AN ABSTRACT OF THE THESIS OF

Ari P. Wendel for the degree of Master of Science in Bioresource Engineering presented on September 13, 1999. Title: Recovery and Utilization of Pacific Whiting Frame Meat for Surimi Production.

Abstract approved: 

Edward R. Kolbe

In surimi manufacturing, less than 25% of the total weight of the fish is utilized. This research focused on meat recovery from fish frames, the residual portion of the fish after filleting headed and gutted fish. A new technology, the water jet deboning (WJD) system, was tested. The WJD system uses oscillating high pressure water jet nozzles to recover edible flesh from the frames without breaking the kidney located under the backbone. To evaluate the function of added salt on dewatering and process recovery, the WJD was operated without NaCl (WJD1) and with 0.2% NaCl added to the discharge slurry (WJD2). In conventional mechanical deboning process (MD), which was the other deboning system applied in the study, no salt was used. The recovered frame meat was further processed to surimi and then stored at -18°C. Meat recovery and surimi processing yields were compared between the three meat recovery processes.
Functional properties of gels (texture and color) were evaluated after 1 and 6 mo frozen storage and compared to commercially manufactured surimi, which served as a control.

As a result of manual trimming, the maximally recoverable meat from the frames was 42.8% of frame weight. MD showed the highest mince yield (mince prior to cryoprotectant addition), 24% of frame weight, while the two WJD methods resulted in only 5% yield. Color and shear strain for gels from WJD1, MD surimi and mixtures of those and control (10-20% frame mince surimi/80-90% control), were comparable to control. Gels from WJD2 showed significantly lower lightness (L*) but did not differ otherwise. Shear stress values of all frame meat surimi gels and the gels from mixtures of those and the control were significantly lower than the control. This low shear stress is probably due to a difference in processing equipment and processing conditions between the lab scale and the commercial scale.

Due to the promising processing yield for the MD system an additional study was performed where effects of kidney and kidney blood contamination in the frame mince were investigated. Pacific whiting frames were mechanically deboned with/without kidney and the frame mince further processed into surimi. Functional properties of gels (texture and color) were evaluated after 1 and 6 mo frozen storage and compared to commercially manufactured surimi, which served as a control. At 1,2,4, and 6 mo, salt extractable proteins (SEP) concentration, dimethylamine (DMA) formation and pH were measured to monitor protein denaturation. Removing the kidney and washing the frames prior to MD resulted in higher gel strength after 1 and 6 mo frozen storage.
However, the same treatment did not lead to any significant difference in dimethylamine (DMA) formation or pH. After 1 mo the salt extractable protein concentration was higher for the surimi from the washed frames.
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I want to dedicate this thesis to my fiancé Sigrun Elva Einarsdottir and my mother Svanhild Wendel. Without their support I would not be here.
CONTRIBUTION OF AUTHORs

Dr. Jae W. Park and Dr. Edward R. Kolbe were involved in the design, analysis, and writing of each manuscript. Dr. Kristberg Kristbergsson assisted in data collection for the study.
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INTRODUCTION

Surimi is stabilized fish mince that is made from deboned, washed fish meat mixed with cryoprotectants, such as sugar and sorbitol. The cryoprotectants are added to minimize protein denaturation during frozen storage. Protein denaturation can result in decreased gel strength (MacDonald and Lanier, 1991) and undesirable gel colors in the surimi products (Park, 1995a). Surimi is further processed into surimi seafood, i.e. surimi crab legs.

Surimi manufacturing results in approximately 70-75% solid waste based on whole fish weight. The fish waste is either utilized in fish hydrolysate and fishmeal or is discarded. In 1998, total catch of Pacific whiting for the West Coast was 318,300 metric tons (Warren et al., 1999). Frames, the residual portion of the fish after filleting headed and gutted fish, are considered 15-17% of the total fish weight (MacDonald and Lanier, 1988; Crapo et al., 1988; Anonymous, 1988). Based on the total Pacific whiting catch in 1998, 47,700-54,100 metric tons of frames were generated. Substantial amounts of meat can be recovered from the frames by various methods. Most researches have focused on using mechanical deboning (MD). Using this method, Crapo and Himelbloom (1994) recovered 31.4% of Alaska pollock frame weight as
unwashed frame mince; Kim et al. (1996) reported 15-16% surimi yield of channel catfish frames and Hastings et al. (1990) accomplished surimi yield of 26.7% and 40.6% for haddock and whiting frames, respectively.

A major problem associated with recovered frame meat is the reduction of meat quality during frozen storage (Crapo and Himelbloom 1994, Jahncke et al., 1992). Textural hardness of unwashed mince increased, while color lightness (L*) and surimi gel cohesiveness decreased. These changes are believed to be largely due to enzymatic and microbial contamination from the kidney and kidney blood (Kristbergsson, 1998; Chang and Regenstein, 1997). The kidney is located underneath the backbone. During mechanical deboning the bone column breaks and the reddish kidney or its fluid is easily mixed with the frame mince (Kristbergsson, 1998).

To avoid quality problems associated with kidney and kidney blood contamination, the Scandinavian research group Nordfood used a high pressure water jet deboning system (WJD) for meat recovery from cod frames (Kristbergsson, 1998). In this system, the frames are conveyed through high pressure oscillating water jets (40-70 bar) that remove the flesh from the frames. The recovered meat then goes to a rotary screen, which filters out broken bones and skin particles. A small holding tank stores the mince until it is pumped to larger storage or settling tanks. The system leaves the bone column and kidney intact, resulting in a white flesh mince. However, this system is not flawless. It consumes high quantities of water during the WJD process and difficulties in de-watering the resulting product have also been reported.

According to other studies addressing this problem (Jahncke et al., 1992; Dingle and Hines, 1975), the kidney was removed prior to deboning or the frame mince was
washed. These studies indicate that washing the frame meat or mince contaminated with kidney tissue could be more effective than removing the kidney tissue prior to deboning in order to decrease textural degradation and protein denaturation.

The objectives of this study were: (1) to optimize the two main processing parameters (water pressure and conveyor speed) for the WJD system with respect to meat removal from Pacific whiting frames; (2) to compare WJD and conventional MD for Pacific whiting frames with respect to (a) process yield, and (b) quality of surimi; (3) to determine the effects of kidney tissue contamination on the quality of MD frame mince surimi during frozen storage.
LITERATURE REVIEW

Surimi processing

Process description

Surimi processing can be divided into two stages. The first stage involves processing whole or gutted fish into mince. Usually, the fish arrives whole so the process starts by gutting and de-heading. The fish is then filleted and the fillets are fed into a mechanical deboner. In the mechanical deboner the fish flesh is forced by means of a rubber conveyor belt through a perforated drum with 3-5 mm openings. The skin and bones from the fillets remain on the outside of the drum, while the mince is collected from the inside. The second processing stage consists of repeated washing of the mince, refining, mixing of cryoprotectants, packing and block freezing. The washing process involves mixing the mince with cold water (<5°C) and then removing the water by screening or centrifugation. The number of washing cycles and water/meat ratio used in the wash varies between processors, but 2-4 washing cycles and total water/meat ratio of 12:1 to 24:1 is common for on-shore processors (Lin, 1996).

Washing serves the purpose of removing water soluble proteins. The washed and dehydrated mince, 5-10% solids (Park, 1995a), is then treated in the refiner, a screening mechanism, where the remaining connective tissues and bones are separated from the mince. After refining, the mince goes through a final dehydration in a screw press. The washed mince, at a moisture content of 80-82 % (Park, 1995a), is then mixed with cryoprotectants that are a mixture of mono- or disaccharides and low molecular weight polyols. As a commercial application a mixture of 4-5% sugar, 4-5% sorbitol and 0.2-
0.5% polyphosphate is widely used (MacDonald and Lanier, 1991, Park, 1994) giving the surimi a final moisture content of 72-75%. The final step in the process involves packing the surimi into 10 kg plastic bags and freezing in plate freezers.

**Material flow - mass balance**

In surimi processing only a small portion of the total fish weight is utilized in the final product. Toyoda et al. (1992) and Chang-Lee et al. (1990) reported that after filleting and mincing a 32 - 36% yield can be achieved from whole fish to mince. When the mince goes through the following washing, refining and de-watering steps, an additional 33-50% of the mince weight is lost, mainly in the form of water soluble proteins and connective tissue (Toyoda et al., 1992; Chang-Lee et al., 1990, Anonymous, 1988). The final surimi processing yield of whole fish weight is therefore 17-24%. In Fig. 1.1, a general processing flow chart for surimi with mass balance is presented.

**Deboning methods and potential use for recovered frame meat**

**Frame meat recovery**

Due to high production volumes in the surimi industry, a large amount of solid waste is often generated in a relatively short time. If byproduct processes, such as fish meal or fish hydrolysate, are not available, the waste is either disposed at sea or used for landfill. Often, these options have proven to be expensive for the processors, with disposal cost in the range of $10-100/ton reported (Goldhor et al., 1996, Hilderbrand, 1998).
Fig. 1.1 - Surimi processing flow chart with mass balance.

Based on Alaska pollock surimi processing (Anonymous, 1988) and Pacific whiting processing (Crapo et al., 1988). All numbers are percentage of whole fish weight.
The fish frames account for approximately 20-29% of the solid waste weight (Toyoda et al., 1992; Chang-Lee et al., 1990, Anonymous, 1988) and contain a significant amount of meat. By manually deboning Pacific whiting frames, Lin and Park (1996c) reported that an additional yield increase of (4%) of total fish weight could be accomplished. Currently, fish frames are not utilized as an edible meat source, but are either processed into low value byproducts or discarded (Jahncke et al., 1992; Crapo and Himelbloom, 1994). Over the last thirty years, several studies have addressed the potential utilization of fish frames as edible meat. The main focus has been placed on utilizing the frame meat as unwashed or washed mince, which could then be further processed to surimi.

**Mechanical deboning**

In the majority of frame meat recovery studies, mechanical deboning (MD) has been used to separate the meat from the frames. Kim et al. (1996) studied meat recovery from Channel catfish frames and indicated that a mince yield of 50-60% of frame weight could be achieved. For Alaska pollock frames, Crapo and Himelbloom (1994) reported a meat recovery of 31.4%, while Hastings et al. (1990) received 48% and 57% mince yield from haddock and whiting frames, respectively. When mechanically deboned Channel catfish frame mince was further processed into surimi by applying 3 washing cycles to the mince, a total surimi yield of 15-16% of the total frame weight was accomplished (Kim et al., 1996). For haddock and for the whiting frames Hastings et al. (1990) reported a surimi yield of 26.7% and 40.6%, respectively.
Water jet deboning

A Scandinavian research group took another approach for frame meat recovery by using a water jet deboning system (WJD). With this method the frames are conveyed under several high pressure water jet nozzles which rinse the meat from the bones. The recovered meat must then be separated from the water in a subsequent dewatering process. For cod, this method resulted in 1-4% yield increase of total fish weight, depending on the adequacy of the filleting operation (Kristbergsson, 1998).

The design of the WJD system is outlined in Fig. 1.2. The frames are fed by an elevator conveyor onto the upper conveyor belt (1). The belt transports the frames under the first set of high pressure nozzles (2). When the frames reach the end of the conveyer belt, they are guided down a chute (3) which turns the frames over while moving them to the lower conveyor belt (4). The lower conveyor belt moves the frames under the second set of nozzles (5). The frames (bones) are then transported from the end of the lower conveyor belt into an offal bin. The fish particles, which are removed from the frames, are carried with the water into a rotary screen (6) to remove skin and bones. From the rotary screen, the slurry (meat and water) goes into a holding tank (7) located under the screen. There, a pump, activated by a high level sensor, moves the slurry into bigger holding tanks or to dewatering systems. Both conveyor belts (1,4) are made of polyethylene (PE) with 4 mm openings for the meat particles to pass through. The nozzles (2,5) are a rotating pencil jet type, creating a high speed water beam that rotates in an approximately 50 mm diameter circle. Three nozzles are in each set.
End view

Part # | Part name
--- | ---
1 | Upper conveyor belt
2 | 1st high pressure nozzle set
3 | Chute
4 | Lower conveyor belt
5 | 2nd high pressure nozzle set
6 | Rotary screen
7 | Holding tank
8 | Stationary high pressure nozzle
9 | Stationary low pressure nozzles

Side view

Fig. 1.2 - Outline of the water jet deboning system for fish frames.
The operating water pressure, 40-70 bar, is generated by a 4 cylinder piston water compressor. The rotary screen of the machine is made of stainless steel with a mesh diameter of 1.24 mm. Inside the screen, a high pressure stationary fan (wide angle) nozzle (8) is located to flush the mince through the perforation. To prevent clogging, eight low pressure nozzles (9) are lined up on the outside of the screen. The slurry pump in the holding tank is a high speed centrifugal pump. All structural parts of the machine are made of stainless steel.

The WJD system has two main processing parameters; water jet pressure and conveyor speed. For cod frames two optimum WJD meat recovery conditions were found (water jet pressure/conveyor speed): 63 bar/1.4 m/min and 72 bar/0.9 m/min (Kristbergsson, 1998).

The main problems in the WJD process have been high water consumption, severe protein loss in the dewatering steps and difficulties in reducing the water content of the mince down to commercial standards. To search for causes of these problems, researchers compared particle size from WJD and MD processes using staining and image analyzing (stereoscopic 6.5x and 100x magnification). Although the data contains high standard deviation, the results indicates that particle size is smaller from the WJD system than the MD (Table 1.1). This is the most likely cause for the excessive loss of protein in the dewatering steps. From the image analysis the proteins appeared more swollen at higher water jet pressure. This could possibly explain the dewatering difficulties.
Table 1.1 - Length and width of particles from water jet and mechanically deboned frame meat.

