A SMALL SCALE SOLAR HEATED FISH MEAL PRODUCTION SYSTEM: DESIGN, OPERATION, EVALUATION AND PRODUCT NUTRITIONAL ASSESSMENT BY CHEMICAL AND BIOLOGICAL METHODS

By

Douglas Kirkpatrick Hall

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Animal Science

1981

ABSTRACT

A SMALL SCALE SOLAR HEATED FISH MEAL PRODUCTION SYSTEM:
DESIGN, OPERATION, EVALUATION AND PRODUCT
NUTRITIONAL ASSESSMENT BY CHEMICAL AND BIOLOGICAL METHODS

By

Douglas Kirkpatrick Hall

A small scale solar heated fishmeal production system was built and an operating procedure developed. This included fish silage storage, cooking, pressing and drying systems.

The raw fish material was cooked with 0.15 liters of water per kg of product to a maximum of 71° C. A hand operated fish press removed 8% moisture from cooked product. The drum cabinet combination dryer had an average efficiency of 44.1% ($\frac{\text{moisture removal}}{\text{potential moisture removal}}$) under solar heat alone. A batch of fish product dried in 12 hours of solar heated operation. A kerosene fired auxillary heat source was developed for increasing drying rate and for cloudy periods. Fifty kilos of dry product per sun day can be produced.

Operating expenses were $0.25/kg dry product (U.S.) and the operation under Belize conditions had positive net revenue.

Proximate analysis of fish meals and crustatean meals produced in this process are presented. Fish meal crude protein ranged from 56.6 to 78.2% (dry basis).

Broiler feeding trials compared commercial menhaden fish meal to experimental fish meal at graded dietary levels. Fish meal source had

no significant effect on liveweight nor feed conversion except at the highest level (75% of supplemental protein) where the birds fed commercial fishmeal were significantly ($P<.01$) heavier and of improved feed conversion. Fish meal type did not affect feed consumption.

Dedicated to my wife

Julia

TABLE OF CONTENTS

	Page
List of Tables	
List of Figures	
OBJECTIVES OF THE BELIZE TRASH FISH MEAL PROJECT	1
INTRODUCTION	2
REVIEW OF LITERATURE	4
Description of Fish Meal	4
World Production of Fish Meal	4
Chemical Compositions of Established Varieties of Fish Meal	4
Methods of Manufacture of Fish Meal	19
Use of Fish Meal in Livestock Diets	28
Fish Silage	31
Drying Aspects of Fish Meal	34
Solar Technology	35
Project Background Information	42
MATERIALS AND METHODS	48
Development of the Drying Facility	48
Initial Assumptions	48
Design and Construction of the Drying Components	49
Fish Silage	83
Operating Sequence	86
Evaluation of Finished Product	93
Chemical Analysis of Fish Products	93
Microbial Analysis	95
Analysis of PH	95
Broiler Feeding Trials	96
RESULTS	108
Solar Collectors	108
Rotary Drum Dryer	108
Drum/Cabinet Dryer	114
Cost Analysis of Production of Fish Meal Operating Costs	114
Chemical Analysis of Fish Products	121
Broiler Trials	124
DISCUSSION	134
Drying Facility	134
Chemical Analysis of the Fish Products	141
Feeding Trials	143

CONCLUSIONS 145

RECOMMENDATIONS FOR FURTHER STUDY 146

LIST OF REFERENCES 147

APPENDICES 153
Appendix A Composition of "Belize" Vitamin and Trace Mineral Premixes 153
Appendix B Summaries of Statistical Analysis 154
Appendix C Microbial Analysis Methods and Materials 169

LIST OF TABLES

Table		Page
1	Ten Leading Fish Meal Producing Countries, Volumes and Major Fish Species Processed	5
2	Approximate Composition of Raw Fish and Shell Fish	7
3	Amino Acid Composition of Five Major Fish Meals and Shrimp Meal	8
4	Proximate Analysis and Calcium and Phosphorus Levels of Five Major Fish Meals and Three Shrimp Meals (dry matter basis)	13
5	Mineral Content of Five Fish Meals	15
6	Vitamin Analysis of Selected Fish Meals Mg/100 g	16
7	Fatty Acid Composition and Iodine Number of Fish Lipids from an "Oily Fish" Species and a "White Fish" Species	18
8	Absorptance and Emmittance of Possible Absorber or Reflector Materials (0^{o} Angle of Incidence)	40
9	Properties of Glazing Materials	41
10	Description of Rations	97
11	Nutrient Composition of Major Ration Components (Dry Basis)	98
12	Formulation of Broiler Starter Diets (NRC Protein Level)	99
13	Formulation of Broiler Starter Diets (Sub-NRC Protein Level)	100
14	Formulation of Broiler Finisher Diets	101
15	Calculated Nutrient Concentrations in Broiler Starter Diets (NRC-Protein Level)	102
16	Nutrient Contents of Broiler Starter Diets (Sub-NRC Protein Levels	103

Table		Page
17	Calculated Nutrient Contents of Broiler Finisher Diets	104
18	Energy Output of Collectors Tilted at 40° and 20° Above Horizontal on Clear, Bright Days	109
19	Energy Output of Individual Collectors Tilted at 20° Above Horizontal on Clear Days	110
20	Efficiency of Rotary Drum Dryer	112
21	Efficiency of Drum Cabinet Dryer with Solar Energy Only	115
22	Moisture Content of Fish Product During Drum Cabinet Drying Evaluation (% Moisture)	117
23	Efficiency of Drum Cabinet Dryer with Supplemental Heat Source	118
24	Summary of Operating Costs of Drum/Cabinet Drying Sequence Using Solar Energy	119
25	Estimated Cost of Production of 400 Lbs Ensiled Fish	119
26	Summary of Operating Costs of the Drum/Cabinet Drying Sequence Using Ensiled Fish and Solar Heat Only	120
27	Estimated Operating Cost of Supplemental Heat to Drum Cabinet Dryer per Hour of Operation ($BH)	120
28	Proximate Analysis, Calcium and Phosphorus of Raw Material Sources % (as is basis)	122
29	Proximate Analysis Calcium and Phosphorus of Dried Meals % (as is basis)	123
30	Proximate and Mineral Analysis of Fish Meals Used in the Feeding Trials (as is basis (dry matter basis))	125
31	4 and 8 Week Liveweight Treatment Means (grams)	126
32	0-4 and 4-8 Week Average Daily Feed Per Bird Treatment Means (grams)	130
33	0-4 and 4-8 Week Feed Conversion Treatment Means	132
A-1	Guaranteed Minimum Analysis of Vitamin and Mineral Pre-Mixes Used in Broiler Trial Rations	153
B-1	Factoral Analysis of Variance for 4 Week Weights	154

Table		Page
B-2	Factorial Analysis of Variance for 8 Week Weights	154
B-3	Factorial Analysis of Variance for Feed Consumption 0-4 Weeks	155
B-4	Factorial Analysis of Variance for Feed Consumption 4-8 Weeks	155
B-5	Factorial Analysis of Variance for Feed Conversion 0-4 Weeks	156
B-6	Factorial Analysis of Variance for Feed Conversion 4-8 Weeks	156
B-7	Analysis of Orthogonal Polynomial Contrasts in 4 Week Weight for the Levels of Supplementation with Commercial Fish Meal at NRC Protein Levels	157
B-8	Analysis of Orthogonal Polynomial Contrasts in 4 Week Weight for the Levels of Supplementation with Belize Fish Meal at NRC Protein Levels	157
B-9	Analysis of Orthogonal Polynomial Contrasts in 4 Week Weight for the Levels of Supplementation with Commercial Fish Meal at Sub-NRC Protein Level	158
B-10	Analysis of Orthogonal Polynomial Contrasts in 4 Week Weight for the Levels of Supplementation with "Belize" Fish Meal at Sub-NRC Protein Level	158
B-11	Analysis of Orthogonal Polynomial Contrasts in 8 Week Weight for the Levels of Supplementation with Commercial Fish Meal at NRC Protein Level	159
B-12	Analysis of Orthogonal Polynomial Contrasts in 8 Week Weight for Levels of Supplementation with Belize Fish Meal at NRC Protein Level	159
B-13	Analysis of Orthogonal Polynomial Contrasts in 8 Week Weight for the Levels of Supplementation with Commercial Fish Meal at Sub-NRC Protein Level	160
B-14	Ananysis of Orthogonal Polynomial Contrasts in 8 Week Weight for Levels of Supplementation with Belize Fish Meal at Sub-NRC Protein Level	160
B-15	Analysis of Orthogonal Polynomial Contrasts in 0-4 Week Feed Consumption for the Levels of Supplementation of Commercial Fish Meal at NRC Protein Level	161

Table Page

B-16 Analysis of Orthogonal Polynomial Contrasts in 0-4 Week Feed Consumption for the Levels of Supplementation of Belize Fish Meal at NRC Protein Level 161

B-17 Analysis of Orthogonal Polynomial Contrasts in 0-4 Week Feed Consumption for the Levels of Commercial Fish Meal at Sub-NRC Protein Levels 162

B-18 Analysis of Orthogonal Polynomial Contrasts in 0-4 Week Feed Consumption for Levels of Supplementation of Belize Fish Meal at Sub-NRC Protein Levels 162

B-19 Analysis of Orthogonal Polynomial Contrasts in 4-8 Week Consumption for Levels of Supplementation of Commercial Fish Meal at NRC Protein Levels 163

B-20 Analysis of Orthogonal Polynomial Contrasts in 4-8 Week Feed Consumption for Levels of Supplementation of Belize Fish Meal at NRC Protein Levels 163

B-21 Analysis of Orthogonal Polynomial Contrasts in 4-8 Week Feed Consumption for Levels of Supplementation of Commercial Fish Meal at Sub-NRC Protein Levels 164

B-22 Analysis of Orthogonal Polynomial Contrasts in 4-8 Week Feed Consumption for Levels of Supplementation of Belize Fish Meal at Sub-NRC Protein Levels 164

B-23 Analysis of Orthogonal Polynomial Contrasts in 0-4 Week Feed Conversion for the Levels of Supplementation with Commercial ;ish Meal at NRC Protein Levels 165

B-24 Analysis of Orthogonal Polynomial Contrasts in 0-4 Week Conversion for the Levels of Supplementation with Belize Fish Meal at NRC Protein Levels 165

B-25 Analysis of Orthogonal Polynomial Contrasts for 4-8 Week Feed Conversion for Levels of Supplementation with Commercial Fish Meal at NRC Protein Levels 166

B-26 Analysis of Orthogonal Polynomial Contrasts for 4-8 Week Feed Conversion for Levels of Supplementation with Belize Fish Meal at NRC Protein Levels 166

B-27 Analysis of Orthogonal Polynomial Contrasts for 4-8 Week Feed Conversion for Levels of Supplementation with Commercial Fish Meal at Sub-NRC Protein Levels 167

Table Page

B-28 Analysis of Orthogonal Polynomial Contrasts for 4-8 Week Feed Conversion for Levels of Supplementation with Belize Fish Meal at Sub-NRC Protein Levels 167

B-29 Bonferroni Test Statistics for Contrasts of Treatment Means 168

LIST OF FIGURES

Figure		Page
1	Schematic Representation of Two Processing Operations Involved in the Manufacture of "White" Fish Meal	20
2	Schematic Representation of the Major Processing Operations Involved in Manufacture of Fish Meal Products	22
3	Model Small Scale Fish Meal Production Facility	27
4	Three Basic Solar Collector Designs	38
5	Rainfall in Centimeters - San Pedro Ambergris Cay, Belize 1952-1970	44
6	Rain Days per Month - San Pedro, Ambergris Cay, Belize 1952-1970	44
7	Grouper Filet Waste at the Caribena Coop	46
8	Custom-made Grinder Plates for Commercial Meat Grinder	50
9	Cut-away Drawings of Rotary Fish Mincer	52
10	Direct Cooking System	56
11	Hand Operated Fish Press	57
12	Fish Press Seive and Press Cake	58
13	Wooden Solar Collector	61
14	Metal Solar Collector	62
15	Orientation of Solar Collectors	65
16	Front View Blower Unit	67
17	Top View Blower Unit	68
18	End View Blower Unit	69
19	Cabinet Dryer	72

Figure		Page
20	Dry Coarse Fish Meal Produced in Cabinet Dryer	74
21	Rotary Drum Dryer	75
22	Drum Cabinet Dryer	78
23	Front View Drum Cabinet Dryer	79
24	End View Drum Cabinet Dryer	80
25	Air Flow Pattern Drum Cabinet Dryer	82
26	Experimental Silage Treatments in 5 Gallon Plastic Buckets	84
27	Diagram of Production Sequence	87
28	Fish Paste Draining on Screen Rack	89
29	Coarse Dried Fish Meal	94
30	Broiler House Central Farm, Cayo, Belize	106
31	Energy Out-Put of the Individual Solar Collectors at 20^{o} Tilt	111
32	Mositure Content of Product Over Time in the Rotary Drum Dryer	113
33	Moisture Content of Product Over Time in the Drum Cabinet Dryer	116
34	Four Week Liveweight Response Curves to Level of Supplementation of Fish Meal	127
35	Eight Week Liveweight Response Curves to Level of Supplementation of Fish Meal	128

OBJECTIVES OF THE BELIZE TRASH FISHMEAL PROJECT

1. To design a low cost, low fossil fuel requiring fishmeal production unit that would be effective in a wide variety of locations.

2. To produce a wholesome fishmeal which can be used in livestock rations in Belize.

3. To develop and implement a complete small scale fishmeal production facility specific for Ambergris Cay, Belize, Central America.

4. To biologically evaluate low heat processed fish meal manufactured in this system.

INTRODUCTION

The increase in human population of the world has caused food production to become a major concern to government planners. An important component of the ever increasing food requirment is protein. Protein is important to the diet in quantity but also in quality of amino acid composition. Animal products can provide the essential amino acids required for humans.

Proteins are also needed in diets of livestock produced for the purpose of human consumption. Protein sources that are outside the human food chain are needed for this purpose if an economical use of this nutrient resource is to be made. Fish meal can be a livestock protein source of high amino acid quality that is not consumed normally by humans.

Annually, about four million tons of fish meal is produced for a variety of purposes, the greatest portion being used as livestock protein concentrates. Over ninety percent of the world production is manufactured in ten countries. These countries are either highly industrialized and can afford large capital expenditures for facilities or have high levels of raw material sources and can have large operations with large volume through-put. Countries not possessing these traits are presently unable to take full advantage of this potential protein resource.

This thesis describes the development of a low capital requiring small scale fish meal production scheme using low-heat levels and solar energy that can be used in areas of low to moderate raw material

availability.

The prototype drying facility described is located in San Pedro, Ambergris Cay, Belize, Central America. Design, construction and evaluation of this facility was promoted by the Belize Trash Fish Meal Project, a division of the Belize Livestock Feeds Project. The project was financially supported by the Caribena Producers Cooperative Society of Ambergris Cay, Belize and the Ministry of Natural Resources, Government of Belize.

REVIEW OF LITERATURE

Description of Fish Meal

"Fish meal is the clean, dried, ground tissues of undecomposed whole fish or fish cuttings, either with or without the extraction of part of the oil", (Feed Industry Red Book 1977). It is used primarily as a protein source for swine and poultry diets but may also be used as a fertilizer or as a protein source for humans.

World Production of Fish Meal

World production of fish meal in 1978 was 4,390,000 tons and has been at approximately that level for the previous seven years (FAO, 1978). Production of fish meal by the ten leading countries for the year 1978 is listed in Table 1.

Chemical Composition of Established Varieties of Fish Meal

"Generally fish flesh contains water, proteins, fats and traces of carbohydrates, free amino acids, minerals and vitamins." The elemental composition of raw fish flesh on an as-is basis is approximately as follows: (Woolen, 1969)

75% Oxygen
10% Hydrogen
9.5% Carbon
2.5-3% Nitrogen
1.2-1.5% Calcium
.6-.8% Phosphorus
.3% Sulfur
Traces 60 other elements

TABLE 1

TEN LEADING FISH MEAL PRODUCING COUNTRIES,
VOLUMES AND MAJOR FISH SPECIES PROCESSED

Rank	Country	% of World Prod	1978 Production (1000 Metric Tons)	Major Species
1	Japan	18.2	797.4	Pilchard, Herring
2	Peru	15.3	669.7	Anchovy
3	USSR	11.5	503.4	
4	U.S.A.	10.9	476.7	Menhaden, Tuna Mackerel
5	Chile	8.6	379.1	Anchovy, Pilchard Mackerel
6	Norway	7.6	331.5	Herring
7	Denmark	6.2	273.0	Herring, Spat, Mackerel
8	Iceland	4.6	202.8	Capelin, Herring
9	So. Africa	4.3	190.6	Mackerel, Anchovy, Pilchard
10	Thailand	3.2	141.5	
	TOTAL	90.4	3965.7	

Source: FAO Year Book of Fishery Statistics
Fishery Commodities
Volume 47 1978

The protein content among various species of fish does not vary greatly from the level of 16% of raw fish flesh, however, fat content can be extremely variable.

Species, seasonality, annual feeding cycle, and breeding cycles are primarily responsibly for the wide variation in fat content within a single species. Fat content of pelagic species can vary from less than one percent to greater than 30 percent (Woolen, 1969). Water content is variable among species and ranges from 60% to 82%. In species with high fat content, low moisture levels are found. Leaner species have greater moisture content. Referring to the moisture content of raw fish flesh, Woolen (1969) stated "at a rough estimate it can usually be taken as 80 percent minus fat content". Speculation as to fish composition without the results of careful proximate analysis can be misleading. The variation in composition among some species of fish is presented in Table 2.

Amino Acid Composition of Selected Fish Meals

The nutritional value of fish meal protein is dependent upon the raw material source and the effects of processing and handling conditions (Osterhout and Snyder, 1962; Smith and Scott, 1965a).

Table 3 illustrates the variation in amino acid composition of five major varieties of fish meal and shrimp meal.

Effect of Processing Conditions on Amino Acid Composition

Temperature levels, pressure and time duration of processing operations affect fish meal protein utilization of livestock. Nesheim and Carpenter (1967) reported digestibility of heat damaged cod flour

TABLE 2

APPROXIMATE COMPOSITION OF RAW FISH AND SHELL FISH
(Woolen 1969)

Species	Composition %			
	Water	Protein	Fat	Carbo-Hydrate
Cod, Haddock, Whiting	81	16	.5	0
Hake	78	16	3	0
Flat Fish	79	16	2	0
Halibut	76	16	5	0
Skates, Rays	80	16	1	0
Dog Fish	78	13	5	0
Cat Fish	78	16	3	0
Herring, Pilchards	66	16	15	0
Sprats	72	15	10	0
Grey Mullet	78	16	3	0
Mackerel	73	16	8	0
Salmon	67	17	14	0
Crabs	73	20	4	0
Shrimps	69	21	2	1
Lobster	73	20	4	2
Oysters	78	10	2	6
Scallops	78	18	1	0
Mussels	82	12	2	2

TABLE 3

AMINO ACID COMPOSITION OF FIVE MAJOR FISHMEALS AND SHRIMP MEAL

SPECIES	% CP	AMINO ACID AS % OF CRUDE PROTEIN																
		LYS.	MGT.	CYS.	TRY.	HIS.	ARG.	THR.	VAL.	ISO.	ELU.	TYR.	PHL.	ALA.	ASP.	SER.	GLU.	PRO.	GLY.
Norwegian Herring[a]	75.3	7.59	2.83	.96	1.03	2.51	5.86	3.94	5.33	4.49	7.15	3.03	3.73	5.93	8.69	3.50	12.27	4.18	6.16
Atlantic Coast Herring[b]	73.6	8.13	2.88	.04	1.36	3.17	6.46	4.51	5.33	4.32	7.88	3.37	4.03	6.53	9.74	3.97	12.80	4.42	5.52
Menhaden[c]	66.3	7.58	2.72	.85	.94	2.97	6.17	3.87	5.01	4.12	6.77	2.97	3.74	6.41	8.73	3.58	12.62	5.02	7.59
Anchovy[d]	67.0	8.01	3.05	.89	1.17	2.64	5.92	4.33	5.46	4.80	7.60	3.41	4.54	6.26	9.52	3.73	12.91	4.12	5.57
Tuna[e]	53.24	6.88	2.67	.89	1.05	3.43	6.35	4.19	5.17	4.25	6.94	3.14	3.94	6.66	8.88	3.79	11.74	5.55	8.64
Sun-Dried Shrimp[f]	47.8	6.17	2.84	1.59	1.26	1.90	6.31	4.28	4.42	3.26	7.57	3.63	4.56	5.29	10.74	4.53	15.46	3.44	4.29

[a] Kifer et al 1969b

[b] Power et al 1969

[c] Kifer et al 1969a

[d] Kifer et al 1969c

[e] Kifer et al 1969d

[f] Meyers et al 1973

protein to be 77% compared to 90% protein digestibility in unheated cod flour. Significantly greater quantities of heat damaged protein were found in gut contents of chicks three hours after feeding compared to those fed unheated protein. This evidence led to the hypothesis that intramolecular binding among components of the protein forms complexes which are undigestible in the natural gut environment. Bjarnason and Carpenter (1970) using bovine plasma albumen as an intact protein substrate demonstrated that heating to 115° C for 27 hours resulted in appreciable loss of lysine and cystine. This loss was evident by the evolution of ammonia and hydrogen sulfide from heated protein. A correlation between the degree of lysine binding and ammonia evolution (Bjarnason and Carpenter, 1970) suggests that a complex is formed between the ε amino group of lysine and the amino group of asparagine or glutamine. They also noted a 50% loss in availability of cystine due to formation of complexes of ε amino groups of lysine with destruction products of cystine. A wide variety of carboxyl groups (Nesheim and Carpenter, 1967) and hydroxyl groups (Smith and Scott, 1965a) also formed complexes with the ε amino group of lysine. A depression in the availability of a wide variety of essential amino acids under simulated mild processing conditions (115° C) has not been demonstrated. It was concluded by Smith and Scott (1965a) that intramolecular binding can take place without unduly influencing the amino acids found between the linkages. Excessive heat however is thought to bring about binding of such magnitude as to depress protein availability as a whole (Smith and Scott, 1965d).

Heat treatment also reduces the availability of amino acids. Smith and Scott (1965b) found lysine and theonine availability to be depressed

when studying the essential amino acids of heated and unheated fish meal. Heat treatment of 116° C for a duration of 27 hours resulted in reduced availability of 50% for lysine, 66% for methionine and 44% for tryptophan (Varnish and Carpenter, 1975b). This reduction is due in part to the unnatural amide linkages formed with the free ε amino group of lysine residues. Compounds containing amide linkages with ε amino groups of lysine have been synthesized and fed in experiments to learn more about the action by which availability is decreased. Bjarnason and Carpenter (1969) reporting on work with acylated lysine units determined ε-N-acetyl-L-lysine to possess half the availability of L-lysine and that ε-N-propionyl-L-lysine had negligible activity. Significant elevation in fecal lysine and little increase in urinary lysine support the hypothesis of decreased digestibility and absorbability of complexes of lysine at the amino acid level. Waibel and Carpenter (1972) following the theory of crosslinkage formation between the reactive ε amino group of lysine and glutamine found that hydrolysis does not occur in the intestinal lumen of rats or chicks. Infusion intravenously of ε-(N-L-glutamyl)-L-lysine however did support growth equal to that demonstrated with similar amounts of L-lysine. Hydrolysis of the linkage is said to take place in the intestinal wall and no increase in urinary lysine was observed in the treatment. This evidence demonstrates that the hindrance of digestion and absorption is the reason why crosslinked compounds present lower lysine activity.

Ammino Acid Assay

The analysis of amino acids in processed fish meal does not accurately measure nutritive value due to the inability of assay techniques

to determine the availability of amino acids from heat treated products. "The amino acid content of heated and unheated fishmeals as determined by chemical means, were not different, indicating that no appreciable alteration of amino acids was brought about by heating, even under conditions of prolonged heating", (Smith and Scott, 1965b). This alteration has in fact been proven to exist in heated fish meal. Biological assay techniques have been developed to account for the alteration. Smith and Scott (1965a) describe an assay technique which makes use of diets containing amino acids in crystaline form for all essential amino acids other than the one in question, which is supplied by the test protein. Bird weight gains are compared to those fed standard diets of known amino acid level. This assay has been demonstrated to be very sensitive for lysine and threonine assay. Differences in response can be attributed however to an unidentified growth promoting factor charactistic to fish meal, the actual availability being tested or an imbalance in amino acids in the test diet (Smith and Scott, 1965c).

Hurrell and Carpenter, (1974) outline chemical procedures to determine the lysine in bound and reactive forms. This assay calls for treatment of the test protein with fluordinitrobenzene then hydrolysis with acid to yield "reactive" lysine in the form of dinitrophenyl-L-lysine. This is measured colormetrically with adjustments for losses. "Bound" lysine is determined by chemical methods or calculated by difference from total lysine.

Varnish and Carpenter (1975a) report that misleading values are often the result of microfloral production of ammonia in the lower

gut of test animals used in biological evaluations. It is suggested that ileal contents rather than fecal matter be used in digestibility or availability trials. Results of research strongly confirm the accuracy of this procedure by comparison with values generated from growth measurement (Varnish and Carpenter (1975b).

Likuski and Dorrell (1978) describe a rapid bioassay determination of amino acid availability values. Roosters are force-fed 25 grams of the test sample after 45 hours of fasting. Apparent amino acid availability is determined from intake and fecal amino acids and is converted to "corrected amino acid" availability after accounting for metabolic fecal and endogenous urinary amino acids.

The conditions of heat and pressure and the effect these factors have on the availability loss of amino acids can only be expressed in general terms. The determination of this effect is only as good as the assay technique used and each has biased components (Hurrell and Carpenter, 1974). It can be stated however, that the destructive effect appears to be continuous and that threshold levels are not established. It was stated by Hurrell and Carpenter (1974) that storage of fish meal at 37° C for periods of 10 days resulted in measurable destruction of lysine availability and that 30 days of storage resulted in greater losses. Heat processing speeds loss of availability of lysine but is not necessary for it to proceed.

Proximate Analysis and Calcium and Phosphorus Levels of Selected Fishmeals

Fishmeal prepared from the various species of fish and shell fish also varies in proximate analysis. Table 4 lists the five most prominent

TABLE 4

PROXIMATE ANALYSIS AND CALCIUM AND PHOSPHORUS LEVELS OF FIVE MAJOR FISHMEALS AND THREE SHRIMP MEALS (DRY MATTER BASIS)

Species	Moisture %	Crude Protein %	Ash %	Total Fat %	Calcium %	Phosphorus %
Norwegian Herring[a] (Clupidae harengus and C. sprattus)	6.60	75.34	10.14	10.58	1.95	1.50
NRC - Herring[c]	8.00	70.6			2.94	2.20
Atlantic Coast Herring[b]	6.70	73.6	11.04	8.89	2.09	2.12
Menhaden[d] (Brevoortia tyrannus)	3.06	66.3	17.07	13.84	4.74	2.61
NRC - Menhaden[c]	8.00	61.3			5.49	2.81
Anchovetta[e] (Engraulis ringens)	7.68	67.0	14.54	10.12	3.38	2.22
NRC - Anchovy[c]	7.00	66.0			4.50	2.85
Tuna (Mixed Species)[f]	6.20	53.24	27.52	11.19	8.85	4.66
Dehydrated Shrimp Meal[g]		28.5[h]	38.2	1.3	15.0	2.2
Sun-Dried Shrimp Meal[g]		47.8[h]	26.9	2.9	7.0	1.5
Shrimp Head Meal[g]		53.5[h]	22.6	8.9	7.26	1.68
Shrimp Hull Meal[g]		22.8[h]	31.7	0.4	11.10	3.16

[a]Kifer et al., 1969b

[b]Power et al., 1969

[c]National Research Council, 1977

[d]Kifer et al., 1969a

[e]Kifer et al., 1969c

[f]Kifer et al., 1969d

[g]Meyers et al., 1973

[h]Protein corrected for chitin

fishmeal types and the respective analysis of each. Also included in this table are the NRC values for herring, menhaden and anchovy.

Mineral and Vitamin Analysis of Selected Fish Meals

The mineral contents of five prominent fish meals are listed in Table 5. Vitamin analysis for fish meal prepared from Atlantic Coast herring, menhaden and tuna are listed in Table 6. The vitamins contributed by fish meal however, are looked upon only as nutritional insurance in most poultry rations due to the low cost of synthetically produced vitamins (Power et al., 1969). However, the nutritional contribution is considered when least cost rations are formulated.

Processing Effects on Vitamin Analysis

Conditions of heat and volume of air in the drying process have an effect on the vitamin analysis of fish meals. Jungsoyr et al. (1953) analyzed for riboflavin, vitamin B_{12}, and pantothenic acid in commercial fish meals processed at several temperatures in flame-dryers and in an air dryer. Destruction was found to be 19.1%, 35.1% and 43.5% for riboflavin, vitamin B_{12} and pantothenic acid respectively for meal produced in driers with outlet temperatures of 110^{o} - 122^{o} C. Minimal vitamin losses (<4.0%) were demonstrated for flame driers or steam driers with outlet temperatures of 75^{o} - 84^{o} C. Moderate losses of 6.4%, 10.0% and 19.0% for riboflavin, vitamin B_{12} and pantothenic acid, respectively occurred in the air dry system (dried in an abundance of air) even when low outlet temperatures (50^{o} C) were used.

TABLE 5

MINERAL CONTENT OF FIVE FISH MEALS

	Sodium	Magnesium	Potassium	Iron	Copper	Zinc	Manganese
	%			ppm			
Norwegian Herring[a]	.42	.11	1.20	150	5.4	120	2
Atlantic Coast Herring[b]	.61	.15	1.20	117	4.4	112	--
Menhaden[c]	.53	.16	1.35	430	5.8	108	23
Anchovy[d]	1.10	.27	.89	226	9.2	100	9
Tuna[e]	.73	.23	.73	367	10.7	212	9

[a]Kifer et al., 1969b

[b]Power et al., 1969

[c]Kifer et al., 1969a

[d]Kifer et al., 1969c

[e]Kifer et al., 1969d

TABLE 6

VITAMIN ANALYSIS OF SELECTED FISH MEALS
Mg/100 g.

