A High-Speed Fish Evisceration System (FES) for Bycatch and Underutilized Fish Stocks

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ABSTRACT—*Development of a high-speed and high-yield water-powered fish evisceration system (FES) to efficiently preprocess small fish and bycatch for producing minced fish meat is described. The concept of the system is propelling fish in a stream of water through an arrangement of cutting blades and brushes. Eviscerated fish are separated from the viscera and water stream in a dual screen rotary sieve. The FES processed head off fish, weighing 170–500 g, at the rate of 300 fish/min when used with an automatic heading machine. Yields of mince produced from walleye pollock,* Theragra chalcogramma*; and Pacific whiting,* Merluccius productus*; processed by the FES ranged between 43% and 58%. The maximum yield of minced muscle from fish weighing over 250 g was 52%, and the yield of mince muscle from fish weighing less than 250 g was 58%. Test results indicated that surimi made from minced meat recovered from fish processed with the FES was comparable in quality to commercial grade surimi from conventional systems. Redesigned for commercial operation in the Faeroe Islands (Denmark), the system effectively processed North Atlantic blue whiting,* Micromesistius poutassou*, with an average weight of 110 g at a constant rate of 500–600 fish/min, producing deboned mince feeding a surimi processing line at a rate of 2.0 t/h. Yields of mince ranged from 55% to 63% from round fish. Surimi made from the blue whiting mince meat produced by the FES was comparable to surimi commercially produced from blue whiting by Norway and France and sold into European markets.*

Introduction

The 1996 reauthorized Magnuson-Stevens Fishery Conservation and Management Act (PL 94-265) defines bycatch as fish harvested in a fishery which are not sold or kept for personal use and includes economic and regulatory discards. Economic discards are targeted fish that are not retained because they are undersized, the wrong sex, or of poor quality (Benaka and Dobrzynski, 2004).

Consideration of economic discards is important because they represent that portion of the targeted catch that are unused or are underutilized, and they result in an economic loss to the fisheries, though still contributing to the total allowable catch. Alverson et al. (1994) estimated that discards in the midwater trawl fishery for walleye pollock, *Theragra chalcogramma,* in the Bering Sea Aleutian Islands (BSAI) and Gulf of Alaska to be about 6% of the landed weight of about 1.05 million t (NMFS, 1994).

Regulations were issued in 1997 requiring that by 1998 all processors at sea in the BSAI retain all Pacific cod, *Gadus macrocephalus,* and pollock bycatch and by 2003 all rock sole, *Lepidopsetta bilineata;* and yellowfin sole, *Limanda aspera* (NPFMC, 1998). An improved retention and utilization program had already been approved as part of the Fisheries Management Program in 1996, addressing the larger issue of about 273,000 t/yr of groundfish discards in the BSAI fisheries, with the bulk of the discards classed as economic discards (NPFMC,1998). Prior to these regulations, undersized bycatch of directed species could be discarded if not economically feasible to process into products for human consumption.

The commercial fishery for Pacific whiting, *Merluccius productus*, on the U.S. Pacific coast, lands about 200,000 t/yr (NMFS, 2007). About 70% of the catch is harvested and processed at sea, and the remainder processed by shore-based operations (NMFS, 1996, 1999). An estimated 1,800 t of hake were discarded from this fishery in 2005.[1]

As in the pollock fishery, specialized processing equipment is used to process the fish into edible products. Filleting machines, designed specifically to process round fish, such as pollock, whiting and cod, are usually calibrated to be size-specific and will perform optimally when fish are of uniform size (NMFS, 1988). Generally, fish longer than 38 cm are selected for filleting, as they result in a better economic yield per effort using current processing technology.

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[1]Estimated 2005 Discard and total catch of selected groundfish species. James Hastie, Fishery Resource and Monitoring Division, Northwest Fisheries Science Center, 2725 Montlake E. Blvd., Seattle 98112 and Marlene Bellman, Pacific States Marine Fisheries Commission, 205 SE Spokane St., Suite 100, Portland OR 97202. Unpubl. rep., Dec., 2006, available online at www.nwfsc.noaa.gov/research/divisions/fram/observer/datareport/docs/totalmortality2005_final.pdf.