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<tr>
<td>MD mince</td>
<td>4.06 ± 2.02</td>
<td>0.29 ± 0.11</td>
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<tr>
<td>WJD 30 bar mince*</td>
<td>1.19 ± 1.21</td>
<td>0.22 ± 0.16</td>
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<tr>
<td>WJD 60 bar mince*</td>
<td>0.93 ± 0.97</td>
<td>0.17 ± 0.10</td>
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Kristbergsson (1998). Average length and width in mm (± standard deviation). *WJD 30 bar and WJD 60 bar mince are the mince products from the WJD system operated at 30 bar and 60 bar water jet pressure, respectively.
Other options for meat recovery

Meat recovery from fish frames in the form of washed or unwashed mince is not the only possible option. Carey & Whitney (1991) recovered fish meat from frames by cooking the frames prior to water jet deboning. When cooked, the blood or organs within the frame became congealed and thus, were rendered stable and more fixed to the bones. In that way the meat could be recovered from the frames without the blood or organ residuals. The product was described as cooked fish chunks with no off-colors or off-flavors to white fish products. Potential use for the product would be in soups, chowders or fish dishes.

Tschersich and Choudhury (1998) used Arrowtooth flounder protease to digest and separate proteins from pollock frames. The investigators achieved 64.1% recovery of proteins from the frames into the liquid phase hydrolysate. The research however, did not address separation of the proteins from the liquid, nor how these proteins could be used. Utilization of hydrolyzed proteins in food is not likely to be successful according to Borresen (1990), who reported that hydrolyzed protein products have bitter taste.

Frame mince characteristics

When the frames are subjected to mechanical deboning, the bone column breaks and the large, reddish colored kidney located under the backbone column, mixes with the mince and contaminates the product (Kristbergsson, 1998). The kidney and kidney blood contains high concentrations of the enzyme trimethylamine oxide (TMAO) dimethylase. When introduced to the mince, TMAO dimethylase causes chemical
reactions and protein interactions during frozen storage (dimethylation), which lead to
textural toughening and loss of protein functionality (Hultin, 1992). The mixing of
kidney blood and viscera residuals into mince has also been found to decrease color
quality of the unwashed mince (Crapo and Himelbloom, 1994; Kristbergsson, 1998;
Borresen 1990). The quality of frame mince however, is not only affected by kidney
blood contamination and dimethylation. Compared to fillet or V-cut mince, frame
mince was also found to have lower salt extractable protein (SEP) concentration
(Rodgers et al., 1979; Matthews et al., 1979); higher level of bones in the mince, which
leads to unfavorable texture and higher ash content (Crapo and Himelbloom, 1994,
Kristbergsson 1998); parasite and bacterial contamination (Collins et al., 1984; Lee,
1989); impurities and off-colors from skin (Crapo and Himelbloom, 1994; Collins et al.,
1984; Lee, 1989); higher fat content (Hastings, 1990) and off-flavor formation during
frozen storage (Crapo and Himelbloom, 1994; Jahncke et al., 1992). A summary of
reported quality problems in frame mince is presented in Table 1.2.
**Table 1.2 - Quality problems for frame mince and frame mince surimi.**

<table>
<thead>
<tr>
<th>Quality problems</th>
<th>Fish species</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>low color quality*</td>
<td>pollock</td>
<td>Crapo and Himelbloom (1994),</td>
</tr>
<tr>
<td></td>
<td>cod</td>
<td>Jahncke et al. (1992)</td>
</tr>
<tr>
<td>impurities</td>
<td>pollock</td>
<td>Crapo and Himelbloom (1994)</td>
</tr>
<tr>
<td>bone fragments</td>
<td>pollock</td>
<td>Crapo and Himelbloom (1994)</td>
</tr>
<tr>
<td>high extractable moisture*</td>
<td>cod</td>
<td>Dingle and Hines (1975)</td>
</tr>
<tr>
<td>reduction in salt extractable protein concentration*</td>
<td>cod</td>
<td>Dingle and Hines (1975)</td>
</tr>
<tr>
<td>toughening*</td>
<td>cod</td>
<td>Jahncke et al. (1992)</td>
</tr>
<tr>
<td>low quality cooked texture*</td>
<td>pollock</td>
<td>Crapo and Himelbloom (1994),</td>
</tr>
<tr>
<td></td>
<td>cod</td>
<td>Jahncke et al. (1992)</td>
</tr>
<tr>
<td>off-flavors*</td>
<td>pollock</td>
<td>Crapo and Himelbloom (1994),</td>
</tr>
<tr>
<td></td>
<td>cod</td>
<td>Jahncke et al. (1992)</td>
</tr>
<tr>
<td>higher fat content</td>
<td>whiting</td>
<td>Hastings (1990)</td>
</tr>
<tr>
<td></td>
<td>haddock</td>
<td></td>
</tr>
</tbody>
</table>

* Only related to frozen storage and/or increased during frozen storage.
Several studies have searched for ways to improve the quality of frame mince. Washing the frame mince, removal of kidney tissue prior to deboning and additions of cryoprotectants have all proved to be effective (Rodgers et al., 1979; Dingle and Hines, 1975; Chang and Regenstein, 1997). Other studies were pursued to make surimi from frame meat. Kim et al. (1996) processed surimi from Channel catfish frames and Hastings et al. (1990) utilized haddock, whiting, and saith frames. The catfish frame meat surimi was found to be of acceptable quality with respect to gel strength, color, and extractable moisture. On the contrary, the haddock, whiting, and saith frame meat surimi was of low quality. This was due to high counts of impurities, soft gels, reduced color quality, and low sensory scores. The difference in quality between the two studies though, could partly be due to varied freshness of the frames prior to processing.

**Surimi quality**

Since surimi is the raw material for surimi seafood processing its quality is of great importance. During frozen storage, surimi quality can change significantly depending on the initial properties of the mince and storing conditions.

**Moisture content**

Moisture plays a major role in the denaturation of myofibrillar proteins during frozen storage. The formation of ice crystals, dehydration of proteins and increase in salt concentration caused by freezing promote protein aggregation and loss of solubility (Shenouda, 1980). Moisture content in commercial surimi is generally 72-76%. In conventional Japanese grading system, surimi with higher moisture content can be downgraded (Lanier, 1998).
Salt extractable proteins (SEP)

Salt extractable proteins are the functional proteins in surimi gel formation (Niwa, 1992). These proteins are more often referred to as myofibrillar proteins, the proteins that make up the muscle fibers themselves. Other protein types found in fish muscle are stroma proteins (connective tissue) which are almost totally insoluble in water and saline, and sarcoplasmic proteins which are water and partly salt soluble. The sarcoplasmic protein group contains various undesirable compounds for surimi. Myoglobin and hemoglobin, the pigment proteins of blood and red muscle fibers, can cause discoloration of the surimi and lipid oxidation (Lanier, 1998). Some of the sarcoplasmic proteins in surimi are enzymes, such as trimethylamine oxide dimethylase and several proteolytic enzymes. The washing steps in the surimi process serve the purpose of removing the sarcoplasmic proteins. Because of this washing and removal of sarcoplasmic proteins, SEP measurements are commonly used to monitor myofibrillar protein concentration in surimi, although sarcoplasmic proteins could theoretically contribute to the SEP concentration.

Initially, myofibrillar proteins account for approximately 66-77% of the total protein concentration of the fish flesh (Suzuki, 1981; Lin and Park, 1996a). In surimi washing, up to 50% of the total proteins can be lost (Adu et al., 1983; Pacheco-Aguilar et al., 1989; Lin and Park, 1997), indicating that 24-35% of the myofibrillar proteins could be lost. During frozen storage, concentration and functionality of these proteins is further reduced via protein denaturation (Park et al., 1988; Sych et al., 1990a).
**pH**

Myofibrillar proteins of various animal species are most stable at neutral pH. Fukuda et al. (1981) used ATPase activity to measure denaturation rate with respect to pH of mackerel actomyosin during frozen storage. The denaturation rate increased rapidly when pH was lower than 6.5. Gel forming ability also decreased with reduction in pH (Fukuda et al., 1981). Lanier (1992) reported that pH of surimi was related to water-holding and gel-forming properties of cooked gels, but did not necessarily influence the latter. Effects of pH on gel strength are compounded for Pacific whiting. Its proteolytic enzyme activity is highly affected by low pH and causes gel strength reduction (Morrissey et al., 1993; 1995).

Changes in pH during frozen storage seem to be species dependant. The reduction of pH values mainly occurred in dark flesh such as sardine and mackerel (Fukuda et al., 1981) while cod mince showed small increase or no change in pH (Chang and Regenstein, 1997). A decrease in pH during frozen storage is likely to be associated with protein denaturation. Buttkus (1970) and Jiang et al. (1988) both proposed that protein aggregation was partly caused by disulfide bonding. As a result of the bonding the hydrogen ions of the former sulphydryl group are liberated. Consequently the concentration of free hydrogen ions is increased resulting in a drop in pH.

Cod frame mince (Dingle and Hines, 1975) and cod mince contaminated with kidney tissue (Chang and Regenstein, 1997) showed a larger increase in pH than fillet mince during frozen storage. Freshness of the fish when processed can also affect the pH of the surimi. Post mortem breakdown of glycogen results in lactic acid formation which then lowers the pH in the muscle (Huss, 1988).
Freeze denaturation

Shenouda (1980) reported that formation of ice crystals, dehydration of proteins and increase in salt concentration promote protein aggregation and loss of solubility. Buttkus (1970) proposed that freeze denaturation was associated with a myosin aggregation mechanism that involved disulfide-sulfhydryl exchange reactions between activated myosin molecules and aggregates. Jiang et al. (1988) suggested that freeze denaturation of actomyosin was mainly caused by formation of disulfide, hydrogen, and hydrophobic bonds.

The rate of protein denaturation is dependant on several factors, such as fish species, rate of freezing, postmortem state of muscle, storage temperature, and types of cryoprotectants used (Fennema, 1973; Park et al., 1988; Sych et al., 1990a; Sych et al., 1990b; Srikar and Reddy, 1991). Freeze denaturation of proteins can affect the quality of mince and surimi in several ways. Drastic decreases in gel forming ability, lower water holding capacity and reduced fat emulsifying capacity have been reported (Iwata and Okada, 1971; Park et al. 1988; Sych et al., 1991; Yoon and Lee, 1990). In addition, color (Lin and Park, 1997; Magnusdottir, 1995) and pH changes (Lanier, 1992; Chang and Regenstein, 1997) were found to be associated with denaturation of myofibrillar proteins during frozen storage.

In gadoid fish the protein denaturation during frozen storage can also be driven by means of enzymatic and non-enzymatic chemical reactions. In the enzymatic pathway, trimethylamine oxide (TMAO) in the muscle is degraded in an equal molar amount to dimethylamine (DMA) and formaldehyde (FA) by the enzyme TMAO dimethylase (TMAO-e). Formaldehyde is then hypothesized to be involved in protein
interactions that could result in protein insolubility and textural deterioration (toughness) in the muscle tissue (Hultin, 1992). The concentration of TMAO-e in kidney, spleen, and gall bladder is extremely high, exceeding 1000-fold that of the concentration found in muscle (Rehbein and Schreiber, 1984). Studies of frame meat mince and mince with added kidney tissue have shown high DMA formation during frozen storage and severe reduction in textural quality (Jahncke et al., 1992; Crapo and Himelbloom, 1994; Chang and Regenstein, 1997).

The non-enzymatic decomposition of TMAO leads to the formation of TMA, DMA and FA (Vaisey, 1956; Ferris, 1967). Although the reaction was only found to occur during frozen storage, it seems to be dependant on muscle temperature prior to freezing (Spinelli and Koury; 1979, 1981).

Several cofactors have been found that are necessary for the two reactions to occur. These are low molecular weight compounds, including flavin mononucleotide, NAD(P)H, ascorbic acid, hemoglobin, myoglobin, Fe^{++} and cysteine (Hultin, 1992).

**Proteolytic enzyme activity**

Proteolytic enzymes are heat stable enzymes found in fish muscle. These enzymes are responsible for myosin heavy chain (MHC) degradation during post-harvest storage and during surimi gel preparation (Morrissette et al., 1993; Lin and Park, 1996b). Proteolytic enzyme activity has an adverse effect on gel forming of surimi unless food grade enzyme inhibitors are added (Chang-Lee et al., 1990; Morissette et al., 1993) or a rapid heating rate is applied using a device such as ohmic heating (Yongsawatdigul et al., 1995).
Impurities

Connective tissue, bones, and heme pigments can reduce quality and value of surimi and surimi gels. Bone and skin particles cause visual and textural defects (Crapo and Himelbloom, 1994; Hastings et al., 1990), while protein-bound pigments reduce color quality during frozen storage (Mutsumoto and Matsuda, 1967). Heme pigments (myoglobin and hemoglobin) can also be involved in the non-enzymatic breakdown of TMAO to DMA and FA (Hultin, 1992).

Surimi gel quality

Shear strain/shear stress

When measuring surimi gel texture with a torsion tester, shear strain is used to indicate the cohesiveness (deformability) of the gels and shear stress the gel strength (hardness). Both values are recorded at the breaking point of the gels. Several compositional factors can influence gel strength. Moisture content affects shear stress of gels significantly. Hamann and MacDonald (1992) found that addition of 5% and 10% water, above the 78% moisture content, reduced shear stress of top grade pollock surimi by 29% and 46%, respectively. Yoon et al. (1997) found a linear relationship between shear stress and moisture content for pollock and whiting surimi gels, where the shear stress decreased by 4-6 kPa for each 1% in increase in moisture content.

