VPI-T-82-002 C. 2

CIRCULATING COPY
Sea Grant Depository

# ENGINEERING AND ECONOMICS OF THE OYSTER STEAM SHUCKING PROCESS

LOAN COPY ONLY

Second Edition

Edited by:

Frank Huang, Chieko E. Hebard, and J. Kenneth Riggins

Published by:

Department of Food Science and Technology
Seafood Processing Research and Extension Unit
Virginia Polytechnic Institute and State University
Hampton, Virginia

and

National Fisheries Institute, Inc.
Washington, D. C.

VPI-SG-82-07

NATIONAL SEA GRANT DEPOSITORY
PELL LIBRARY BUILDING
URI, NARRAGANSETT BAY CAMPUS
NARRAGANSETT, RI 02882

U. S. Department of Agriculture

U. S. Department of Commerce
National Sea Grant College Program

TABLE OF CONTENTS

## General Description and History of Heat Shucking Process

George J. Flick

A field study, designed to evaluate the commercial heat-shock method of preparation of oysters for shucking as recommended by the Cooperative Program, was conducted by the South Carolina State Board of Health in cooperation with the Gulf Coast Shellfish Sanitation Research Center in the early 1960's.

In addition to the cooperative field study, a laboratory study was undertaken by the Research Center. This study was carried out to give a more carefully controlled and detailed research evaluation of the heat-shock method of opening oysters.

The objective of the field study as well as the controlled laboratory study was to evaluate the heat-shock method as practiced in South Carolina and to determine whether the method could be incorporated in the Shellfish Manual on the same basis as is given to the normal cold shucking method or, if this were not indicated, to determine what special requirements might be necessary.

This was to be accomplished by studying the commercial heat-shock process by accepted bacteriological parameters. Included would be (1) a study of the comparative effect of the heat-shock process and normal cold shucking methods of opening oysters on the bacteriological quality of shucked shellfish meats and (2) an examination of the sanitary aspects of the process. Information about factors influencing the public health aspect of the process would be collected and any sanitary requirements determined and appropriate revisions, if required, inserted in the Manual. The results of the laboratory study would serve to provide information obtained under more carefully controlled conditions.

The field study consisted of the bacteriological examination of traced lots of oysters taken from various stages of the heat-shock process and the examination of the immersion water. The oyster samples represented shell-stock opened before immersion, immediately after immersion and after remaining on the shucking bench for various lengths of time. The water samples represented the immersion water at the time the oysters were dipped.

Five commercial plants were involved in the cooperative study. The study of the sanitary aspects of the process in each plant was accomplished by recording information on harvesting area, date and time of harvest, length of storage and storage conditions, ambient air temperature, volume and temperature of immersion water, volume of oysters per dip, period of time of heat shock, condition of shellstock and any unusual condition of processing.

The water and oysters were examined for coliform and fecal coliform MPNs and by standard 35°C (95°F) plate counts.

In the laboratory study, a specially designed all glass water bath with a constant agitation of distilled water was used for immersion of the oysters. The temperatures were controlled with an electric immersion heater in an outer water bath coupled with an electronic thermoregulator. Both Alabama oysters and South Carolina oysters were used in the laboratory studies.

The heat-shock method of preparing oysters for shucking, as carried out in South Carolina, is based upon the premise that immersing the oyster in hot water at a given temperature for a definite period of time, followed by immediate chill down, will result in a product that is easier to open but one that may be approved by the Cooperative Program. The results of the study indicated that certain changes due to the process may be expected to occur in the bacteriological indices used as a measure of the sanitary quality of shellfish. The effect of the heat-shock process was a reduction in the density of the bacterial indices measured. This reduction was evident both in the over-all mean values for the indices from the before immersion stage of the process to the after immersion and shucking bench stages of the process and also in the mean ratios of the bacterial indices at the various stages in the process on a traced lot basis.

Thirty-two lots of shellfish meats and process waters collected at various stages of the commercial process were examined.

The bacterial content of the immersion waters was found to be consistently low. Viable coliform organisms were recovered in only 2 of 31 samples tested. Viable fecal coliforms were recovered in only 1 of the 31 samples. The 35°C (95°F) plate count ranged from 5 to 3,000 organisms per milliliter with a median value of 120 organisms per milliliter.

Variations in the densities of the selected bacterial indices at three stages of the heat-shock process are summarized in Table 1.

Values listed at the three percentile levels were derived from the probability plots with no attempt at traced lot analysis. The heat-shock process resulted in an over-all reduction in the coliform and fecal coliform MPNs at all percentile levels. The greatest reduction occurred in the samples examined immediately after shocking. Holding on the shucking bench appears to result in a slight increase in these two groups of bacterial indices as compared to oysters examined immediately after shocking. However, these levels remain significantly lower than the levels obtained from samples from the cold shucking process.

The 35°C (95°F) plate count showed a slight decrease at the 25 and 50 percentile levels both in oysters immediately after shocking and in shocked oysters held on the shucking bench. At the 90 percentile level, the plate count of the oysters immediately after shocking was comparable to the count obtained from cold shucked oysters. At this percentile level, counts from shocked oysters held on the shucking bench were slightly higher than counts obtained from cold shucked oysters or oysters examined immediately after shocking.

The average percent change in coliform and fecal coliform densities examined on a traced lot basis is shown in Table 2. In most instances the shocking process resulted in a reduction of the coliform and fecal coliform MPNs in the shocked oyster meats. A comparison of oysters examined immediately after shocking with cold shucked oysters indicated a reduction in coliform and fecal coliforms of 50 percent and 25 percent, respectively. A comparison of shocked oysters held on the shucking bench with oysters examined immediately after shocking indicated a 40 percent increase in coliform MPN and a 10 percent increase in fecal coliform MPN.

A comparison of shocked oysters held on the shucking bench with cold shucked oysters showed a 47 percent reduction in coliform MPN and a 17 percent reduction in fecal coliform MPN of the shocked oysters over the cold shucked oysters.

In 87 percent of the lots of shocked oysters tested immediately, the shocked oysters showed a decrease or no increase in coliform density when compared with cold shucked oysters. In 72 percent of the lots tested, the shocked oysters showed a decrease or no increase in fecal coliform densities.

In a comparison of the shocked oysters examined immediately with shocked oysters held on the shucking bench, 53 percent of the lots tested showed a decrease or no increase in coliform MPN. In the remaining 47 percent of the lots, however, there was an increase in coliform MPN. On the same basis of comparison, 43 percent of the lots showed a decrease or no increase in fecal coliform MPN, and 57 percent of the lots showed an increase in fecal coliform density.

In a comparison of shocked oysters held on the shucking bench with cold shucked oysters, 80 percent of the lots tested showed a decrease or no increase in coliform MPN with 20 percent of the lots showing an increase. With respect to fecal coliform MPN, 71 percent of the lots tested showed a decrease or no increase and 29 percent of the lots showed an increase.

The laboratory investigations conducted to determine the influence of the heat shocking process on the bacteriological parameters consistently resulted in reductions in coliforms MPNs, fecal coliform MPNs and 35°C (95°F) plate counts in both Alabama and South Carolina oysters.

A comparison of results (Table 3) shows that the percent reduction in the selected bacterial parameters was significantly higher in the South Carolina oysters. This difference in bacterial reduction appears to correlate with the heat penetration differential determined in the oysters from the two sources. The average internal temperature of the South Carolina oysters at the end of three minute immersion was found to be higher than the Alabama oysters immersed for the same period of time.

Table 1. Densities of Selected Bacterial Indices at Three Stages of Processing of Oyster Meats - Field Study

| | Cold Shucking Process | | | Shock Process | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Immediately After Shocking | | | Shucking Bench | | |
| | MPN/100g | | | MPN/100g | | | MPN/100g | | |
| Percent Occurrence | Coliform | Fecal Coliform | 35°C Plate Count/g | Coliform | Fecal Coliform | 35°C Plate Count/g | Coliform | Fecal Coliform | 35°C Plate Count/g |
| 25 | 370 | 21 | 1,100 | 130 | 8 | 700 | 150 | 11 | 760 |
| 50 | 900 | 84 | 1,800 | 330 | 29 | 1,300 | 430 | 45 | 1,600 |
| 90 | 4,800 | 1,100 | 4,600 | 1,900 | 350 | 4,500 | 3,100 | 680 | 6,000 |

Table 2. Changes in Coliform and Fecal Coliform Densities During Processing on a Traced Lot Basis - Field Study

| | Heat Shock Process | | Shucking Process | | Over-all Process | |
|---|---|---|---|---|---|---|
| | Coliform | Fecal Coliform | Coliform | Fecal Coliform | Coliform | Fecal Coliform |
| No. of lots tested | 30 | 28 | 32 | 30 | 30 | 31 |
| Percentage of lots showing: | | | | | | |
| (a) No change | 20 | 11 | 12 | 20 | 20 | 23 |
| (b) Density decrease | 67 | 61 | 41 | 23 | 60 | 48 |
| (c) Density increase | 13 | 28 | 47 | 57 | 20 | 29 |
| Average Percent Change | -50 | -25 | +40 | +10 | -47 | -17 |

Table 3. Comparative Reduction in Selected Bacterial Parameters in Alabama and South Carolina Oysters Immersed Three Minutes at 66°C (150°F)

| Sample Source | Percent Reduction (1) MPN/100g Coliform | Fecal Coliform | Plate Count/g 35°C |
|---|---|---|---|
| Ala. Oyster | 82.8 | 79.6 | 75.0 |
| S.C. Oyster | 97.8 | 83.0 | 99.4 |

(1) Based on the average of six determinations.

Because of the above study, the Public Health Service recognized that, with proper sanitary precautions, the heat-shock process could be utilized with beneficial results. Consequently, the heat shock method for shucking was permitted by the State of North Carolina shellfish sanitation authorities.

The following guidelines are taken from Appendix C of "Heat Shock Method of Preparation of Oysters for Shucking," published in *The Public Health Service's Shellfish Manual*. While the guidelines were intended to apply only to the cluster-type oyster, it was recognized that they may be applicable to other species.

1. Washing of Shell-Stock

Shell-stock subjected to the heat shock process shall be washed immediately prior to the heat shock operation in potable water. Experience has shown that wash water temperatures between 18°C (65°F) and 24°C (75°F) are effective for adequately washing shell-stock. Shell-stock shall be protected from contamination prior to and during the prewash cycle.

*Public-health explanation.*

Although it is required that shell-stock be washed reasonably free of bottom sediments and detritus as soon after harvesting as is practicable, it is necessary to again wash shell-stock immediately prior to heat shocking to reduce the bacterial load in the dipping tank. Invariably some mud or detritus will adhere to the shell-stock; hence the necessity to again wash the shell-stock before it is immersed in the heat shock water where the mud or detritus may be released by the warmer water. The cleaner the shell-stock, the more rapidly the oysters will arrive at the optimum temperature for shucking and there will be less variation in heat transfer among different lots.

*Satisfactory compliance.*

This item will be satisfied when--

a. All shell-stock subjected to the heat shock process are washed immediately prior to the heat shock operation in flowing potable water. Water temperatures not less than 18°C (65°F) nor more than 24°C (75°F) are recommended.

b. Shell-stock are handled in a manner which prevents their contamination during the pre-wash cycle.

2. Temperature and Change of Dip Water

During the heat shock process the water shall be maintained at not less than 63°C (145°F) or more than 66°C (150°F). The water shall be completely drained or removed from the heat shock tank at least once each 3-hour period. An accurate[1] indicating or recording thermometer shall be available and used during the heat shock process for temperature measurements. Recording thermometers are recommended so as to provide a record of the temperatures used.

*Public-health explanation.*

Experience and research indicates the temperature range of 63-66°C (145-150°F) to be adequate to facilitate removal of oysters from the shell without apparent physical change to the oyster. A temperature range is specified rather than an exact temperature because of varying climatic conditions during the year. Dip water is required to be changed at least every 3 hours to avoid bacterial concentration or build-up of mud or detritus.

---

[1]Thermometers should be accurate to within 1°C (2°F); should have scale divisions not greater than 1°C (2°F); and should be so installed as to be easily read. Accuracy of thermometer should be checked at least once each year by the State regulatory agency.

