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Experiment to Determine Split Fish Equivalent Factor for Salted Codfish in Bulk

by

Canada Fisheries and Oceans

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FOREWORD

This experiment was conducted during the summer of 1983, by the Enforcement Section (Offshore), Fisheries Operations Branch, Newfoundland Region, with the collaboration of the Canadian Saltfish Corporation. Fishery Officers Leo Strowbridge and Lawrence Penney from the Enforcement Section (Offshore), were designated project officers.

Dr. Ross Peters of the Faculty of Engineering, Memorial University, reviewed the experimental design and analyzed the data.

This project was funded through the office of the Assistant Deputy Minister, Atlantic Fisheries, Ottawa.

ACKNOWLEDGEMENTS

This experiment was made possible through the combined efforts of the Department of Fisheries and Oceans and the Canadian Saltfish Corporation. A special thanks to Mr. Bren Kennedy and his staff at Southside Fisheries Limited.

We wish to acknowledge the work of the Inspection Staff, Department of Fisheries and Oceans, Newfoundland Region. To Ms. Bonnie Bruce, we express our thanks for typing the report and to Ms. Judy Gibson for editing the report.

Throughout the experiment, the advice and assistance of the Fisheries Officers from the Enforcement Section (Offshore) was greatly appreciated.

We also wish to thank Mr. E. B. Dunne for his support throughout the project.

1. INTRODUCTION

1.1 Background

Suspicions of widespread misreporting within the saltfish fleets go back before 1980, but it was not until that year that concrete steps were taken in an attempt to halt this major enforcement problem. In the spring of 1980, Enforcement Section (Offshore) personnel collected information from all recognized sources in an effort to establish an acceptable procedure to convert salted codfish volumes to split and round weight equivalents. By 1983 there were still no conclusive data to support definitive split and round weight equivalent factors.

During the summer of 1980, surveillance officers initially used salted codfish density factors as low as 544 kg/m^3. As the year progressed, new information was supplied which resulted in density factors of 800-1050 kg/m^3 being used in vessel inspections. In October of 1980, density factors as high as 1200 kg/m^3 were derived from a small-scale experiment in Cupids, Newfoundland. This wide range of density factors demonstrated the need for further experimentation in the field of salted codfish production. Throughout the period 1980-83, surveillance officers continued to use the mid-range factors of 800-1050 kg/m^3, and this use identified several variables that significantly affected the conversion of salted codfish volumes to split/round codfish equivalents.

The saltfish experiment was designed to simulate the salting and curing practices in the offshore fishing fleet; the effects of the identified variables were investigated, as well as others, some of which later turned out to be significant.

1.2 Objectives

The principal objective of the following study was to determine a split codfish equivalent of salted codfish in bulk at various stages of the curing process, isolating the following variables:

(a) the quantity of salt per hundredweight of split codfish (salting ratio).

(b) the bulk height (compression).

(c) high catch rates (continuous salting).

2. PROCEDURE

To achieve the above objective, three experiments were undertaken to isolate the aforementioned variables. Measured quantities of split codfish were salted into six enclosed pallets described in Section 2.6.

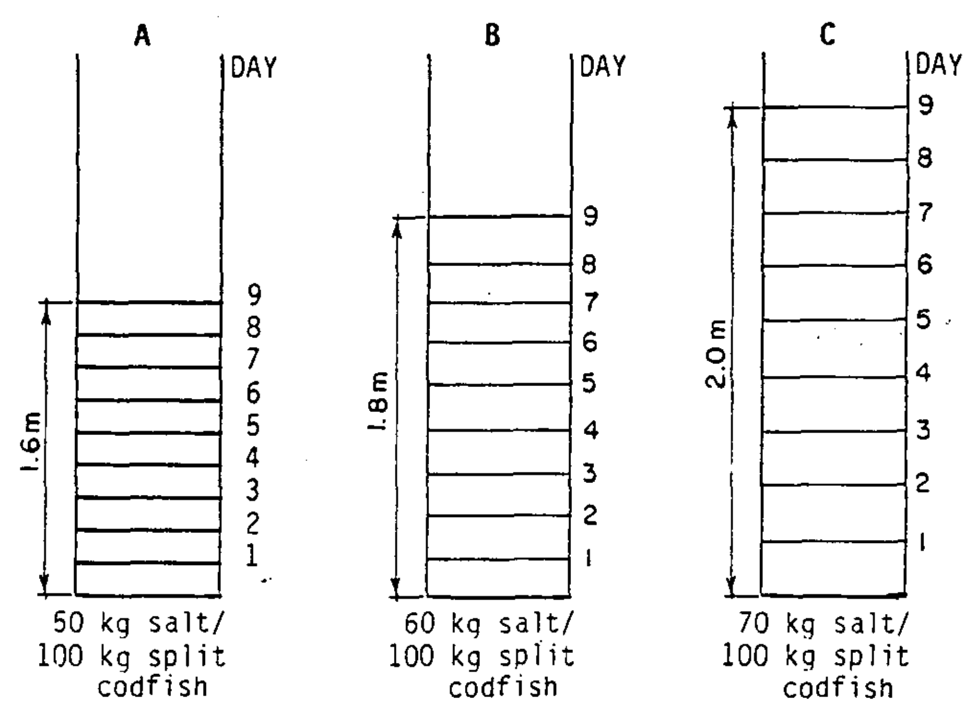
2.1 Experiment #1 - Effect of Salt to Fish Ratio

Experiment #1 used three of the six enclosed pallets, which were labelled A, B, and C. To measure the effects of varying percentages of salt per hundredweight of split fish, daily quantities of between 250-300 kg of split codfish were salted into each pallet at ratios of 0.5, 0.6 and 0.7, respectively. These daily additions of split codfish and salt were continued for 9 days until pallet C (greatest percentage of salt) maintained a height of approximately 2.0 m. The other two pallets, A and B, were approximately 1.6 and 1.8 m high upon completion of the 9 days' salting. See Figure 1 below.

FIGURE 1

Pallets

A, B and C



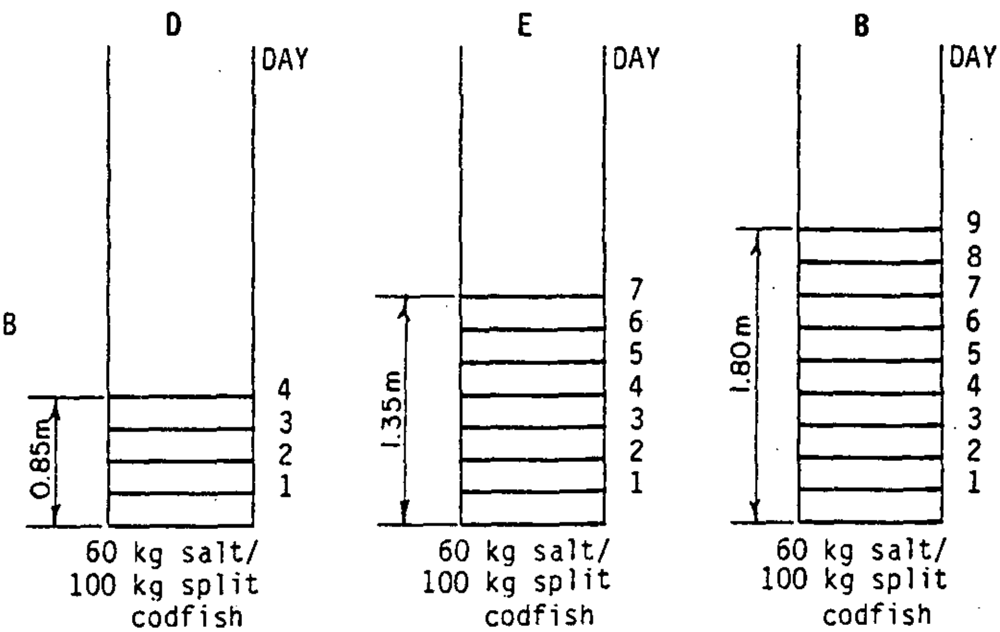
2.2 Experiment #2 - The Effect of Bulk Height (Compression)

Experiment #2 used two pallets, labelled D and E, together with pallet B from the first experiment. To measure the effects of compression due to bulk height, daily quantities of 250-300 kg of split codfish were salted into each pallets D and E until the bulks reached heights of 0.85 m and 1.35 m. Data was obtained for these pallets and for pallet B, which was approximately 1.8 m high in bulk of salt and fish. All three pallets had been salted with the same percentage of salt to fish (60 per cent).

FIGURE 2

Pallets

D, E and B



2.3 Experiment #3 - Simulated High Catch Rate (Continuous Salting)

Experiment #3 used one of the six enclosed pallets, labelled F. Split codfish was salted at a ratio of 60 kg of salt to 100 kg of split fish in one continuous period of approximately 9½ hours, at which time it measured 2 m, and was allowed to cure. The data obtained from this experiment were compared with the data from Experiments 1 and 2.

2.4 Data Collection

Prior to salting each day's allotment into pallets A to E, the heights of all previous daily allotments were measured for volume changes. Each daily layer of fish and salt was separated from other layers by a sheet of burlap. Each pallet was also weighed to obtain the net weight loss for each bulk. The brine runoff was collected in containers and weighed to verify the weight loss of each bulk and to enable calculation of a complete mass balance.

These measurements and weighings were performed throughout the salting and curing phases until the bulk volumes and weights had not changed significantly for a period of two weeks. At this time, each daily layer of salted codfish and excess salt was removed from the pallets A to F by hand, and fish and salt were separated.

2.5 Facilities and Equipment

The facilities and equipment used to complete the experiments were as follows:

1) A large chillroom 84 m^2, in which the average temperature was 12°C. and the relative humidity was 75 per cent (the variation from these figures was very slight). (See primary data volume.)

2) Six enclosed pallets - specifications as shown in Figure 3, following Section 2.6.

3) Forklift - lift capacity of 5 t.

4) Volumetric container - base 1 m^2 and height 0.5 m.

5a) Cardinal scale (SN 40828) - weight limit 4 t.
 b) Dove Scale - weight limit of 7 kg.

6) Baader 440 fish splitting machine.

7) Barometer

8) Sling Psychrometer

9) Thermometer

10) Salometer

2.6 Pallet Design

The experiments required six enclosed pallets of specified dimensions and sufficient strength to withstand any stresses imposed on them. The pallets also had to allow adequate brine drainage and visual access to the individual daily levels of split codfish and salt. Newton Engineering Limited of St. John's was awarded the contract to design the pallets. Figure 4 shows an isometric view and gives dimensions of the experimental pallet. Exact details of specifications are contained in blueprints #83-181, obtainable from Newton Engineering and Associates Limited, 51 O'Leary Avenue, St. John's, Newfoundland, Canada A1C 6C4.

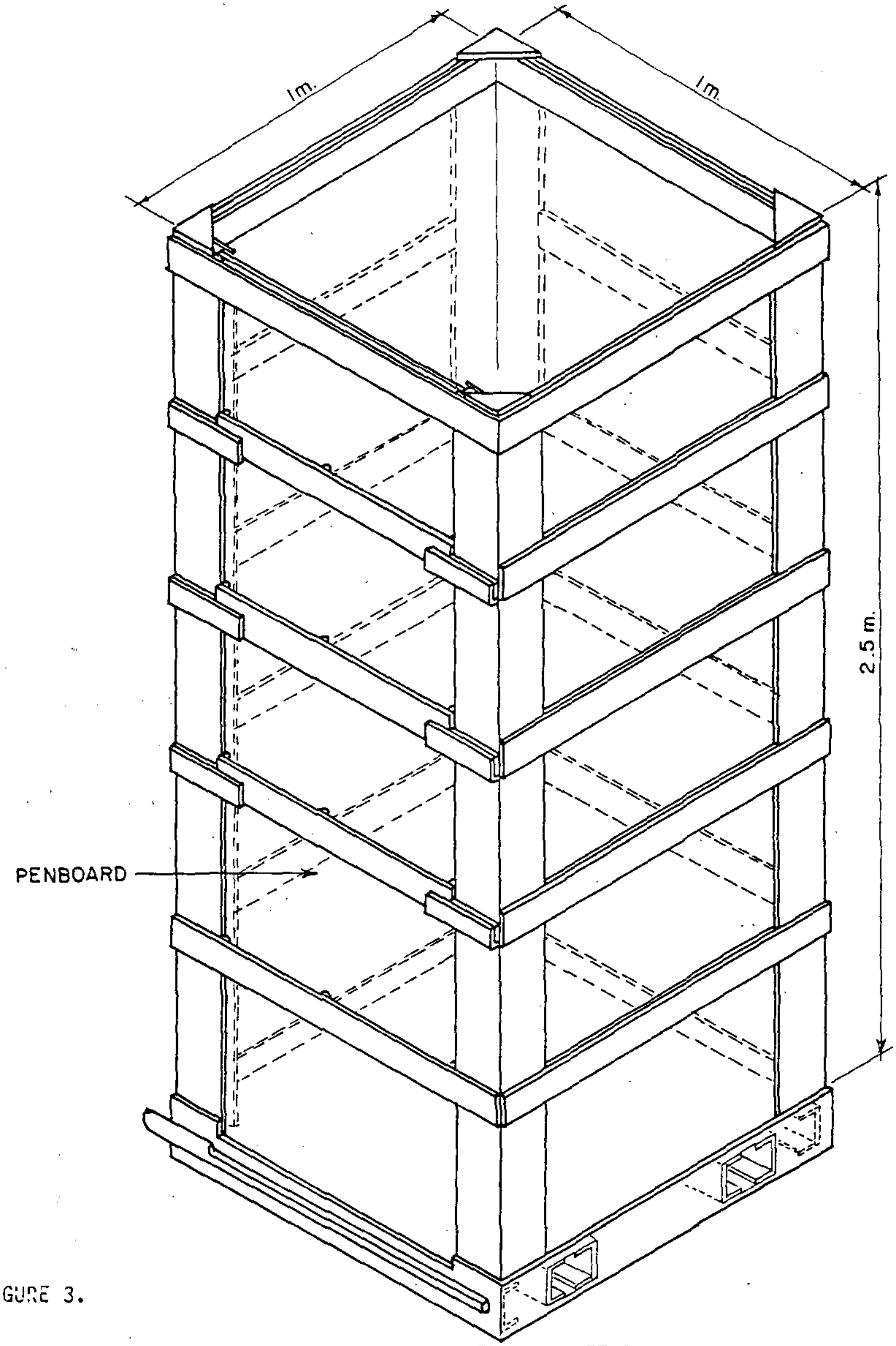


FIGURE 3.