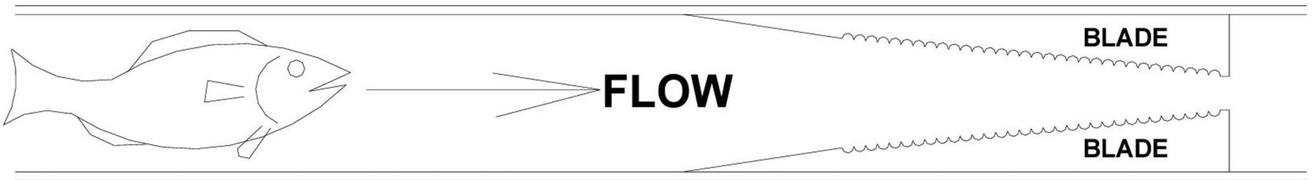

Figure 1.—Cross section of cutting module showing two of six blades.

For example, whiting of an average length of 41 cm will yield about 30% of body weight in skin off, bone out fillet meat whereas, a 47 cm fish will yield about 40% (NMFS, 1988). Similar results would be expected for pollock and cod. In a 1998 NMFS observer sampling of pollock landings on at-sea-processing vessels, approximately 10% of the fish sampled were 38 cm or less in length (Berger[2]). About 1.1 million t of pollock were landed in 1998 (NMFS, 1999). Similarly, it is estimated that about 13% of the Pacific coast whiting landings would be made up of <38 cm fish (Dorn[3]).

In addition to undersized bycatch of foodfish, small fish are harvested for reduction that could be used directly for human food if processing economics could be improved for the recovery of edible muscle from these fish. Accordingly, we initiated studies to develop a processing system designed to recover edible meat economically from underutilized fish and bycatch such as pollock, whiting, and Pacific cod.

Volume throughput is the limiting factor for the economical production of minced fish meat from many underutilized fish. Volume is limited by the mechanical conveying design of current fish processing machinery that uses belts and pulleys to move fish. The new process described here uses a stream of water to entrain fish and move them rapidly through cutting and evisceration modules located in a pipe. By eliminating all mechanical conveying parts, the volume of processed fish is increased to economically viable levels.

Materials and Methods

Process Description

This is an entirely new concept for the processing of fish. Initial studies had to begin with the design, selection of components, assembly, and testing of the basic elements of the system. The basic concept of this process is "shooting" fish down a pipe in a stream of water (Fig. 1–3). The target ratio of water to fish was 17 parts water to one part fish wt/wt. Fixtures in the pipe orient the fish along the center of the pipe and through an arrangement of cutting blades and cleaning brushes.

At a flow rate of 2,000 L/min the fish were accelerated to a velocity of 8.7 m/s in the 7 cm diameter cutting section to facilitate passage through the cutting knives. The lengthwise cut fish then passed through circular sections with evenly spaced inward bristles that removed soft tissue such as viscera and portions of the head.

The stream of water containing the eviscerated fish and viscera exits the pipe to a rotary coarse sieve that separates the eviscerated fish from the water and secondary material. The water containing viscera, eyes, gill pieces, and other nonedible portions of the fish pass through the coarse sieve and fall outward to a fine-mesh sieve that is concentric to the coarse sieve. This outer screen removes the offal and recovers water for recycle to the system and eventual discharge.

For some fish species under 300 g, it is not necessary to remove the heads to produce usable deboned mincemeat. This allows a much greater volume of small fish to be processed. For fish above 300 g, and fish with bony heads or discoloration in the head, partially cutting the head off in front of the gill plate increases mince flesh quality. Figure 1 is a side view showing a fish flowing in a circular pipe. Figure 2 is a view along the axis of the circular pipe showing a cross-section of the fish and the six knives for cutting the fish.

A Cornell 8NHPP pump (Cornell Pump, Portland, Oreg.)[4] was used in this study. The pump has an 8-in diameter suction and discharge, and is capable of flows up to 5,000 L/min. The pump is used in the food industry to transfer fruit, vegetables, fish, and other large food products with minimum damage.

A custom aluminum feed tank directs fish and water to the pump through a short section of pipe. The tank has an overflow trough that captures and pipes used water to discharge. Makeup water, representing about 10% of pump process water, is continuously added to maintain water quality. Recycled water is returned to the feed tank from the rotary sieve described below. Fish for evisceration are poured directly into the tank by hand or conveyor. No fish orientation is required, eliminating the need for a worker at this stage.

