total phosphorus, cations (sodium, ammonium, potassium, calcium, and magnesium) and anions (chloride and sulfate). The results are presented in Tables 22, 23, 24, and 25 in the following and are later summarized in Appendix C.

Table 22. Characterization of effluent wastewater from processing with the HSS.

Sample	Temperature °C	pH	True Color (Color units)	Apparent Color (Color units)	Turbidity (NTU)	Alkalinity (mg/L $CaCO_3$)
initial	-	7.03	0	10	-	40
1	18.5	7.06	10	20	12	39
2	17.0	7.13	15	25	14	68
3	16.0	6.86	15	30	7	40

The only effluent characteristic from Table 22 which are regulated under state and federal regulations is pH. The regulations require that the effluent pH be within the range of 6 to 9. The pH values recorded are within this range, however, this is only significant for the small quantity of crab claws (1.52 lb) input into the system. Generally, the pH of the processing water will increase as more crab claws are input into the system because more contact with seawater, which has a pH of about 8, will occur. Thus, these pH values will tend to increase if the HSS were to be operated on a larger scale. However, from the observations by Harrison (1993), the pH of the effluent from mechanized crab claw processing is not anticipated to be out of the acceptable range.

Though not directly regulated, the temperature of the wastewater should be within in 16°C and 30°C in order to be considered as "acceptable." The HSS effluent was

within this range, although the reported values are significant only for the small quantity of crab claws processed at the time of testing. The temperature would most likely increase some from these values if the operation time is increased due to increased mechanical activity, such as pumping, although it is not expected that the temperature would exceed the acceptable range.

Generally, the color, both true and apparent, and the turbidity of the processing water increased as the crab claws were input into the system. It is expected that the alkalinity of the water also should tend to increase when contact with crab claw meat and shells occurs and small particles are left in suspension. This increase is probably due to the accumulation of ammonia and other nitrogen containing compounds, such as amines, which are normally present in the meat. This characteristic trend is only noted in the second sample however. The lack of a noticeable increase in the other samples is likely due to the small input quantity, which was apparently not enough to significantly increase the alkalinity.

Table 23. Characterization of effluent wastewater from processing with the HSS.

Sample	BOD_5 (mg/L)	Total COD (mg/L)	Soluble COD (mg/L)	DOC (mg/L)	TSS (mg/L)	VSS (mg/L)
initial	19	30	(1)	-	2	2
1	66	120	113	42.2	21	21
2	96	137	109	38.5	14	12
3	68	111	80	29.9	13	10

(1) Essentially no solids, so that soluble measurements should be approximately equal to total.

Overall, the soluble COD was between 72% and 94% of the total COD. The five day BOD was between 55% and 70% of the COD. The volatile, or organic, portion of the suspended solids was between 77% and 100% of the total suspended solids. These percentages indicate that a large portion of the effluent pollutant strength is due organic matter, largely the result of unsettled meat particles. The wastewater will be readily degradable.

The wastewater concentrations of BOD_5 and TSS are of the most concern, since these are regulated by Virginia DEQ. According to the 1992 rate schedule, the Hampton Roads Sanitation District ordered that industries pay a surcharge of $20.65 and $23.55 per 100 pounds of BOD and TSS in excess of 250 mg/L. While the reported values in Table 23 do not exceed these, it is likely that large-scale operation of the HSS would result in wastewater concentrations which would be in excess. The HSS produced only fractions of a pound, while typically, plants will produce meat in quantities often exceeding 2,000 pounds per day. There is no evidence to suggest that the BOD and TSS effluent strength will increase in direct proportion to the number of pounds processed, however, it is likely that such a large increase in processed meat will deposit high levels of organic matter in the wastewater. An assumed directly proportional increase can be used to represent the worst case scenario.

The wastewater characteristics summarized in Table 24 are not controlled under state or federal regulations. However, as noted with BOD and TSS previously, the Hampton Roads Sanitation District (1992 rate schedule) indicated that phosphorus concentrations in excess of 6 mg/L would incur a surcharge of $114.00 per hundred pounds and that TKN in excess of 35 mg/L would be subject to surcharges of $31.13 per hundred pounds. While the concentrations presented in Table 24 do not exceed these values, if a directly proportional increase is assumed to represent the worst case scenario, then production of 1,000 to 2,000 pounds of crabmeat could result in up to 4,800 mg/L TKN and 2,000 mg/L phosphorus in the wastestream. Thus, if the production were to increase, then the wastewater would likely be in excess of the acceptable concentrations and would be subject to the described surcharges.

Table 24. Characterization of effluent wastewater from processing with the HSS.

Sample	NH_3 (mg/L)	TKN (mg/L)	Phosphorus (mg/L)
initial	-	-	-
1	0.24	2.4	1.0
2	0.30	3.0	0.6
3	0.24	7.6	0.8

The wastewater ion concentrations shown in Table 25 were generally found to increase with the introduction of crab claws into the system for most of the ions. The concentrations of magnesium and calcium ions however, were relatively unaffected by the input of the small quantities of crab claws processed during the course of these trials.

Table 25. Characterization of effluent wastewater from processing with the HSS.

Sample	Na^+ (mg/L)	NH_4^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)
initial	7.8	3.1	3.6	1.4	26.6	19.7	36.1
1	13.5	7.7	7.8	1.5	26.6	31.1	35.6
2	14.7	8.9	8.9	1.5	26.0	33.2	35.5
3	13.4	6.8	8.1	1.5	27.2	31.4	35.6

The effluent loadings presented in Table 26 are based on the pound yield derived from the respective trials. The values tabulated in Table 26 are also based on a 29 gallon total volume in the HSS channel, pipes, and recirculation basin.

Table 26. Effluent loadings from processing with the HSS. Values are expressed in pounds per 1,000 pounds of product.

Sample	BOD_5 (lb/1000lb)	COD (lb/1000lb)	Soluble COD (lb/1000lb)	TSS (lb/1000lb)	VSS (lb/1000lb)	NH_3 (lb/1000lb)	TKN (lb/1000lb)	PO_4-P (lb/1000lb)	Cl^- (lb/1000lb)
1	61	112	105	20	20	0.2	2.2	0.9	29
2	97	138	110	14	12	0.3	3.0	0.8	33
3	-	-	-	-	-	-	-	-	-

The effluent BOD_5 and TSS loadings are the only parameters in Table 26 which are now regulated by Virginia DEQ. The BOD_5 is in excess of the maximum and average limits for new sources (existing sources are not subject to BOD_5 limits). The TSS is slightly in excess of the average limit for existing sources and in excess of both the average and maximum limits for new sources. Thus, the wastewater flow would presumably require some treatment in order to meet effluent standards. The relatively high percentage of organic matter and relatively low chloride ion concentration characteristic of this wastestream would most likely make it amenable to biological treatment.

The pollutant loadings as listed in Table 26 are "worst case" values for two main reasons. One is that the values measured were for very small portions of crab meat and thus represent a large source of error if, as is done in the calculations, it is assumed that the pollutant concentrations will increase in direct proportion to the mass of crab claws input to the system. There is no evidence to confirm or disprove this assumption, and thus, it is used in order to approximate the net pollutant effect of the treatment process.