Vitamin	Species		
	Atlantic Coast Herring[a]	Menhaden[b]	Tuna[c]
Thiamine	<.1	<.02	
Riboflavin	.623	.935	.680
Pantothenic Acid	1.29	2.88	
Niacin	10.03	15.5	14.3
Choline	635	454	
Biotin	.041		
Folic Acid	.293		
Vitamin B_{12}	.027	.024	.031
Pyridoxine		.320	

[a]Power et al., 1969

[b]Kifer et al., 1969a

[c]Kifer et al., 1969d

TABLE 6

VITAMIN ANALYSIS OF SELECTED FISH MEALS
Mg/100 g.

Vitamin	Species		
	Atlantic Coast Herring[a]	Menhaden[b]	Tuna[c]
Thiamine	<.1	<.02	
Riboflavin	.623	.935	.680
Pantothenic Acid	1.29	2.88	
Niacin	10.03	15.5	14.3
Choline	635	454	
Biotin	.041		
Folic Acid	.293		
Vitamin B_{12}	.027	.024	.031
Pyridoxine		.320	

[a]Power et al., 1969

[b]Kifer et al., 1969a

[c]Kifer et al., 1969d

Lipids in Fish Flesh

Lipid compounds within the fish carcass vary in quantity more than any other chemical component (Stansby, 1973; Glittins, 1968; Woolen, 1969). Variation in fat content is evident both among and within species (Stansby, 1973). Since species is the most prominent factor affecting fish carcass fat content, the classification system for fish within the industry utilizes fat content to distinguish fish groups. Fish for fish meal manufacture fall into two broad categories, those with low oil content (less than 5%) are termed "white fish" and those with high oil at content (greater than 5%) are termed "oily fish" (Glittins, 1968). Difference in processing methods will be discussed later in this paper. Fish representative of the "oily" fish category would be anchovy, herring, pilchards, sardine and mackerel. The "white fish" category would include cod, haddock, whitting and hake (Glittins, 1968). A majority of the world's production is from "oily" species (Gohl 1978).

The lipid material of fish occurs primarily as phospholipids and triglycerides. All fish species contain a minimum of .5 per cent fat in the form of phospholipids which are associated with cell membrane structure. The fatty acids found in this form are highly polyunsaturated compared to the fatty acids found in triglyceride (Glittins, 1973). The lipid component of "white fish" carcasses is found almost exclusivelly as phospholipid. "Oily fish" contain membrane phospholipids but also substantial amounts of lipid in the form of tricylycerides, which are found in fat deposits throughout the body. A predominent portion of the lipids of oily fish is in the form of triglyceride (Glittins, 1973).

TABLE 7

FATTY ACID COMPOSITION AND IODINE NUMBER OF FISH LIPIDS FROM AN "OILY FISH" SPECIES AND A "WHITE FISH" SPECIES (Woolen, 1969)

Fatty Acid (C-Atoms: Double Bonds)	"Oily Fish" (Herring Oil)	"White Fish" (North Sea Cod Oil)
	%	%
14:0	6.4	0.5
16:0	12.7	20.6
16:1	8.8	1.6
18:0	1.0	4.2
18:1	12.7	10.1
20:1	14.1	1.5
20:4	0.3	2.9
20:5	8.4	14.6
22:1	20.8	Trace
22:6	4.9	35.4
Total	90.1	91.4
Iodine Value	126	255

The fat concentrations of different parts of the body of the same fish also varies. Generally fat content in fish can be characterized in the following ways (Glittins, 1973).

1. Fat content is greater in the head area and gradually decreases toward the tail.
2. The belly area of a fish is likely to contain greater fat content than the rest of the fish.
3. Red or dark muscle contains a much higher fat content than white muscle.

The fatty acid composition of lipid from the commercially important species of fish does not vary markedly (Woolen, 1969). Ninety percent of the lipid is comprised of eight to ten major fatty acids. A comparison of fatty acid composition and iodine number of the lipid of an "oily fish" species (herring) and a "white" fish species (North Sea Cod) is presented in Table 7.

Methods of Manufacture of Fish Meal

There are three basic systems used in the production of fish meal. Figure 1 describes the two processes commonly used to prepare fish meal from "white fish" flesh.

"White fish" meal is made from the whole eviscerated fish carcass or cuttings and trimmings from species of fish which contain 3-5% total fat. The fresh fish flesh which contains about 20% solids and 80% water is either minced then dried or minced, cooked, pressed and dried to a moisture level of about 10% (Richardson, 1946). The major difference in the two schemes is that the cooking process sterilizes the product before drying. This step increases shelf life, aids in oil and water

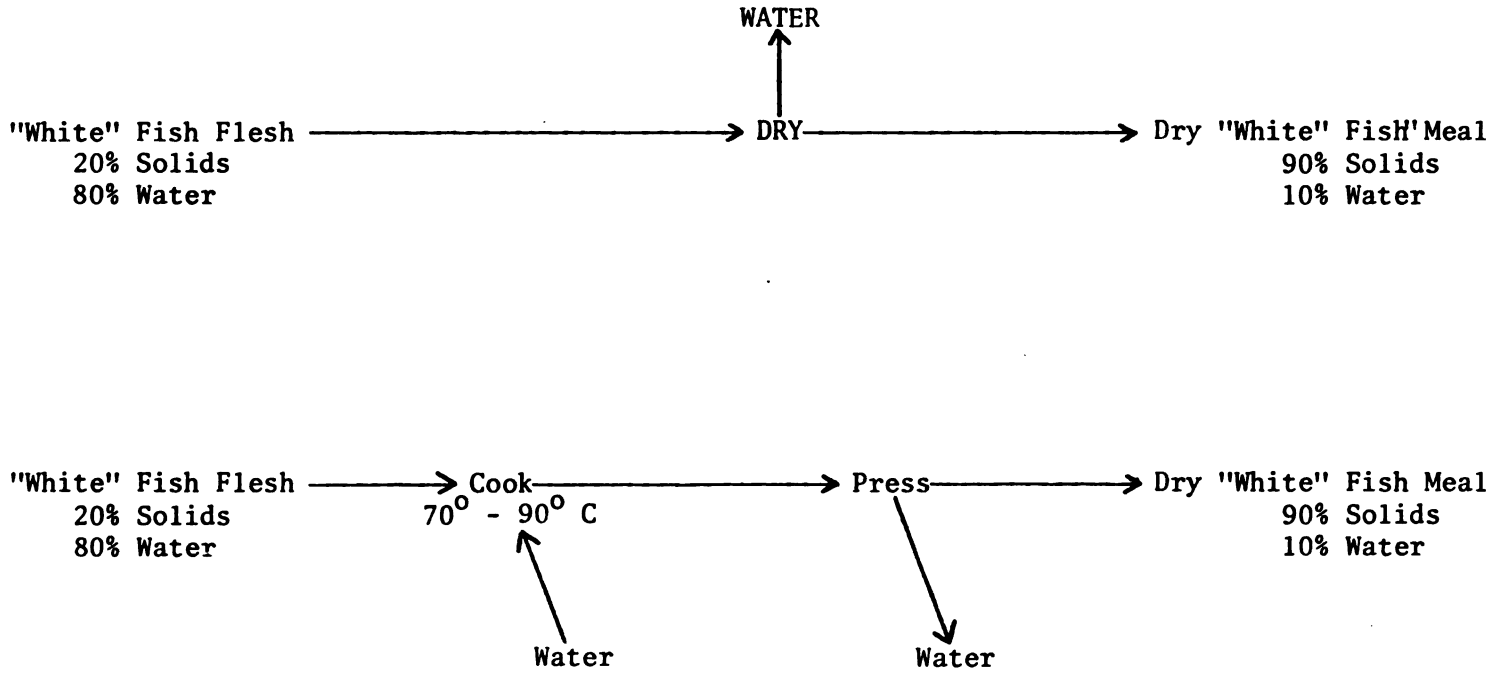

Figure 1. Schematic Representation of Two Processing Operations Involved in the Manufacutre of "White Fish" Meal.

removal during the press phase and denatures the fish protein increasing water release from bound form. Stansby (1963) has reported that cooked fish dries at a rate three times that of raw fish.

"Oily" fish meal (also known as dark fish meal or fish meal) is manufactured as described in Figure 2. "Oily fish" flesh of about 20% solids, 70% water and 10% fat is cooked and pressed. Cooking is accomplished in large continuous or batch cookers which operate at temperatures of 95-98^{o} C. Two critical factors in commercial fishmeal production of this type are: the time at the high point temperature and volume through put. Cookers utilize direct or indirect high pressure steam heat exchangers. Pressing is accomplished by either a high powered hydraulic system (20 ton) or a continuous screw press. The objective of the press operation is to remove as much oil and water from the product as possible. Fish cake exiting the press is likely to contain about 42% solids, 52% water and 6% oil. The press-cake is then placed in a drum dryer where moisture is removed using hot air (up to 150^{o} C) until the product contains 10% moisture or less. The product at this point is termed "pressed-cake meal" with a composition of 80% solids, 10% moisture and 10% fat. The liquid portion of the fish product separated during the pressing operation is termed press liquor and contains about 6% solids, 80% water and 14% oil. This product is centrifuged to remove the fish oil. The water phase separated in the centrifuge operation, termed stick water, is partially dehydrated and acidified to make condensed fish solubles containing 40% solids and 60% water. If the stick water is acidified and "flash" dried to 5% moisture it is termed "dried fish solubles". Many operations

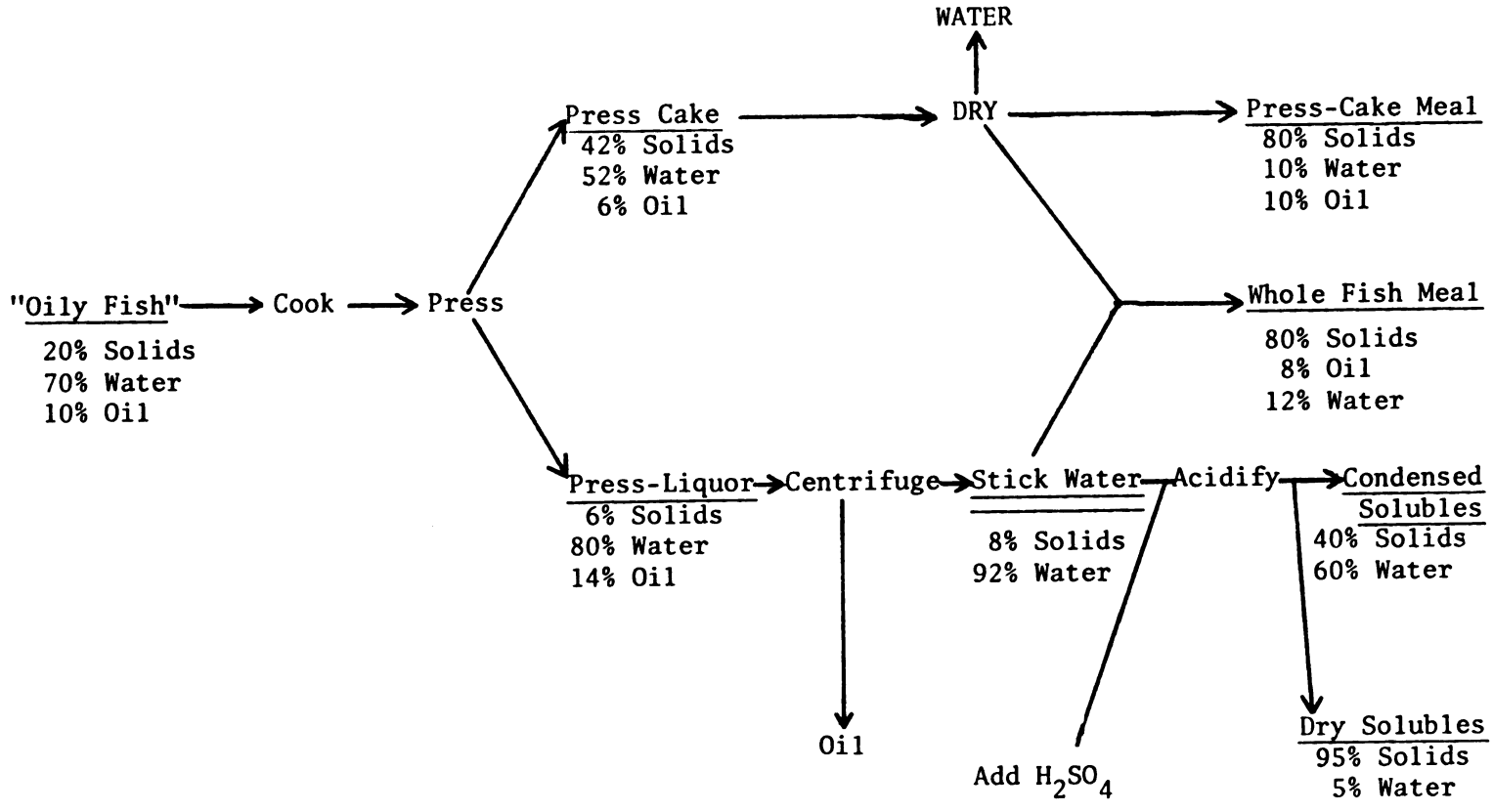

Figure 2. Schematic Representation of the Major Processing Operations Involved in Manufacture of Fish Meal Products.

incorporate the stick water back into the pressed cake meal in which case the product is termed "whole fish meal" with a composition of about 80% solids, 8% oil and 12% water.

Alternative Methods of Fishmeal Manufacture

Flash Drying Method

Harte (1952) describes a flash drying procedure in which moist press-cake or centrifuged solid cake is fed into a vertical stream of rapidly moving very hot air. The air path serves to suspend and convey the particles up the column of air to a cyclone separator. The air is heated with flue gases from an oil or gas furnace. Inlet air temperatures vary from 149° C (300° F) to 260° C (500° C) and discharge temperatures vary from 60° C (140°F) to 71° C (160° F). The advantage of this system (Harte, 1952) lies in decreased processing time. Disadvantages are high fuel cost and loss of nutritional value due to extremely hot temperatures and case hardening.

Heat Transfer Method

Kiffer et al. (1969a) describes the "heat transfer" method of fish meal manufacture. First, raw fresh fish are put through a prebreaker to cut the carcass into 2.54 cm (1") chunks. The chunks are placed in a device termed a disintegrator which contains fish oil from a previous batch of processed meal. The whole mass is cooked and stirred to a slurry of pea soup consistency. Moisture is removed in a two-stage vacuum evaporator utilizing steam pressure. Design of the evaporator is such that the wet slurry cascades down 40 feet over steam

heated tubes. In this process the oil is the heat transfer medium for dehydration of the protein by mild deep fat frying action without scorching the amino acids. Large super-decanters centrifuge off most of the oil from the slurry. This cake is further defatted with special expellers which along with the previous operations are totally enclosed. Air pollution in this process is minimal. The expelled product is ground to uniform partical size and the oil is returned to the system for dehydrating more fish meal or refined and sold as fish oil. Total fat composition of the finished product is about 11%, as compared to 10% for fish meal processed under normal systems.

Solvent Process

Lee (1963) describes the solvent process of fish meal manufacture which is used when fish oil is the primary product. Raw fish is handled in one of two procedures: by an azeotropic process using a non-miscible solvent with water or by direct extraction where the water is removed along with lipid from the fish carcass. Dichloroethane or hexane are suitable solvents for this process. Solvent and equipment cost discourage this process from being used for large scale production of fish meal for animal feed but the manufacture of high quality "fish flour" for human consumption is possible (Olden, 1960; Pariser, 1961).

Small Scale Production of Fish Meal

Small scale production of fish meal throughout the world uses a wide variety of methods. Presented here are several of the methods described in the literature.

Sparre (1953) recommended cooking fish destined for fish meal

production for 20-25 minutes in water in small scale operations. Stansby (1963) recommended autoclaving (pressure cooking) for 7-10 minutes under 5-10 pounds pressure as a method of cooking fish meal material. The time of cooking is of great importance too, as raw and insufficiently cooked fish takes longer to dry. Prolonged cooking, however, adversely affects the quality of the finished product (Hamm et al., 1944).

Temperature level and duration of the cooking phase in small scale fishmeal systems has been studied by Bredon and Marshall (1954) with fish offal from the fish processing industry at Lake George, Uganda, Africa. The following methods of processing were studied.

1. Drying roughly chopped offal material by hot air current.
2. Drying minced material by the sun.
3. Drying minced material by air current.
4. Drying minced material by hot air current.
5. Drying boiled minced and squeezed material by all of the above methods.
6. Drying minced then boiled and squeezed material by hot air current.
7. Drying minced then steamed and squeezed material by hot air current.
8. Drying minced then autoclaved and squeezed material by hot air current.

Results of the investigation indicate that there is considerable advantage in drying time of cooked over uncooked fish but there is very little difference between sun and hot air current drying. Further

investigation by Bredon and Marshall (1954) indicate that the optimum procedure for processing fish offal in a small scale fish meal production scheme is to mince the product, boil for five minutes in two liters of water and dry in a hot air current (70° C).

Schmidt and Lantz (1952) investigating fresh water fish meal production in Central Canada reported a similar method of production of fish meal. Raw fish was cooked for 15 minutes in water at 80° C (175° F), drained and pressed while still hot. The resulting cake was then dried in a wind tunnel. Drying conditions of inlet air were 29.3° C (85° F) and a relative humidity of 26% with an air velocity of 230 feet per minute. Cooked fish required 120 hours of tumble drying under these conditions to reach 12% mositure. This slow rate was attributed to the low temperature conditions within the tumble dryer which represented ambient conditions of central Canada. Best drying conditions were obtained with cakes not over 2 cm. (3/4 inch) thick. Spoiled fish produced a paste-like composition which resulted in poor pressing and drying performance.

Goh (1975) recommends a relatively simple, small scale machine for fish meal production. The facility which is presented in Figure 3 consists of a mincer, conveyor belt, dehydrator tank which has a screen bottom and a hot air blower. Recommendations call for mixing equal volumes of dry fish meal with wet fish before mincing and air temperatures of 80-90° C with occasional stirring. The report states 500 kg of fish will dry in about six hours. A fuel oil consumption of about 50 liters (13.2 gal) was reported.

Mathew et al. (1949) describe an oil extraction process suitable for small scale fish meal production. This process is

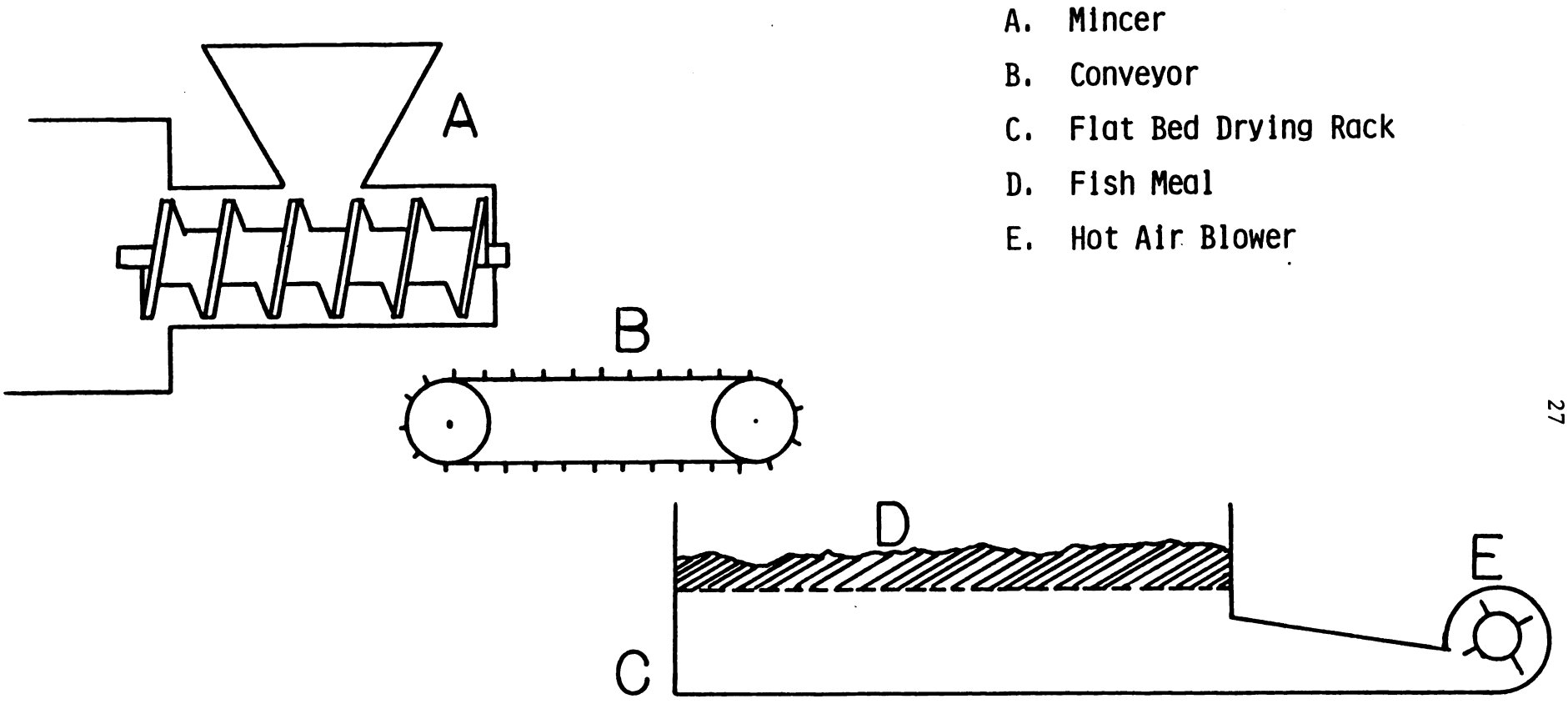

Figure 3. Model small scale fish meal production facitity

termed the "fermentation process". Fresh minced fish of a variety of species was mixed thoroughly with one ounce defatted buttermilk for each six pounds of fish and a minimum amount of water. The pH was maintained at 4.5 to 5.0 and the temperature at 30-35° C (85-90° F) for a period of four hours. It was reported that keeping the container in lukewarm water or exposure to sunlight was sufficient for the fermentation process to continue. The material was pressed and allowed to dry in the sun. The dried fermented fish product was found to have better appearence than the simple sun dried product. Chemical analysis of the product indicated that reduction of fat in the fermentation processed meal is equal to that of the cooking/pressing process. The appearence and quality of meals prepared from shark and other oily smelling fish suggest that this method lowers fishy flavor and odor in fish meal. It is cautioned, however, that the fermentation process alters the fish lipid component and thus this process should not be used if recovery of fish oil is desired (Mathew et al., 1949).

Use of Fish Meal in Livestock Diets

Fish meal is a highly digestible source of protein for livestock diets that has been in use from before 1900 (Karrick, 1963). The high quality amino acid composition of fish proteins has been discussed previously in this paper. Fish meal, unlike the other major protein sources does not produce an amino acid imbalance if fed as the sole protein supplement to swine rations (Card and Nesheim, 1972). Soybean meal is limiting in methonine, meat and bone meal is limiting in tryptophan, blood meal in isoleucine and most other plant proteins are limiting in lysine and methionine (Card and Nesheim, 1972). Fish meal

is also the highest of all major protein sources in metabolizable energy with 2640 - 3190 Kcal/kg (Card and Nesheim, 1972). Fish meal is an dietary source of vitamins calcium, phsophorus, microminerals and essential fats for livestock rations (Kifer et al., 1968).

It was generally accepted that fish meal possesses an unidentified growth promoting effect (Woodmare and kvans, 1951; Carpentar et al., 1956; Smith and Scott, 1965c).

Fish Meal in Swine Diets

There is considerable documentation of the superior performance of fish meal over other protein sources in swine diets. Laksesvela (1961) presented evidence that increased levels (1% through 8%) of herring meal substituted for soybean meal in diets for growing pigs (20-50 kg) produced increased rate of gain and feed efficiency. Kronacher et al. (1932) reported that replacement of two thirds of the fish meal supplement with soybean meal adversely affected performance of pigs. Other researchers (Kirsch, 1959; Kirsch and Fender, 1960; Jaucian et al., 1969) however found no elevated performance in diets supplemented with fish meal over rations utilizing soybean meal protein. Palmer et al. (1970) reported that fish meal supplementation at 6.7% resulted in significantly increased average daily gain of gilts and sows during gestation and resulted in highly significant increases of 0.9 piglets per litter at birth. Palmer et al. (1970) also reported significant total litter weight increases from the sows fed fish meal over those fed control diets comprised of plant protein sources. Baker et al. (1974) reported similar results with 0.55 more piglets per litter at birth, 0.45 more piglets weaned per litter and total litter weights averaging

3.55 kgs more for the sows fed fish meal supplemented gestation and lactation rations.

Fish meal, fish silage and other ingredients which contain large components of fats predisposed to oxidation may cause strong oily or fishy off-flavor in fresh pork and especially cured hams and bacon (Pond and Maner, 1974). Vestal et al. (1945) and Asköe and Madsen (1954) have determined that the fishy and oily flavor is caused by highly polyunsaturated fatty acids in the fish component of the ration. Laksesvela (1961) using organoleptic tests of pork reported little fish odor or flavor when pigs were fed rations containing 6-8 percent herring meal containing seven percent fat, but that feeding 12% herring meal of the same fat content did produce off flavors. In both instances the pigs were fed the fish meal diets to 80 kg then converted to a non-fish meal diet a nd slaughtered at 90 kg. Göhl (1975) suggested a level of seven percent fish meal for swine grower rations with a maximum limit of fish oil in the entire diet to be 1.0 to 1.5%. A maximum limit of 5% fish meal in the diet is recommended for the latter pa rt of the finishing period of pigs (Göhl, 1975).

Fish Meal in Poultry Diets

Increased performance of poultry fed fish meal-containing diets has also been reported. Peischel et al. (1976) reported significant increases in egg production and feed conversion with the incorporation of 2% fish meal into the ration of layers. There was no significant interaction of energy source when corn or sorghum or a combination of the two was fed. Broiler strains of chicks exhibited superior gain and feed conversion when fed diets containing 5% fish meal (Peischael et al., 1976b).

However, Kubena et al. (1976) reported more frequent intestinal and gizzard lesions in birds fed 7 or 12 percent Peruvian fish meal in the finisher phase than in birds fed menhaden fish meal or a control ration. Johnson and Pinedo (1971) hypothesized that such lesions were caused by the deteriorated quality of the fish meal, specific to each load, rather than type of fish. Kubena et al. (1976) could not substantiate this claim due to similar and very limited peroxidation tests in various boat loads of fish meal. Thus, the etiology of the lesions was not identified (Kubena et al., 1976). Göhl recommends maximum levels of 10% fish meal for broiler starter diets and 8% for broiler finisher diets. The rule of thumb of a maximum of 1 to 1.5% fish oil also applies for broilers. The fish meal recommendation for layer rations is a maximum limit of 5 to 6% (Göhl, 1975).

Fish Silage

Fish silage is a system of storage of raw waste fish or fish offal destined for fish meal manufacture. Two basic methods are presently being used both commercially and with small scale operations. One method is known as the acid ensiling process and the other is the carbohydrate ensiling process.

Acid Fish Silage Production

Acid fish silage is produced when one of several acids are added to the minced fish or fish waste. The principle (storage of fish in acid silage form) is that acid added to the fish will lower pH and prevent bacterial putrefaction, and enzymes present in the fish will start to liquify the fish (Göhl, 1975). These enzymes, known as

cathepsins, are found in the muscles and stomach of the fish and become more active in low pH conditions. Optimum conditions for maximizing enzyme activity are pH 4-5 and 37° C (Göhl, 1975).

The three basic steps in acid ensiling fish are (1) to chop the product, (2) acidify and (3) store in an airtight container (Göhl, 1975; Wignall and Tatterson, 1976). Reece (1980) recommends a mixture of formic and sulfuric acids at a ratio of 1:2 on a molar basis. Storormo and Stroem (1979) recommend equal parts of propionic and formic acids while Göhl (1975) states phosphoric, formic and acetic acids are preferred. Hydrochloric acid causes the product to have an overly salty taste and sulfuric acid precipitates calcium sulfate (Göhl, 1975).

Warm climates speed the ensiling process so that fish silage stabilized at pH 5 or lower will liquify in 24 hours except for scales and larger bones. If pH conditions are maintained the product will last for months.

Carbohydrate Fish Silage Production

Carbohydrate fish silage is similar to the process of ensiling other agricultural products. An anaerobic environment supporting lactic acids producing bacteria is essential to the storage process. Carbohydrate is essential to the maintenance of the lactic acid forming microorganism and since fish flesh contains little carbohydrate, it must be added. Carbohydrate sources could be rice bran, wheat bran, potatoes, cassava, molasses, corn or citrus pulp (Göhl, 1975). Percentages vary from 60% fish and 40% carbohydrate source, in the case of dry materials (rice bran or wheat bran), to 90% fish and 10% molasses or fresh potatoes. It is also suggested that if starch alone is used to supply carbohydrate,

then malt should be added as a source of amylase to cleave the carbohydrate into glucose molecules (Göhl, 1975; Yeoh et al., 1981). The mixed silage product must be packed in an air tight container. Plastic containers or oil drums painted with acid resistant paint inside and out to resist corrosion of the acid silage serve this purpose well. Carbohydrate fish silage has been stored in warm climates for up to 5 months, provided air tight conditions are maintained (Göhl, 1975).

Feeding of Wet Fish Silage

Fermented fish silage may be fed directly to animals as a wet feed (Disney, 1979; Javed and Winter, 1979). Bross (1975) states that fish silage is used extensively for livestock production in Denmark and Poland where it is delivered to customers by road tanker on a scheduled basis. Thirumalai et al. (1978) has investigated the use of fish silage in chick diets with mixed results.

Quality of fish silage is very important when feeding animals. Silage of insufficient acidity can be very poisonous (Göhl, 1975). The silage should smell pleasant when opened and should be fed promptly. Neutralization of acidity of fish silage is recommended with the addition of limestone or other basic compounds (Göhl, 1975). Bross (1975) states that the composition of the fish silage is based on the raw material from which it was made allowing for the dilution from added acid or carbohydrate source. It is also stated (Bross, 1975) that, unlike fish meal production which destroys much of the natural vitamin activity, fish silage contains 80% of the original vitamins.

Drying Aspects of Fish Meal

Myklestad (1973) undertook investigations to determine the characteristics of evaporation and diffusion of moisture from fish. Pressed cake from three species of fish with various levels of stick water added were dried in copper trays 50 x 50 mm square, filled to heights of 5 or 20 mm. The trays were placed in a wind tunnel for drying. Four stages of drying were recognizable. These stages were: (1) a decline in free moisture (kg/kg) from 1.0 to 0.8 at a drying rate that declined from 1.4 to 1.0 kg/kg/h; (2) a decline in free moisture from 0.8 to 0.2 at the declining rate of 1.0 to 0.6; (3) a decline in free moisture from 0.2 to about 0.1% at the declining drying rate of 0.6 to 0.4 and (4) a decline in free moisture from about 0.1% to 0 at the declining rate of 0.4 to 0 kg/kg/h. (Myklestad, 1973). These results, although not developed on a particle size basis, do lend support to the assumption that fish flesh drying follows the drying theory developed for other agricultural products.

