AN INTEGRATED APPROACH TO RECOVERY AND UTILIZATION OF LOUISIANA CRAWFISH PROCESSING WASTES

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ABSTRACT
The Louisiana crawfish culture industry comprises the largest crustacean farming operation in the United States. Processing plants throughout the culture region generate as much as 80 million pounds of peeling waste annually during recovery of the 15% (by weight) edible tail meat. Development of an oil extraction process for carotenoid astaxanthin from the waste has allowed establishment of a commercial industry for by-products. Pigment concentrations as great as 1,500 ppm have been recovered. Currently it is being utilized in Japan as a natural red colorant for red sea bream culture. Remaining protein waste and extracted presscake find application as ingredients in commercial diets and baits in crustacean aquaculture. Chitin-chitosan and carotenoid-chitin-protein complex investigations have demonstrated functional and physiologically active properties of these crawfish-derived products. Recent analytical studies have revealed the presence of important, and potentially recoverable, flavors in fresh waste material. Work in progress is evaluating the feasibility of food-grade meat recovery from the crawfish claws, currently included in the waste fraction. A multi-product recovery schematic is presented with emphasis on applications and opportunities in world markets.

INTRODUCTION
Louisiana has the largest and oldest successful crustacean farming industry in the United States, namely that of the red swamp crawfish (or crayfish) Procambarus clarkii. This aquaculture industry has grown from less than 900 hectares in 1960 to a projected size of nearly 150,000 hectares or more by the end of the present decade. Popularity of ethnic “Cajun” foods and development of several prepared gourmet crawfish consumer products have contributed to the significant growth of the industry. Harvests are from ponds as well as marshes, the latter designated as “wild crop.” Increasing effort is directed toward the regulated pond approach, enhancing the predictability of the yearly harvest. It was not until 1984 that local attention focused on processing by-product recovery in an environmentally and economically sound manner. Prior to this, disposal of crawfish waste (head and tail carapace residue) in poorly controlled landfills was costing the state of Louisiana tens of millions of dollars annually, in addition to creating serious local environmental problems. A demonstrated means to convert such waste into commercially valuable products, and increasing federal regulatory pressure, were catalysts that changed traditional thinking in this long-established industry (Anonymous 1989).

The magnitude of crawfish culture is seen in the over 100,000,000 pounds of whole animal harvested. In spite of this volume, tail meat recovery (at 14%-16%) is a manual peeling operation, although several mechanical peeling designs have been tried without commercial success. The “total product” recovery approach reported here may serve as a guide in other crustacean processing operations leading to economically viable by-product recovery and application.

The premise of our investigations over the past two decades generally has been twofold, i.e., minimizing seafood waste disposal, both for crawfish as well as for shrimp, and establishing profitable markets for processing by-products through an active research and development program. The term “integrated” in the title is used to imply establishment of a multi-by-product
Table 1. Critical factors in economically viable recovery and utilization of crawfish wastes.

<table>
<thead>
<tr>
<th>Resource availability</th>
<th>Ease of recovery</th>
<th>Processing requirements</th>
<th>Volume and economic value</th>
<th>Competitive products</th>
<th>Applications and markets</th>
</tr>
</thead>
</table>

Table 2. Chemical composition of crawfish whole meal and shell.

<table>
<thead>
<tr>
<th>Composition</th>
<th>Whole meal</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein (%)</td>
<td>35.8</td>
<td>16.9</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>9.9</td>
<td>0.6</td>
</tr>
<tr>
<td>Fiber (chitin) (%)</td>
<td>16.5</td>
<td>23.6</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>38.1</td>
<td>63.6</td>
</tr>
<tr>
<td>Minerals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca (%)</td>
<td>12.3</td>
<td>24.8</td>
</tr>
<tr>
<td>P (%)</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>K (%)</td>
<td>1.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Mn (ppm)</td>
<td>545</td>
<td>200</td>
</tr>
<tr>
<td>Fe (ppm)</td>
<td>1,610</td>
<td>180</td>
</tr>
<tr>
<td>Astaxanthin (ppm)</td>
<td>78</td>
<td>108</td>
</tr>
</tbody>
</table>

Table 3. Carotenoid concentrations from four crustacean meals.

<table>
<thead>
<tr>
<th>Source</th>
<th>Pigment concentration (μg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrimp meal (Penaeus)</td>
<td>2–10</td>
</tr>
<tr>
<td>Shrimp head meal (Penaeus)</td>
<td>31</td>
</tr>
<tr>
<td>Shrimp meal (Pandalus) (Vacuum-dried)</td>
<td>104</td>
</tr>
<tr>
<td>Crawfish meal (Procambatus)</td>
<td>137</td>
</tr>
</tbody>
</table>

base, varying in its economic value and application.

It is necessary to look at some of the constraints and critical factors involved in realistic projection of seafood by-product recovery such as that described in Table 1 for crawfish processing. The same constraints apply equally to other rendering industries where commercial seafood waste utilization facilities are proposed. Foremost, predictable volumes of fresh waste in a logistically feasible area is a critical consideration for establishment of an economically viable operation. In one Louisiana area alone, approximately 50 miles in radius, it is possible to recover in excess of 25 million pounds of fresh waste annually. The freshness of the waste becomes even more significant when potential food applications are being considered. Multi-product use certainly is another major advantage to allow expansion of the economic base.

EXPERIMENTAL DATA

Figure 1 illustrates the utilization concept developed in our laboratory (Meyers 1987; No 1987) and the current and potential by-products focused upon. Information such as this is needed before a realistic economic overview on product application can be developed. Each of these product areas is discussed in this paper; however, major attention is given to the pigmented oil, presently the basis of a commercial industry in Louisiana. The flavor analysis work from our department, and current efforts to recover food-grade meat from the discarded crawfish claws (now a portion of the waste), are also areas of inquiry.

Composition of Crawfish Meal and Shell

The compositions of crawfish whole meal and shell are compared in Table 2. Application of the pigmented shell with its high concentration of astaxanthin (108 ppm), as well as its potential value as a source of chitin, will be discussed. The whole crustacean meal and the partially extracted (spent) presscake, the latter still containing considerable residual astaxanthin, has application in many crustacean diets in aquaculture. Frequently, formulations include as much as 15%–20% shrimp or other crustacean meals if available. With significant worldwide increases in marine shrimp culture, the market will continue to utilize large volumes of crustacean meal as a source of marine protein, carotenoids, and chitin. Several nutritionists and feed formulators consider inclusion of a dietary preformed chitinous ingredient highly desirable for optimal shrimp growth and related molting activities. In Louisiana, whole or spent crawfish meal is included as a feeding attractant in crawfish trap baits.