Shear strain is less sensitive to moisture content. However, at severely elevated or decreased moisture content, from the standard 72-76%, the effects are considerable. Shear strain is directly related to the concentration and/or the quality of salt extractable proteins in the surimi (Park et al., 1988). Types and levels of cryoprotectants or enzyme
inhibitors used can also affect gel strength. Beef plasma protein (BPP), a common protease inhibitor for Pacific whiting surimi, was found to increase significantly both shear strain and stress in Pacific whiting surimi gels (Morrissey et al., 1993).

Color

Color of surimi gels is commonly evaluated using the CIE Lab color scale (Commission Internationale de l'Eclairage). Commercial surimi has four or five different grades based on the L* and b* values of the cooked gels (Park and Morrissey, 1994). Several factors can affect surimi gel color. Park (1995c) showed that water addition increased lightness (L*) and decreased yellowness (b*) of the gels. However, gel color was not affected by washing time, number of washing cycles nor water/meat ratio unless it was reduced below 2:1 (Lin and Park 1997). Freeze-thaw abuse of Pacific whiting surimi reduced lightness significantly (Lin and Park 1997) and Magnusdottir (1995) found that whiteness (L*-3b*) of Pacific whiting mince was affected both by cryoprotectants and frozen storage time. Surimi gel color can also be affected by physical conditions, such as gel setting treatment and temperature of gels when measured.

Processing parameters

Deboning

According to several studies on mechanical deboning, deboner types, pressure settings, and mince source (fillets, frames, fillet trimmings) can lead to a significant difference in ash content, due to contamination of bone fragments. Crapo and Himelbloom (1994) found the ash content of their unwashed Alaska pollock frame
mince to be 6.2%, while commercial mince from fillet trimmings had 3.2% ash content. Using a different deboner type, Jahncke et al. (1992) reported 1.0% and 1.1% ash content in cod fillet and frame mince, respectively.

Higher belt pressure applied on mechanical deboners results in higher mince yield. However, increased belt pressure can lead to lower frozen storage stability due to increased cellular rupture in the mince, affecting the gelling properties, water holding capacity, and lipid oxidation (Hsieh et al., 1992).

**Washing**

In the washing process, sarcoplasmic proteins, minerals, blood, fat, and other nitrogenous compounds are removed from the mince. Texture, color, and odor of the final product are greatly improved by washing out these impurities (Lin and Park, 1997). Parameters such as water/meat ratio, washing time, and washing cycles, greatly affect mince yield and quality (Lin and Park, 1997). Wash water properties like pH, salt concentration, and temperature are also important (Lin and Park, 1997; Watanabe et al., 1990). In the mince washing process approximately 50% of the total proteins are removed (Adu et al., 1983; Pacheco-Aguilar et al., 1989). In addition to the removal of all the water soluble proteins, 20-30% of total proteins, the washing process therefore results in a significant loss of the myofibrillar proteins (Lin and Park, 1996a). Washing also affects proteolytic enzyme activity in the surimi. An et al. (1994) found that extensive washing resulted in substantial reduction in cathepsin B and H activity while cathepsin L still remained active.

In the dimethylase system, most of the TMAO can be reduced by washing (Yoon, 1991; Lee, 1985). Kristbergsson (1998) reported that over 76% of the TMAO
was removed in the WJD process and additional two washing cycles resulted in 87.6% and 96.7% TMAO reduction. The two additional washing cycles also increased cohesiveness and hardness of gels when analyzed in Instron universal testing machine. Yoon et al. (1991) found reduction in TMAO by washing not sufficient enough to prevent textural hardening in hake mince during frozen storage.

Hultin (1992) suggested that removal of known cofactors of the dimethylation reaction could be more successful than removal of the TMAO itself. Phillippy and Hultin (1993) reported that neither TMAO nor TMAO-dimethylase were likely to limit the rate of dimethylation in red hake muscle. The same researchers reported that concentration of cofactors such as flavin mononucleotide and NADH could have greater effects on the reaction.

Several studies have addressed the effects of washing on dimethylation and protein denaturation during frozen storage. Matthews et al. (1979) found that washing of cod frame mince did not decrease loss of salt extractable proteins during frozen storage (-7°C) but it could reduce DMA formation significantly when compared to unwashed and trimmed frame mince. Dingle and Hines (1975) reported similar results when comparing washed and unwashed cod frame mince stored at -5°C. Rodgers et al. (1979) used salt extractable protein (SEP) concentration to monitor protein denaturation in washed and unwashed cod frame and V-cuts mince. The frame mince had lower initial SEP concentration and washing resulted in more SEP losses in the frame meat. After 20 weeks storage, proportional reduction in SEP for washed and unwashed mince was very similar, resulting in a lower final concentration for the washed mince. The washed V-cuts mince had higher SEP concentration than the washed frame mince but
not in excess of the initial difference. Both the frames and the V-cuts had been stored in ice for 5 days prior to deboning. This could possibly explain lower SEP concentration in the frame mince, as frames have been found to have elevated protease activity when compared to other fish parts (Lin and Lanier, 1980; Rehbein, 1988).

**Cryoprotectants**

Cryoprotectants are food grade additives that significantly minimize protein denaturation during frozen storage. A variety of carbohydrates, polyols, and phosphates have been found to be successful (Park et al., 1997). In commercial applications a mixture of 4-5% sucrose, 4-5% sorbitol and 0.2-0.5% polyphosphates is common (Park, 1994; MacDonald and Lanier, 1991).

Various compounds have been tested as inhibitors of the TMAO-e system. Chang and Regenstein (1997) reported that sodium hexametaphosphate and sucrose/sorbitol or polydextrose improved expressable moisture, water uptake ability, cook loss and tenderness in unwashed cod mince during frozen storage at –14°C. Racicot et al. (1984) showed that formation of DMA and FA in unwashed red hake mince could be reduced significantly by 0.05-0.25% addition of H₂O₂, while Ponte et al. (1985a,b) used certain hydrocolloids for the same purpose. Both studies showed that along with reduction in FA and DMA formation, changes in appearance and textural properties could be limited. Rodgers et al. (1979) compared effects of three cryoprotectants (lactose, monosodium glutamate, sodium citrate) on SEP reduction during frozen storage in washed and unwashed, V-cuts, and frame mince. The results were that lactose could significantly decrease SEP loss in V-cuts at –29°C, but at higher
storage temperatures no significant effects were noted. For unwashed and washed frame mince the effects of the cryoprotectants on SEP losses were small.

Care must be taken to ensure that cryoprotectants and dimethylation inhibitors do not work against each other. Hultin (1992) reported that when red hake fillets were dipped in sodium tripolyphosphate, the fillets showed accelerated DMA formation and textural toughening. Phosphate is added to surimi as a cryoprotectant at 0.25-0.3% as a mixture (50:50) of sodium tripolyphosphate or tetratosodium pyrophosphate. However, it is still not clear how the phosphate works as a cryoprotectant. The most likely explanation is its function as a metal chelator and/or antioxidant. In addition, due to the strength of the phosphate to raise pH, the water holding/binding of the gel improves and better salt solubilization of myofibrillar proteins is achieved (Park, 1999).

**Removal of kidney tissue from frames**

When studying cod mince, Dingle and Hines (1975) found kidney tissue to be a more effective contributor to dimethylation than kidney blood. Dingle et al. (1977) found that addition of 20% of fish tissue containing the enzymatic demethylating system to 80% tissue, without any active enzymes, produces as much TMAO demethylation as in the enzyme enriched tissue itself. Thus, if the enzyme is present in high concentration in tissue, mixing that tissue with tissue not containing the enzyme should not slow down the reaction rate in the mixture.

Jahncke et al. (1992) compared various properties of unwashed cod frame mince with and without kidney tissue. The results were that during frozen storage (-14°C), fillet mince showed slowest formation of DMA and lowest increase in hardness, while the frame mince with the kidney tissue showed the most rapid DMA formation and a
significant increase in hardness. Similar results were reported by Chang and Regenstein (1997), when they studied effects of kidney tissue and cryoprotectants on textural and functional properties of unwashed cod mince.

Matthews et al. (1979) found that removal of kidney from cod frames prior to deboning did not affect DMA formation, during storage at -7°C, when compared to untreated frame mince. Proportional losses of SEP were also similar, indicating limited effects of kidney removal.

**Temperature during frozen storage**

Effects of frozen storage temperature on the TMAO-e system in red hake fillet block was studied by Licciardello et al. (1982). Below -20°C the rate of the reaction was very low. The reaction rate increased over a temperature range of -20°C to -12°C and then accelerated rapidly with increasing temperature from -12°C to 0°C.

Rodgers et al. (1979) used SEP concentration and SDS-PAGE gel analysis to monitor protein denaturation in cod during frozen storage. Frame mince and V-cuts mince were stored at -7°C, -14°C and -29°C, in washed and unwashed state for 20 weeks. At the two higher storage temperatures the reduction in SEP was 70-80%, while the mince stored at -29°C showed 45-60% reduction. The SDS-PAGE gels gave somewhat similar results, indicating almost complete loss of myosin heavy chain, actin and myosin light chain after 8 w frozen storage at -7°C, but slightly less losses at -14°C. The mince stored at -29°C for the same time showed similar protein pattern as the fresh mince.
References


Chapter 2

COMPARISON OF WATER JET AND MECHANICAL DEBONING TO RECOVER MEAT FROM WHITING FRAMES

A. Wendel, J. W. Park, K. Kristbergsson, and E. Kolbe
Abstract

In surimi manufacturing, less than 25% of the total weight of the fish is utilized. This research interest was focused on meat recovery from fish frames, the residual portion of the fish after filleting headed and gutted fish. As a new technology, a water jet deboning (WJD) system was tested. The WJD system uses oscillating high pressure water jet nozzles to recover edible flesh from the frames without breaking the kidney located under the backbone. To evaluate the function of added salt on dewatering and process recovery, the WJD was operated without NaCl (WJD1) and with 0.2% NaCl added to the discharged slurry (WJD2). In the conventional mechanical deboning process (MD), which was the other deboning system applied in the study, no salt was used. The recovered frame meat was further processed to surimi and then stored at –18°C. Meat recovery and surimi processing yields were compared between the three deboning processes. Functional properties of gels (texture and color) were evaluated after 1 and 6 mo frozen storage and compared to commercially manufactured surimi, which served as a control.

As a result of manual trimming, the maximum recoverable meat from the frames was 43%. MD showed the highest mince yield, 24% of frame weight, while the two WJD methods resulted in only 5% yield. Color and shear strain for gels from WJD1, MD surimi and mixtures of those and control (10-20% frame mince surimi/80-90% control), were comparable to the control. Gels from WJD2 showed significantly lower lightness (L*) but were not otherwise different. Shear stress values of all frame meat surimi gels and the gels from mixtures of those and the control were significantly lower
than the control. This low shear stress was thought due to a difference in processing equipment and processing conditions between the lab scale and the commercial scale.

**KEYWORDS:** Pacific whiting, frame meat, surimi, surimi quality.
Introduction

Manufacturing of Pacific whiting surimi results in approximately 75-80% solid waste based on the whole fish weight. This solid waste is either utilized in by-products, i.e. fishmeal or is discarded. In 1998, total catch of Pacific whiting for the West coast was 318,300 metric tons (Warren et al., 1999). Frames, the residual portion of the fish after filleting headed and gutted fish, are considered 15-17% of the total fish weight (MacDonald and Lanier, 1988; Crapo et al., 1988; Anonymous, 1988). Based on the total Pacific whiting catch in 1998, 47,700-54,100 metric tons of frames were generated.

Substantial amounts of meat can be recovered from the frames by various methods. Most of the past research, was focused on using mechanical deboning (MD). Using this method, Crapo and Himelbloom (1994) recovered 31.4% of Alaska pollock frame weight as unwashed frame mince and Kim et al. (1996) reported 15-16% yield in surimi processing of Channel catfish frames. In addition, Hastings et al. (1990) reported 40.6% and 26.7% surimi yield from whiting and haddock frames, respectively.

The main drawback in utilizing recovered frame meat as unwashed mince has been impurities, bone fragments leading to high ash content, low color quality, off flavors, and undesirable cooked texture (Crapo and Himelbloom, 1994; Jahncke et al., 1992; Hastings et al., 1990). Many of the quality reductions occur during frozen storage (off flavors, texture, and color). For the washed mince or surimi products made from recovered frame meat, similar quality problems have been reported, such as high counts of impurities, higher fat content than regular mince, lower water holding capacity, and lower gel strength (Hastings et al., 1990). However, Kim et al. (1996)
made surimi from Channel catfish frames that reportedly was of acceptable quality, with respect to gel strength and color. Those investigators though, did not report how long the surimi was stored at -20°C prior to gel preparation. Effects of protein denaturation during frozen storage, therefore, might not have been accounted for.

Many of the chemical and textural changes that take place during frozen storage are believed to be caused by enzymatic and microbial contamination from the kidney or kidney blood (Chang and Regenstein, 1997; Jahncke et al., 1992; Hultin, 1992). The kidney is located under the backbone. During mechanical deboning the bone column breaks and the reddish kidney is mixed with the frame mince (Kristbergsson, 1998). To avoid the quality problems associated with kidney and kidney blood contamination, the European research group Nordfood (Kristbergsson, 1998), used a high pressure water jet deboning (WJD) system for meat recovery from cod frames. In this system, the frames are conveyed through high pressure oscillating water jets (40-70 bar) that remove the flesh from the frames. The recovered meat then goes to a rotary screen, which filters out broken bones and skin particles. The system leaves the bone column and kidney intact, giving a wet white mince product. However, this system consumes a large amount of water resulting in difficult de-watering (Kristbergsson, 1998).