Factors Affecting Drying Efficiency

The major factors responsible for the efficiency of dryer performance as presented by Foster (1973) are:

1. conditions prevailing in the environment of the dryer
2. characteristics of the product being dried
3. design and operation of the dryer.

Efficiency Calculations of Dryer Performance

Efficiency calculations presently used to document dryer performance are: (Foster, 1973)

$$\text{drying efficience} = \frac{\text{heat utilized to remove the } H_2O}{\text{heat available for drying}}$$

$$\text{fuel efficiency} = \frac{\text{heat utilized to remove the } H_2O}{\text{heat content of fuel supplied}}$$

Solar Technology

Solar Energy

The origin of solar energy is thermonuclear reactions in the core of the sun. This solar energy is emitted primarily in the form of shortwave length radiation. This radiation passes through space in a straight line until it strikes matter and is absorbed, reflected or passed thru. Solar radiation in space proceeding toward earth encounters little matter to alter its intensity until it reaches the gasses of the earth's atmosphere. Solar radiation is about 45156J/hr-Ft^2 just beyond the atmosphere (Midwest Plan Service, 1980). The amount of energy reaching the surface of the earth at any one point is dependent on the hour of the day in solar time, season of the year, atmospheric effects of suspended particulates, and latitude.

Radiation levels within the hours of daylight are related to solar time. Radiation reaching a specific location in early morning or late evening must pass through proportionately more atmosphere, encountering more matter and diffusion will be greater.

In the month of June, the center of the earth is a greater distance from the sun (95.9 million miles) and thus there is greater diffusion of radiation than in December when the earth is nearer (89.8 million miles) (Midwest Plan Service, 1980). Due to the 23.5^{o} angle of tilt

between the axis of rotation of the earth and the plane of the orbit around the sun, the solar altitude is also affected by season. The lower solar altitudes of winter in the northern hemisphere causes radiation emitted from the sun to pass through greater distance of atmosphere compared to the radiation emitted from the sun when its altitude is greatest in summer. Radiation loads are theoretically greater in summer.

Natural atmospheric features such as water vapor, clouds and carbon dioxide or unnatural features in the form of suspended particulates from air pollution also affect the level of solar radiation reaching the earth's surface.

The radiation load for a given location is in constant shift as a result of these changing factors. On a clear day, the maximum amount of radiant energy reaching the earth's surface is about 316,516J/hr-fT2 which is less than 75% of that available outside the earth's atmosphere.

The radiation actually reaching the earth is present in two forms, beam radiation or diffuse radiation. Beam radiation is that radiation which passes directly from the sun without striking matter. Diffuse radiation is that radiation which has struck matter, scattering it or reflecting it to the earth's surface. On a clear day about 85% of the radiation reaching a specific location on the earth's surface is beam radiation. Cloud cover and other atmospheric effects increase scattering (Midwest Plan Service, 1980).

Capture of Solar Radiation

Solar radiation may be captured and utilized directly or indirectly. Direct absorption of solar energy occurs when solar energy is directly

passed from radiant form to heat or chemical energy in the medium requiring energy. An example of this is the drying of grain on flat surfaces. Indirect absorption and utilization occurs when a medium other than the terminal energy absorber is exposed to solar radiation and transforms this energy to heat which is transmitted to the intended destination. Utilization of direct solar radiation has disadvantages in that the total energy input is dependent on the absorptance characteristics of the target material and its surface area. Indirect methods on the other hand utilize solar collectors designed to efficiently absorb solar radiation and transfer it to a medium of transport such as air or water. This method is much more flexible in application.

Design of Solar Collectors

There are three principle collector designs used to heat air (Midwest Plan Service, 1980). The flat plate collector, the flat plate collector with reflectors and the concentrating collector (Figure 4).

Flat Plate Collector

The flat plate collector contains a flat, crimped or finned solar absorbing surface. A stream of moving air (heat transport medium) passes over the absorbing surface to pick up heat. A cover surrounding the absorber through which the air stream passes is opaque on the sides and rear and a clear material (glazing) forms the front face through which the solar energy must pass to strike the absorbing surface.

The short wavelength radiation striking the absorber surface is either absorbed or reflected. The proportion of absorbance or

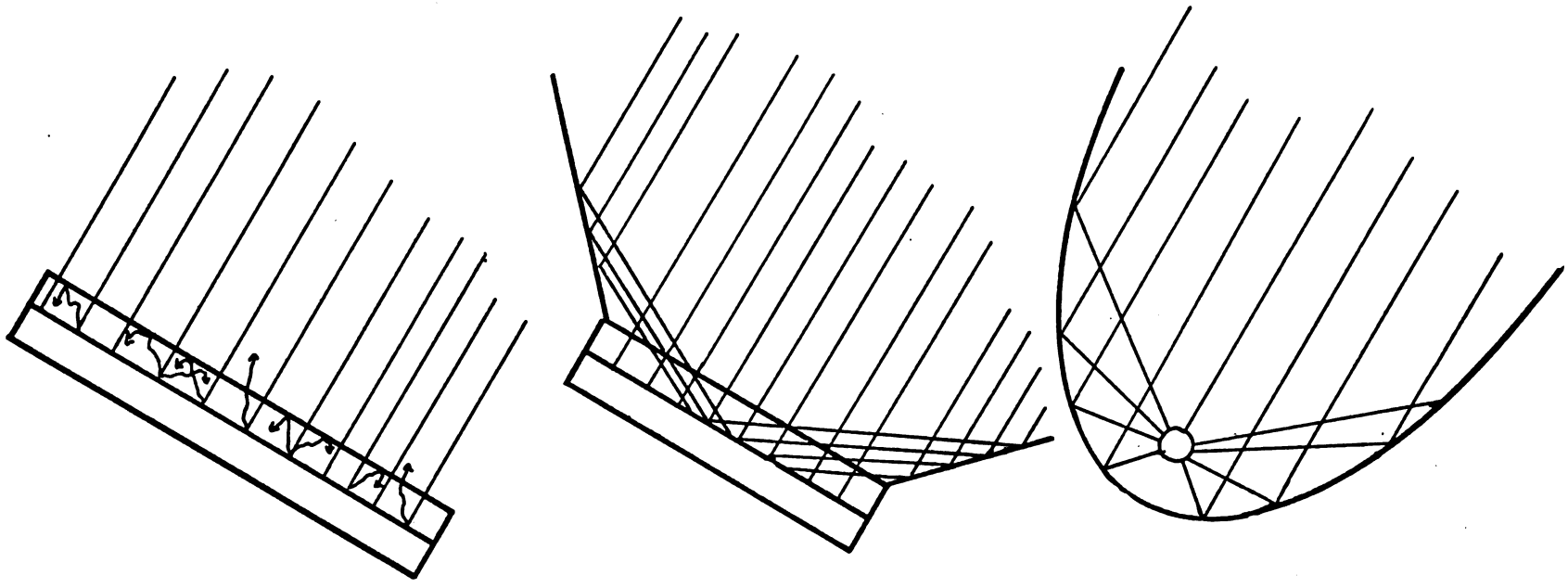

FIGURE 4. Three basic solar collector designs.

reflectance is dependant on the angle of incidence of the beam radiation striking the absorber and the relative absorptance value of the surface. The angle of incidence is said to be 0^{o} if the line of the beam radiation is perpendicular to the plane of the absorber and 90^{o} if it is parallel to the plane. The smaller the angle of incidence the greater the absorption of energy by the absorber. The surface of the absorber affects the proportion of energy absorbed or reflected. Generally dark, flat finish materials have higher absorptance values than light colored shiny surfaces. Solar radiation absorptance and reflectivity for some absorber surfaces is listed in Table 8.

The heat generated by the absorption of solar radiation in the absorber is transferred to the passing air within the air channel, conducted through the walls of the collector faces, or emitted as long wave-length radiation. Since as much heat is to be transferred to the air as possible, insulation of the collector faces is essential and selection of an absorber surface low in emittance is important. Unfortunately most surfaces having high absorptance also have high long wavelength emittance characteristics.

Glazing Material

The glazing material should be of high solar trasnsmittance and low, long wavelength transmittance. A list of possible glazing materials is presented in Table 9 with corresponding solar and long wavelength transmittance. Glazing material is normally applied in two layers with a dead air space between to deminish convection losses of heat through this face.

TABLE 8

ABSORPTANCE AND EMITTANCE OF
POSSIBLE ABSORBER OR REFLECTOR MATERIALS
(0^{o} Angle of Incidence)

Surface	Solar Absorptance[1]	Long Wavelength Emittance[2]
Flat Black Paint[3]	0.95 - 0.99	0.95 - 0.99
Copper Treated with Sodium Hydroxide and Sodium Clorite[3]	0.89	0.17
Copper, Aluminum or Nickel Plate with Copper Oxide Coating[3]	0.80 - 0.93	0.09 - 0.21
Weathered Galvinized Steel[3]	0.80	0.28
Bright Aluminum Paint[3]	0.30 - 0.50	0.40 - 0.60
White Paint[3]	0.23 - 0.49	0.92

[1] The fraction of total incident radiation absorbed by the surface.

[2] The fraction of perfect emissivitity emitted by the surface.

[3] Midwest Plan Service Structures and Environment Hand Book.

TABLE 9

PROPERTIES OF GLAZING MATERIALS

Material	Solar Transmittance[1]	Long Wavelength Transmittance[1]
Class 1/8"[3] Double Strength	0.88	0.03
Flat FRP[2] (25 mil)[3]	0.83	0.12
Flat FRP[2] (40 mil)[3]	0.73	0.06
Corrugated FRP Coated with Polyvinyl Fluoride (40 mil)[3]	0.79	0.07
Polyenhylene (4 mil)[3]	0.89	0.80
Polyester (5 mil)[3]	0.87	0.32
Polycarbonate (1/16")[3]	0.84	0.06
Polyvinyl Fluoride (3 mil)[3]	0.91	0.43
Kalwal[4,5]	0.881	
Polyvinyl Cloride[4]	0.937	
Cellulose Acetate Butyrate[4]	0.905	
Monsanto 602[4,5]	0.902	

[1]Transmittance = the fraction of the total radiation load which passes through the material.

[2]Fiberglass reinforced plastic.

[3]Midwest Plan Service Structures and Environment Hand Book

[4]Vita 1978

[5]E.I. DuPont De Nemours 1007 Market St. Wilmington, Delaware 19898

[6]Monsanto Company 800 N. Lindbergh Blvd. St. Louis, MO 63166

Flat Plate Collector with Reflectors

The addition of reflectors to the flat plate collector results in greater amounts of solar radiation striking the absorbing surface. The reflector surface should have a low solar absorptance and high long wave length emittance such as bright aluminum paint or white paint. A diagram illustrating this design of a solar collector is presented in Figure 4.

Concentrating Collector

The concentrating collector design (Figure 4) is basically a parabolically or hyperbolically curved reflector which focuses beam radiation from the width of the mouth of the curve to a small absorber area. This design is often employed when greater temperatures are required than can be generated with flat collectors.

Project Background Information

Location

Belize is located on the eastern coast of Central America between the latitudes of 15^{o} 53' N and 18^{o} 30' N. The latitude of San Pedro is 18^{o} 10' North.

It is bounded on the south and southwest by Guatemala, the north and northwest by Mexico and the entire eastern edge by the Caribbean Sea. In addition to the land mass of 22,653 square kilometers a total of 300 square kilometers of the country exists as tiny offshore islands spreading from north to south along the coast of Belize. This project was located at the village of San Pedro on the island of Ambergris Cay.

Climate

The North Atlantic anticyclone is a permanent controlling factor of climatic conditions of Central America and the Caribbean. These warm, moist winds bring distrubances and increased intensity of rainfall through the months of May to October (Jenkin et al., 1976).

Monthly average rainfall and number of rain days per month, based on 19 years of records, for the village of San Pedro are presented in Figures 5 and 6.

Relative humidity or humidity ratio is not recorded on a regular basis in Belize.

The hours of bright sunshine were not recorded at the San Pedro weather station, however, the Central Farm Agricultural Research station in Belize, using the Campbell-Stokes sunshine recorder, do report figures. Hours of sunshine per month at Central Farm range from about 120 for September and November to about 280 in April and May. San Pedro is expected to have greater hours of sunshine per month than Central Farm.

Sources of Raw Material

The following fishing practices employed in Belize are described as they affect raw material supplies for fish meal production.

Shrimp Trawling

In the process of shrimp trawling an estimated 680 kg (1500 lbs) (Nunez, 1980) of small unsalable fish are caught in the nets with the shrimp by each shrimp trawler each evening. Presently seven shrimp trawlers are in operation in the Belize area. These fish, of a variety

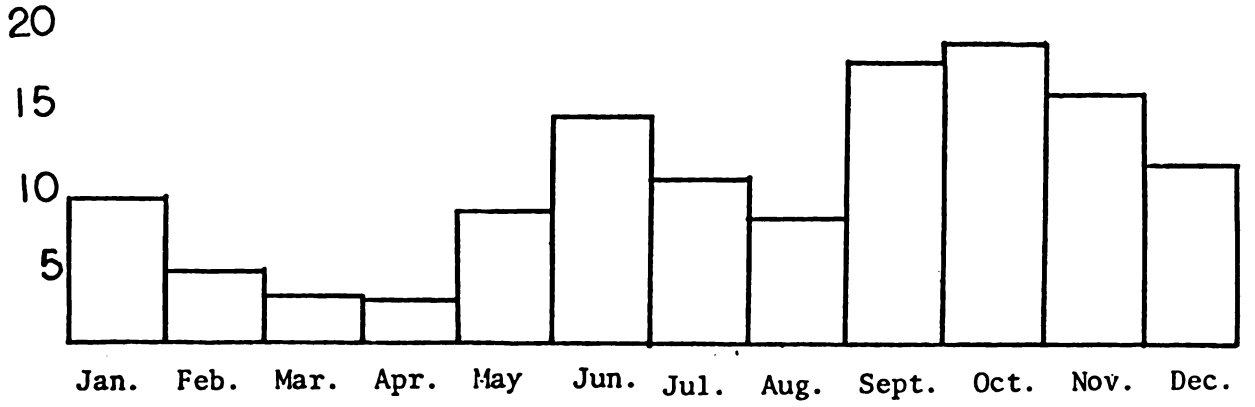

Figure 5. Rainfall in centimetimeters San Pedro, Ambergris Cay, Belize 1952-1970 (from: Walker 1973).

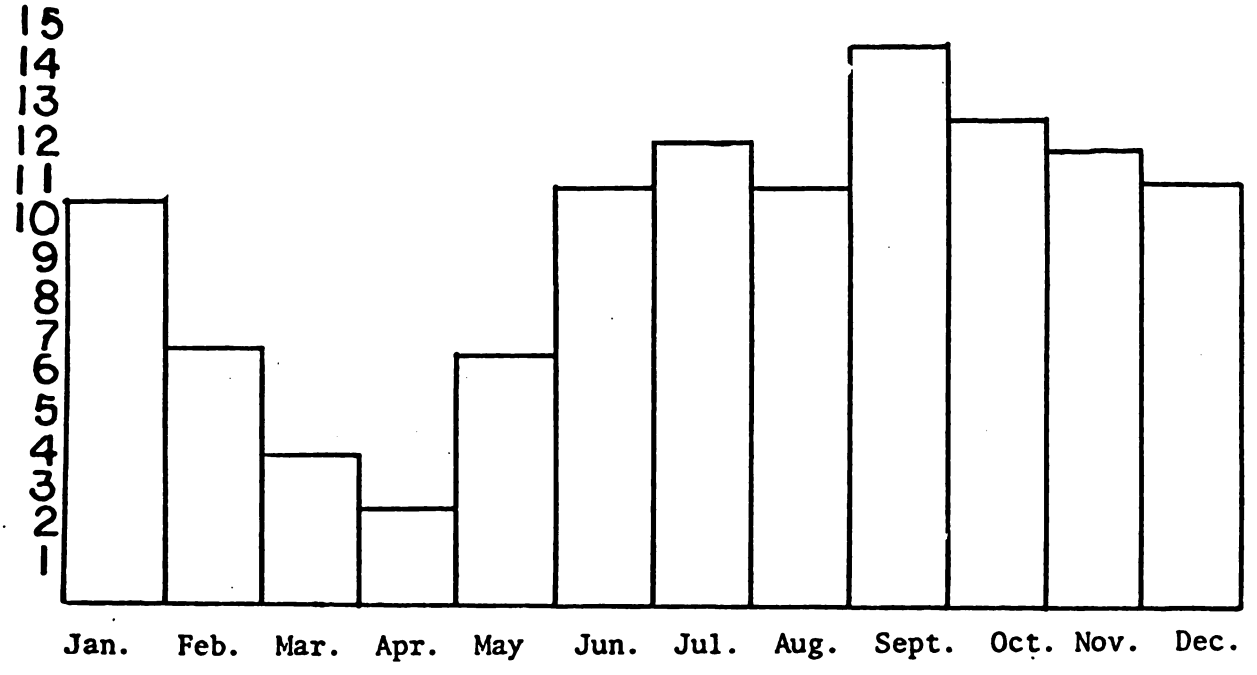

Figure 6. Rain days per month. San Pedro, Ambergris Cay, Belize 1952-1970 (from: Walker 1973)

of species, range in length from 7.6 - 12.7 cm (3 to 5 inches) are all killed in the process of trawling and selection and are discarded overboard. An expense is incurred by the fisherman in the disposal of this waste product because the boat must travel outside the fishing grounds to dump it. Usually shrimp boats remain away from port for up to 12 days and cold storage of the waste catch would be impractical. To take advantage of this potential resource a daily shullte which collects the waste from all the boats operating in the area appears to be the most efficient method of collection.

Fish Traps

Fish traps catch a wide variety of fish both salable a nd unsalable. Of the unsalable fish, most species can be utilized for the manufacture of fish meal. Fishermen could deliver fish to a collection station as they are delivering the salable fish. The potential volume of fish suitable for fish meal manufacture acquired through this resource is unknown since waste or second class fish are not presently brought to the buying points.

Cleaning and Fileting

In the process of cleaning and fileting of fish, valuable fish flesh is discarded into the ocean on the way to or at the fish buying stations (Figure 7). When a grouper or red snapper is fileted, about 62% of the orignal weight of the fish carcass is discarded as waste (Keenan, 1978). This waste is comprised of the head, guts, gills, pectoral area, back bone and tail (Figure 7). When whole fish are cleaned, the guts and gills amount to 8% of the original weight of the fish (Keenan, 1978). This waste can be collected at the processing

Figure 7. Fileting operations Caribena Coop, San Pedro, Ambergris Cay, Belize

site for fish meal manufacture.

Shrimp and Lobster Heads and Shells

The heads and shells of shrimp and lobster are removed for the most part at sea and discarded. Collection of this resource could be encouraged at the buying points. The cold storage of product of as low a value as shrimp and lobster heads is not economical. Possibly waste from the final period of fishing could be salvaged however.

MATERIALS AND METHODS

Development of the Drying Facility
Initial Assumptions

A list of conditions and standards under which the project was to be guided was developed at the onset of the program. These conditions and standards were as follows.

1. Capital investment requirements must be small compared to completely commercial operations to facilitate access by less industrialized communities. Furthermore, low volume through-out plants adapt more economically to smaller volume fisheries.

2. Non-fossil fuel energy sources must be emphasized. High cost and periodic scarcity of the standard fosssil fuels, gasoline diesel fuel, kerosene and butane, are frequent problems in lesser industrialized systems. Electricity is available at the project site, however, use of this energy source for purposes of heating air is frequently very costly. Solar power is to be emphasized as much as possible. Wood and other burnables are usually in erratic supply in San Pedro and it was decided this was likely the case at most other project locations.

3. Man power requirements of operation of the facilities were to be such that constant surveillance was not required. This situation was thought to be advantageous to the small scale producer so that he may be engaged with other activities a majority of the day.

4. The system would be capable of producing wholesome fish meal using a process with relatively unskilled personnel.

5. The system should be flexible enough to accomodate all types of marine products.

6. The facility is to be designed with a component so that innovations can be added without rebuilding the entire system.

Design and Construction of Drying System Components

An in depth discussion of each phase of the drying scheme is found in the following section.

Mincing

A Hobart, one half horse-power, commercial meat grinder was used to mince all fish products used in operation of this project. The grinding plate supplied with the machine had holes of 1.58 mm (1/16 inch). This plate would not allow large bones to pass through. Flesh however would pass through in an almost liquid state. It was apparent that larger openings were required for this machine to effectively mince fish waste.

Two hardened steel plates (Figure 8) were custom made with larger openings. One of the plates had openings of 9.53 mm (3/8 inch) diameter evenly spaced around the circular plate while the other was designed to have open quadrants. The percentages of openings in the two plates were 30% and 62%, respectively. Both plates proved satisfactory in mincing grouper filet waste including bones, but the plate with round holes accomodated less volume per minute than the quadrant design and the plate with round holes produced a finer cut with considerably more liquification of minced product. The minced product produced with the quadrant plate was uniform in consistency with the flesh cut to

Figure 8. Custom made grinder plates for commercial meat grinder.

chunks of one to two centimeters in diameter and bones ranging from shreds to shafts of up to 2 cm in length. The quadrant design proved superior to the original equipment plate or the custom made plate with 9.38 cm diameter holes because of greater volume capacity and the coarse chunk nature of the minced product was more uniform. Maximum capacity for this machine using the quadrant plates was 136 kg/hr (300 lbs/hour) for grouper filet waste with large bones and 363 kg/hr (800 lbs/hr) for small whole fish averaging 10-15 centimeters in length (shrimp boat waste). This machine using the quadrant plate was used as the primary mincing device for the duration of this project.

Although this machine performed satisfactorily, it was evident that few small scale operations would have the capital to invest in such a commercial meat grinder and that a less costly device would be more appropriate.

This led to the construction of a rotary mincer (Figure 9) consisting of a rotating garden compost shreder blade mounted on a 19.05 mm (3/4") shaft held by a pair of self-lubricated pedestal ball bearings. The shaft was turned at 1145 revolutions per minute by a two horse power, 3-phase electric motor by means of a 10.2 cm (4 inch) motor pulley and a 15.2 cm (6 inch) shaft pulley with a B size automotive fan belt. A cover constructed from pieces of a standard 55 gallon oil drum was mounted around the blade. A spout was attached to the cover over the path of the rotating blade and an adjustable opening was placed below the blade on the opposite side of the circular cover. As fish were dropped into the spout they fell onto the whirling blades and were broken and torn as they were thrown around inside the cover until the minced material exited through the lower opening. Size of

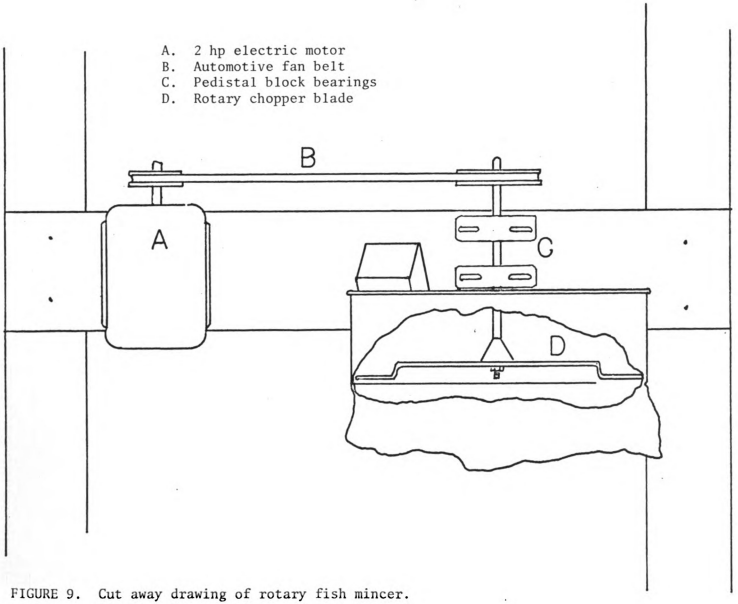

FIGURE 9. Cut away drawing of rotary fish mincer.

chunks produced was regulated to a certain extent by the size of the lower opening. A heavy cloth shroud directed the chopped product into a container placed below the machine. This machine yielded a wide variation in particle size which was related closely to the type of fish product minced. It was necessary to run the product through the machine a second time to produce fish chunks of sufficiently small size to dry properly. Volume capacity was at any one time less than that of the commercial meat grinder, however, due to the efficient loading and discharge of this machine the hourly production was greater and was approximately 408 kg (900 lbs) per hour regardless of fish product used.

Cooking Systems

Cooking of the fish product must be sufficient to denature the protein of the fish muscle but not so great as to reduce protein digestibility.

A temperature of 71^{o} C (160^{o} F) was established as the end point temperature of the cooking process. Temperature readings were made on the fish during cooking with a "Fluke" digital thermocouple. Cooking the minced wet product in an ordinary vessel without the addition of water proved unsatisfactory. Fish adjacent to the hot vessel surface were burned before internal flesh temperatures were raised sufficiently to denature protein. Stirring of the product proved to be impractical. A person cooking fish in this manner would have to be continuously occupied as the cooking process was proceeding and even then burning of some fish was likely.

A double boiler system was designed and constructed to solve the

problems of stirring and burning. The water jacket (lower vessel) and the fish pan (upper vessel) were both constructed from a single standard 55 gallon oil drum. The drum was split in half lengthwise. The water jacket was constructed from one half of the drum by cutting the ends of the drum from a point halfway between the two edges of the drum to the rim. The two edges of the drum were spread apart an additional 10.2 cm (4 inches). The wedge shaped openings resulting were closed with triangular pieces of metal bolted or riveted and sealed to the ends of the drum. The fish pan was constructed by shortening the other drum half by 10.2 cm (4 inches) to allow it to fit into the water jacket. The seams were sealed and wooden handles on metal brackets were attached to the ends to allow the hot pan to be lifted.

Cooking of fish in the double boiler was accomplished by placing the water jacket partially filled with water on a rack suspended over a fire. After the water was boiling, the pan filled w ith 23 kg (50 lbs) of wet minced fish was placed in the water. The minced fish were occasionally stirred and periodically measured for temperature at various points within the pan 5 cm (2 inches) from the rounded bottom. The cooking process continued until the internal temperature of 71^{o} C (160^{o} F) was reached consistently at the measuring depth after rigorous stirring.

Only occasional stirring was required for even heating in this unit and fish waste burning did not occur. However, this system was found to be particularly slow. Cooked fish production per hour was dependent on the fire level, with an average of 68 kg (150 lbs) of product cooked per hour.

Direct cooking with the addition of water was then tried to see if cooking capacity could be increased. A 55 gallon oil drum containing 45 kg (100 lbs) of minced fish plus 15 liters of water was placed on a rack over a fire (Figure 10). Forty five kilos (100 pounds) of fish proved to be the maximum amount which could be stirred effectively and the 15 liters (4 gallons) of water per 45 kg (100 lbs) was found to produce an ideal consistency for prevention of burning and adequate stirring. Up to four one hundred pound batches could be processed per hour. After rigorus stirring temperature readings were made at a point 7.6 cm (3 inches) up from the flat bottom of the drum.

This system became the preferred cooking method adopted by the project for production of fish meal.

Using this method, whole small fish would disintegrate with stiring and cooking, and the product was similar to the minced cooked fish product.

Fish Press

A lever operated fish press was designed and constructed as illustrated in Figure 11. Frame construction was of wood and a 19 liter (5 gal) pail served as the sieve or basket in which the fish was pressed. Pressure generated with the device was 20 kg/m^2 (3.3 lbs/in^2 when using 80 kg (175 lbs) of weight on the lever and a 30.4 (12 in) diameter plunger. This device generated pressure capable of making a fragile pressed cake which contained on the average 8.5% lower moisture than the raw fish product. Figure 12 shows the sieve used for pressing the fish product and the fragile press cake as it appeared after the press operation.

Figure 10. Direct cooking system.

Figure 11. Hand operated fish press.

Figure 12. Pish press seive and press-cake.

Direct Drying by Horizontal Trays

Screen trays measuring 45.7 cm x 61 cm x 10.2 cm (18" x 24" x 4") were constructed of 1.2 cm x 1.2 cm (1/2" x 1/2") wire mesh. They were then lined with galvinized household window screen. Simple wooden supports were placed on concrete building blocks at heights of 45.7 and 91.4 cm (18 and 36 inches) from the ground with the baskets resting on the supports in such a way as to allow free air movement over, under and around all baskets. The racks at the two levels were placed in an area of continous sunshine and where air movement was not obstructed. The baskets were filled to a depth of 38.1 (1 1/2 in) with shole raw, chopped raw, or chopped cooked fish and observed for drying characteristics. The whole raw and chopped raw fish attracted flies immediately, with the cooked chopped material attracting them after a period of 30 to 45 minutes. The product in all three treatments was covered with maggots by the afternoon of the second day.

A dried crust formed over the surface of the chopped product. Shrinkage due to surface drying occurred and regular agitation of the baskets was necessary to break up the crust and allow interior surfaces exposure to the air. Complete drying of the product took about three days depending on the temperature, relative humidity and air movement about the fish. Spoilage of the fish was evident by the heavy infestation of maggots, the putrid aroma of the product and a presence of ammonia. The whole fish treatment developed a foul order beginning the second day with little apparent loss of moisture before it had to be discarded. This sytem of drying was determined unsatisfactory and further research on this method was discontinued.

Dryer Components

Solar Collectors

Two solar collectors were built, one primarily of wood and the other primarily of sheet metal and their performance was compared. Drawings of the two solar collector designs are presented in Figures 13 and 14.

The basic size and shape of the two solar collectors was the same however, the following design features were different.

The major construction material of the two collectors differed. The wooden collector, henceforth known as collector number 1, was designed with sides of 2.54 x 20.3 cm (1" x 8") lumber a double wall insulated rear face and two layers of flat Kalwal® [1] glazing. The metal collector, number 2 was constructed of 18 guage sheet metal sides, a single celetex layer rear face and two layers of clear corrugated fiberglass [2] as glazing material. The wooden collector was much heavier than the metal collector and did not prove as durable to the outdoor conditions.