Table 3 compares pigment concentration in crawfish meal with other crustacean meals. While Pandalus borealis is relatively rich in astaxanthin, we are not aware of current efforts to extract its pigment on a commercial scale. Also, the vacuum-dried process, while producing a high quality meal, is no longer op-
Figure 1. Total utilization of crawfish waste.
Table 4. Acid ensilage of crawfish waste prior to pigmentation extraction.

| Increased concentration of the astaxanthin oil extract by 40–50% |
| Increased oil recovery by 10% |
| Twofold increase in free amino acid nitrogen |
| Reduction (70%) in exoskeleton calcium carbonate |
| Correlation between CaCO₃ solubilization and pigment release in relation to silage pH |

From Chen and Meyers 1983.

Table 5. Crawfish waste and pigment recovery research.

| Waste utilization in crustacean feeds and attractant in crawfish baits (Meyers and Thibodeaux 1984) |
| Pigment characterization of waste (Meyers and Bligh 1981) |
| Development of soy oil pigment extraction process (Chen and Meyers 1982a) |
| Ensilage treatment of waste (Chen and Meyers 1983) |
| Effect of anti-oxidants on astaxanthin stability (Chen and Meyers 1982b) |
| Color stability in astaxanthin pigmented rainbow trout (Chen et al. 1984) |
| Analysis of crawfish oil extract (Omara-Alwala et al. 1985) |

Pigment Research

Acid Ensilage of Crawfish Waste

Results of efforts to enhance pigment recovery through controlled acid pretreatment (Chen and Meyers 1983) are enumerated in Table 4. The increased concentration of astaxanthin in the oil extract is especially noteworthy. Ensilage approaches are now being evaluated on a practical basis to store ground crawfish waste at satellite facilities during the peak season (May-July), with subsequent pigment removal at the extraction plant. Comparable variable processing loads in all likelihood exist at other crustacean facilities and must be considered in projections of efficient by-product recovery. Crawfish waste is extremely reactive due to high concentrations of proteolytic enzymes and must be used fresh or properly preserved to avoid decomposition.

Astaxanthin Extraction

The patented process (Meyers and Chen 1985) for recovery of the valuable astaxanthin pigment is illustrated in Figure 2 and is further discussed by Chen and Meyers (1982a). In essence this comprises a controlled release of the carotenoid into an oil phase, using either a vegetable (i.e., soy) or a fish oil. The initial grinding through a vertical attrition mill is essential to properly size the puree fraction and to remove up to 10% (by weight) of the shell portion. This ratio can be adjusted according to screen size used, and varies with the crustacean species. The recovered pigmented shell has special applications because of its carotenoid-protein-astaxanthin complex. The efficiency of the process will vary with the oil used and the stages of extraction. While pigment extraction may be somewhat higher in fish (menhaden) oil, soy oil is currently being used as stipulated for the Japanese market. A final terminal polisher has been installed to further enhance stability during storage and shipment overseas.

Carotenoid concentrations from crawfish, red crab, and shrimp meal are noted in Figure 3. Red crab was the focus of considerable studies in the late 1970s (Spinelli and Mahnken 1978); however, the current limited availability of this resource precludes its use as a commercial source of astaxanthin. Single-stage oil extractions of crawfish waste average from 750 to 1,300 ppm. Concentrations in the range of 1,500–1,700 are obtainable with two-stage extraction (Chen 1981). It does not appear to be economically feasible to proceed beyond the second extraction stage. Pigment concentration is a reflection of seasonal development of the crawfish and use of young vs. older animals, the latter with a deep-redish, highly calcified exoskeleton. Astaxanthin concentrations as high as 2,000 ppm have been obtained at certain periods of the year.

The majority of our composite pigment-related
investigations, in progress since 1976, have been published and are generally summarized in Table 5. The importance of a sound research and development program cannot be over-emphasized.

The crawfish carotenoid astaxanthin (3,3’ dihydroxy-4,4’-diketo-β-carotene) currently is being utilized in Japan as a natural red intensifier for the large commercial red sea bream farming industry in that country. Astaxanthin has widespread application in aquaculture (Meyers and Chen 1983) and the role of carotenoids in salmonids has been extensively investigated (Torrissen et al. 1989). Natural astaxanthin is especially desired in Japan where the crawfish-derived carotenoid has found a ready market because of regulatory restrictions on use of synthetic colorants in food products. However, serious competition from synthetic astaxanthin and the potential impact of the pigment derived from the yeast Phaffia rhodozyma (Johnson 1989) in other world aquaculture markets must be considered in this decade.

Analysis of Crawfish Oil Extracts

A few observations on the crawfish pigment are in order, notably the composition of the pigment and the concentrations from the extraction process. The majority of the pigment is in the mono- or di-ester form, with considerable variation in concentrations obtainable (Omara-Alwala et al. 1985). The extraction process results in a pigmented oil rich in omega-3 fatty acids and sterols, in all likelihood enhancing its value as an ingredient in aquaculture diets. Analyses reveal as much as 8% linolenic acid (18:3 omega-3) and a high proportion of other long-chain polyunsaturated fatty acids, i.e.,
20:5 omega-3 (2.3%) and 22:6 omega-3 (1.5%). Sterol levels of 5.9 μg per mg have been obtained. Such enriched, or further fortified, pigmented oil may possess a competitive advantage in specialized markets.

**Chitin-Chitosan**

As part of our investigation of crawfish waste, we have given considerable attention to isolation and characterization of the chitin component (No 1987; No et al. 1989). Crawfish shell waste is an excellent source of chitin, 23.5% on a dry weight basis (Table 2). Most efforts to isolate chitin from crustacean processing operations have been with shrimp and crab waste shell (Johnson and Peniston 1982). While chitin and chitosan currently are not being produced in the commercial crawfish pigment recovery process, considerable interest has been shown, and the economics may justify a combined cost-efficient integrated approach. In the interim, a good data base on crawfish chitin-chitosan has been established in our laboratory with special emphasis on the nature and biological efficiency of the chitin-carotenoid complex.