EXPERIMENTAL PALLET - ISOMETRIC VIEW

SPECIFICATIONS:

A) THE ENTIRE PALLET SHALL BE CONSTRUCTED OF ALUMINUM WELDED TOGETHER, EXCEPT FOR THE PALLET PENBOARDS.
B) THE PALLET PENBOARDS SHALL BE PLEXI-GLASS.
C) THE PALLET SHALL HAVE AN EXACT INSIDE DIMENSION OF 1 m^2 AND A HEIGHT OF 2.5 m.

3. OUTLINE OF PROJECT ACTIVITIES

3.1 Preparation

Day 1 - Monday, July 18, 1983:

Day 1 involved the completion of such last-minute details as:

1) Checklisting, labelling and certifying all equipment.

2) Arranging the daily delivery of fresh codfish.

3) Finalizing the procedures to be followed in carrying out the experiments.

The procedures which were followed from the initial delivery of round codfish to the actual daily salting into pallets are outlined in the Flow Chart (Figure 4, page 9). It should be noted that all handling of codfish to the split form was completed in a processing area; the split fish was then transported to the chillroom for salting. A chillroom was specifically assigned and secured for the experiments.

3.2 Salting Phase

Day 2 - Tuesday, July 19, 1983:

Experiment #3 simulated a high catch rate (approximately 2 t of split fish were salted into pallet F in a period of 9.4 hours) and did not require the separation of daily quantities of fish. It was decided, therefore, to proceed first with this experiment since it provided an opportunity to streamline the entire processing operation.

The experiment began with the delivery of approximately 3400 kg of fresh round codfish. Length frequencies were conducted on 25 per cent

DAILY PROCEDURE OF FISH SALTING
(FLOW CHART)

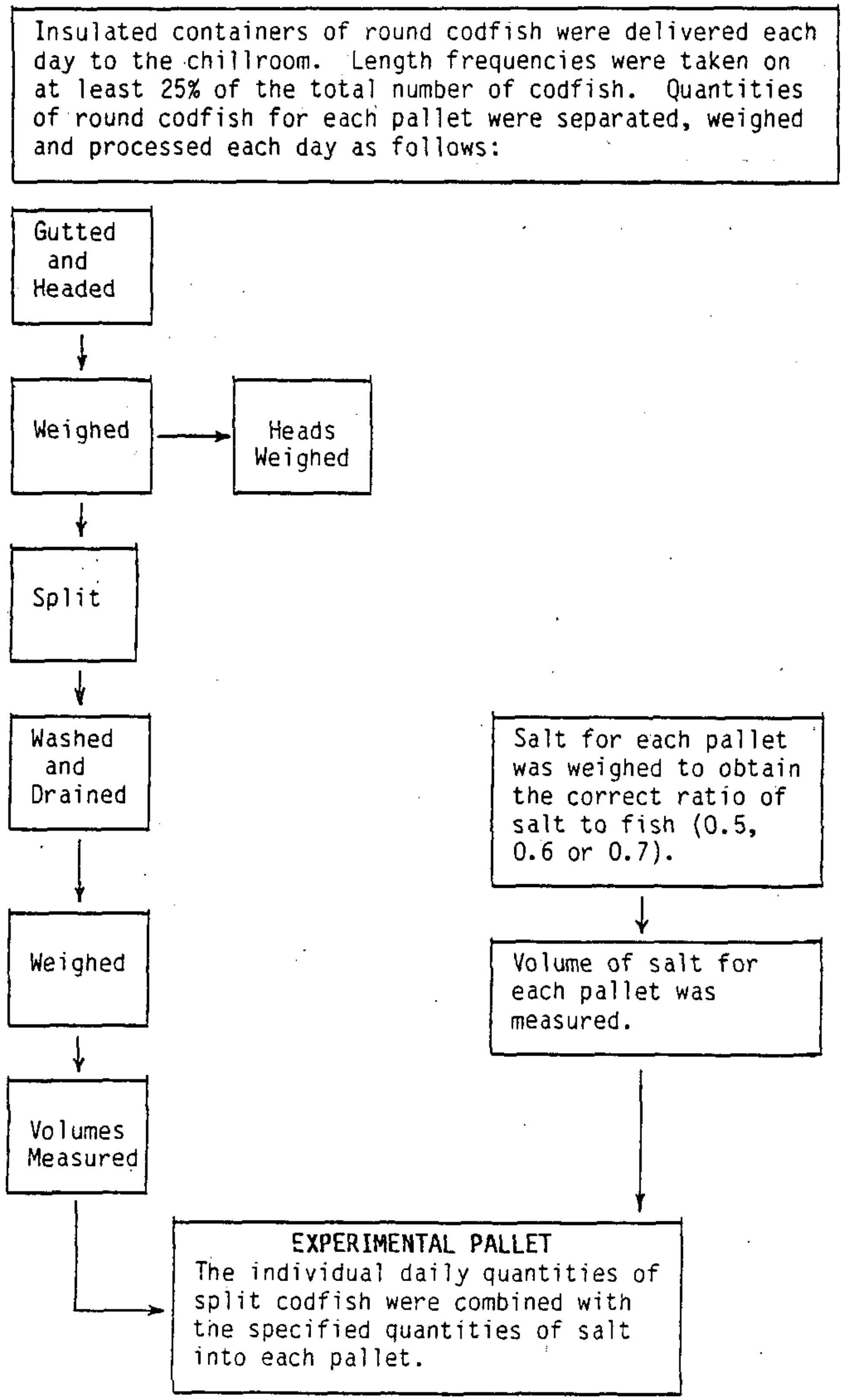


FIGURE 3

of the total, and 3 medium-sized fish were extracted for moisture analysis. The round codfish was then weighed in lots of approximately 350 kg for ease in handling, and after heading and gutting were completed, was weighed again. The heads removed during processing were also weighed to distinguish between percentages of head and gut content. The total gutted, head-off fish was then processed by a Baader 440 splitting machine, and after being washed, drained, and weighed was ready for salting. The weighings between each step in processing were taken to obtain yield factors for the various types of product. Volumes of split fish were also measured in a volumetric container to provide data on split fish density.

The amount of salt necessary to obtain a percentage of 60 per cent for pallet F was weighed and measured for volume. Then the salting process began. From 1800 hours on July 19 to 0330 hours on July 20 a total of 1895.2 kg of split fish was salted with 1137.2 kg of salt into pallet F. Upon completion of salting, the total volume of the bulk was recorded. Throughout the initial 48 hours after salting, brine runoff was collected at 3-hour intervals. For the remainder of the curing phase of the experiment, brine was collected at the time of each daily weighing and volume calculation in order to verify mass balance.

Day 3 - Wednesday, July 20, 1983:

With the salting phase of Experiment #3 (pallet F) completed, work began on Experiment #1 (the effects of salt per hundredweight of split fish) and Experiment #2 (the effects of bulk height).

Experiments 1 and 2 involved the salting of approximately equal quantities of split fish with predetermined percentages of salt into pallets A to E over a four-to-nine day period.

Each daily layer of split fish and salt was separated by a sheet of burlap, so that data could be obtained on daily changes of volume in the layer. Each pallet was weighed on the Cardinal scale daily, to obtain data on the weight of each new layer of salt and fish as well as the changes in weight of the bulk as a whole.

Day 3 began with the delivery of approximately 2300 kg of round codfish. Length frequencies were conducted on 25 per cent of the total, and 3 medium-sized fish were taken for moisture analysis. The round codfish was then weighed in five lots of 450 kg each (individual pallet allotment), and headed and gutted. The resulting product was weighed. Once again, the heads were weighed as in Experiment #3 in order to distinguish between percentages of head and gut content. The total gutted, head-off fish was split, washed and drained, and volume measurements were taken.

The five allotments of split fish were salted into pallets A to E with the percentages of salt as follows:

PALLET	% SALT	EXPERIMENT #
A	50	1
B	60	1, 2
C	70	1
D	60	2
E	60	2

Volumes and weights of each bulk were taken upon completion of salting as described in Experiment #3.

Throughout the initial 24 hours after the curing phase had begun, brine runoff was collected at 3-hour intervals. From then on until the curing phase was completed brine was collected at the time of each daily weighing and volume measurement.

Day 4 (Thursday, July 21, 1983) to Day 9 (Friday, July 29):

The processing and salting procedures outlined in the preceding section were followed during this period. The only additional procedure involved the volume calculation of each daily layer of split fish and salt (height between sheets of burlap).

Table 1 gives a summary of amounts of fish and salt used in the three experiments.

TABLE 1
Recap of the Salting Phase

The following table outlines the total amounts of fish, split fish and percentage of salt by individual pallets.

EXP	PALLET	TOTAL ROUND WEIGHT (KG)	TOTAL SPLIT WEIGHT (KG)	TOTAL SALT (KG)	PERCENTAGE OF SALT	TOTAL NO. OF DAYS (LAYERS)
1	A	4,119.8	2,461.5	1,234.1	50.1	9
	B	4,113.8	2,507.9	1,504.9	60.0	9
	C	4,121.9	2,514.1	1,759.4	69.9	9
2	D	1,816.1	1,068.1	640.9	60.0	4
	E	3,075.9	1,854.6	1,113.0	60.0	7
	B	4,113.8	2,507.9	1,504.9	60.0	9
3	F	3,302.9	1,895.2	1,137.2	59.9	1
MEAN		-	-	-	60.1	-

NOTE: On Sunday, July 24, 1983, processing or salting of codfish did not occur due to the unavailability of fresh codfish.

3.3 Curing Phase

Day 10 (Saturday, July 30, 1983) to Day 76 (Monday, October 3):

As per experimental design, weighings and volume calculations were taken until there were no significant changes for a period of two weeks. Throughout the curing phase, the temperature and humidity of the chillroom were monitored and varied only slightly from averages of 12°C. and 75 per cent relative humidity.

In the first week of the curing phase, individual pallet weighings and volume calculations, as well as brine sampling, were taken daily. As the curing phase progressed, weight loss in the bulk and brine runoff diminished to the point that data collection was felt to be necessary only twice a week. These twice-weekly measurements continued for a period of four weeks, after which data collection was felt to be necessary only every two weeks.

By Day 70 (September 28) changes in the weights and volumes of individual pallets were insignificant, thus removal from salt was scheduled for the following week.

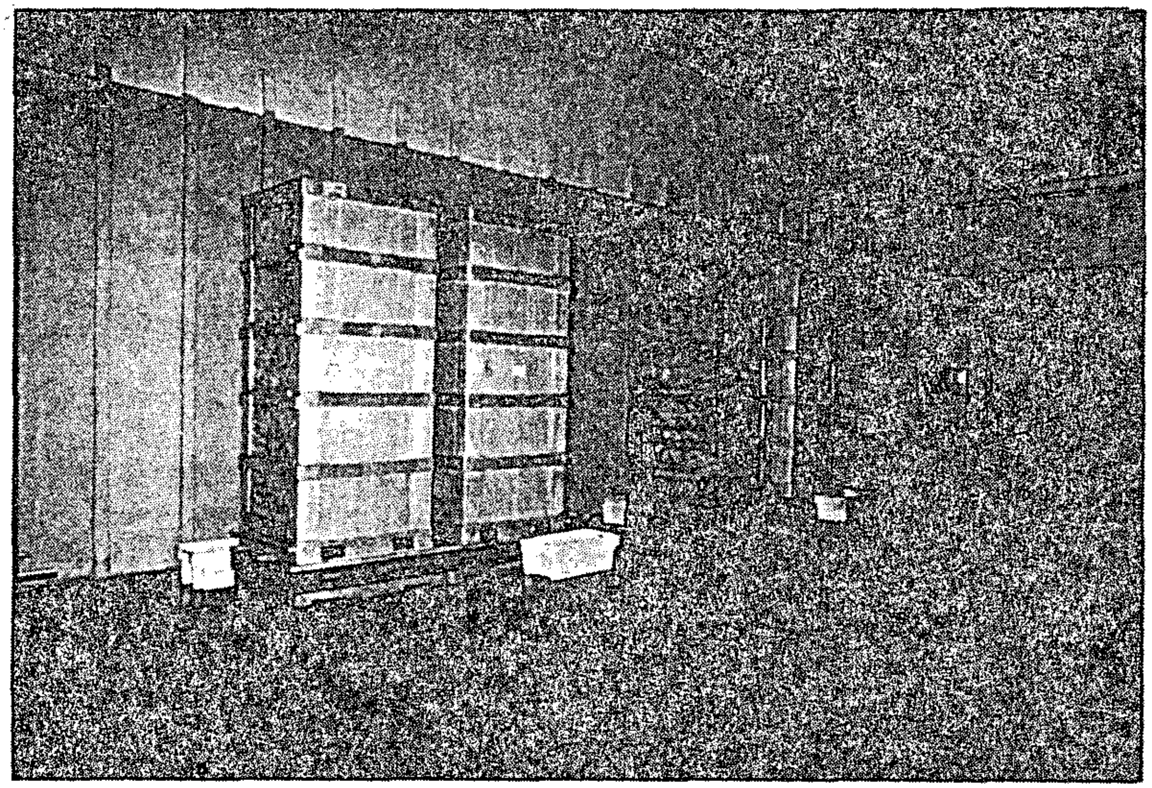
3.4 Removal from Salt

Day 76 (Tuesday, October 4, 1983) to Day 86, (Thursday, October 13):