Water and fish discharged from the pump pass through a custom stainless-steel reducer that constricts the flow from 20 cm to 10 cm feeding into the cutting section containing the knives. Reducing the diameter of the pipe to the cutting section accelerates flow and provides the power that drives the fish through the cutting knives. The knives, which are adjustable, are set inward

[2]Berger, J. Resource Ecology and Fisheries Management Division, NOAA, NMFS, AFSC, 7600 Sand Point Way N.E., Seattle, WA 98115. Unpubl. data, 2001.

[3]Dorn, M. Resource Ecology and Fisheries Management Division, NOAA, NMFS, AFSC, 7600 Sand Point Way N.E., Seattle, WA 98115. Unpubl. data, 2001.

[4]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

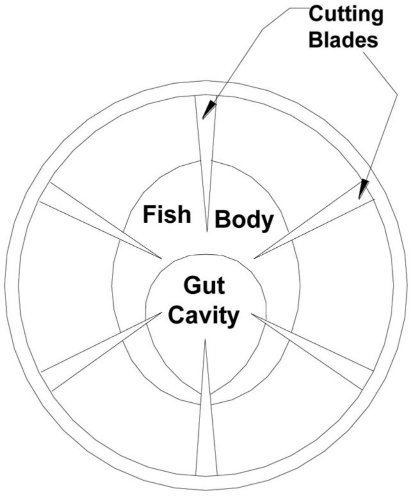

Figure 2.—Axial view of fish mid-body cross section in cutting blades.

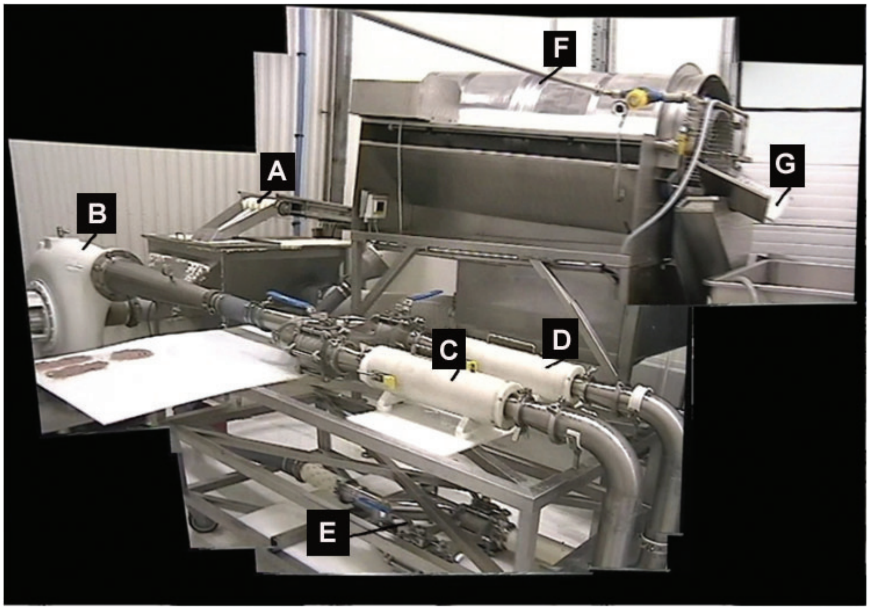

Figure 3.—Water Powered Fish Evisceration System and components: A) Conveyor for feeding fish to water tank and pump inlet below. B) Cornell pump showing discharge reducer sending fish to cutting sections. C) Cutting section containing knives for slicing fish. This section is in use indicated by the open position of the valve handle. D) Secondary cutting section. Flow is off indicated by position of valve handle. These cutting sections can be turned on or off and quickly removed for maintenance or adjustment. E) Brush sections and valves. These can be turned on or off and quickly removed for maintenance or adjustment. F) Rotary sieve for separating cleaned fish from viscera and water stream. G) Eviscerated fish discharge chute.

along the cutting path to the final depth depicted in Figure 2.

The function of the cutting section is to slice the fish lengthwise along six lines. The belly cavity is completely cut open by a minimum of two knives to expose and remove the viscera. For small head-on fish, the knives split the skull for gill removal. Remaining cuts through the skin and muscle of the fish expose more surface area for better recovery of minced muscle during deboning.

After splitting, the fish enter a section of pipe with brushes and bristles. As the fish pass through this section, viscera and soft tissue in the belly cavity are loosened and removed. A flexible 10 cm hose carries the split and eviscerated fish and water from the cutting and brushing sections to a separation sieve. A double drum rotary sieve is used to separate eviscerated fish, recover viscera and waste, and capture sieved water for recycling or discharge.