The procedure used for isolation of crawfish chitin is shown in Figure 4, and its characterization noted in Table 6. The presence of small residual amino acids in the final product indicates that protein is bound by covalent bonds to chitin, forming a stable complex. The astaxanthin-chitin bond is difficult to break. It may be
Table 6. Characterization of crawfish chitin.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (%)</td>
<td>7.01</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>ND¹</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>0.1</td>
</tr>
<tr>
<td>Acetyl (%)</td>
<td>19.6²</td>
</tr>
<tr>
<td>Deacetylation (%)</td>
<td>7.5</td>
</tr>
<tr>
<td>Solubility (%)</td>
<td>26.4³</td>
</tr>
<tr>
<td>Color</td>
<td>white</td>
</tr>
<tr>
<td>Residual amino acids (mg/g)</td>
<td>6.5</td>
</tr>
</tbody>
</table>

¹ND = not detectable.  
²Theoretical value = 21.2%.  
³N,N-dimethylacetamide containing 5% LiCl.

Table 7. Percent recovery of amino acids

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Am-Cu-chitosan¹</th>
<th>Am-Cu-chitosan and chitosan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspartic acid</td>
<td>85</td>
<td>82</td>
</tr>
<tr>
<td>Threonine</td>
<td>93</td>
<td>90</td>
</tr>
<tr>
<td>Serine</td>
<td>84</td>
<td>77</td>
</tr>
<tr>
<td>Proline</td>
<td>21</td>
<td>9</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>77</td>
<td>79</td>
</tr>
<tr>
<td>Glycine</td>
<td>15</td>
<td>71</td>
</tr>
<tr>
<td>Alanine</td>
<td>47</td>
<td>89</td>
</tr>
<tr>
<td>Valine</td>
<td>51</td>
<td>37</td>
</tr>
<tr>
<td>Methionine</td>
<td>79</td>
<td>75</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>54</td>
<td>57</td>
</tr>
<tr>
<td>Leucine</td>
<td>62</td>
<td>63</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>86</td>
<td>84</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>Lysine</td>
<td>49</td>
<td>36</td>
</tr>
<tr>
<td>Histidine</td>
<td>59</td>
<td>63</td>
</tr>
<tr>
<td>Arginine</td>
<td>73</td>
<td>72</td>
</tr>
</tbody>
</table>

¹Am-Cu-chitosan = amino-copper-chitosan.

more economically feasible to produce a pigment-rich chitinous product for specialized markets. Animals with active indigenous or constitutive chitinase enzymatic systems, or with chitinolytic gut bacteria, can readily utilize the astaxanthin at very low concentrations (Lee 1985). Several investigations are being done on use of the astaxanthin-chitin complex as a composite pigmentation source in poultry diets. Application as a biologically active substrate in aquaculture diets is another possibility. In culture of some shrimp species, especially the giant tiger prawn *Peneaus monodon*, workers in the Philippines have reported that astaxanthin supplementation is required to maintain optimal exoskeleton coloration, a factor of importance in some world markets. Furthermore, astaxanthin appears to facilitate prawn physiological processes under low oxygen conditions, possibly serving as a free-radical capture agent comparable to vitamin E.

From a chemical point of view, there are two distinct structural units in the crustacean shell: an acidic polypeptide fraction with a strong affinity for calcium ions (mineralization matrix), and a high molecular weight chitin-protein complex (carrier protein) with no affinity for calcium, arranged in the form of sheets. There are several potential sites in the chitin-polysaccharide polymer where covalent binding can occur, but binding to these sites has not been confirmed. Dissolution of chitin composites is accompanied by degradation of both the protein and chitin components; thus, efforts to ascertain the structure of binding sites by solution techniques have not been successful. Astaxanthin is ionically bonded to chitin. There is a well-established stoichiometric relationship between astaxanthin, as a prosthetic group, and protein for carotenoid attachment sites. In order to comprise a prosthetic group, astaxanthin and astaxanthin ester have free carbonyl groups in 4 and 4' positions on the terminal ionone rings. Further studies of these units should shed information on the apparent biological efficiency of the astaxanthin-chitin complex.

Chitosan-Related Investigations

Further chitin-chitosan research has involved development of recovering the organics, especially amino acids, from the oil extraction processing discharge stream (No and Meyers 1989a, 1989b). The percent recovery of amino acids at pH 8 using this analytical approach is given in Table 7. Recovery efficiency is pH-dependent, with lower efficiency yield at higher pH values. The eluate was completely free of copper ions from the initial copper-chitosan column when treated with a second crawfish chitosan column. Once the second column is saturated with copper ions, it can be used effectively as the initial column for primary sorption of amino acids from the supernatant. The amino acids recovered by this treatment have potential product-related applications.
Table 8. Comparison of amino acid composition of coagulated solids from crawfish wastewater with shrimp waste protein.

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Content (mg/g)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crawfish</td>
<td>Shrimp</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>61.6</td>
<td>63.4</td>
</tr>
<tr>
<td>Threonine</td>
<td>21.1</td>
<td>25.3</td>
</tr>
<tr>
<td>Serine</td>
<td>19.1</td>
<td>26.7</td>
</tr>
<tr>
<td>Proline</td>
<td>11.5a</td>
<td>20.3</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>121.3</td>
<td>91.2</td>
</tr>
<tr>
<td>Glycine</td>
<td>17.2</td>
<td>25.3</td>
</tr>
<tr>
<td>Alanine</td>
<td>43.0</td>
<td>31.2</td>
</tr>
<tr>
<td>Valine</td>
<td>22.7</td>
<td>26.1</td>
</tr>
<tr>
<td>Methionine</td>
<td>10.1</td>
<td>16.8</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>13.7</td>
<td>19.2</td>
</tr>
<tr>
<td>Leucine</td>
<td>48.1</td>
<td>44.6</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>16.3</td>
<td>21.4</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>18.8</td>
<td>26.9</td>
</tr>
<tr>
<td>Lysine</td>
<td>35.5</td>
<td>36.4</td>
</tr>
<tr>
<td>Histidine</td>
<td>8.1</td>
<td>11.2</td>
</tr>
<tr>
<td>Arginine</td>
<td>43.5</td>
<td>37.2</td>
</tr>
<tr>
<td>Total</td>
<td>511.6</td>
<td>523.2</td>
</tr>
</tbody>
</table>

1From Toma and Meyers 1975.