The second reason is that the presented loadings are effective only for the specific yield derived from the process. The yield in the HSS was highly variable; however, the samples were taken at HSS operating parameters (flow rate, settling length, input claw quantity) which were not shown to result in the highest yield. The choice of HSS settings was made in order to achieve a useable quantity of meat product for testing, and not to maximize the yield. This choice, however, may have had an adverse affect on the environmental results. Since the system was operated at a larger quantity of input sample, the yield, as a percentage, decreased due to the piling of settled materials which constricted the flow within the HSS. This decrease in yield may have resulted in a larger quantity of small meat and shell particles which remained in suspension which would in turn increase the pollutant concentrations. Further, if the yield in the HSS were to increase with the same operating parameters, then the overall loading as expressed in Tables 25 and 26 would also mathematically decrease. Section 4.4.4 discusses some of

the observations which were made relative to their potential for increasing meat product yield.

4.4.4 Observations and Recommendations for Improvements of HSS Performance

The yield results for the HSS were nearly as good, or better, than the approximate yield obtained from the industry's Harris Claw machine for the same batch of crab claws. However, the process still left a significant portion of the meat uncollected, and therefore could be improved by a number of modifications. The observations and following recommendations for improvements are described in the following.

As mentioned in Section 4.4.1, the use of Plexiglas allowed visual observations of the processes taking place within the HSS. During operation of the HSS, it was observed that some of the meat particles remained in suspension due to the turbulence created near the control section. Thus, the performance of the HSS might be improved by installing a conveyor collection system before the control section. This would be appropriate if the conveyor and associated material did not interfere with flow conditions. Such a conveyor would allow more meat to be collected, since the meat would not have to be forced through the narrow control section.

Another observation made during the operation of the HSS, was that the settled particles (mostly shell) tended to create a pile which constricted flow through the channel. Since the settled pile blocked flow, it caused any meat or shell particles which came in contact with it to remain on the pile, and it decreased the depth available for settling within the channel causing many particles to be removed which would not have given the full available depth. This problem could be eliminated by the installation of conveyor along the bottom of the channel which would move the settled particles to a screw-type conveyor which would continuously remove the settled particles from the channel.

A preliminary laboratory test was conducted in which air stone was used to suspend particles. Samples of pulverized crab claws were dropped into the tank, and the settling characteristics were observed. It was noted that the air flow tended to stir all of the particles, and increase the settling time of the meat particles by holding them in the suspension for a longer period of time. It was also observed that the air flow had little effect on the settling time of the shell particles. The results of this experiment indicate that the use of diffused aeration throughout the settling length of the channel could improve the net yield by causing mixing which could facilitate the separation of attached meat and shell particles and causing an increased settling time for the meat particles.

A final recommendation for yield improvement in the HSS is the possible use of an additional mechanical separator such as the Baader machine, a meat/bone separator for the tank residual from the HSS. The separator machines are capable of producing a minced meat product at fairly a high yield from products containing meat and bone or shell which would otherwise be waste products. The machines operate in a manner similar to the mechanical fish deboners which were originally developed in Japan, but have been in widespread use in the US for around seventy years. The input product undergoes a pulverization in a crusher roll, and then is conveyed between a rotating stainless steel perforated drum and a continuous rubber belt under tension. The muscle, or meat, tissue is relatively soft and is squeezed through the perforations on the drum by pressure forces. The skin, bones, or shell material remains on the outside of the drum and is scraped into a waste chute. An open end on the steel drum allows the meat product to be continuously collected. (Stansby, 1963) The HSS tank residue, since it was found to contain a relatively high percentage of protein (19.34% protein), could be appropriately applied to a Baader machine. The additional processing could significantly increase the overall yield of the HSS.

4.4.5 Modeling of HSS to Larger Scale

The pilot-scale HSS, as built, can only accommodate the input of a fraction of a pound of crab meat. With the incorporation of conveyors as mentioned in Section 4.4.4, the HSS would likely be able to process an increased quantity of crab claws. However, it still may be necessary or desirable to model such a design to a larger scale system for use in the processing industry. The theory to such a modeling endeavor is explained in the following (Kornhauser, 1996).

The main system design parameters include the flow rate, Q, the cross-sectional area, A, the settling length, L, and the settling depth Δh. The horizontal velocity in the system, v_h, is then the flow rate divided by the cross-sectional area ($v_h = Q/A$), and the detention time for system, t, is then related to the flow rate, area, and length:

$$t = \frac{AL}{Q} \qquad [4.1]$$

The meat and the shell particles each have different corresponding vertical (settling) velocities, v_{vm} and v_{vs}, respectively, due to their relative densities and sizes. Thus, for the given detention time, the meat and shell particles will each fall a vertical distance given by:

$$\Delta h_m = v_{vm} t = \frac{v_{vm} AL}{Q} \qquad [4.2]$$

$$\Delta h_s = v_{vs} t = \frac{v_{vs} AL}{Q} \qquad [4.3]$$

If the vertical distance of fall for both the meat and shell particles is set as the Δh, the total settling depth as measured from the water level in the channel to the bottom surface of the control section (1.5 inches above the bottom of the channel), then the maximum vertical velocity which a particle may obtain and still be carried through the control section is:

Figure 18. Theoretical curve of maximum vertical velocity for carry-over versus the percentage of meat carry-over. The distribution is based on measured meat settling velocities. The curve would be used for modeling the HSS to a larger scale.

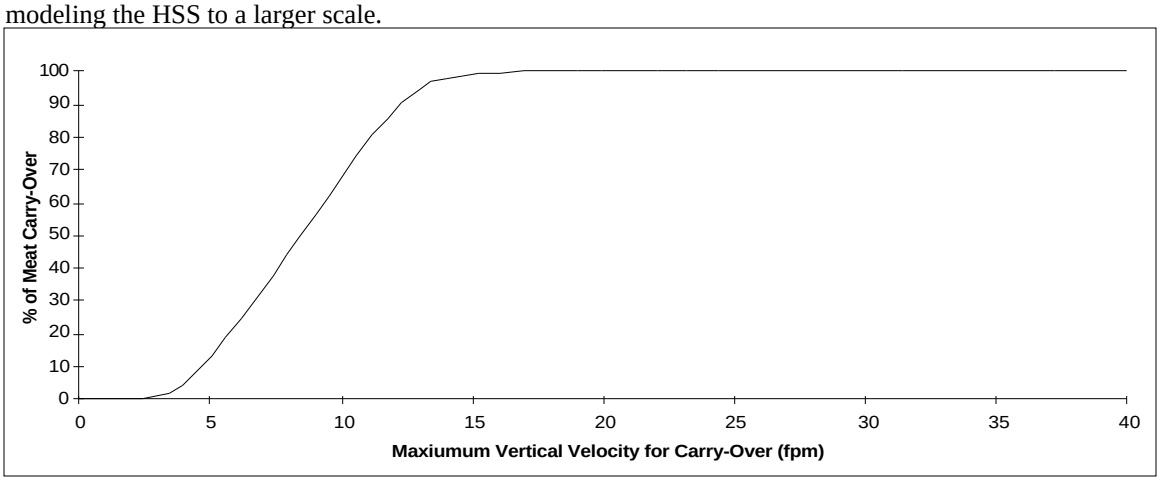


Figure 19. Theoretical curve of maximum vertical velocity for carry-over versus the percentage of shell carry-over. The distribution is based on measured shell settling velocities. The curve would be used for modeling the HSS to a larger scale.