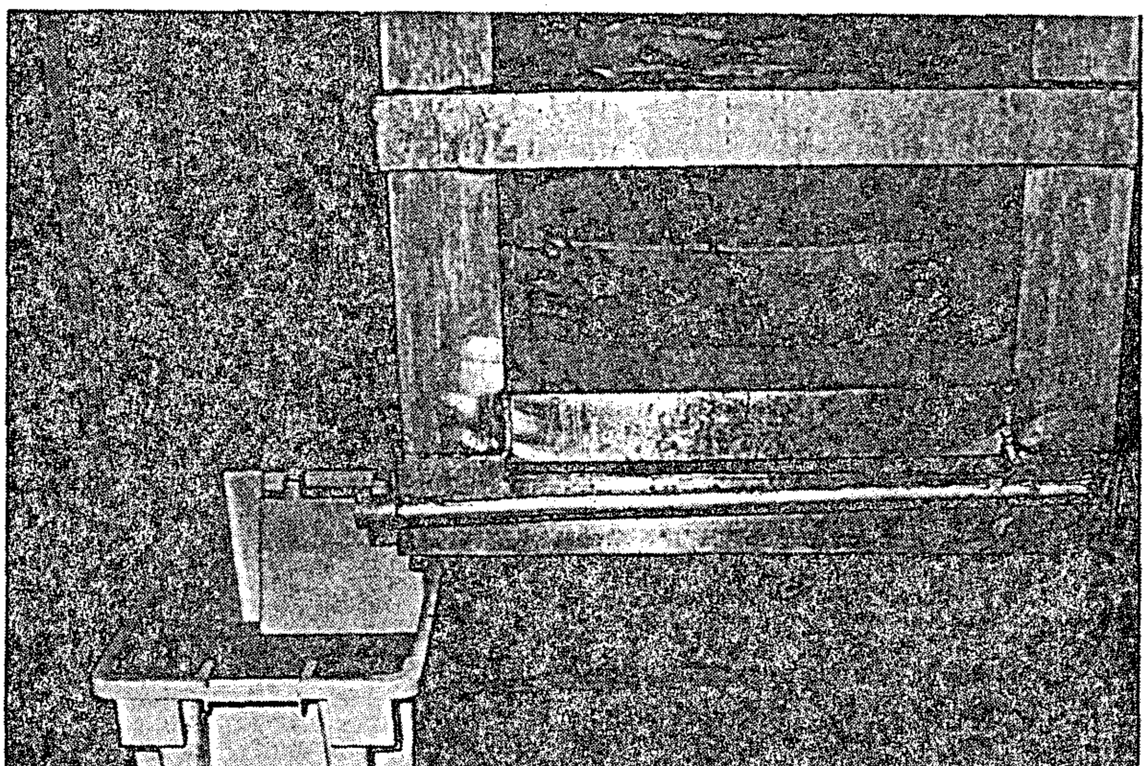
Once the final bulk weight and volume of pallet F (Experiment #3) were recorded, the removal of fish and salt commenced. On October 4 and 5, 1983, the split fish was removed from the bulk by hand, shaken vigorously over the pallet to dislodge the particles of salt adhering to the fish, and weighed. The salt remaining in the pallet was weighed to obtain a mass balance. Three samples from the top, middle, and bottom of the bulk, comprised of 3 medium-sized fish in each sample (for a total of 9 fish from the whole bulk) were removed. These samples were sent to the Inspection Laboratory, Department of Fisheries and Oceans, for salt and moisture analyses.

During the period October 6-13, 1983, removal of fish from pallets A to E was completed. The same procedure as for pallet F was followed, except that 3 medium-sized fish were removed from each layer for salt and moisture analyses.

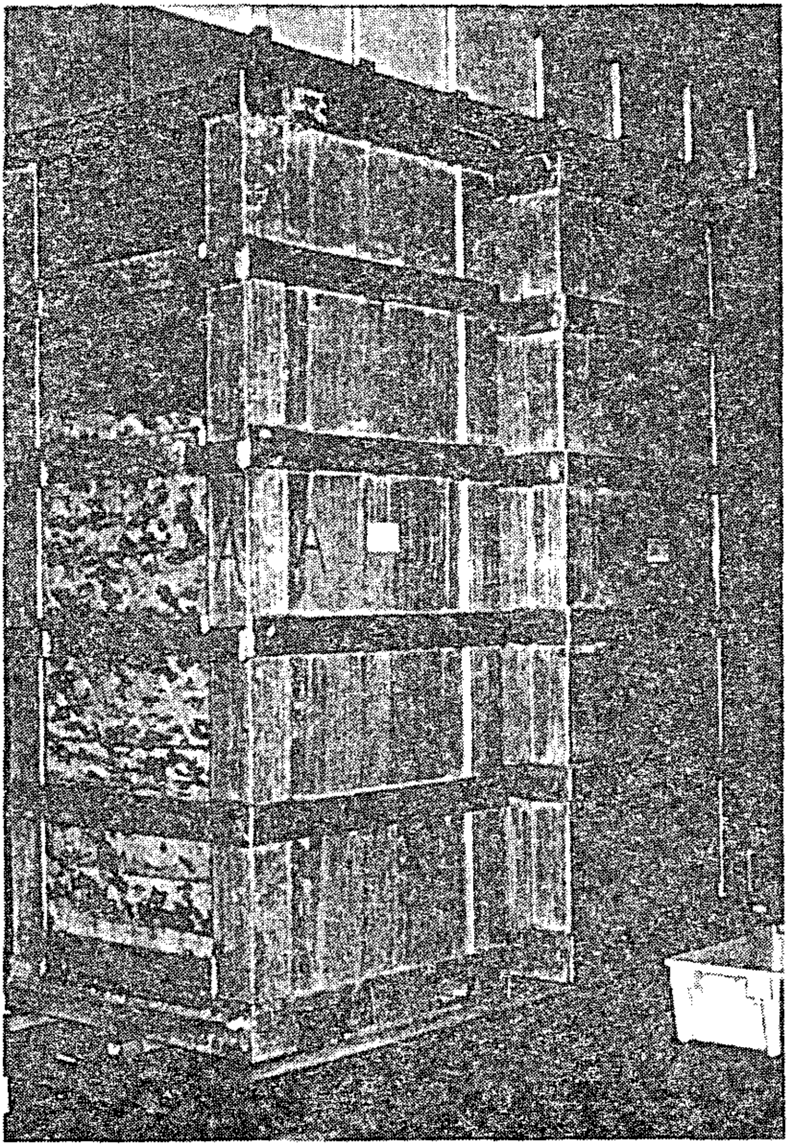
The following photographs were taken at the final stages of "The Saltfish Experiment"



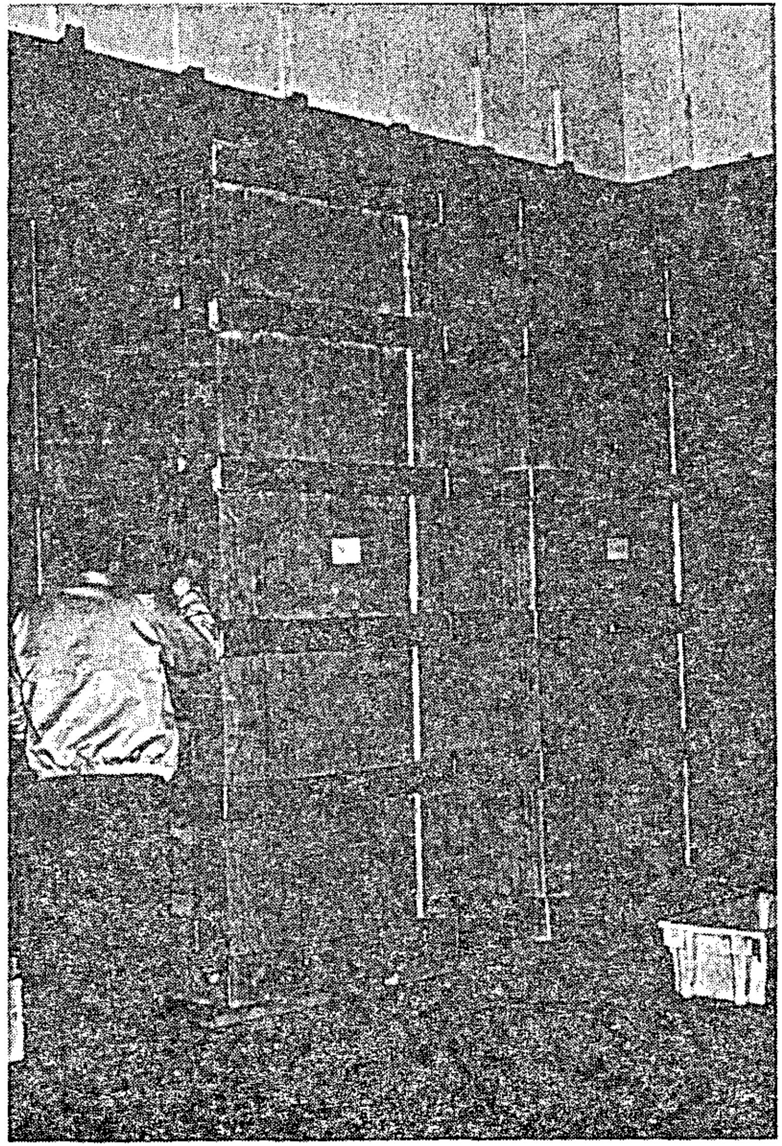
1. Overall view of Experiment (L-R Pallets A-F)



2. Brine Collection



3. Pallet 'A' during curing phase.
Note the division of daily levels.



4. Pallet'E' during curing phase.
Pallet dimensions 1 m. by 1 m.

4. EXPERIMENTAL RESULTS

4.1 Data

In order to keep this report to a manageable size, the original data have been collected in a separate section of the report. Summaries of data are presented only where necessary to clarify and support the main conclusions drawn in the sections to follow. Tables 2, 3, 4 contain some of these basic data.

4.2 Mass of Split Fish per Unit Bulk Volume

A major objective of the experiment was to obtain a split fish equivalent factor which could be used to convert directly from a measured volume of salted fish to the mass of split fish originally salted in the bulk. The factor was expected to depend on several variables, including the original ratio of salt to fish, the height of the bulk and the stage of curing process.

In each of the five pallets A through E, approximately 250-300 kg of split fish was salted each day. In pallet F, salting was continuous over a 9.4 hour period, simulating a high catch rate. The value of split fish equivalent factor - say E - at any time can be calculated by dividing the original split fish weight (in a layer of bulk, as appropriate) by the corresponding volume. For any one layer, this value increases monotonically with time from a value E_0 (which depends on the original salt to fish ratio, as we shall see) to E_f, which depends on the salt-to-fish ratio and several other variables. The addition of a quantity of new fish to a bulk will have the effect of reducing E.

TABLE 2

Basic Data Summary

	PALLET						
	A	B	C	D	E	F	MEAN
Round Fish - kg	4120	4114	4122	1816	3076	3303	
Split Fish - kg	2462	2508	2514	1068	1855	1895	
Salt Used - Kg	1234	1505	1759	641	1113	1137	
Moisture content at end of experiment	51.1±1.1*	51.1±0.7	50.9±0.8	51.5	51.4±0.8	53.2	51.5%
Salt content at end of experiment	18.3±0.6*	19.1±0.8	18.8±0.5	19.4	19.3±0.4	18.6	18.9%
Weight of fish taken from salt	1485	1498	1485	673	1128	1143	
Weight of excess salt	487	745	1004	319	555	568	

Average moisture content of fish before salting = 81.1% ± 0.6 (mean of 30 fish taken from the experiment during period July 19-29).

* Standard deviation when more than 4 samples. Number of samples:
A:9, B:9, C:9, D:4, E:7, F:3.

TABLE 3

Measurement of Split Fish Bulk Density

DATE	PALLETS	WEIGHT OF SPLIT FISH KG	VOLUME M^3	BULK DENSITY KG/M^3
July 19	F	1895	1.92	987
20	A-E	1289	1.35	955
21	A-E	1329	1.37	970
22	A-E	1348	1.29	1045
23	A-E	1320	1.37	964
25	ABCE	1122	1.12	1002
26	ABCE	1116	1.13	988
27	ABCE	1167	1.12	1042
28	ABC	844	0.83	1017
29	ABC	873	0.87	1003

MEAN $997 \pm 3\%$

TABLE 4

Measurement of Salt Bulk Density

SALT WEIGHT KG	VOLUME M^3	BULK DENSITY KG/M^3
1137.1	0.850	1338
129.3	0.094	1376
154.7	0.112	1381
178.3	0.130	1372
155.6	0.122	1275
155.6	0.122	1275
773.5	0.580	1334
131.1	0.098	1338
161.9	0.118	1372
188.7	0.139	1358
162.4	0.118	1376
155.6	0.121	1286
799.7	0.593	1349
132.9	0.098	1356
161.0	0.120	1342
185.9	0.139	1337
479.8	0.356	1348

MEAN $1342 \pm 2.5\%$

Tables 5 and 6 give the volume and weight measurements as the pallets were filled. E was calculated as explained above and bulk density D is simply the ratio of the mass of the bulk to its volume. Figures 5 and 6 show graphs of E with time for the six pallets.