Applications as Pigmenting Sources

Most recent work has involved examination of the crawfish shell as well as attributes of the pigment-shell and pigment-chitin complex. Current research has focused on the pigmented shell itself, recovered in the initial separation process (Figure 2), or from the spent meal. The latter still has a notable concentration of astaxanthin present in its shell.

Research with crawfish by-products has looked at potential applications in the poultry industry, both in laying hens and in broiler diets (Lee 1985). For use of the crawfish pigment in its various forms as an egg yolk pigment, experimental test diets were developed varying the ratio of yellow corn to concentration of astaxanthin (ppm) from three different sources. The concentration of astaxanthin in the crawfish whole meal was 82 ppm, in the pigmented shell 97 ppm, and in the pigmented soy oil 350 ppm. Total concentration of lutein in the yellow corn meal was 15 ppm. The latter is slightly lower than the average concentration (22 ppm) of lutein in yellow corn.

The effect of the crawfish astaxanthin source on the color score of egg yolks is shown in Tables 9 and 10. All three dietary sources, i.e., whole meal, pigmented oil, and pigmented shell, imparted significant egg yolk pigmentation even at astaxanthin concentrations as low as 1 ppm using comparatively low levels of yellow corn. To achieve the optimal target egg yolk color score (a yellow-orange hue most desired by U.S. consumers) of 10–11, produced by 51% yellow corn meal in the diet, levels of this meal as low as 20% can be effectively combined with crawfish astaxanthin at a final 1 ppm concentration. Thus, as much as 30% yellow corn meal can be spared by use of the crawfish pigment.

As shown in Table 10, crawfish astaxanthin is biologically available even at concentrations as low as 1%. The value of the pigmented shell is especially noteworthy. Probably this is due to differences in the biological availability of the shell pigment product (a calcium-chitin-astaxanthin complex) for laying hens with both indigenous and induced active chitinolytic enzymes in their digestive tract. Work with rainbow trout has shown that fish fed carotenoid-protein diets, compared with those containing free pigment, exhibited greater pigmentation rates.

Organics and Flavor Compounds

Most recent research from the Louisiana State University Food Science Department documents yet another facet of potential by-product recovery, namely that of several volatile flavor compounds in crawfish waste and in the tail (Vejaphan et al. 1988; Tanchotikutik
Table 9. Fletcher color score of egg yolks.

<table>
<thead>
<tr>
<th>Yellow corn %</th>
<th>Concentration of astaxanthin (ppm)</th>
<th>0</th>
<th>1.0</th>
<th>2.5</th>
<th>5.0</th>
<th>7.5</th>
<th>10.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>ND</td>
<td>*</td>
<td>1</td>
<td>1</td>
<td>15</td>
<td>15</td>
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<tr>
<td>10</td>
<td>ND</td>
<td>6</td>
<td>13</td>
<td>14</td>
<td>14</td>
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<td>5</td>
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<td>12</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

ND = not detectable.
*Out of scale.

Table 10. Effect of astaxanthin source on Fletcher color score of egg yolks.

<table>
<thead>
<tr>
<th>Yellow corn %</th>
<th>Source</th>
<th>Concentration of astaxanthin (ppm)</th>
<th>0</th>
<th>1.0</th>
<th>2.5</th>
<th>5.0</th>
<th>7.5</th>
<th>10.0</th>
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<tr>
<td>0</td>
<td>P</td>
<td>2</td>
<td>13*</td>
<td>14*</td>
<td>14</td>
<td>14</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>2</td>
<td>13*</td>
<td>12*</td>
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<tr>
<td></td>
<td>W</td>
<td>2</td>
<td>13*</td>
<td>13*</td>
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<td>14</td>
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<tr>
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<td>P</td>
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<td>11</td>
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P = pigmented oil, S = pigmented crawfish shell, W = whole crawfish meal.
*Faint color.

and Hsieh 1989). A total of 70 volatile compounds have been characterized in the tail meat and over 117 identified in the processing waste. Some of the more desirable aromas may be contributed by the claw meat component of the waste. Careful selection and recovery of important authentic crawfish flavor components from the abundant waste resource may further enhance its composite economic value.

**SUMMARY**

Clearly, the designation “waste” is a misnomer when it refers to recoverable and usable by-products from seafood processing operations. Prudent examination of the composition of the processing material, traditionally discarded or used for composting or minimal cost feed or fertilizer, can reveal profitable alternatives leading to valuable products of commerce. More integrated approaches, such as utilization of Louisiana crawfish processing by-products, are needed to accurately address resource needs of this decade.

**ACKNOWLEDGMENTS**

The research reported was supported by the Louisiana Sea Grant College Program, NOAA, U.S. Depart-
REFERENCES CITED


QUESTIONS AND ANSWERS

Q. Recently a natural source of astaxanthin has been discovered, from a yeast Phaffia rhodoxyma.

A. Yes.

Q. Have you made some comparison about your production and the potential impact of this new technology in the production of astaxanthin?

A. Yes. I'm familiar with Phaffia rhodoxyma, and I think it is a potential competitor in the world market. At this time, I do not believe it is being used commercially. There is pilot production of it. We also must point out that there's a giant out
there, namely Hoffman-LaRoche, that is producing a synthetic astaxanthin. I haven’t had a chance to compare it. But as I pointed out at the beginning, part of the homework is to establish your specific market. The people from Japan who are now utilizing astaxanthin pigment worked with this Louisiana company for three years before going into production. We have now established a five-year contract. There is no guarantee that the market we have today will be the same one in five years. But that’s one of the reasons we’re setting up a multi-product base, and I think it is very foolish if one doesn’t do it.

Within five years we may find that the pigmented chitin or that the chitin-chitosan people suddenly say, “Hey, we have an economic base now. We can come into this company, and we can produce chitin-chitosan at half the cost. And why don’t we think about a pigmented chitin for a large part of an industry.” Yes, I agree with you, there are competitors, but there’s an advantage to a natural pigment.