The coarse inner drum consists of a cylinder of parallel bars with 1–3 cm openings to separate eviscerated fish from the water stream and discharge them to the processing line feeding deboning equipment. The water and viscera stream pass to the outer concentric drum with a 20-mesh screen where viscera and waste are captured and sent to the offal stream. Screened water is captured in a collection pan and recycled to the pump feed tank or discharged. A high capacity spray bar continuously cleans the outer 20-mesh screen. The spray water continuously refreshes the recycled water to limit build-up in concentration of blood from the fish.

Pilot Production Measurements

For pilot production tests, from 1 to 4 t of fish were used. Fish were weighed on host production plant scales in tared fish totes that held up to 600 kg. Tared 20 L buckets were used to weigh heads, viscera, processed fish, or recovered mince on host plant product scales for yield data.

Fish Head Removal

In tests measuring the efficiency of processing head-off fish, three machines were used. For pollock, a Baader model 417 (Baader North America, Auburn, Wash.) was used. For ocean caught Pacific whiting, a pocket belt with head saw arrangement was used. These two head-cutting machines required one to three operators to orient fish into the machines. A Baader model 424 combined with an “OTTO” fish feeding machine (Neptune Dynamics Ltd., Richmond, B.C., Can.) was used to process smaller Pacific whiting from inshore waters.

Mince Meat Recovery

For pollock, a Baader 699 meat separator with 3 mm openings was used. For all Pacific whiting, a Toyo model 405 (Toyo Suisan Kikai Co., Ltd., Osaka, Jpn.) with 3 mm openings was used. North Atlantic blue whiting mince, *Micromesistius poutassou,* was recovered with a Sepematic 2000 (Modernpack Hoppe GmbH, Bergisch Gladbach, Ger.) with 3 mm openings.

To measure the yield of minced meat from eviscerated fish all loose meat was cleaned from the surfaces of the perforated drum. Weighed batches of fish were fed to the meat separator, and minced meat was collected and weighed for yield calculation.

Surimi Manufacture and Testing

Surimi is purified muscle made by washing and straining minced meat to remove fat, soluble protein, and connective tissue. Two processes were used to produce commercial-grade frozen surimi dependent on the production equipment of the host processing plants visited during trials of FES.

One surimi process, based on traditional Japanese manufacture, was used for pollock and ocean-caught Pacific whiting (Lin, 2005). The newer decanter process was used to make surimi from inshore-caught Pacific whiting as described by Babbitt et al. (1993). Surimi quality evaluation was conducted along guidelines by Babbitt and Reppond (1988). The fold test (AFDF[5]) was used for quick evaluation of cooked surimi samples.

Concept Scale-up and Testing

This is an entirely new concept for the processing of fish. Equipment development and pilot studies were conducted at the NMFS Northwest Fisheries Science Center in Seattle and at commercial fish-processing plants in Alaska, Oregon, and British Columbia. In trials conducted in commercial fish processing plants, the experimental results could be compared to the commercial operations using fish from the same landings being processed at the time.

Important economic metrics measured were product yield, volume throughput, and the quality of surimi made from FES. The information from these studies was used to construct a commercial FES for the preparation of North Atlantic blue whiting for surimi production. In-plant production tests were limited and were coordinated with the host facility based on in-season processing schedule to not interfere with the facility. Operation of FES also depended on fishing conditions to provide raw material of similar quality to commercial production for comparison.

For the microbiological assessment of surimi produced from whiting processed by the FES in Canada, ready-made 3M Petrifilm Products (St. Paul, Minn.) that contain standard methods nutrients and indicators that facilitate colony enumeration were used. Both aerobic and coliform counts were made.

Chemical and Physical Properties

Measurement of pH, gel strength, moisture, brix, and visual defects of surimi made from pollock and whiting processed by the FES were made according to the surimi industry accepted methods described by Babbitt and Reppond (1988), the AOAC (1985), and AFDF[5].

System Development

The first evisceration system was initially assembled at the NMFS Northwest Fisheries Science Center in Seattle, Wash., where preliminary tests were made. Small batches of fresh 250–400 g Pacific whiting were processed to establish operational parameters such as flow rate, knife settings, and bristle-style brushes to produce acceptably eviscerated fish. At completion of the initial tests, the prototype system was shipped to Kodiak, Alaska, and set up in the Alaska Pacific Seafood's (APS) processing plant for further testing.