4.3 Effect of Salt per Kilogram of Split Fish (Experiment #1)

Pallets A, B and C contained fish salted with 50, 60 and 70 kg of salt per 100 kg of split fish, respectively. In each case, one layer of fish was salted per day (except on day 4) until there were nine layers. All the curves have the same general shape, but clearly come to different final values of E (E_f). The initial value of the split fish equivalent factor, E_0, also depends on the original salt/fish ratio. Table 7 gives the values of E_0 and E_f estimated from Experiment #1. Pallets D and E have also been included from Experiment #2. In a later section analysis will show how they compare with a simple theoretical model.

TABLE 5

Split Fish Equivalent (E) and Bulk Density (D)

DATE/DAY		50 KG/100 KG PALLET A		60 KG/100 KG PALLET B		70 KG/100 KG PALLET C		REMARKS
		E kg/m^3	D kg/m^3	E kg/m^3	D kg/m^3	E kg/m^3	D kg/m^3	
20/07/83	0	759	1139	696	1114	670	1140	Salting approximately 270 kg.
21	1	897	1164	824	1162	818	1221	Split fish each day.
22	2	1005	1221	912	1209	849	1192	
23	3	1039	1202	946	1184	904	1213	
24	4	1179	1195	1089	1209	1006	1214	No salting.
25	5	1096	1180	1021	1195	963	1214	
26	6	1132	1202	1058	1224	967	1208	
27	7	1152	1201	1058	1204	989	1223	
28	8	1162	1188	1091	1230	1005	1230	
29	9	1201	1217	1110	1229	1026	1235	Last day salting, A, B, C.
30	10	1289	1218	1185	1241	1088	1243	
31	11	1338	1217	1235	1240	1127	1240	
1/08/83	12	1368	1219	1254	1234	1143	1234	
2	13	1383	1215	1273	1237	1153	1231	
3	14	1391	1210	1286	1238	1169	1237	
5	16	1407	1207	1299	1235	1180	1236	
8	19	1423	1206	1313	1234	1192	1236	
11	22	1439	1210	1327	1237	1203	1238	
15	26	1457	1213	1334	1235	1209	1236	
19	30	1465	1214	1341	1235	1215	1236	
26	37	1474	1212	1348	1233	1220	1233	
9/09/83	51	1492	1214	1363	1235	1232	1234	
22/09/83	64	1501	1213	1370	1242	1238	1233	
3/10/83	75	1510	1210	1378	1235	1251	1239	

TABLE 6

Split Fish Equivalent (E) and Bulk Density (D)

DATE/DAY		PALLET D		PALLET E		PALLET F		REMARKS
		E	D	E	D	E	D	
20/07/83	0	721	1153	719	1152	862	1378	End salting pallet F.
	1	840	1179	808	1132	1036	1236	
	2	911	1206	877	1160	1149	1229	
	3	971	1205	964	1188	1207	1242	End salting, pallet D.
	4	1709	1212	1101	1230	1247	1245	
	5	1136	1204	1029	1210	1263	1249	
	6		1211	1055	1225	1281	1249	
	7	1187	1206	1072	1230	1294	1249	End salting pallet E.
	8	1200	1204	1166	1231	1303	1250	
	9	1207	1202	1212	1234	1303	1244	
	10	1214	1203	1228	1231	1307	1243	
	11	1221	1203	1253	1238	1307	1241	
	12	1221	1196	1262	1233	1312	1240	
	13					1316	1241	
	14	1235	1201	1279	1232			
	15					1316	1235	
	16	1242	1203	1292	1234			
	17					1325	1237	
	19	1249	1200	1306	1237			
	20					1335	1239	
	22	1257	1200	1320	1241			
	23					1335	1236	
	26	1272	1209	1329	1243			
	27					1339	1235	
	30	1272	1203	1329	1235			
	31					1344	1234	
	37	1272		1344	1241			
	38					1354	1238	
	51	1279		1354	1239			
	64	1287		1354	1232			

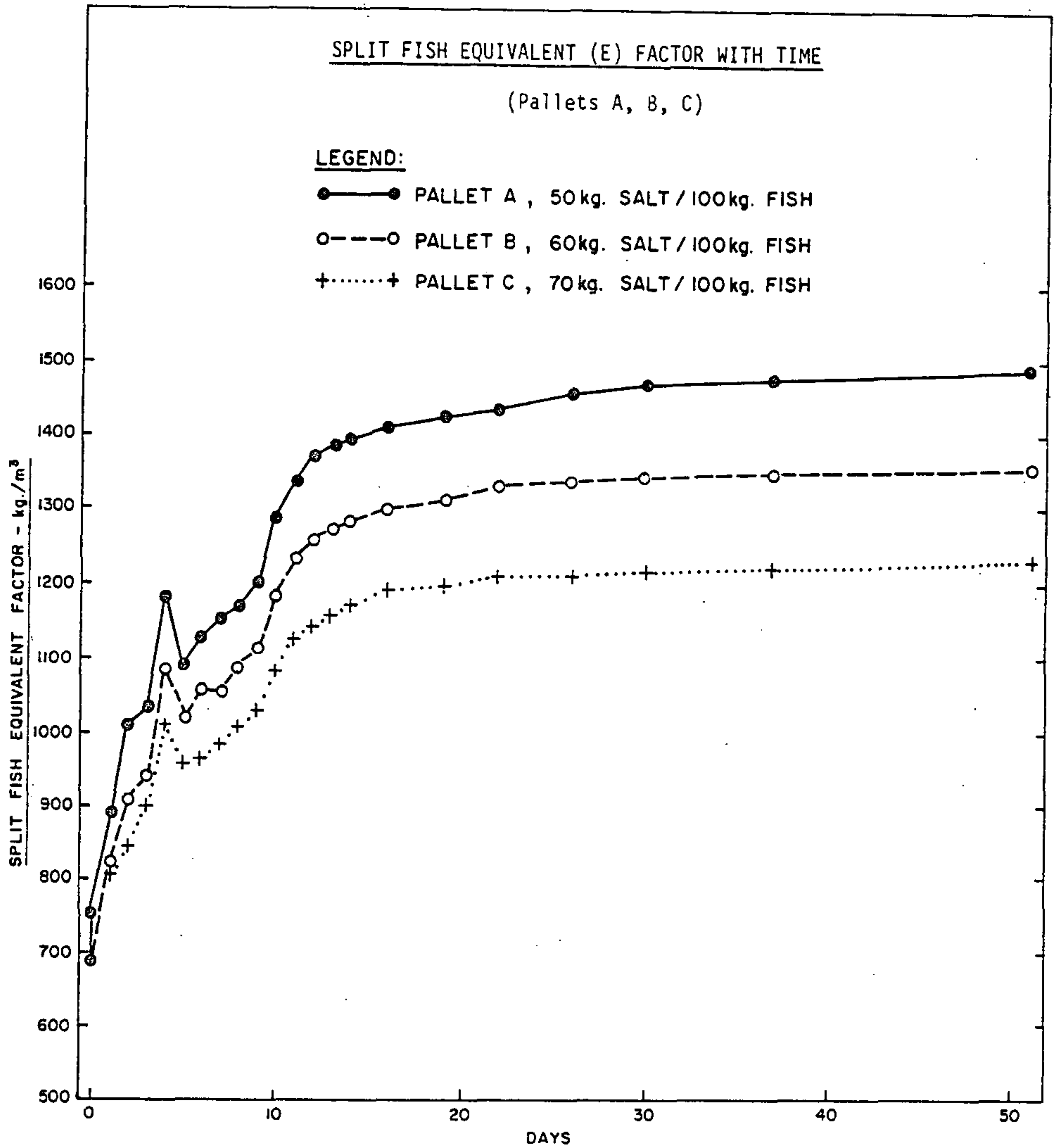


FIGURE 4. Split fish equivalent factor (E) with time (Pallets A, B, C)

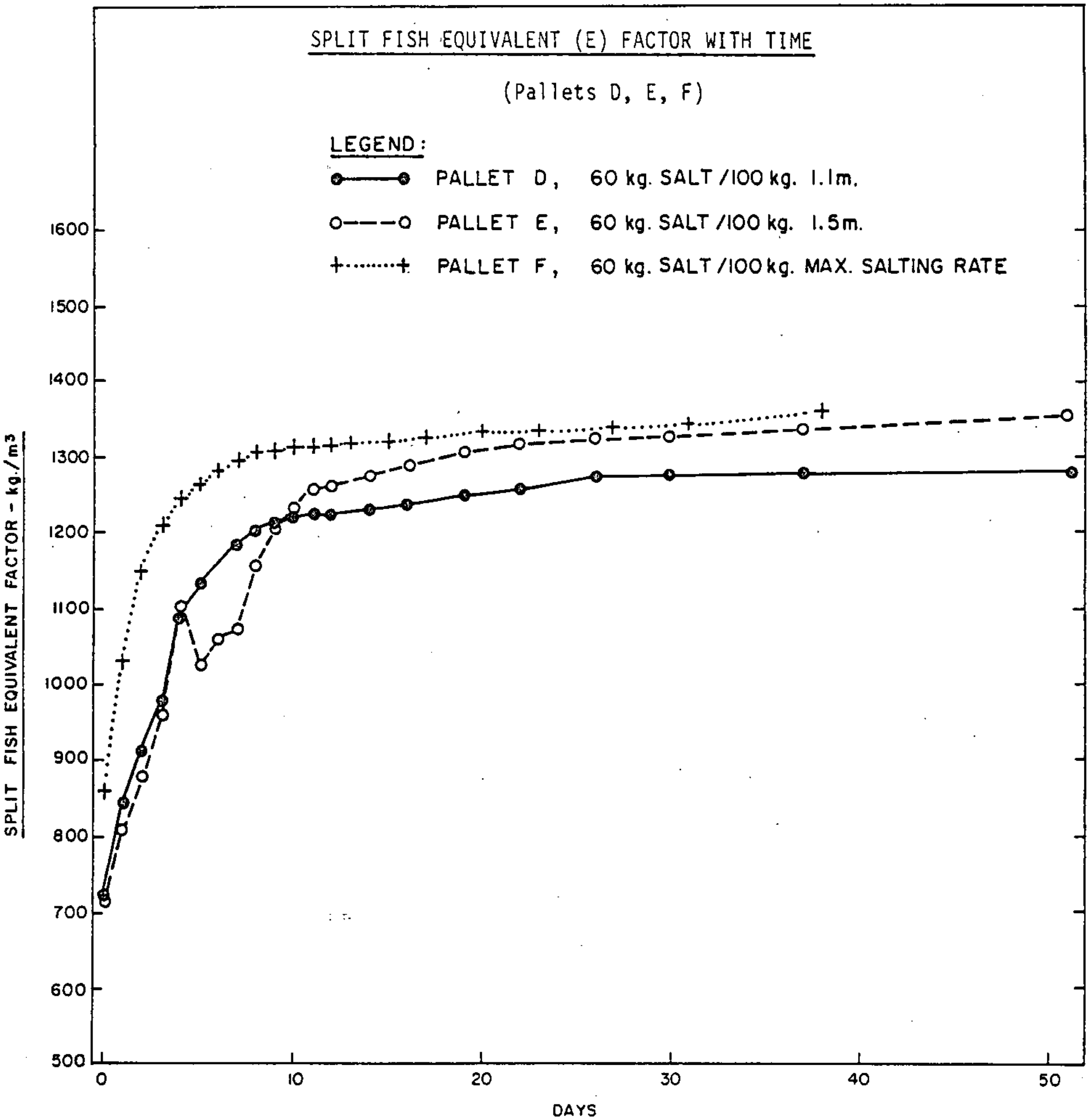


FIGURE 5. Split fish equivalent factor (E) with time (Pallets D, E, F)

TABLE 7

Initial and Final Values of E
(As Estimated from Experiment #1)

PALLET	ORIGINAL SALT TO FISH RATIO	E_0 kg/m^3	E_f kg/m^3
A	50	760	1480
B	60	690	1350
D	60	720	1280
E	60	720	1350
F	60	862	1350
C	70	660	1220

4.4 Effect of Bulk Height (Experiment #2)

As described in the experimental procedures, pallets B, D, E were loaded to different total heights, all other variables being kept constant. The percentage of salt used was 60 per cent for all three pallets. The main effect was on the value of E_f, and the results are summarized in Table 8.

TABLE 8

Effect of Bulk Height
(Experiment 2)

PALLET	FINAL HEIGHT	E_f
D	0.85	1280
E	1.35	1350
B	1.8	1350

The effect of different bulk height was only noticeable between the lowest pile (0.85 m) and the next highest (1.35 m), and the change in E_f was just over 5 per cent. This is reasonably presumed to be the effect of compression in the lower layers of the pile due to the weight above. Practical observation also leads us to believe that the compression effect is most pronounced at the start of the process of building a bulk. The amount of additional compression of a layer of fish rapidly approaches zero as the pile of fish above it increases, and once the layer has been compressed by a meter or so of fish, it is very difficult to compress it further. This is a reasonable explanation of why there was no noticeable difference between the 1.35 m and 1.8 m high pallets.