And there’s one other point I want to make. I encourage those people, particularly in the Atlantic salmon industry and the culture industry. I know it doesn’t exist in Alaska, but certainly in other states, small producers are going to look for the consumer image of all natural pigment, no additives. And I feel that with the environmental thrust, the image of total recovery of food and feed grade products from natural resources is going to have tremendous appeal.

Q. What is the concentration actually delivered in the red bream feed?

A. We can produce pigment with a two stage extraction, depending on the season, as high as 1,900 ppm. We can regularly get 800 ppm with a single stage extraction. We are now running a two stage extraction where we can get about 1,300 to 1,400 ppm. But we have found earlier that with enzyme, a proteolytic enzyme treatment, we can get a greatly enhanced pigment recovery by a mild solvent extraction. This company right now is making money and producing pigment without any of the technological innovations. But as the market tightens we could always shift to those so that there’s always that possibility. We’re talking about 1,300 to 1,500 ppm.
PRODUCT RECOVERY FROM SURIMI WASH WATER

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OBJECTIVE

The objective of this research project was to test and develop membrane filtration systems suitable for recovery of fish protein currently lost in the wash water and the dehydrator water, and to explore potential uses for the recovered protein fraction.

BACKGROUND

In processing Alaskan pollock into surimi (Figure 1), a substantial amount (approximately 30%-40%) of the protein (fish meal) is lost in the washing and dehydration operations. If this protein could be recovered, a better product utilization would occur, the environmental impact from the disposal of the waste water would be reduced, and the fresh water demand could be reduced through the recycling of the process waters.

With this potential in mind, the National Marine Fisheries Service entered into a cooperative agreement with the National Food Processors Association to investigate the potential of applying membrane technology for recovery of by-products from the process water.

INDUSTRY COOPERATION

To ensure the maximum benefit from this undertaking, an industry advisory committee representing the processors and the membrane system manufacturers was formed. This committee has met throughout the project period for selection of test sites, review of test plans, and evaluation of results, and has provided valuable input to the project.

The initial testing in National Food Processors Association laboratories and pilot plant showed, not unexpectedly, that in order to obtain representative process water for testing, it would be necessary to perform the test at a plant site. Based on the committee’s recommendation, tests were carried out at three different plant sites in Alaska, each having slightly different operations.

If the protein fraction from the dehydrators can be utilized for addition to surimi, the payback becomes very attractive. Initial testing indicates that 5%-10% might be possible, but further developments are needed. Recovery of suspended solids from dehydrators by means of decanter centrifuge produces a fraction with characteristics like surimi; this has a very attractive payback even if no other recovery takes place.

SCOPE OF STUDY

The study had the following objectives.

By means of ultrafiltration membranes:
1. Recover protein from surimi process water.
2. Reduce waste-water impact on the environment.
3. Explore potential for recycling of process water.

Investigate potential for utilizing recovered product:
1. Adding back to surimi.
2. Fish meal.
3. High-grade fish meal.
4. Ingredients and other uses.

Membrane Study

During the course of the study, tubular and plate-and-frame membrane system configurations were tested. After the initial phases of testing, the plate-and-frame configuration was selected as the system most capable of handling the highly viscous product in an economically feasible manner. Even with this system, it was necessary to operate at significantly higher flow rates than normal in order to reduce protein buildup on the membrane surfaces; this will increase electrical cost for pumping. Prefiltration in a decanter centrifuge seemed necessary to reduce or eliminate product buildup in pumps, fittings, and membrane channels.
Figure 1. Surimi processing diagram showing mass balance and potential recoveries.
However, the added cost of installing the decanter centrifuge for the removal of suspended solids from dehydrator water would be justified by the additional product recovery when the suspended solids were added back to the surimi line.

Membrane Selection

A total of nineteen membranes of various materials and selectivities were tested under plant conditions. The best performing membrane was a "regenerated cellulose" membrane whose slightly hydrophilic character reduced the tendency of material to adhere to the membrane surface. Other membranes, such as polysulfone, showed a slightly lower performance.

Tests involving different pore sizes (molecular weight cut-off) showed little difference in performance, probably due to development of a product layer on the membrane surface (generation of a dynamic membrane) which acted as the determining membrane for molecules retained. A membrane with molecular weight cut-off of 10,000 was judged to be slightly better than the rest and was used for the long-term testing.

Cleaning

Cleaning with commercial detergent cleaners at pH 11–12 was sufficient to restore fluxes with more dilute fluids and shorter operating periods. However, after extended periods of operation and/or high concentration levels (>16% solids), cleaners with protein-degrading enzymes (proteases) and elevated temperatures (80°C–130°F) were necessary to clean the membranes and restore fluxes.

Product Evaluation

Protein content of the recovered protein concentrate was lower than that of whole pollock, but it was about 80% of the solids. (Whole pollock proteins are about 89% of the solids; process water protein before membrane filtration is about 66% of the solids.) Membrane filtration served to remove ash from the process water; in the recovered protein concentrate the ash was only about 3% of the solids, compared to 6% for whole pollock, and 17% for process water before the membrane filtration. Amino acid composition of the recovered protein concentrate was similar to pollock and surimi. (Heating of the concentrate brought the color closer to that of surimi.) Gel strength of recovered protein concentrate with and without added salt were comparable to second grade surimi, but it was more brittle.

Product Utilization

Adding Recovered Protein Concentrate to Surimi

Product recovered from the dehydrators was added to surimi at levels ranging from 5% to 20% product. Initial testing showed that adding up to 10% product resulted in no measurable decrease in gel strength of surimi. Storage at the 10% level showed satisfactory folding tests after two months. After six months of storage, the product had become more brittle and less elastic; however, it would still meet the standards for second grade surimi. The blend developed a fishy odor, which will need to be addressed before commercialization. The product color was stable over time, but slightly more yellow than second grade surimi.

Fish Meal

If the recovered product is added to fish meal, the high protein content in the recovered fraction seems sufficient to increase the overall protein level of the fish meal (including bones) to 65%.

High-Protein Fish Meal

A lobster feeding study was carried out to explore the potential of the recovered product as aquaculture feed. The composition of amino acids and high protein concentration indicate a good potential; however, this feeding study did not give satisfactory growth rates.

Specialty Products

The product was evaluated by some of the major meat processors. The indications are that the recovered fraction might have several potential uses due to its unique gelling properties. However, the lack of availability of the product makes product development less likely in the near term.