The objectives of this research were: 1) to determine maximal meat recovery from Pacific whiting frames, 2) to optimize processing parameters (water pressure and conveyor speed) for the WJD system with respect to meat removal from Pacific whiting frames, 3) to compare WJD and conventional mechanical deboning (MD) for Pacific whiting frames with respect to: i) process yield and ii) quality of surimi made from recovered meat.
Materials and methods

Maximum meat recovery

In order to estimate the meat recovery efficiency of the two deboning systems, a maximum (theoretical) meat recovery from the Pacific whiting frames was determined by manually removing all meat from 20 randomly selected frames. The meat was scraped from the bones using an oyster knife and the maximum meat recovery determined as meat percentage of total frame weight. As Pacific whiting meat is soft and easily removable from the frames, it was estimated that close to 100% meat removal from the frames was achieved. Frames were collected from a Baader 182 filleting machine in a local surimi processing plant.

WJD processing optimization

Optimization for WJD processing parameters, with respect to meat removal efficiency, was carried out using a two factor central composition experimental design (Box et al., 1978) which falls under response surface methodology (RSM). Thirteen test runs were made using about 100 frames (5.18 kg) wherein each test run a different combination of water pressure and conveyor speed was applied. These two parameters are the main processing control variables for the system. The water pressure was applied in the range 45-65 bar and the conveyor speed in the range 12-16 m/min (exposure time = 1.2-0.8 s/frame). The WJD processing optimization of further described in Appendix 1.
For each experiment 50-100 kg of frames were received from a local surimi processing plant in August 1998. The fish had been harvested and stored in refrigerated sea water (RSW) less than 18 hours prior to processing. The frames were collected from a Baader 182 filleting machine and stored on ice overnight prior to deboning. Using the WJD system (Water Jet Deboning Machine prototype, Klaki, Reykjavik, Iceland), the slurry (recovered meat and water) from the machine was pumped to a 500 L plastic bin. The slurry was then run through a hose to a rotary screen (100 μm) and the resulting mince run through a screwpress (Model SD-8, Ikeuchi Tekkosho/Sano, Japan). The dehydrated mince was then run through a refiner (Model S1, Ikeuchi Tekkosho, Ltd. Japan) before mixing with cryoprotectants (4% sucrose, 5% sorbitol, and 0.3% sodium tripolyphosphate) in a Stephan chopper (Model 5289, Spephan Machinery Corp., Columbus, OH) for 3 minutes at low speed setting (1500 rpm). Two batches of frame meat surimi were made, using the WJD. In one of the batches no salt was added to the slurry (WJD1), but in the other 0.2 % NaCl was added (WJD2).

For the MD system the recovered mince from a Model 805 Ikeuchi mechanical deboner (Ikeuchi Tekkosho, Ltd. Japan) was washed twice in cold water (<5°C ) for 5 minutes, using a water/meat ratio of 3:1 for the first wash and 2:1 for the second wash. Following each washing, the mince was dewatered in the rotary screen (100 μm) and then run through the same dewatering, refining and cryoprotectant mixing procedure as the WJD mince. The surimi from the three recovery processes (WJD1, WJD2 and MD) was formed into approximately 3 cm thick blocks and packed in polyethylene bags.
before freezing and storing at -18°C. Sample preparation for each process was carried out in duplicate.

To determine process yield for the WJD and MD systems, samples from both the solid and liquid phase for all process steps were collected. The samples were vacuum-packed and then stored in a -40°C freezer until analyzed. Moisture, protein, and ash content were measured according to AOAC (1990). Total protein was determined by the Kjeldahl method and was calculated using total nitrogen (N) x 6.25.

**Surimi gel preparation**

After 1 and 6 mo storage (-18°C) the surimi blocks were thawed at room temperature for 2-3 hr. Gels were made from frame mince surimi (WJD1, WJD2, MD), control surimi (C), and mixtures of both, which included 10% frame, 90% commercial and 20% frame, 80% commercial respectively. The control (C) used was a FA grade (high quality) commercial surimi obtained from a local surimi manufacturer. The control surimi was manufactured July 28th 1998. Before gel preparation, moisture content of the surimi was measured using Model AD-4914A Infrared moisture determination balance (A&D Co., Ltd. Tokyo, Japan). Based on the measured moisture content all samples were adjusted to 78% moisture using ice. In addition, 2% NaCl was added to the mince as well as 1.5% beef plasma protein, which functioned as a protease inhibitor. During the chopping/mixing the temperature was maintained at or below 8°C using a refrigerated circulator (RTE-100LP, Neslab Instruments, Inc., Newington, NH). The paste was packed in polyethylene bags and extruded into stainless steel cooking tubes (i.d. = 19 mm) using a sausage stuffer (Model 14208, The
Sausage Maker, Buffalo, NY). The paste was heated at 90°C for 15 min followed by chilling in ice water for 1 hr. The gels were stored at 4-5°C in a refrigerator overnight prior to gel analysis.

**Torsion test**

Gels were allowed to reach room temperature and milled into hour-glass shapes (min diameter = 10mm) using a torsion sample milling machine (Gel Consultants, Model 91, Raleigh, NC). Samples were subjected to torsional shear in a Hamann torsion gelometer (Gel Consultants, Raleigh, NC). Shear stress and shear strain values at failure were calculated using the equations of Hamann (1983). For each treatment, 5-10 samples were analyzed.

**Color measurement**

A Minolta Chroma Meter CR-300 (Minolta Camera Co. Ltd., Osaka, Japan) was used to measure the color of the gels (3 samples from each treatment). CIE L*, a*,b* values were measured, where L* represents lightness, a* green/red and b* blue/yellow.

**Statistical analysis**

Analysis of variance (ANOVA) was conducted on torsion and color data to determine the significance of treatments, using STATGRAPHICS version 6 (STATGRAPHICS, Manugistics, Inc., Rockville, MD). Fisher’s least significant difference (LSD) at p≤0.05 was used to determine the significant difference between mean values. With this method there is a 5.0% risk of calling each pair of means significantly different when the actual difference equals 0.
Results and discussion

Process yield comparison

As a result of manual trimming, the maximum recoverable meat from the frames was 43%. Meat removal efficiency from the WJD and MD systems was 40% and 47.5% respectively. The MD meat removal, which exceeded the maximum possible meat content, suggest the MD is adding non-meat components like bones, skin and viscera residuals to the mince. The MD process also showed the highest process yield (washed, dewatered, refined mince prior to cryoprotectant addition), 24% of frame weight, while the WJD method only showed about 5% yield (Fig. 2.1). The MD process yield indicates that mechanical deboning of Pacific whiting frames can lead to a yield increase of 3.8% whole fish weight, which could give a 15-19% yield increase in surimi manufacturing, depending on filleting efficiency. Optimum operation conditions for the WJD system were 55 bar water pressure and 14 m/min conveyor speed (water jet exposure time = 0.96 sec/frame). The WJD systems used 1330-1510 L water for every 100 kg frames (Fig. 2.2. and Fig. 2.3), while the MD system only used 260 L (Fig. 2.4). Difference in recovery between the two systems mainly results from the high losses of meat in the de-watering steps of the WJD process (Fig. 2.1). Meat losses in the rotary screen were 82.5% and 73.8% for the WJD1 and WJD2, respectively. The 0.2% salt addition to the slurry in the WJD2 process resulted in a visible difference in protein precipitation and can probably account for the reduced loss of protein in the rotary screen. Several studies have indicated that losses of myofibrillar proteins during washing, could be reduced by using 0.1-0.3% salt in the washing process (Lin and Park,
Fig. 2.1 – Process yield for the three Pacific whiting frame meat recovery systems. WJD1: Water jet deboning, WJD2: Water jet deboning with 0.2% NaCl added to slurry, MD: Mechanical deboning. Names of process steps according to Fig. 2.2-2.4. Mince percentage of total frame weight is based on 85% moisture.
Fig. 2.2 - Mass balance for water jet deboning (WJD1) of Pacific whiting frames.
Fig. 2.3 - Mass balance for water jet deboning of Pacific whiting frames with 0.2% NaCl added to slurry (WJD2).
Fig. 2.4 – Mass balance for mechanical deboning (MD) of Pacific whiting frames.
1996a; Park, 1995a). For the MD process the meat loss after two washing and
dewatering steps was only 37%. This protein loss is in the 30-45% range reported by
Pacheco-Aguilar et al. (1989) and MacDonald and Lanier (1988).

**Surimi composition**

Compositional properties of frame meat and frame meat surimi are presented in
Table 2.1. For all the surimi types processed, there were difficulties bringing the
moisture content down to 74-75%. The moisture content for WJD1 and MD was
83.29% and 79.63% respectively, while the moisture content for WJD2 was
significantly lower (76.88%). This indicates that the salt addition in the WJD2 process
facilitated the dewatering process.

When investigating unwashed Alaska pollock frame meat, Crapo and
Himelbloom (1994) reported high ash content (6.2%), due to introduction of bone
fragments. As seen in Table 2.1, bone fragments were not a problem in this study. The
ash content was reduced from 1.03% in the fish down to 0.45-0.72% in the surimi. This
agrees with results from Pacheco-Aguilar (1986), who reported that ash content could
be reduced by 60-80% during surimi washing. The additional refining step in the surimi
process is likely to reduce the amount of bone fragments in surimi, compared to
unwashed mince. Deboner type and belt pressure applied to the frames are also likely to
cause different levels of bone fragments in the mince.
Table 2.1 - Compositional properties of Pacific whiting frame meat and surimi.

<table>
<thead>
<tr>
<th></th>
<th>Moisture (%)</th>
<th>Protein (%)</th>
<th>Ash (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame meat</td>
<td>85.01±0.32</td>
<td>12.72±1.07</td>
<td>1.03±0.03</td>
</tr>
<tr>
<td>WJD1 surimi*</td>
<td>83.29±0.51</td>
<td>6.73±1.42</td>
<td>0.50±0.02</td>
</tr>
<tr>
<td>WJD2 surimi*</td>
<td>76.88±0.73</td>
<td>12.81±1.29</td>
<td>0.72±0.02</td>
</tr>
<tr>
<td>MD surimi*</td>
<td>79.63±0.16</td>
<td>10.32±1.34</td>
<td>0.45±0.02</td>
</tr>
</tbody>
</table>

*All frame meat surimi contains 9.3% cryoprotectants
Gel texture

Highest shear strain was 2.49 for the gels made from WJD1 surimi stored for 1 mo (p<0.05). The other frame meat surimi gels and the control (C) had shear strain values in the range of 2.05-2.32 (Fig. 2.5) and were not found to be statistically different. In addition, no significant difference in shear strain was found when gels from frame meat surimi stored for 1 and 6 mo, respectively, were compared, except for WJD1. On the other hand, shear strain for the C decreased from 2.20 to 1.44, which also lowered the shear strain of the gels made from the mixtures of 6 mo stored surimi. According to Hamann et al. (1990), acceptable surimi should have a minimum shear strain value of 2.0.

The highest shear stress, 23.9 kPa, was found for C stored for one mo. This was approximately twofold higher than the shear stress for the frame meat surimi gels (Fig. 2.6). When preparing the gels 1.5% BPP was added to all surimi. It was not known that the control already contained 1.1% BPP as a part of the ingredients mixture. When the moisture of the control surimi had been adjusted to 78% moisture the total BPP content was therefore about 2.3%. From data presented by Morrissey et al. (1993) it can be estimated that this increase in BPP concentration could increase shear stress approximately 15% but should not affect shear strain significantly. The corrected shear stress for the control would therefore be approximately 21 kPa.

Of the frame meat surimi gels, 6 mo WJD1 had the lowest shear stress, 9.1 kPa. The other frame meat gels were not significantly different in shear stress, ranging from 12.1 kPa to 14.2 kPa. As with shear strain, the control showed a significant decrease in shear stress from 1 to 6 mo frozen storage. Later, it was determined that the control (FA
grade Pacific whiting surimi) had been accidentally mixed with insufficiently washed frame meat in the processing plant. The supplier experienced similar quality reduction, and had to lower the quality grade of this surimi. The plant has now made necessary improvements in their processing to avoid future occurrences of this problem. The control used in this study is therefore of lower quality than ideal commercial surimi.

In previous Pacific whiting surimi gel studies, shear strain has been 2.1-2.4 for surimi processed in our laboratory (Simpson et al., 1994) and 2.5-2.7 for FA grade commercial surimi (Park, 1995b; Yoon et al., 1997). Shear stress for gels made from surimi processed in the laboratory and FA grade commercial surimi were reported as 12-15 kPa (Simpson et al., 1994) and 30-38 kPa (Park, 1995b; Yoon et al., 1997).