The air space of Collector #1 was much smaller 0.397 m^3 (14.67 ft^3) than the air space of Collector #2 0.618 m^3 (8.08 ft^3). This was primarily due to the addition of an insulated rear face and recessed glazing of Collector #1. Effect on the collector was that the air of this chamber had more intimate contact with the absorber surface. Collector #1 also had a wire mesh painted flat black suspended withing the air space above the absorbing surface and below the glazing. This

[1] The DuPont Corporation

[2] Purchased locally

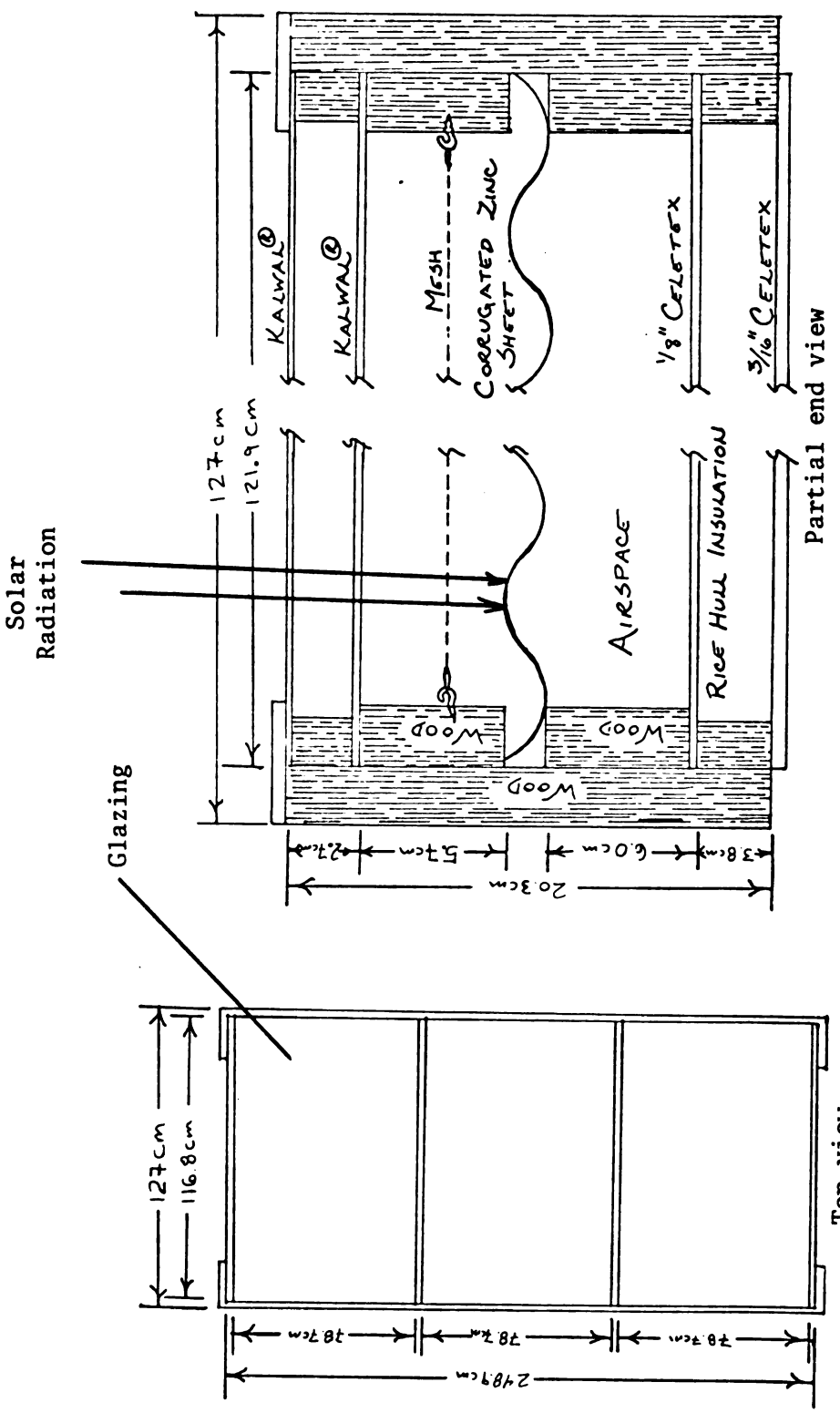

FIGURE 13. Wooden solar collector (#1).

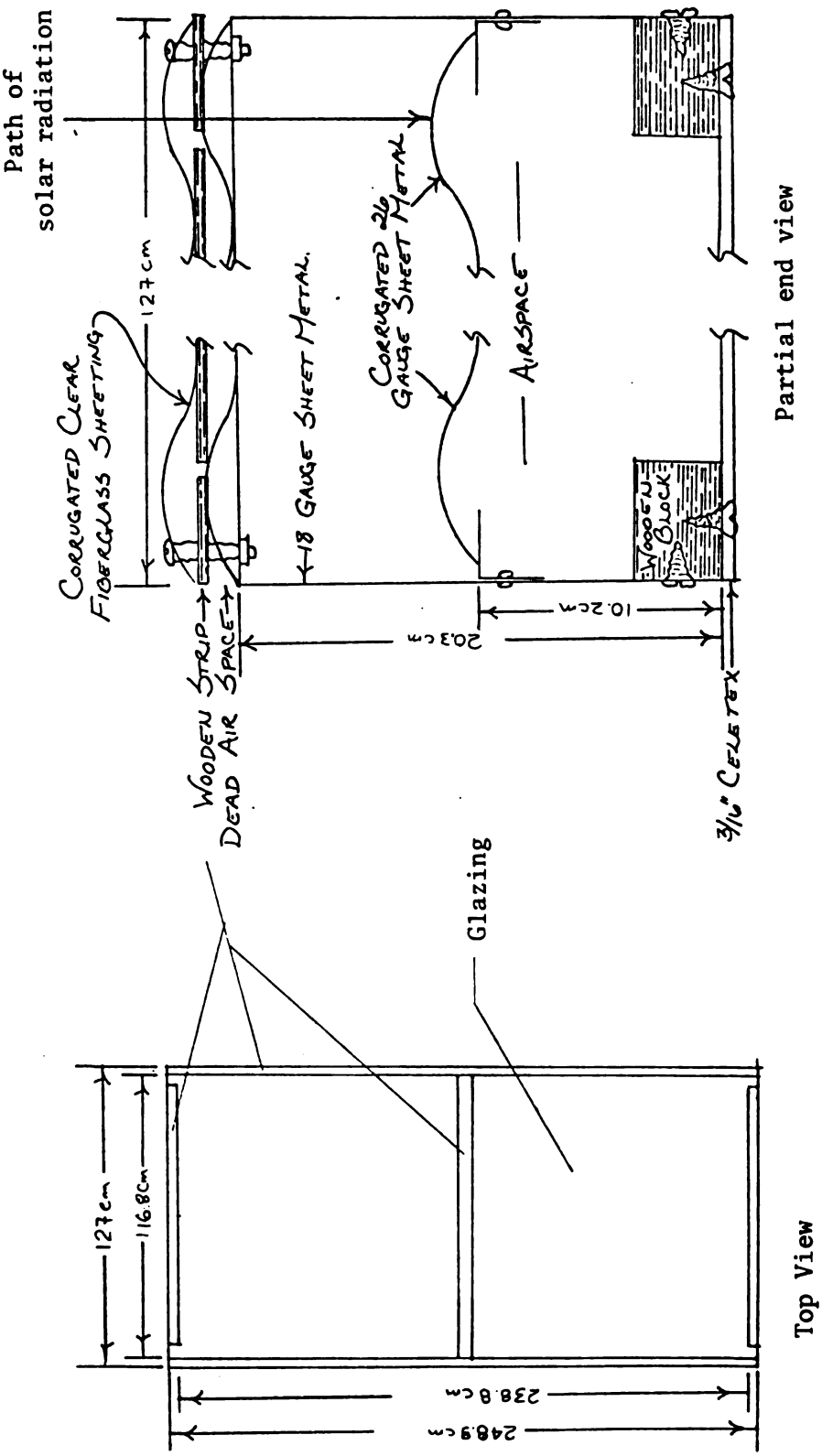

FIGURE 14. Metal solar collector (#2).

increased turbulance and, being painted flat black, absorbed energy and transmitted it to the air flow.

Inlet and exit design differences also affected the air flow. Collector #1 had inlet and exit ports of 0.159 m^2 (247.25 in^2) compared to 0.246 m^2 (382.00 in^2) for Collector #2. The difference in inlet and exit ports caused differing resistance to air flow resulting in a difference in the air volume-per-minute ratings for the two collectors.

The effective solar absorbing surfaces of the two collectors was 2.745 m^2 (4255 in^2) and each was painted with flat black "Rustoleum" brand paint. The metal backing of the absorbing surfaces differed as 18 guage c orrugated galvinized steel sheet metal roofing was used in the case of Collector #1 and 1.58 mm (1/16") corrugated aluminum roofing was used in Collector #2.

The glazing material of Collector #1 was flat Kalwal® sheets separated by 2.54 cm (1 in) dead air space. The glazing of Collector #2 consisted of two layers of clear corrugated roofing fiberglass 2.54 cm apart. Due to the corrugations in the fiberglass roofing this space did not function as an absolute dead air space.

Insulation of the two collectors also differed. Collector #1 with its wooden frame and insulated rear face possessed a greater total insulation value than Collector #2 with its single layer sheet metal sides and uninsulated rear face. Insulation of Collector #2 was not added because at that point in the development it was not thought that the temperature gradient between inside and outside the collector would be great enough to benefit from insulation.

Evaluation of Solar Collectors

The solar collectors were coupled in a parallel arrangement as shown in Figure 15 with the long axis aimed in a due southerly direction. The collectors were tilted at either 20^{o} or 40^{o} above horizontal for the purpose of combined performance evaluation. Energy output in terms of BTU per minute was calculated from measured air flows and wet and dry bulb temperatures. Values were converted to joules/minute. Measurements were taken at two hour intervals during daylight hours beginning at 8:00 AM San Pedro time and ceasing at 6:00 PM.

Procedures for Measurements and Calculations

Air volume expressed as cubic meters of air per minute flow through the collectors was determined in the collecting funnel between the solar collectors and blower unit. This volume was calculated as the product of the cross sectional area of the conduit and the velocity of the air flowing thru it. Cross sectional area was calculated from the formula area = πR^2 and air flow velocity was determined by averaging four propellar type anemometer readings from four points within the air path. The four points of air velocity measurement were equally spread along the radius from the center to outer edge of the air path. All other air volume references in this thesis were determined for specific locations in this manner.

Dry and wet bulb temperatures were determined with a Fluke digital thermometer with copper and constantan leads. Wet bulb temperatures were obtained using a thermocouple lead with attached wick wetted with distilled water. Temperatures were recorded at the intake opening of the collectors and at the funnel end. Data were recorded for the

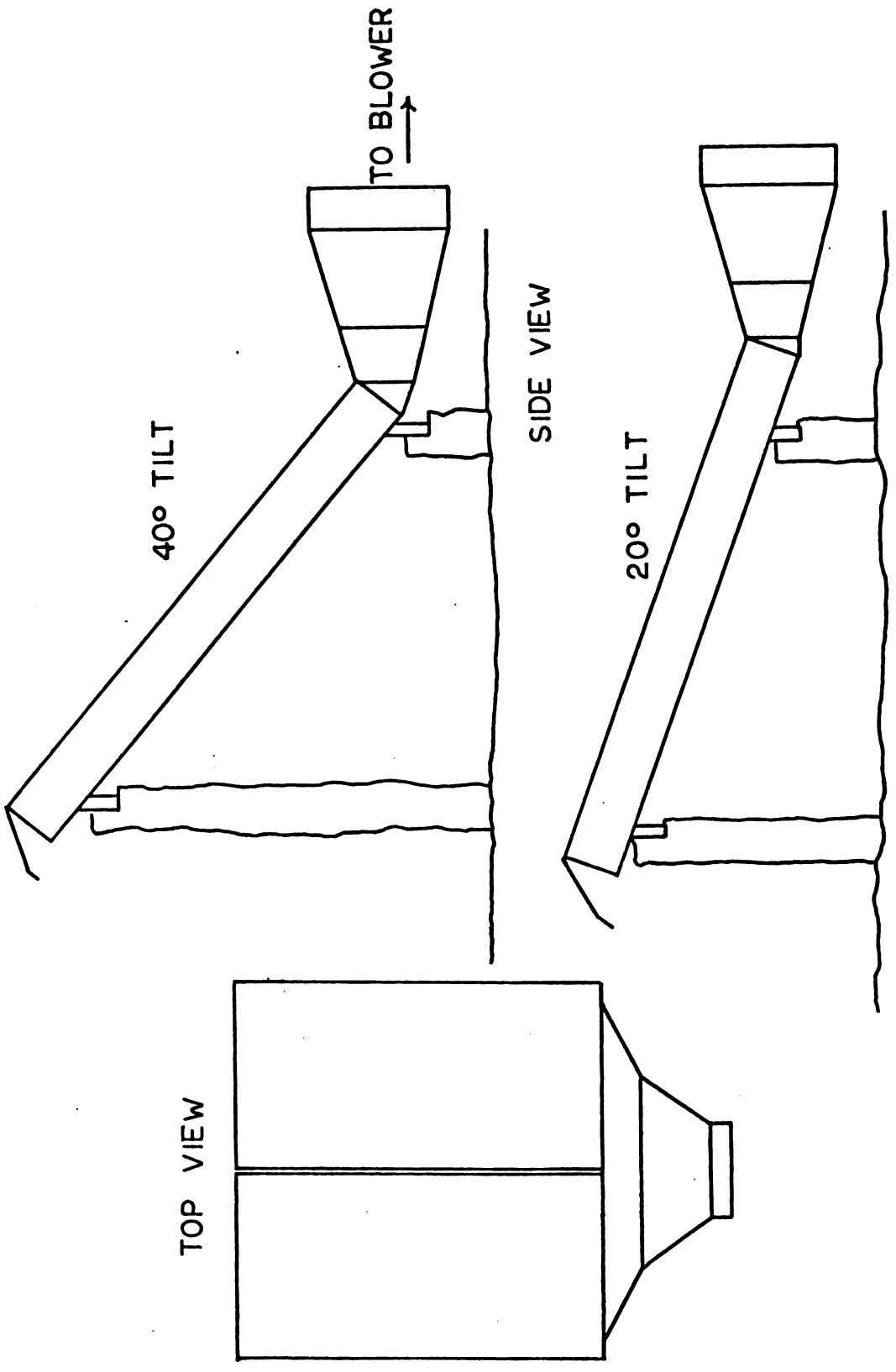

FIGURE 15. Orientation of solar collectors.

combined heat production and individual collector heat production. Temperature readings were converted to net change in BTU per lb of dry air using a psycrometric chart. Values were converted to joules per lbs dry air.

Wet and dry bulb intersections for the two conditions were plotted. Entalpy content (BTU per lb dry air) under each condition is determined by the extension of each point to the enthalpy scale. Change in enthalph was determined as the difference in the values associated with each point. Total BTU out-put per minute was determined by the product of air velocity in terms of lbs of air per minute and the BTU per lb of dry air then converted to joules out-put per minute. A conversion factor of 14.4 cubic feet per pound dry air was sued to correct air velocity units from cubic feet per minute to pounds of dry air per minute.

Blower and Auxilary Heat Unit

The original design of the blower unit consisted only of an electric motor driven fan blade suspended in a sheet metal housing. This design was later modified to accomodate the addition of a kerosene fired supplementary heat source. The modified design including the kerosene heat source is shown in Figures 16, 17 and 18.

The frame of the blower housing was made of 2.54 x 2.54 cm (1" x 1") angle iron welded at all joints. The total length of the unit was 162.5 cm (64 inches) with a width of 62.2 cm (24 1/2" and a height of 76.2 cm (20").

Twenty-four gauge flat sheet metal was fitted to the frame to serve as the blower housing. A 55.8 cm (22 ") diameter, five-bladed

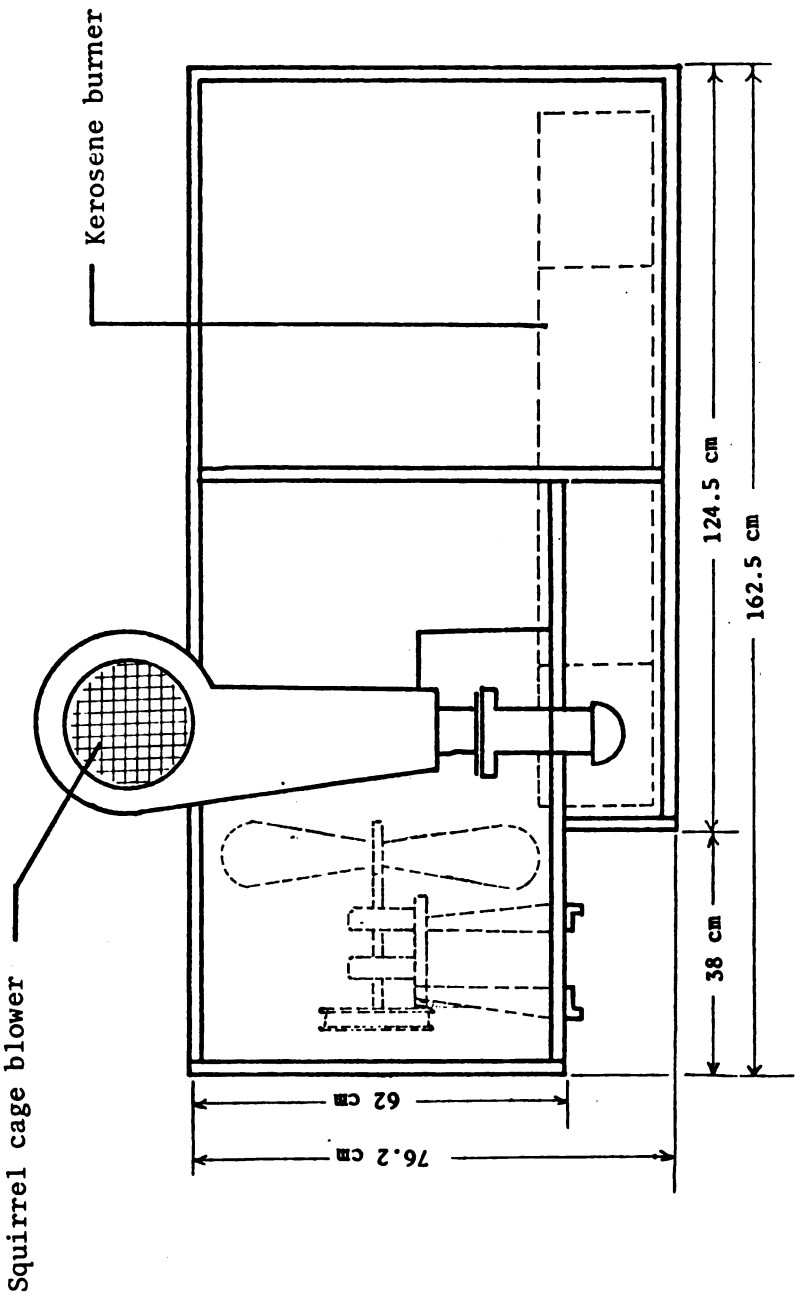

FIGURE 16. Front view blower unit.

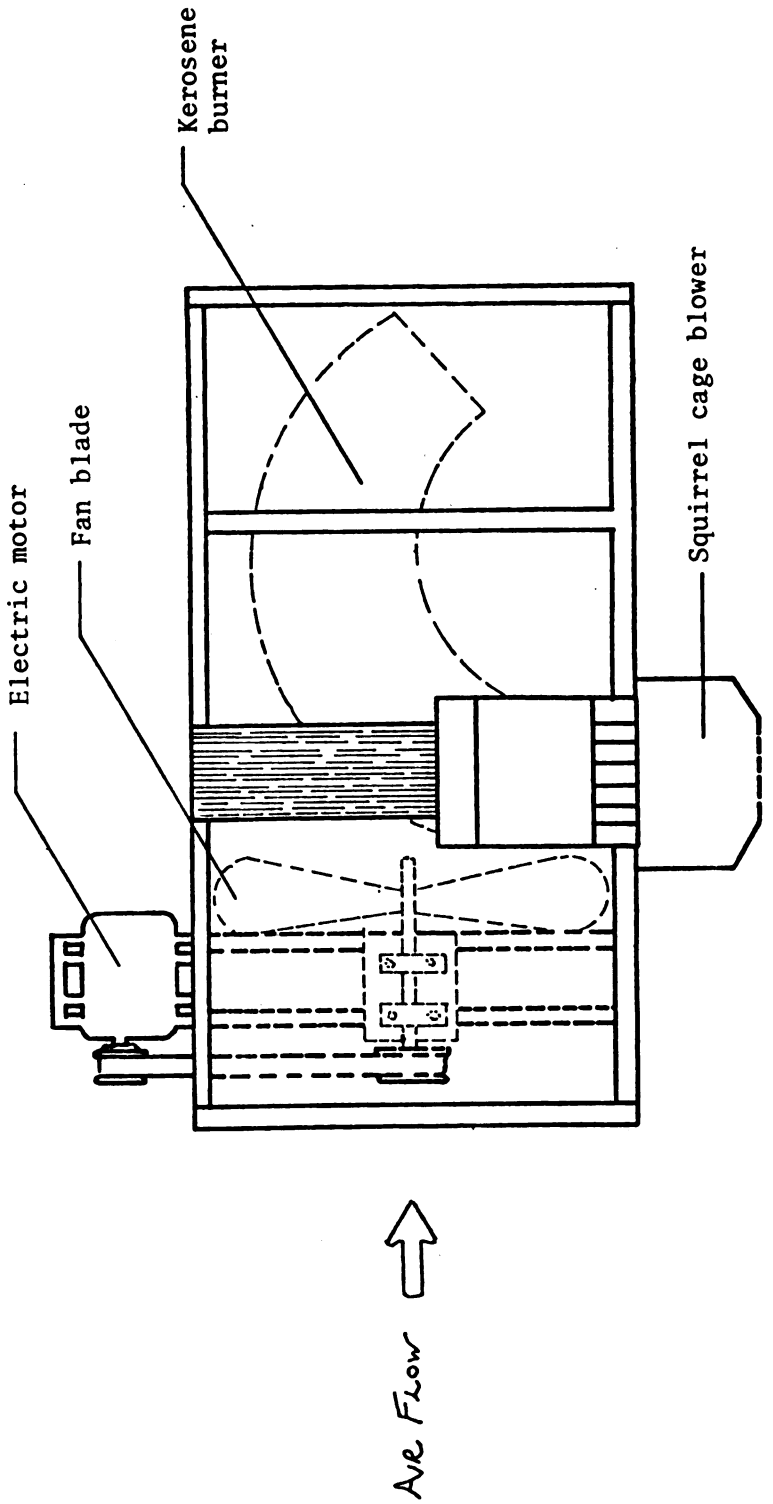

FIGURE 17. Top view blower unit.

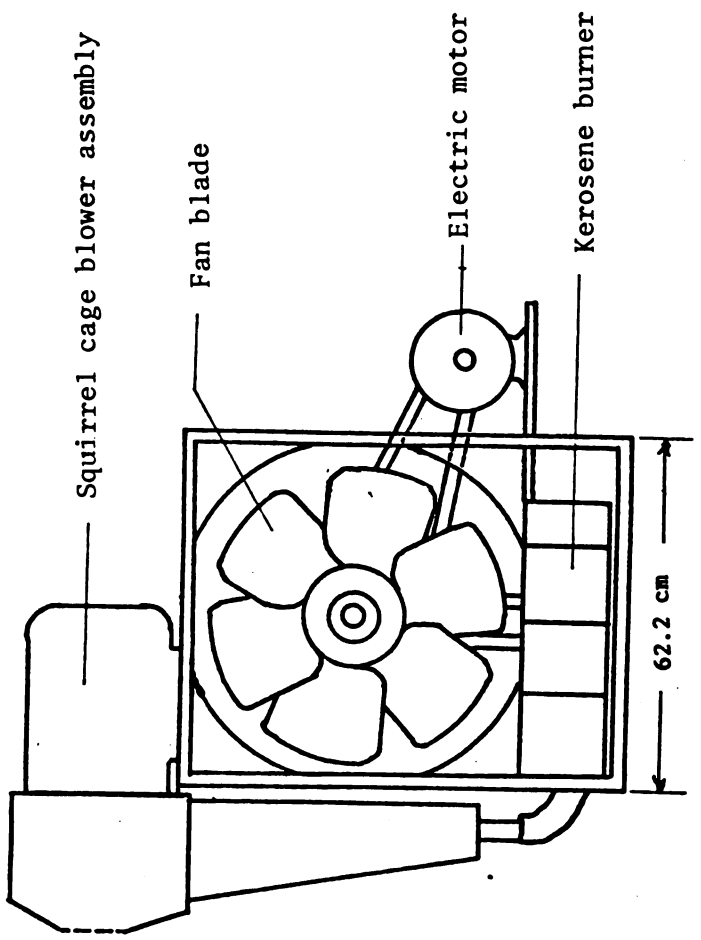

FIGURE 18. End view blower unit.

fan blade was suspended in the frame to allow a 0.63 cm (1/4") gap between the fan blade and the blower housing. The fan blade was mounted on a 15 mm (5/8") shaft which turned in two pedestal block bearings mounted on a platform within the air space. The shaft was belt driven by a 2 horsepower, three phase electric motor turning at 1735 rpm. A motor pully of 8.80 cm (3 1/2") diameter and a shaft pully of 13.97 cm (5 1/2") result in a blade rpm of 1104.

A squirrel cage blower powered by a 1/2 horsepower electric motor was mounted on top of the blower frame to supply a kerosene fired burner with the large volume of air necessary for clean burning of fuel and efficient heat production. Air from this source was channeled through the side of the blower and into the air intake of the burner.

The burner unit used as the auxillary heat source for this project was acquired as a discarded component of an automated tortilla oven. The burner, as shown in Figure 16, was made of 3/8" steel formed in a rectangular tube which was bent in an arc. The top one inch of the interior of the rectangular tube was filled with a porrous ceramic material. Fuel placed on the ceramic material was spread by the porous nature of the material to the entire interior surface. Air was forced into the tube by the squirrel cage blower and the fuel burned on its ceramic surface. Hot gases were ejected out the bottom of the unit and joined the air flow from the collectors. Heat was also transferred to the air path from contact with the hot surfaces of the burner itself. Smoke from the burner was negligable due to the efficiency of combustion when the unit was supplied by an abundance of forced air.

Kerosene or diesel fuel was supplied to the burner from an external fuel tank. Gravity flow of fuel was regulated by means of a line valve

and visible drip indicator. Fuel consumption during continuous use of the burner was determined to be 3.29 liters of kerosene per hour or 3.60 liters of diesel fuel per hour as calculated from the entire test phase.

Drying Units

Cabinet Dryer. A cabinet dryer shown in Figure 19 was constructed and tested as the initial attempt to develop a simple mechanical drying system. The cabinet dryer itself was constructed of an angle iron rack capable of supporting eight pairs of screen shelves each measuring 2' x 5'. Doors on both sides of the structure opened to allow easy access to shelves and fish. The remainder of the walls and bottom were covered with 24 gauge sheet metal and the open top of the cabinet was covered by a corrugated metal roof raised four inches off the cabinet.

Heated air was forced into the bottom of the closed cabinet by a blower unit, described fully in the section termed Blower and Auxillary Heat Source, connected with the two solar collectors. The air then passed up through the fish product placed on the shelves and out the gap below the roof.

The procedure for the operation of this machine was that chopped cooked fish were drained on screen racks outside the dryer for a period of 15 minutes, then placed on the dryer rack at rates of 22.7 kg (50 pounds) of product per rack. Air movement through the entire fish product required even spreading within each shelf of the dryer. Air was supplied to the unit at the rate of 65.11 m^3 (2300 ft^3) per minute and was heated by the solar collectors in parallel orientation and tilted at 40^o from horizontal.

Figure 19. Cabinet Dryer

Flies were greatly attracted to the raw fish in this drying system. The force of air did not discourage fly infestation of the product.

Drying of the raw fish was drastically hampered due to crusting of the exterior of particles. Hard, glue-like crusts formed, especially on the screen itself and precluded air flow. Scraping of the trays was required at intervals of 15 minutes to prevent sticking and crusting. Approximately 50% of the area of the screen rails at the end of drying a batch was obstructed and required much time to clean before the next batch. Damage to the screens occurred when removing the hard crusted material. Crusting with cooked fish was not as pronounced as with raw fish. The crusted fish product could be picked up in large flat pizza-like pieces from the screen but human attention was required to crumble the pieces in order to allow drying of all surfaces. The dry product resulting from 50 pounds of cooked chopped fish on a screen rack after removal of the shelf is shown in Figure 20.

Dryer inlet temperatures ranged from 35° C to 40.5° C (95 to 105° F) depending on the environmental conditions and solar radiation. Drying time for this machine was about two days.

Due to the great labor input required to dry the fish in this system and the slow drying rate, an alternative rotary drying system was developed.

Rotary Drum Dryer. The rotary drum dryer as shown in Figure 21 was developed in an attempt to overcome the problem of partially dried fish sticking to the screen racks. A complete description of the drum assembly is included in the description of the drum cabinet dryer on page 72. Pedestal block bearings were bolted to 5.1 cm x 15.2 cm

Figure 20. Dry coarse fishmeal produced in the cabinet dryer.

Figure 21. Rotary Drum Dryer

(2" x 6") steel channel which was supported by 5.1 cm x 10.2 cm (2" x 4") lumber legs and 2.5 cm x 15.2 cm (1" x 6") lumber supports. Air flow from the collectors and blower was channelled by means of a 40 mil black plastic tube. The plastic tube which was 60.9 cm (24") in diameter remained inflated as long as the blower was in operation and collapsed when inoperative. This conduit system functioned well, was durable and easily constructed.

The operating procedure for the drying of fish with this drying system was as follows. Cooked fish was allowed to drain for 15 minutes to remove excess water from the cooking process. The drained fish product was placed in the rotary drum at the rate of 90.7 (200 lbs) per batch, the blower and drum rotation motors were turned on and the fish was allowed to dry. The process was begun at 8:00 AM and proceeded until 6:00 PM at which time the blower and drum were turned off for the night. Drying commenced at 8:00 AM the following morning and proceeded until a product dry matter of at least 90% was achieved.

Evaluation of the performance of the rotary drum dryer. A batch of 90.7 kg (200 lbs) of cooked, chopped grouper chest was established as the test material with which opperational parameters were compared.