Drying of Recovered Protein Concentrate

Drying of the product may open up a variety of potential uses. A few experiments were run. It appears that the recovered protein dries satisfactorily. It is brittle and flaking with a brownish appearance. If dried at temperatures below 50°C, it can be rehydrated, absorbing 80%–90% of the amount of water removed by drying. It retains some of its gelling properties.

Waste Water

The analysis of the permeate (filtrate) from the membrane system indicates that it will meet fish meal plant effluent requirements, which are among the most stringent.
Denaturation

The results indicate potential feasibility of recovering by pH adjustment (to pH 5–5.5) plus heat (about 80°C). These tests were carried out on a very small scale, and it was not possible to test settling or centrifugation as a separation technique. It is difficult to comment on the separation that might be obtainable on a larger scale, but the results may still be quite acceptable considering the high recovery level obtained in these tests.

Economics

Utilizing the recovered fraction for fish meal supplement seems to result in a reasonable payback. If benefits from avoided waste water treatment cost can be incorporated, the payback becomes even more attractive (estimated at less than a year).

QUESTIONS AND ANSWERS

Q. Did you have a prior treatment to remove the solids from the effluent before going through the membrane, rather than putting all the pressure on the membrane itself?
A. We use decanter centrifuging which takes out the suspended solids.

Q. And what then is left? In other words, what I’m really saying is that you may not be able to get all the squal out, but is it possible that one may have a modified approach to at least recover what would be economically viable?
A. We take out the suspended solids because if you can take it out in the centrifuge, it’s a lot cheaper. It should be done that way. So we are only talking about the soluble solids, and again since we are working with this 50,000 molecular weight membrane, we are talking about fairly big molecules, molecules that can be coagulated and have certain physical properties. We’re not talking about the low end of it.

Q. What was the price that you were basing the 2.3 return on?
A. I’m basing it on $800 a ton of fish meal for a couple of reasons. First, that was the price at the time we did the economical calculation. Second, with 80% protein and 3% ash, if you make the mass balance on the whole thing you should be able to get a protein out that meets the 65% commercial grade, and you won’t have to take any bones out. If our numbers are right, it should not be necessary to take any bones out. That’s why I used a high fish meal price.

Q. Two questions. One, have you evaluated the quality of the protein through any type of feeding studies? Is it equivalent to surimi? Is it equal to egg? What is it equivalent to? Have you done any nutritional studies on it?

And second, have you tried spray drying it?
A. I’ll start with the last one. No, we have not tried to spray dry it. If we could get a hint of what it could be used for, then we could start working on the drying procedure.

A. (John French) It’s a very highly soluble protein. It contains significant amounts of actomyosin and other myofibrillar proteins, and of course contains many insoluble proteins. There appears to be very little protein denaturation occurring during this treatment process. In other words, it appears by all measures I’ve used so far to be a very high-quality, highly viable available protein.
STRUCTURE FORMATION DURING PRODUCTION OF FOOD ANALOGS

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Gel formation is the basis of a technology for determining the structural properties of analog food products. The gel formation capability of surimi has been extensively studied and depends on many factors (Dudziak et al. 1988, Kim and Lee 1987, Babbitt and Reppond 1988, Hennigar et al. 1988, Lee 1987, Niwa et al. 1988). One of these factors is the preliminary “sol keeping” properties, also called “setting.” It is known that setting influences the strength and elasticity of thermoprocessed gel (Nishimoto et al. 1987).

The main objective of our investigations is to study the process of gel formation and variations in structural-mechanical properties of the formulation, which appear at setting (Sawari in Japanese literature).

METHODS

The formulation consisted of: Alaska pollock specified mince, 71.5%; squid fillet, 7.1%; potato starch, 5.0%; egg protein, 5.7%; water, 5.7%; common salt, 2.0%; and other flavor additives, 3.0%.

The formulation was prepared by grinding for 25 minutes. Samples 20 mm thick were packed into plastic film. Setting was carried out in an ILKA temperature chamber in a steam and air medium. Samples were removed after 30 minutes.

Gel formation was assessed by the quantity of water pressed from the samples and by the breaking strength of samples that were thermoprocessed at 90°C for 15 minutes. The quantity of pressed water was expressed in percent of the sample mass. Breaking force was determined by a rheometer “food-checker.” The ultrastructure of samples was examined by electron microscopy of EMV-100L-type (Miyake 1965).

RESULTS AND DISCUSSION

Investigations of gel formation during setting of the formulation carried out at 15°C, 20°C, 30°C, and 40°C have shown that gel formation over time is accompanied by a decrease of pressed (weakly bonded) water (Figure 1). Weakly bonded water becomes part of the structure.

As seen from Figure 1, the most water was bound at 20°C and 30°C. At 30°C, setting was complete in 120 minutes, whereas at 20°C, setting required 180 minutes. The most rapid binding of water took place at 40°C (complete in 60 minutes), but that temperature was least effective.

As seen in Figure 2, setting (Sawari) depends on time and temperature. The strongest gel formed at 15°C and the weakest at 30°C. When gel strength was plotted against time, the asymptote was approached at about 90 minutes for all temperatures. Nishimoto et al. (1987) found a peak gel strength at 25°C and decreased gel strength with increased temperature.

Our results could be explained by a presence of sarco-plasmatic and other proteins in the formulation that were not influenced by the process of gel formation at lower temperatures. Thus, the presence of proteins, which have different links and serve as the gel matrix, could influence the quality of the initial formulation, and the character and properties of gel formation.

The results of organoleptic investigations during chewing found the most acceptable and similar properties were those samples setting at 15°C for 120 minutes and at 40°C for 30 minutes. The similar organoleptic properties may be explained by the quantities of water retained in the gel structure during setting, very similar for these two sets of samples.

The investigation of ultrastructure of the above samples has shown that the formation of areas with small granular structure is found in samples setting at 40°C within 30 minutes (Figure 3a and 4a) and the formation of areas with dense cell structure is found in samples setting within 120 minutes at 15°C (Figure 3b and 4b) (Sato et al. 1984). The character of gel structure
Figure 1. Changes in pressed water extruded as a function of setting regime.

Figure 2. Changes in breaking force of samples as a function of setting regime.

Table 1. Gel structure character and strength after thermoprocessing.