Other studies, however, have not agreed when comparing the quality of frame meat surimi and commercial surimi. When studying Channel catfish frame meat, Kim et al. (1996) reported that compressive force values for the surimi gels were comparable to that of commercial Alaska pollock surimi gels. Kim, however, did not report how long the surimi was stored at -20°C prior to gel testing. Hastings et al. (1990), used folding test, Correx strain gauge, puncture test, compressive test and sensory panel to compare gel quality of several types of frame meat surimi and fillet surimi. In all cases, the frame meat surimi showed very low gel strength and textural quality compared to the fillet surimi.
Fig. 2.5 – Shear strain for Pacific whiting surimi gels. WJD1: Surimi from water jet deboning, WJD2: Surimi from water jet deboning with 0.2 NaCl added to slurry, MD: Surimi from mechanical deboning, C: Commercial surimi. Ratios 10/90 and 20/80 indicate mixtures of frame meat surimi/commercial surimi. Hatched bars represent 1 mo storage and solid bars 6 mo.
Fig. 2.6 – Shear stress for Pacific whiting surimi gels. WJD1: Surimi from water jet deboning, WJD2: Surimi from water jet deboning with 0.2 NaCl added to slurry, MD: Surimi from mechanical deboning, C: Commercial surimi. Ratios 10/90 and 20/80 indicate mixtures of frame meat surimi/commercial surimi. Hatched bars ☐ represent 1 mo storage and solid bars ■ 6 mo.
**Color**

After 1 mo storage, WJD2 gels showed lightness (L*) of 71.29, which was significantly (p<0.05) lower than the lightness for the other frame meat surimi gels and the control (Table 2.2). Lightness for all gels showed a general decreasing trend from 1 to 6 mo storage time, although this trend was not statistically different for all samples. After 6 mo gels made from MD surimi had the highest lightness 75.26, but the WJD1 and WJD2 showed the lowest. Decrease in lightness during frozen storage The majority of the gels made from the mixtures (frame meat surimi/control) did not show a significant difference in lightness compared to the control. Gels made from WJD1 surimi showed lowest yellowness (b*) values, 1.16 and 1.65 after 1 and 6 mo storage, respectively, while the control showed the highest. No significant increase in yellowness was found with increased storage time (p<0.05). When Hastings et al.(1990) compared frame meat surimi and fillet surimi of several fish species, frame meat surimi had lower L* values, higher a* values, but similar b* values as the fillet surimi.
Table 2.2 – Color of Pacific whiting surimi gels as affected by storage time.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1 month</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L*</td>
<td>b*</td>
</tr>
<tr>
<td>WJD1 100</td>
<td>74.17±0.63</td>
<td>1.16±0.26</td>
</tr>
<tr>
<td>WJD1 10/90</td>
<td>75.18±0.63</td>
<td>2.26±0.26</td>
</tr>
<tr>
<td>WJD1 20/80</td>
<td>74.08±0.63</td>
<td>2.00±0.26</td>
</tr>
<tr>
<td>WJD2 100</td>
<td>71.29±0.63</td>
<td>2.19±0.26</td>
</tr>
<tr>
<td>WJD2 10/90</td>
<td>73.72±0.63</td>
<td>2.41±0.26</td>
</tr>
<tr>
<td>WJD2 20/80</td>
<td>73.59±0.63</td>
<td>2.50±0.26</td>
</tr>
<tr>
<td>MD 100</td>
<td>75.26±0.63</td>
<td>1.91±0.26</td>
</tr>
<tr>
<td>MD 10/90</td>
<td>76.08±0.63</td>
<td>2.50±0.26</td>
</tr>
<tr>
<td>MD 20/80</td>
<td>74.06±0.63</td>
<td>2.87±0.26</td>
</tr>
<tr>
<td>C 100</td>
<td>73.25±0.45</td>
<td>2.73±0.18</td>
</tr>
</tbody>
</table>

WJD1: Surimi from water jet deboning, WJD2: Surimi from water jet deboning with 0.2 NaCl added to slurry, MD: Surimi from mechanical deboning and C: Commercial surimi. Ratios 10/90 and 20/80 indicate mixtures of frame meat surimi/commercial surimi.
Conclusion

The project results indicate that mechanical deboning of Pacific whiting frames can lead to a yield increase of 3.8% whole fish weight, which could give a 15-19% yield increase in surimi manufacturing, depending on filleting efficiency. Water jet recovery systems showed considerably less recovery, mainly due to high losses in the rotary screen. We experienced difficulties, however, in dewatering the frame meat mince to the standard surimi moisture content of 74-75%. This could be caused by moisture absorption in the frame meat during pre process storage or deficiency in dewatering equipment. Color and shear strain values for the recovered surimi gels from WJD1 and MD, indicated acceptable quality compared to the control (C), while shear stress values were significantly lower than those for C. This low shear stress is probably due to a difference in processing equipment and processing conditions between the lab scale and commercial scale. Addition of NaCl to slurry increased WJD2 yield, but resulted in reduced surimi color quality.

Mixing frame meat surimi with C, resulted in gels that had equal or lower shear strain than gels made from 100% frame meat surimi or C, respectively. However, gels from mixtures of frame meat surimi and C, showed higher shear stress than 100% frame meat surimi gels, reaching 65-95% of the shear stress of C.

The main conclusion of this research is that Pacific whiting frame meat can be successfully recovered using the MD system. The resulting surimi is comparable to commercial FA grade surimi, except in shear stress.
References


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Chapter 3

EFFECTS OF KIDNEY BLOOD CONTAMINATION ON QUALITY OF SURIMI FROM MECHANICALLY DEBONED WHITING FRAMES

A. Wendel, J. W. Park, K. Kristbergsson, and E. Kolbe
Abstract

Utilization of mechanically deboned frame meat has been limited, due to severe protein denaturation and textural changes during frozen storage. This denaturation is caused by enzymatic contamination from kidney tissue and blood, which is introduced to the mince when the backbone breaks in the deboning process.

The focus of the study is to examine the effect of removing kidney tissue prior to deboning on surimi quality during frozen storage. Pacific whiting frames were mechanically deboned with/without kidney and the frame mince further processed into surimi. After storing the surimi at -18°C for 1 and 6 mo, surimi gels were analyzed for gel strength and color. At 1, 2, 4, and 6 mo, salt extractable proteins (SEP) concentration, dimethylamine (DMA) formation and pH were measured to monitor protein denaturation.

Removal of kidney from Pacific whiting frames prior to deboning resulted in higher gel strength, but similar rate of protein denaturation during frozen storage. Frame meat surimi gels showed low shear stress, but acceptable shear strain and color when compared to commercial Pacific whiting surimi.

KEYWORDS: Frame meat, surimi, surimi quality, protein denaturation
Introduction

Presently, only 20-25% of whole fish weight is utilized when Pacific whiting is processed into surimi. The solid fish waste resulting from the process is either utilized for animal feed or fertilizers. Otherwise it is discarded. Frames, the residual portion of the fish after filleting headed and gutted fish, are considered 15-17% of the whole fish weight (MacDonald and Lanier, 1988; Crapo et al., 1988; Anonymous, 1988). In a previous study water jet (WJD) and mechanical deboning (MD) of Pacific whiting frames was undertaken to determine recovery rates and quality of recovered meat (Wendel et al., 1999). The maximum recoverable meat by manual trimming was 43%. Meat removal efficiency of the MD systems was determined to be 47.5% of total frame weight, resulting in a process yield (washed, dehydrated, refined mince prior to cryoprotectant addition) of 24% of total frame weight. In 1998, the total catch of Pacific whiting for the West Coast was 318,300 metric tons, resulting in approximately 47,700-54,100 metric tons of frames. By recovering frame meat using the MD system 12,800-14,500 metric tons of surimi could be processed. The MD process added small amounts of non-meat components like bones, skin and viscera residuals to the mince, but washing and refining steps in the subsequent surimi process removed most of these components. In unwashed mince, potential problems include impurities, high ash content due to bone fragments, low color quality and textural changes during frozen storage (Crapo and Himelbloom, 1994).

Many of the chemical and textural changes that take place in frame mince during frozen storage are believed to be caused by enzymatic and microbial contamination
from the kidney or kidney blood (Kristbergsson, 1998, Chang and Regenstein, 1997; Jahncke et al., 1992; Hultin, 1992; Dingle and Hines, 1975). When the frames are subjected to MD the bone column breaks and the large, reddish colored kidney, located under the backbone column mixes with the mince and contaminates the product (Kristbergsson, 1998). Kidney and kidney blood contain high concentrations of the enzyme trimethylamine oxide demethylase (TMAO-e). This enzyme, when introduced to the mince, increases breakdown of trimethylamine oxide (TMAO) into dimethylamine (DMA) and formaldehyde (FA) during frozen storage (Amano and Yamada, 1964). Formaldehyde is then postulated to interact with proteins causing toughening and loss of functional properties in fish fillets and mince (Hultin, 1992).

Kim et al. (1996) found that washing of Channel catfish frame mince and addition of cryoprotectants significantly improved the quality of the mince. The surimi gels made from the mince had compression stress values comparable to commercial Alaska pollock surimi gels and acceptable color. When making surimi from whiting, haddock and saith frame meat, Hastings et al. (1990) experienced high counts of impurities, higher fat content, decreased water holding capacity and reduced gel strength compared to fillet surimi. Hastings reported surimi yield in the range 26.7 - 40.6% (of total frame weight) for haddock and whiting frames respectively, while Kim et al. (1996) achieved 16% surimi yield from the catfish frames.

Jahncke et al. (1992) improved the quality of unwashed cod frame mince by removing the kidney tissue prior to deboning. Removal of kidney tissue decreased DMA formation and Instron hardness during frozen storage, but those properties were
also affected by storage time of the frames on ice prior to processing. Kidney removal also increased the lightness (L*) and lowered the yellowness (+b*) of the mince.

The main objective of this study was to compare the quality of surimi and surimi gels made from Pacific whiting frames with/without kidney tissue to commercial surimi and surimi gels. Another objective was to monitor protein denaturation in the surimi during frozen storage using salt extractable protein (SEP) concentration, DMA formation and pH changes.

Materials and Methods

Surimi sample preparation

For each experiment, 50-100 kg of Pacific whiting frames were collected from a Baader 182 filleting machine at a local surimi processing plant in September 1998. Fish had been harvested and stored in refrigerated sea water (RSW) less than 18 hrs prior to processing. Two batches of frames (50-100 kg) were compared. For one batch, the kidney was removed by knife and kidney blood cleaned by brushing the frames in running water. In the other, the frames were not subjected to any cleaning. Both batches were stored on ice overnight prior to deboning.

After deboning (Model 805 Ikeuchi mechanical deboner, Ikeuchi Tekkosho, Ltd. Japan), the mince was washed twice in cold water (<5°C) for 5 min, using water/meat ratio 3:1 for the first wash and 2:1 for the second wash. Following each wash, the mince was dewatered in a rotary screen (100 µm) and the resulting mince run through a screwpress (Model SD-8, Ikeuchi Tekkosho/Sano, Japan). The dehydrated mince was then run through a refiner (Model S1, Ikeuchi Tekkosho, Ltd. Japan) before mixing it
with cryoprotectants (4% sucrose, 5% sorbitol and 0.3% sodium tripolyphosphate) in a Stephan chopper (Model 5289, Stephan Machinery Corp., Columbus, OH) for 3 min at low speed setting (1500 rpm). The surimi was formed into ≈ 3 cm thick blocks and packed in polyethylene bags before storage at -18°C. Sample preparation for each treatment was carried out in duplicate. The surimi from the prewashed frames, with the kidney removed, was labeled WF and the unwashed frame surimi was labeled F.

Samples from the frame meat and from the surimi product were collected, vacuum-packed and then stored in a -40°C freezer for proximate analysis. Moisture, protein and ash content were measured according to AOAC (1990). Total protein was determined by the Kjeldahl method and was calculated using total nitrogen (N) x 6.25.

Salinity and pH

Meat from 20 frames was manually removed and homogenized in an Osterizer blender (Model 860-61K, Oster Corporation, Milwaukee, WI). The pH was measured directly from the homogenized fish samples using a Corning pH/ion analyzer 240 (Corning, NY). The same method was used to measure the pH in the surimi. Salinity was measured using an Oakton TDSTester #3 (Oakton, Singapore) from 20-fold water diluted samples, filtered through Whatman #54 filter paper. A standard curve was made using 0.01-0.05 % NaCl solutions.

Surimi gel preparation

After 1 and 6 mo storage (-18°C), the surimi blocks were thawed at room temperature for 2-3 hrs. Gels were made from frame mince surimi, control surimi, and mixtures of both, which included 10% frame mince, 90% commercial and 20% frame
mince, 80% commercial, respectively. The control (C) used was a FA grade (high quality) commercial surimi obtained from a local surimi manufacturer. Due to a short Pacific whiting surimi season in 1998, the control was 2 mo old at the time the experiment began. Therefore the control had been stored for 3 and 8 mo, when the frame meat surimi was analyzed after 1 and 6 mo frozen storage. Before gel preparation, moisture content of the surimi was measured using Infrared moisture determination balance (Model AD-4914A, A&D Co., Ltd. Tokyo Japan). Based on the measured moisture content all samples were adjusted to 78% moisture using ice. In addition, 2% NaCl was added to the mince as well as 1.5% beef plasma protein, which functioned as a protease inhibitor. The chopping/mixing was carried out under vacuum (0.6 bar) in a Stephan silent cutter (Model 5289, Stephan Machinery Corp., Columbus, OH). During chopping the temperature was maintained at or below 8°C using a refrigerated circulator (RTE-100LP, Neslab Instruments, Inc., Newington, NH). The paste was packed in polyethylene bags and extruded into stainless steel cooking tubes (inner diameter = 19 mm) using a sausage stuffer (Model 14208, The Sausage Maker, Buffalo, NY). The paste was heated at 90°C for 15 min followed by chilling in ice water for 1 hr. The gels were stored at 4-5°C in a refrigerator overnight prior to gel analysis.

**Torsion test**

Gels were allowed to reach room temperature and milled into hour-glass shapes (min diameter = 10 mm) using a torsion sample milling machine (Gel Consultants, Model 91, Raleigh, NC). Samples were subjected to Hamann torsion gelometer (Gel
Consultants, Raleigh, NC). Shear stress and shear strain values at failure were calculated using the equations of Hamann (1983). For each treatment, 5-10 samples were analyzed.