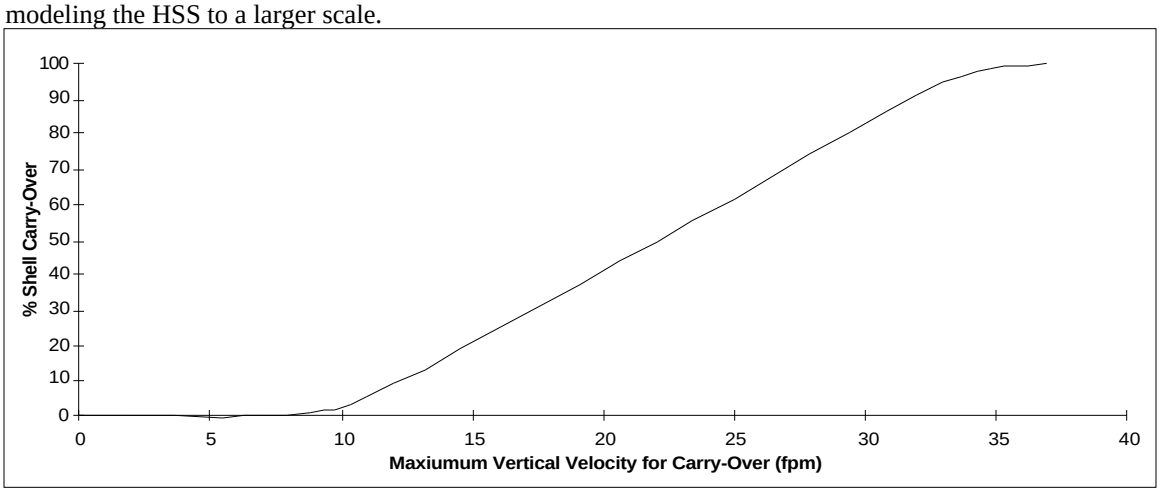
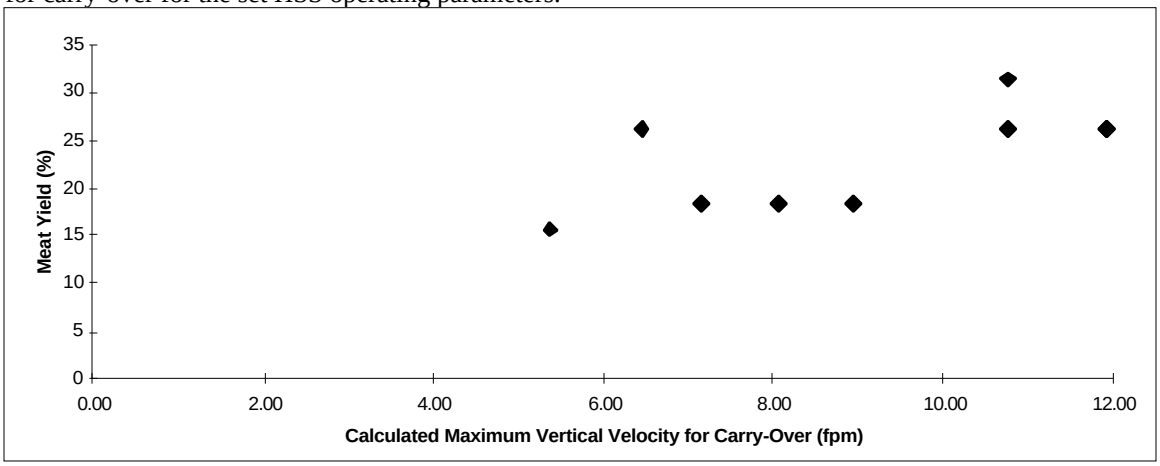


Figure 20. The measured meat yield versus the calculated maximum vertical velocity of a particle required for carry-over for the set HSS operating parameters.



$$v_v = \frac{Q\Delta h}{AL} \qquad [4.4]$$

If, during operation of the HSS, careful measurements of the percentage of meat carried out of the system and the percentage of shell carried out of the system were taken, (assuming that an equal amount of crab claws were input per square area per unit time), then the results could be used to model the system to a larger scale. Figures 18 and 19 are such plots, but are theoretical, based on the settling velocity results of Section 4.1.2. Such plots could be used to appropriately set the desired operating conditions, maximizing the percentage of meat carried over and minimizing the percentage of shell carried over, by choosing an operating velocity. Then, the system could theoretically be designed on any scale, using the relationships between vertical velocity, flow rate, settling depth, cross-sectional area, and settling length.

The measured results, from Table 19, of the HSS were used to calculate the theoretical maximum velocity for carry-over as described above. The settling depths were found from the results of Table 18. The average cross-sectional area at each flow rate was calculated using the data from Table 14, with interpolation to calculate the width at the specific measured water depth. Figure 20 shows the plot of the meat yield as a percentage versus the calculated velocity (theoretical). This plot would theoretically resemble that shown in Figure 18, however, due the large variability resulting from the relatively small sample sizes, the plot also displays large variability. However, if the improvements mentioned in section 4.4.4 were used and a larger sample size were thus appropriate, the plot of the measured results would most likely display a closer resemblance to that of Figures 18 and 19.

4.5 Dense Media Separation

The Harris Claw machine at a blue crab processing industry in Hampton, Virginia, was operated for three separate trials. In each of the three trials, a different solution was used in the "brine bath" tank of the machine as a dense media for the separation of crab claw meat and shell. In the first trial, a 30.0% (v/v) Staley 1300 corn syrup solution was used, in the second trial, a 22.5% (v/v) Staley 1300 corn syrup solution with 5.0% (w/v) salt was used, and in the third trial, the commercial brine solution (approximately 19.0% saturated salt solution) was used. The meat product derived from these tests was measured and analyzed and the wastewater from the processing tank was sampled and analyzed to allow comparisons between the processing solutions to be made.

During processing, with each trial, samples were taken of the liquid in the Harris Claw machine separation tank. Samples were taken before any crabs were processed (initial sample), after approximately 4 (out of a total 7) barrels of crab claws were processed (middle sample), and after 7 barrels of crab claws were processed. These samples were analyzed for their physical properties, such as the specific gravity and viscosity, in order to classify the separation media and to determine the effects of the physical properties on the separation of crab meat and shell. The specific gravity measurements (at room temperature) and the viscosity measurements (at room temperature) are presented in Table 27.

Table 27. Physical properties of dense media solutions.

Solution	Sample	Specific Gravity	Viscosity (CP)
30.0% corn syrup	initial	1.102	2.84
	middle	1.095	2.71
	final	1.117	3.55
22.5 % corn syrup + 5.0% salt	initial	1.122	2.41
	middle	1.134	2.48
	final	1.094	3.00
brine	initial	1.122	1.68
	middle	1.109	1.86
	final	1.138	1.73

Overall, the specific gravity of the 30.0% corn syrup solution tended to be slightly lower than the other samples, but the viscosity tended to be the highest. The viscosity of the brine solution tended to be the highest. In all samples, the final viscosity was higher than the initial viscosity, though each did not display constant trends. It was expected that the solution consistencies would vary since, during the trials, the solutions were adjusted and changed as more water, corn syrup, or salt were added and product absorbed the solution.

4.5.1 Yield

The quantity of meat product was compared to the initial weight of the crab claws processed for each trial. The results are summarized in Table 28. The meat product for each trial was categorized as either “better” meat or “swaco” meat. The swaco product is a lesser value product. The yield, expressed as a percentage, is the overall yield, or the percentage of better meat plus swaco meat out of the total quantity of crab claws processed.

