FILE: AQUACULTURE

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THE ROLE OF A FOOD ENGINEER IN FISH DIET RESEARCH AND FORMULA DEVELOPMENT

by

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The Role of a Food Engineer in Fish Diet Research and Formula Preparation

INTRODUCTION

For some years we have been hearing glowing accounts of the tremendous fish farming and aquaculture industry that will be a major source of "animal" protein for the world. Over the past ten years there have been many studies by such groups as the Technical Advisory Committee for Fisheries Research (TAC, 1972), the International Development Research Center (IDRC, 1976) and the National Academy of Sciences (NAS, 1977). In general, studies for this past ten year period have drawn the same conclusions: namely, we that we need more knowledge in reproductive physiology, nutritional requirements, disease and parasite control, and relationship with environmental factors. The response to these many studies with their universal conclusions has been to establish research centers and research programs and to make more studies. Yet, relatively little progress has been made toward commercial mass production of fish by aquaculture. Why?

Over the past two or three decades, the food processing industries have undergone a major transition from "Ma and Pa" operations to large companies processing mass quantities of foods for an ever-increasing population. This relatively rapid change in the industrial complex has presented many production problems, most of which involve the application of engineering principles in the final practical solutions. Without continuing these drastic technological changes in our food industry, the per capita supplies of the right kinds of foods for animal and human consumption will continue to diminish as the population increases at a greater rate than the production of food. The manufacture of fish feed for aquaculture falls in the same category as the general food industry. Sanitary standards and quality control procedures must be rigorous in order to insure healthy, wholesome fish as food for humans. In addition fish must be produced at a price that will be mutually beneficial to the fish farmer and the consumer.

As food engineers and technologists we must continually enlarge our knowledge of the multi-discipline areas necessary for filling the requirements for fish feed manufacture. This includes procurement of raw materials, handling, processing, packaging, transportation and marketing of finished feeds. The ability to apply basic engineering principles in these areas is most important to the healthy growth of aquaculture, but unfortunately has been given minor emphasis in past aquaculture programs.

It is my firm belief that part of the problem will be resolved by this new journal dealing with the technological aspects of aquaculture and emphasizing the role of engineers, technologists and others schooled in the applied physical rather than the biological sciences. This will create interest in the technology that will be a major contribution to hastening the practical reality of commercially rearing edible fish and shellfish. Either directly or indirectly all of the factors recommended by the previously mentioned surveys for concentrated emphasis in future research and development are heavily dependent on facilities design, mechanical operations, environmental control, processing and handling of fish for market, and feed development and manufacture. I should like to concentrate on the latter item as an example of why Food Engineers are so important to the rise or demise of aquaculture, although a strong case can be built for technology in each area.

The typical concept of the aquaculturist toward feed is that ingredients are mixed, then heated, dried or in some manner processed prior to pelleting and packaging (Fig. 1). In reality, the growth and health of the fish as well as the economics of the process are directly dependent on the properties of the component ingredients that go into the feed and the subsequent detailed processing techniques. For example, ask a researcher doing feed studies on diets utilizing fish meal about the source of the meal. The usual answer is that "it is commercial fish meal." The source and processing (especially drying) techniques are usually not known, nor even available to the purchaser. However, the results of a test involving growth from such a diet are immediately suspect if extensive chemical and biological testing is not carried out since the available or digestible protein and values of other nutrient components vary tremendously depending on the processing time and temperature and the type of drying technique to which the drying fish was subjected.

THE PROCESS ENGINEER IN AQUACULTURE

An engineer who is going to be active in the design, construction and operation of feed manufacturing facilities should be educated in the food field after he has gained a good basic background in engineering. This normally requires study beyond a four year degree program. On the other hand, the fisheries biologist and the aquaculture manager should have an exposure to the applications of engineering principles necessary to manufacutre high quality feed and the subsequent handling, storage and use conditions required to maintain that quality. In summary, the tremendous march forward that must be made in aquaculture feed technology and manufacture over the next decade must be made by biologists, aquaculturists and technologists working hand-in-hand and not in competition. We should not attempt to make an engineer out of a biologist nor a biologist out of an engineer, but we should give each an appreciation of the other's field so that communication between the two areas is more effective.