**Color measurement**

A Minolta Chroma Meter CR-300 (Minolta Camera Co. Ltd., Osaka, Japan) was used to measure the color of the gels (3 samples from each treatment). CIE L*, a*, b* values were measured, where L* represents lightness, a* green/red and b* blue/yellow.

**Dimethylamine (DMA)**

DMA content was measured according to the method of Dyer and Mounsey (1945) with the following modifications: Toluene was used instead of benzene, 6% PCA instead of 6.25% TCA and the amount of copper ammonia reagent and acetic acid was increased by 1 ml. In addition, the shaking period, after heating, was increased from 5 to 30 min. DMA results were reported as mg DMA/100 g surimi, at 74% moisture content.

**Salt extractable proteins (SEP)**

Extraction of the salt soluble proteins was carried out according to the method of Jiang et al. (1985), with one exception. The mince sample size used, was 2.5 g and the mince was homogenized with 25 ml 0.6 M KCl solution using a Kinematic blender (Polytron H-6010, Switzerland). The samples were homogenized for 3 min and then centrifugated at 10,000 x g for 10 min. Supernatant was diluted (75-100x) before protein concentration was determined by Lowry assay (Lowry et al., 1951) using BSA as a standard. The SEP concentration was expressed as percentage of total proteins.
Statistical analysis

Analysis of variance (ANOVA) was conducted on test results to determine the significance of treatments, using STATGRAPHICS version 6 (STATGRAPHICS, Manugistics, Inc., Rockville, MD). Fisher’s least significant difference (LSD) at $p \leq 0.05$ was used to determine the significant difference between mean values. With this method there is a 5.0% risk of calling each pair of means significantly different when the actual difference equals 0.

Results and discussion

Surimi control behavior

At the end of the research it was determined that the control surimi (FA grade Pacific whiting surimi) had accidentally been mixed with insufficiently washed frame meat in the processing plant. The supplier experienced significant quality reduction in the product, and finally had to lower the quality grade of the surimi. This explains the exceptionally high DMA values, low SEP and reduced gel strength with increased storage time. After the 6 mo storage time, protein aggregation was clearly visible in the form of small separated granules.

Surimi composition

The frame meat had a moisture content of 85.01% (Table 3.1). This is considerably higher than the 81-82.5% moisture content that Sylvia et al. (1994) reported as the average for Pacific whiting harvested in September. The initial salt content in the frame meat was 0.62%. This indicates that the frame meat might have absorbed some water during the pre-process storage time.
Table 3.1 - Compositional properties of Pacific whiting frame meat and surimi.

<table>
<thead>
<tr>
<th></th>
<th>Moisture (%)</th>
<th>Protein (%)</th>
<th>Ash (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame meat</td>
<td>85.01±0.32</td>
<td>12.72±1.07</td>
<td>1.03±0.03</td>
</tr>
<tr>
<td>F surimi*</td>
<td>79.65±0.39</td>
<td>9.95±1.22</td>
<td>0.45±0.02</td>
</tr>
<tr>
<td>WF surimi*</td>
<td>80.10±0.52</td>
<td>9.60±1.13</td>
<td>0.45±0.02</td>
</tr>
</tbody>
</table>

F: Surimi from unwashed frames, WF: Surimi from washed, kidneyfree frames.
* All frame meat surimi contains 9.3% cryoprotectants
For the frame meat surimi, some dewatering difficulties were experienced and moisture content could not be brought down to 74-75%. The elevated moisture content, low ionic strength and deficiency in dewatering equipment are likely explanations for this. Lin and Park (1996a) reported that 0.25% NaCl added to the final wash water could increase recovery and facilitate dewatering. The ash content in the frame mince (after deboning) was 1.08%. This indicates that the mince yield of the mechanical deboner (47.5%), which is exceeding manually recovered meat yield from the frames (43%), results mainly from skin and viscera residuals and not bones. The ash content of the frame mince from this study was significantly lower than 6.2% reported by Crapo and Himelbloom (1994) for their mechanically deboned Alaska pollock frame mince. This indicates that types of deboners and pressure applied in the process can lead to different amounts of bone fragments introduced to the mince. Kidney and kidney blood contamination could very likely be affected by those same parameters.

**Shear stress and shear strain**

After 1 mo frozen storage there was no significant difference (p>0.05) in shear strain between the gels made from frame meat surimi and the control which at that time had been in frozen storage for 3 mo (Fig. 3.1). On the other hand, after 6 mo frozen storage, shear strain of the frame meat surimi gels had not changed significantly, while the gels made from the control (8 mo) had decreased approximately 50% in shear strain. At that time WF showed the highest shear strain.

The shear stress, however, showed a different trend (Fig. 3.2). After 1 mo, the WF surimi gels showed the highest shear stress 25.5 kPa, while the F gels had shear
Fig. 3.1 – Shear strain for Pacific whiting surimi gels. F: Surimi from unwashed frames, WF: Surimi from washed, kidneyfree frames, C: Commercial surimi. Ratios 10/90 and 20/80 indicate mixtures of frame meat surimi/commercial surimi. Hatched bars represent 1 mo storage and solid bars 6 mo.
Fig. 3.2 – Shear stress for Pacific whiting surimi gels. F: Surimi from unwashed frames, WF: Surimi from washed, kidneyfree frames, C: Commercial surimi. Ratios 10/90 and 20/80 indicate mixtures of frame meat surimi/commercial surimi. Hatched bars represent 1 mo storage and solid bars 6 mo.
stress of 14.2 kPa. At this time the control (3 mo) showed shear stress of 20.3 kPa. The shear stress for WF decreased to 15.7 kPa after 6 mo storage and at that time, was not significantly different to the shear stress of C (8 mo), but was still higher than F.

In previous Pacific whiting surimi studies, shear strain was reported as 2.1-2.4 for surimi processed in our laboratory (Simpson et al., 1994) and 2.5-2.7 for FA grade commercial surimi (Park, 1995b; Yoon et al., 1997). Shear stress for gels made from surimi processed in our laboratory and FA grade commercial surimi were reported as 12-15 kPa (Simpson et al., 1994) and 30-38 kPa, respectively (Park, 1995b; Yoon et al., 1997).

Hastings et al. (1990) used a punch test to evaluate gel quality for frame meat surimi gels processed from several British fish species. In this study, the best gel quality was from haddock frame surimi gels, with breaking force 168 gf and breaking distance 3.9 mm. These values can be converted into torsion test values, using relationships found by Park (1991), where:

\[
\text{Punch test breaking force (g)} = 5.43 \times \text{shear stress (kPa)} + 90.2 \\
\text{Punch test deformation (cm)} = 0.27 \times \text{shear strain} + 0.35
\]

The shear stress for the haddock frame meat surimi gel would then be approximately 14.3 kPa, but the shear strain only around 0.2. This shear strain is extremely low, which corresponds to Hastings report that all frame meat surimi gels were very soft. Another study by Kim et al. (1996) used an Instron testing machine to determine catfish surimi gel quality. Those results could not be converted to torsion test
form, but the investigators claimed that the compression force values were comparable to commercial Alaska pollock surimi gels.

Color

Gels made from frame meat surimi and commercial surimi did not show a significant difference in lightness (L*) and yellow (b*) values (Table 3.2). From 1 to 6 mo storage the surimi gels showed an increasing trend in b* values, although the difference was not statistically significant (p>0.05). In addition, compared to gel color of Pacific whiting surimi previously processed in our laboratory and commercial surimi, the frame meat surimi gels showed lower lightness values, L* = 73-75, compared to the L* = 77-80 for gels made from FA grade commercial surimi (Park, 1995c).

pH

Initial pH of the frame meat was 6.94. After 1 mo storage, the pH for F and WF surimi was 7.33 and 7.31 respectively (Fig. 3.3). The increase in pH between the frame meat and the surimi is due to the 0.3% sodium tripolyphosphate added as a cryoprotectant. During the rest of the storage time the pH decreased gradually, reaching 7.23 after 6 mo. Throughout the storage time no significant difference was detected in pH values between WF and F. The pH for the control, however, showed more stable behavior, decreasing from 7.07 after 3 mo to 7.02 after 8 mo. Unlike our observations on pH, literature values indicated that pH increased during frozen storage. Dingle and Hines (1975) reported that pH in unwashed cod frame mince increased from 7.1 to 7.45 during 17 days storage of the mince at -5°C. When Chang and Regenstein (1997)
Table 3.2 – Color of Pacific whiting surimi gels as affected by storage time.

<table>
<thead>
<tr>
<th></th>
<th>1 month</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L*</td>
<td>b*</td>
</tr>
<tr>
<td>F 100</td>
<td>75.25±1.30</td>
<td>1.91±0.38</td>
</tr>
<tr>
<td>F 10/90</td>
<td>76.08±1.84</td>
<td>2.50±0.71</td>
</tr>
<tr>
<td>F 20/80</td>
<td>74.06±1.28</td>
<td>2.87±0.24</td>
</tr>
<tr>
<td>WF 100</td>
<td>73.35±0.53</td>
<td>1.46±0.97</td>
</tr>
<tr>
<td>WF 10/90</td>
<td>73.70±0.86</td>
<td>2.37±0.58</td>
</tr>
<tr>
<td>WF 20/80</td>
<td>73.95±1.69</td>
<td>2.52±0.34</td>
</tr>
<tr>
<td>C 100</td>
<td>73.50±0.75</td>
<td>2.47±0.24</td>
</tr>
</tbody>
</table>

F: Surimi from unwashed frames, WF: Surimi from washed, kidneyfree frames, C: Control. Ratios 10/90 and 20/80 indicate mixtures of frame meat surimi/control. 1 3 months frozen storage, 2 8 months frozen storage.
Fig. 3.3 – pH for Pacific whiting surimi as affected by storage time. 
F: Surimi from unwashed frames, WF: Surimi from washed, kidneyfree frames, C: Control.
studied cod mince stored at -14°C for 12 weeks, they found pH to increase from 7.0 to 7.15 and 7.75, for fillet mince and mince with kidney tissue, respectively. For kidney contaminated mince with various cryoprotectants, the pH ranged from 7.4-7.6 at the end of the storage time. The difference in the pH results seems to be due to a difference in freezing temperatures and postmorten storage conditions.

**Dimethylamine (DMA)**

The frame meat surimi showed only detectable levels of DMA after 6 mo frozen storage, 7.6 mg/100g and 5 mg/100g for F and WF, respectively (Fig. 3.4). There was no significant difference (p>0.05) between the two treatments. The control showed rapid increase in DMA formation, reaching a value of 125 mg/g surimi after 6 mo and a final value of 218.1 mg/100g surimi after 8 mo storage. It has previously been shown that washing effectively reduces DMA formation in frame mince. Dingle and Hines (1975) reported that washed cod frame mince, without any cryoprotectants, showed only about 10% of the DMA formation in the unwashed frame mince, when stored at -5°C for 17 days. The same study also compared DMA formation in mince, contaminated either with kidney or kidney blood. The results showed that kidney tissue was more effective in DMA formation than kidney blood, although the latter also was found to contribute significantly. When Chang and Regenstein (1997) compared mince with/without kidney tissue after 12 weeks of storing at -14°C, the DMA was approximately 3 times higher for the kidney contaminated mince.
Fig. 3.4 – Dimethylamine (DMA) for Pacific whiting surimi as affected by storage time. F: Surimi from unwashed frames, WF: Surimi from washed, kidneyfree frames, C: Control.
The same investigators also reported that DMA formation in kidney tissue contaminated mince could be significantly reduced by using polydextrose or sodium hexametaphosphate and sugar/sorbitol mixture.

**Salt extractable protein (SEP) concentration**

After 1 mo the SEP for the WF surimi was 44%, a significantly higher value than the 36.1% measured for F (Fig. 3.5). The SEP values for F and WF after 2 and 6 mo storage time were not significantly different. All samples showed a decrease (p<0.05) in SEP concentration with increased storage time. The control showed surprisingly low SEP values, starting at 12.4% after 3 mo storage and decreasing to 7.3% after 8 mo storage.

Sych et al. (1990) monitored SEP changes in cod surimi with various cryoprotectants. Cod surimi with no cryoprotectants had initially 38.7% SEP (before freezing), but after 16 weeks storage at −20°C the SEP decreased to 20.3%. Cod surimi with 8% sucrose/sorbitol did not show significant changes in SEP over 16 weeks storage time. Park et al. (1988) determined that Alaska pollock surimi with 8% sucrose/sorbitol and 0.5% STP, decreased approximately 14% in SEP over the storage at −28°C for 8 mo. The 36-43% reduction of SEP of the frame meat surimi, therefore, seems high.