Table 28. Crab claw meat yields for processing with different dense media.

Solution	Crab Claws Processed (lb)	Better Meat Product (lb)	Swaco Meat Product (lb)	Yield %
30.0% corn syrup	347	108	8	33.4
22.5% corn syrup + 5.0 % salt	347	100	6	30.5
brine	368	95	13	29.3

Overall, the yields from each solution were comparable. The yield was slightly higher for the 30.0% corn syrup solution. The brine solution had the lowest overall yield, but also contained the highest quantity of swaco meat.

The yield did not appear to be very dependent on the specific gravity, as long as the specific gravity is sufficient to achieve separation. However, as presented in Table 27, the yield did appear to increase with increasing solution viscosity.

Another measure of comparison of the yield of each solution is the protein content of the tank residue and the crab scrap. While the total quantity of each was not measured, the concentration of proteins of these wastes is some measure of the inefficiencies of each system. These measurements are listed in Table 29.

Table 29. Protein content of the solid waste products derived from processing crab claws with different dense media.

Solution	Protein Content of Tank Residue (%)	Protein Content of Crab Scrap (%)
30.0% corn syrup	14.6	12.9
22.5% corn syrup + 5.0% salt	17.8	11.1
brine	30.6	12.4

Thus, it can be seen that because the protein content of the tank residue is highest for the commercial brine bath trial, the process can be seen as the most inefficient in terms of its ability to retain the available protein. The protein content of the crap scrap is comparable for all solutions. As previously stated, the viscosity and specific gravity may be important factors affecting the meat yield.

4.5.2 Meat Product Quality

The crab claw meat product quality from each separation solution was measured in terms of the microbial quality, taste and appearance, and salt and sugar content.

Microbial Analyses

The recovered crab meat from the each of the separation solutions was tested for mesophilic aerobic plate count at 35°C, total coliforms, and fecal coliforms at 0, 4, 6, 8, 11, and 13 days from processing. The results are presented in Tables 30, 31, and 32.

Table 30. Aerobic plate count at 35°C of crab claw meat processed with dense media.

Solution	Aerobic Plate Count @ 35°C (cfu/g)					
	Day 0	Day 4	Day 6	Day 8	Day 11	Day 13
30.0% corn syrup	4.5×10^5	5.4×10^5	5.1×10^5	1.8×10^6	2.9×10^6	2.3×10^6
22.5% corn syrup + 5.0% salt	2.2×10^5	2.6×10^6	8.0×10^6	3.6×10^6	1.6×10^7	1.4×10^7
brine	7.4×10^4	8.9×10^6	2.0×10^6	1.4×10^6	8.4×10^6	5.8×10^5

Table 31. total coliform content of crab claw meat processed with dense media.

Solution	Total Coliform (MPN/g)					
	Day 0	Day 4	Day 6	Day 8	Day 11	Day 13
30.0% corn syrup	>180	520	410	300	760	TNTC
22.5% corn syrup + 5.0% salt	450	110	120	60	70	90
brine	50	13	9	13	17	31

Table 32. Fecal coliform content of crab claw meat processed with dense media.

Solution	Fecal Coliform (MPN/g)					
	Day 0	Day 4	Day 6	Day 8	Day 11	Day 13
30.0% corn syrup	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
22.5% corn syrup + 5.0% salt	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
brine	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3

The initial APC of the 30.0% and 22.5% corn syrup solution products exceeded the regulatory limit of 100,000/g, suggesting that the handling or the corn syrup solution quality should be investigated. There was fluctuation in the counts, but overall, if the shelf-life of the meat is considered as the point at which the count reaches 10^7, then the 22.5% corn syrup solution product had a shelf-life of approximately 11 days, and the 30.0% corn syrup and the brine solutions had shelf-lives slightly over 2 weeks.

The brine solution caused a reduction in both the total microbial populations and total coliforms. The sugar solutions, however, provided a sparing effect on the organisms and may have stimulated growth. Fecal coliforms were either not present or occurred in undetectable quantities. The low numbers during the 13 day storage period indicates the claws and meat were produced under sanitary conditions.

Since most mechanically produced claw meat is marketed pasteurized and frozen, the elevated total plate counts would not adversely impact shelf-life. However, large microbial populations could result in the production of detectable quantities of ammonia or ammoniacal compounds which could result in products being judged as decomposed.

Sensory Evaluation: Appearance and Taste

The appearance and taste ratings were evaluated for the HSS meat product and for hand-picked crab claw meat, both stored on ice. The evaluations were made on days 5, 8, and 13. The results are summarized in Table 33.

Table 33. Sensory preference ratings for crab claw meat processed with dense media.

SAMPLE	APPEARANCE SCORE *			TASTE SCORE *		
	Day 5	Day 8	Day 13	Day 5	Day 8	Day 13
Hand-Picked Claw	13.15^{A}	12.35^{A}	12.29^{A}	14.07^{A}	10.49^{A}	13.57^{A}
30.0% C.S.**	8.65^{B}	7.03^{B}	7.15^{B}	8.14^{B}	9.97^{A}	7.12^{B}
22.5% C.S. ** + 5.0% salt	8.96^{B}	6.36^{B}	9.33^{B}	8.65^{B}	9.95^{A}	9.06^{B}
Brine	9.25^{B}	7.47^{B}	7.72^{B}	6.45^{B}	4.62^{B}	4.86^{C}

* Score is the average score, based on a preference line location, with a maximum of 16.0 cm. Means within
a column followed by different letters (A, B, C) are significantly different ($P<0.05$)
** C.S. = corn syrup.

The statistical analysis performed on the taste panel results as presented in Table 33 yielded a number of overall observations, based on a significance level of 0.5%, and the Duncan groupings. In the appearance category, the hand-picked sample was rated as significantly better than the mechanically treated samples on each day of testing. There was no significant difference between the appearance of the treated samples on any day of testing.

The ratings for taste showed more differences. On day 5, the hand-picked sample was rated as significantly better than the treated samples. No significant difference was found between the three treated samples, although the average of the commercially treated meat product was lower than the corn syrup samples. On day 8, the hand-picked sample, the 30.0% corn syrup sample, and the 22.5% corn syrup sample were rated as having no significant difference between each other, and were rated significantly better than the commercially treated sample. On day 13, the hand-picked sample was rated as significantly better than the treated samples. The 30.0% corn syrup and 22.5% corn syrup samples were rated as having no significant difference between each other, but were rated as significantly better than the commercially treated sample. Thus, overall, the taste results indicated that the corn syrup solutions significantly improved the taste of the product as compared to the commercially treated product, though the samples were

not as good as a hand-picked claw meat. The appearance was not significantly affected by the type of treatment solution used, although mechanical treatment significantly lowered the appearance of the sample as compared to hand-picked meat.

An additional sensory analysis, a "triangle taste panel," was performed in order to compare the meat products of the different processing solutions when mixed with hand-picked crab claw meat. The machine processed crab claw meats were mixed with the hand-picked meat at a ratio of 1 to 4, and panelists were asked to determine if a difference could be detected between the mix and hand-picked claw meat on the basis of appearance and taste. The findings, based on a significance level of 0.5%, are summarized in Table 34 in the following.

Table 34. Sensory ratings to determine the difference between hand-picked crab claw meat and hand-picked crab claw meat mixed at 4 to 1 with meat processed with dense media.