Whereas normal engineering applications deal with chemical and physical aspects, the design, construction and operation of commercial feed manufacturing facilities must consider the biological factors. Flavors, odors, color, texture, body, nutritional components, etc. are not only related to the physical and chemical changes affecting fish feeding but to the influence of microorganisms and their metabolic products.

WHAT ARE ENGINEERING PRINCIPLES?

In general, engineering is the applied aspect of basic science. Applied research is a continual effort of trying until a scientifically sound and duplicable solution is found for a practical problem. The basic laws of physics, chemistry and biology as expressed in the language of mathematics show us the relations between many of the elements composing a "system" whether it be a small piece of machinery or the planet on which we live. However, due to many shortcomings of man's knowledge of these relationships, precise relationships are not determinable without the use of experimentally designed constants and secondary relationships that balance the equations and make them useful for application to practical situations. Hence, when we refer to the application of basic engineering principles, we mean the use of experimentally determined information combined with the basic scientific laws in such a manner that we can design a successful plant, design and build machinery for economically handling, transporting, processing and packaging feed and feed ingredients. Finally, and perhaps most important of all, we must compile records and information on production performance so that processing facilities and techniques can be improved or newly developed.

The problems of utilizing the engineer's tools in the feed industry are all too traditional. We need and must rely upon basic engineering data for the study of processing techniques and the commercialization of these techniques. This includes:

1. The changes in weight and composition that occur in feeds and components during processing.
2. The pack densities and specific gravities and compressibilities that are brought about in loading bins, storage tanks and vats.
3. The safe loading depths for fresh or raw products during transportation and storage.
4. The flow properties for various feeds and components in different forms and process states.
5. The properties of viscous materials such as purees, pulps, slurries, etc.
6. The specific heat, heat capacity and heat conductivity of feed in all states of preservation. This is particularly important where simultaneous mass and heat transfer occur.
7. The effects of particle size on various processes. This has a bearing on many processes, such as spray drying, grinding, filtering slurries and miscellanea and disintegration operations.

These often unknown items are related to many important parameters in a feed such as solubility, bindability, nutrient stability, and tendency to float or sink.

In the past, processing and handling machinery and equipment have all too often been based on history and tradition rather than efficient functioning, easy maintenance and sanitary requirements. Sadly enough, major technical developments in the industry, as with many other industries, are often guided or determined by political rather than by sound scientific and economic factors.

BASIC PROCESSING TECHNIQUES

The quality of all components in fish feed must be known in order to formulate a diet meeting certain specifications and then the effect of the final feed mill process must be considered. Processing involves a wide variety of operations. However, the steps in preparing a feed can be separated into two categories. These are:

(1) Preservation to extend shelf life and insure safety of feed by reducing, inactivating or eliminating spoilage and disease organisms.

(2) Mechanical handling, including formulation, mixing, particle size control, and packaging or holding in containers to protect feed from damage and spoilage during shipping and storage.

PRESERVATION METHODS

There are four basic methods being used to preserve feeds. Most processes involve a combination of two or more of the techniques which involve addition of chemicals, adding or removing heat, and removing water.

Adding Chemicals

Chemical additives are used in feed primarily to stabilize the lipid portion of the diet. However, other effects of chemicals used in processing are often more important than realized. For example, consider a product such as a hydrolysate extracted at a low pH and then neutralized prior to drying (Fig. 1). The normally available product, in this case Fish Protein Hydrolysate (FPH), is neutral at a pH of 7.0 whereas the superior amino acid retention (Table 1) is in the product at the processing condition of pH 3.8. We have demonstrated that the non-neutralized, and much cheaper, product is equal or superior to the standard material when used as a inder and protein source in a larval feed being developed at the University of Washington (Gabaudan et al. 1980).