The behavior of the control surimi further emphasizes that utilization of frame meat in surimi, mixed with fillet mince or not, requires careful processing. Several factors must be considered. 1) Washing efficiency will affect the initial concentration of TMAO, TMOA-e and most of the cofactors that are necessary for the dimethylation
Fig. 3.5 – Salt extractable proteins (SEP) for Pacific whiting surimi as affected by storage time. F: Surimi from unwashed frames, WF: Surimi from washed, kidney-free frames, C: Control.
(Hultin, 1992, Dingle and Hines, 1975). 2) Mixing frame meat with fillet mince prior to frozen storage could be critical. Dingle et al. (1977) reported that the addition of 20% of fish tissue that had the enzymic dimethylation system to 80% tissue that did not contain active enzyme, produced as much TMAO dimethylation as in the enzyme-rich tissue itself. Washing, however, should decrease this problem by reducing the TMAO-e concentration in the frame mince and the cofactors concentration in the fillet mince. 3) Effects of cryoprotectants and other surimi ingredients on dimethylation. Sodium tripolyphosphate (STP) 0.3% is commonly used as cryoprotectant in Pacific whiting surimi and 1-1.5% beef plasma protein (BPP) is also added as protease inhibitor. Hultin (1992) reported that dipping red hake fillets in STP accelerated dimethylation. Hultin also listed hemeproteins (hemoglobin and myoglobin), along with Fe⁺², as some of the potential cofactors involved in the decomposition of TMAO to DMA and FA. BPP is likely to contain some of these substrates and could therefore induce the reaction. 4) Surimi quality could also be more vulnerable to pre-process storage conditions if the frames need to be stored prior to processing. Several studies have shown elevated alkaline protease activity in frame meat, kidney tissue and kidney blood (Lin and Lanier, 1980, Rehbein, 1988). This protease activity has been related to softer texture of cooked fillets and gel strength reduction in PW surimi gels (Morrissey et al., 1993). Protease activity does not only occur at elevated temperatures. Lin and Park (1996b) reported that 24 hr storage of whole PW at 0°C resulted in 30% degradation of myosin heavy chains. This degradation can lead to lower process yield due to higher solubility and cause reduced gel forming properties (Park et al., 1997). Because of higher protease activity, frame meat could be sensitive to storage time prior to processing.
Conclusion

Removal of kidney tissue prior to mechanical deboning, resulted in higher shear stress and shear strain when surimi gels were compared after 1 and 6 mo frozen storage. On the other hand, no difference was detected in color, SEP concentration, DMA formation and pH, with the exception of SEP concentration after 1 mo, which was higher for the WF surimi. Shear strain and color of frame meat surimi was close to that of control surimi, but shear stress was significantly lower. However, as the control surimi underwent severe protein denaturation during frozen storage, results for the control from 8 mo storage time are likely to indicate lower quality of the control than undefected commercial surimi would have given.
References


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CONCLUSION

Maximum recoverable meat from Pacific whiting frames was approximately 43% of total frame weight. The two deboning systems, WJD and MD, successfully removed most of this meat from the frames. When the recovered meat was processed into surimi, the WJD system showed about 5% process yield (dewatered, refined mince prior to adding cryoprotectants) while the MD system achieved 24% process yield. The difference in yield was mainly due to high protein loss in the WJD dewatering steps.

After 1 and 6 mo frozen storage, quality of the frame mince surimi gels was comparable to the control (FA grade commercial surimi), except in shear stress. The lower shear stress values were probably due to differences in processing equipment and processing conditions between the lab scale and commercial scale.

Removing the kidney and washing the frames, prior to deboning, resulted in higher shear stress and shear strain when surimi gels were compared after 1 and 6 mo frozen storage. When protein denaturation in the surimi during frozen storage was monitored with SEP concentration, DMA formation and pH, no significant difference was found between the two treatments.

In conclusion, meat from Pacific whiting frames meat can be successfully recovered using the MD system. Utilizing the frame meat for surimi processing could result in approximately 4% yield increase of whole fish weight. The quality of the frame surimi is comparable to commercial FA grade surimi, except in shear stress.
BIBLIOGRAPHY


Appendix

AN ENGINEERING STUDY OF THE WATER JET DEBONING SYSTEM

A. Wendel, E. Kolbe and J. W. Park
1. Introduction

This appendix contains an engineering study of the water jet deboning (WJD) system. The objective of this study is to record what work has been done with the WJD system and to make recommendations for future research so a better system can be developed. The study is divided into 4 sections. In section 2 the WJD system is described and a review of previous WJD studies is presented. Section 3 contains results from work done with Pacific whiting here at the OSU Seafood Laboratory. In section 4 an engineering analysis of the system is carried out. The system design parameters, processing parameters and dewatering options are specified and their effects on the process speculated. Section 5 contains a summary including recommendations for future testing of the system.

2. Previous WJD studies

System description

In Fig. 1 the design of the WJD system is explained. The frames are fed by an elevator conveyor onto the upper conveyor belt (1). The belt transports the frames under the first set of high pressure nozzles (2). When the frames reach the end of the conveyer belt, they are guided down a chute (3) which turns the frames over while moving them to the lower conveyor belt (4). The lower conveyor belt moves the frames under the second set of nozzles (5). The frames (bones without meat) are then transported from the end of the lower conveyor belt into an offal bin. The fish particles, which are removed from the frames, are carried with the water into a rotary screen (6). Skins and bones are removed from the mince by forcing the mince through the screen openings by means of
a heavy metal cylinder that rotates freely inside the screen. From the rotary screen, the slurry (meat and water) goes into a holding tank (7) located under the screen. There a pump, activated by a high level sensor, moves the slurry into bigger holding tanks or to dewatering systems. Both conveyor belts (1,4) are made of polyethylene (PE) with 4 mm openings (38% open surface) for the meat particles to pass through (series 900 open grid plastic modular chain, Introlux, Amsterdam, Netherlands). The nozzles (2,5) are a rotating pencil jet type (model ST 57-2, Suttner, Bielefeld, Germany), creating a high speed water beam that rotates on the conveyor surface in approximately 50 mm diameter circles. The water jet angle is 15° and the nozzle clearance (height above conveyor) is approximately 100 mm. Three nozzles are in each set. Inside the screen, a high pressure stationary fan nozzle (8) is located to flush the mince through the perforation. To prevent clogging, eight low pressure nozzles (9) are lined up on the outside of the screen. The slurry pump in the holding tank is a high speed centrifugal pump. All structural parts of the machine are made of stainless steel.

Previous WJD studies

The Project Water Jet Deboning was a four year NordFood Program supported by the industry, The Nordic Industry Fund and by the national science funds of Iceland, Norway and Sweden. The project was divided into two parts; 1) meat recovery from fish backbones, and 2) meat recovery from bones of various farmed animals (backbones from pigs and cattle, turkey legs, pig heads). The results are presented in a final NordFood project report by Kristbergsson (1998). This chapter is completely based on that report.
<table>
<thead>
<tr>
<th>Part #</th>
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<tbody>
<tr>
<td>1</td>
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<td>2</td>
<td>1st high pressure nozzle set</td>
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<td>3</td>
<td>Chute</td>
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<tr>
<td>4</td>
<td>Lower conveyor belt</td>
</tr>
<tr>
<td>5</td>
<td>2nd high pressure nozzle set</td>
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<tr>
<td>6</td>
<td>Rotary screen</td>
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<tr>
<td>7</td>
<td>Holding tank</td>
</tr>
<tr>
<td>8</td>
<td>Stationary high pressure nozzle</td>
</tr>
<tr>
<td>9</td>
<td>Stationary low pressure nozzles</td>
</tr>
</tbody>
</table>

**Fig. 1** - Outline of the Water jet deboning system for fish frames.
In part 1 that directly relates to this study, the fish meat recovery experiment was carried out in three steps; I) nozzle type selection, II) processing parameters optimization (water pressure, conveyor speed and salt addition), and III) dewatering method selection.

As surimi is not currently produced in Iceland, where most of the study took place, the product from the WJD system was aimed to be used for fish-burgers, fish-sticks, and other related mince products.

System setup

In the experiments that the Nordfood group performed, the following system setup was used. From the WJD holding tank the slurry was pumped to two settling tanks. There the slurry was allowed to settle for 30 min before taken to a rotary screen with a mesh size of 0.4 mm. The mince was then further dewatered in a gravitational plate sieve (using cheese cloth) for 15 min before going to a final dewatering in a screw press. The experimental design used in the study is described in Fig. 2.

I. Nozzle type selection

Three types of nozzles were compared;

1) Nozzles with rotating pencil jets (model ST 57-2, Suttner, Bielefeld, Germany). Two sets of 3 nozzles were used, one for each side of the frames.

2) Nozzles with oscillating fan jets (model not specified in reference). Two sets of 3 nozzles were used, one for each side of the frames.

3) Nozzles with stationary fan jets (model not specified in reference). Two nozzles were used, one for each side of the frames.

The nozzles were compared with respect to i) process yield, ii) water usage, and iii) particle size of the discharge slurry from the WJD machine. The process yield was
I. Nozzle selection

![Diagram](image)

Nozzle type → WJD → Process yield (Dewatered mince weight/frame weight) → Water usage (L/dewatered mince kg) → Particle size (mm/particle)

II. Process optimization

![Diagram](image)

Water pressure, Conveyor speed → WJD → Rotating pencil jets → Dewatering → Process yield (Dewatered mince weight/frame weight) → Moisture content (moisture % of dewatered mince) → Particle size (mm/particle)

III. Dewatering method selection

![Diagram](image)

Decanter, Slot strainer, Rotary screen → Dewatering → Process yield (Dewatered mince weight/frame weight) → Moisture content (moisture/dewatered mince)

Fig. 2. – Experimental design for the NordFood WJD study
determined as weight ratio of end product (dewatered mince) to fish frame feed weight and corrected to 82% moisture content. Water usage was recorded as total liters water used in the system per kilogram end product. Particle size was compared by using staining process and stereoscopes/microscopes that were connected to high resolution video cameras from where the pictures could be transported to computers for further processing. Unfortunately the Nordfood report did not specify some important design factors, i.e. nozzle placement and nozzle clearance (height above the conveyor).

The results were that at a water jet pressure of 60 bar the rotating pencil jet nozzles gave the highest process yield, approximately 15.5% compared to 7% of the two other nozzle types. The lowest water usage (L per kg dewatered mince) was found for rotating pencil jets and stationary fan nozzles, 26 L/kg and 40 L/kg respectively. Particle size was not significantly different between the three nozzle types. Figures 3 and 4 present results for water usage and yield for the three nozzle types. The researchers reported that when the rotating pencil jet nozzles were used they counted for approximately 60% of the total water usage in the system, while the nozzles inside and outside of the WJD rotary screen used 40%.

II. Process parameters optimization

In this part of the study, tests were run according to a central composite experimental design which falls under response surface methodology (RSM) experimental design with three factors (water pressure, conveyor speed and salt addition) at 5 levels. As a result of the nozzle type study, rotating pencil jet nozzles were used. The water pressure was varied 63, 66, 69,72, and 75 bar, while the conveyor was run at 6, 10, 14, 18, and 22 m/min.
Fig. 3 - Water usage for different nozzle types at 60 bar.
1: Rot. pencil jet, 2: Osc. fan jet, 3: Stat. fan jet

Fig. 4 - Yield for different nozzle types at 60 bar.
1: Rot. pencil jet, 2: Osc. fan jet, 3: Stat. fan jet
In the settling tanks the salt concentration was adjusted to 0, 0.15, 0.25, 0.45, and 0.9% (w/v). The settling time was 1 hour.

The results from the processing parameter optimization are presented in figure 5 and 6. Reduction of conveyor speed increased yield and salt addition proved an important factor for yield and moisture content reduction. When salt addition was evaluated with conveyor speed, the highest yield was found at salt concentration up to 0.5% and conveyor speed of 6 m/min. Lowest moisture content achieved was 84.6% also with 0.5% salt addition. When water pressure was also considered, the results were more complex. This was evident when the yield was plotted as a function of water pressure and salt addition (Fig. 5) and as a function of water pressure and conveyor speed (Fig. 6). Two optimums seemed to exist. One at 63 bar and approximately 14 m/min and another one at 75 bars approximately 10 m/min. However, due to the design of the experimental procedure no replicas (only one measurement) were behind the two extreme pressure values (63 and the 75 bars). The meat removal from the frames was on average 22.5% of the total frame weight. The process yield was about 9.6% on average.

When determining effects of water pressure and salt addition on particle size the researchers used the same salt concentration range as before but ran the system at water pressure 30, 40, 50 and 60 bars. Generally there seemed to be a trend indicating that higher pressure (60 bar) resulted in smaller particle size (length = 0.9 mm) when compared to particle size (length = 1.2 mm) from lower pressure (30 bar) settings. However due to high standard deviation the difference was not statistically significant. Neither did salt concentration have significant effects on particle size.
Fig. 5 – Yield as a function of water pressure and added salt.

Fig. 6 – Yield as a function of pressure and conveyor speed.
III. Dewatering method selection

As only 50% of the meat removed from the frames was recovered as end product (dewatered mince) with the original system setup, the researchers tried three additional dewatering methods.

*Decanter*

The only available decanter was an Alfa Laval NX 207 designed for oil removal from pelagic fish in fish meal and fish oil process. The machine was adjusted after consultation with the manufacturer. In spite of this the separation of dry matter and water could not be successfully achieved.

*Slot strainer*

A strainer with a slot size 0.08 mm was purchased from LKM in Denmark. The researchers did not explain in detail how this device works, but in Fig. 7 a system setup drawing is presented. The slurry was entered into the strainer where particles in the fluid were separated around the strainer element. When the strainer became clogged with particles it could be cleaned by either removing and cleaning the strainer element or reversing the flow direction through the strainer (back flush). The degree of filtering was controlled by the filter elements slot size. The strainer did not prove to be a successful dewatering device. The strainer clogged quickly in back flushing was applied frequently and the protein that were stuck in the slots became denaturated.
In order to improve recovery from the existing system setup the researchers first changed the screen size in the rotary screen. The woven nylon mono filament with mesh openings of 0.4 mm that was used in the prototype was replaced with polypropylene filter (not woven) that had mesh openings of 0.1 mm. This new screen became clogged and lost its ability to dehydrate the slurry after a very short processing time.