Solution	0.5% significance level	
	Appearance	Taste
30.0% corn syrup	significant difference	no difference
22.5% corn syrup + 5.0% salt	no difference	significant difference
Brine	significant difference	significant difference

The product mix containing the 30.0% corn syrup meat was determined to display no significant difference from the pure hand-picked meat in terms of the taste. The meat product from the 30.0% solution had a lighter flavor than the other two solutions and added no characteristic flavor, such as salt, which could be detected. The difference, in terms of the actual numbers of panelists reporting detectable difference, was more significant with the commercially processed meat than the 22.5% corn syrup solution.

Water Phase Salt

The water phase salt content of the crab meat products processed with salt solutions were compared to the water phase salt content of hand-picked crab claw meat in order to determine the affect of the solutions on the meat product. The water phase salt content of hand-picked crab meat was 1.03%. The meat product derived from the 22.5% corn syrup plus 5.0% salt solution had a water phase salt content of 0.68%, showing no comparative increase due to the salt content of the processing solution. The product of the commercial brine solution was found to have a substantially increased water phase salt content of 4.13%. Thus, the salt content of the meat product was not found to increase with low salt content processing solutions, but showed a dramatic increase when treated with the commercial, high salt content solution. This is in agreement with the findings of the previous study by Hong (1990).

Reducing Sugars

The reducing sugar contents of the crab claw meat products were analyzed in order to determine the quantity of sugar absorbed during processing with the corn syrup solutions. The reducing sugar concentration of the meat processed in the 30.0% corn syrup solution was 49.9 mg of sugar per gram of crabmeat (5.0%). The meat processed in the 22.5% corn syrup solution had a reducing sugar concentration of 49.8 mg/g (5.0%), and the meat processed in the brine solution had a concentration of 1.03 mg/g (0.1%). These results indicated that the reducing sugar concentrations increased in the crab meat products due to processing with the corn syrup solutions, however, this increase was not proportional to the concentration of corn syrup in the processing solution. This is similar to the results found in the previous study by Hong (1990).

4.5.3 Wastewater Characterization

Wastewater samples were collected during crab claw processing with the Harris Claw machine with the different dense media solutions. Samples were collected before processing (initial sample), after approximately 4 barrels were processed (middle sample), and at the end of the trial (final sample) for each solution. A total of 7 barrels, or approximately 350 pounds, of crab claws were processed for in each trial solution. The samples were analyzed for temperature, pH, color (true and apparent), turbidity, alkalinity, five day biological oxygen demand, chemical oxygen demand (total and soluble), dissolved organic carbon, suspended solids (total and volatile), ammonia, organic nitrogen, total phosphorous, cations (sodium, potassium, calcium, and magnesium) and anions (chloride and sulfate). The results are presented in Tables 35, 36, 37, and 38 in the following and are summarized in Appendix C.

Table 35. Characterization of effluent wastewater from processing in the Harris Claw machine with different dense media.

Solution	Sample	Temperature °C	pH	True Color (Color units)	Apparent Color (Color units)	Turbidity (NTU)	Alkalinity (mg/L $CaCO_3$)	pH at 14 days
30% corn syrup	initial	25	6.09	100	190	1.0	-	4.00
	middle	25	7.40	2800	4200	88	17	4.93
	final	24	7.64	1500	6800	170	94	5.23
22.5% corn syrup + 5.0% salt	initial	26	6.18	170	290	39	-	4.46
	middle	26	7.38	950	4800	65	107	5.46
	final	25	7.75	1600	8500	137	128	5.47
brine	initial	25	7.45	75	80	2.9	62	7.40
	middle	25	8.39	650	5750	127	361	8.25
	final	24	8.36	1550	8500	316	521	8.18

As noted previously with regard to the HSS effluent in Section 4.4.3, the only effluent characteristic from Table 35 which is regulated by Virginia DEQ is the pH. The effluent pH's of the final samples were all within the required range of 6.0 to 9.0. However, the commercial salt solution caused an increase in pH compared to the other

two solutions, and this resulted in a final pH which was relatively alkaline, though acceptable under regulations.

As with the HSS effluent, the temperature of all of the effluents listed in Table 35 was within the acceptable range of 16°C to 30°C. Since there is no temperature change directly involved in the process, there is again, no reason that the temperature of the effluent wastewaters should be a concern.

The color, both true and apparent, and the turbidity again increased with the input of crab claws for processing due to the tendency for small meat and shell particles to remain in the solutions. The color was relatively unaffected by the separation solution, but the turbidity tended to be augmented due to the use of the brine solution as compared to the other solutions. This is possibly the result of the decreased yield of the brine solution, and therefore an increase in the quantity of particles remaining in suspension, and an increase in suspended particles due to the precipitation of salt.

The alkalinity also tended to increase with the increasing addition of crab claws for processing. The alkalinity was significantly higher with the brine solution effluent than with the other effluents. This is largely due to the fact that the alkalinity was measured 14 days after sampling. All alkalinity samples were stored at 4°C for 14 days, however, there was a dramatic decrease in the pH after storage for the two corn syrup solutions (as seen in the fourth and last columns of Table 35). This decrease in pH resulted in an unmeasurable or decreased alkalinity of the corn syrup wastewater samples. This decrease in pH was possibly due to anaerobic biological activity in the corn syrup samples which was not possible in the brine solution samples due to inhibition or toxicity effects of the salt.

The effluent characteristics in Table 36 indicate that the BOD_5, COD, and DOC were considerably higher for the corn syrup solutions than the commercial brine solution due to the sugar content in the syrup. The effluent TSS and VSS were also considerably higher for the corn syrup solutions, however, this was likely due to the difficulty of filtering the thick corn syrup solutions. This resulted in considerably lower

concentrations of fixed suspended solids (FSS) for the corn syrup solution as compared to the brine solutions. The FSS concentrations, in fact, increased with the concentration of salt in the solutions, and therefore, were largely due to the precipitation of salt.

Table 36. Characterization of effluent wastewater from processing in the Harris Claw machine with different dense media.

Solution	Sample	BOD_5 (mg/L)	Total COD (mg/L)	Soluble COD (mg/L)	DOC (mg/L)	TSS (mg/L)	VSS (mg/L)	FSS (mg/L)
30% corn syrup	initial	78,000	178,000	168,000	62,400	910	890	20
	middle	-	256,000	242,000	101,000	13,200	13,000	200
	final	304,000	315,000	280,000	117,000	38,600	38,300	300
22.5% corn syrup + 5.0% salt	initial	108,000	172,000	180,000	87,600	980	960	20
	middle	-	295,000	277,000	92,000	14,500	14,200	300
	final	263,000	303,000	281,000	111,000	21,000	20,500	500
brine	initial	-	3,990	-	1,760	1,560	50	1,510
	middle	-	-	-	11,220	9,800	2,140	7,660
	final	5,440	16,100	-	3,770	14,800	2,380	12,420

For the 30.0% corn syrup solution, the final soluble COD was 88% of the total COD, the final BOD_5 was 97% of the COD, and the final VSS was 99% of the TSS. For the 22.5% corn syrup plus 5.0% salt solution, the final soluble COD was 93% of the total COD, the final BOD_5 was 87% of the COD, and the final VSS was 98% of the TSS. These results indicate that the pollutant strengths of the corn syrup solutions were overwhelmingly due to soluble, organics, which are largely degradable. The brine solution effluent concentrations, in contrast, indicated that the BOD_5 was only 34% of the COD and that the VSS was only 16% of the TSS. The pollutant content of the effluent from processing with this solution, therefore, was largely resultant from non-degradable inorganics, such precipitated salt.