4.5 High Catch Rate (Experiment #3)

Pallet F was salted with 60 kg/100 kg split fish in one continuous pile to a total height of about 2 m over a 9.4 hour period. This was intended to simulate a period of high catch rates. As we shall see, this experiment also provided basic information from which the variation of the split fish equivalent factor (E) during intermittent salting and afterwards can be predicted.

Figure 6 shows the graph of split fish equivalent factor (E) with time. In this case E rises quickly to a final value of about 1350 kg/m^3. This value is consistent with pallets B and E, with the same salt to fish ratio and similar height. After two days in salt, the value of E has reached 1150 kg/m^3 or 81 per cent of its final value, and has reached 96 per cent of its final value in 8 days.

4.6 Mass Balance for Salt

It was of some interest - both for checking the accuracy of the experiment and to obtain certain experimental constants useful in the later analysis - to do an overall mass balance for salt. The amount of salt initially used was measured, as were brine volume and density, the final amount of undissolved salt, and the final salt content of the fish. Table 9 summarizes the results. Measurements of specific gravity showed that the brine draining from the bulk of fish was saturated. The amount of salt unaccounted for is quite small (between 2 and 5 per cent for the six pallets).

TABLE 9

Mass Balance for Salt

	PALLET					
	A	B	C	D	E	F
Salt taken from bulk - kg.	486.6	744.9	1003.6	318.6	554.8	568.1
Measured salt content (average) %	18.3	19.1	18.8	19.4	19.3	18.6
Salt in fish - kg	271.7	286.1	279.1	130.5	217.7	212.5
Volume of brine collected - Litre	1677	1684	1687	642	1214	1143
Mass of salt lost in brine (saturated) - kg	436	438	439	167	316	297
Total salt accounted for - kg	1194	1469	1722	616	1089	1078
Salt originally used - kg	1234	1515	1759	641	1113	1137
% accounted for (mass balance)	97	98	98	96	98	95

5. ANALYSIS

5.1 Initial Value of Split Fish Equivalent Factor

An attempt can be made to predict the initial or "instantaneous" value of E (say E_0) immediately after a layer of fish has been salted. This simple model will neglect any compression effect, and will also ignore voids. Considering the situation before any solution of salt has occurred, we can obtain the total volume of a fish and salt bulk by adding together the volumes of fish and salt. A straightforward analysis then shows that

$$E_0 = \frac{d_{sf}\, d_s}{d_s + r\, d_{sf}} \quad \text{................ Equation (1)}$$

where d_{sf} = bulk density of split fish

d_s = bulk density of salt

r = ratio of salt to fish

Table 10 shows theoretical values according to equation (1) as well as the measured values of E for the first layers salted for each pallet. These values of E_0 are reasonably close to the initial measurements, keeping in mind that by the time the measurement was made, some solution of salt had taken place and the value of E was already rising as shown in Figures 5 and 6.

TABLE 10

Initial Value of Split Fish Equivalent Factor

PALLET	SALT TO FISH RATIO, r	E_o EQN. (1)* kg/m^3	FIRST MEASURED E_o kg/m^3	TIME TO SALT FIRST LAYER-hr
A	0.50	727	759	1.0
B	0.60	690	696	1.3
C	0.70	656	670	2.5
D	0.60	690	721	2.6
E	0.60	690	719	1.2
F	0.60	690	862	9.4

* Split fish density = 997 kg/m^3, salt density = 1342 kg/m^3.

In addition to the experimental data in Table 10 for the first layers on each pallet, it is possible to use all the layers, noting the time it took to build them, and then extrapolate linearly to zero time to obtain another experimental estimate of E_o. However, the thickness of a pile of fish is not easy to define precisely; there is scatter in the data, and not a high correlation with time. A plot of the data in Table 10 for pallets B, D, E and F nevertheless gives very good agreement with the value of E_o from equation (1).

In conclusion, equation (1) gives a very reasonable estimate of E_o, and has the great virtue of simplicity. The estimate is slightly conservative, by which is meant that if it were used to calculate the

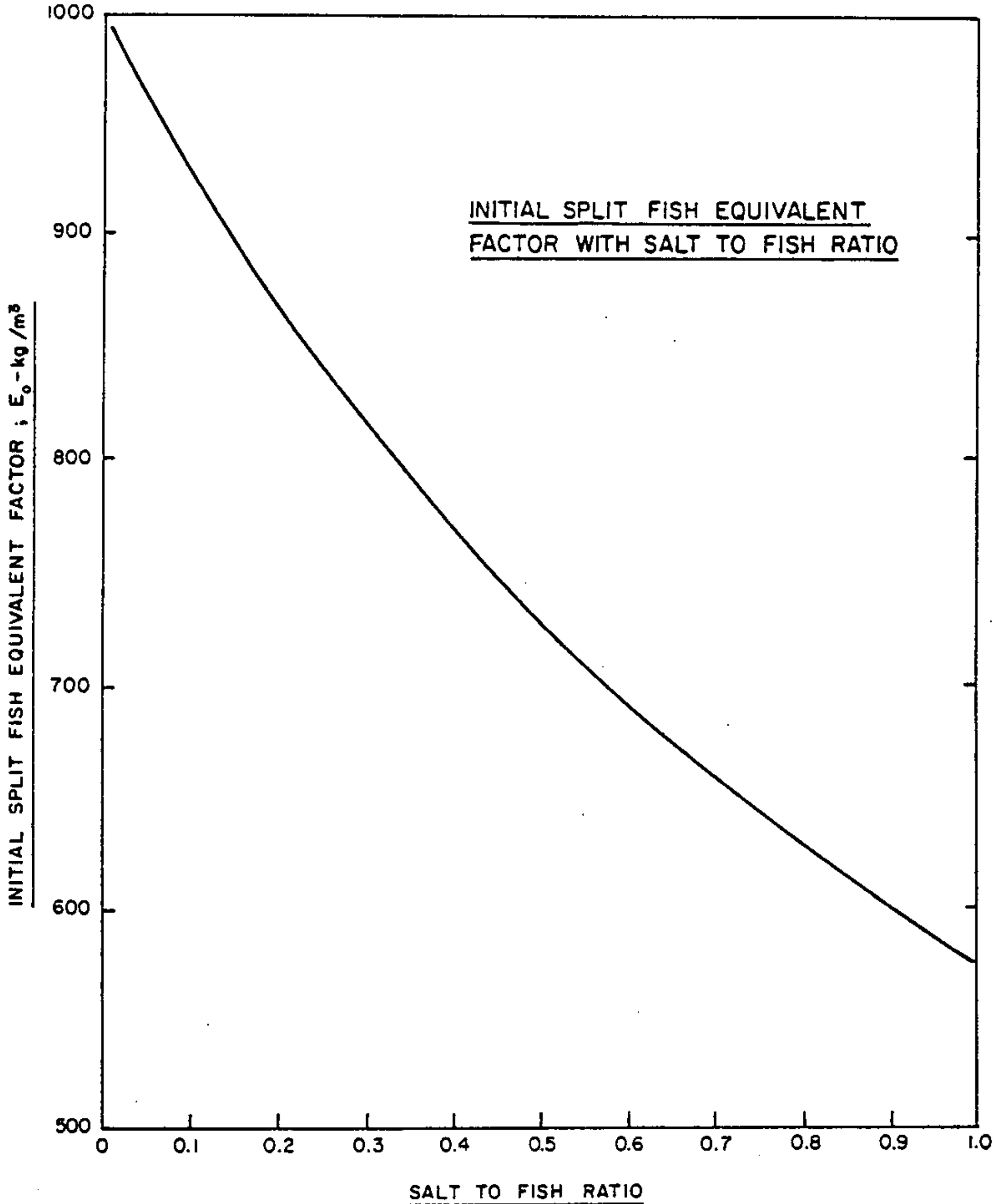


FIGURE 6. Initial split fish equivalent factor with salt to fish ratio

amount of split fish in a vessel, the estimate would likely be slightly below the actual weight. This is due to certain assumptions which are discussed below. Figure 7 shows a graph which gives E_0 for various salt to fish ratios, based on equation (1).

5.2 Equilibrium Value of E

The graphs of E with time (Figures 5 and 6) show that after a certain period, the split fish equivalent factor approaches what appears to be an equilibrium or final value - say E_f. As with E_0, it is possible to predict a theoretical value for E_f, but the process is somewhat more complex, and involves several other variables such as moisture content, salt content, and the density of fully cured salt fish. Again, we will make certain simplifying assumptions. In particular we neglect compression in the pile, assume there are no voids, neglect the small loss of protein through solution in the brine, and assume the brine which flows away is fully saturated with salt. These simplifications are not unreasonable in the light of experimental measurement, but we must not lose sight of them when the theoretical model is to be interpreted.

We start by equating the volume of the final bulk to the sum of the volume of the salted fish and the remaining salt in the pile. The weight of fish is clearly determined by the original amount of split fish, its initial and final moisture content, and the salt content. The weight of salt remaining is determined by the original amount used, the amount absorbed by the fish and the amount drained away in the brine. After some algebra, (see Appendix II) we arrive at the following equation:

$$E_f = \frac{d_{cf} d_s}{d_s \left[\frac{1-M_o}{1-M_f-S} \right] + d_{cf} \left[r - \frac{S(1-M_o)}{1-M_f-S} - 0.36 \left[\frac{M_o(1-S)-M_f}{1-M_f-S} \right] \right]} \quad \text{......... Equation (2)}$$

Where d_{cf} = bulk density of cured fish, kg/m^3

d_s = bulk density of salt, kg/m^3

M_o = original moisture content of fish (fraction of wet weight)

M_f = final moisture content of fish (fraction of wet weight)

S = salt content of fish (fraction of wet weight)

r = ratio of weight of salt used to weight of split fish

E_f = final split fish equivalent factor, kg/m^3

All of the variables in equation (2) except for d_{cf}, the density of cured fish, have already been discussed or established by direct measurement. This final variable can also be estimated from the experimental data since the weight and volume of the total bulk and the salt were measured at the end of the experiment. If we neglect the effect of any voids, an effective bulk density for cured fish can be calculated. Table 11 gives the data and estimated values of d_{cf}.

TABLE 11

Bulk Density of Cured Fish

PALLET	FINAL VOL m^3	WT. SALT REMAINING kg	VOL SALT m^3	WT. CURED FISH kg	DENSITY CURED FISH kg/m^3
A	1.63	487	0.36	1485	1169
B	1.82	745	0.56	1498	1189
C	2.01	1004	0.75	1485	1179
D	0.83	319	0.24	673	1141
E	1.36	555	0.41	1128	1187
F	1.38	568	0.42	1143	1191
					1176 (Mean)

The values of d_{cf} in Table 11 show quite reasonable consistency from pallet to pallet, and have a mean value of 1176 kg/m^3.

One could now produce a comparison of experiment and theory for each pallet. Since all the fish received a similar treatment however, in that result should be heavysalted saltbulk, it is perhaps more realistic to take the average values of the variables in equation (2) (e.g. final salt and moisture contents, which vary slightly from pallet to pallet) and compute theoretical values for E_f for comparison with experimental results. We therefore set values as follows:

M_o = 0.811 (Table 2); M_f = 0.515 (Table 2);

S = 0.189 (Table 2); d_s = 1342 (Table 4);

and d_{cf} = 1176 (Table 11).

Allowing r to take values from 0.3 to 1, we get a set of values for E_f as given in Table 12, which includes the experimental values.

TABLE 12

Equilibrium Values of Split Fish Equivalent Factor

SALT TO FISH RATIO*	E_f FROM EQN. (2) kg/m^3	EXPERIMENTAL	
		PALLET	E_f**
0.3	1827		
0.4	1608		
0.5	1436	A	1480
0.6	1297	B	1350
0.6	1297	D	1280
0.6	1297	E	1350
0.6	1297	F	1350
0.7	1183	C	1220
0.8	1087		
0.9	1006		
1.0	936		

* If this ratio is less than approximately 0.30, there will not be sufficient salt to saturate all the water present, and fully salted fish will not be obtained.

** See Table 7.

Apart from pallet D, the experimental values are slightly higher than the theoretical ones by up to approximately 4 per cent. In our view that is excellent agreement. Both the compression of the bottom layers and the loss of protein through solution have been neglected in the model, and these assumptions should lead to errors which compensate each other. Furthermore, it is interesting to note that the only experiment which gives a lower value of E_f than the theoretical model in equation (2) is one in which the pile was lowest, and therefore compression effect least (pallet D, height 0.85 m).

Figure 8 shows graphs of E_f with r for two different final moisture contents. In our experiments M_f was measured to be about 52 per cent (wet basis), which is a little below what one normally expects for salt bulk fish. This may have been due to slight loss of moisture in the lab before analysis, or perhaps to the fact that previous experience is based on cured fish washed prior to drying, which is probably slightly higher in moisture. Similar variations in initial moisture content and salt content also affect E_f. Equation (2) can easily be used to investigate these effects. More importantly, it provides the means of generalizing our results to other moisture contents, salt contents, and salt-to-fish ratios. The ability to predict E_0 and E_f is thus of some significance , and when combined with the results from the experiment with pallet F (Experiment #3), enables the prediction of the value of E as it changes from E_0 to E_f in the salting process, as we shall see in the next section.