*Satisfactory compliance.*

This item will be satisfied when--

a. Heat shock water is maintained at not less than 63°C (145°F) or more than 66°C (150°F).

b. The heat shock watertank is completely flushed at 3-hour intervals or less in such manner that all mud and detritus remaining in the dip tank from previous dippings is eliminated.

c. An indicating or recording thermometer, accurate within 1°C (2°F) between 63°C (145°F) and 66°C (150°F) is available and is located in the heat shock water during all periods of shock operation.

3. Time Interval of Immersion

Shell-stock subjected to the heat shock process shall not be immersed in the heat shock water for periods longer than 3 minutes. An accurate timing device shall be available and used to control the time of immersion. Only approved containers of 1/2-bushel[2] capacity shall be used in the heat shock process. It is recommended that an automatic timer or an automatically electrically controlled timer be used.

*Public-health explanation.*

Industry practice and investigation reveals that an immersion time varying between 2 and 3 minutes is all that is necessary to facilitate the shucking process. A maximum time of immersion is specified to prevent any physical change in the oyster which would prevent it from being classified as a fresh product. The maximum time specified is based on the use of 1/2-bushel quantities of shell-stock in 1/2-bushel wire baskets or other 1/2-bushel containers approved by the shellfish sanitation control agency.

*Satisfactory compliance.*

This item will be satisfied when--

a. Shell-stock is not subjected to the heat shock process for periods longer than 3 minutes.

[2] Defined as 1,075.2 cubic inches or as one-half the U.S. standard bushel of 2,150.4 cubic inches.

b. An accurate timing device is available and used to control the time of immersion.

c. Only approved containers of 1/2-bushel capacity are used during the heat shock process.

4. Dip Tank Volume

At least 8 gallons of heat shock water shall be maintained in the dip tank for each 1/2-bushel container of shell-stock being heat shocked.

*Public-health explanation.*

The minimum of 8 gallons of dip water per 1/2-bushel is necessary to prevent bacterial buildup and extreme variations of temperature in the heat shock water.

*Satisfactory compliance.*

This item will be satisfied when there are at least 8 gallons of heat shock water in the heat shock tank for each 1/2-bushel container of shell-stock undergoing the heat shock process.

5. Cooling of Heat Shocked Shell-Stock

On removal from the shock immersion water, all heat shocked shell-stock shall be subjected to an immediate cooldown with potable tap water. Heat shocked shell-stock shall be handled in a manner which prevents contamination reaching the shell-stock during the cooling operation.

*Public-health explanation.*

After undergoing the heat shock process, the internal temperature of the oyster meat was elevated to temperatures within a range of $37^{\circ}C$ ($98^{\circ}F$) to $43^{\circ}C$ ($110^{\circ}F$) in field studies and $47$-$64^{\circ}C$ ($116$-$147^{\circ}F$) in laboratory studies. It is therefore necessary to reduce the internal temperatures of the oyster meat immediately to prevent bacterial growth, but not to the extent that the purpose of the process is nullified.

*Satisfactory compliance.*

This item will be satisfied when--

a. All heat shocked shell-stock are subjected to cooling with potable tap water immediately upon removal from heat shock process water.

b. All heat shocked shell-stock are handled in such manner as to preclude contamination during the cooling process.

6. Refrigeration of Shocked Shucked Shellfish

The oyster meats from all shell-stock which have been subjected to the heat shock process shall be cooled to an internal temperature of 7°C (45°F) within 2 hours after the heat shocking process.

*Public-health explanation.*

Oyster meat temperatures of shell-stock which have been subjected to the heat shock process are higher than those of conventionally shucked oysters. Therefore, it is necessary that such meats be cooled quickly to 7°C (45°F) after the heat shock process to deter bacterial growth.

*Satisfactory compliance.*

This item will be satisfied when all oyster meats of shell-stock which have been subjected to the heat shock process are cooled to at least 7°C (45°F) within 2 hours after the heat shock process and are placed in storage at 7°C (45°F) or below. (This requirement will require the use of ice in the shucking containers, blowers, skimming tables, or wash tanks, or the use of refrigerated water, wherein the meats will be in direct contact with crushed or flaked ice, or with refrigerated water.)

7. Records of Heat Shock Time and Temperatures

Each plant operating the heat shock process shall maintain an accurate daily record, on a ledger form satisfactory to the State supervisory agency, of the time and temperature of immersion of at least three lots of shellfish during each day of operation as well as recording the time of change of heat shock water. It is preferable that records show the time of day each recorded lot is immersed and the time of day each recorded lot is removed from the water, and that the individual recordings be at intervals of 2 or 3 hours. These records shall be preserved for at least 3 months for the information of the supervising State agency.

*Public-health explanation.*

Records are needed to maintain a summary or abbreviated history of each hot dip operation. They are of assistance to the supervisory agency in determining whether the operation is carried out in accordance with these or other State regulations covering the process. They are also of assistance to the operator in maintaining the process within the limitations imposed by State authorities.

*Satisfactory compliance.*

This item will be satisfied when--

a. Each operator maintains an accurate daily record of the time and temperature of immersion of at least three lots of shellfish during the day of operation and records the time of change of heat shock water. This record shall be on ledger forms satisfactory to the State supervisory agency. (Plants using recording thermometers will be deemed in compliance with this item if suitable indication is made on the chart when the shell-stock are first immersed and when they are removed from the heat shock water, as well as the time of change of heat shock water.)

b. The above records are preserved and are on file at the plant for inspection by State authorities.

8. Cleaning and Bactericidal Treatment of Heat Shock Process Tank

At the close of each day's operation, the heat shock tank shall be completely emptied of all water, mud, and detritus, and shall be cleaned in accordance with the requirements for cleaning of equipment. Prior to the start of the next day's operation, the heat shock tank shall be given required bactericidal treatment. Heat shock process tanks shall be of such construction that they may be easily cleaned.

*Public-health explanation.*

If the water, mud, and detritus were allowed to remain in the heat shock tank under declining temperature conditions, it would constitute an excellent medium for growth of bacteria. Emptying the tank and cleaning it at the close of the day's operation will more likely insure that the next day's dipping operation will start under optimum conditions of cleanliness. Bactericidal treatment prior to the start of the next day's operation will insure destruction of any pathogenic bacteria remaining after the cleaning operation or introduced during the interim storage period. It will also prevent carryover of thermophillic or thermoduric bacteria from the previous day's operation.

*Satisfactory compliance.*

This item will be satisfied when--

a. The heat shock process tank is thoroughly cleaned at the close of each day's operation in accordance with the requirements for cleaning of equipment.

b. The heat shock process tank is flushed with water from an approved source after cleaning and is allowed to drain and dry overnight.

c. Required bactericidal treatment is provided the heat shock tank prior to the start of the day's dipping operation.

d. All heat shock process tanks are of such construction that they may be easily cleaned.

## Development of a Pasteurized Oyster Product*

D. Goldmintz, R. C. Ernst, and J. Rasekh

### I. INTRODUCTION

The Charleston Laboratory of the Southeast Fisheries Center, National Marine Fisheries Service, has been investigating the use of steam for the production of a pasteurized oyster that is an intermediate of the raw oyster and commercially sterilized product. Our objective is to produce a lightly heated product that has high microbiological safety and quality with acceptable yields and organoleptic characteristics.

The primary criterion for oyster pasteurization was that the process would provide conditions sufficient for destruction of organisms of public health concern. To accomplish this, we established times and temperatures of exposure of shell-stock that would destroy heat-resistant inoculated Salmonella as indicators of destruction of other microorganisms in shell-stock. This information has been presented at other meetings and is now in press. Those experiments will not be discussed here except to say that the target temperatures for the pilot production of steamed-in-shell oysters were based on the conditions previously determined necessary to destroy these public health and other spoilage microorganisms. It is important to stress that the term pasteurization is used advisedly, since we are in the process of investigating any possibility of potential problems due to anaerobic sporeformers such as Clostridium botulinum in lightly heat-treated oysters.

In the development of a "pasteurized" oyster, we began with shell-stock rather than shucked oysters. It was felt that heating the shell-stock would make shucking easier and also sanitize shell surfaces, which can be a source of contamination.

Atmospheric pressure steam was chosen for pasteurization after evaluation of several criteria that included consideration of:

*This paper was previously presented at the Third Annual Tropical and Subtropical Fisheries Technology Conference of the Americas.

1) initial cost
2) operating cost
3) availability of equipment
4) familiarity with process
5) process effect on product quality
6) recovery of by-products

Among the methods considered were: hot water immersion, use of dry heat, microwave heating, and elevated and atmospheric pressure steaming.

Hot water immersion generates a large volume of waste water. Direct exposure to water during heating can cause leaching of soluble protein and flavor components. In addition, recovery of oyster liquor from large quantities of water is impractical.

Dry air heating has the obvious drawback of potential dehydration of the product during heating.

Microwave heating could be used for pasteurization. There is a rather high initial equipment cost, however, and it has been reported that microwave treatment can produce undesirable flavor changes in food.

When using elevated pressure steam for pasteurizing shell-stock, significant problems were encountered in loading retorts, resulting in non-uniform heating.

The use of non-pressurized steam for oyster pasteurization has a relatively low initial operating cost. The equipment is readily available and easy to operate. The process is a familiar one with much information available on the effects of steam processing on various foods. Also, the liquor expressed during pasteurization could be recovered.

II. METHODS

Single layers of oysters were steamed on trays in a cabinet. The temperature was monitored using thermocouples inserted into the oyster belly masses through holes drilled into the shells. Single layers of oysters were used because stacking caused unacceptable disparity in heating. In addition, the oysters were separated into batches by weight so time/temperature variations due to size could be minimized. The cabinet used was a converted 12 cubic feet upright freezer with sanitary sparger. As soon as the average internal temperature of the oysters reached the desired level, the steam was removed and the oysters were cooled with sprayed water to 30°C (86°F). They were then shucked and the yields determined.

Further tests included total counts on Standard Methods Agar and coliform determinations using standard MPN's and Violet Red Bile Agar. Shear press measurements were performed using a Kramer Shear Press equipped with a 1500 lb ring. Organoleptic evaluations were performed using triangulation taste panel testing with at least twelve panelists.

## III. RESULTS

Table 1 shows the reduction in total plate count and coliforms as a function of temperature at the come-up time. The temperatures we chose to test were those for which the thermal death times of heat-resistant bacteria had been established in previous investigations. At 60°C (140°F) the total count was sharply reduced and the coliforms were virtually eliminated. The remaining total aerobic count was due to Bacillus. No aerobic spoilage or public health significant organisms could be detected. It appears, therefore, that steaming oysters to 60°C (140°F) or slightly above may be adequate for pasteurization.

Table 2 shows the yield of shucked meats compared to shell-stock after heating. At 60°C (140°F) there is approximately a 20% yield loss compared to the raw product whereas there is a 70% yield loss of the fully cooked product. The raw and pasteurized products are similar visually, except that the pasteurized oysters are more uniform in color.

Once the initial microbiological criteria for pasteurization were satisfied, the food technological aspects of pasteurization of oysters were evaluated. Raw and pasteurized products were offered to taste panelists in order to ascertain differences and preferences. Acceptability was satisfactory. At a recent test comparing raw and pasteurized oysters which were deep fried, the majority of the panelists could not differentiate between the two products. Of those who could tell the difference, preference was equally divided. We also had a workshop at our laboratory in College Park to demonstrate the product to local industry members who commented favorably on the product and are considering similar processing techniques.

To determine factors that influence taste panelists' judgments, we used a shear press to investigate the texture of the pasteurized product. To our knowledge, this type of work has not been done with oysters. The results of shear tests of raw, pasteurized, and cooked oysters with and without the adductor muscle are compared in Table 3. Without the muscle, the changes due to heating were relatively small. However, when the muscle was present, the shear press values increased sharply. These data support the observations of taste panelists who noted increased firmness in the texture of the adductor muscle after heating. It appears, therefore, that the shear press can be a useful tool for measuring the texture of oyster products.

The "pasteurized" product can be economically produced with slight modification on the equipment currently available in the industry. Table 4 shows the economic information for this product based on 14- and 50-bushel-per-day capacity pilot apparatus. These are incremental costs--that is, above the cost of the raw product. The labor cost per bushel for the larger production drops due to use of the same people for raw and pasteurizing operations and the fact that manipulations for both 14- and 50-bushel quantities are not significantly different.