Experimental Results and Discussion

Pollock Trials

Average fish size for walleye pollock landed in Kodiak is in the 900–1,000 g range. Plants with automated filleting machines adjusted for fish of this size cannot efficiently process pollock under 500 g, which are subsequently sent to reduction. These discarded fish required head removal for evisceration in the FES. Batch trials using fish that were headed between the eye and edge of gill plate yielded > 95% fish fully eviscerated and suitable for further processing to minced meat.

Surimi Experiment

To determine if fish processed with the FES were suitable for surimi production 1,000 pollock with an average weight of 495 g, normally destined for reduction, were processed to surimi. Heading removed 34% of the fish weight. All fish were eviscerated in 4.5 min for a throughput of 222 fish/min and weight of 72 kg/min. Evisceration was complete or satisfactory for all of the fish. Headed and eviscerated fish represented 59.8% of beginning round fish weight.

The fish were transferred to a conveyor feeding into the surimi production plant in the same manner as regular plant production. Mince meat yield measurements from round fish processed with the FES were 52%. The mince was examined by the lead surimi operator for the plant and judged to be as good as or better than mince produced by the plant for regular production.

The minced meat was washed, drained, and refined before final dehydration in a 300 mm diameter screwpress. At this point the final volume of processed fish meat was not large enough to completely pass through the screwpress resulting in partially dewatered final product that had higher moisture content than commercial surimi. Nevertheless, the fish meat was transferred to the blending and packing line where it was mixed with cryoprotectants (sugar, sorbitol, phosphates), extruded into 10 kg blocks, and frozen.

Samples of the frozen FES surimi were subsequently evaluated at the Fisheries Industrial Technology Center of the School of Fisheries and Ocean Science, University of Alaska Fairbanks (FITC), in Kodiak and also by the APS quality control staff (Table 1). Evaluation of the higher moisture content experimental surimi (almost 80%) made it difficult to compare with standard surimi product which would have a moisture content of about 75% and correspondingly higher protein content.

High water content affects both firmness (stress) and elasticity (strain). The L* color scores for whiteness exceeded 76 which is the value for top grade

[5]AFDF. Alaska Fisheries Development Foundation. 1987. Surimi. It's American now. Project summary 1982–1987. Anchorage, AK.

Table 1.—Properties of surimi made from walleye pollock processed by water evisceration.

Sample	Moisture surimi	Cook temp. (°C)	Stress (g)	Strain (cm)	GS[1] (g) (cm)	L*[2]	Defects[3]	Fold[4] test
FITC[5]	79.7	90	191	1.21	234	76.7	NA[6]	NA
		25/90[7]	247	1.29	319	78.1	NA	NA
		60/90			Soft	78.7	NA	NA
APS[8]	NA	90	154	1.18	182	79.3	7	5+

[1]GS = Gel Strength.
[2]L value describes whiteness; b value describes yellow/blue on the Hunter scale.
[3]Defects describe degree of contamination on a scale of 1 – 10 where 10 means no contamination.
[4]Fold test rating based on a scale of 1–5 where 5 is the highest number of folds.
[5]FITC = Fisheries Industrial Technology Center.
[6]NA = Not analyzed.
[7]Single and dual cooking temp determine gelling.
[8]APS = Alaska Pacific Seafoods.

Table 2.—Summary of average minced meat yields from walleye pollock, Pacific whiting, and North Atlantic blue whiting (NABW).

Date	Location	Fish wt. avg. (g)	Species	Head off	Yield (%)
Sept. 98	Alaska	495	Pollock	Yes	52
March 99	Canada	220	Whiting	No	47
July 99	Oregon	325	Whiting	Yes	44
Sept. 99	Oregon	340	Whiting	Yes	43
March 00	Canada	360	Whiting	Yes	45
March 01	Canada	170	Whiting	No	58
March 01	Canada	280	Whiting	Yes	50
Jan. 04	Faeroe Isl.	115	NABW	No	55 to 63

SA surimi. The defects (skin, bone, impurity) score was 7 on a scale of 10 assessed by the plants quality control department.

Test results in Table 1 indicated that under steady production conditions, it would be expected that mince produced from headed and water eviscerated fish would produce surimi with impurity and color scores comparable to higher grade surimi. The high moisture content of the test surimi resulted in low gel strength (GS) values.