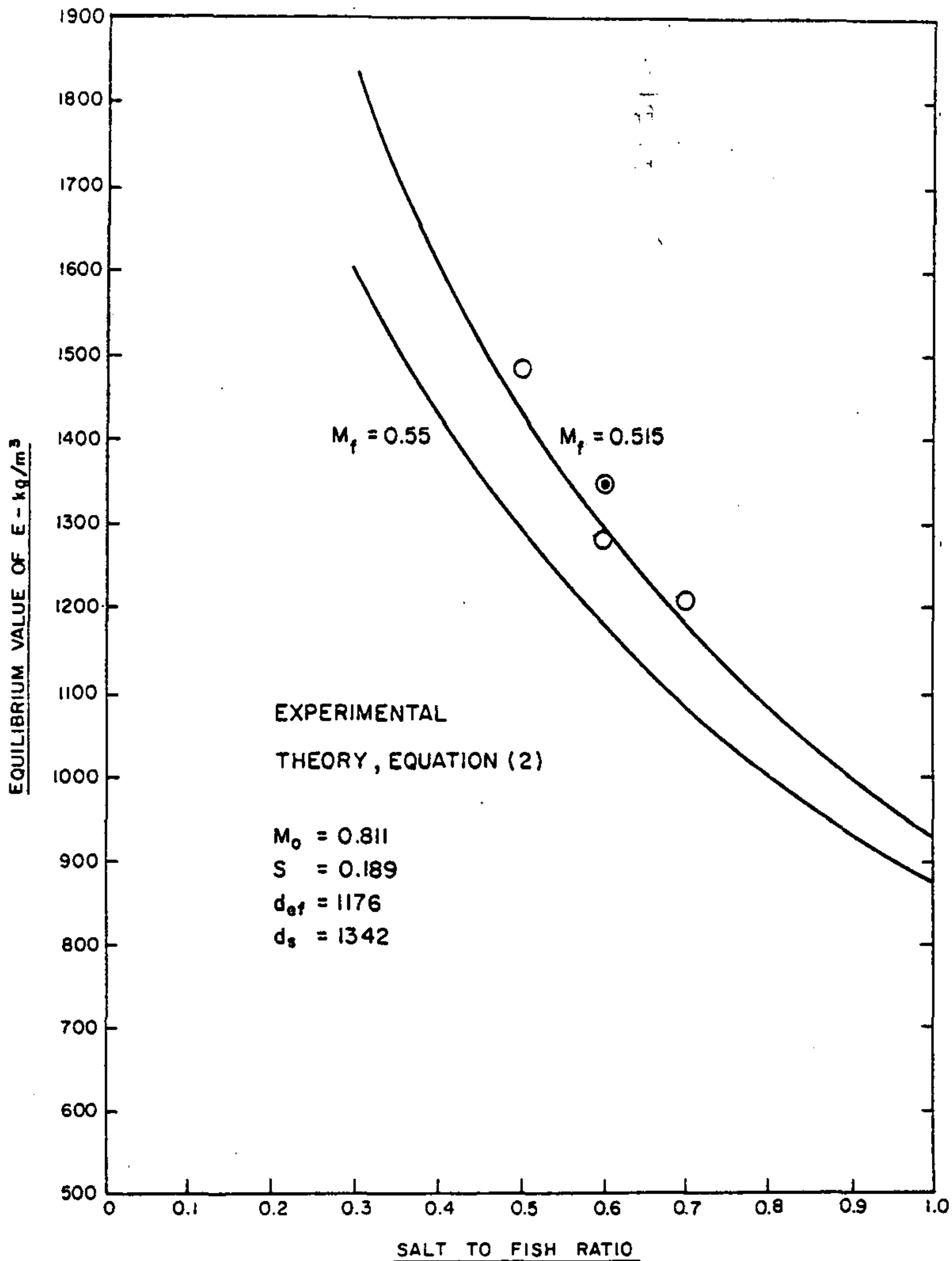


FIGURE 7. Equilibrium value of split fish equivalent factor

5.3 Variation of E with Time

Figures 5 and 6 show E rising from E_0 to E_f for the bulk as a whole. As each layer is added, its value of E begins at E_0 and follows the pattern shown by pallet F as time goes on, to eventually approach E_f. This variation from E_0 to E_f happens simultaneously at all levels in the bulk, and the value of E for any layer depends on the length of time it has been salted. The overall value of E is a combination of the values of E for the various layers, as each layer decreases in thickness. Analysis shows that at any time the overall value of E for the bulk is the weighted average of those of all the layers, where the "weights" in the average are the layer thicknesses. A more detailed discussion of this variation is found in Appendix II.3.

It will be helpful if we deal with the dimensionless ratio R given by

$$R = \frac{E - E_0}{E_f - E_0} \quad \text{.............................. Equation (3)}$$

As E varies from E_0 to E_f, R varies from 0 to 1. If we now have a bulk consisting of N layers, each having values of E corresponding to the period in salt, such that for each layer R takes values R_1, $R_2 \ldots R_n$, then the result of the mathematics is that

$$\overline{R} = \frac{\sum \frac{F_n R_n}{1+(E_f/E_0-1)R_n}}{\sum \frac{F_n}{1+R_n(E_f/E_0-1)}} \quad \text{...................... Equation (4)}$$

where the summation is over all the N layers, and

$$R_n = \frac{E_n - Eo}{E_f - E_o} \quad \text{for layer } n$$

E_f = equilibrium value of E

E_o = initial value of E

F_n = fraction of total bulk in layer n

When $\overline{R}$ has been found, E for the whole bulk can be calculated from reversing the process in equation (3), i.e.

$$\overline{E} = (E_f - E_o)\,\overline{R} + E_o \quad \text{........................ Equation (5)}$$

The value of R for any layer depends on the time it has been in salt. For the purpose of this analysis, we will measure time in days. In Experiment #3 (pallet F) salting was as fast as possible, and there was essentially one layer. We now construct a model in which the variation of E with time for this pallet is used to simulate each layer in a bulk of fish. All the layers are then combined using equation (4) to obtain a model for the whole bulk.

A graph of R with time for pallet F is shown in Figure 9. To construct this curve the value of E_o has been taken as 690 kg/m^3, as given by equation (1), but the value of E_f is the experimental estimate, i.e. 1350 kg/m^3. This final value is not critical to the simulation, but it is convenient and realistic not to have R exceed 1. After passing a smooth curve through the experimental points of Figure 9 and interpolating where necessary, we can construct a table of model values of R with time (Table 13).

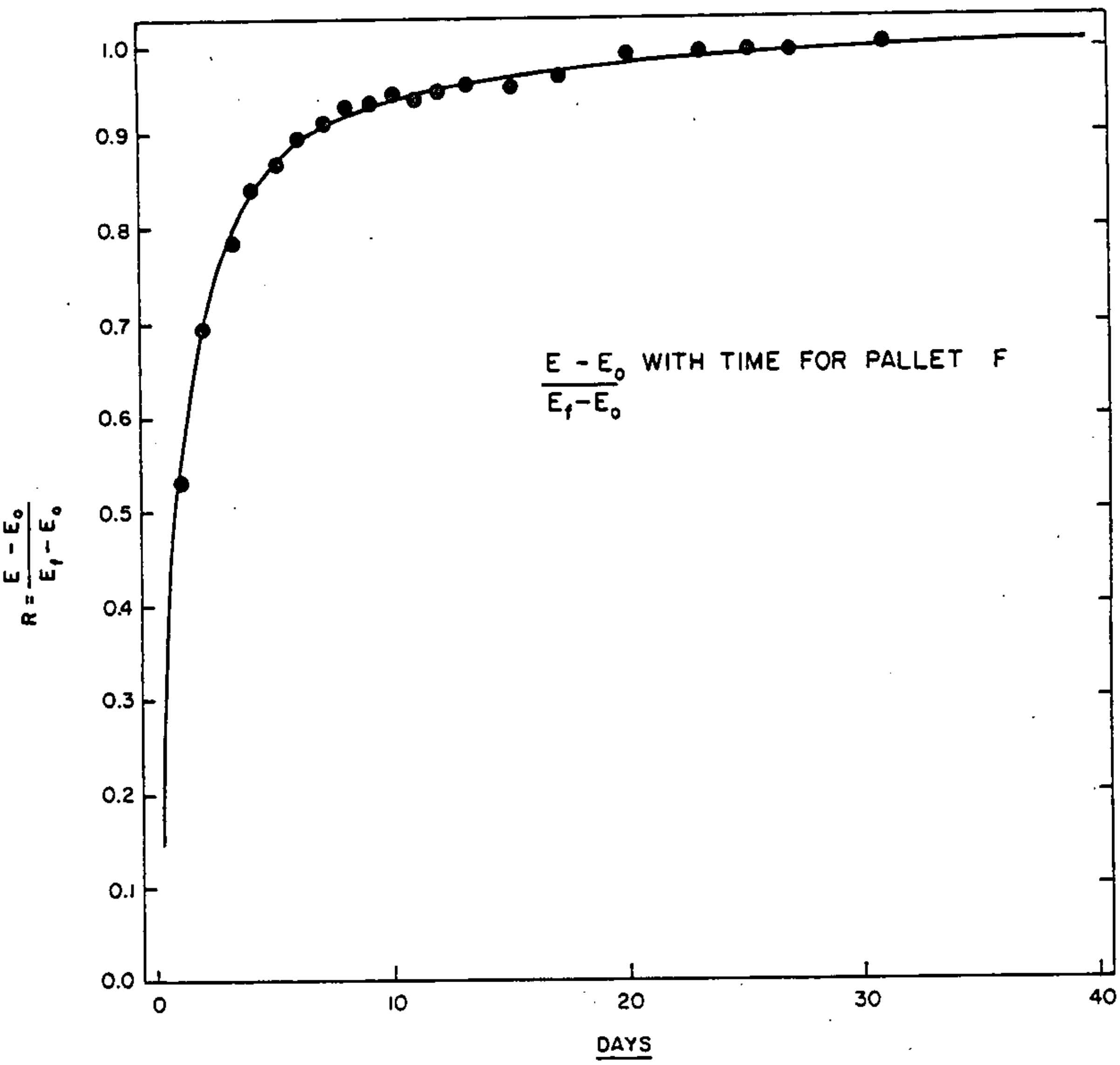


FIGURE 8. R as a function of time for pallet F

TABLE 13

Model Values of R with Time

TIME DAYS	R	TIME DAYS	R	TIME DAYS	R	TIME DAYS	R
0	0	10	0.94	20	0.97	30	0.99
1	0.52	11	0.94	21	0.97	31	0.99
2	0.69	12	0.95	22	0.97	32	0.99
3	0.78	13	0.95	23	0.98	33	0.99
4	0.84	14	0.96	24	0.98	34	0.99
5	0.87	15	0.96	25	0.98	35	0.99
6	0.89	16	0.96	26	0.98	36	0.99
7	0.91	17	0.97	27	0.98	37	0.99
8	0.92	18	0.97	28	0.98	38	0.99
9	0.93	19	0.97	29	0.99	39	1.0

The values of F_n in equation (4) are determined by the fraction of total split fish originally put in each layer (i.e. the fraction of split fish which will be of a particular age). These data are shown in Table 14 for all pallets except F, in which there was only one layer.

TABLE 14

Distribution of Split Fish by Layers and Days in Salt (Age)

LAYER	DAY SALTED*	PALLET A		PALLET B		PALLET C		PALLET D		PALLET E	
		KG	F	KG	F	KG	F	KG	F	KG	F
1	0	258.0	0.105	257.6	0.103	254.5	0.101	259.5	0.243	259.0	0.140
2	1	262.2	0.107	269.7	0.108	269.0	0.107	269.7	0.253	258.4	0.139
3	2	263.5	0.107	266.5	0.106	265.8	0.106	263.1	0.246	289.2	0.156
4	3	275.8	0.112	284.9	0.114	277.1	0.110	275.8	0.258	205.9	0.111
5	5	277.1	0.113	279.2	0.111	281.7	0.112			284.2	0.153
6	6	282.6	0.115	282.9	0.113	285.5	0.114			264.9	0.143
7	7	293.0	0.119	285.5	0.114	295.1	0.117			293.0	0.158
8	8	261.3	0.106	289.6	0.115	293.0	0.117				
9	9	288.0	0.117	292.1	0.116	292.4	0.116				
TOTAL (rounded)		2462	1.00	2508	1.00	2514	1.00	1068	1.00	1855	1.00

* Note that no fish was salted on day 4.

A computer program was written to carry out the calculations required by equation (4) as a bulk of fish was salted and curing proceeded. For any simulation the inputs to the model are the initial value of E given by equation (1), the final value of E given by equation (2) and the age distribution of the fish, as given in Table 14, for example. The program contains the standard data in Table 13, which is used to generate the correct value of R for each layer of fish as time progresses.

Figure 10 shows graphically comparisons of simulated and experimental data for pallets A and C. Comparisons for the other experiments are similar, and in one case (pallet D) the agreement is better than the example given in Figure 10.

It will be seen that the model can predict the behavior of E with time very well indeed - in spite of what looked like quite irregular variation in Figures 5 and 6. The difference between simulation and experiment as E nears equilibrium is a direct result of the fact that the theoretical E_f from equation (2) is somewhat below the experimental value, as we have previously discussed. It has to be kept in mind that the model neglects compression effect and will likely underestimate E_f. For the low pile (pallet D) the agreement between experimental and theoretical E_f is better - with the theoretical value actually being a little higher than experimental.