IV. CONCLUSIONS

A lightly heat-treated oyster product has been developed as an alternative to the raw product. Its closer similarity to raw oysters than to commercially sterilized products indicates that it may find use as an adjunct to the raw product. It is also likely, with the sharp decrease in microbial load and the destruction of oyster enzymes at pasteurization temperatures, that shelf-life could be extended beyond that of the raw product. It was also noted in our studies that steaming reduces undesirable coloration occasionally present in raw oysters. Last, but not least, application of steam for pasteurization of shell oysters facilitates shucking. Table 5 summarizes the product characteristics.

Future studies with pasteurized oysters will include further comparison of shear press measurements (using a shear compressions cell to measure elasticity), taste panelists' evaluations, and continuation of work on the significance of anaerobic sporeformers in shell-stock that may affect the safety and quality of heat-treated products. Long-term storage studies at 5°C (41°F) and at freezer temperature -40°C (-40°F) have begun to evaluate product stability with reference to bacterial, organoleptic, and chemical characteristics.

Table 1. Effect of Steaming on Survival of Bacteria in Shell-stock

| Internal Temperature | Come-up Time (min) | TPC | | Coliforms | |
|---|---|---|---|---|---|
| | | Before Steam | After Steam | Before Steam | After Steam |
| 56°C (133°F) | 4.8 | 62,000 | 900 | 910 | 30 |
| 60°C (140°F) | 5.5 | 47,000 | 230 | 1700 | 2 |
| 65°C (149°F) | 6.0 | 55,000 | 29 | 340 | <1 |
| 71°C (160°F) | 7.0 | 31,000 | 17 | 420 | <1 |
| 84°C (183°F) | 12.0 | 51,000 | 15 | 1300 | <1 |

Table 2. Effect of Steaming on the Yield of Shucked Oysters

| Treatment | | Yield | |
|---|---|---|---|
| | | From shell stock | From raw shucked |
| Raw | | 12 - 15% | 100% |
| Heated to: | 60°C (140°F) | 9.5 - 11% | 80% |
| | 71°C (160°F) | 7.5 - 9.5% | 65% |
| | 84°C (183°F) | 5.0 - 6.0% | 40% |
| Autoclave (Comparable to commercially sterilized product) | | 4.5% | 30% |

Table 3. Effect of Steaming on Oyster Texture

| Treatment | Internal Temperature (°C) | Shear Values (lbs/sq.in.) |
|---|---|---|
| Raw w muscle | 18 | 172 |
| w/o | | 144 |
| Pasteurized w muscle | 62 | 388 |
| w/o | | 196 |
| Cooked w muscle | 84 | 493 |
| w/o | | 206 |

Table 4. Estimated Incremental Cost of Pasteurization

| Capacity | 14 bu/day | | 50/bu/day | |
|---|---|---|---|---|
| Initial Equipment Cost | $500.00 | | $2000.00 | |
| | $/bu | $/day | $/bu | $/day |
| Equipment | 0.15 | 2.08 | 0.17 | 8.33 |
| Labor | 1.72 | 24.00 | 0.48 | 24.00 |
| Utilities | 0.22 | 3.08 | 0.19 | 9.50 |
| TOTAL | 2.09 | 29.16 | 0.84 | 42.23 |

Table 5. Summary of Product Characteristics

| Raw | Pasteurized |
|---|---|
| 2-Week shelf-life | 3-Week shelf life* |
| Public health organisms possibly present | Eliminates coliforms and related organisms |
| Spoilage bacteria increase in 2 weeks | Bacteria essentially 0 |
| Taste panel acceptable 2 weeks | Taste panel acceptable 2 weeks + (still under investigation) |
| Require skilled shucker | Shucking facilitated |
| May have undesirable coloration | Uniform color |
| --- | 0.30/lb. for 14 bu/day<br>0.12/lb. for 50 bu/day<br>(Cost addition to raw) |

*Possibly longer depending on results of future taste panels and chemical analyses.

# Case Study on Oyster Steam Shucking - Yield, Efficiency, and Quality

Frank Huang

## I. INTRODUCTION

Hand shucking of oysters is a skill-demanding and time-consuming process. A live oyster exerts considerable force with its adductor muscle when it is being pried open. Application of sufficient heat to live oysters can, however, ease the shucking effort considerably by relaxing the adductor muscle through heat shock.

In Virginia, several processors have experimented with the steam shucking process to induce heat shock on oysters prior to hand shucking. In the process, a tunnel is constructed for heating the oysters and retaining steam. A transporting system is used to control the heating time as well as to move the oysters (Fig. 1). There are two major transporting systems; baskets on a monorail and a continuous conveyor belt.

The steam tunnels are made of plywood, stainless steel, or other material with a sturdy frame, with steam pipes laid on the bottom.

A typical oyster steam shucking process is depicted by the block diagram (Fig. 2). The shell-stock is unloaded from a boat or truck into holding crates, or in piles in a shell-stock storage area. Oysters are then shoveled into baskets or onto a conveyor belt. Sometimes, they are bulldozed into a hopper, then released intermittently into baskets that transport them through the steam tunnel to the shucking table. At the shucking table, oysters are opened and the meat is collected in shucking buckets containing water and ice. The meat is then drained and weighed at the weighing station. The shucked oysters are transferred and kept in 5-gallon pails until the time for blowing. Blowing normally consists of 5 minutes of blowing agitation followed by 20 minutes of soaking in chilled water. After soaking, the oysters are briefly drained at a skimming table before packing. Packed oyster products are iced and stored in a cooler prior to shipment.

## II. CASE STUDY

The study of three different steam tunnel installations in Virginia was conducted with the cooperation and support of the plant management. In the study, every effort was made to minimize disturbance to plant production, and the data collected include normal production variables. For comparison, certain oyster samples were shucked aseptically or treated under simulated conditions.

A small hole was drilled into the shell where a copper-constantan thermocouple was inserted and fastened with a rubber band. In each test run, one such oyster specimen was placed on the bottom, at the center, and near the side of a basket which was filled with oysters in the usual manner. On the conveyor belt, one specimen was placed on each side and in the middle of a cross-section of the belt along with oysters to be steam-treated. An additional thermocouple was attached to the basket or placed on the conveyor belt over the oysters. As the basket or belt moved from entrance to exit, temperatures of the oysters and the air in the tunnel were recorded by using a data logger (Monitor Labs Model 9300, Monitor Labs, Inc., San Diego, CA 92131). Two to three visits were made to each plant, and at least ten duplicate test runs were conducted at each visit.

Product yield was determined by the weight of shell-stock and the oyster meat obtained from it. The moisture content of the oysters at various production stages was also monitored. The oysters' moisture content was determined by draining the samples on a food strainer for 5 minutes followed by drying in an air oven at 100-110°C (212-230°F) for 18 hours. For appearance and other organoleptic qualities, oysters were examined visually during production.

Based on the observation of the tunnel construction, steam utilization, work efficiency, line layout, etc., and the data collected, the following analyses were made.

### A. Case A

A monorail transport system was used (Fig. 1) in Case A. The thermometer inserted in the steam tunnel recorded the temperature changes at that particular spot during the process. These temperature readings did not reflect the temperature throughout the entire tunnel. With the use of thermocouples, it became apparent that the temperature increased almost linearly in the first 1/3 section and fluctuated in the remainder of the tunnel (Fig. 3). Temperature fluctuation observed in the last 2/3 of the tunnel may be due to improper steam injection, inadequate insulation, inappropriate steam pipe layout, or a combination of these. A proper setup should provide maximum energy utilization indicated by an even temperature throughout the tunnel.

The temperature of the oysters increased gradually from an average of 13 to 28°C (55-82°F) as they were transported through the tunnel. The increase was rather small. On the other hand, the temperature difference between the tunnel and oysters was quite large, indicating inefficient transfer of heat energy from steam to the oysters. Moreover, due to insufficient heating, oysters did not receive the "heat shock" effect that the steam treatment was designed for. In fact, the mild increase in temperature might have stimulated the oysters' muscular activity, making the shucking more difficult during the winter season.

Oyster is a cold-blooded animal, and its body temperature varies with environment. In the tunnel, each oyster's temperature is directly affected by the amount and temperature of steam, length of time it remains in the tunnel, chemical composition of the meat, thickness of shell, and amount of mud and soil on the shell. Mechanically, the tunnel structure, the steam distribution and air current in the tunnel, the size, shape, material of the basket or carrying containers, and the location of the oyster in the container are all significant factors governing the heating of oysters in the tunnel. After exiting from the tunnel, the oyster temperature is influenced by the ambient temperature as well as the processing and storage conditions. For sanitation purposes, the lag time between the heat treatment and shucking/cooling should be reduced to a minimum.

In Case A, it appeared that the geometric shape of the basket, the loss of steam from the open ends of the tunnel, and the steam distribution pattern contributed to impair an efficient heating of oysters. It also appeared that the number of layers of oysters in the basket needs to be reduced to achieve thorough heat penetration. Perhaps there should be no more than one to two layers of oysters on each heat-receiving surface. Introduction of a hollow core with a wire mesh cylinder in each basket is an ingenious approach to improve the heat utilization and distribution.

Escaped steam not only constitutes a large energy loss but also creates high humidity and condensation problems in the operation area. Therefore, insulation is an important factor in retaining the heat and maximizing the steam utilization. Likewise, heat barriers installed at the entrance and exit of a tunnel can greatly reduce steam loss.

B. Case B

The second plant studied had a setup very similar to the first one (Fig. 1). But the second plant used different baskets and the manually controlled steam main. The baskets were V-shaped troughs built with stainless steel plates. Circular holes one inch in diameter were drilled on the side panels to facilitate heat penetration. Oysters were carried in the basket on a monorail through the tunnel and to the shucking tables.

As shown in Fig. 4, the tunnel temperature was raised to an average of about 60°C (140°F) at the entrance section. It increased to 85°C (185°F) in the first half of the tunnel and dropped off rapidly in the last 1/3, where live steam was not fed. The oyster temperature varied a great deal, which can be attributed largely to poor heat penetration through the layers of oysters. The oysters in the center of the basket tended to be cooler than those located near the perimeter of the basket and exposed directly to the steam.

Despite the inadequate basket design, the steam seemed to have been used adequately. The heat energy was largely absorbed by the shell-stock, as indicated by the smaller temperature difference between the tunnel and the oysters, when compared with the previous case.

At this installation, exhaust hoods equipped with fans were employed to vent the steam from both ends of the tunnel. In addition, no steam was injected in the last 1/3 of the tunnel. As a result, the humidity and condensation problem in the plant was largely eliminated. However, to use 1/3 of the tunnel for collecting steam appears to be somewhat wasteful.

C. Case C

The third plant employed a continuous wire mesh belt conveyor to transport oysters through the steam tunnel (Fig. 1). Normally, only one or two layers of oysters were spread on the belt. Steam was sprayed on the oysters from underneath the belt. The steam main was connected near the middle of the tunnel to the pipes laid on the bottom in the tunnel.

The tunnel was situated so as to have an inclination of approximately $9^o$, making the exit end higher than the entrance. When steam was turned on, it tended to travel upward in the pipes. Only a small portion of the steam moved to the entrance section. As heat rose, the steam and hot air in the tunnel had a tendency to shift towards the higher exit end, then up the chimney. As a result, the entrance section of the tunnel was rather cold (Fig. 5), and much of hot steam was lost up the chimney. Therefore, a steam could not be used efficiently until the oysters traveled almost to the end of the tunnel. Due to this inefficiency, the advantage of a conveyor belt system could not be demonstrated convincingly, although the oyster temperature appeared to rise at a more acceptable rate than that in Case A.

When the oysters are evenly spread as in this case, there should be little variation in the temperature of the oysters on the belt. However, temperature variations among the oysters as shown in Fig. 5 were larger than expected. This was due to the production variability, the excessive amount of mud adhering to the shells, and/or faulty steam distribution.

III. ORGANOLEPTIC QUALITY

There was no appreciable organoleptic difference between steam shucked and fresh shucked oysters. This was also found in the Pringle report in 1961 when oysters were heated in $60^oC$ ($140^oF$) hot water for 5 minutes. However, a "dry" appearance was occasionally noticed on the oyster immediately after the steam treatment. It disappeared readily after soaking in water.

IV. PRODUCT YIELD

A 20% loss in product yield was reported in the oyster products processed by the Goldmintz pasteurization process. Shucked oyster yield vs. oyster temperature was plotted on Goldmintz's data (Fig. 6). When the oyster temperature was 60°C (140°F), only 80% yield was possible. However, if the lines are extrapolated, it appears that a 100% yield could be achieved as long as the oyster temperature remains below 49°C (120°F).