Adding Heat

Probably the preservation process that has the major effects on the nutritional value of feed ingredients and final prepared feed is the addition of heat. Heating is used to preserve food by (1) pasteurization to reduce organisms, thus extending shelf life and minimizing public health risks and (2) sterilization to kill all organisms, thus allowing long term storage of a properly packaged feed. The cooking effect of heating changes the texture, taste and acceptability of some products. Also, as will be discussed later, most conventional drying operations involve heating to increase the rate of drying.

Heat not only alters the nutritional value of component materials but also causes physical and chemical changes that affect the economics of growing fish. The extent of protein denaturation by heat changes the water solubility and binding characteristics, thus affecting the water solubility and stability of the feed particles. Heat increases the oxidation rate for fats, destroys many of the heat labile vitamins and promotes the Maillard browning reaction.

Removing Heat (Refrigeration)

Removing heat from a product reduces the growth of microorganisms and the reaction rates of enzyme action. After sufficient heat is removed to freeze a feed, the microorganisms become dormant but the enzymes continue to be active. Thus, degradation of nutrient ingredients continues while a raw material or a prepared feed is being held in the frozen state. It is interesting to note that the only major nutrient damage to a feed during freezing is air oxidation if the product is exposed to air. However, a considerable degradation takes place during frozen storage when both chemical and physical degradation is caused by the changing relationship between free water and enzymes. The storing of frozen feeds is expensive, not only in the cost of maintaining and operating freezing and cold storage facilities but also in the loss of nutritional value.

Removing Water (Dehydration or Drying)

Drying is a word that is universally understood for the removal of water. In its broadest sense, it refers to the removal of a liquid from a solid by evaporation. The required heat of evaporation is provided to