However, from prior experience, the gel strength of the surimi would be expected to increase from 400 to 600 points if dewatered to a standard moisture content of 75% (Reppond and Babbitt, 1997). This would yield a final GS of up to 850 points, which is very good quality. No cracking of a double-folded sample, using the fold test, also indicated that the elasticity of the test surimi was very good.

A simple industry yield metric is the mince weight to surimi product ratio which is generally 0.55 to 0.6. Based on 52% mince yield (Table 2), a quick estimate of surimi yield from whole fish would be 28.6–31.2%. This is a sizable increase in surimi yield compared to the industry average of 20–22% (AFDF[5]).

Results of the trials in Kodiak indicated that the FES could produce market-grade surimi at heightened yields from walleye pollock of up to 500 g. This has the potential to greatly increase the use and value of these smaller discarded fish.

Inshore Pacific Whiting Trials

After completion of the trials in Alaska, the FES was set up in a surimi manufacturing plant (Port Fish Ltd.) in Port Alberni, B.C., Can., where there was an active fishery for Pacific whiting that are caught in the inside waters of the Straits of Georgia. These fish are usually of good quality due to very low infection rate of Myxosporean parasites common to the larger ocean-caught Pacific whiting (Kabata and Whitaker, 1985). The fish traditionally average less than 300 g in weight, ideal for the FES.

Initially, 300 fish with an average weight of 262 g were randomly pulled from the processing line. After processing the whole fish through the FES, a random sample of 70 eviscerated fish had an average weight of 223 g. This was approximately 85% of the beginning fish weight. Minced meat recovery of 8.5 kg from the 70 fish sample gives an estimated 46.3% mince yield from whole fish. The mince was indistinguishable from the mince being produced by the plant as judged by the plant foreman and quality control (QC) personnel. Comparatively, mince flesh yield from backbone in butterfly filleted fish in the plant was approximately 34%.

After the initial test on whiting, the average size of the landed fish increased significantly, and satisfactory water evisceration could not be achieved on a consistent basis. A number of batch runs were conducted using partially headed fish that were hand cut between the back of the eye and the back edge of the gill plate.

After water evisceration, the fish trunks sent to deboning represented 61–66% of the original fish weight. The yield of minced meat on a whole fish basis ranged from 42% to 47%. Yield was most influenced by the condition of the fish used and operation of the deboning machine.

Whiting Surimi Test

In this test, 75.4% of the whole fish weight remained after heading. Evisceration with FES reduced beginning round fish weight to 64.2% of the beginning weight. Twenty kilograms of the eviscerated fish were deboned, yielding 13.6 kg of minced meat resulting in a yield of 43.7% from round fish. The remaining 800 kg of headed and eviscerated fish were used to process into surimi.

The yield of fish meat produced by the experimental system was not unduly influenced by the absorption of water. The moisture content of the mince produced from whole FES processed fish and headed FES processed fish was 84.2% and 84.3%, respectively. The moisture content of minced meat produced in the plant with conventional filleting equipment was 84.3%. Thus, we concluded that the increased yields of minced meat were not due to absorption of water by the fish meat.

The gel strength of the experimental surimi and surimi made by the plant from the same lot of fish 10 h earlier are shown in Table 3. Gel strength results were lower for the FES experimental surimi.

The results may be related to the handling of the fish. The fish were from a full-boat delivery of 90 t. They were over 24 h old when processed to produce the regular production sample above and over 34 h old when finally processed by the experimental method. The fish were held for 4 h with only top ice before heading.

After heading the fish were held for another 3 h with top ice before water evisceration. The eviscerated fish were held for another hour without ice before being processed in the surimi plant. This extra time and handling of the fish combined with some temperature rise may have contributed to loss in the functional gel value of the final surimi product. The defect score (Table 3), however, was very good.

Estimating a final yield of surimi from round fish using 43.7% mince recovery with a moisture content of 84.3% and final moisture content of the surimi at 75%, would result in a surimi yield of 26.7%. The plant at the time was averaging 19.4% product yield from raw material. The increase in yield, based on the above numbers, would be 37.6% using the FES.

Microbiological tests (Table 4) in the form of total aerobic plate counts (APC's) and total coliform counts were made on surimi products produced by water evisceration in this study. These were compared to microbiological tests made on surimi product manufactured by the host processing plant.