The next step, was to increase the length of the existing screen in order to increase efficiency. This was done by adding another rotating screen in continuity with the first one, and with the same type of screen (0.4 mm mesh). The results from these changes were that the moisture content was brought down an additional 1%, from 96% with the first screen to 95% with the second screen.
Summary

The main results for meat recovery from cod frames were that; i) rotating pencil jets nozzles resulted in highest recovery and lowest water usage, ii) an optimum processing yield of 15.5% (weight of recovered meat as percentage of total frame weight) was achieved at water pressure 63-75 bar and conveyor speed of 10-14 m/min, iii) protein losses in the dewatering steps were large (>50%) and the mince could not be dewatered efficiently (moisture content was 84-86%), and iv) the characteristics of the mince were found to fall between regular fish mince made from trimmings and surimi.

3. WJD for Pacific whiting frames

This section contains the results from the tests that were performed at the OSU Seafood Laboratory using the WJD system. The main object of the study was to determine if the WJD system could be used to recover Pacific whiting frame meat for surimi manufacturing. Secondary object was to determine if conventional surimi processing equipment could result in better recovery and more efficient dewatering than the previous methods tested by the Nordfood group.

System setup

In the whiting study an equipment setup representing a commercial surimi process was used. The slurry from the WJD machine was pumped to a 500 L plastic bin. In the tests where salt additions were required, the salt was added into that plastic bin. The slurry was then run through a hose to a rotary screen with a mesh size of 0.1 mm. The mince from the rotary screen was then run through a screw press (Model SD-8, Ikeuchi Tekkosho Ltd., Japan). The dehydrated mince was then run through a refiner
(Model S1, Ikeuchi Tekkosho, Ltd. Japan) before mixing with cryoprotectants (4% sucrose, 5% sorbitol, and 0.3% sodium tripolyphosphate) in a Stephan chopper (Model 5289, Stephan Machinery Corp., Columbus, OH) for 3 minutes at low speed setting (1500 rpm).

**Processing parameters**

In the Pacific whiting study an optimization for water jet pressure and conveyor speed was carried out, using a two factor central composition experimental design (Box et al., 1978) which falls under response surface methodology (RSM). We wanted to carry out the optimization over the water pressure range of 45, 50, 55, 60, 65 bar and conveyor speed of 12, 13, 14, 15, 16 m/min. This would result in 25 water pressure / conveyor speed combinations. The experimental design gave thirteen test runs to be performed and from these datapoints the method predicted results for the other 12. In that way a surface, showing yield as a function of water jet pressure and conveyor speed is formed. In Fig. 9 the results from the thirteen test runs are presented. In the figure, process yield is presented at each conveyor speed / water pressure combination. The five center points (14 m/min, 55 bar) results are used by the method to determine the accuracy of the surface prediction. Unfortunately the figure showing the predicted surface could not be presented due to software problems. The method found 40.2% optimum meat removal of frame weight, at water jet pressure of 55 bar and conveyor speed of 14 m/min.

Water usage was significantly higher than the Nordfood group reported. For the whiting frames the WJD used 230-310 L/kg dewatered mince, while the Nordfood group reported approximately 27 L/kg for the cod frames. The difference can possible be
explained by the frame size and feeding rate. As the cod frames probably have 4-6 larger surface area than the whiting frames, the cod frames utilize the nozzle spray area on the conveyor better. Also the feeding rate for the whiting frames might have been too low, although we estimated it to be about 100 frames/min, using two persons to feed the conveyor.

Fig. 8 – WJD process yield for Pacific whiting frames. Process yield is reported as percentage of dewatered mince from total frame weight.

Dewatering

The rotary screen increased the solid content from 0.33% to 2.8%. When 0.2% salt was added to the slurry the solid content after the rotary screen was increased further to 4.1%. From the screw press the solid content was 10.6% for the mince where no salt had been added to the slurry, but 15.2% for the mince where the 0.2% salt had been added to the slurry. This indicates that adding salt to the slurry can bring the moisture
content close to the 82-83% that is considered commercially acceptable. Adding salt to
the slurry also decreased the protein loss in the rotary screen from 82.5% (no salt) to
73.8% (0.2% NaCl), which converts to approximately 50% yield increase. The final
processing yield (dewatered mince weight as percentage of whole frame weight) for the
WJD with and without salt was 5.5% and 4.7% respectively. The salt addition therefore
resulted in approximately 17% yield increase when compared to the yield when no salt
was used.

To compare other commercially surimi dewatering options, i.e. decanter, the plan
was to install the WJD system in one of the local surimi plants. However, due to an
exceptionally short surimi season, the plants had stopped production when the project
reached that stage.

4. WJD engineering study

In this section the WJD system will be further studied with respect to system
design and processing parameters. The purpose of this section is to help future studies
dealing with the WJD to improve the system. To begin the system will be described in
detail and all the design parameters listed. Then the effects of these parameters on the
system will be speculated.

System design

In Fig 9, a more detailed drawing of main functional parts of the WJD system is
presented. The drawing shows the main design parameters that can affect meat removal
efficiency, water usage and system capacity. The parameters are listed in table 1.
Fig. 9 – Outline drawing showing nozzle setup for the WJD system
Table 1 - WJD design parameters

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<th>Design Parameters</th>
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<td>Nozzle clearance (h)</td>
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</tbody>
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Several of these parameters are related. Water jet diameter (D) can be increased by increasing the nozzle clearance (h). The water jet zone (L) is affected by number of nozzles, nozzle spacing (l), and water jet diameter (D).

**Design parameters**

**Nozzle type**

In the previous WJD studies the rotating pencil jet nozzles showed highest recovery and lowest water usage. However in the Pacific whiting study the water usage at optimum processing conditions was very high 1300-1500 L / 100 kg frames, resulting in 230-310 L/kg dewatered mince. The search for more efficient nozzles or nozzle arrangement should therefore be continued.

**Nozzle quantity and spacing**

Due to the high water usage in the Pacific whiting study, using fewer nozzles could be feasible. However, decreasing nozzle numbers would lead to reduced water jet exposure time. This time difference could be compensated for by having the two nozzles in line or having them side by side and lowering the conveyor speed.
Nozzle clearance

The clearance (h) of the nozzles over the conveyor will affect both the water jet diameter (D) and therefore the water jet exposure time. Water pressure or velocity are also likely to be affected by the nozzle clearance.

Nozzle orientation

Changing the impact angle of the water jet might effect meat removal efficiency. However, for lighter weight frames, such as Pacific whiting, too large an impact angle might force the frames to the sides of the conveyor and even tilt them on their side.

Conveyor width

The conveyor width is likely to affect the capacity of the machine, as a wider belt allows frames to be arranged side by side on the conveyor. However, too wide a conveyor can result in the frames rotating and blocking the conveyor. In the case of the whiting frames, the light weight frames had a tendency to “bounce” to the sides of the conveyor, sometimes ending on their side and resulting in reduced meat removal efficiency.

Processing parameters

Water pressure

Water pressure affects meat removal efficiency and water usage. Particle size might also be affected by water pressure and in that way water pressure might influence yield from dewatering equipment.
Conveyor speed

Conveyor speed affects water jet exposure time and therefore meat removal efficiency. Capacity of the system (frames/time unit) is also dependant on the conveyor speed. If we assume that feed rate is not limited, the capacity of the system will be conveyor speed divided by the average length of the frames. In the case of the Pacific whiting frames that were run at 14 m/min, a capacity of $14 \text{ m/min} / 0.2 \text{ m/frame} = 70$ frames/min would be accomplished. Then if the conveyor width allows more than one frame width, the capacity can be multiplied by the number of frames that can be arranged side by side. When running the whiting frames the conveyor width was set for two frame widths. Commercial filleting machines (Baader or Tojo) average 200 fish/min.

Salt addition

In commercial surimi processing, salt is commonly added to wash water to facilitate dewatering and decrease myosin loss in the dewatering steps (Lin and Park, 1996; Park 1995). The salt changes the ionic strength in the water and can in that way be used to control the solubility of the myosin. Less solubility increases recovery from the dewatering steps.

Water temperature

In surimi processing, temperature of the mince during the process is very important. In commercial surimi manufacturing chilled water (2-5°C) is used for filleting machines and mince washing. This along with the low temperature of the fish from the commonly used refrigerated sea water (RSW) holding tanks helps to maintain low product temperature. Commercially 13°C is often used as acceptable final product
temperature. The WJD system was found to increase temperature from 3 -5°C in the ingoing water to approximately 8 -12°C in the slurry. In the dewatering process the mince temperature will be increased further. In a tests performed at a local processing plant the temperature of wash water going into decanter was 4 -5°C but the dewatered mince coming out was 14 -17°C. Therefore a chilling step after the WJD deboning might have to be added to the process.

Dewatering options

*Rotary screen*

Rotary screens consist of a stainless steel screen drum that is rotated by an electric or hydraulic motor. The screens are usually made from stainless steel mesh or punched stainless steel plates. The mesh opening or hole diameter is commonly 0.5 mm. Dewatering efficiency and the amount of solids lost in the rotary screen are likely to be related to:

- Screen length (increased residual time => lower moisture content)
- Mesh size (larger mesh size => less clogging, easier water separation, but more solid loss)
- Feed rate (too much volume “fills” the screen and the slurry flows through it)

In the whiting study a rotary screen with a mesh size of 0.1 mm was used to dewater the slurry prior to the final dewatering in a screw press. Despite of the small mesh size 82.5% of the recovered meat was lost in this process step.

*Decanter*

The main component of a decanter centrifuge (Fig 10) is the rotating bowl, which consists of a cylindrical part and a conical part. Inside the bowl a screw conveyor, which rotates at a slightly different speed than the bowl, conveys the solids towards the
solid discharge ports. A stationary inlet pipe is inserted to the center of the conveyor.

The bowl is enclosed in a vessel with discharge arrangements and mounted on a base frame. The three main factors that influence the separation of mince and water in a decanter are (Lanier et al., 1992):

1. The design of the decanter (geometrical configuration)
   - Bowl diameter and length
   - Centrifugal speed
   - Differential speed of the conveyor relative to the bowl and conveyor type

2. Composition of the liquid and the particles to be separated
   - Density
   - Viscosity
   - Size
   - Concentration of the particles (solid content)

3. Process-related aspects
   - Temperature
   - Feed rate

A large bowl diameter increases the solid-handling capacity but also dictates a lower main speed in order not to exceed mechanical limitations. Increasing the length of the bowl generally improves the liquid clarification as the residence time in the gravitational field will increase. Increasing the bowl speed increases the gravitational force, which results in better clarification and drier solids cake. However, the shear forces on the feed increases as well, which results in higher amounts of smaller particles to be separated (Lanier et al., 1992). The differential speed between the bowl and conveyor affects the dewatering and solid recovery efficiency of the centrifuge (Webster, 1999). Higher differential speed results in higher moisture content of the solids cake and reduced solids recovery due to shorter residence time. Each centrifuge has its own efficiency curve, where solid recovery can be plotted as a function of feed rate. At optimal conditions,
centrifuges should be capable of recovering at least 75% of solids in surimi wash water (0.3-0.5% solid content, from rotary screens and screw press). The solid recovery will then decrease in an inverse relationship with feed rate. A typical efficiency curve for decanter is presented Fig. 11.

5. Recommendations for WJD modifications and future studies

Design

Two rotating pencil jet nozzles should be located side by side over the conveyor, with different rotating direction, so the frames would be directed between the two nozzles. To increase the water jet exposure time the conveyor speed would have to be lowered or the height (h) of the nozzles raised.

The rotary screen in the machine should be removed as the surimi mince refiner is capable of doing a better job in removing skin and bone residuals. This would increase recovery and reduce water usage 40%, as none of the stationary fan nozzles associated with the rotary screen would be needed. The prototype was equipped with a centrifugal pump. Centrifugal pumps are generally avoided for mince/slurry transportation in the surimi process, as they run at high speed and risk of shear and air mixing is high. It is therefore recommended to replace that pump with a conventional agar pump.

Processing parameters

Instead of using an optimizing procedure, like the NordFood group applied where the 3 main parameters (water pressure, conveyor speed, salt addition) are varied at the same time, another approach is recommended. 1) Start by finding an optimum salt addition with respect to protein concentration in the slurry, maximizing the process
Fig. 10 – Outline drawing of a centrifuge/decanter (Lanier et al., 1992).

Fig. 11 – Typical centrifuge efficiency curve for solid recovery from surimi wash water (Webster, 1999).
yield. The protein concentration can be estimated by meat recovery efficiency from the frames (weight of frames after WJD as percentage of frame weight before WJD) and the water usage (L/frame weight). The process yield will be the weight of dewatered mince as a percentage of frame weight. A centrifuge should be used as the dewatering equipment. When optimum salt addition has been found for every protein concentration it becomes unnecessary to include salt addition in the following processing optimizations. 2) By varying water pressure and conveyor speed, find a combination of the two variables that gives the highest process yield from the dewatering step. Use the previously found salt addition optimum based on the protein concentration of the slurry. While carrying out the process parameter optimization, determine the relationship between water pressure and water usage. As the system capacity (frames/min) is based on the conveyor speed, a feasibility study can now be performed. The feasibility study could give an optimum combination of process yield, water usage and capacity, which could then be back-calculated to the water pressure and conveyor speed.

Dewatering methods

Based on high protein losses in previous WJD studies when rotary screens have been used, it is recommended to use a centrifuge (decanter) for dewatering. Centrifuges have proven to be efficient in recovering solids from surimi wash water with low solid content (0.3-0.5%). The size of the centrifuge must be carefully selected based on the flow rate from the WJD system, as the solid recovery from the centrifuge is highly dependant on the feed rate. Temperatures of the dewatered mince must be monitored and a pre-chilling step might have to be added to the process.
References