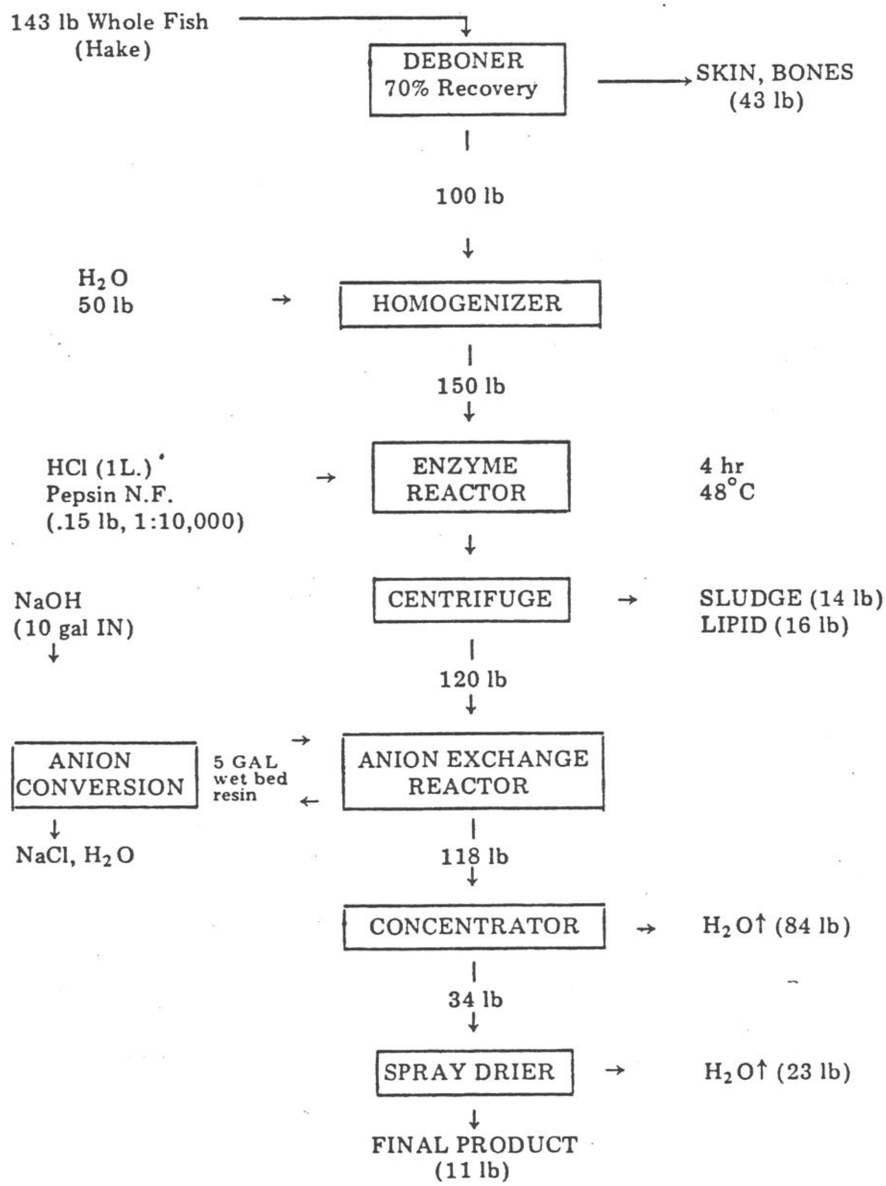

FIG. 1. PILOT PLANT MATERIAL BALANCE AND FLOW CHART

[Basis: 100 lb deboned fish]

Reference - Pigott, 1978

Table 1. Fish Protein Hydrolysate: Amino Acid Profile vs. pH Treatment

Amino Acid	Amino Acid Content (g/100 gm protein)	
	pH 7.0	pH 3.8
Arg	6.0	5.7
Iso	3.7	5.3
Leu	6.1	7.2
Lys	7.3	7.8
Met	1.9	2.3
Phe	2.8	3.5
Thr	3.9	4.7
Val	3.6	4.4

(Ref: Gabaudan *et al.*, 1980)

the material being dried by conduction from a solid surface, by convection from a gas, radiation from another surface, or some combination of these transfer mechanisms. Feeds are dried or dehydrated for (1) preservation to increase storage life, (2) reduction of the cost and the problems associated with packaging, handling, storing and shipment and (3) preparation of products having certain desired chemical and physical properties important for maximum feed efficiency under certain environmental conditions or for specific requirements of the species being fed.

Two fundamental and simultaneous processes occur during drying: (1) heat is transferred to evaporate liquid and (2) mass is transferred as a liquid or vapor within the solid and as a vapor from the surface. The factors governing the rates of these processes taking place determine the drying rate. Temperature, humidity and velocity of air, surface area, pressure or vacuum, and direction of air movement are the external conditions which determine the rate of evaporation. Diffusion in continuous homogenous solids, capillary flow in granular solids, gravity shrinkage and pressure gradient determine the internal liquid flow.

The interrelationships of the controlling factors in drying of a solid preclude one smooth continuous drying rate. However, there are two distinct phases of drying that have a major bearing on the quality of the final product and on the cost efficiency of drying. A wet solid loses moisture first by evaporation from the saturated surface. During this period the evporation proceeds in a manner similar to that of a liquid whereby the evaporation is controlled by the amount of heat input. This, the so-called constant rate period, is essentially independent of the nature of the solid and is controlled by the rate of heat transfer to the evaporating surface.

At a point during the drying process a critical moisture content is reached at which point diffusion of water to the surface is not rapid enough to maintain the constant evaporation rate. At this critical moisture content which differes for each material, the drying is no longer constant and the rate of drying becomes dependent on the rate of water diffusion to the surface. This mass transfer controlled portion of the drying cycle is called the falling rate period. The effects and changes of diffusion, capillary and pressure gradients caused by shrinkage and the nature of the base starting material are most important during the falling-rate period. Final nutritive value of a dried feed or feed component (*i.e.*, fish meal) is quite dependent on the knowledgeable control of these drying variables.