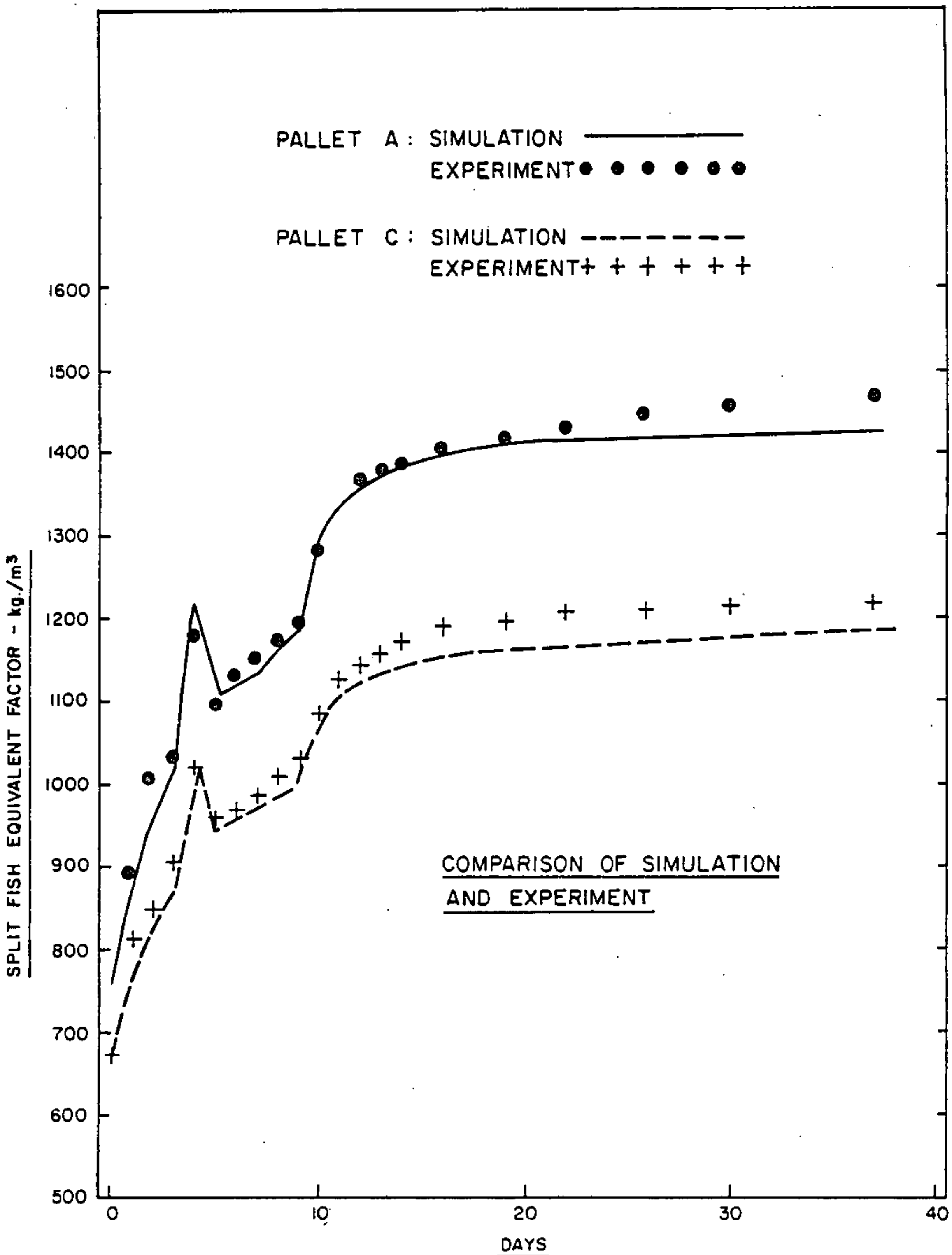


FIGURE 9. Comparison of simulation and experiment

6. APPLICATION

If we assemble equations 1, 2, 4, 5 and the information in Table 13, we have a model which has been able to predict the split fish equivalent factor to within 4 or 5 per cent for all the experiments carried out in the project. The inputs and parameters necessary to run the model are assembled in Table 15. The output is a set of values of split fish equivalent factor for each day (or other selected time interval) from the time the first fish was salted (day zero) to 40 days.

It will perhaps be useful to apply this model to a number of "scenarios" corresponding to imaginary fishing and salting practices at sea. In all cases the following values of parameters will be used, unless otherwise specified: $r = 60\%$; $M_0 = 81\%$; $M_f = 52\%$; $S = 19\%$, and other constants (e.g. densities) as in Table 15. For these data $E_0 = 690\ kg/m^3$ and $E_f = 1273\ kg/m^3$.

The scenarios chosen were as follows:

(a) Slow fishing: 5% of total bulk daily for 20 days.

(b) Fast fishing: 20% per day for 5 days.

(c) Intermittent: 20% every third day.

(d) "Mostly last three days": 10% in each of first two days followed by five days of no fish caught, then 20%, 30% and 30% in next three days.

The results of these calculations are shown in Figure 11. Curves (a) and (b) in Figure 11 show how the value of E is depressed while new

TABLE 15

Parameters for Split Fish Equivalent Factor Model

PARAMETER	DESCRIPTION AND VALUES USED
d_{sf}	bulk density of split fish (997 kg/m^3)
d_s	bulk density of salt (1342 kg/m^3)
r	salt to fish ratio
E_0	Initial value of E. Output from eqn. (1), input to (4)
d_{cf}	bulk density of cured salt bulk fish (1176 kg/m^3)
M_0	Moisture fraction, split unsalted fish (0.80 - 0.82)
M_f	Moisture fraction, cured salt bulk (0.50 - 0.55)
S	Salt fraction, cured salt bulk (0.18 - 0.20)
E_f	Equilibrium value of E. Output from eqn. (2) input to (4)
R	See equation (3). Values of R go from 0 to 1 as fish cures and, based on experiment, describe the variation of E with time. Standard data is contained in Table 13 and the computer program.
F_n	Fraction of bulk contained in n^{th} layer as originally salted. Input to equation 4, and program.
t	time in days. Input to computer.
E	Split fish equivalent factor. Output from program, for any requested day up to 40.

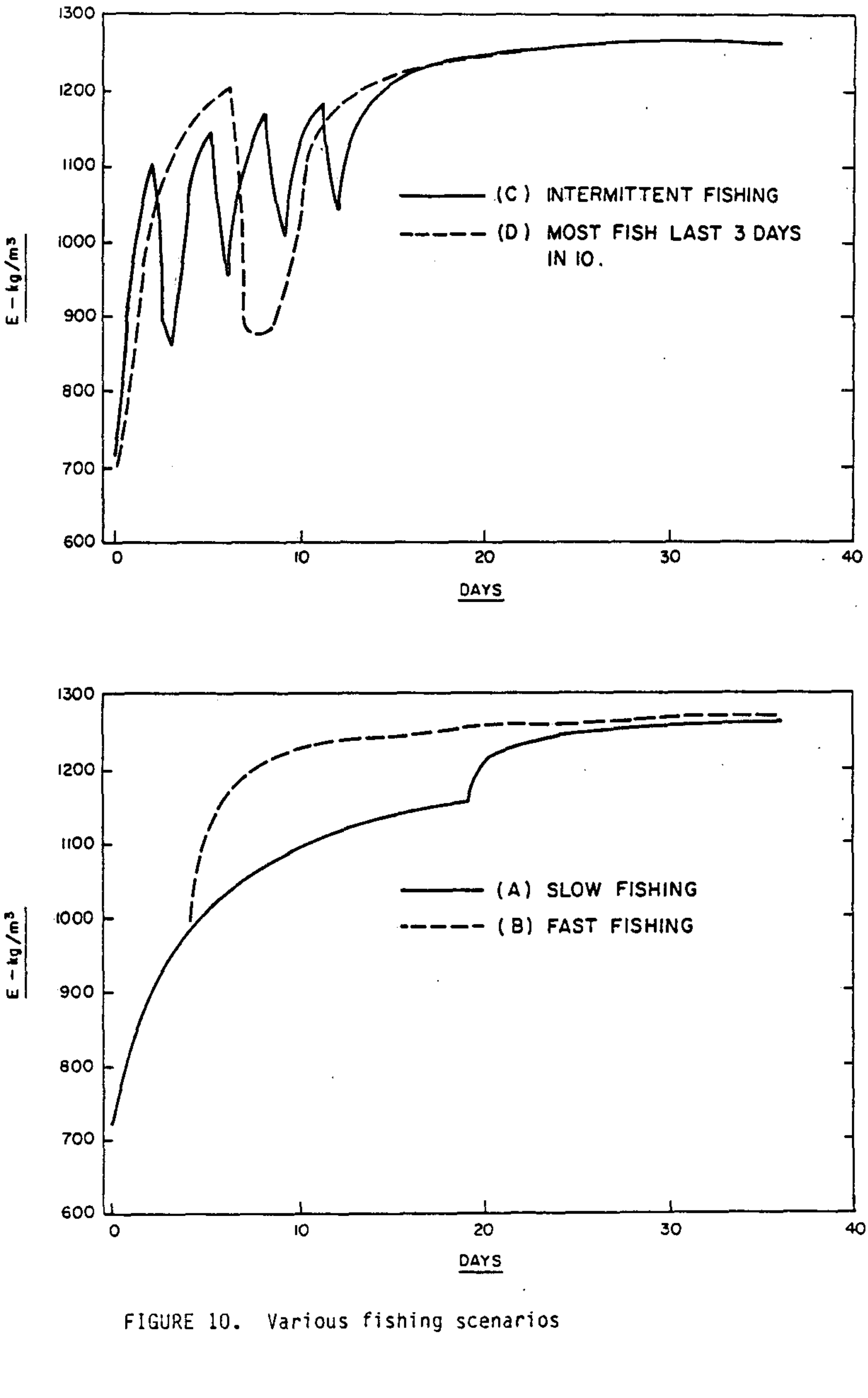


FIGURE 10. Various fishing scenarios

fish is being salted, compared to the rapid rise towards equilibrium when salting is complete. The breaks in both curves (a) and (b) occur when salting ends. Scenarios (c) and (d) lead to highly variable patterns for the split fish equivalent factor during the intermittent fishing period. The addition of new fish again forces the value of E lower, and it rises quickly unless fish is being added.

It is difficult to give general rules which would apply in all situations, and it would obviously be very useful to consider practical cases based on experience. Perhaps one general rule is that by seven days after the end of salting, no matter what the fishing pattern has been, the value of E has reached about 96 per cent of its final value.

7. CONCLUSIONS

The answers to the basic questions which arise from the study objectives (see Section 1.2, page 2) are contained in Tables 5 and 6 and Figures 5 and 6. The salt to fish ratio controls the initial value of the split fish equivalent (conversion) factor, as given by equation (1). In addition to the salt/fish ratio, moisture fraction and salt content also affect the final or equilibrium value of the factor. This equilibrium value can be calculated from equation (2). The variation from initial to final values is predictable, and the addition of new fish tends to reduce the factor. A set of equations has been derived and combined in a fairly simple computer program which enables the calculation of conversion factors consistent with the experiments, and which allows us to generalize the results. The effect of compression in the bulk is to slightly increase the conversion factor predicted by theory for pile depth greater than about one meter. The difference is approximately 5 per cent.

Once the values of the parameters (Table 15) have been quantified, it is possible to calculate a definitive conversion factor within the range of 600 to 1500 kg/m^3.

APPENDIX I

A.1 RECOVERIES

One of the byproducts of this experiment was a set of data from which the "recovery" or weight of cured fish per kg of split could be calculated. In principle this should be a straightforward calculation, based on a mass balance, provided moisture and salt contents are known before salting and at the stage the recovery is to be calculated. There is generally some discrepancy with theory, however, since protein is always lost in the brine solution, and there is no simple theoretical way to account for this.

The mass balance before and after the salting and curing process gives the following equation:

$$\frac{W_{cf}}{W_{sf}} = \frac{1 - M_o}{1 - M_f - S} \quad \text{.......................... Equation (A1)}$$

Where W_{cf} = weight of cured fish

W_{sf} = weight of split fish

And other variables have been previously defined.

For fish that has been "struck" and not dried, it is also a fact that the moisture present in the flesh is completely saturated with salt. For a saturated salt solution, $\frac{S}{M_f} = 0.36$, and one of these variables can be eliminated in equation (A1). In the experiment here, however, both M_f and S were measured and we can use the values which were found independently.

The theoretical and actual values are presented in Table A1, together with other pertinent data. The actual recovery is about 5 per cent lower than that predicted by equation (A1), and it is probably reasonable to assume that this is due to protein loss in solution during the brining process.

It is important to note that the overall recovery that can be expected depends rather heavily on initial and final moisture contents. This is shown in Figure A1. For example, a change in final moisture from 52 to 56 per cent will increase recovery from 0.65 to 0.76.