Product dry matter was determined at two hour intervals using 100 g samples in aluminum foil pans dried to a constant weight in a drying oven of 105^{o} C. Weights were determined before drying and after cooling in a desiccator with a triple beam balance. Dryer efficiency was calculated from a psycrometric chart using wet and dry bulb temperature readings from the air path immediately before and after the drying unit. Temperatures were determined with the Fluke

digital thermometer as previously described. Drying rate was expressed as the change in moisture of the fish product over time.

Drum-Cabinet Dryer. This drying unit was a combination of the two drying systems previously tested in that it was comprised of a drum section used to dry the product sufficiently such that sticking did not occur and a cabinet section to greatly increase volume output of the unit.

Description of the drum-cabinet dryer. Drawings of the drum-cabinet dryer is presented in Figures 22, 23 and 24. The two basic assemblies were the enclosed cabinet section below and the drum pictured above.

The drum assembly was constructed of two standard 55 gallon oil drums measuring 55.9 cm (22") in diameter and 87.6 cm (34.5") in length, each welded end to e nd. The bottoms and tops of both drums were removed and replaced by angle iron spokes. An axle consisting of a galvinized 6.35 cm (2.5") steel pipe was passed through and welded to the hub of the spokes. Agitation within the drum was caused by a series of eight vanes bolted to the inside of the drum dispersed at quadrants around the perimeter. Vane dimensions were 10.2 x 20.4 cm (4" x 8") which resulted in the vanes extending one third of the distance from the perimeter toward the axle of the drum. The ends of the drum were covered with 3.2 x 3.2 mm (1/8" x 1/2") wire mesh to prevent blowing out of the partially dried fish product. Material was added and removed through hinged doors in the walls of the drum. The axle of the drum assembly rotated on two 5.7 cm (2.25") pedestal block ball bearings which were bolted to the dryer frame. An air lock minimizing

Figure 22. Drum Cabinet Dryer

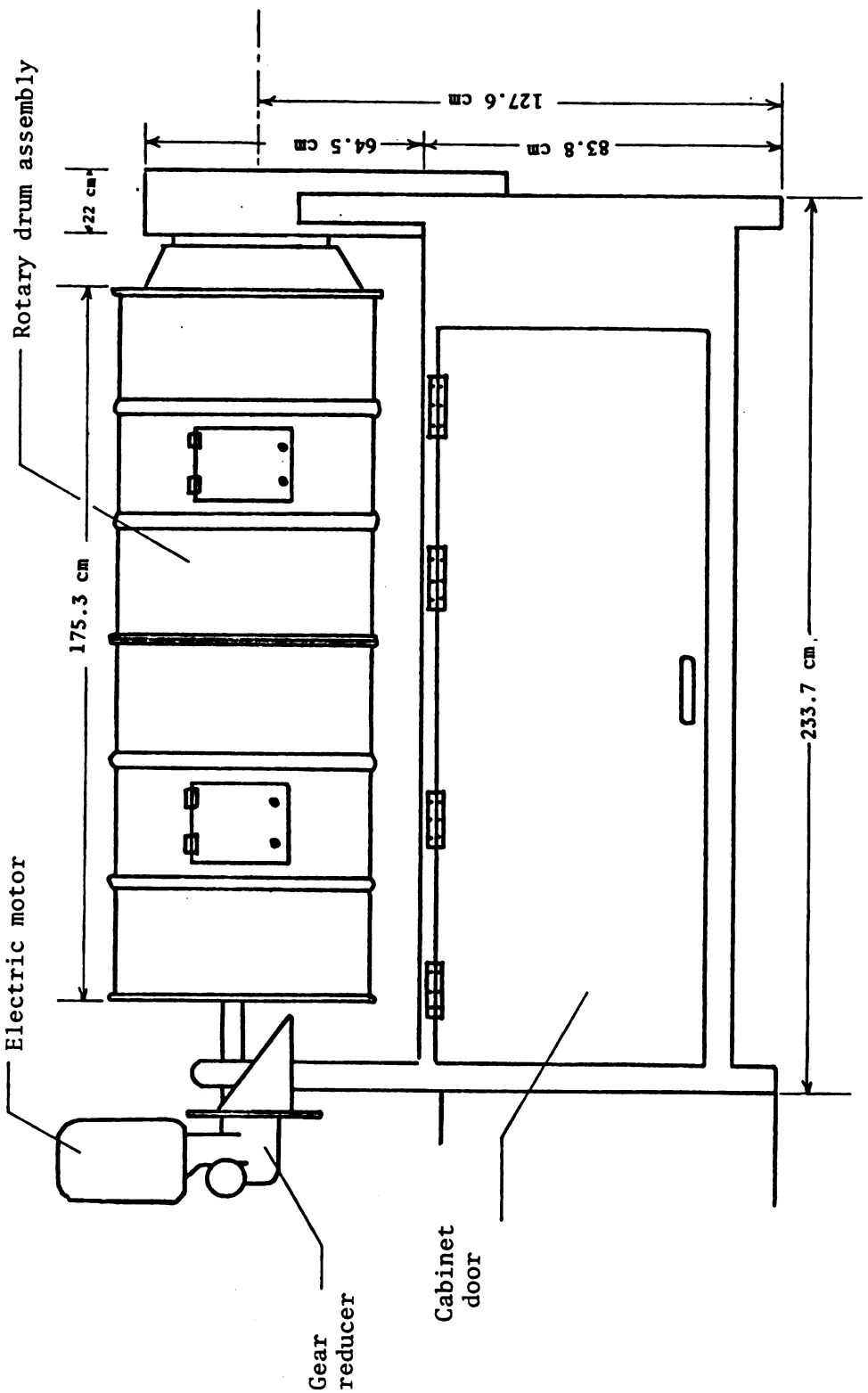

FIGURE 23. Front view drum cabinet dryer.

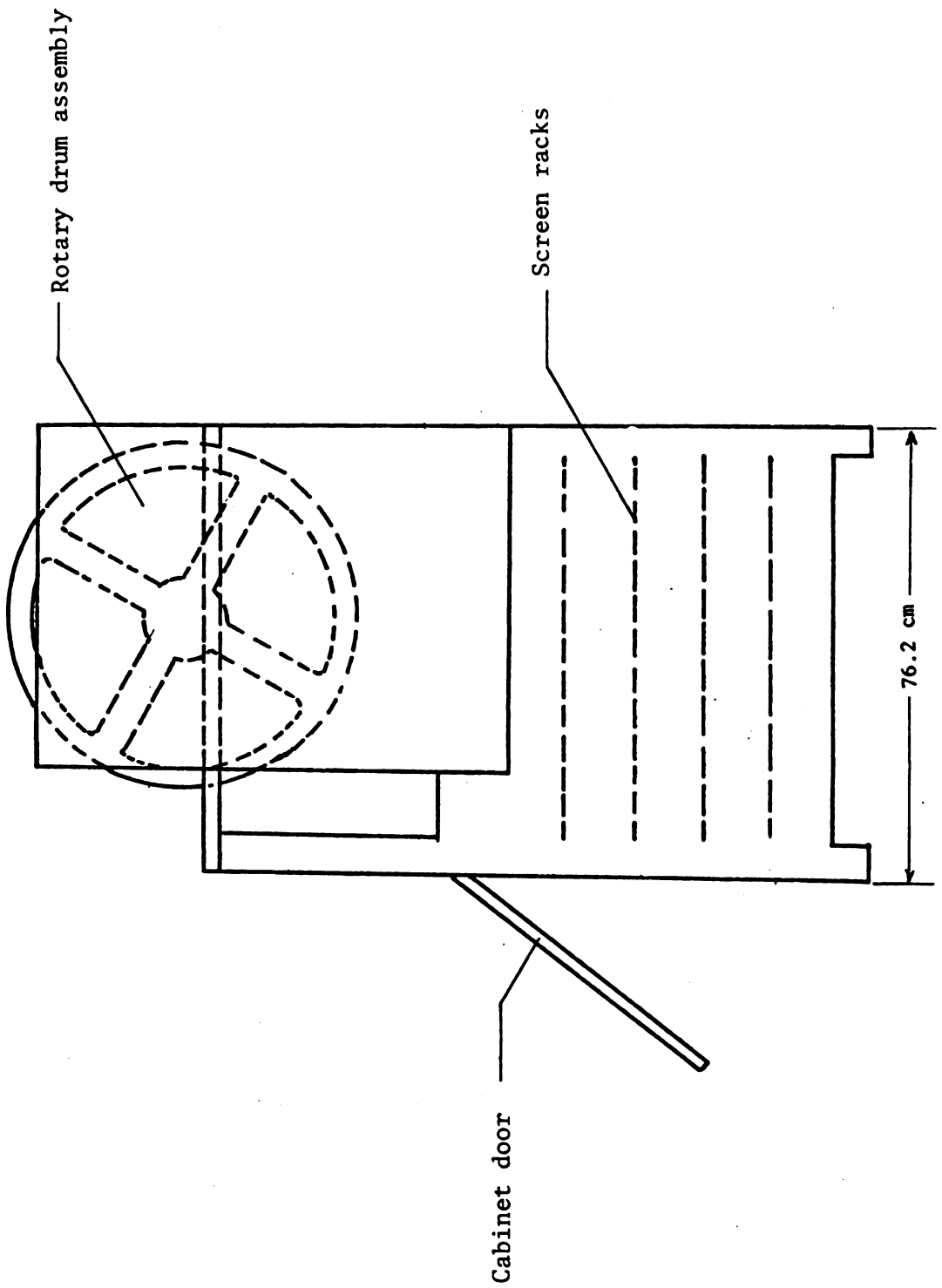

FIGURE 24. End view drum cabinet dryer.

air loss was located at the leeward end of the drum where the stationary air duct from the cabinet met the rotating drum. A 1/2 horsepower single phase motor coupled to a gear reducer with final speed of 10 rpm was mounted on the exhaust end of the dryer frame and used to rotate the drum assembly.

The cabinet and frame section of the dryer unit was supported by a lumber frame. Legs at each end of the unit supported cross bars 127 cm (47 1/2") above the ground to which the drum bearings were attached. B etween the legs was a double walled insulated sheet metal cabinet. This cabinet was insulated with 3.81 cm (1 1/2") of high heat resistant fiberglass batting. A door was placed in the front of the cabinet and angle iron brackets were bolted to the interior walls of the cabinet to support four screen racks. The racks measuring 152.4 x 60.9 cm (60" x 24") built . be slid in and out of the brackets and could be removed through the door. The mesh covering these racks was galvanized household screen reinforced with 3.2 mm (1/8") rods to hold the weight of the fish.

The air flow pattern in this dryer is shown in Figure 25. Air from the blower moves across the racks of drying fish product, then up through a sheet metal channel through the air lock and past the tumbling fish and finally out through the end of the drum. The warmest, dryest air passed the racks of low moisture fish before passing to the fish of higher moisture in the drum.

Evaluation of the performance of the drum cabinet dryer with supplemental heat. Evaluation of the performance of the drum cabinet dryer with supplemental heat was conducted in the following manner.

Shrimp boat waste in batches of 90.7 kg (200 lbs) was prepared for drying by cooking and pressing as described in the section headed "Established Operating Sequence". At 9:30 AM, 1:30 PM and 3:30 PM the supplementary heat was ignited. One half hour folhowing the initiation of supplementary heat, dry and wet bulb temperatures were taken at the described points. Dryer efficiency, energy out-put of the solar collectors and energy out-put of the supplementary heat source were all calculated with a psycrometric chart.

Fish Silage

A study of fish ensiling techniques was initiated for two reasons. First, an economical, wholesome method of storage of fish product was required to utilize the abundance of fish procurred during heavy harvest periods. Secondly, fish silage could be utilized as a feed in itself.

It was recognized that a carbohydrate type ensilage method was more practical than the acid ensilage system due to the inavailability of acids required for the latter.

Small experimental silage systems were developed using plastic, five gallon buckets with sealable tops (Figure 26). The following ensiling treatments were studied: a) chopped fish only, b) chopped fish plus 10% cane molasses, c) chopped fish plus 10% rice bran and d) chopped fish plus 10% wheat bran, all on a weight basis. Holes were drilled in the bottom of the bucket to allow for drainage. A second treatment of chopped fish plus 10% molasses was placed in a bucket without holes. All treatments were sealed, located in the shade and allowed to ferment for a period of six weeks. Observations of the silage were recorded on a daily basis throughout the experiment.

Figure 26. Experimental silage treatments in 5 gallon buckets.

Upon opening, the appearance, aroma, consistency, fly infestation and pH of the nesiled fish was recorded.

A larger volume silage system was also developed using 55 gallon drums. The drums were prepared by removing one end. Twelve equally spaced holes of 9.5 mm (3/8") diameter were drilled through the opposite end of the drum for drainage. The interior of the drum was then painted with two coats of rust-resistent paint. A strip of metal 12.7 mm (1/2") wide was removed from the rim of the removed end of the drum to allow clearance around the inside of the drum. All sharp edges and protrusions were ground down with an electric grinder. A foundation to support the weight of the full drums was made using partially buried cement blocks. A platform of 5 cm x 15 cm lumber was placed across the blocks at a height of 10 cm above ground level.

Preparation of Fish Silage in 55 Gallon Drums

Grouper filet waste weighing 204 kg (450 lbs) was ground in the Hobart commercial meat grinder using the course quadrant grinding plate. The chopped fish was divided into portions weighing 22.7 kg (50 lbs) each. Five pounds of cane molasses was added to each 22.7 kg (50 lbs) portion and mixed thoroughly. The molasses distributed well through the chopped fish waste due to the wet consistency of both products. After mixing, each portion was poured into the drum silo and packed to eliminate air pockets. The 224.5 kg (495 lbs) batch of fish molasses mix filled the drum to a depth of 71.1 cm (28"). The remaining space within the drum was required to allow for expansion of the silage during fermentation. A piece of black 40 ml plastic 1.83 m x 1.83 m (6' x 6') was laid over the surface

of the fish molasses mixture. The modified lid was then placed in the drum and pressed down over the plastic evenly packing the silage. The plastic falling over the rim of the drum was gathered and pleated as evenly as possible to exclude all the air possible. A triple turn of wire was placed around the drum below the rim over the plastic to prevent entry of air. This system of sealing the silo allowed for the expected expansion and subsequent contraction of the silage in the process of fermentation. A cement block of 6.8 kg (15 lbs) was placed on the lid to aid in the compaction of the product and to provide insurance against entry of air into the silo.

In this state the product was allowed to ferment for a period of four weeks, at which time the previously described observations of the product were made.

Operating Sequence

The established operating sequence for the production of fish meal on a routine basis is schematically presented in Figure 27. This scheme was developed as a result of actual production experience. obtained in the testing phase of the project

Collection of Fish Waste

The fish waste was collected in drums placed at the fish landing in the form of whole fish, filet waste or guts and fills. The fish waste was either cooked, pressed and dried or it was stored for future use in the form of silage. The decision to store the product or to process it into fish meal directly was based upon the availability of dryer capacity in the next 24 hours. If the entire volume received could be dried in the next 24 hours the product

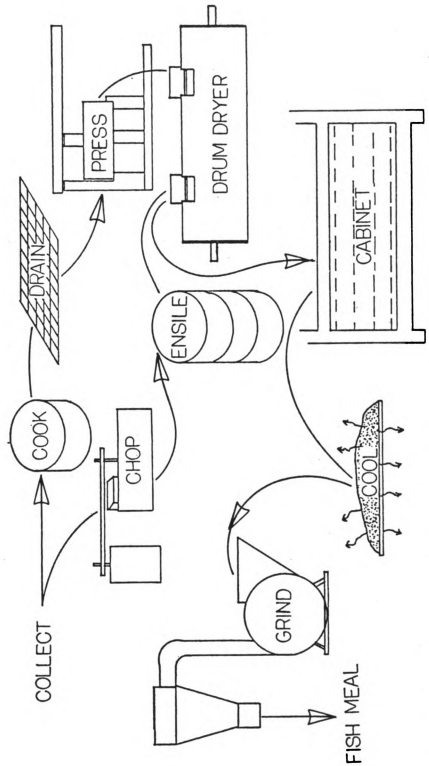

FIGURE 27. Diagram of production sequence.

went to the cooker and dryer directly. If the dryer was not available, the product was ensiled for later use. The arrival of fish waste suitable for fish meal production was unscheduled and unpredictable in type and volume; thus, storage for future processing was the most likely alternative.

Cooking and Pressing of the Product

If the product was to be processed immediately it was cooked to a temperature maximum of 71° C (160° F) in the method described in the section headed Cooking Systems. At approximately 60° C (140° F) the fish flesh flaked away from the bones and was broken up by the mechanical force of stirring. At the end point temperature the product assumed the form of a paste and was poured on to screen racks for drainage. A period of 15 minutes was allotted for the fish paste to drain. The appearance of the product is shown in Figure 28. It can be seen that there are globular particles of fish flesh the size of marbles mixed with bare bones.

The drained product was pressed in loads of approximately 15 pounds each and placed in the drum section of the drum cabinet dryer. Cooking, draining and pressing of the product required 35-40 minutes if one person operated the unit. Batches were cooked and pressed to be ready for drying as close as possible to the regular two hour cycle of the drum dryer.

Because of the weaker integrity of the tissue, guts and gills were handled in a slightly different manner. If possible, the guts and gills were combined with a batch of fish flesh at a ratio of 1:5. If the firm flesh was not available, the procedure was modified

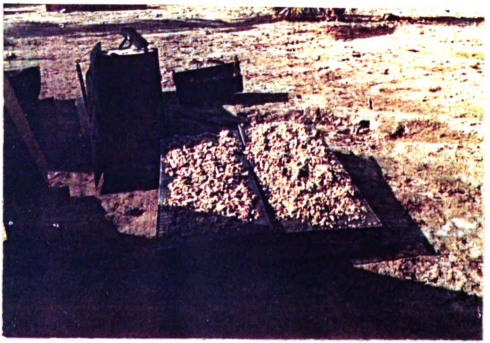

Figure 28. Cooked fish paste draining on screen rack.

as follows. The gills and guts were cooked as was the standard product. Continual stirring and cooking caused the highly vascularized gills and s ofter tissues of the digestive system to disintegrate long before the muscular stomach. At this point only the soft tissues were removed and allowed to drain on screen racks while the muscular organs were cooked at a maximum temperature of 71° C (160° F) several minutes longer. Care was taken when the soft tissues of gills and guts were pressed due to the weakness of the tissue, as the product tended to be forced through the holes in the press seive. Less pressure was applied and thus less moisture removal was possible. The firm musculature of the stomach was pressed as the whole fish material. The two types of pressed cake were combined in one drum load of the dryer and were mixed as drying occured.

Storage of Raw Fish

It will be necessary to ensile raw fish product during times of heavy catch or processing backlog. The product to be ensiled was chopped to maximum particle size of approximately 1 cm in one of the two mincing machines previously discussed. The product was completely mixed as previously described and packed in a 55 gallon drum silo. The silage was allowed to ferment a period of 14 days, after which it was ready to be dried at any time the dryer was available. Cooking of the product was not necessary due to disintegration of the fish product through acid denaturation of protein and the action of natural enzymes in the fish tissue. Pressing was not required in most cases since the silage which was

allowed to drain lost moisture in the ensiling process. Especially wet silage required pressing but moisture removal was minimal.

All areas of surface spoilage were removed before placing the product in the dryer and care was taken to inspect the material in the interior of the silo before dumping it. This could be done easily by dumping the ensiled fish from the oil drum silo on to a screen rack or smooth solid surface for inspection. Small shovels could then be used to transfer the wholesome product to the drum dryer.

Drying of Fish Meal

At this point in the production sequence, all raw material types were handled similarly. The sequence to be followed in drying fish raw product under conditions of solar heat only and clear sky conditions is described as follows.

Specific hour references will be used for the purpose of time reference.

One hundred pounds of pressed cake or silage were placed in the drum portion and tumbled while exposed to the warm air flow for a period of two hours. The partially dry product was removed at 10:00 AM and placed on the upper rack inside the dryer cabinet. The second batch of two hundred pounds of pressed fish material was placed in the empty dru. At 12:00 noon the top rack containing the first batch was lowered one shelf. The partially dry product from the drum was then removed and placed on the vacated upper rack. The third batch of the day was then placed in the drum. AT 2:00 PM a similar repositioning of racks occured and an optional forth batch of cooked fish could be added. The machine was allowed

to remain thus until it was turned off at 6:00 PM. The following morning at 6:00 AM the dryer was started and run for a period of two hours. At 8:00 AM the fish product in the cabinet portion was dropped one level, and the drum contents placed on the upper shelf. A freshly cooked batch of fish product was added to the drum. At 10:00 AM the first batch of dry fish begun the previous day was removed from the dryer, all racks were lowered one level, the product was removed from the drum and a new load was added. This sequence of four 45.4 kg (100 lbs) loads added per day proceeded satisfactorly with only the input of solar energy provided the days were clear. Intermitent cloud cover, brief showers or mechanical failure delayed drying and thus slowed the turn-over of dry fish meal. When cloud cover limited heat input or brief rains slowed drying, the procedure was altered in one of two ways. The affected fish material could be dried for an additional day or the addition of heat from the supplementary derosene burner could be utilized to make up for the poor drying conditions. Under conditions of humidity approaching 100%, partially dry produce could not be left in the dryer over night without deterioration.

Cooling of Coarse Dry Fish Meal

The fish product removed from the cabinet portion of the drying operation was in the form of course chunks of dried flesh imbedded with small sharp bones, fish scales and larger dry bones free of flesh (Figure 28). The product was removed from the dryer at 8.3 - 11.1^{o} C (15-20^{o} F) above ambient temperature and placed on elevated screen racks at a maximum depth of 3.8 cm (1.5") on a large sheet of plastic

spread at a maximum depth of 1.9 cm (0.75") for a period of three hours. This procedure was required before further processing to minimize the effects of spontaneous heating.

Grinding of Course Fish Meal

The coarse fish meal (Figure 29) including bones was ground in a hammer mill such that the particles passed through a #10 U.S. Standard seive. Care was taken in milling so that high heat was not generated by over-loading of the grinder. The product was bagged in clean, dry, synthetic woven feed bags of 45.35 kg (100 lbs) capacity. The filled bags were left free standing for a period of 24 hours before being stacked on elevated pallets at a maximum depth of three sacks until used.

Evaluation of Finished Product

Chemical Analysis of Fish Products

Samples of 500 grams of raw chopped fish or crustacean parts were randomly collected, placed in heat sealable plastic sample pouches and frozen until transport to the laboratory.

Dry matter determinations of partially dried fish products for use in dryer evaluation were made immediately. One hundred gram samples were taken at two hourly intervals and at the conclusion of the drying sequence. Drying of the samples was by means of an improvised drying oven maintained at 105^{o} C. Samples were cooled in a desicator and weighed on a triple beam balance.

Proximate analyses of all samples of raw and dried fish product was obtained from the Government of Belize Agricultural Chemistry

Figure 29. Coarse dried fish meal.

Laboratory or the Department of Animal Science, Nutrition Laboratory Michigan State University. Dry matter analyses of all samples were obtained using the A.O.A.C. method (A.O.A.C. 1975).

Nitrogen was determined by the semimicro Kjeldhl method. Ether extract was determined using a Goldfisch apparatus. Crude fiber was determined by the A.O.A.C. method (A.O.A.C. 1980). Ash was determined by difference after ignition.

Micro-mineral analyses of the fish meals used in the feeding trial were made at the Agricultural Chemistry Laboratory, Central Farm, Cayo Belize. Analysis of manganese, zinc, iron, magnesium and copper were made with flame atomic absorbtion methods, and potassium with atomic emission methods.

Microbial Analysis

Microbial Analysis of the Fish Products

Microbial analysis of cooked, uncooked and ensiled fish products was conducted by Dr. Mel Yokohama at the Animal Science Microbiological Laboratory, Michigan State University. Materials and procedures used in this analysis are presented in Appendix C.

Analysis of pH

The pH analyses of the fish products at the Animal Science Microbiological Laboratory were made with a pH meter.

Analyses of silage treatments at the project site were made with pH test strips in the range pH 3-5 and 4-7. Procedures for this test were to place the strips in the moist silage for a period of two minutes, then compare them to a color chart.

Broiler Feeding Trial

In order to compare the nutritional value of low heat processed fish meal (Belize fish meal) to commercially available fish meal, a feeding trial with broilers was conducted and run at Central Farm, Agricultural Station, Belize, Central America.

Trial Diets

Diets were formulated to compare the two types of fish meal at varying levels in the diets, providing NRC recommended total protein levels and sub-NRC protein levels. A three-way factorial design (level of supplementation x type of fish meal x total protein level) of treatment diets was established with corn/soy diets at the two total protein levels served as controls. The experimental diets are listed in Table 10.

The nutrient composition of the major diet components is presented in Table 11. Formulations of broiler starter diets of the NRC protein level series and the sub-NRC protein level series are presented in Tables 12 and 13, respectively. Formulations of the NRC protein and sub-NRC protein level finisher diets are presented in Table 14. Calculated nutrient concentrations of the broiler starter diets of the two protein level series are presented in Tables 15 and 16. Table 17 lists the calculated nutrient concentrations of the two finisher diets.

Supplementation levels of fish meal protein were 75%, 50% or 25% of the total protein supplied to the diet as a protein supplement for the NRC recommended protein level diets. Supplemental levels of fish meal in the sub-NRC levels are also referred to as

TABLE 10

DESCRIPTION OF RATIONS

Code		
111	Commercial fish meal at 75% supplementation	NRC Protein Level
121	Belize fish meal at 75% supplementation	NRC Protein Level
211	Commercial fish meal at 50% supplementation	NRC Protein Level
221	Belize fish meal at 50% supplementation	NRC Protein Level
311	Commercial fish meal at 25% supplementation	NRC Protein Level
321	Belize fish meal at 25% supplementation	NRC Protein Level
401	Corn/soy 0% Fishmeal	NRC Protein Level
112	Commercial fish meal at 75% supplementation level #1	Sub-NRC Protein Level
122	Belize fish meal at 75% supplementation level #1	Sub-NRC Protein Level
212	Commercial fish meal at 50% supplementation level #2	Sub-NRC Protein Level
222	Belize fish meal at 50% supplementation level #2	Sub-NRC Protein Level
312	Commercial fish meal at 25% supplementation level #3	Sub-NRC Protein Level
322	Belize fish meal at 25% supplementation level #3	Sub-NRC Protein Level
402	Corn/soy 0% fish meal	Sub-NRC Protein Level

TABLE 11

NUTRIENT COMPOSITION OF MAJOR RATION COMPONENTS[b] (DRY BASIS)

Nutrient	Ingredients			
	Belize fish meal	Commercial fish meal	Soybean meal	Yellow corn (Belize)
Dry matter, %	88.5	91.4	90.0	86.0
Crude protein, %	56.6	64.8	44.0	8.0
Lysine, %	4.95[a]	4.83	3.0	.24
Methionine, %	1.9[a]	1.8	.65	.20
Cystine, %	.6[a]	.6	.67	.20
Sulfur amino acids, %	2.5[a]	2.4	1.32	.38
Tryptophan, %	.68[a]	.68	.63	.09
Crude fiber, %	4.00	3.50	6.10	1.3
Ether extract, %	7.60	8.20	.80	3.5
Ash, %	2.50	2.10	.62	1.6
Calcium, %	7.50	7.80	.25	0.02
Phosphorus, %	2.50	2.27	.15	.1
CA/P ratio	3.00	3.44	1.67	.2
Maganese, ppm	30	37	29	5
Zinc, ppm	143	79	27	10
Iron, ppm	244	243	120	35
Sodium, %	.40	.47	.34	.02
Magnesium, %	.19	.16	.27	.12
Copper, ppm	7	15	36	3.4
Potassium, %	.40	.73	2.00	.30
ME, kcal/kg	2000*	2230*	3090	3325

[a]Estimated amino acid composition of Belize fish meal.

[b]Analyses supplied by Belize Agricultural Chemistry Laboratory Central Farm, Belize.

TABLE 12

FORMULATION OF BROILER STARTER DIETS
(NRC Protein Level)

Ingredient	Composition, %						
	Percent fish meal protein of total supplemental protein						
	75%		50%		25%		0
Commercial fish meal	16.0	--	10.5	--	5.5	--	--
Belize fish meal	--	18.5	--	12.25	--	6.25	--
Soybean meal	8.0	8.0	15.5	15.75	24.25	24.75	33.0
Corn	74.5	72.0	72.5	70.5	68.75	67.5	65.5
Vitamin premix	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Mineral premix	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Salt	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Amprolium	2.025	0.025	0.025	0.025	0.025	0.025	0.025

TABLE 13

FORMULATION OF BROILER STARTER DIETS
(Sub-NRC Protein Level)

Ingredient	Composition %						
	Percent fish meal protein in total supplemental protein						
	75%		50%		25%		0
Commercial fish meal	16.0	--	10.5	--	5.5	--	--
Belize fish meal	--	18.5	--	12.25	--	6.25	--
Soybean meal	3.0	3.0	10.5	10.75	19.25	19.75	28.0
Corn	79.5	77.0	77.5	75.5	73.75	72.5	70.5
Vitamin premix	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Mineral premix	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Salt	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Amprolium	0.025	0.025	0.025	0.025	0.025	0.025	0.027

TABLE 14

FORMULATION OF BROILER FINISHER DIETS

Ingredient	Composition, %	
	NRC protein level	Sub-NRC protein level
Commercial fish meal	--	--
Belize fish meal	--	--
Soybean meal	24.5	19.5
Corn	74.0	79
Vitamin premix	0.5	0.5
Mineral premix	0.5	0.5
Salt	0.5	0.5

TABLE 15

CALCULATED NUTIENT CONCENTRATIONS IN BROILER STARTER DIETS
(NRC-PROTEIN LEVEL)

Nutrient	Composition % Percent Fish Meal Protein in Total Supplemental Protein						
	75		50		25		0
	CFM[a]	BFM[b]	CFM[a]	BRM[b]	CFM[a]	BFM[b]	Control
Crude protein, %	20.00	21.1	20.40	20.70	21.10	21.00	21.30
Lysine, %	1.27	1.39	1.20	1.29	1.18	1.27	1.15
Methionine, %	.49	.53	.44	.46	.39	.41	.35
Cystine, %	.34	.36	.33	.35	.34	.35	.34
Sulfur amino acids, %	.83	.89	.77	.81	.73	.76	.69
Tryptophan, %	.21	.23	.23	.24	.25	.25	.27
Crude fiber, %	1.30	1.40	1.80	2.10	2.10	1.90	1.90
Ether extract, %	3.80	3.90	3.60	3.60	2.40	2.30	2.70
Ash, %	6.00	6.00	4.40	53.0	4.10	4.50	3.20
Calcium, %	1.70	2.00	1.20	1.30	.93	1.10	.50
Phosphorus, %	.59	.67	.50	.53	.41	.44	.32
Ca/P ratio	2.88	2.98	2.4	2.45	2.27	2.50	1.56
Manganese, ppm	77	80	63	70	73	57	57
Zinc, ppm	86	103	94	91	91	89	86
Iron, ppm	157	380	147	283	193	273	103
Sodium, %	.31	.17	.36	.14	.27	.28	.16
Magnesium, %	.14	.14	.14	.16	.16	.14	.16
Copper, ppm	11	23	24	22	16	14	15
Potassium, %	.40	.40	.47	.50	1.00	1.00	1.13
ME, kcal/kg							

[a]Commercial fish meal.