The DOC concentrations of the brine solution as shown in Table 36 are likely to contain some degree of error due to the fact they did not account for the effects of a precipitate which occurred in the filtered brine samples after acidification. This precipitate was measured for the middle and final samples. The precipitate from the middle sample was measured to be 8% by volume, with a solids concentration of 1.32

g/mL of precipitate, and a volatile solids concentration of 0.21 g/mL of precipitate. The final sample was found to be 4% by volume, with a solids concentration of 2.50 g/mL, and a volatile solids concentration of 0.17 g/mL.

As mentioned in Section 4.4.3, the only wastewater characteristics listed in Table 36 which are regulated by Virginia DEQ are the BOD_5 and the TSS. These are additionally of concern because, again, they are subject to the surcharges mentioned in Section 4.4.3 when discharge is to a POTW. All of the processing solutions tested yielded effluent BOD_5 and TSS concentrations which would be subject to such surcharges.

The effluent characteristics listed in Table 37 are not controlled by federal or state regulations, however, are again subject to surcharges as listed in Section 4.4.3. The surcharges are enforced for TKN concentrations above 35 mg/L and for phosphorus concentrations above 6 mg/L. The effluent concentrations for all of the studied separation solutions were found to be in excess and therefore, subject to surcharges.

Table 37. Characterization of effluent wastewater from processing in the Harris Claw machine with different dense media.

Solution	Sample	NH_3 (mg/L)	TKN (mg/L)	PO_4-P (mg/L)
30% corn syrup	initial	0.35	84	0.19
	middle	-	286	-
	final	10.7	631	51
22.5% corn syrup + 5.0% salt	initial	0.50	43	0.44
	middle	-	669	-
	final	17.0	686	36
brine	initial	0.99	51	2.2
	middle	-	429	-
	final	12.5	674	80

In general, most of the ion concentrations listed in Table 38 increased with the input of the crab claws for processing. The concentrations of potassium, calcium, magnesium, and sulfate ions were relatively unaffected by the use of different separation media. The sodium and chloride ions, however, showed a dramatic increase for the separation media which contained salt. The chloride ion concentrations of these effluents

is of concern because the high chloride ion concentrations cause toxicity to microorganisms and can render these waste streams untreatable.

Table 38. Characterization of effluent wastewater from processing in the Harris Claw machine with different dense media.

Solution	Sample	Na^+ (mg/L)	K^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)
30% corn syrup	initial	20.7	2.2	29.3	2.44	45.2	39.0
	middle	116	88	49.9	9.68	209	46.2
	final	224	218	117	22.6	445	57.3
22.5% corn syrup + 5.0% salt	initial	1,592	9.2	31.7	3.72	3,029	35.4
	middle	2,116	126	120	18.2	3,595	56.1
	final	2,096	254	113	24.0	3,661	53.5
brine	initial	72,200	24	37.4	4.22	158,273	49.8
	middle	54,800	150	67.5	15.5	128,823	54.7
	final	53,800	222	69.2	20.0	130,344	56.8

The concentrations of sodium and chloride did not vary dramatically for the 22.5% corn syrup plus 5.0% salt solution. Some variation can be attributed to the difficulty in mixing the viscous corn syrup solution in the Harris Claw machine and the need to change the mix slightly during processing because the liquid was absorbed by the product and had to be replaced. Some loss of ion concentrations could be expected due to the tendency for the salt to be retained on the meat product. With the commercial brine solution, the chloride ion concentration tended to decrease more dramatically during processing. This is most likely due to the loss of considerable quantities as the salt tended to adhere or absorb into the crab shell and meat particles. This is evidenced by the dramatic increase in the salt concentrations of the crab meat product processed with the commercial salt solution (Section 4.5.2).

Table 39 indicates the effluent loadings from the waste stream associated with each of the separation media. The BOD_5 has no set limit for existing sources, however, the waste streams from each processing solution exceed the new source limits (both average and maximum limits) for BOD_5, and both the new source and existing source limits for TSS. This indicates the necessity for treatment studies, and as indicated previously, the excessive chloride ion concentration of the salt solutions are not amenable

to biological treatment. The corn syrup solutions, however, displayed an excessive organic content, but is largely readily degradable.

Table 39. Effluent loadings from processing with different dense media in the Harris Claw machine. Values are expressed in pounds per 1,000 pounds of product.

Solution	Sample	BOD_5 (lb/1000lb)	COD (lb/1000lb)	TSS (lb/1000lb)	VSS (lb/1000lb)	NH_3 (lb/1000lb)	TKN (lb/1000lb)	PO_4-P (lb/1000lb)	Cl^- (lb/1000lb)
30% corn syrup	final	4,154	4,305	527	523	0.15	8.6	0.70	6
22.5% corn syrup + 5.0% salt	final	3,933	4,532	314	307	0.25	10.3	0.54	55
brine	final	80	236	217	35	0.18	9.9	1.2	1,913

4.6 Comparison of Final Product from Processed Crab Claws

Crab cakes, a final product, were prepared from the crab claw meat products from processing with the two corn syrup solutions, the commercial brine solution, the HSS, and from hand-picking operations. The crab cakes were prepared using the same recipe for each meat sample type and were compared on the basis of appearance and taste.

Table 40. Sensory preference ratings for crab cakes from meat products processed with various methods.

SAMPLE	APPEARANCE SCORE *	TASTE SCORE *
Hand-Picked Claw	10.75^A	9.38^A
HSS	8.75^B	8.22^A
30.0% C.S.**	9.40^A	9.81^A
22.5% C.S. ** + 5.0% salt	8.82^B	9.40^A
Brine	9.07^A	5.45^B

* Score is the average score, based on a preference line location, with a maximum of 16.0 cm. Means within a column followed by different letters (A, B, C) are significantly different ($P<0.05$)

** C.S. = corn syrup.

The results shown in Table 40 were statistically analyzed with a 0.5% significance level. The analysis indicated that in the appearance category, the hand-

picked product, the 30.0% corn syrup product, and the brine product all received better scores than the 22.5% corn syrup product and the HSS product. There was no significant difference between the hand-picked product, the 30.0% corn syrup product, and the brine product, and there was no difference between the 22.5% corn syrup product and the HSS product.

In the taste category, the hand-picked product, the HSS product, the 30.0% corn syrup product, and the 22.5% corn syrup product were rated as having no significant difference between them. All four products were rated as significantly better than the brine product.

4.7 Overall Comparison of Separation Methods

It is important to note that the results discussed in the previous sections, specifically the yield, biological analyses, and wastewater characterizations are presented in order to give an approximate range of the parameters. These parameters are expected to vary significantly depending on the location and season of a particular harvest and the quality controls applied to the crab processing. However, it is anticipated that any future studies would observe the same general trends.

In terms of the yield, the investigated alternative separation methods were found to be comparable to the standard brine bath. The reported yields of the hydraulic separator system for all of the different operating conditions varied from 12% to 32%. The lower range of yields is significantly less than the yields reported for the various dense media, 33.4% for the 30.0% corn syrup solution, 30.5% for the 22.5% corn syrup solution, and 29.3% for the brine solution, however, it is relatively comparable to the Harris Claw brine bath yield of approximately 15% for the same batch of crab claws. Overall, the corn syrup solutions were found to have improved yield as compared to the brine bath, and the HSS, was found to also be capable of improving yield, if the operating conditions were to be optimized on a full-scale system.