In our study, most of the oysters were seldom heated above 60°C (140°F). Little difference in yield was found between fresh shucked and steam treated oysters. Both shucking methods yield approximately 12% by weight, calculated from shell-stock. In the plot (Fig. 6), a 12% yield from shell-stock is roughly equivalent to 100% from raw shucked oysters. This result seems to support the assumption derived from the Goldmintz' data.

The moisture content of the oysters changed during processing (Fig. 7). Oysters from the water of high salinity (New Jersey) had lower moisture content than those from brackish water (Maryland). Water pick-up rates of the two kinds of oysters during the processing were also different. This may be due to the difference in the osmotic pressure.

Comparing the meat of oysters from the same source, the fresh oyster meat showed lower moisture contents than that treated with steam. Oysters normally continued their biological functions for a period of time after shucking. They bled quite readily immediately after shucking, loosing their body fluids. In the oysters treated with steam, on the other hand, the biological function may have been impaired or even stopped due to a sudden temperature increase. Consequently, the moisture content of steam shucked oysters tended to be higher than that of shucked and drained fresh oysters.

After soaking in ice water for 1/2 to 1 hour, the fresh shucked oysters appeared to have a higher moisture content than their steam-shucked counterparts. The heat might have partially denatured the latter's protein membrane, retarding the normal osmotic migration, thus changing the water absorption rate. During this initial soaking period, the water pick-up rates of the oysters from different sources varied in the steam-shucked samples, but were fairly constant in the fresh shucked ones. Protein denaturation occurred to a greater extent in the Maryland oysters than the New Jersey oysters, perhaps because of the osmotic pressure difference between the two.

After prolonged soaking -- that is, after washing, blowing and packing in water, the oysters from one source approached a similar moisture level, regardless of whether they were shucked with or without steam treatment. This common moisture level may well be the osmotic equilibrium for the oyster in a water medium. Based on this finding and the direct product yield calculation shown earlier (Fig. 6), it is conceivable that the final product yield needs not suffer as a result of the steam shucking process.

## V. CONCLUSION

The major advantages of the steam shucking process can be summarized in three categories. First, the heat from steam tends to relax oyster's adductor muscles, making shucking easier and more efficient. The productivity is upgraded. Second, oddly shaped and sized oysters, which are normally discarded, can be utilized with the steam shucking process. Third, the steam shucking method may alleviate the labor supply problem, because, with the use of steam treatment, workers with little experience and training can be put on the line to do the hand shucking. The steam shucking process did not set back the yield, or organoleptic or microbiological qualities of the oyster products. It is our feeling that the implementation of the steam treatment should be beneficial to the oyster industry.