MECHANICAL HANDLING

Whereas the preservation methods directly affect the physical and chemical properties as well of the nutritive value, the mechanical aspects of handling primarily affect the physical properties that relate to presentation of a feed to the fish. Mechanical operations include:

1. Mixing ingredients to ensure a uniform diet.
2. Grinding, homogenizing or otherwise reducing particle size.
3. Screening to select desired particle size ranges.
4. Extruding, pelleting or otherwise forming pellets of a desired particle size and density.

5. Conveying ingredients or finished diet by mechanical or pneumatic means.

6. Weighing and packaging finished products.

The two primary problems in these and other mechanical handling and processing techniques are particle attrition and heating due to friction. Attrition, of course, results in particle size changes that reduce the efficiency of a diet formulated for a specific size fish. Heating of the products occurs during grinding and pelleting operations. The ultimate adverse effect of overheating is to reduce the diet efficiency through destruction of certain nutritive values. Good engineering design and selection of facilities and careful plant operation can substantially reduce problems associated with all phases of feed production.

FUTURE APPLICATIONS

Aquacultural Engineering has not been precisely defined and will probably evolve over many years as a composite of many engineering and scientific disciplines. It is doubtful that any one individual will accumulate the vast background necessary to handle all engineering tasks involved in a complete aquaculture operation. A parallel example of a specialized engineering area involve the Agricultural Engineer who is primarily in the mechanical area involving farm machinery design, development, and operation. The Aquacultural Engineer may well also be oriented in mechanical engineering whereby he would be active in fish handling, feeding, harvesting and environmental control machinery, equipment and facilities. As in the case of agricultural engineers, the civil engineering aspects of design and construction and the processing engineering area involving fish processing and feed developmen' and manufacture would be required to complete the engineering compliment. However, since all of these areas are related to the application of engineering to aquaculture, like the Agricultural Engineering publication, the Aquaculture Engineering journal should provide a sounding board for all engineering applications to the field of aquaculture. Hence this new journal is a welcome addition to many engineers, like myself, who have had to publish some of their engineering papers in more basically scientific journals that are not really oriented toward these applied areas.

The first million years in which the earth was inhabited by man has ended with a population of over 4 billion peple and a large majority of the prime agricultural areas have been exploited by this population. However, this population figure will most likely continue to increase to the extent that we could find ourselves facing a most bleak future indeed. Analyzing the shortages of food that will become disastrous, depletion of conventional sources of power and raw materials, and an expanding population to feed, clothe and house leads one to conclude that the future of mankind on our earth is quite dependent on the applied application of engineering principle for the design, construction and operations related to both economics and the effect on the environment. Aquacultural Engineers can be most effective in helping us realize the tremendous potential of raising desperately needed high quality protein food in such a large scale as to have a major impact on mankinds survival.

REFERENCES

Gabaudan, J., Pigott, G.M., Halver, J.E., 1980. "The Effect of Processing on Protein Ingredients for Larval Diets," Proceedings of World Mariculture Society Annual Meeting, New Orleans, La., U.S.A., March 5-9.

NAS, 1977, "World Food and Nutrition Study -- The Potential Contributions of Research", prepared by the Steering Committee on World Food and Nutrition of the Commission on International Relations, National Research Council, National Academy of Sciences, Washington, D.C.

Pigott, G.M. and Bucove, G., 1978. "Engineering a Plant for Enzymatic Production of Supplemental Fish Proteins," J. Fd. Proc. and Pres., 2:33-54.

TAC, 1974. Consultative Group on International Agricultural Research, Technical Advising Committee, Aquaculture Research Programme: Report of the TAC subcommittee on Aquaculture, DDDR/IAR/74/25 Restricted.