The microbial analyses of the meat product derived from the different separation methods indicated that the shelf life of the products of the new methods would most likely be less than the brine bath. However, the shelf-life could be improved by pasteurization.

The sensory evaluations of the meat products indicated that the corn syrup solutions improved the flavor of the crabmeat as compared to the brine solution. The meat product of the HSS was not found to be improved because the water washed out the characteristic crab flavor, however, the sensory evaluation of the crab cakes indicated that the flavor of the final product was improved. The crab cakes made from the meat processed in the corn syrup solutions also had improved flavor as compared to the brine bath.

The wastewater characterization study results showed that the corn syrup solution effluents had significantly higher BOD_5 concentrations, 304,000 mg/L for the 30.0% corn syrup solution and 263,000 mg/L for the 22.5% corn syrup solution, than the brine solution effluent concentration of 5,440 mg/L. The TSS was also significantly higher, 38,600 mg/L for the 30.0% corn syrup solution and 21,000 mg/L for the 22.5% corn syrup solution as compared to 14,800 mg/L for the brine solution. These concentrations are of particular concern for processing plants which already meet the current regulations. However, in the case of a new processing plant, or in the event that more stringent standards are passed, the untreatability of the brine solution effluent due to the high chloride ion concentration of 130,344 mg/L and low percentage of degradable organics (BOD_5 was only 34% of the COD and VSS was only 16% of the TSS) becomes a concern. While the pollutant strength of the corn syrup solution effluents is very high, the treatability of the effluent is also high (BOD_5 was 97% of the COD and the VSS was 99% of the TSS for the 30.0% corn syrup solution and BOD_5 was 87% of the COD and VSS was 98% of the TSS for the 22.5% corn syrup solution), making the corn syrup solutions more viable processing options.

The HSS effluent loadings, as larger-scale estimates, were found to contain a BOD_5 of 61 to 97 lb/1,000 lb and a TSS of 14 to 20 lb/1,000 lb. This is comparable to the output of 80 lb BOD_5/1,000 lb and 217 lb TSS/1,000 lb for the brine solution. The effluent of the HSS was found to consist of relatively degradable matter (BOD_5 was 55 to 70% of the COD and VSS was 77 to 100% of the TSS) and contained between 29 and 33 lb Cl^-/1,000 lb as compared to the brine solution which contained 1,913 lb Cl^-/1,000 lb, making the treatability of the HSS effluent a significant improvement.

It is also important to note that the following overall changes in other waste streams and overall wastewater quantities. With regards to effluent characterization, only the brine bath effluent was measured. The shell waste effluent was found by Virginia Polytechnic Institute and State University (1995) to contain a chloride concentration ranging from 100,160 mg/L to 112,170 mg/L, and the claw room cleanup effluent concentration was approximately 26,000 mg/L. The use of the corn syrup solutions and the HSS for processing would reduce these chloride concentration to yield more treatable waste streams. Similarly, the claw meat conveyor wash effluent was found to contain a chloride concentration ranging from 3,000 mg/L to 15,000 mg/L in the study by Virginia Polytechnic Institute and State University (1995). The use of the corn syrup solutions would again reduce these concentrations and increase the waste stream treatability, and the use of the HSS would effectively eliminate the need for this waste stream. The elimination of the additional waste stream would save 1,800 gallons to 9,715 gallons of wastewater per day of production (Virginia Polytechnic Institute and State University, 1995).

The overall cost of each of the processing media should also be considered as a comparison between the various methods. The cost of the corn syrups needs to be compared to the cost of the salt, but also the disposal costs for the wastewaters and any change in product yield and price should be examined for a thorough cost comparison. The HSS would eliminate the purchasing costs for chemicals.

CHAPTER 5. CONCLUSIONS

The conclusions derived from this study are as follows:

1. A hydraulic separator system (HSS) was designed and tested as an alternative to the Harris Claw machine for crab claw meat processing. The measured yields of the system, on a pilot-scale study, varied significantly for different operating conditions, but were comparable to the approximated yield from processing the same batch of crab claws in the Harris Claw machine.
2. Two alternative corn syrup solutions, a 30.0% (v/v) solution and a 22.5% (v/v) solution with 5.0% (w/v) salt, were tested in full-scale trials as possible alternative separation media. The yields were comparable, but slightly higher than the yield of the brine solution typically used in the Harris Claw machine.
3. The meat product from the HSS was found to have a shelf-life of approximately one week. This was significantly lower than the approximate shelf life of 2 weeks for the meat products of the 30% corn syrup solution, the 22.5% corn syrup solution, and the brine solution. However, this could be improved by additional treatment of the meat product; e.g., pasteurization.
4. The meat produced in the HSS had a flavor which was rated significantly lower than a hand-picked claw meat reference sample. The meats produced in the corn syrup solutions were also generally rated lower than the hand-picked sample, but with less difference in score than the HSS meat. The meats produced in the corn syrup solutions were rated higher than the meat produced in the brine solution.
5. Wastewater loadings from the HSS were found to be similar in strength to the loadings from the brine solution processing; however, the HSS eliminates the problems associated with the high chloride ion concentrations of the Harris Claw

brine solution. The HSS also reduces water consumption. The BOD_5 of the corn syrup solution was, of course, very high; much greater than that of the HSS or brine effluents.

6. A final product, crab cakes, was made from the meat products of the alternative separation methods and a sensory evaluation was performed. The results indicated that the tastes of the HSS product, the 30.0% corn syrup product, and the 22.5% corn syrup product were significantly better than the taste of the brine solution product.
7. The HSS is recommended for future, full-scale studies because it can potentially improve the treatability of the effluent wastewater, reduce the overall water consumption, and generate crab claw meat more valuable than the currently used Harris Claw system. Sugar could be added later to the claw meat separated by the HSS in the event that consumers preferred a sweeter taste.

CHAPTER 6. REFERENCES

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APPENDIX A
HSS DESIGN CALCULATIONS

Assumptions

H = 8”
T = 5”
V = 0.5 fps
v_s = 0.25 fps

Calculations

Flow rate:

$$Q = \left(\frac{2}{3}\right) HTV$$

$$Q = \left(\frac{2}{3}\right)\left(\frac{8}{12}\right) ft \left(\frac{5}{12}\right) ft \left(0.5 \frac{ft}{s}\right)$$

$$Q = 0.0926 \frac{ft^3}{s}$$

$$Q = 41 \text{ gpm}$$

Control Section:

$$H + \frac{V^2}{2g} = d_c + \frac{v_c^2}{2g} + 0.1\frac{v_c^2}{2g}$$

$$d_c = \frac{v_c^2}{g}$$

$$H + \frac{V^2}{2g} = 2\frac{v_c^2}{2g} + \frac{v_c^2}{2g} + 0.1\frac{v_c^2}{2g} = 3.1\frac{v_c^2}{2g}$$

$$\frac{v_c^2}{2g} = \frac{1}{3.1}\left(H + \frac{V^2}{2g}\right) = \frac{1}{3.1}\left(\frac{8}{12} ft + \frac{\left(0.5 \frac{ft}{s}\right)^2}{2\left(32.2 \frac{ft}{s^2}\right)}\right)$$