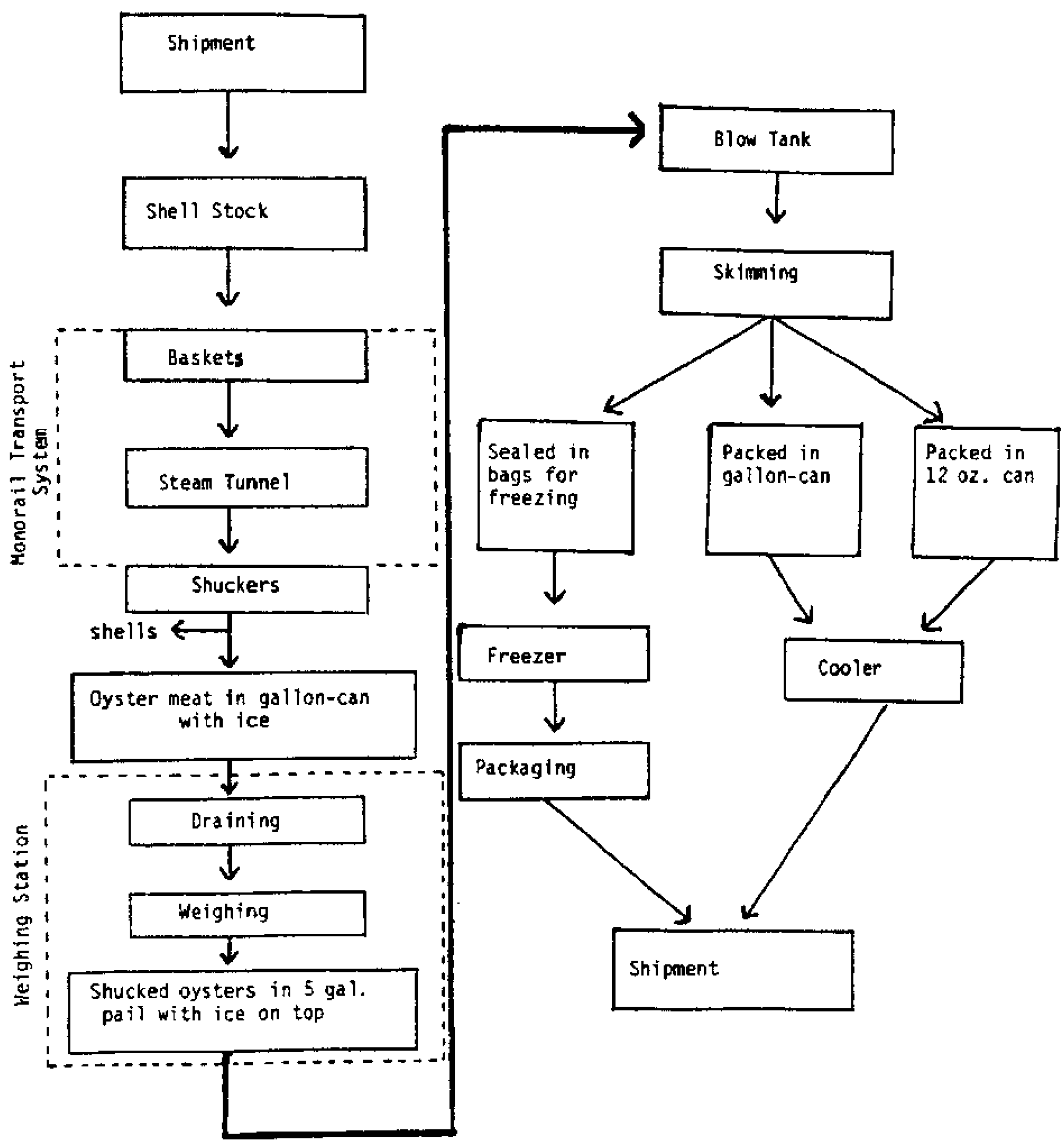



Figure 1. Block diagram of an oyster steam shucking process

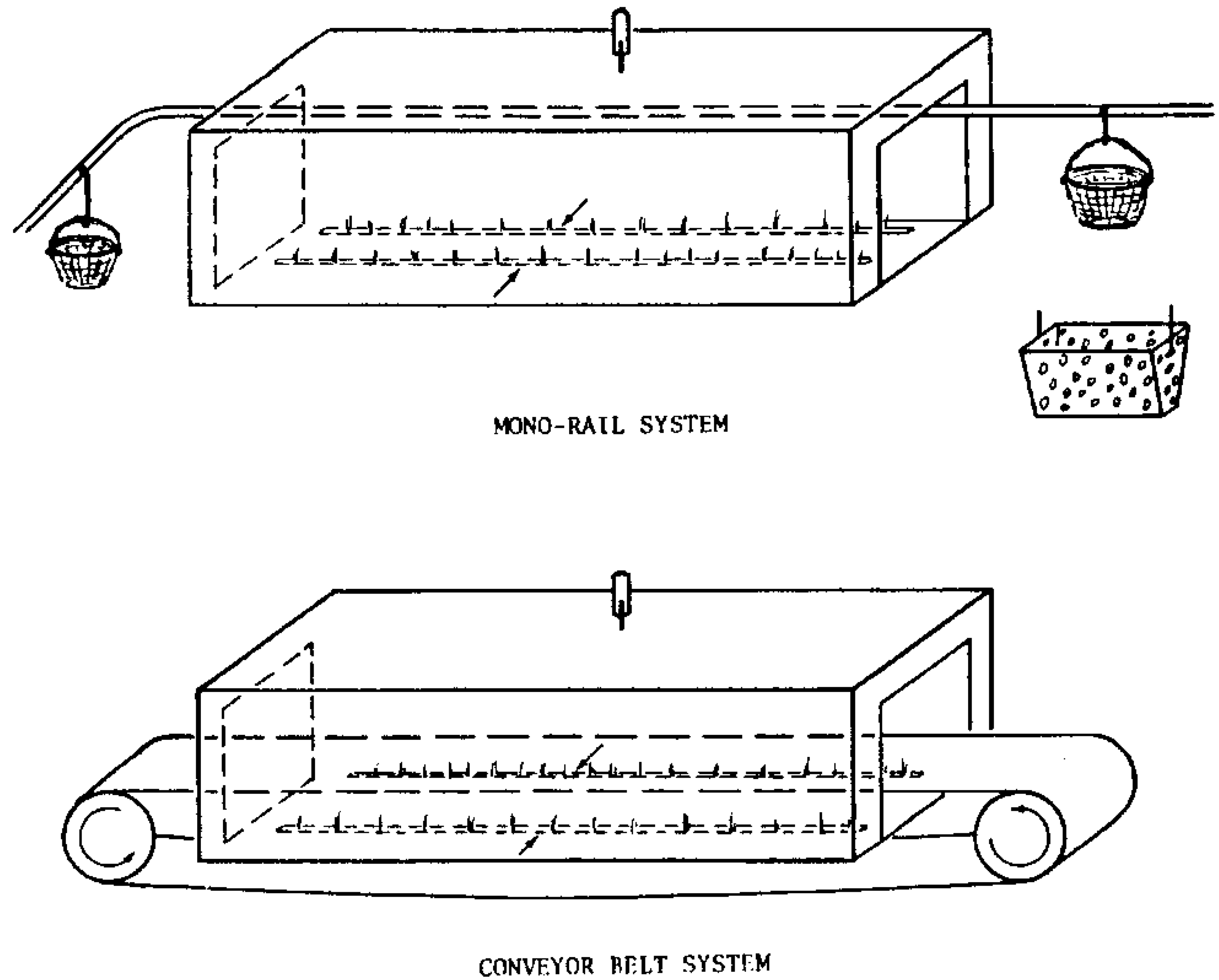



Figure 2. Steam tunnel construction and transport system

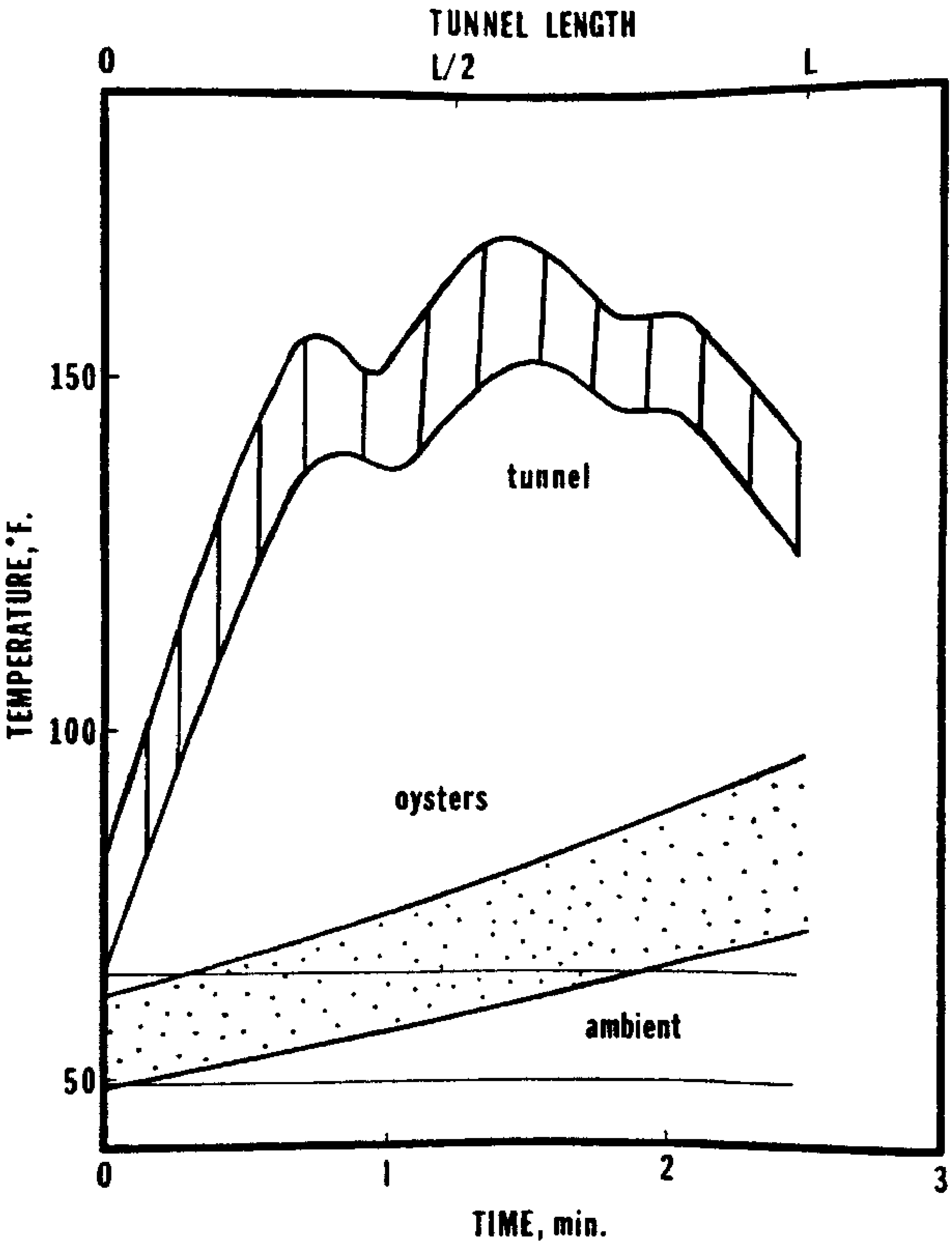



Figure 3. Temperature profiles of steam tunnel and the oysters in transit
Case A

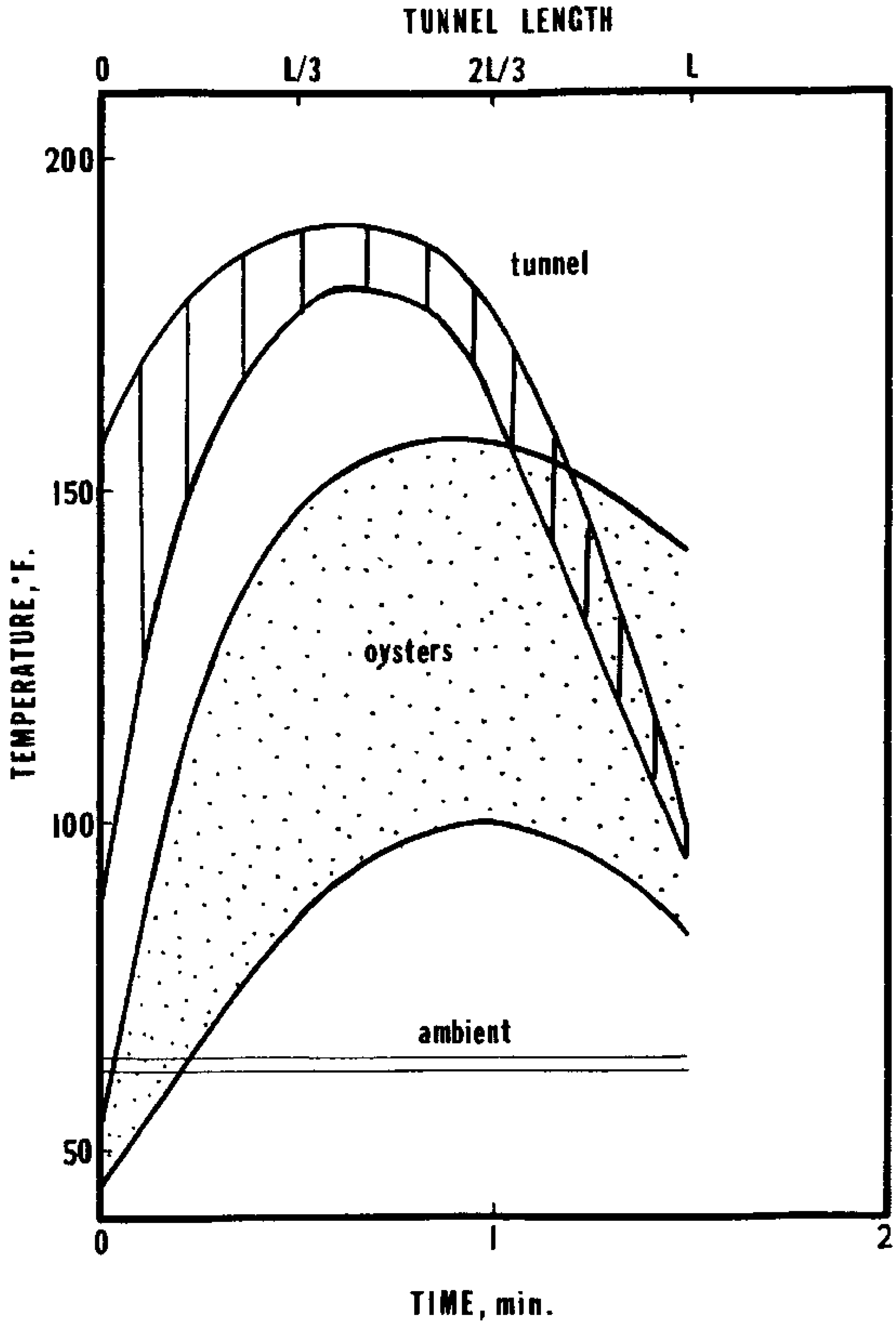



Figure 4. Temperature profiles of steam tunnel and the oysters in transit
Case B

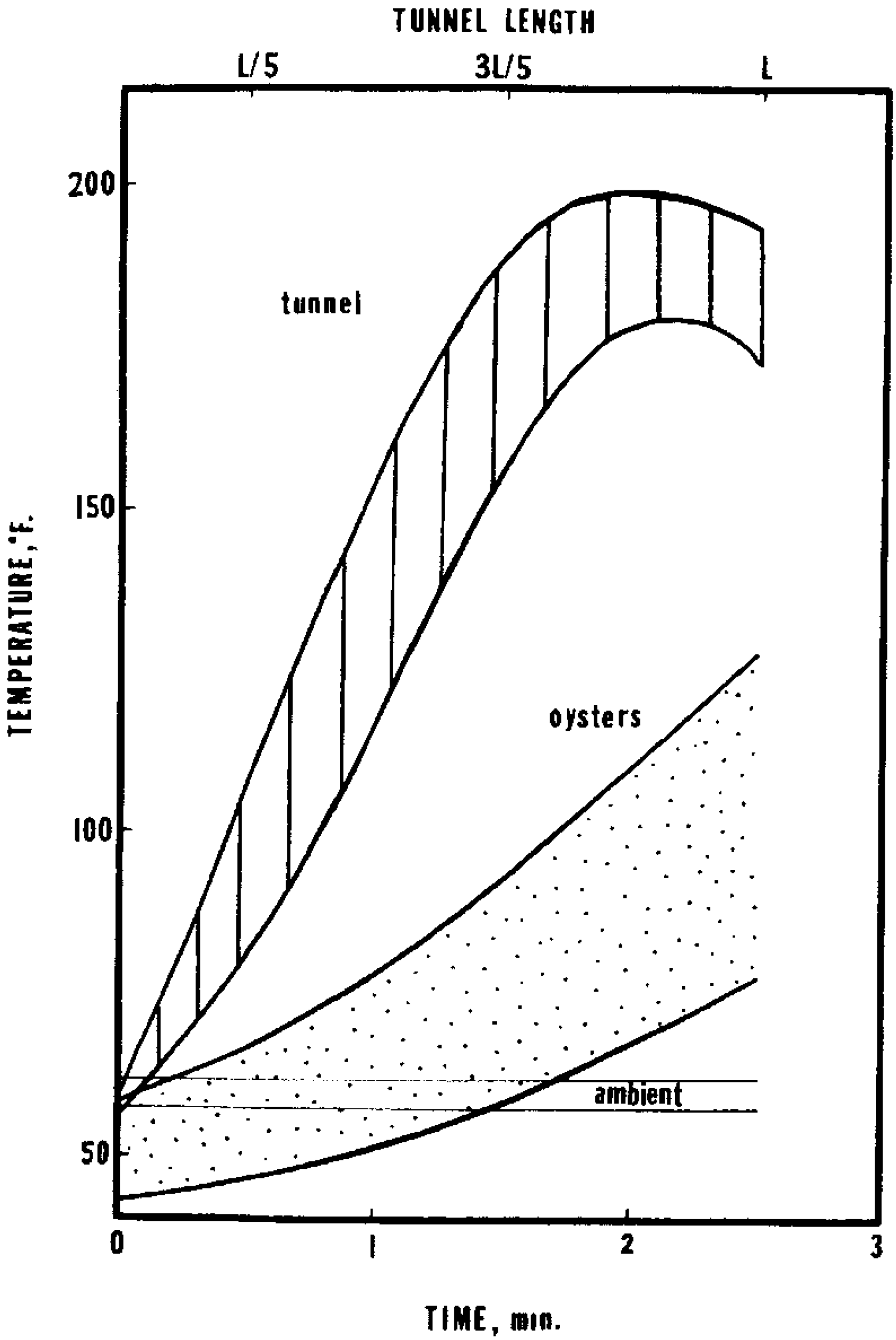



Figure 5. Temperature profiles of steam tunnel and the oysters in transit Case C

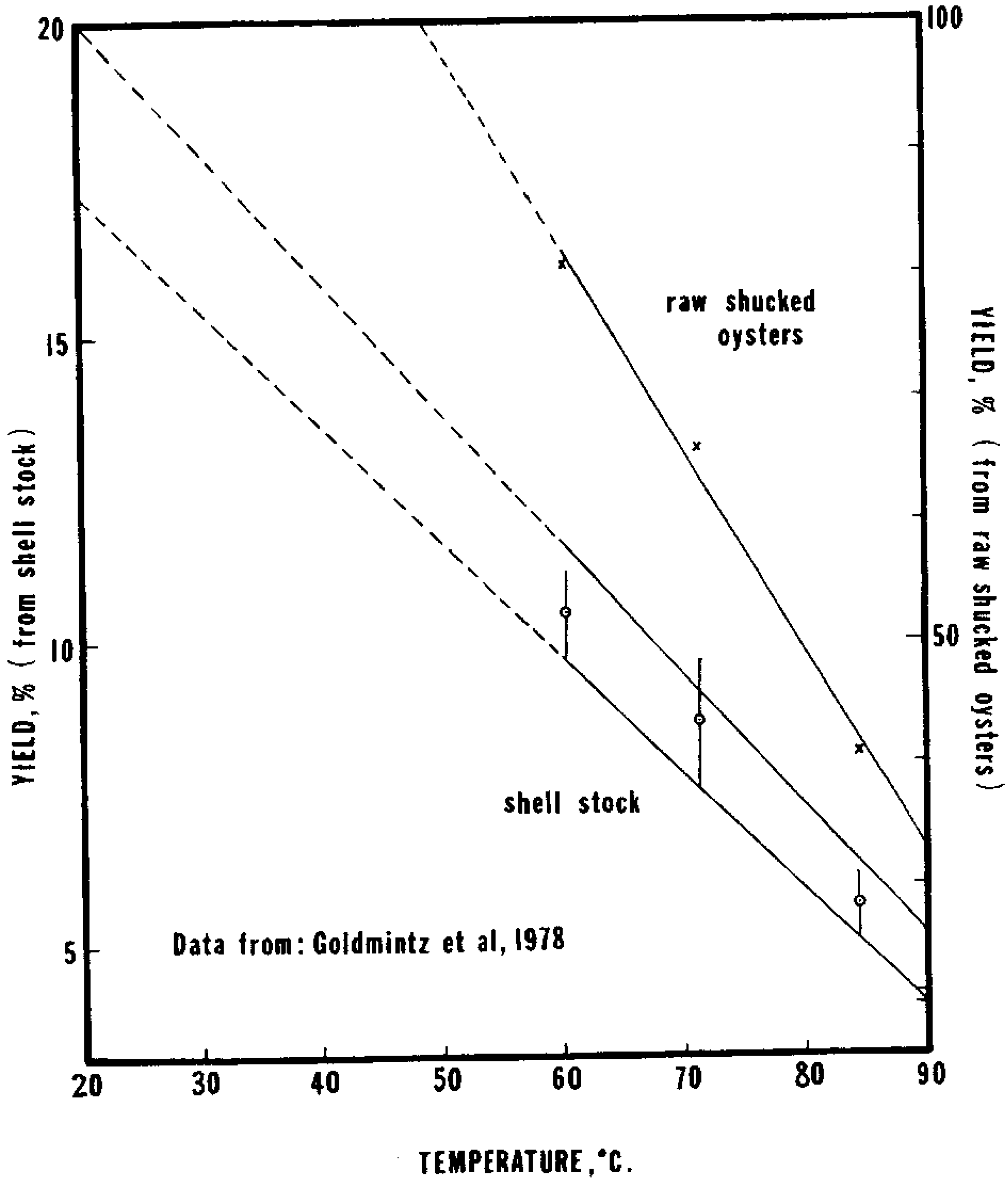



Figure 6. Product yield of oysters as affected by the heating temperatures

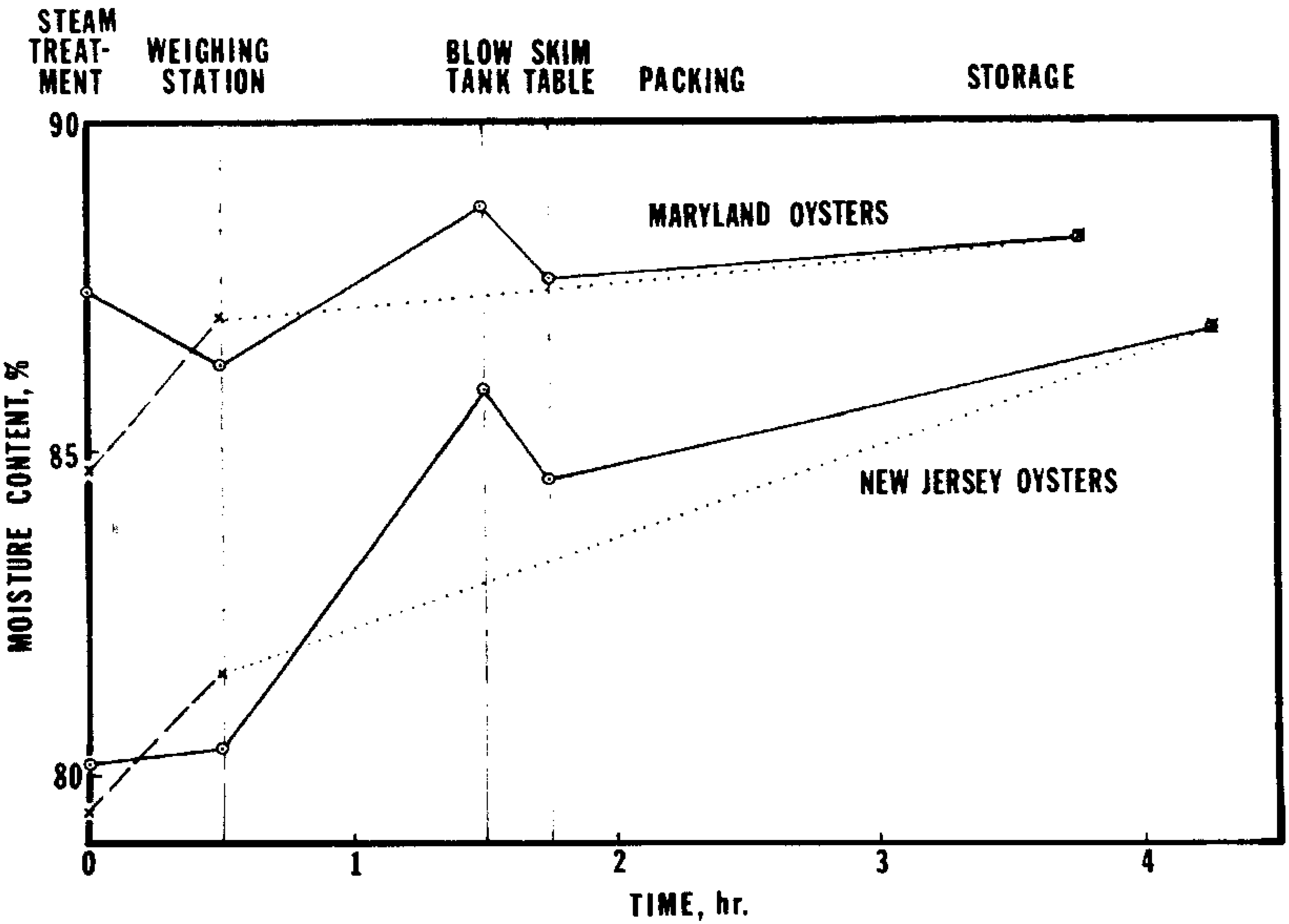



Figure 7. Changes of oyster's moisture concent at various processing stages

# Microbiological Aspects of Steam Shucking

Donn R. Ward

Steam shucking offers some very positive features to the processors of fresh oysters. In addition to facilitating the removal of oyster meats from the shell, there exists an ancillary benefit potential; the destruction and/or injury of a portion of the bacterial population associated with the oyster.

This presentation could be summarized by stating "steam shucking improves the microbiological quality of fresh shucked oysters." However, stating this without qualification would be a disservice to users and potential users of steam shucking. Although steam shucking does appear to be helpful from a microbiological perspective, the steamed oysters are handled in the same manner subsequent to steaming as traditionally shucked oysters. Thus the same opportunity for bacterial contamination still exists and still occurs.

The data in Tables 1 and 2 are representative of what is found in steam shucking operations. The data indicate that the standard plate count is significantly reduced after the oysters have passed through the steam tunnel, but that increases in the bacteriological character of the oysters occur as the oysters move through the various processing steps. The oysters pick up a significant bacterial load from the skimming table at the weighing window, which is due primarily to surface contamination. The skimming tables in the plants sampled appear to be clean having been rinsed with a water spray following the weighing-in of each shucker's buckets, which is the practice in most oyster plants. Nonetheless, skimming tables (or any surface with perforations) are very difficult to clean and to keep clean. A quick rinse with water or water with added chlorine is not always sufficient; the table must be scrubbed periodically on top and bottom. Some of the contaminants encountered in oysters sampled at the skimming table undoubtedly come from the shucker during the shucking operation.

It is apparent that the contamination observed at the skimming table is a surface contamination, since oysters emerging from the blowing tank (the next step in the process) are of lower bacteriological counts. It could be argued that, since oysters do pump while in the blowing tank, some depuration may be occurring. However, since the oysters are in the tank only for a limited period of time, the amount of depuration should not be a significant factor. During the next step in the sequence -- another skimming table, there again is an increase in bacterial counts due to contamination. From these examples, it appears that the benefit derived from steaming could be negated by post processing contamination.

Studies on oysters, *Crassostrea virginica*, report that the predominant microflora of oyster meats harvested in the Chesapeake Bay are *Pseudomonas*, *Vibrio*, *Moraxella-Acinetobacter*, *Cytophaga*, and *Flavobacterium*. Those who are familiar with microbiology would recognize these genera as all gram negative organisms. This is significant in view of the relative heat resistance of microorganisms, since gram negative bacteria tend to be less heat-resistant than gram positive bacteria. Furthermore, most of the food spoilage organisms are gram negative and, consequently, the reduction of this population could increase shelf life of the foods.

Bacteria are located on the surface of the oyster shells in the mud and are probably a mixture of gram negative and gram positive bacteria. Bacteria are also associated with the surface of the animal and the digestive tract. As oysters pass through a steam tunnel, the outer shell of the oyster receives the most direct and prolonged application of steam, thus achieving the highest temperature. The data collected from various steam tunnels in this study indicate that the maximum temperatures recorded in the tunnels range from 155 to 200°F. One would expect the outside surface temperature of the oyster shells to approach these temperatures and therefore to have a very positive effect in destroying and/or injuring some of the bacteria associated with the surface mud. This in turn may produce a beneficial effect on the degree of contamination transferred from the shuckers and shucking knives to the shucked oysters.