[b]Belize fish meal.

TABLE 16

NUTRIENT CONTENTS OF BROILER STARTER DIETS
(SUB-NRC PROTEIN LEVELS)

Nutrient	Composition % Percent Fish Meal Protein in Total Supplemental Protein						
	75		50		25		0
	CFM[a]	BFM[b]	CFM[a]	BFM[b]	CFM[a]	BFM[b]	Control
Crude protein, %	18.10	18.10	18.5	18.9	17.8	20.2	19.5
Lysine, %	1.13	1.26	1.06	1.15	1.05	1.10	1.01
Methionine, %	.47	.51	.41	.44	.37	.39	.38
Cystine, %	.31	.33	.31	.32	.31	.32	.32
Sulfur amino acids %	.78	.84	.72	.76	.68	.71	.70
Tryptophan, %	.19	.20	.20	.21	.22	.23	.24
Crude fiber, %	1.80	1.90	1.50	2.60	1.80	1.80	1.90
Ether extract, %	3.40	3.80	3.50	3.80	3.40	3.80	3.20
Ash, %	5.30	6.0	4.50	5.40	3.7	4.10	2.80
Calcium, %	1.60	2.30	1.50	1.60	.90	1.10	.40
Phosphorus, %	.56	.61	.47	.38	.53	.44	.24
CA/P ratio	2.86	3.77	3.19	4.21	1.70	2.50	1.67
Manganese, PPM	103	60	73	70	67	57	90
Zinc, PPM	101	90	87	74	100	76	74
Iron, PPM	193	333	137	93	310	157	107
Sodium, %	.31	.24	.31	.21	.23	.19	.15
Magnesium, %	.16	.11	.11	.11	.12	.11	.13
Copper, ppm	16	9	7	13	13	19	14
Potassium, %	.60	.50	.67	.67	.46	.73	.80
ME, kcal/lb							

[a]Commercial fish meal

[b]Belize fish meal

TABLE 17

CALCULATED NUTRIENT CONTENTS OF BROILER FINISHER DIETS

Nutrient	Composition, %	
	NRC protein level	Sub-NRC protein level
Crude protein, %	16.00	13.80
Lysine, %	.91	.76
Methionine, %	.31	.29
Cystine, %	.30	.27
Sulfur amino acids, %	.61	.56
Tryptophan, %	.22	.14
Crude fiber, %	1.30	1.20
Ether extract, %	2.90	3.40
Ash, %	6.20	4.30
Calcium, %	.20	.20
Phosphorus, %	.43	.65
CA/P ratio, %	.46	.31
Manganese, ppm	105	45
Zinc, ppm	90	78
Iron, ppm	135	115
Sodium, %	.18	.20
Magnesium, %	.16	.13
Copper, ppm	33	36
Potassium, %	1.8	1.1
ME, kcal/kg		

Figure 30. Broiler House, Central Farm, Cayo, Belize

The chicks were also weighed individually on the 14th, 21st, 28th, 42nd and 56th day of the trial, with feed consumption recorded for each weigh period. Starter diets were fed the first 28 days of the trial; finisher diets were fed the final 28 days.

Statistical Procedures

Three-way factorial analysis of variance was used to analyze the treatments means of individual bird weights and pen means of feed consumption and feed conversion at four and eight weeks. The mean square error developed in this analysis was used for the remaining analysis of these data.

Orthogonal polynomial contrasts, as described by Gill (1978), were used to analyze the response to the levels of supplementation of fish meal. Treatment numbers the average number of birds per treatment in the case of bird weights, and two for the two replicate pens in the case of feed consumption and feed conversion.

Analysis of comparisons of selected treatment means was made with a procedure involving Bonferroni T statistics (Miller 1966).

RESULTS

Solar Collectors

Energy out-put of the coupled solar collectors tilted at 40^{o} or 20^{o} from horizontal is presented in Table 18. Peak energy out-put occurred between 12:00 noon and 1:00 pm and was 589,745 and 740,821 Joules per minute for the unit tilted at 40^{o} or 20^{o}, respectively.

Energy out-put of the two collector designs individually when tilted to 20^{o} above horizontal is presented in Table 19 and Figure 31. At all times measured, collector number 2 (sheet metal) produced greater Joules out-put per minute than number 1 (wood). However, in Joules per kg dry air, collector number 1 was consistantly greater.

Rotary Drum Dryer

Rotary drum dryer evaluation results of four test batches of product run on clear days with cooked grouper chest are presented in Table 20. Efficiency of the dryer in terms of mositure removed over potential moisture pickup was variable, and generalizations about efficiency over time or efficiency over input temperatures can not be made. Efficiency averaged 29% over the entire drying period with a range of 19% to 50%.

The moisture levels of the product at two hour intervals during the drying sequence of the same test batches as described above are presented in Figure 32.

TABLE 18

ENERGY OUTPUT OF COLLECTORS TILTED AT
40^{o} AND 20^{o} ABOVE HORIZONTAL
ON CLEAR, BRIGHT DAYS

Time	Air volume (m^3/min)	ΔKJ/kg D.A.[a]		KJ output/min	
		40^{o}[b]	20^{o}[b]	40^{o}[b]	20^{o}[c]
8:00 am	65.1	3.72	5.12	269.5	370.7
10:00 am	65.1	6.98	7.91	505.6	573.0
12:00 noon	65.1	8.14	10.23	589.7	741.5
2:00 pm	65.1	7.44	9.54	539.2	690.9
4:00 pm	65.1	6.51	5.58	472.3	404.4
6:00 pm	65.1	.47	.47	33.6	33.6

[a]Change in Joules per kg of dry air.

[b]Values taken May 10, 1980.

[c]Values taken May 11, 1980.

TABLE 19

ENERGY OUTPUT OF INDIVIDUAL COLLECTORS
TILTED AT 20° ABOVE HORIZONTAL
ON CLEAR DAYS

Collector time	Air volume (m^3/min)	ΔKJ/kg D.A.[a]	KJ output per minute
#1 8:00 am	27.34	5.58	170.9
#2 8:00 am	37.77	4.65	195.5
#1 10:00 am	27.34	8.84	268.8
#2 10:00 am	37.77	7.21	303.0
#1 12:00 noon	27.34	10.93	332.6
#2 12:00 noon	37.77	9.77	410.5
#1 2:00 pm	27.34	10.70	325.6
#2 2:00 pm	37.77	8.61	361.6
#1 4:00 pm	27.34	6.28	191.1
#2 4:00 pm	37.77	5.12	215.0
#1 6:00 pm	27.34	.47	14.0
#2 6:00 pm	37.77	.47	19.5

[a]Change in J/kg dry air.

[b]Values derived as average of measurements during 4 sunny days in the period May 12, 1980 to May 20, 1980.

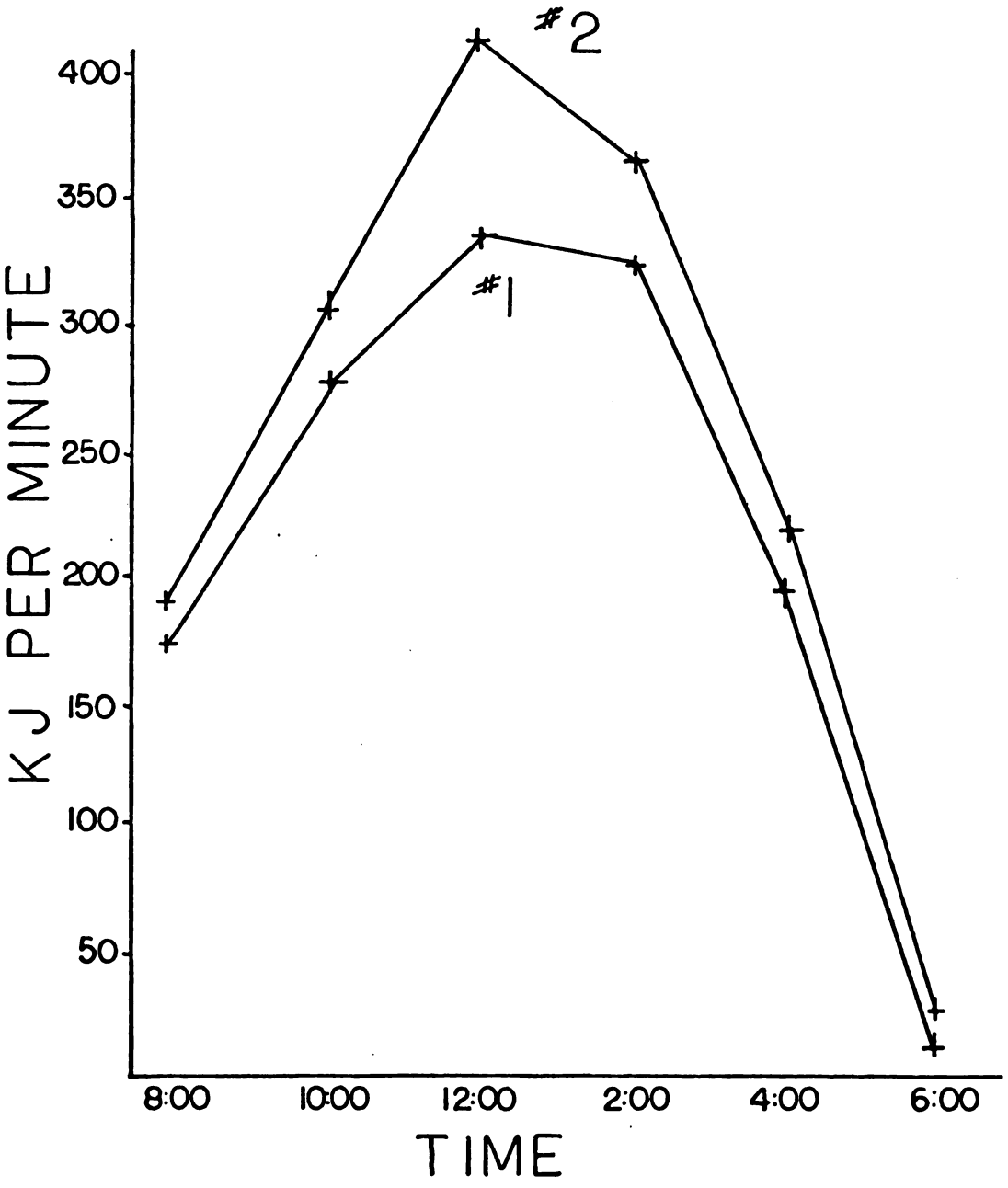

FIGURE 31. Energy out-put of individual solar collectors at 20° tilt in kilo Joules per minute.

TABLE 20

EFFICIENCY OF ROTARY DRUM DRYER

Time	Date	Ambient conditions			Input temp.		Efficiency[a]
		Dry bulb temp.		Humidity			
		°F	°C	ratio	°F	°C	%
8:00 am	6/7/79	87.0	30.6	.0210	94.1	34.5	26
	6/81/79	85.0	29.4	.0210	88.9	31.6	33
	6/5/79	86.6	30.3	.0204	93.0	33.9	31
	4/9/79	86.0	30.0	.0178	91.2	32.9	30
	6/5/79	92.3	33.5	.0230	103.9	39.9	37
10:00 am	6/5/79	90.0	32.2	.0214	99.8	37.7	35
	6/6/79	94.6	34.8	.0216	105.2	40.7	26
12:00 noon	6/7/79	92.9	33.8	.0216	106.3	41.3	50
	6/8/79	83.0	28.3	.0210	104.6	40.3	39
	6/5/79	90.9	32.7	.0210	103.4	39.7	22
	6/6/79	91.4	33.0	.0226	106.4	41.3	25
	4/9/79	89.9	32.2	.0186	104.8	40.4	24
2:00 pm	6/7/79	90.0	32.2	.0218	102.1	38.9	30
	6/8/79	89.4	31.9	.0218	102.2	39.0	34
	6/5/79	90.1	32.3	.0226	104.6	40.3	19
	4/9/79	86.4	30.2	.0188	103.2	39.6	29
4:00 pm	6/7/79	88.7	31.5	.0214	99.9	37.7	18
	6/5/79	90.4	32.4	.0212	99.0	37.2	21
	4/9/79	86.6	30.3	.0186	94.4	34.7	19
6:00 pm	6/7/79	82.6	28.1	.0194	84.6	29.2	38
	6/5/79	83.1	28.4	.0194	83.9	28.3	29
	4/9/79	81.2	27.3	.0176	81.8	27.7	29

[a] $\frac{\text{Moisture removal}}{\text{Potential moisture removal}}$

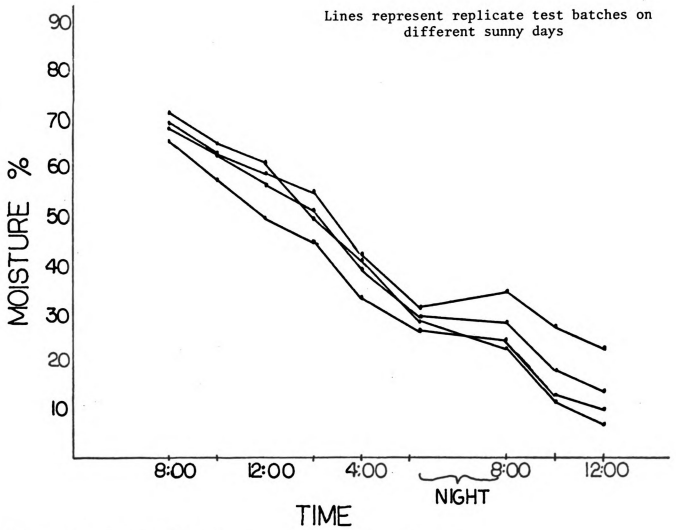

FIGURE 32. Moisture content of fish product over time in the rotary drum dryer.

Drum Cabinet Dryer

A summary of results of four drum cabinet dryer test batches with solar energy as the only heat source on clear days is presented in Table 21. Efficiency of the unit under the conditions present during the test phase averaged 44.1% with a range of 38% to 52%.

Moisture concentrations of the product initiahly and at two hour intervals through the test sequence are presented in Table 22 and graphically presented in Figure 33.

Results of evaluation of the drum cabinet drying system with the addition of heat from the kerosene burner are presented in Table 23. Ambient conditions, solar collector and kerosene supplemental burner contribution in Joules and as a percent of total added energy are also presented. The efficiency of moisture removal averaged 22% with a range of 19% to 28%. The solar heat contribution to the system in percent of total heat supplied ranged from the mid-twenties in the late afternoon to nearly 50% at 2:00 pm.

Cost Analysis of Production of Fish Meal Operating Costs

Analysis of the operating costs as encountered in the production of fish meal from shrimp boat waste using the described operating scheme of cooking and drying in the drum cabinet dryer is summarized in Table 24.

A summary of operating costs incurred in drying a batch (180 kg) of ensiled fish product is presented in Table 26.

When supplemented heat is required additional expenses for fuel and electricity are required. The cost of supplemental heat on an hourly basis is presented in Table 27.

TABLE 21

EFFICIENCY OF DRUM CABINET DRYER
WITH SOLAR ENERGY ONLY

Time	Date	Ambient conditions			Input temp.		Efficiency[a]
		Dry bulb temp.		Humidity ratio	°F	°C	%
8:00 am	8/1/80	89.9	32.2	.0208	98.5	36.9	48
	8/3/80	88.8	31.6	.0206	97.8	36.6	42
	8/5/80	85.6	29.8	.0214	96.2	35.7	47
	8/8/80	86.4	30.2	.0220	96.9	35.9	50
10:00 am	8/1/80	92.4	33.6	.0210	105.0	40.1	39
	8/3/80	91.6	33.1	.0208	103.6	39.7	40
	8/5/80	89.2	31.7	.0218	103.2	39.6	50
	8/8/80	90.4	32.4	.0222	103.8	39.9	48
12:00 noon	8/1/80	93.8	34.3	.0212	110.2	43.4	52
	8/3/80	93/2	34.0	.0210	109.8	43.2	44
	8/5/80	91.4	33.0	.0220	108.8	42.7	39
	8/8/80	92.6	32.4	.0218	108.2	42.3	44
2:00 pm	8/1/80	92.8	33.7	.0208	107.8	42.1	52
	8/3/80	91.9	33.3	.0210	107.6	42.0	47
	8/5/80	90.8	32.7	.0218	106.6	41.4	46
	8/8/80	91.4	33.0	.0216	107.2	41.8	42
4:00 pm	8/1/80	90.2	32.3	.0204	99.8	37.7	48
	8/3/80	89.1	31.7	.0208	99.6	37.6	38
	8/5/80	87.3	30.7	.0214	99.0	37.2	39
	8/8/80	89.0	31.7	.0212	97.2	36.2	41
6:00 pm	8/1/80	83.4	28.6	.0194	84.8	29.3	40
	8/3/80	83.0	28.3	.0202	84.2	29.0	46
	8/5/80	82.1	27.8	.0214	82.8	28.2	38
	8/8/80	83.2	28.4	.0208	84.0	28.9	39

[a] $\frac{\text{Moisture removal}}{\text{Potential moisture removal}}$

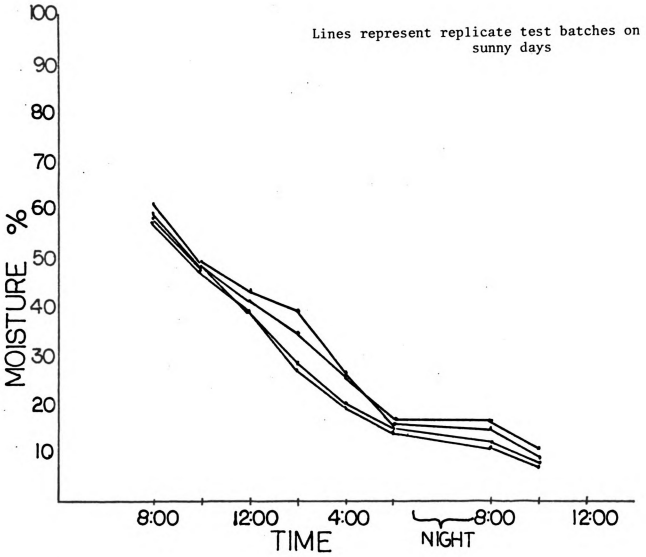

FIGURE 33. Mositure content of fish product over time in the drum/cabinet dryer.

TABLE 22

MOISTURE CONTENT OF FISH PRODUCT DURING
DRUM CABINET DRYING EVALUATION
(% Moisture)

Date	Type of Product	TIME 8:00	10:00	12:00	2:00	4:00	6:00	8:00	10:00
8-1-80	Shrimp Boat Waste	60.9	49.2	42.8	38.8	26.0	15.8	14.2	8.8
8-3-80	Shrimp Boat Waste	58.5	48.0	41.2	34.1	25.8	16.2	16.0	10.1
8-5-80	Shrimp Boat Waste	57.0	48.0	38.1	28.0	20.1	14.2	11.8	6.8
8-8-80	Shrimp Boat Waste	57.9	48.5	38.5	26.5	19.8	14.0	11.8	7.8

TABLE 23

EFFICIENCY OF DRUM CABINET DRYER WITH SUPPLEMENTAL HEAT SOURCE

		Ambient conditions				Solar contribution		Supplement contribution		Total added heat	Input air conditions			Efficiency[a]
Time	Date	Temperature °F	Temperature °C	KJ/kg da	Humidity ratio	KJ	% of supplement	KJ	% of total	KJ	Temperature °F	Temperature °C	KJ	%
10:00 am	8/6/80	89.8	32.1	101.9	.0204	3.69	38.9	5.80	61.1	9.49	132.4	55.8	55.7	25
10:00 am	8/10/80	88.6	31.4	104.7	.0212	3.59	40.5	5.28	59.5	8.86	128.8	53.8	56.3	28
2:00 pm	8/6/80	90.6	32.6	104.2	.0210	4.43	43.7	5.69	56.3	10.12	138.2	59.0	57.4	22
2:00 pm	8/10/80	90.2	32.3	105.2	.0214	4.43	48.9	4.64	51.1	9.08	134.8	57.1	56.7	19
4:00 pm	8/6/80	87.8	31.0	104.1	93.0208	2.53	27.3	6.75	72.7	9.28	132.0	55.6	56.5	20
4:00 pm	8/10/80	87.2	30.7	102,7	98.0211	2.43	24.7	7.39	75.3	9.81	128.6	58.3	56.4	21

[a] $\frac{\text{Moisture removal}}{\text{Potential moisutre removal}}$

TABLE 24

SUMMARY OF OPERATING COSTS OF DRUM/CABINET DRYING SEQUENCE USING SOLAR ENERGY

Item	Rate (per load)	$U.S.
Raw fish product	180 kg at $.033/kg	$5.94
Labor	4.5 hrs at $100/hr	4.50
Electricity	19.5 Kilowatt hr at $0.15/Kh	2.93
Fire wood	10 kgs dry wood at $0.11/kg	1.10
Maintenance grease, oil, fan belt		.13
Total estimated operating expenses		$14.60
Estimated operating cost/kg		$ 0.29

TABLE 25

ESTIMATED COST OF PRODUCTION OF 400 LBS ENSILED FISH

Item	Rate	Cost $U.S.
Raw fish product	180 kg at $0.033/kg	$5.94
Molasses	18 kg at 0.055/kg	9.99
Spoilage	5%	0.34
Total cost		$7.27
Cost/kg		$ .04

TABLE 26

SUMMARY OF OPERATING COSTS
OF THE DRUM/CABINET DRYING SEQUENCE
USING ENSILED FISH AND SOLAR HEAT ONLY

Item	Rate (per batch)	Cost $U.S.
Ensiled fish	180 kg	$7.27
Labor	4.5 hrs at $1.00/hr	3.50
Electricity	20.0 Kilowatt hrs at $0.15/Kwh	3.00
Maintenance		.25
Total estimated costs		$14.02
Estimated operating cost per kilo finished product		$ 0.25

TABLE 27

ESTIMATED OPERATING COST OF SUPPLEMENTAL
HEAT TO DRUM CABINET DRYER PER
HOUR OF OPERATION ($BH)

Item	Rate (per batch)	Cost $U.S.
Kerosene or Diesel fuel	3.29 liter at $0.40/liter 3.60 liter at $0.36/liter	$1.32 1.30
Electricity	.5 Kwh at 0.15/Kwh	.08
Total cost		$1.40 or $1.38
Cost/kg/hr if 180 kg batch is dried		$0.008

Expected Income

The expected production of fish meal from 180 kgs of shrimp boat waste (24.9% DM) as represented in the cost analysis is 49,66 kg. This product at an average world price of $0,55/kg is worth $27.31. If 180 kgs of ensiled fish (28% D.M.) are used in the dryer, batch production is expected to be 55.88 kg of silage fish meal. This silage fish meal has a value of $0.35/kg (prorated from the value of fish meal accounting for the molasses content and value) has a total value of $21.79.

The estimated net profit excluding capital costs, marketing and machinery depreciation under conditions of solar drying are $12.71 when fish is direct dried or $7.77 if the product was made from ensiled fish. When supplemental heat is utilized to dry the product the operating margin will be lo wered $1.40 in the case of kerosene fuel or $1.38 in the case of diesel fuel. However, it must be kept in mind that if not for the use of supplemental heat the entire product may have spoiled resulting in lost opportunity cost, increased labor to clean the machinery and loss of dryer time.

Chemical Analysis of Fish Products

Raw Material Sources

Proximate analyses and calcium and phosphorus concentrations in raw product sources are presented in Table 28. Values are presented on an as is basis.

Dried Fish Meal

Proximate analyses and calcium and phosphorus concentrations in dried fish meal samples are presented in Table 29. Values are presented on an

TABLE 28

PROXIMATE ANALYSIS[a], CALCIUM AND PHOSPHORUS
OF RAW MATERIAL SOURCES
% (as is basis)

Material	Dry Matter	Crude Protein	Ash	Ether Extract	Crude Fiber	Calcium	Phosphorus
Grouper Filet Waste	34.7	20.8	10.7	3.8	0.14	1.37	1.43
Grouper Chest	27.1	21.2	5.7	1.4	.19	.79	1.56
Whole Grouper	23.2	17.5	4.1	3.5	.17	1.20	1.43
Boney Fish	25.1	17.7	4.5	3.1	.13	.60	1.08
Jack Gill & Guts	23.4	17.2	4.6	1.1	0.07	.52	.55
Shad	24.3	15.1	3.6	5.7	1.7	.73	.30
Shrimp Heads & Shells	30.1	13.8	5.3	7.7	1.6	.48	.26
Lobster Heads	32.5	9.1	7.2	.84	4.29	.20	.57
Shrimp Boat Waste	24.3	13.8	3.2	1.8	.97	1.82	.61
Silage (Grouper Chest)	31.9	19.38	5.3	1.3	.16	.71	1.40

[a]Obtained from Agricultural Chemistry Lab, Central Farm, Cayo, Belize

TABLE 29

PROXIMATE ANALYSIS CALCIUM AND PHOSPHORUS
OF DRIED MEALS
% (as is basis) dry basis

Meal Type	Dry Matter	Crude Protein	Ash	Ether Extract	Crude Fiber	Calcium	Phosphorus
Group Fillet Waste[a]	90.1	(54.0) 59.8	(16.8) 18.7	(9.4) 10.4	(0.44) 0.48	(3.56) 3.95	(3.68) 4.08
Grouper Chest[b]	89.0	(69.6) 78.2	(14.5) 16.3	(4.6) 5.2	(0.67) 0.75	(2.62) 2.94	(4.46) 5.01
Whole Grouper[a]	89.8	(67.7) 75.4	(13.0) 14.5	(13.3) 14.8	(0.66) 0.73	(4.60) 5.12	(5.43) 6.05
Boney Fish[a]	88.4	(61.7) 69.8	(15.7) 17.8	(11.1) 12.6	(0.46) 0.52	(2.22) 2.51	(3.73) 4122
Jack (Gills & Guts)[a]	87.8	(63.6) 72.4	(17.0) 19.4	(4.1) 4.7	(0.33) 0.38	(2.14) 2.44	(2.35) 2.68
Shad Meal[b]	91.5	(56.9) 62.2	(13.9) 15.2	(9.6) 10.5	(6.42) 7.02	(2.75) 3.00	(1.67) 1.82
Shrimp Head Meal[b]	87.3	(40.1) 45.9[c]	(15.4) 17.6	(3.6) 4.2	(4.64) 5.32	(6.18) 7.08	(1.50) 1.72
Lobster Head Meal[b]	85.6	(23.8) 27.9[c]	(19.7) 22.8	(1.8) 2.1	(9.3) 10.7	(11.3) 13.2	(.54) .63
Shrimp Boat Waste Meal[a]		(50.1) 56.6	(11.3) 12.8	(6.7) 7.6	(3.5) 4.0	(6.6) 7.5	(2.2) 2.5
Silage Meal[a]	91.8	(56.0) 61.0	(13.1) 14.3	(3.8) 4.1	(.46) .50	(2.25) 2.45	(3.79) 4.13

[a]Analysis obtained from Agricultural Chemistry Labs., Central Farm Cayo, Belize

[b]Analysis obtained from Animal Science Nutrition Laboratory, Michigan State University

[c]Significant amounts of chitin

as is basis as well as a dry matter basis.

Fish Meals Used in Feeding Trial

Proximate and mineral analyses of the test fish meals used in the feeding trial are presented in Table 30.

Broiler Trials

Live Weight

The effects of treatments on four and eight week live weight are presented in Table 31 and Figures 34 and 35.

Belize vs Commercial Fish Meal

The average live weight at four weeks of age was significantly ($P<.01$) greater for birds fed Belize fish meal containing rations (799 g) than for birds fed diets containing commercial fish meal (786 g). The effect of fish meal type was not significant on eight-week final weights.

Fish Meal Supplementation Level

Birds fed fish meal containing diets had greater live weights at four and eight weeks when it was increased from 0 to 25% of supplemental protein but resulted in a decrease in live weight when included at 50 to 75% supplementation in all treatment combination except one.