Total mean APC's for surimi made from FES processed fish were relatively low, and coliform counts were within acceptable count levels. By comparison, APC's for surimi produced by the processing plant were slightly higher and coliform counts slightly lower than the comparative microbial assessment of surimi made from fish processed by the FES.

Table 3.—Properties of surimi made from inside whiting processed by water evisceration compared to surimi made from Pacific whiting processed by conventional technology.

Sample	Moisture (%) Mince	Moisture (%) Surimi	Cook temp. (°C)	Stress (g)	Strain (cm)	Gel strength (g)(cm)	Defects[1]
Test surimi	82.25	73.5	90	491	1	491	8
Plant surimi	82.3	NA[2]	90	462	1.21	559	NA

[1] Defects describe degree of contamination on a scale of 1–10 where 10 are fewest contaminants.
[2] NA = Not analyzed.

Table 4.—Microbial loads on surimi made from Pacific whiting processed by the fish evisceration system (FES[1]) vs. surimi produced by conventional technology.

Sample source	No. of samples	Aerobic plate count (CFU/g)[2] Mean	Low	High	Coliforms (MPN/g)[3] Mean	Low	High
FES	2	68,500	53,000	115,500	59	2	160
Port Fish[4]	1	224,000			11		

[1] FES = Fish Evisceration System.
[2] Colony forming units/g (CFU/g).
[3] Most probable number/g (MPN/g).
[4] Port Fish Ltd., Port Alberni, B.C., Can.

Table 5.—Quality control results for surimi produced from ocean caught Pacific whiting.

Sample time[1]	Whiteness[2]	Stress (g)	Strain (cm)	Gel strength (g) (cm)	Impurity[3] score
18:00 h	46.1	1018	1.52	1547	5 (moderate)
19:00 h (FES)	45.1	872	1.48	1290	3 (few)

[1] Experimental mince meat from FES tagged onto conventional commercial production for comparison.
[2] Hunter Whiteness Colorimeter. Nippon Denshoku, Kogyo Co., Ltd., Tokyo, Japan.
[3] Impurity score company specific vs. other trials.

Pacific Ocean Whiting Trials

The FES was set up and operated in a surimi processing plant in Hammond, Oreg. The results of a test to measure the yield of minced meat from FES and Toyo filleting machines used in the plant were 44.9% and 39.5%, respectively. The mince yield of 44.9% from whole fish using FES was consistent with results from previous tests.

In a follow-up test to make surimi, 3,300 fish with an average weight of 328 g were processed. The fish were headed and eviscerated in 17 min. The headed and eviscerated fish were transferred to the Toyo 405 deboner and into the surimi process. The strategy was to "tag" this fish meat onto the last of the regular plant production.

A sample of the experimental surimi and regular production surimi, produced an hour before, were tested by the plant quality control technicians (Table 5). The cooking regimen for these samples used a 30°C "suwari" set (AFDF[5]) before a final cook at 90°C. This method produces stronger GS than the more widely used 90°C single cook method for sample preparation and measurement.

The GS for the experimental surimi was slightly lower (1,290) than for the plant produced surimi (1,547). The whiteness color measure for FES produced surimi exceeded high grade FA surimi grading standards and the impurity score was lower than the commercially produced surimi produced just prior to FES surimi.

Headed Whiting Trials

This trial used an automated heading step prior to the FES. Pacific whiting of predominantly 220–360 g fish with an average weight of 280 g attained a peak throughput of 300 fish/min. Average yield of headed and eviscerated trunks was 67% of whole fish and the measured yield of mince was 50% from whole fish.

The quality of the mince was judged identical to mince that was being produced by the plant processing the same lot of fish and using a conventional Toyo 711 filleting machine with two opera-

Table 6.—Summary of quality control results for surimi commercially produced from North Atlantic blue whiting processed by the water evisceration system (FES).

Mfg date	Sample time	Grade[1]	pH	Moist. (%)	Defects[2]	L[3] value	b[4] value	Strain (g)	Stress (cm)	Gel strength (g) (cm)
8 April 04	17:00	KB	7.32	74.48	1	71.73	3.6	376	1.09	410
8 April 04	19:25	KA	7.28	73.13	1	70.35	3.6	554	1.11	615
9 April 04	13:00	KB	7.27	73.04	2	71.33	3.1	519	0.96	498
9 April 04	17:00	KB	7.26	74.04	2	70.78	3.7	441	0.97	428
9 April 04	NA[5]	KB	7.27	73.85	3	70.78	9.4	496	1.08	536

[1]Second grade: KA and KB.
[2]Defects describe degree of contamination on a scale of 1–10 where 10 are fewest contaminants.
[3]L value describes whiteness.
[4]b value denotes yellow/blue.
[5]NA = Not available.

tors processing a total of 100 fish/min. During this trial period, the plant produced mince at a yield of 35% from whole fish. Table 2 summarizes the minced fish yields from the various fish processing trials made with the FES.