The maximum internal temperature of the oysters achieved range from 96 to 160°F and the minimum 70 to 100°F. While it is uncertain if any significant bacteriological destruction occurs in oysters achieving a minimum heating (i.e., 70 - 100°F), internal oyster temperature reaching 140°F has a very positive influence. This latter statement is based on work performed by the National Marine Fisheries Service on the pasteurization of oysters.

Another important consideration regarding the effectiveness of steam shucking on the destruction of bacteria is the time of exposure at a given temperature. The pasteurization of milk is the classic example of the increased killing efficiency at higher temperatures. Milk can be pasteurized by heating it to a temperature of 145°F and maintaining that temperature for 30 minutes, or by heating to 161°F for 15 seconds. An 11% increase in temperature reduces the time required for an equivalent process by over 99%.

In summary, steam shucking offers a tremendous potential for improving the bacteriological quality of oysters. However, due to the processing subsequent to steaming, the benefits derived from steaming can be negated unless strict attention is given to sanitation and good manufacturing practices.

One final word of caution, heating of the oysters by steam necessitates cooling of the oysters to refrigerated temperatures (≤40°F).

TABLE 1. Results of bacteriological analysis of oysters at various points in a steam shucking plant (Plant A)

| | Before Steaming | After Steaming | Skim Table at Weighing Window | Blow Tank | Skim Table |
|---|---|---|---|---|---|
| Standard Plate Count /g | a) 20,150<br>b) 12,300 | a) 2,550<br>b) 3,600 | a) 1,485,000<br>b) 189,000 | 5,500 | 11,100 |
| Fecal Coliforms MPN /100g | a) <20<br>b) <20 | a) <20<br>b) <20 | a) <20<br>b) 80 | <20 | <20 |
| Coliforms MPN /100g | a) 220<br>b) 230 | a) 330<br>b) 330 | a) 1,410<br>b) 3,450 | 1,300 | 1,720 |

TABLE 2. Results of bacteriological analysis of oysters at various points in a steam shucking plant (Plant B)

| | Before Steaming | After Steaming | Skim Table at Weighing Window | Blow Tank | Skim Table |
|---|---|---|---|---|---|
| Standard Plate Count /g | 2,055,000 | 65,000 | 189,500 | 29,900 | 89,500 |
| Fecal Coliforms MPN /100g | 20 | 230 | <20 | <20 | <20 |
| Coliforms MPN /100g | 70 | 460 | 230 | 230 | 330 |

## Steam Shucking of Oysters - Public Health View Point

Cloyde W. Wiley

### I. BACKGROUND

Following a search of many years, tempered by frequent trial and errors, several Virginia oyster packers introduced a revolutionary oyster opening system which is credited with increasing both production and worker earnings by approximately 40%. The first known oyster steam tunnel system in the United States was installed in August, 1977, at Remlik, Virginia. The "Heat Shock Treatment" of oysters is expected to ease the seafood industry labor problems, and in a few years, many additional processors will be using the system.

Basically, the system involves shocking oysters with steam as they pass through a tunnel to the extent they relax their adductor muscle so the shell gapes at the bill. This permits the shucker to insert a knife and remove the meat easily. The oyster meat is not affected by the steam, thus permitting the product to be marketed as fresh.

Various prototypes of the heat shock treatment (steam application) have evolved for the shucking of oysters. There are two basic types: automatic tunnel (horizontal or inclined) and manual box system. The tunnels are automated and utilized in conjunction with a monorail and/or belt conveyor system for heat shocking and delivery to the bench for shucking. Exhaust fans are used to reduce condensation. Sophisticated controls are used to maintain temperature and variable speed motors control the exposure time. The box system primarily involves placing the shellfish manually in a box and exposing them to steam for a predetermined time.

The industry advises that the heat shock method of operation provides the following advantages:

1. An individual with no previous shucking experience can readily learn to shuck and produce enough product to provide a decent day's wages.

2. Experienced shuckers can shuck more oysters during a work day, thereby increasing their earnings by 35-40%.

3. Oysters are considered fresh and not cooked.

4. Oysters have a more uniform, bright color and appear plump.
5. Total plant operation time is reduced.
6. Cluster oysters are readily shucked.
7. Packed product yield is about the same as regularly shucked oysters.
8. Pink discoloration previously associated with seasonal algal blooms is eliminated.
9. Bacterial counts are reduced.
10. Shelf-life of product is increased.