This exception occured in diets containing commercial fish meal at NRC-protein level. Maximum live weight response (850 g) at four weeks over all the diets tested occured with the Belize fish meal diets at 25% supplementation and NRC protein levels. The maximum liveweight response (840 g) to diets containing commercial fish meal was found with 75% supplementation and NRC protein levels. The maximum bird live weight

TABLE 30

PROXIMATE AND MINERAL ANALYSIS[a]
OF FISH MEALS USED IN THE FEEDING TRIALS
(as is basis (dry matter basis))

Nutrient	Fish Meal	
	Commercial Fishmeal (Menhaden)	Belize Fish Meal
Dry Matter %	91.4 (100)	88.5 (100)
Crude Protein %	64.8 (70.9)	56.6 (64.0)
Ash %	2.1 (2.3)	2.5 (2.8)
Ether Extract %	8.2 (9.0)	7.6 (8.6)
Crude Fiber %	3.5 (3.8)	4.0 (4.5)
Calcium %	7.8 (8.5)	7.5 (8.5)
Phosphorus %	2.3 (2.5)	2.5 (2.8)
Manganese ppm	37 (40)	30 (34.0)
Zinc ppm	79 (86)	143 (162)
Iron ppm	243 (265)	244 (276)
Sodium %	.47(.51)	.40 (.45)
Magnesium %	.16(.18)	.19 (.21)
Copper ppm	15(16)	7 (7.9)
Potassium %	.40(.44)	.73 (.82)

Obtained from the Agricultural Chemistry Lab, Central Farm, Cayo Belize

TABLE 31

4 and 8 WEEK LIVEWEIGHT TREATMENT MEANS
(grams)

Protein supplementation Level	Type	NRC protein level 4 wk/wt	NRC protein level 8 wk/wt	Sub-NRC protein level 4 wk/wt	Sub-NRC protein level 8 wk/wt
75%	Commercial	840	2,060	660	1,940
75%	Belize	754	1,800	746	2,070
50%	Commercial	799	1,970	799	2,140
50%	Belize	808	1,990	801	2,070
25%	Commercial	791	2,080	824	2,170
25%	Belize	850	2,090	835	2,120
0%	-	739	1,840	719	2,030

Standard error 4 week wt = ± 50

Standard Error 8 week wt = ± 143

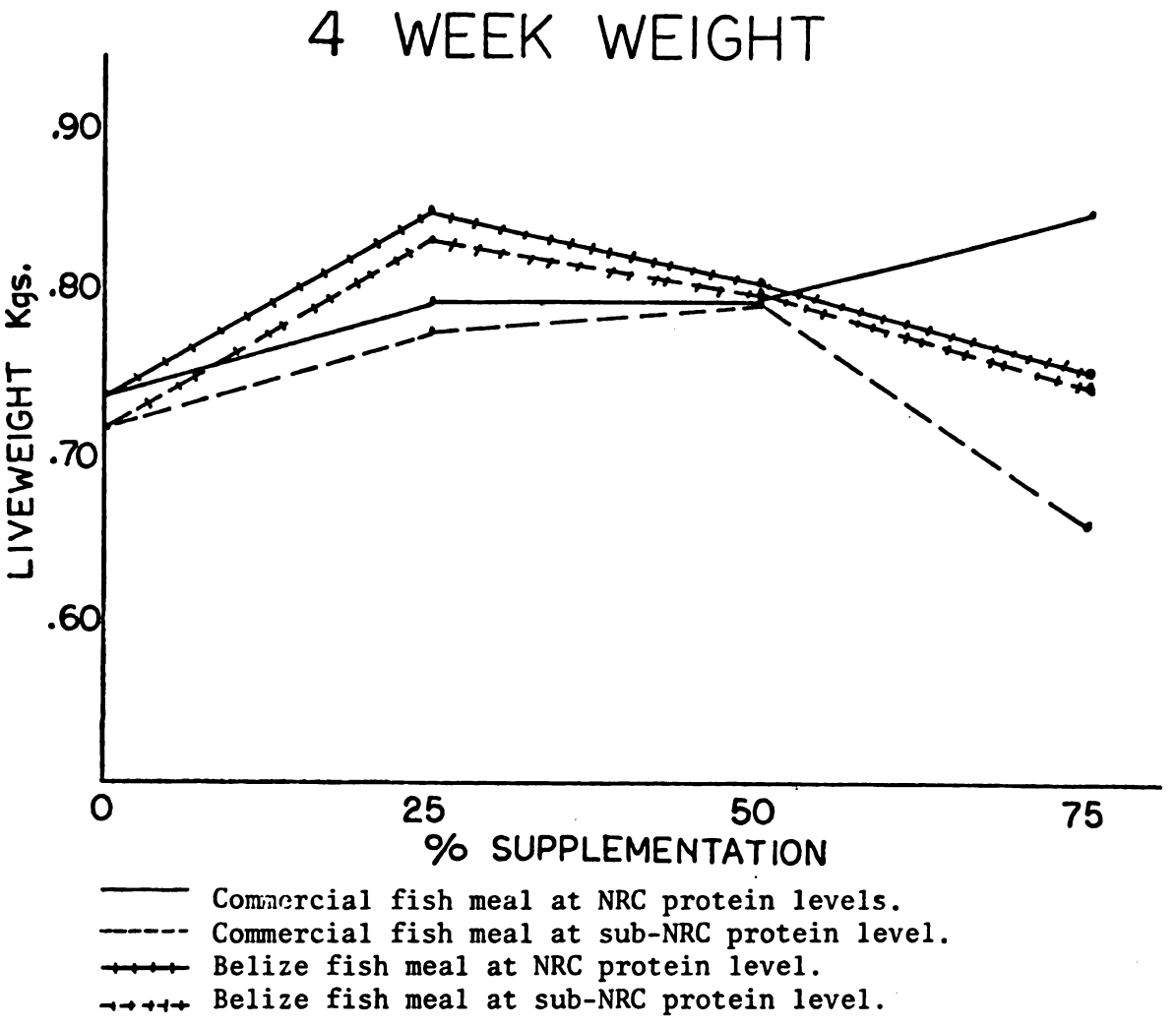

FIGURE 34. 4-week live weight response curves to level of supplementation of fish meal.

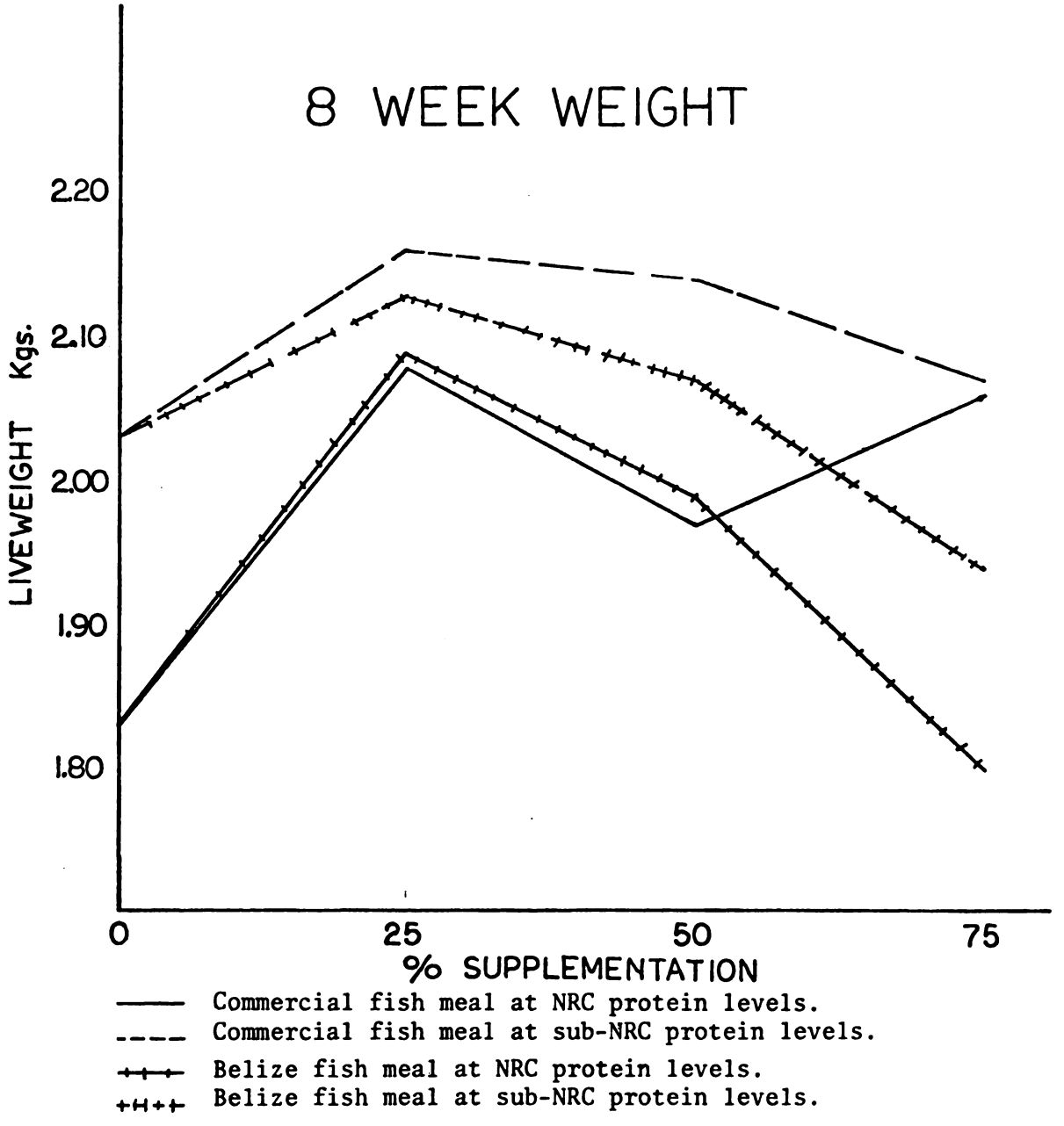

FIGURE 35. 8-week live weight response curves to levels of supplementation of fish meal.

at eight weeks occured in the 25% supplementation rations of all combinations of fish meal type and protein level. Live weights of birds at eight weeks of age ranged from 1.80 kg to 2.17 kg.

Protein Level

The four week live weights of birds fed NRC or sub-NRC protein level diets did not significantly differ at 0, 25 and 50% supplementation. A significant difference ($P<.01$) did occur between birds fed diets containing commercial fish meal at 75% supplementation at NRC (840 g) and sub-NRC protein level (660 g). Eight week live weights showed that a significant ($P<.01$) difference between NRC and sub-NRC protein levels was found only between diets of Belize fish meal at 75% supplementation. In this case the sub-NRC diets (2.07 kg) resulted in greater live weight than NRC protein level diets (1.80 kg).

Feed Consumption

Feed consumption levels of the diets tested is presented in Table 32.

Belize vs Commercial Fish Meal

The type of fish meal used in the test diets did not effect feed consumption for the 0-4 week starter period nor the 4-8 week finisher period.

Fish Meal Supplementation in Diets

The level of fish meal supplementation was found to have an effect on feed consumption. Feed consumption increased from 47.6 g to 61.8 g per bird per day for commercial fish meat at NRC protein as supplementation was increased from 0 to 75%. For birds bed Belize fish meal at

TABLE 32

0-4 and 4-8 WEEK AVERAGE DAILY FEED
PER BIRD
TREATMENT MEANS (grams)

Protein Supplementation		NRC Protein Level		Sub-NRC Protein Level	
Level	Type	4 wk/wt	8 wk/wt	4 wk/wt	8 wk/wt
75%	Commercial	61.8	125	62.0	131
75%	Belize	47.1	120	53.0	126
50%	Commercial	45.9	144	46.8	121
50%	Belize	55.1	152	49.6	139
25%	Commercial	59.2	165	48.0	133
25%	Belize	55.5	125	50.9	158
0	-	47.6	133	68.5	147

Standard error 0-4 wk A.D.F. = $\pm$ 2.91.

Standard error 4-8 wk A.D.F. = $\pm$ 13.38.

sub-NRC protein levels, consumption was decreased from 68.5 g to 53.0 g per day as supplementation was increased. Feed consumption of the commercial fish meal containing diet decreased when supplementation was increased from 0 to 25% and increased as supplementation was increased from 50 to 75%. The opposite was true of birds fed Belize fish meal containing diets as consumption increased as supplementation was increased from 0 to 25% and decreased as the fish meal was added at 50 to 75%. There was no significant effect of supplementation level found in the feed consumption of birds in the 4-8 week finisher period.

Protein Level

Protein level did not effect feed consumption for either the starter period nor the finisher period.

Feed Conversion

Feed conversion reported as units of feed per unit of gain for the 0-4 week starter period and the 4-8 week finisher period are presented in Table 33.

Belize vs Commercial Fish Meal

The type of fish meal affected feed conversion during the starter period. Feed conversion for birds on diets containing commercial fish meal was 2.13 and was 2.02 for birds containing Belize fish meal.

Fish Meal Supplementation Levels

The level of supplementation of fish meal also affected feed conversion. Feed conversion of birds fed commercial fish meal containing diets at NRC protein levels for the starter period ranged from 1.69 at the 50% supplementation level to 2.20 at the 25% supplementation level. Feed

TABLE 33

0-4 and 4-8 WEEK FEED
CONVERSION TREATMENT MEANS

Protein supplementation		NRC protein level		Sub-NRC protein level	
Level	Type	0-4 wk	4-8 wk	0-4 wk	4-8 wk
75%	Commercial	2.16	2.90	2.80	2.85
75%	Belize	1.83	3.63	2.11	2.65
50%	Commercial	1.69	3.47	1.74	2.53
50%	Belize	2.01	3.61	1.84	3.00
25%	Commercial	2.20	3.84	1.84	2.80
25%	Belize	1.93	2.73	1.82	3.34
0	---	1.84	3.40	2.77	3.20

Standard error 0-4 week feed conversion = $\pm$ .117

Standard error 4-8 week feed conversion = $\pm$ .293

conversion for the starter period for Belize fish meal fed birds did not differ however for supplementation level at NRC protein levels and averaged 1.90 with a range of 1.83 to 2.01. Supplementation level did not affect feed conversion for the finisher period.

Protein Level

The level of protein in the diet of birds during the starter period did not affect feed conversion. Feed conversion was not affected by total protein level of the diet in the finisher period and ranged from 2.73 to 3.84.

DISCUSSION

Drying Facility

Solar Collectors

The 8:00 am to 2:00 pm energy out-put of the coupled collectors at 20^{o} above horizontal was greater than that of the collectors when tilted at 40^{o} above horizontal. The greater out-put of the 40^{o} tilt angle in the hours of 4:00 pm through 6:00 pm was s function of the more advantageous angle of incidence of the solar rays with the absorbing surface during those hours. The advantage of the 40^{o} collector tilt for the later hours of the day does not warrant changing of the tilt angle during operations.

The output of BTU's per minute at 40^{o} and 20^{o} above horizontal increased with each two hour increment beginning at 8:00 am until 12:00 noon. After 12:00 noon each time increment resulted in a decrease in energy out-put.

The energy out-put values of the individual collectors at 20^{o} above horizontal show that the two collector types differ in both KJ out-put per kg of dry air and in terms of KJ per minute. Solar collector number one produced more KJ per kg of dry air at all times except 6:00 pm when very low BTU values were generated. This may be explained by the smaller air chamber size in the wooden collector allowing more intimate contact of warm air and with the absorbing surface. Another factor may be the increased air contact with the absorber caused by the wire mesh stretched above the air chamber in the path of air. The greater energy output per kg dry air could also be caused by the greater

time one kg of air was exposed to the absorbing surface as a result of the lower air velocity in the wooden collector. The insulative value of the wooden collector was much greater than that of the metal design thus, holding more heat for transfer to air as it passed. Due to the constraints of design and instrumentation available at the site during the testing phase, measurement of the extent to which each of these design components affected heat transfer was not possible. Further refinement and testing is required to maximize energy output from solar collectors of this basic design and constructed of these basic materials.

BTU out-put per minute showed, however, that the metal collector design added more total energy to the system. This was a result of the difference in volume of air sent through each unit per minute. Each pound of air passing through did not absorb as much energy in the metal collector but the greater volume caused the total out-put to be greater. It would be useful to evaluate the effect of various air velocities on the heat exchange capabilities of this system and on each component.

Performance of the Dryer

Efficiency, $\left(\frac{\text{moisture removed}}{\text{potential moisture removal}}\right)$ of this unit was low in comparison with commercially produced low heat, high volume grain dryers. However, this machine under solar heat generation alone can be inefficient and yet still be economical. The heat generated in a solar system does not have a generation, or fuel cost beyond the cost of the solar collectors and the cost of moving the air.

Secondly, a system designed to dry fish must remove great quantities of moisture in a short period of time. Units designed for drying products less prone to spoilage than fish can achieve higher efficiency by passing

heated air by larger quantities of product.

Several modifications of the existing unit could be considered to increase efficiency. More intimate contact of drying air and the fish product inside the drum would be desirable. This could be achieved by lengthening the paddles to run the full length of the drum. This would lift and drop all particles of fish more often (up to four times per rotation) thus allowing more intimate air contact. The present design allowed the lumpy fish to slide around the interior of the drum until striking a paddle, at which time it was lifted and dropped only once per revolution. Increased drum rotation to about 30 rpm should also be considered as an aid to the increase of air and product contact. The increased speed of the drum would toss the product and tend to break up chunks more than the present design. Increased power requirements for drum turning would be necessary, however.

Efficiency of the system was somewhat lower when heat was supplied by a combination of solar energy and supplemental heat than with solar alone. The design of the dryer, air flow rates and product characterics do not allow sufficient moisture removal from high temperature (53.3^{o} C - 58.8^{o} C) (128^{o} F - 138%) drying air. Modification of the drum and a speed increase in drum rotation would increase efficiency but increased insulation around the burner housing and drum would also be necessary.

Efficiency could also be increased in the cabinet section of the dryer by lowering the bottom of the cabinet and directing the air flow up through the fish product rather than across the product as is presently done. Racks of fish could be loaded from the bottom up. Drying would also proceed from the bottom rack upward and it would not be necessary to rotate the screen racks.

Mechanical Reliability of the System

The design of the drum cabinet dryer is essentially a sheet metal tube connecting collectors and drum through which warm air passes and dries the fish. With the exception of the fan blade, the blower used to charge the supplemental heat source, and the rotating drum, all other parts are stationary.

The fan assembly had no mechanical difficulties during testing operations. Lubrication of bearings and inspection of fan belt tension assured proper performance.

No problems were encountered with the supplemental heat source after balancing and adjustment of the squirrel cage blower were made.

There was difficulty with the mechanism for rotating the drum. Operations had to be halted on several occasions. The breakdown however, was a function of leakage of a bearing seal in the commercially manufactured gear reducer and not in the project developed equipment.

The air seal connecting the leeward end of the rotating drum and the stationary cabinet proved satisfactory for the entire testing period.

The use of a gear reducer at this point in the design is costly and overly complicated for the system. A simple easily maintained belt or chain drive to large diameter sprockets or pulleys may be considered. In this system the motor shaft would be parallel to the drum rotation, a system of pulleys or sprockets could be constructed and maintained locally and the drum speed could be changed.

Operating Sequence

The decision whether to store the raw fish product in ensiled form or to dry it directly was of major importance to the operation of this

unit. Direct processing required immediate cooking and pressing followed by placement in the dryer. Ensiling required chopping, mixing of molasses and a proper environment for ensiling but did allow for flexibility in raw material utilization.

Microbial evaluation of the three product types revealed unwholesome fish meal when cooking or ensiling was not used. Therefore, it is certain that one or the other systems must be used.

The pressing operation, when direct drying was used, was effective in removing only about 8% moisture from the product. Considering this machine was hand operated and the time requirement for operation was minimal, this method of decreasing moisture was highly efficient in terms of time, solar energy and maitenance of scheduling. The moisture reduction could be increased with greater pressure, however. Fish presses in commercial operations produce pressed cake with moisture levels of approximately 50%. This represents up to two hours of drying time. When greater pressures are applied to the moist fish, greater quantities of stick water are produced and its use must then be considered. Stick water contains soluble nutrients that can be used if processed properly. Development of a new product of dried fish solubles (dried stick water) would be difficult for a small scale operation.

Whole fish meal (dried fish solubles and dried press cake) has produced superior performance in weight gain and feed conversion as compared to fish meal without solubles; therefore, incorporation of the nutrients of the stick water back into the fish meal is advisable. No technique was developed incorporating the stick water nutrients back into the fish meal due to the relatively small volume of stick water produced.

Future development of this technique will be necessary if greater press pressures, producing greater amounts of stick water are used.

The drying phase of the sequence could be streamlined in terms of manpower requirements. With simple modifications of the drum and cabinet, it would be possible to reduce the time required to transfer the drying product. In the sequence described, time is spent removing product from the drum, placing it on racks and then later adjusting the racks. Increasing the width of the door to the full elngth of the unit would speed product removal. Construction and reinforcement of the drum in its present design would allow such a modification. The top of the cabinet would be removable so that product from the drum could be dropped directly from the open drum doors on to the empty top rack of the cabinet. With the modified air path previously described and this loading operation, rearrangement of the racks would not be necessary and time would be saved.

Operating Economics

The cost of collection of raw fish products for use in the manufacture of fish meal is the most important cost factor in fish meal production. A price of $0.033 per kg was used in the cost analysis, but raw material cost will fluctuate with type and season. A price level of $0.033 per kg was set because a large portion of the potential raw product is discarded at the cooperative itself and thus would be aquired free for the collection. Other sources, however, would require that the fishermen delay dumping fish or fish parts until they reached a collection point where they could be paid for the raw material.

Suppmental heat and the cost of fuel also affects the economics of the operation. With clear skys and relatively dry conditions, the operation can satisfactorily proceed on solar heat alone; but in the event of poor drying conditions, the supplemental heat source must be used. Analysis of the economics of supplemental heat requires the balance of that cost against the cost of the raw material, the opportunity cost of the fish meal to be produced and the cost of complete cleaning of the dryer interior if the fish product should spoil before it is dried. Supplemental heat is insurance against a spoiled product.

The price of the fish meal product also dictates very greatly the profitability of a unit. The profit analysis presented previously sets estimated product price at $0.55 per pound which is an approximation of the world fish meal price at this time. It is unlikely that the project will produce sufficient quantities of fish meal to enter world markets and, thus, locally produced fish meal would be priced at its substitution value compared to imported protein sources. The substitution value is greater than the world price of fish meal. The product not only supplies protein to livestock rations but also reduces foreign exchange reliance. The local economy is also stimulated. This unit is profitable when world prices of fish meal are used and would be even more profitable if it were priced according to its import substitution value.

The man-hours required per day were estimated to be 4.5. This work requirement was spread over a 12 hour period. A second job could easily be organized around the time requirements, thus, the cooperator can be fully employed.

Chemical Analysis of the Fish Products

Raw Material

The raw material types encountered during this project are shown in Table 38. They can be subdivided into four basic blasses, which are whole fish, fish parts, crustatean waste and ensiled fish. Proximate analysis of the types within the whole fish classification (whole grouper, boney fish, shad and shrimp boat waste) indicate similar composition. Dry matter percentage among the types was very similar. Protein was higher in the boney fish and grouper than shrimp wastes and shad. This is possibly due to the fact that these fish were much larger although, small groupers and boney fish were not encountered. Ash was also greater in the larger fish and especially in the boney fish. Ether extract of the shad was apparently greater than in the other whole fish, however, none was extremely high.

The second classification, fish parts, was much more variable in composition, since different portions of the carcass were represented. Grouper filet waste was substantially higher in dry matter (34.7%) than guts and gills (23.4%) or grouper chest (27.1%).

Crustacean wastes (shrimp heads and shells, and lobster heads) were similar in dry matter percentage as a raw material, but differed substantially in crude protein, crude fiber, calcium and phosphorus.

Silage made from chopped grouper chests and molasses was slightly higher in dry matter than the raw product, and the nutrients were found in levels slightly below the original product.

Dried Meals

Fish meals produced from whole fish sources resulted in crude protein analyses as follows: grouper, 75.4%; boney fish, 69.8%; shad, 62.2%; and shrimp trawler waste, 56.6% on a dry matter basis. Ash was 14-15% for three of the meals but was only 11.3% for the shrimp boat waste. Crude fiber determinations for whole grouper and boney fish were less than one percent, except for shrimp trawler waste which was up to 4%, and 7% for shad. Calcium and phosphorus was variable within the class with ranges of 2.5% to 7.5% for calcium, and 1.8% to 6.0% for phosphorus.

Regardless of the variation in composition among the raw materials, it is suggested that a small scale fish meal facility not attempt to produce separate meals from each type within this class.

The fish meals produced from fish parts varied considerably in analysis among each other. The most important difference was evident in the crude protein determination. Grouper chest (solid muscle plus bone) contained 78.2% crude protein, guts and gills (highly vascular tissue and organs) contained 72.4% crude protein, while grouper filet waste contained 59.8% crude protein. Ash was higher in the grouper parts (18.7% and 21.0% compared to 17.3%) than in the original carcass. Crude fiber was less than 1% for all the types. Calcium and phosphorus were higher for the grouper parts than the guts and gills, likely due to the greater bone content.

Depending on the production levels of each product type, the fish meal produced from fish parts may or may not be incorporated with that of the whole fish. If large volumes of a single product come in with

regularity, a separate product would be feasible; however, any advantage in separate batches would be offset by small volumes.

Shrimp and lobster product meal should definitely be separated from the meals of fish origin due to the low crude protein values. Substantial portions of this protein are derived from chitin which is unavailable.

Silage meal made from grouper chests differed substantially from the fish meal prepared from grouper chest without ensiling. Crude protein levels lowered from 78.2% to 61% when the same product was ensiled. In a similar manner ash, ether extract, crude fiber, calcium and phosphorus were all greater in the meal prepared without ensiling compared to that ensiled.

Feeding Trials

Comparisons of the feeding value for broilers of commercial and Belize fish meal showed differences in gain, feed intake and feed efficiency.

When Belize fish meal was incorporated into diets, the maximum response in live weight gain at 4 weeks of age occurred at the 25% supplementation level. This was equal to the greatest gain response with commercial fish meal and was significantly ($P<.01$) greater than the control diet. Feed consumption levels with the Belize fish meal diets decreased as supplementation increased in the starter rations. Feed conversion did not significantly differ among the combinations.

Weight gain responses to commercial fish meal supplementation were linear over the levels tested, thus, no optimal level of supplementation for fish meal was estimated from these data. Feed consumption, at both NRC and sub-NRC protein levels increased as fish meal supplementation

was increased in the diets during the starter period. The opposite was true during the finisher periods. Feed conversion values for the commercial fish meal diets at NRC protein levels did not significantly differ, but at the sub-NRC level, the 50% supplementation level resulted in greater efficiency of gain than higher or lower levels.

From this work it appears that Belize fish meal, unlike commercial fish meal, should be incorporated in the diet at 25% supplementation level and at NRC protein levels. Use of these levels may yield greater bird weight, similar feed consumption and more efficient feed conversion than a corn-soy based diet.

Unlike the commercial fish meal, the Belize fish meal diets produced greatest live weight gains at the relatively low supplementation level of 25%.

CONCLUSIONS

1. Solar energy as the primary source of heat may be used to produce fish meal from fish offal and unsalable fish. However, an auxillary heat source is required.
2. Carbohydrate fish silage is an effective method of storing raw moist fish products for future use in fish meal manufacture.
3. Positive net revenue was achieved in the manufacture of fish meal with this system when estimated costs of resources at the project site during th e testing phase of the project and accepted world prices of fish meal of the same time period were used in analysis.
4. Fish meal prepared in the described system performed comparably in live weight gain, feed consumption and feed conversion with commercially available menhaden fish meal.

RECOMMENDATIONS

Based on the experience gained in operating the described fish meal production facility and the results of dryer operations, chemical analyses and feeding trials, the following recommendations for further investigation are made.

1. Modification of the cooking and pressing operation to utilize fully the soluble nutrients found in the stick water.
2. Modification of the drum cabinet dryer as described in the discussion to increase the efficiency of the dryer.
3. Long term documentation of cost and income of the facility is necessary to get a more accurate picture of the financial aspects.
4. Microbiological and toxicological tests of greater numbers of samples of fish meal prepared by the low heat method to verify wholesomeness of the fish meals.
5. Further studies to determine how the fish meal could be most efficiently utilized in rations comprised of ingredients from Belize.
6. Bioavailability determinations of the individual amino acids in fish meal prepared by the low heat method.

LIST OF REFERENCES

LIST OF REFERENCES

Asköe, R., and J. Madsen. 1954. A Chemical Test for Estimating Oily Flavors and Fishy Off Flavor in Bacon. ACTA. Agric. Scand. 4:266.

Baker, D.H., B.A. Molitoris, A.H. Jensen and B.G. Harmon. 1974. Sequence of Protein Feeding and Value of Alfalfa Meal and Fish Meal for Pregnant Gilts and Sows. Journal of Animal Science 38:325.

Bjarnason, J. and K.J. Carpenter. 1969. Mechanisms of Heat Damage in Proteins. 1. Models with Acylated Lysine Units. British Journal of Nutrition 23:859.

Bjarnason, J. and K.J. Carpenter. 1970. Mechanisms of Heat Damage in Proteins. 2. Chemical Changes in Pure Proteins. British Journal of Nutrition 24:313.

Bross, C.A.B. 1975. Optimum Use of Fish Wastes. South Africian Food Review 2(6):117.

Carpenter, K.J., D. Duckworth, I.A.M. Lucas, D. H. Shrimpton and D.M. Walker. 1956. Nutrient Interactions in Pig Nutrition. I. Factors Affecting the Response to Vitamin B_{12} in Growing Pigs. Journal of Agricultural Science 47:435.

Esmay, E., Soemangat Eriyatno and Allan Phillips. 1979. Rice Postproduction Technology in the Tropics. The University Press of Hawaii, Honolulu.

F.A.O. 1978. Year Book of Fishery Statistics - Fishery Commodities. 47:232-240. United Nations Food and Agriculture Organization, Rome.

Feed Industry Red Book. 1973. Communications Marketing, Inc. 5100 Edina Industrial Blvd. Edina Minnesota.

Foster, G.H. 1973. Heated - Air Grain Drying Grain Storage: Part of a System. Chapt. 8. The AVI Publishing Company, Inc. West Port, Conn.

Gill, J.J. 1978. Design and Analysis of Experiments in the Animal and Medical Sciences. Vol. I. The Iowa State University Press, Ames, Iowa.

Ginzberg, A.S. 1958. Grain Drying and Dryers. 3rd Edition. Khlebizdat Moscow.

Glittins, R. 1968. Fishmeal Modern Manufacturing Process. Food Manufacturing 40:41-47.

Göhl, B. 1975 Tropical Feeds: Feeds Information Summaries and Nutritive Value. Food and Agriculture Organization of the United Nations. Rome.

Hamm, W.S., C. Butler and M. H errot. 1944. Food Fish Dehydrate Well. U.S. Department of Interior Fish and Wild Life Service. Fishery Leaflet 120.

Harte, W.H. 1952. Top Quality Drying in a Flash. Food Engineering. McGraw-Hill Publishing Co., Inc. New York.

Hurrell, R.L., and K.J. Carpenter. 1974. Mechanisms of Heat Damage to Proteins. 4. The Reactive Lysine Content of Heat-Damaged Material as Measured in Different Ways. British Journal of Nutrition 32:589-604.

Jaucian, A.A., M.G. Supnet, R.B. Puyaoan and E.M. Rigor. 1969. Comparison of Fish Meal, Blood Meal and Meat and Bone Meal for Growing-Finishing Swine. Philippine Agriculturist 57:242-248.

Jenkins, R.N., R. Rose-Innes, J.R. Dunsmore, S.H. Walker, C.J. Birchal and J.S. Briggs. 1976. The Agricultural Development Potential of the Belize Valley. Land and Resources Division, Ministry of Overseas Development, Tolworth Tower Surbiton, Surrey, England KT67DY.

Johnson, D.C. and Pinedo, D. 1971. Gizzard Errosion and Ulceration in Peru Broilers. Avian Disease 15:835-37.