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<th>Setting regime</th>
<th>Gel structure</th>
<th>Breaking force (g)</th>
<th>Pressed water(%)</th>
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<td>$\bar{x}$</td>
<td>$S$</td>
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<td>653.3</td>
<td>43.6</td>
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<tr>
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<td>cell</td>
<td>716.2</td>
<td>26.3</td>
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<td>$40^\circ$</td>
<td>small-granular</td>
<td>689.0</td>
<td>19.1</td>
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$\bar{x}$ = arithmetical average.
$S$ = standard deviation.
$S^2$ = dispersion.
Figure 4: Ultrastructure of thermoprocessed samples. (a) Set at 15°C, 24 hr, (b) Set at 25°C, 30 min, (c) No setting.
is correlated with its strength after thermoprocessing (Table 1).

The structure of the formulation prior to setting has a blurred appearance (Figure 3c). Differences can also be noted in the thermoprocessed samples (Figure 4c). Gel tested prior to setting differs by having a lower strength and a lower broken consistency.

Thus, it was shown that through the process of water binding, setting at 15°C is much slower than at 40°C. Gel formation, as it is seen from values and the character of breaking force variations and ultrastructure, is affected by setting temperature. The presence of a low-temperature structure formation is confirmed by other works (Noguchi 1986) that found a vivid zone of variation of dynamic viscous-elastic properties of surimi in the 15°–17°C range.

From the results obtained, it follows that for a given formulation, gel formation is most effective at 15°C; however, from the point of view of economy and technology, setting at 40°C during a 30-minute period could be recommended for production of analog foods.

REFERENCES


COMPOSTING SEAFOOD PROCESSING BY-PRODUCTS: SOLUTIONS FOR THE 90s

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ABSTRACT

Composting processes for rendering fish scraps have been established as a useful and economical alternative to costly and unsafe disposal practices for the fish industry. The process will remove some economic and environmental pressure from the waste producers, while enabling an agriculturally useful material to be generated.

Composting fish scraps is a means of bio-thermal degradation to safely and uniformly reduce fish by-products into a useful soil amendment. It is appropriate where fish waste spoils rapidly and where economics do not favor other forms of rendering wastes.

A composting process begins with an inventory and analysis of fish scrap by-products, followed by identification of complementary "carbonaceous" wastes. It is then necessary to scientifically formulate a compost mix based on ideal moisture, texture, and carbon:nitrogen ratios. Compost piles are set up and subsequently monitored for heating and compositional changes to produce a stable compost product.

INTRODUCTION

In this paper, I present information about composting projects we have recently undertaken at Woods End Research Laboratory. Composting is a form of controlled bio-thermal degradation (Bertoldi et al. 1987). Long considered to be strictly an agricultural process, composting is finding a home in the fishing industry (K. Coons pers. comm.). Not considered meritorious for mention as a viable processing method in 1981 (Otwell 1981) and even as recently as 1986 (New England Fisheries Development Foundation 1986), composting has now been formally endorsed as "an operationally feasible byproduct processing alterna-

tive" by the Maine Governors Fishery Byproduct Task Force (Brennan 1988) as well as by traditional fishing industry representatives (K. Coons pers. comm.). The reason for this acceptance in New England is that we undertook specific research projects with the stated objective of testing the feasibility (Brinton and Seekins).

The utilization and disposal of fish processing by-products is an increasing subject of discussion. On the East Coast of the United States, there are few attractive disposal methods for fish scraps. We have recently pursued composting as a means to produce a safe, nutrient-rich fertilizer from fish scraps.

The fish by-products, or wastes, most typically selected for composting include aquaculture mortalities, hatchery effluent, fish gurry, groundfish racks, whole herring, shellfish scrap such as mussels, clams, and scallops, and crustaceans such as lobsters and crabs. As a general group, these materials are relatively rich in protein and therefore putrefy rapidly after processing. We have developed composting projects for many of the above materials.

Concern for fish by-product utilization is arising chiefly from a perceived environmental crisis in disposal of fish scraps through landfills, land application, or ocean-dumping, all of which have severe limitations. There are forms of rendering wastes into meal and hydrolysates which do not lead to environmental problems, and which we are not addressing.

Large opportunities exist agriculturally for recovery and utilization of nutrients contained in fish wastes. In particular, nitrogen and to a lesser extent phosphorus, plus calcium and magnesium, are plentiful in many by-products. In some cases, these by-products comprise from 30% to 80% of the bulk of processed fish, with crab waste falling in the 30% to 33% range (Otwell 1981).

Traditionally, these agricultural opportunities have centered on rendering into forms of feed additives, such as fish meal, silage, and hydrolyzed protein (New England Fisheries Development Foundation 1986), and to a much lesser extent into fish emulsion used as
a plant foliar spray. But long before these processing techniques were generally known, American Native Indians used fish scrap as fertilizer. Composting is recovering an age-old tradition, but in our approach, implementing it on a massive and economically attractive scale.

We perceive that composting can exist side-by-side with current forms of rendering, since in many cases no single technology can solve the fish scrap problem. For example, despite a thriving fish meal rendering technology, more than 40% of Nova Scotia herring waste is ocean-dumped or put into landfills (D. Fraser pers. comm.). Furthermore, a large quantity of fish by-products, including shellfish and crustacean materials plus fish gurries and hatchery wastes, simply cannot be rendered easily or economically into marketable supplements. Throughout coastal America, fish scraps are dumped, put into landfills, or discarded in ways that neglect the inherent nutrient value of the material. In the Florida gulf area, there are approximately a dozen blue crab processing plants producing between 1,300 and 3,500 tons per year of wastes, most of which are trucked to the county landfill (Andre 1988). These crab scraps consume more than 1% of the landfill and as much as 25% of the operating costs (Jacobs 1987). A very similar situation exists in Maryland with crab scrap (Hatem 1981, Cathcart et al. 1987). Lack of compliance with environmental guidelines for disposal is forcing us into a crisis situation (Brennan 1988).

**COMPOSTING: THE PROCESS**

The basis for composting is the oxidative metabolism of carbohydrate by microorganisms—bacteria and fungi—in an environment with adequate nutrients and moisture. Traditionally, the emphasis is on mixing energy-containing matter (carbon) with nutrient-containing matter (nitrogen) in ratios dictated by microbial metabolic requirements. For example, for each 30 parts of cellulose consumed, microorganisms will need approximately one part nitrogen. It is also important for aerobic microorganisms that the compost mass be porous and contain enough water to achieve a 60% to 70% saturation of the water-holding capacity. Understanding the nutritional requirements of microorganisms, therefore, forms a basis for composting recipe development.