The one disadvantage reported is the need to control completely the temperature and exposure time. One operator suggests that a temperature of 180°F (82°C) minimum with a 190°F (88°C) maximum facilitates opening and prevents overcooking. If the shell oyster is overexposed, dehydration occurs and yield is reduced.

Although technological advances are a must, they bring with them their own peculiar problems regarding sanitation and protection of public health. Presently, there are four automated "steam tunnel" systems being utilized in Virginia for the processing of oysters and one small manually operated "steam box" system.

## II. DESIGN AND OPERATION

### A. System No. 1

The shell oysters are stored in large rectangular wire baskets. The baskets are then dumped into a hopper for dispensing to the steaming baskets. Each steaming basket has a wire center adapted for more efficient steaming of the oysters. Baskets travel on a monorail from the basket filler, then through the steam tunnel and continue on over the shucking benches.

The steam tunnel is 24 feet long and is built on a concrete shucking bench. The monorail has a variable speed control, and the baskets remain in the tunnel from 1 to 2 minutes depending on the age, size, harvesting area, and temperature of the shellstock. Oyster baskets enter the tunnel through an entrance hood which resembles an inverted box that has plastic flaps to retain steam in the tunnel. On the exit end of the tunnel there are similar flaps and a 90° metal hood to retain the steam. Attached to each end on the top of the hoods is a single vent pipe which connects to a vertical discharge for removing steam.

Steam is introduced into the tunnel through two one-inch pipes. These pipes are located in each corner of the bottom of the tunnel. Each of the horizontal pipes has 1/8 inch holes drilled 8 inches apart in them for dispersing steam.

The interior of the tunnel is constructed with 1/8 inch aluminum and is rectangular. Approximately 2 inches of insulation separates the interior and exterior walls of the tunnel. The outside closure is formed from plywood.

Internal temperature is registered by a straight stem dial thermometer which has the probe inserted in the middle of the tunnel. The internal temperature is controlled by a thermoregulator that closes and opens a magnetic steam valve. Steam flow and basket movement are manually controlled by toggle switches. Temperature studies conducted by Dr. Huang (see Chapter III) demonstrated varied temperatures existed in different areas of the tunnel. The maximum temperatures ranged from 152°C (306°F) to 170°C (338°F) through the entire tunnel. At the entrance end and for about one third way in the tunnel, the range was 50°C (122°F) to 60°C (140°F). At the exit end the range was 70°C (158°F) to 96°C (205°F).

The steamed oysters travel above the shucking benches on the monorail and are dumped by the shuckers as needed. The person operating the basket filling machine is responsible for controlling the steaming rate. When there are more oysters in baskets than are needed by the shuckers, the steam is turned off and the monorail is stopped. When this occurs, the tunnel temperature cools to about 50°C (122°F) in about 2 minutes. This rather quick cool down in the tunnel is probably a result of air flow in the exhaust system.

A bacteriological profile shows 3 out of 28 shucked and shell oyster samples which had received heat shock exceed the national shellfish bacteriological standards for fecal coliform. One sample was unsatisfactory for the standard plate count. It appears that applying steam to oysters decreases the bacteria population and increases the shelf-life of the product. But it is not likely that the temperature and exposure time is great enough to destroy bacteria in the meat. The steam treatment does remove much of the mud that increases the bacterial count while shucking oysters.

Another factor influencing bacterial population in shucked oysters is the length of time between shucking and packing. Steam shocking reduces this time considerably. All oysters that have received heat treatment are shucked in buckets with ice. This practice also retards the bacterial increase.

Problems and Recommendations

1. The tunnel should be designed to give easy access to the interior for cleaning and inspection.
2. The inside surface should not have exposed pipes near the inside walls to avoid shells getting lodged in the cracks.
3. The tunnel should have some incline for proper drainage.
4. The temperature of the process should be controlled by an automatic device.
5. The conveyor track should not be exposed to steam, and a food-grade lubricant should be used.
6. Oysters should be shucked in ice and the 45°C (113°F) packing temperature strictly observed.
7. The monorail should not have water standing in it. This water should not drip on shucking benches.
8. The baskets should be cleaned. No shells or organic material should remain in them after clean-up.

B. System No. 2

Oyster meats are removed from the shells after they are subjected to steam. The oysters are stored in large wire-mesh containers. The storage containers are moved to the steaming room and are shoveled onto the steamer belt at the rate needed by the shuckers.

After the oysters have been heat shocked by passage through the tunnel, they slide down a stainless steel chute onto the conveyor belt of the shucking table. The operator that shovels the oysters onto the steamer belt then goes to the shucking room, starts the shucking table conveyor, and uses a wooden stick about two feet long to slide the oysters off the belt in front of each shucker.

The steamer is a wire-mesh belt modified from a clam-grading conveyor. The bottom is covered and a raised cover is attached to the top of the unit to retain the steam. Under the wire-mesh belt there are two perforated pipes that eject steam onto the oysters. These pipes extend lengthwise and are about ten feet long. The belt is moved by a variable speed gear motor. Oysters are exposed to steam for approximately three minutes and travel twelve feet during the steaming operation. A thermometer and a thermoregulator probe are positioned near the top and midway of the steamer. Exposure is 168° - 180°F (76° - 82°C).

The steamer has a slope of twenty-two inches in twelve feet. There are no exhaust pipes connected to the steamer. There is a steam hood over the exit end of the steamer. It is constructed of stainless steel and discharges through the wall at the end of the shucking room. The slope of the steamer and the forward movement of the belt causes almost all the steam to travel to the exit end.

Oysters enter the shucking room via a chute in an opening in the wall. The shucking table is thirty-five feet long, accommodating shuckers on both sides. Shells are discarded in a gutter and are conveyed out of the shucking room by a belt under the shucking table. Outside the building there is a shell pile conveyor for moving shells away from the building.

The bacteriological profile on this system for one year is very good for steam treated oysters. A metal conveyor belt appears to have merit for a commercial heat shock method for preparing oysters for shucking because the steam is directed on individual oysters which are dispersed on the belt.

Problems and Recommendations

1. The motor and chain should be moved more to the side of the conveyor. If this was done it would eliminate two problems: the motor would not be exposed to moisture damage, and the lubricant would not touch the food product.

2. The top and the bottom of the steamer should be removable for inspection and cleaning.

3. Since the steamer has an incline, all the water and oyster liquor drains on the floor where the oysters are shoveled onto the steamer belt. A gutter should be attached to the lower end of the steamer to convey the liquid to a drain.

4. The stainless steel steam hood should be moved nearer the end of the steamer where it would be more effective in removing the steam.

C. System No. 3

The oysters are stored in the shell storage room, and from this room, they are hand-shoveled into the monorail baskets.

The steam tunnel is attached to the ceiling of a shell storage room. It is "L" shaped and is approximately 16 feet long. There are eight steam jets spaced approximately two feet apart. These jets are 1/4 inch pipe nipples that extend into the tunnel on the lower side facing the room. An automobile temperature gauge indicates the inside temperature of the tunnel. The internal temperature is not automatically controlled. The steam flow is manually controlled by an electrical valve connected to an external temperature control which is adjusted to the desired operating temperature. A pair of switches located outside the shell room turn the steam entering the tunnel on or off and start or stop the monorail.

The monorail is powered by a variable speed motor. Baskets remain in the tunnel for 2 minutes. The automobile thermometer maintains the internal temperature at 200°F (93°C). After remaining in the tunnel for two minutes, oysters reach a temperature of 110°F (43°C). After leaving the tunnel, the temperature in the oyster continues upward reaching 124°F (51°C). After the maximum temperature is reached, cooling is rather rapid.

The baskets are spaced about 44 inches apart on the monorail. They are filled at the rate needed by the shuckers. Baskets are not filled to capacity so that better steam penetration can be achieved.

Both the entrance and exit hoods of the tunnel are equipped with dual swing doors that are forced open by the entrance of a wire basket of oysters, and then closes as the basket passes. After a few months' operation, plastic strips were attached to the hoods for more efficient retention of steam. The interior of the tunnel is galvanized metal. It is insulated with styrofoam. The exterior plywood shell was never completed. Only one steam exhaust pipe is used. This pipe is vertical and terminates above the roof of the building.

After the baskets leave the steam tunnel, they go to the far end of the building before they are distributed to the shucking benches. The oysters are shucked in buckets containing ice.

The steam tunnel is supplied with steam from a Columbia Boiler with an input of 840,000 Btu, a gross output of 658,000 Btu and a net output of 486,000 Btu.

Problems and Recommendations

1. Since the tunnel for this steam is attached to the ceiling and has a 90° bend, it is almost impossible to clean or inspect.
2. The monorail is in the steam chamber which subjects oysters to the lubricant. A food grade lubricant should be used on the monorail.
3. There is a considerable amount of condensation in the steaming room.
4. As the oyster baskets travel from the steamer to the end of the shucking bench, they drip at the receiving window and wash-up sinks. These areas should be protected from the dripping.

D. System No. 4

Oysters are removed from the shells after they have been heat shocked. Containers that move on a monorail are filled from a shell hopper. The wire baskets that had been used for approximately one year were replaced by V-shaped stainless steel containers. The new containers were installed for easier cleaning and better heat contact with the shellstock.

Oysters move on the monorail and into the steam tunnel. They are inside the tunnel for 2 minutes and reach a temperature of 180°F (82°C). The internal temperature of the tunnel is automatically controlled by a steam solenoid valve actuated by a thermoregulator. The thermoregulator is positioned midway in the tunnel. Toggle switches located near the shell room shut off steam and stop the monorail movement when the shucking benches are filled.

The interior of the tunnel has the geometric shape of an isosceles triangle. The interior of the tunnel is lined with 1/16 inch galvanized metal. The exterior shell is plywood, and 2 inches of styrofoam is used for insulation.

Steam is injected in the tunnel by a single horizontal pipe that has holes drilled in it. This pipe is located approximately 4 inches from the vertex (bottom of tunnel). The steam supply enters the tunnel midway by a single pipe system. A Y-type strainer precedes the solenoid-operated valve. An automotive-type thermometer probe enters the tunnel at the same general location as the thermoregulator.

At each end of the tunnel there are hoods for collecting escaping steam. Originally the ends of the hoods had canvas flaps, but they have been replaced with plastic strips.

After the oysters receive the heat shock treatment, they move on the monorail to the shuckers. The oysters are shucked in buckets containing ice.

Fecal coliform bacteriological populations covering seventeen months of heat shock treatment were very low for the first year (1977). From June 1978 to January 1979, 47% did not meet the market standards. Some of the standard plate counts also exceed the standards.*

Problems and Recommendations

1. The monorail track passes through the tunnel and there is possible lubricant contamination of the product. Food grade lubricant should be used.
2. The geometric shape of the tunnel and the steam pipe causes shells to become lodged in the base of the tunnel. The tunnel should be constructed so that it can be dismantled for cleaning and inspection.
3. Oysters are dumped on top of oysters already on the shucking bench.
4. The monorail should have weep holes in the bottom so that water will not be carried over the shucking tables.

E. System No. 5

The manually operated box is approximately 5' x 3½' x 4', constructed of wood. Operation has been intermittent and few data are available.

---

*The unsatisfactory fecal coliform bacteriological samples occurring from June 1978 to January 1979 were, most likely, caused by hot weather conditions. This heat shock operation is the only one that processes oysters throughout the entire year. All the unsatisfactory samples during this time span occurred in June, September, October, and December. One-half of the shellstock was unsatisfactory before processing. One of the samples was from the York River, and the rest of the samples were from out of state waters. The bacteriological findings, therefore, are not considered to be attributed to heat shock processing.