TABLE A1

Theoretical and Actual Recoveries

PALLET	RECOVERY		M_o	M_f	S	S/M_f
	THEORY	ACTUAL				
A	0.618	0.603	0.811	0.511	0.183	0.358
B	0.634	0.597	0.811	0.511	0.191	0.374
C	0.630	0.591	0.811	0.509	0.188	0.369
D	0.649	0.630	0.811	0.515	0.194	0.377
E	0.645	0.608	0.811	0.514	0.193	0.375
F	0.670	0.603	0.811	0.532	0.186	0.350
MEAN	0.640	0.605	0.811	0.515	0.189	0.367

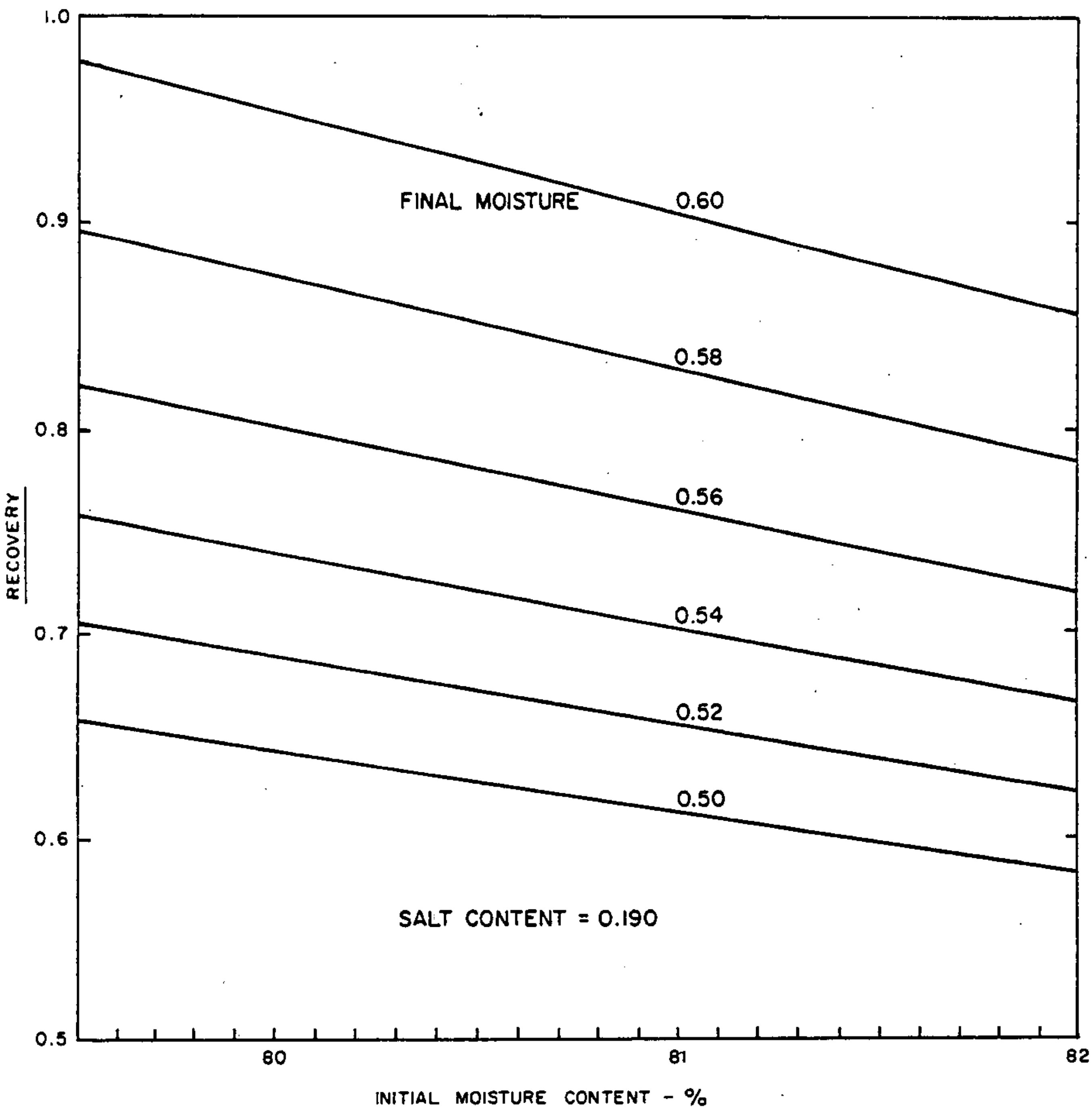


FIGURE A1. Theoretical recoveries

APPENDIX II

DEVELOPMENT OF EQUATIONS IN REPORT

"EXPERIMENT TO DETERMINE SPLIT FISH EQUIVALENT FACTOR

FOR SALTED CODFISH IN BULK"

DEVELOPMENT OF EQUATIONS IN REPORT "EXPERIMENT TO DETERMINE SPLIT FISH EQUIVALENT FACTOR FOR SALTED CODFISH IN BULK"

1. Initial Value of E

$$E_o = \frac{d_{sf}\, d_s}{d_s + r\, d_{sf}} \qquad \text{(Equation 1 in Report)}$$

Where d_{sf} = bulk density of split fish, kg/m^3

d_s = bulk density of salt, kg/m^3

r = ratio of weights of salt to fish

E_o = initial split fish equivalent factor

When the salt and fish are initially combined, total volume = volume of split fish + volume of salt.

ie. $V_o = V_{sf} + V_s$ .... (1)

d_{sf} = weight of split fish / V_{sf} = W_{sf} / V_{sf}

d_s = weight of salt / V_s = W_s / V_s

Also $E_o = W_{sf} / V_o$, and substituting into equation (1), we get

$$\frac{W_{sf}}{E_o} = \frac{W_{sf}}{d_{sf}} + \frac{W_s}{d_s} = \frac{W_{sf} d_s + W_s d_{sf}}{d_{sf}\, d_s}$$

Rearranging,

$$E_o = \frac{d_{sf}\, d_s}{W_{sf}\, d_s + W_s\, d_{sf}} \quad W_{sf}$$

$$= \frac{d_{sf}\, d_s}{d_s + r\, d_{sf}} \text{, as required}$$

2. Final Value of E

$$E_f = \frac{d_{cf}\, d_s}{d_s\left(\frac{1-M_o}{1-M_f-S}\right) + d_{cf}\left(r - \frac{S(1-M_o)}{1-M_f-S} - 0.36\left(\frac{M_o\ (1-S)-M_f}{1-M_f-S}\right)\right)}$$

(Equation 2 of Report).

where E_f = Final split fish equivalent, kg/m^3

d_{cf} = bulk density of cured fish, kg/m^3

M_o = original moisture content of fish (fraction)

M_f = final moisture content of fish (fraction)

S = salt content of fish (fraction of wet weight)

r = salt to fish ratio

We again start with the obvious statement that the final volume of the bulk of fish and excess salt is given by:

$V_f = V_{cf} + V_{xs}$ .... (2)

where V_{xs} = volume of excess salt in bulk

V_{cf} = volume of cured fish

V_f = total final volume

Note that voids are being neglected

Now $V_{cf} = \frac{W_{cf}}{d_{cf}}$, $V_{xs} = \frac{W_{xs}}{d_s}$ .... (3)

where W_{cf} = weight of cured fish

W_{xs} = weight of excess salt in bulk

The weight of excess salt is simply the original amount of salt used less the amounts absorbed by the fish and that lost in the brine which has drained away. The amount absorbed by the fish is S W_{cf} where S is the fractional salt content (wet basis). Since the experiment showed that the brine draining away from the fish was saturated, the amount of salt lost in this way is 0.36 times the amount of water lost, which is $M_o W_{sf} - M_f W_{cf}$, where W_{sf} is the weight of split fish originally salted. We therefore get that

$$W_{xs} = W \;\; - S\, W_{cf} - 0.36\,(M_o W_{sf} - M_f W_{cf}) \;\ldots\ldots\ldots\ldots\ldots\ldots \;(4)$$

The weight of cured fish is simply given by the weight of original split fish less the water lost plus the weight of salt gained,

ie.

$$W_{cf} = W_{sf} - (M_o W_{sf} - M_f W_{cf}) + S\, W_{cf}$$

which gives

$$W_{cf} = \frac{W_{sf}\,(1 - M_o)}{1 - M_f - S} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \;(5)$$

Incidentally, $\dfrac{W_{cf}}{W_{sf}} = \dfrac{1 - M_o}{1 - M_f - S}$ is the "theoretical recovery" or the ratio of cured product to initial split fish weight given in equation A1 of the report.

If we now combine equations (5), (4) and (3), and substitute into (2), we get:

$$V_f = \frac{W_{sf}\,(1-M_o)}{d_{cf}\,(1-M_f-S)} + \frac{W_s - S\,W_{cf} - 0.36\,(M_o W_{sf} - M_f W_{cf})}{d_s} \;\ldots\ldots\ldots\ldots\ldots \;(6)$$

Dividing both sides of this equation by W_{sf}, noting that $\frac{W_s}{W_{sf}} = r$ (the salting ratio) and taking the reciprocal of both sides of the result gives:

$$\frac{W_{sf}}{V_f} = E_f = \frac{d_{cf}\, d_s}{d_s \left(\frac{1-M_o}{1-M_f-S}\right) + d_{cf}\left(r - \frac{S(1-M_o)}{1-M_f-S} - 0.36\left(\frac{M_o\ (1-S)-M_f}{1-M_f-S}\right)\right)}$$

which is the equation for E_f, as required.

3. Variation of E from E_o to E_f (Section 5.3 of the Report)

Consider a bulk of fish and salt consisting of N layers or, more precisely, amounts of fish of various "ages", or periods in salt. In this model the various layers correspond to the daily amounts salted, but the time scale is not important to the argument in general. At any time the values of E for the layers will be E_o, E_1, E_2, ...E_n ...E_N, depending on whether it has just been salted (E_o) or has been there for a period of n days. The overall value of E for the bulk - call this $\bar{E}$ - will depend on the "age history", or the proportion of fish in the total bulk of various individual ages, and therefore in different stages of curing. We let the fraction of total bulk which is in the n^{th} layer be F_n, ie.:

$$F_n = \frac{\text{weight of split fish in layer } n}{\text{total weight of split fish in bulk}}$$

A key point is the recognition of the simple fact that since the mass of split fish in a given layer does not change with time, the change in E results entirely from the decreasing volume of the layer - which is essentially the effect of decreasing thickness, since its area may be reasonably considered to be fixed. In other words, E_n is directly proportional to $\frac{1}{t_n}$ where t_n is the thickness of the n^{th} layer. Thus at any time,

$$E_n t_n = E_o t_o \quad \ldots\ldots (7)$$

where t_o is the thickness of this layer at day 0.

Now the total bulk volume is the sum of all the layer volumes, and the total split fish is the sum of all the amounts in the various layers. The total amount of split fish in the n^{th} layer is $E_n t_n A$ where "A" is the area of the layer, and the total volume of the layer is $t_n A$.

$$\text{Hence } \overline{E} = \frac{\sum E_n t_n A}{\sum t_n A} = \frac{\sum E_n t_n}{\sum t_n} = \frac{\sum E_o t_o}{\sum t_n} \quad \ldots\ldots (8)$$

A convenient way to deal with the experimental variation of E from E_o to E_f is to define the dimensionless ration R by

$$R = \frac{E - E_o}{E_f - E_o} \quad \ldots\ldots (9)$$

Thus R varies from 0 to 1 as E varies from E_o to E_f. From experiment 3, as described in the report, we can derive a table of R as a function of time. This is given in Table 13. For the n^{th} layer, of course, we have

$$\text{that } R_n = \frac{E_n - E_o}{E_f - E_o}$$

$$\text{ie. } E_n = R_n (E_f - E_o) + E_o \quad \ldots\ldots (11)$$

What we now need is the value of R for the whole bulk - call this $\overline{R}$. Using (9) and (8) we get:

$$\overline{R} = \frac{\overline{E} - E_o}{E_f - E_o} = \frac{\dfrac{\sum E_n t_n}{\sum t_n} - E_o}{E_f - E_o}$$

which simplifies to:

$$\overline{R} = \frac{\sum R_n\, t_n}{\sum t_n} \quad \ldots\ldots (12)$$

which is analogous to (8). The variable in (12), which is not immediately available, is the value of t_n the layer thickness. But from (7), $t_n = \dfrac{E_o\, t_o}{E_n}$, keeping in mind here that t_o is the initial thickness of the n^{th} layer, and is not generally the same for all layers. We can, however, make use of the fact that $F_n = \dfrac{E_o t_o A}{W_{sf}}$ which gives $E_o t_o = \dfrac{F_n\, W_{sf}}{A}$.

Hence:

$$t_n = \frac{F_n\, W_{sf}}{A\, E_n} \quad \ldots\ldots (13)$$

Substituting this in (12), and cancelling the constants W_{sf}/A in numerator and denominator gives:

$$\bar{R} = \frac{\sum \frac{R_n F_n}{E_n}}{\sum \frac{F_n}{E_n}} = \frac{\sum \frac{R_n F_n}{R_n (E_f - E_o) + E_o}}{\sum \frac{F_n}{R_n (E_f - E_o) + E_o}}$$

$$= \frac{\sum \frac{R_n F_n}{R_n (E_f/E_o - 1) + 1}}{\sum \frac{F_n}{R_n (E_f/E_o - 1) + 1}}$$

(dividing by E_o in numerator and denominator)

which is the required equation (4) in the report. In the model program $\bar{E}$ is then calculated from:

$$\bar{E} = \bar{R} (E_f - E_o) + E_o.$$

4. A Simpler Equation for $\bar{E}$

Upon further examination, it turns out that a more direct and less elaborate expression for $\bar{E}$ can be found directly from equation (8). $E_n t_n A$ in equation (8) is F_n times the total weight of split fish in layer n - let us call this W_{sfn}. Hence (8) gives:

$$\bar{E} = \frac{\sum F_n W_{sfn}}{\sum \frac{F_n}{E_n} W_{sfn}} = \frac{\sum F_n}{\sum \frac{F_n}{E_n}} \quad \text{.................................... (14)}$$

But $\sum F_n = 1$, and since $E_n = R_n\,(E_f - E_o) + E_o$, this gives:

$$\overline{E} = \frac{1}{\sum \dfrac{F_n}{R_n\,(E_f - E_o) + E_o}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

Equation (15) is somewhat simpler than (4), in the report, and avoids consideration of the intermediate variable $\overline{R}$ altogether. Of course, in both cases the results are identical.