As a prelude to composting, we normally conduct an inventory of other agricultural and food by-products disposed of in one form or another in an entire region. Because composting depends on mixing proteinaceous matter with carbonaceous ingredients, it is important to compare the proportions of fishery by-products with other commonly encountered wastes including those from food, farm, and municipal sectors. The data are collected and provide numbers to compute realistic and economical "mix recipes" of compatible ingredients to induce successful composting (Seekins and Walton 1988).

The inventory process often indicates that a quantity of carbonaceous material exists whereby composting could be accomplished with a minimum of required transport. Sometimes, however, local shortages exist for carbon. Since we are discussing the development of large projects, the need for volume must be appreciated. Of the needed carbon sources, competition may exist for uses other than in composting. Wood chips are routinely purchased for burning in energy-generating boilers, sawdust and shavings for animal bedding material, and bark for horticultural purposes. Another carbon source is peat moss, which is prized both for composting and horticultural uses elsewhere and is available in great quantities in certain regions. The primary focus of composting projects is fishery by-products high in nitrogen including: dogfish gurry, whole herring, groundfish (flounder rafts), as well as crab and lobster shells (Brinton and Gregory 1990). Most of these materials contain 6% to 11% nitrogen (dry basis) and require a large amount of carbon to bring about a biological optimum ratio of 30:1 (C:N). The carbon:nitrogen (C:N) rations of fishery by-products are very low (i.e., 3 to 5). In contrast, carbonaceous ingredients such as sawdust, wood shavings, and peat range in C:N from 50 to 240. The success of composting will depend on the proper blending of such diverse materials.

For every set of compostable materials, a theoretical ideal combination exists that optimizes C:N ratios, moisture, and texture. The determination of mix ratios is performed by a process called a mix-ratio analysis. We have applied a mathematical algorithm to arrive at an exact measure of the proportions of diverse materials to effect a successful composting process (K. Coons pers. comm., Brinton 1988).

Once begun, the composting materials heat up for four to eight weeks. In this time, the proteins are broken down and stabilized by bacteria in the form of cell tissue and humic compounds. Rapid release of ammonia can cause the pH to rise dramatically in the compost at the outset, but a neutral reaction is reached toward the end.

The final compost products are generally rich in organic matter (40% to 70%) and contain between 1% and 4% nitrogen. They may be applied freely to soils for purposes of texture improvement and to provide slow-release nutrients for sustained growth of crops (Brinton 1989, Brinton et al. 1989). With current
concerns of soil degradation, such compost products may fulfill a very useful purpose.

LITERATURE CITED


QUESTIONS AND ANSWERS

Q. I see applications for your low-cost fishery waste. But I don’t want the audience here to leave with the impression that crustacean wastes are for landfill operations. I strongly encourage you to read some of the articles that are coming out in the Journal of Food Science where they’re recovering valuable by-products, flavors, vitamins, and growth-stimulating products from things like scallop viscera. In areas where a large amount of hand picking, or peeling of crustacean waste is required, the first priority should be to recover economically what can be a valuable food product. The residue I agree can either be dried as meal, or can be used in a landfill operation.

A. I’d like to make an important distinction: Using landfills is not synonymous with composting. In fact it is completely the opposite. With regard to your alternatives, they have been explored. We’ve done studies, and nobody has followed up. Now disposal is in a crisis situation.

With regard to scallop viscera, it goes from boom to bust every other year. One year we had zero. It went up to 40,000 tons of viscera in 1987. The next year it was back down to 6,000 tons. Because of the wide and violent swings, and the lack of money in the fishing industry itself, nobody’s really taken the lead in creating by-products. I agree that if you could create a by-product it would be great, but it’s not happening. In New England we’ve lost our by-product plants because they’re not economically viable in the international market.

So we’re proposing a solution that works now. Incidentally, some compost producers are getting prices half as good as those for fish meal. And their costs are much lower because of the large market for soil amendments. So I think we have to temper your remarks with the fact that we’ve got a very broad market. People may end up making as much money composting as anything else. And it can be implemented on almost any scale. It makes
no difference at the compost facility if nothing comes in one day, and 50 tons comes in the next day. They can tolerate that variability. In that sense it’s more economically durable. Some of the less well-to-do fish processors are choosing the compost option because it is the only choice they can make right now.

Q. How can the produced heat be utilized?
A. Some researchers in Minnesota have been utilizing the heat produced to heat greenhouses.

Q. Do you have any information on the composition of your leachate, particularly when you are using a lot of liquid?
A. When we launched these projects, everybody said, “Are you going to have a lot of leachate?” The environmental regulators came out in force to observe, but we didn’t have any leachate because the material was so dry and porous during the composting. In fact, we have to add water to it. It gets so hot the moisture evaporates. Some facilities are under roofs now, but the problem with going under a roof is that there is no rainfall, and they really have to water their piles. But they do avoid runoff that might occur during a storm.

The surface runoff has a small amount of dissolved nitrogen, but nothing significant enough to severely restrict the implementation of this process.

One of our projects in Maine is being very closely monitored and scrutinized by the environmental department, with monthly monitoring of all the waters coming off the site. After two years, they’re going to rewrite their standards based on the results of our project because they feel that if it’s not a problem, they shouldn’t put so many punitive regulations on this kind of facility. So far, it looks pretty good.

Q. What’s the cost and availability of the carbonaceous material? I presume a lot of this is sawdust or shavings.
A. Each area has something different to offer. In Florida we found mountains of cypress sawdust going begging. In Maine a lot of the shavings and chips are recycled, but sawdust is not particularly preferred, and they also don’t like to burn it in the energy recovery facilities. So sawdust is available. In Canada they have huge reserves of peat moss. The Department of Agriculture in Ottawa has published a few studies on the feasibility of using peat as a compost amendment. And they’re doing that now in New Brunswick. So you have to find the least-cost carbonaceous source in each area. For some composting projects, they’re recycling their carbon material. They screen out the chips of wood, and then reuse it, so they get double duty over time.