$$\frac{v_c^2}{2g} = 0.22 \text{ ft}$$

$$d_c = 2(0.22 \text{ ft}) = 0.44 \text{ ft} = 5.3 \text{ inches}$$

Width (control section):

$$v_c = \sqrt{d_c (2g)}$$

$$v_c = \sqrt{(0.22\ ft)(2)\left(32.2\ \frac{ft}{s^2}\right)}$$

$$v_c = 3.76\ \frac{ft}{s}$$

$$a = \frac{Q}{V}$$

$$a = \frac{0.093\ \frac{ft^3}{s}}{3.76\ \frac{ft}{s}}$$

$$a = 0.025\ ft^2$$

$$w = \frac{a}{d_c}$$

$$w = \frac{0.025\ ft^2}{0.44\ ft}$$

$$w = 0.056\ ft = 0.67\ in$$

Length:

$$L = \frac{HV}{v_s}$$

$$L = \frac{\left(\frac{8}{12}\ ft\right)\left(0.5\ \frac{ft}{s}\right)}{0.25\ \frac{ft}{s}}$$

$$L = 1.3\ ft = 16\ in$$

APPENDIX B.

SAMPLE SENSORY EVALUATION FORMS

Name: _____

Please evaluate all of the crabmeat samples using the reference sample as the standard. Mark the intensity of each attribute by placing a hash mark at the correct location on the line. Place the corresponding sample identification number above each hash mark. During the tastings do not swallow any of the samples. Expectorate in the cup provided. Use the cracker and water to cleanse your palate between samples. Wait approximately 1 minute between each sample. Thank you for your participation.

_____

Poor Appearance Excellent Appearance

_____

Poor Taste Good Taste

Comments:

Name _____ Date _____

TASTE PANEL

ONE OF THE SAMPLES IS DIFFERENT FROM THE OTHER TWO. PLEASE PLACE A MARK BESIDE THE DIFFERENT SAMPLE.

A. Appearance - View the samples and note the different sample

THE DIFFERENT SAMPLE IS:

Sample A _____

Sample B _____

Sample C _____

B. Taste - Taste the samples and note the different sample

THE DIFFERENT SAMPLE IS:

Sample A _____

Sample B _____

Sample C _____

The sample treatment is (I)_____; (II)_____; (III)_____.

Sample Number _____

APPENDIX C. CRAB CLAW PROCESSING WASTEWATER CHARACTERIZATION

Parameter	Sample [1]	HSS [2]	30.0% corn syrup [3]	22.5% corn syrup + 5.0% salt [3]	Brine [3]
Temperature (°C)	1	18.5	25.0	26.0	25.0
	2	17.0	25.0	26.0	25.0
	3	16.0	24.0	25.0	24.0
pH	1	7.06	6.09	6.18	7.45
	2	7.13	7.40	7.38	8.39
	3	6.86	7.64	7.75	8.36
True Color (color units)	1	10	100	170	75
	2	15	2,800	950	650
	3	15	1,500	1,600	1,550
Apparent Color (color units)	1	20	190	290	80
	2	25	4,200	4,800	5,750
	3	30	6,800	8,500	8,500
Turbidity (NTU)	1	12	1.0	39	2.9
	2	14	88	65	127
	3	7	170	137	316
Alkalinity (mg/L as $CaCO_3$)	1	39	-	-	62
	2	68	17	107	361
	3	40	94	128	521
BOD_5 (mg/L)	1	66	7,800	108,000	-
	2	68	-	-	-
	3	40	304,000	263,000	5,400
Total COD (mg/L)	1	120	178,000	172,000	3,990
	2	137	256,000	295,000	-
	3	111	315,000	303,000	16,100
Soluble COD (mg/L)	1	113	168,000	180,000	-
	2	109	242,000	277,000	-
	3	80	280,000	281,000	-
DOC (mg/L)	1	42.2	62,400	87,600	1,560
	2	38.5	101,000	92,000	9,800
	3	29.9	117,000	111,000	14,800
TSS (mg/L)	1	21	910	980	1,560
	2	14	13,200	14,500	9,800
	3	13	38,600	21,000	14,800
VSS (mg/L)	1	21	890	960	50
	2	12	13,000	14,200	2,140
	3	10	38,300	20,500	2,380
NH_3 (mg/L)	1	0.24	0.35	0.50	0.99
	2	0.30	-	-	-
	3	0.24	10.7	17.0	12.5
TKN (mg/L)	1	2.4	84	43	51
	2	3.0	286	669	429
	3	7.6	631	686	674
PO_4-P (mg/L)	1	1.0	0.19	0.44	2.2
	2	0.6	-	-	-
	3	0.8	51	36	80

Parameter	Sample [1]	HSS [2]	30.0% corn syrup [3]	22.5% corn syrup + 5.0% salt [3]	Brine [3]
Na^+	1	13.5	20.7	1,592	72,200
(mg/L)	2	14.7	116	2,116	54,800
	3	13.4	224	2,096	53,800
NH_4^+	1	7.7	-	-	-
(mg/L)	2	8.9	-	-	-
	3	6.8	-	-	-
K^+	1	7.8	2.2	9.2	24
(mg/L)	2	8.9	88	126	150
	3	6.8	218	254	222
Mg^{2+}	1	1.5	2.44	3.72	4.22
(mg/L)	2	1.5	9.68	18.2	15.5
	3	1.5	22.6	24.0	20.0
Ca^{2+}	1	26.6	29.3	31.7	37.4
(mg/L)	2	26.0	49.9	120	67.5
	3	27.2	117	113	69.2
Cl^-	1	31.1	45.2	3,029	158,273
(mg/L)	2	33.2	209	3,595	128,823
	3	31.4	445	3,661	130,344
SO_4^-	1	35.6	39.0	35.4	49.8
(mg/L)	2	35.5	46.2	56.1	54.7
	3	35.6	57.3	53.5	56.8
BOD_5	1	61	-	-	-
(lb/1,000 lb)	2	97	-	-	-
	3	-	4,154	3,933	80
COD	1	112	-	-	-
(lb/1,000 lb)	2	138	-	-	-
	3	-	4,305	4,532	236
TSS	1	20	-	-	-
(lb/1,000 lb)	2	14	-	-	-
	3	-	527	314	217
VSS	1	20	-	-	-
(lb/1,000 lb)	2	12	-	-	-
	3	-	523	307	35
NH_3	1	0.2	-	-	-
(lb/1,000 lb)	2	0.3	-	-	-
	3	-	0.15	0.25	0.18
TKN	1	2.2	-	-	-
(lb/1,000 lb)	2	3.0	-	-	-
	3	-	8.6	10.3	9.9
PO_4-P	1	0.9	-	-	-
(lb/1,000 lb)	2	0.8	-	-	-
	3	-	0.70	0.54	1.2
Cl^-	1	29	-	-	-
(lb/1,000 lb)	2	33	-	-	-
	3	-	6	55	1,913

[1] For HSS, samples 1, 2, 3, refer to trials 1, 2, 3. For 30.0% corn syrup, 22.5% corn syrup, and brine, samples 1, 2, 3 refer to initial, middle, final samples.
[2] The HSS trials correspond to 1.52 lbs of crab claws processed, and corresponding product yields.
[3] The trials correspond to approximately 350 lbs of crab claw processed, and corresponding product yields.