Commercial Application: North Atlantic Blue Whiting

In 2003 a commercial version of the FES was built to process North Atlantic blue whiting (NABW), a small species in the cod family, considered to have great potential for surimi production (Trondsen, 1998). The system was located in Denmark's Faeroe Islands at the Viking Fish Protein processing plant located next to Havsbrun, a large fish meal producer that supplies the island's Atlantic salmon, *Salmo* spp., farms.

The seas around the Faeroe Islands have consistently produced large blue whiting catches of over 400,000 t/yr (Standal, 2006). At the time of the research described here, the majority of NABW landings consisted of 80–160 g fish with an average size of approximately 110 g. Fish were delivered by reduction fish trawlers and were held onboard in refrigerated seawater at 2°C but separate from fish bound for meal processing.

At landing, the fish were iced in fish totes prior to processing. To begin processing, the iced fish were transferred to a feed tank that delivered the fish to a shaker that oriented the fish head first for conveying into the FES. A rate of 500–600 fish/min provided approximately 2.0 t of minced fish muscle/h needed to operate the surimi line.

With firm high-quality fish, feed rates exceeding 1,000 fish/min were achieved for some test runs. Fish exiting the pump and reducer were accelerated up to 14 m/sec before entering the cutting and cleaning sections.

There were two complete cutting and cleaning sections with a selector valve to direct flow (Fig. 3C, D). This allowed the fish flow to be changed to the backup section without stopping the flow of fish. Maintenance, cleaning, or blade settings could be made on the system without interruption to production. Installation of backup cutting and cleaning units to the unused side could be done in less than 5 min.

During steady flow of 3.0–3.5 t of round fish/h, there were few incidents requiring switching of cutting sections with firm fish. The yield of minced flesh ranged from 55 to 63% from round fish and was higher when fish were fresher. The final yield of surimi from the whole fish was 30–33%, the general quality of which is shown in Table 6.

Quality control was a major problem for processing of NABW into surimi. Raw fish quality varied widely. Timely delivery of fish was not always achievable, resulting in landings of mixed quality fish. Softening of the fish was proportional to landed age of the fish and temperature of storage.

Protease activity resulting in softening in the flesh could be controlled by adding protease inhibiting pig plasma that increased gel strength of the NABW surimi more than twofold. Color control of surimi was difficult due to pigments in the fish heads. Similar color and textural problems were also reported by Trondsen (1998) in a study to determine the market value of surimi made from NABW.

In similar work by the authors, the color problem was eliminated during the processing of Pacific whiting by removing the heads. For NABW, it was determined that an automated heading machine such as "OTTO" would greatly improve overall quality control. Owing to an unexpected and extremely weak surimi market that developed at the time of this startup, combined with production problems, management decided to cease surimi production (Nordby[6]).

Conclusion

High volume and high yield has demonstrated the potential of the water evisceration system described in this study to economically produce minced fish meat from several species of round fish (walleye pollock, Pacific whiting, and NABW). A volume throughput rate of up to 6 t of fish/h was achieved.

High volume provides enough raw material to efficiently operate a surimi processing plant using small fish. To achieve this level of fish processing using 200 g fish would require the equivalent of two or three lines of conventional equipment. The cost, operation, and installation space required would be especially prohibitive in close quarters aboard ships at sea.

Increased product yield, using the water evisceration process, would produce an estimated 2.88 t of minced fish meat per hour from 6 t of fish at 48% yield. By comparison, it would require three or four conventional lines and up to eight machine operators to produce the same volume of minced fish meat.

[6]Nordby, M. World Protein, 16008 41 St. N.E. Lake Forest Park, WA 98155. Personal commun., 2007.

The quality of surimi made from minced fish meat produced from pollock and whiting processed by the FES in this study ranged from FA (high grade) to KB (low to average quality). The commercial production of surimi from NABW with the FES was successful in producing a marketable product comparable to the conventionally made blue whiting surimi product currently marketed in western Europe.

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