Jungsoyr, M., G. Boge and T. Sparre. 1953. Relation of Drying Method to Fish Meal Quality. Meldinger FRA SSF, Damsgard; Bergen, Norway 2:22.

Karrick, N. 1963. Industrial Fishery Technology. M. Stansby Editor. Reinhold Publishing Company, London.

Keenan, M. Jan 16, 1979. Personal communication. Grouper and Snapper Fillet Waste Percentages. San Pedro Ambergris Cay, Belize, Central America.

Kifer, R.R., R.J. DeSesa and M.E. Ambrose. 1969a. Nutrient Content of Menhaden (Brevooptia tyranus) Fish Meal Evaluated by Chemical Methods: Manufactured by Heat-Transfer Method. Feedstuffs 41(3):44.

Kifer, R.R., W.L. Payne and M.E. Ambrose. 1969b. Nutritive Content of Norwegian Herring Fish Meal Evaluated by Chemical Methods. Feedstuffs 41(17):18.

Kifer, R.R., W.L. Payne, D. Miller and M.E. Ambrose. 1969c. Nutritive Content of Chilean Anchovetta Fish Meal Evaluated by Chemical Methods. Feedstuffs 41(31):24.

Kifer, R.R., N.L. Karrick, W. Clegg, M.E. Stansby and M.E. Ambrose. 1969d. Nutritive Content of Tuna (mixed species) Fish Meal Evaluated by Chemical Methods. Feedstuffs 41(50):40.

Kifer, R.R., W.L. Payne, D. Miller and M.E. Ambrose. 1968. The Nutritive Content of Menhaden (Brevoortia tyranus and patronus) Fishmeal Evaluated by Chemical Methods. Feedstuffs Vol 40(20):36.

Kirsch, W. 1959. Versuche mit Soja-Extraktions-Schroten an Stelle von Fishmehl Bei der Getreideschnell-Mast von Schweinen. Futter v. Futterung 10(12):96-97.

Kirsch, W. and M. Fender. 1960. Versuche uber den Ersatz von Fischmehl Durch Soja-Extraktions-Schrote Bei der Getreideschnellmast von Schweinen. Z.f. Tierphysiol. Tierernahr. u. Futtermtlk 15(5): 257-265.

Kronache, R.C., J. Kliesch and A. Bucholtz. 1932. Deutch. Landwirtsch. Tierzucht 36:147. (Cited by Braude, 1961).

Kubena, L.F., C.R. Sadler, R.L. Haynes, T.H. Vardman and J.W. Deaton. 1976. Effect of Fish and Poultry by Product Meal on the Small Intestine and Gizzard of Broilers. Poultry Science 55:30-33.

Lakesvela, B. 1961. Graded Level of Herring Meal to Bacon Pigs, Effect on Growth Rate, Feed Efficiency and Bacon Quality. Journal of Agricultural Science 56:307.

Mathew, Nair and Ramackrishnan. 1956. A Fermentation Process for Production of Quality Fish Meal. Current Science 9:293.

Meyers, S. P., J.E. Rutledge and S.C. Sonu. 1973. Variability in Proximate Analysis of Different Processed Shrimp Meals. Feedstuffs 34:34-35.

Midwest Plan Service Structures and Environment Hand Book. 1980. Published by Midwest Plan Service, Iowa State University, Ames, Iowa.

Miller, R.G. Jr. 1966. Simultaneous Statistical Inference. McGraw-Hill Publishing Co., New York.

Myklestad, O. 1973. Physical Aspects of the Drying of Fish Meals. Journal of the Science of Food Agriculture 24(10):1209-1215.

Nesheim, M.C. and K.J. Carpenter. 1967. The Digestion of Heat Damaged Protein. British Journal of Nutrition 21:399-411.

Nunez, B. Personal communication. 1980. Shrimp Trawling Practices of Caribena Coop Members. San Pedro Ambergris Cay, Belize, Central America.

NRC. 1977. Nutriet Requirements of Domestic Animals. No. 1. Nutrient Requirements of Poultry 7th Revised Edition National Academy of Sciences. National Research Council. Washington D.C.

Osterhout, L.F., and D.G. Sny der. 1962. Effects of Processing on the Nutritive Value of Fish Products in Animal Nutrition. Fish in Nutrition. Fishing News (Books) LTO.

Palmer, W.H., H.S. Teague and A.P. Gr ifo, Jr. 1970. Effect of Whole Fish Meal on the Reproductive Performance of Swine. Journal of Animal Science 31(3):535.

Pariser, E.R. 1961 Fish Flour - Technological Developments in the U.S.A. FAO International Conference on Fish in Nutrition R/V 2/4.

Peischel, H.A., P.T.C. Costa, D.D. Lee, G.A.B. Hall, D.A. Stiles and P.E. Sanford. 1976a. Evaluation of Fish Meal and Fermentation Residues by Chick Growth. Paper presented at the 65th Annual Meeting of the Poultry Science Association Inc., Kansas State University, Manhattan Kansas, Aug 2-6, 1976.

Peischel, H.A., D.D. Lee, P.T.C. Costa, G.A.B. Hall, D.A. Stiles and P.E. Sanford. 1976b. Effect of Sorghum Grain, Corn and Fish Meal on the Performance of Laying Hens. Presented at the 65th Annual Meeting of the Poultry Science Association Incorporated. Kansas State University, Manhattan, Kansas, Aug 2-6, 1976.

Pond, W.G. and J.H. Manner. 1974. Swine Production in Temperate and Tropical Environments. W.H. Freeman and Company, San Francisco.

Power, H.E., K.A. Savaganon, B.E. March, and J. Biely. 1969. Assessment of the Nutrient Content of Atlantic Coast Herring Fish Meals. Feedstuffs 41(47):48.

Reece, P. 1981. Control and Reduction of Free Fatty Acid Concentration in Oil Recovered from Fish Silage Prepared from Sprat. Journal of Science and Food Agriculture 31(2):147-155.

Richardson, E.L. 1946. Fish Meal and Herring Meal Processing Machinery Industry and Fish Meal and Herring Meal Processing Industries. B.I.O.S. Final Report No. 1103. Items #22 and 31.

Schmidt, P.J. and Lantz, A.W. 1952. Fish Meal from Fresh Water Fish and Fish Processing wastes. Progress Reports of the Pacific Coast Stations (Canada) #93,

Smith, R.E. and H.M. Scott. 1965a. Biological Evaluation of Fish Meal Proteins as Source of Amino Acids for the Growing Chick. Poultry Science (44):394-400.

Smith, R.E. and H.M. Scott. 1965b. Measurement of the Amino Acid Content of Fish Meal Proteins by Chick Assay. 1. Estimation of Amino Acid Availability in Fish Meal Proteins Before and After Heat Treatment. Poultry Science (44):401-408.

Smith, R.E. and H.M. Scott. 1965c. Measurement of Amino Acid Content of Fish Meal Proteins by Chick Growth Assay. 2. The Effects of Amino Acid Imbalances upon Estimation of Amino Acid Availability by Chick Growth Assay. Poultry Science (44):408-413.

Sparre, T. 1953. Small Scale Manufacture of Fish Meal. F.A.O. Fisheries Bulletin 6, No. 1-2.

Stansby, M.E. 1963. Industrial Fishery Technology A Survey of Methods for Domestic Harvesting, Preservation and Processing of Fish Used for Food and Industrial Products. Reinhold Publishing Corporation, New York.

Stansby, M.E. 1973. Polyunsaturates and Fat in Fish Flesh. Journal of the American Dietetic Association 63(6):625-630.

Strormo, B. and Stroem T. 1979. Ensiling of Fish Viscera. Fishery Technology Research Report (3) 35-37. P.O. Box 1159, Tromsoe, Norway.

Thirumalai, S., Rajagopalan, G., Swaninathan, K. and Venkatakrishnan, R. 1978. Preliminary Investigations on Solid Fish Silage in Chick Rations. Indian Poultry Gazette, Vol 62(1):34-36.

Varnish, S.A. and Carpenter, K.J. 1975a. Mechanisms of Heat Damage in Proteins 5. The Nutritional Values of Heat Damaged and Propionylated Proteins as Sources of Lysine Methionine and Tryptophan. British Journal of Nutrition 34:325-334.

Varnish, S.A. and Carpenter, K.J. 1975b. Mechanism of Heat Damage in Proteins. 6 The Digestability of Individual Amino Acids in Heated and Propionylated Proteins. British Journal of Nutrition 34:359-349.

Vestal, C.M., C.L. Sherweburg, R. Jordon and O. Milligan. 1945. The Influence of Fish Meals and Fish Oil on the Flavor of Pork. Journal of Animal Science 4;63.

Vita News. August 1978. Edited by L. Drugen. Volunteers in Technical Assistance Inc. 3706 Rhode Island Avenue, Mt. Rainier, Maryland 20822.

Waibel, P.E. and K.J. Carpenter. 1972. Mechanisms of Heat Damage in Proteins 3. Studies with ε-(Y-LOGlutamyl)-L-Lysine. British Journal of Nutrition 27:509-515.

Walker, S.H. 1973. Summary of Climatic Records of Belize. Supplementary Report #3. Overseas Development Administration Land Resources Division, Surbiton, Surrey, England.

Wignal, L.D. and I.N. Tatterson. 1976. Commercial Fish Silage. Process Biochemistry 11(10):17.

Woodman, H.E. and R.E. Evans. 1951. Nutrition of the Bacon Pig XIV the Determination of the Relative Supplemental Value of Vegetable Protein and Animal Protein. Journal of Agricultural Science 41:102.

Woolen, A. 1969. Food Industries Manual 20th Edition. Leonard Hill Books, London, England.

APPENDICES

APPENDIX A

COMPOSITION OF "BELIZE" VITAMIN AND TRACE MINERAL PREMIXES

TABLE A-1

GUARANTEED MINIMUM ANALYSIS OF VITAMIN AND MINERAL PRE-MIXES USED IN BROILER TRIAL RATIONS

Vitamin Pre-Mix

Vitamin A	8,000,000 I.U.
Vitamin D_3	1,000,000 I.U.
Vitamin E	20,000 I.U.
Vitamin K	2 g
Riboflavin	4 g
Niacin	30 g
Ca Pantothenate	12 g
Vitamin B_{12}	0.02 g
Choline Chloride	300 g
Antioxidant (BHT)	45 g
Carrier to 1000 grams	

Trace Mineral Pre-Mix

Manganese	50 g
Zinc	70 g
Iodine	0.25 g
Selenium	0.1 g
Copper	8 g
Carrier to 1000 grams	

Each pre-mix is mixed with carrier at a ratio of 1:4 after arrival in Belize, then incorporated at the rate of 0.5% in all rations. The carrier for the vitamin pre-mix is sifted wheat middlings and for the mineral pre-mix is heated rice by-product.

APPENDIX B

SUMMARIES OF STATISTICAL ANALYSIS

TABLE B1

FACTORIAL ANALYSIS OF VARIANCE
FOR 4 WEEK WEIGHTS

Source	d.f.	SS	MS	F	P<
Supplementation Level (A)	2	0.246	0.123	11.96	0.00000956**
Type of Fish Meal (B)	1	0.0277	0.027	2.70	0.10154151
Protein Level (C)	1	0.143	0.143	13.92	0.00022316**
A x B	2	0.054	0.027	2.63	0.0734572
A x C	2	0.156	0.0782	7.62	0.00058046**
B x C	1	0.0731	0.0731	7.12	0.00797857**
Error	338	3.47	0.0103		

* = P<.05
** = P<.01

TABLE B2

FACTORIAL ANALYSIS OF VARIANCE
FOR 8 WEEK WEIGHTS

Source	d.f.	SS	MS	F	P<
Supplementation Level (A)	2	1.26	0.629	7.57	0.00060722**
Type of Fish Meal (B)	1	0.0496	0.0496	0.60	
Protein Level (C)	1	0.702	0.702	8.44	0.00390345**
A x B	2	0.111	0.0554	0.67	
A x C	2	0.0549	0.0275	0.33	
B x C	1	0.270	0.270	3.25	0.07233819
Error	336	0.279	0.0831		

* = P<.05
** = P<.01

TABLE B3

FACTORIAL ANALYSIS OF VARIANCE FOR
FEED CONSUMPTION 0 - 4 WEEKS

Source	d.f.	SS	MS	F	P<
Supplementation Level (A)	2	1.77E-04	8.86E-05	5.24	.02148*
Type of Fish Meal (B)	1	2.60E-05	2.60E-05	1.54	.23676
Protein Level (C)	1	3.41E-05	3.41E-05	2.01	.17943
A x B	2	3.27E-04	1.64E-04	9.66	.00268**
A x C	2	1.20E-04	6.00E-05	3.54	.05915
B x C	1	5.42E-06	5.42E-06	0.32	
Error	13	2.20E-04	1.69E-05		

* = P<.05
** = P<.01

TABLE B4

FACTORIAL ANALYSIS OF VARIANCE FOR
FEED CONSUMPTION 4 - 8 WEEKS

Source	d.f.	SS	MS	F	P<
Supplementation Level (A)	2	1.60E-03	8.01E-04	2.23	.14647
Type of Fish Meal (B)	1	7.70E-07	7.70E-07	0.00	
Protein Level (C)	1	8.93E-05	8.93E-05	0.25	
A x B	2	5.04E-04	2.52E-04	0.70	
A x C	2	6.48E-04	3.24E-04	0.90	
B x C	1	9.09E-04	9.09E-04	2.54	.13524
Error	13	4.6E-03	3.58E-04		

TABLE B5

FACTORIAL ANALYSIS OF VARIANCE FOR
FEED CONVERSION 0 - 4 WEEKS

Source	d.f.	SS	MS	F	P<
Supplementation Level (A)	2	6.95E-01	3.47E-01	12.73	.00868**
Type of Fish Meal (B)	1	1.32E-01	1.32E-01	4.84	
Protein Level (C)	1	1.60E-02	1.60E-01	0.59	
A x B	2	5.08E-01	2.54E-01	9.30	.003103**
A x C	2	5.21E-01	2.60E-01	9.54	.002821**
B x C	1	2.16E-02	2.16E-02	0.79	
Error	13	3.55E-01	2.73E-02		

** = P<.01

TABLE B6

FACTORIAL ANALYSIS OF VARIANCE FOR
FEED CONVERSION 4 - 8 WEEKS

Source	d.f.	SS	MS	F	P<
Supplementation Level (A)	2	1.32E-01	6.60E-02	0.38	
Type of Fish Meal (B)	1	5.42E-02	5.42E-02	0.31	
Protein Level (C)	1	1.51E-00	1.51E-00	8.77	.011010*
A x B	2	4.34E-01	2.17E-01	1.26	.315515
A x C	2	3.17E-01	1.58E-01	0.92	
B x C	1	1.87E-01	1.87E-01	1.09	.315877
Error	13	2.24E-00	1.72E-01		

* = P<.05

TABLE B7

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 4 WEEK WEIGHT FOR THE LEVELS OF SUPPLEMENTATION WITH COMMERCIAL FISH MEAL AT NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	.1827	.0609	5.913*
Linear	1	.1627	.1627	15.801**
Quadratic	1	.0004	.0004	0.035
Cubic	1	.0160	.0160	1.553
Error	112	1.1330	.0103	

P<.05 = 3.93
P<.01 = 6.87
*P<.05
**P<.01

TABLE B8

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 4 WEEK WEIGHT FOR THE LEVELS OF SUPPLEMENTATION WITH BELIZE FISH MEAL AT NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	.0683	.0228	2.217
Linear	1	.0000	.0000	0.001
Quadratic	1	.0395	.0395	19.163**
Cubic	1	.0288	.0288	0.005
Error	112	1.1742	.0103	

P<.05 = 3.93
P<.01 = 6.87
*P<.05
**P<.01

TABLE B9

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 4 WEEK WEIGHT FOR THE LEVELS OF SUPPLEMENTATION WITH COMMERCIAL FISH MEAL AT SUB-NRC PROTEIN LEVEL

Source	d.f.	SS	MS	F
Treatment	3	.3433	.1144	11.102**
Linear	1	.0357	.0357	3.471
Quadratic	1	.2871	.2871	27.878**
Cubic	1	.0205	.0205	1.994
Error	112	1.1536	.0103	

P<.05 = 3.93
P<.01 = 6.87
*P<.05
**P<.01

TABLE B10

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 4 WEEK WEIGHT FOR THE LEVELS OF SUPPLEMENTATION WITH "BELIZE" FISH MEAL AT SUB-NRC PROTEIN LEVEL

Source	d.f.	SS	MS	F
Treatment	3	.2258	.0753	7.312**
Linear	1	.0038	.0038	.366
Quadratic	1	.2022	.2022	19.634**
Cubic	1	.0198	.0198	1.927
Error	112	1.1536	.0103	

P<.05 = 3.93
P<.01 = 6.87
*P<.05
**P<.01

TABLE B11

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 8 WEEK WEIGHT FOR THE LEVELS OF SUPPLEMENTAION WITH COMMERCIAL FISH MEAL AT NRC PROTEIN LEVEL

Source	d.f.	SS	MS	F
Treatments	3	1.0401	0.3467	4.174*
Linear	1	0.4386	0.4386	5.276*
Quadratic	1	0.1631	0.1631	1.963
Cubic	1	0.4386	0.4386	5.276*
Error	112	9.3072	0.831	

P<.05 = 3.93
P<.01 = 6.87
*P<.05

TABLE B12

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 8 WEEK WEIGHT FOR LEVELS OF SUPPLEMENTATION WITH BELIZE FISH MEAL AT NRC PROTEIN LEVEL

Source	d.f.	SS	MS	F
Treatments	3	1.482	0.494	5.944*
Linear	1	0.064	0.065	0.7695
Quadratic	1	1.341	1.341	16.128**
Cubic	1	0.077	0.077	.9231
Error	112	9.3072	0.083	

P<.05 = 3.93
P<.01 = 6.87
*P<.05
**P<.01

TABLE B13

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 8 WEEK WEIGHT FOR THE LEVELS OF SUPPLEMENTATION WITH COMMERCIAL FISH MEAL AT SUB-NRC PROTEIN LEVEL

Source	d.f.	SS	MS	F
Treatments	3	0.7706	0.2569	3.091
Linear	1	0.0980	0.0980	1.179**
Quadratic	1	0.6525	0.6525	7.851
Cubic	1	0.0201	0.0201	0.003
Error	112	9.3072	0.0831	

P<.05 = 3.93
P<.01 = 6.87
**P<.01

TABLE B14

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 8 WEEK WEIGHT FOR LEVELS OF SUPPLEMENTATIN WITH BELIZE FISH MEAL AT SUB-NRC PROTEIN LEVEL

Sources	d.f.	SS	MS	F
Treatments	3	0.1478	0.0493	0.593
Linear	1	0.0052	0.0052	0.063
Quadratic	1	0.0725	0.0725	0.872
Cubic	1	0.0702	0.0702	0.845
Error	112	9.3072	0.0831	

P<.05 = 3.93
P<.01 = 6.87

TABLE B15

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 0-4 WEEK FEED CONSUMPTION FOR THE LEVELS OF SUPPLEMENTATION OF COMMERCIAL FISH MEAL AT NRC PROTEIN LEVEL

Source	d.f.	SS	MS	F
Treatments	3	5.35-04	.0001.7E-04	10.4976*
Linear	1	1.43-04	.0001.43-04	8.4797*
Quadratic	1	9.92-08	9.92-08	.0620
Cubic	1	324-04	3.24-04	19.1844*
Error	4	6.76-05	1.69-05	

P<.05 = 7.71
P<.01 = 21.20
*P<.05
**P<.01

TABLE B16

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 0-4 WEEK FEED CONSUMPTION FOR THE LEVELS OF SUPPLEMENTATION OF "BELIZE" FISH MEAL AT NRC PROTEIN LEVEL

Source	d.f.	SS	MS	F
Treatments	3	1.94-04	6.48-05	3.834
Linear	1	4.00-07	4.00-04	.0213
Quadratic	1	.000126-04	1.26-04	7.4795
Cubic	1	4.9-08	4.9-08	.00289
Error	4	6.76-05	1.69-05	

P<.05 = 7.71
P<.01 = 21.20
*P<.05
**P<.01

TABLE B17

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 0-4 WEEK FEED CONSUMPTION FOR THE LEVELS OF COMMERCIAL FISH MEAL AT SUB-NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	7.49-04	2.50-05	14.763*
Linear	1	4.3-05	4.3-05	2.544
Quadratic	1	6.37-04	6.37-04	37.692**
Cubic	1	8.00-06	8-06	.047
Error	4	6.76-05	1.69-05	

P<.05 = 3.93
P<.01 = 6.87
*P<.05
**P<.01

TABLE B18

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 0-4 WEEK FEED CONSUMPTION FOR LEVELS OF SUPPLEMENTATION OF "BELIZE" FISH MEAL AT SUB-NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	5.301-04	1.76-04	10.455*
Linear	1	2.78-04	2.28-04	13.510*
Quadratic	1	2.20-04	2.20-04	13.0473*
Cubic	1	1.35-05	1.35-05	.7988
Error	4	6.76-05	1.69-05	

P<.05 = 3.93
P<.01 = 6.87
*P<.05
**P<.01

TABLE B19

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 4-8 WEEK FEED CONSUMPTION FOR LEVELS OF SUPPLEMENTATION OF COMMERCIAL FISH MEAL AT NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	1.62-03	5.39-04	1.5055
Linear	1	1.69-05	.69-05	.0472
Quadratic	1	1.30-03	1.30-03	3.633
Cubic	1	3.00-04	3.00-94	.8450
Error	4	1.43-03	3.58-04	

P<.05 = 3.93
p<.01 = 6.87
*P<.05
**P<.01

TABLE B20

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 4-8 WEEK FEED CONSUMPTION FOR LEVELS OF SUPPLEMENTATION OF BELIZE FISH MEAL AT NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	1.18-04	3.95-04	1.1042
Linear	1	1.44-05	1.44-05	.0402
Quadratic	1	2.88-04	2.88-04	.8045
Cubic	1	8.83-04	8.83-04	2.4682
Error	4	1.43-04	3.58-04	

P<.05 = 3.93
P<.01 = 6.87
*P<.05
**P<.01

TABLE B21

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 4-8 WEEK FEED CONSUMPTION FOR LEVELS OF SUPPLEMENTATION OF COMMERCIAL FISH MEAL AT SUB-NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	d3	7.45-04	2.48-04	.6941
Linear	1	3.96-04	3.96-04	1.1087
Quadratic	1	3.12-04	3.12-04	.8729
Cubic	1	3.61-05	3.61-05	.1008
Error	4	1.43-04	3.58-04	

P<.05 = 3.93
P<.01 = 6.87
*P<.05
**P<.01

TABLE B22

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 4-8 WEEK FEED CONSUMPTION FOR LEVELS OF SUPPLEMENTATION OF "BELIZE" FISH MEAL AT SUB-NRC PROTEIN LEVELS

Source	d.f.	SS	MS	G
Treatments	3	1.34-03	4.49-04	1.2542
Linear	1	7.22-04	7.22-04	2.0182
Quadratic	1	2.69-04	2.64-04	.7388
Cubic	1	3.60-04	3.60-04	1.0656
Error	4	1.43-03	3.58-04	

P<.05 = 3.93
P<.01 = 6.87
*P<.05
**P<.01

TABLE B23

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 0-4 WEEK FEED CONVERSION FOR THE LEVELS OF SUPPLEMENTATION WITH COMMERCIAL FISH MEAL AT NRC PROTEIN LEVELS

Sources	d.f.	SS	MS	F
Treatments	3	.3685	.1278	4.5
Linear	1	.0202	.0202	.7418
Quadratic	1	.0060	.0060	.2216
Cubic	1	.3422	.3422	12.5363*
Error	4	.1092	.0273	

P<.05 = 3.83
P<.01 = 6.87
*P<.05
**P<.01

TABLE B24

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS IN 0-4 WEEK FEED CONVERSION FOR THE LEVELS OF SUPPLEMENTATION WITH "BELIZE" FISH MEAL AT NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	.0429	.0143	.5244
Linear	1	.0003	.0003	.0092
Quadratic	1	.0364	.0364	1.3352
Cubic	1	.0062	.0062	.2289
Error	4	.1092	.0273	

P<.05 = 3.83
P<.01 = 6.87
*P<.05
**P<.01

TABLE B25

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS FOR 4-8 WEEK FEED CONVERSION FOR LEVELS OF SUPPLEMENTATION WITH COMMERCIAL FISH MEAL AT NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	.8969	.2990	1.7383
Linear	1	.3497	.3497	2.0331
Quadratic	1	.5101	.5101	2.9654
Cubic	1	.0372	.0372	.2163
Error	4	.684	.172	

P<.05 = 3.83
P<.01 = 6.87
*P<.05
**P<.01

TABLE B26

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS FOR 4-8 WEEK FEED CONVERSION FOR LEVELS OF SUPPLEMENTATION WITH "BELIZE" FISH MEAL AT NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	1.0653	.3551	2.6646
Linear	1	.2465	.2465	1.4331
Quadratic	1	.2281	.2381	1.3840
Cubic	1	.5808	.5808	3.3768
Error	4	.684	.172	

P<.05 = 3.83
P<.01 = 6.87
*P<.05
**P<.01

TABLE B27

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS FOR 4-8 WEEK FEED CONVERSION FOR LEVELS OF SUPPLEMENTATION WITH COMMERCIAL FISH MEAL AT SUB-NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	.4546	.1515	.8810
Linear	1	.1742	.1742	1.0130
Quadratic	1	.2592	.2592	1.5070
Cubic	1	.0212	.0212	.1230
Error	4	.684	.172	

P<.05 = 3.83
P<.01 = 6.87
*P<.05
**P<.01

TABLE B28

ANALYSIS OF ORTHOGONAL POLYNOMIAL CONTRASTS FOR 4-8 WEEK FEED CONVERSION FOR LEVELS OF SUPPLEMENTATION WITH "BELIZE" FISH MEAL AT SUB-NRC PROTEIN LEVELS

Source	d.f.	SS	MS	F
Treatments	3	.5382	.1794	1.0429
Linear	1	.3960	.3960	2.3024
Quadratic	1	.1201	.1201	.6980
Cubic	1	.0221	.0221	.1284
Error	4	.684	.172	

P < .05 = 3.83
P < .01 = 6.87
*P < .05
**P < .01

TABLE B-29

BONFERRONI TEST STATISTICS FOR CONTRASTS OF TREATMENT MEANS

	4 wk			8 wk		
Contrasts	Weight[a]	F/B/D[b]	F/G[b]	Weight[a]	F/B/D[b]	F/G[b]
111 vs 121	3.602**	11.308**	1.997	3.434**	.835	1.760
211 vs 221	.034	7.077**	1.937	.269	1.330	.338
311 vs 321	1.954	2.846	1.634	.130	6.680**	2.676
112 vs 122	.307	6.928**	4.176*	1.732	.835	.4822
212 vs 222	.074	2.154	.484	.900	3.008	1.098
312 vs 322	1.984	2.231	.121	.533	4.178	1.133
111 vs 112	7.189**	.154	3.873*	1.599	1.033	2.362
211 vs 212	0	.692	.303	2.226	3.844	2.267
311 vs 312	.067	8.815**	2.179	.649	5.480**	2.508
121 vs 122	.300	4.538**	1.695	3.567**	1.003	2.363
221 vs 222	.265	4.231*	1.151	.949	2.1727	1.471
321 vs 322	.720	3.538	.600	1.066	5.515**	1.471
411 vs 412	.750	16.076**	5.629**	2.510	2.507	.4822

* = P<.05

** = P<.01

[a] P<.05 = 2.681
P<.01 = 3.193

[b] P<.05 = 3.436
P<.01 = 4.260

APPENDIX C

MICROBIAL ANALYSIS METHODS AND MATERIALS

APPENDIX C

Materials and Methods for Detection and Enumeration of Coliforms and Lactobacilus

Media Preparation

Two media were used for detection and enumeration; (1) EMB (Eosen-methylene blue) agar and (2) LBS (Lactobacilli broth solution) agar. Both were available already prepared from Difco Laboratories, Detroit MI. However, they can be prepared according to the formulation below.

Sample Preparation

The sample to be checked was weighed (1 g), and ste rile distilled water (9.0 ml) added to give a 1:10 ratio (w/v). This was done in a test tube which was stoppered and shaken vigorously. This was a 10^{-1} dilution.

One ml of this 10^{-1} dilution was transferred separately into corresponding 9.0 ml volumes of sterile water in test tubes, (giving dilutions of 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5} etc) using a sterile 1.0 ml pipette with a cotton plug on the mouth end. Between each transfer, the test tubes were stoppered and shaken. For greatest counting efficiency, depending on the sample, dilutions should proceed to 10^{-12}.

With sterile pipettes, 0.1 - 0.5 ml of each dilution was placed on the surface of agar plates. The liquid was spread on the augar surface, by using a 90^{o} bent glass rod, sterilized between spreading by dipping in absolute ethanol and flaming with a Bunsen burner. Plates were labeled

as to dilution.

After innoculation of the plates, they were inverted and placed in a BBL gas pak container (Scientific Products Co. source).

The plates were incubated at 30° C for one week, or until bacterial colonies could be observed.

Plates were counted by back-lighting and use of a plate counter (New Brunswick Co.) or hand counter. About 50-300 counts per plate gave best accuracy.

Bacterial concentrations in the original samples were calculated by multiplying plate counts times dilutions.

EOSINE METHYLENE BLUE AGAR

Prepared according to these proportions:

Bacto peptone		10.0 g
Lactose		5.0 g
Sucrose		5.0 g
Dipotassium phosphate		2.0 g
Agar		13.5 g
Eosin-y		0.4 g
Methylene blue		0.065 g
Distilled water	to	1.0 liter

Final pH 7.2

The agar was gently heated over a bunsen burner until medium boiling. It was then autoclaved at 121° C for 15 minutes in round bottom, thick walled flasks, with cotton plugs. The autoclave must be exhausted slowly so medium doesn't blow out of the flasks.

The agar was mixed frequently while rapidly poured into sterile glass or plastic Petri dishes. These were then cooled until solidified. The plates were inverted to prevent condensation on medium surfaces.

LACTOBACILLI BROTH SOLUTION

Prepared according to these proportions;

Bacto-peptonized milk	15.0 g
Bacto-yeast extract	5.0 g
Bacto-dextrose	10.0 g
Tomato juice (100 ml)	5.0 g
Monobasic potassium phosphate	2.0 g
Tween 80	1.0 g
Bacto-agar	10.0 g
Distilled water	1.0 liter

Protocol for dissolving, sterilization and pouring is similar to EMB Agar.