## III. PUBLIC HEALTH CONCERNS

Bureau of Shellfish Sanitation review of the various operations indicate the following factors should be considered in future steam tunnel construction:

1. Steam tunnels should be so designed to permit the monorail track to be on the outside, with only the baskets passing through the tunnel. Design should not allow undue loss or escape of water vapor. This will eliminate lubrication problems and possible contamination of product. Also, condensate within the monorail should be materially reduced.
2. Present monorails must be lubricated with food grade lubricants.
3. The steam manifolds should be so designed and located as to prevent the catching of oysters and shells. This will aid in the cleanup process.
4. Entrance and exit areas should have flaps or doors of impervious material instead of canvas which will contaminate shellfish.
5. Tunnel bottoms or lower edge, V-shaped or otherwise, should be either hinged or demountable for cleaning and inspection.
6. Monorails should not drip into steamed oysters, shucked oysters, on tables, utensil sinks, delivery window, etc. If already in place, adequate protective barriers or shields should be installed to preclude such occurrences.
7. Monorails should have weep holes bored in the bottom to allow condensate to drain off.
8. Temperatures must be controlled by a thermoregulator.
9. Oysters should be washed prior to subjection to the steam process.
10. Fish hamper type containers used on monorails need redesigning to allow exposure in center of baskets and to facilitate cleaning.
11. All tunnels should be straight with no turns or angles.
12. Any probes to facilitate flow and transport of shellstock should be of inpervious materials.
13. Hoods should be so designed and operated as to prevent loss of steam or water vapor into shucking area. This will eliminate condensation and contamination of product. Condensation associated with the heat shock processing of oysters is both a significant bacteriological and building structural problem. This is most noticeable during cold weather. Steam escapes from the tunnel and also from the heated oysters in baskets after they exit the tunnel.

14. Drive motors and chain drive should be located out of the steam or high water vapor areas.

15. When heated oysters are piled on the shucking bench, careful attention should be given not to cover the ones that are already on the bench so that the shucker will constantly be shucking oysters that have been recently steam treated.

## IV. PROPOSED REGULATIONS GOVERNING THE HEAT SHOCK METHODS OF PREPARATION OF SHELLFISH FOR SHUCKING

1. General plant construction, equipment and associated facilities shall comply with established guidelines. (Shucking and Packing of Shellfish.)

2. The Hot Dip method shall not be used for processing shell oysters or clams due to the detritus accumulation and bacteriological build-up within the dipping tanks.

3. Washing of Shellstock

   Shellstock shall be cleaned or washed at the plant with potable water prior to being subjected to the heat shock method.

4. Construction of Equipment

   a) Processing equipment, including piping, shall be constructed of smooth, non-corrosive material so designed as to drain quickly and to be easily and thoroughly cleaned.

   b) Where belting is used to transport shellstock through the processing equipment, it shall be of such design as to facilitate steam penetration and be easily cleanable.

   c) When wire baskets or other containers are used, they should be so designed as to distribute heat evenly to all shellstock within the container and be easily cleanable.

   d) Proper vents and exhaust systems shall be constructed to remove heat and condensation from the processing room to the outside.

   e) Conveyor belting, baskets, or containers passing overhead shall be provided with adequate protective devices to preclude spillage/drippage on shucking, packing tables or processing equipment.

   f) Monorails used for transporting shellstock through the steam tunnel shall be so designed that the track does not run through the tunnel.

5. Records of Heat Shock Time and Temperatures

   a) Each plant operating a heat shock process shall maintain an accurate daily record of time and temperatures for each batch/lot of shellfish processed.

   b) Recording devices such as recording thermometers and steam inlet control valves shall be provided.

6. Refrigeration

   a) The oyster meats from all shellstock which have been subjected to the heat shock process shall be cooled to an internal temperature of 45°F (7° C) within two hours after the heat shock process.

   b) Refrigeration of the shucked product will be accomplished by the use of ice in the shucking containers, skimming tables, wash tanks, or blowers or by the use of refrigerated water.

7. Cleaning of Equipment and Bactericidal Treatment of Heat Shock Process Facilities

   a) Daily cleaning of all equipment utilized in the heat shock process shall be accomplished. Equipment shall be subjected to an approved bactericidal treatment in accordance with established regulations.

   b) Food grade lubricants shall be used for lubricating conveyor parts, motors, etc. and shall not come into the food product zone.

It is anticipated final regulations governing the heat shock process will be adopted in 1981. In the interim, any Virginia dealer anticipating the installation of a heat shock system should discuss the proposal with a representative of the Bureau of Shellfish Sanitation in order to meet the regulations.

## V. CONCLUSION

The Bureau of Shellfish Sanitation is of the opinion that the Steam Tunnel Heat Shock Method has considerable potential in the oyster processing industry and is vastly superior to the Hot Dip Method for opening oysters.

A report by Bureau of Shellfish Sanitation concerning the steam tunnel process has been referred to the U.S. Food and Drug Administration for evaluation and possible acceptance as an approved processing technique. Food and Drug Administration wants to establish a controlled bacteriological monitoring program before further comments are made. Hopefully this can be accomplished during the next oyster season.

## PLANT SANITATION ASPECT OF THE OYSTER STEAM SHUCKING PROCESS

Stanley D. Ratcliffe

I have been asked to talk about the plant sanitation aspect of good manufacturing practices and its impact on the steam shucking process as perceived by the Food and Drug Administration. I think the best way to start this discussion is to give a brief review and background on the Food, Drug, and Cosmetic Act and the Good Manufacturing Practice regulations (GMP's). The Food and Drug Administration's principal responsibility is to enforce the Federal Food, Drug, and Cosmetic Act (1938) (FDCA or FD&C Act) enacted to insure wholesome foods, harmless cosmetics, and truthful labeling of such products. Important amendments include the Food Additives Amendments of 1958 and the Color Additives Amendments of 1960.

Responsibility in the food area covers essentially all food except raw meat and poultry which are within the authority of the U.S. Department of Agriculture (USDA). However, Agency authority does not extend legally or practically to guaranteeing the safety, purity, and wholesomeness of all foods consumers eat. For example, from a legal standpoint the Agency can act only against food products sold in interstate commerce. Products made and sold entirely within a state must be regulated by that state. The practical barrier stems from the fact that most contamination occurs after food is purchased for home or restaurant use. In addition, with the exception of a limited number of foods such as enriched flours, the Bureau does not set nutritional requirements and has no authority to require manufacturers to produce food that is nutritious. There is a nutrient labeling requirement, but it applies only when a nutrient has been added to a food or when a nutritional claim such as "enriched" or "fortified" is made. The development of GMP's is one of the methods FDA uses to efficiently enforce the FD&C Act and meet its responsibility as set forth by Congress.

I would like to read parts of three sections of the Act that are of major importance to the food processing industry. Section 301 sets forth certain prohibited acts. The prohibited Acts include: delivery for introduction into interstate commerce any food, drug device, or cosmetic as adulterated or misbranded, the adulteration or misbranding of any food, drug device, or cosmetic in interstate commerce, and the receipt in interstate commerce of any food, drug device, or cosmetic that is adulterated.

Good Manufacturing Practice regulations are based on Section 402(a)(3) and (a)(4) of the Act which pertain to the adulteration of food products. These sections are as follows:

Section 402(a)(3): The food is adulterated if the food consists in whole or in part of filthy, putrid, or decomposed substance, or if it is otherwise unfit for food, or

(a)(4): if the food has been prepared, packed, or held under unsanitary conditions whereby it may have become contaminated with filth, or whereby it may have been rendered injurious to health.

The basic thrust of FDA GMP regulations then is to prevent or reduce adulteration or contamination of food material either prior to receipt of or during the processing operation.

In the development of regulations, the public must always be given the opportunity to respond to each proposed document. A frequent industry response is to question FDA's authority to promulgate any new regulations. Section 701 of the Act provides FDA the authority to promulgate additional regulations for the efficient enforcement of the Act. The courts have deemed that Section 701 does in fact give FDA the authority to develop additional regulations including GMP's.

The Food and Drug Administration utilizes "Current Good Manufacturing Practice in Manufacturing, Processing, Packaging, or Holding Human Food" in regulating the processing of human food as a tool for assuring the safety and wholesomeness of food products shipped in interstate commerce.

I want to briefly discuss the relationship between the National Shellfish Sanitation Program and the Good Manufacturing Practice regulations. Since 1925, the sanitary control of shellfish shipped in interstate commerce has been regulated under the guidance of the National Shellfish Sanitation Program (NSSP). Between 1925 and 1968, the Public Health Service administered the federal/state/industry voluntary program. In 1968, in the interest of consolidating all food inspection programs within one agency the Department of Health, Education and Welfare, the NSSP was transferred to the Food and Drug Administration.

The Food and Drug Administration as a participating member of the National Shellfish Sanitation Program has relied on, and will continue to rely on, the states and industry to provide the necessary controls to insure that only wholesome and safe shellfish are processed for shipment in interstate commerce.

The shellfish sanitation control program within FDA may be categorized as a dual program, both regulatory and voluntary in nature. Attempting to effectively utilize these two concepts has created some administrative problems for both FDA and state control agencies.

The agency is presently in the process of revising the umbrella GMP and is proposing to use it as the primary guideline for shellfish processing plants. The revised umbrella GMP would replace Part III of the NSSP Manual of Operations. I would like to highlight several of the sections of the proposed revised GMP's that may affect shellfish processing operations, including the steam shucking plants.

Section 110.37(b)(5) addresses management responsibilities for providing devices or systems to protect against backflow or cross connections between potable water and waste water systems. Any processing operation that utilizes equipment that must be connected to the potable water supply and could be a source of contamination would need to comply with these requirements.

Section 110.80(a) provides guidelines and requirements for assuring the quality and safety of the raw material or products that are brought into the plant for processing. The plant owners or managers need to take the necessary actions to ensure that the incoming raw product does not contain such levels of microorganisms as to produce food poisoning or other diseases and to prevent any other adulteration of the product.

Determining product quality may be accomplished through laboratory testing or product guarantee or certification. The NSSP provides the mechanism for meeting this requirement by state shellfish control officials classifying shellfish growing waters as approved for harvesting and the certification of shellfish shippers and processors. It is the industry's foremost responsibility to purchase shellfish from only certified dealers and to obtain shell-stock that has been harvested from approved waters.

There are continuing problems of shellfish being harvested from contaminated areas and processors knowingly accepting these shellfish for shucking and shipment in interstate commerce. It appears that steam shucking process reduces the initial bacterial count in the shellfish. Some processors may be tempted to take advantage of this condition and use shellfish with high bacterial counts caused by improper handling or those harvested from unapproved areas. The problem is increased when demand is high and supply of high quality shellfish is low.

Systematic quality control can only be obtained by responsible management practices across the entire spectrum of the shellfish industry. Ensuring that only safe and wholesome shellfish are used is the major critical control point in any shellfish processing operation.

Section 110.80(b)(3)(i) gives 45°F as the appropriate temperature for holding foods that can support the rapid growth of microorganisms of public health significance. At the 1968 National Shellfish Sanitation Workshop, the workshop participants agreed that shucked shellfish should be cooled to 45°F within two hours after shucking and stored at 34°F to 40°F. Since controlled studies and industry results show improved product quality and extended shelf-life with the cooler temperature, we anticipate that the industry would continue to hold shucked shellfish at 34°-40°F rather than 45°F. The GMP's are not considered to be maximum requirements, but rather what the food industry can reasonably be expected to meet and maintain.

Section 110.91(a)(1) requires the coding of the finished product by lot number and the plant where the product was processed or packed. This is very important for the shellfish industry. For example, a few months ago, there were several reported illnesses caused by the ingestion of shellfish. Fortunately, adequate records had been kept and both the source and distribution of the product were known. This greatly aided in the study of the disease outbreak and prevented possible closing of several shellfish growing areas.

Section 110.35 pertains to sanitary operations within the processing plant. Subsection 110.35(c) discusses equipment design and construction. This area could have significant impact on developing a shellfish steam shucking operation.

The GMP's require processing equipment be designed for easy cleanability and constructed of material that can be maintained so food will not become contaminated during processing. The type of materials acceptable for equipment construction has been changed in the proposed revised GMP. The revision calls for corrosion-resistant rather than corrosion-free materials. This change allows for other types of material besides stainless steel to be used in the construction of food processing equipment. From the viewpoint of both the regulatory agency and industry, we need to evaluate many different types of materials for use in food processing equipment in order to reduce the cost and still maintain product quality and safety as required under federal and state regulations.

Section 110.35(c) concerns cleaning and sanitizing the processing plant and equipment. The requirements are set forth in general terms to permit the utilization of cleaning and sanitizing methods best suited for a specific processing operation. The Food and Drug Administration's primary concern is that both plant and equipment be cleaned and sanitized so the food product does not become contaminated during processing.

The GMP also requires management to develop and maintain supervision processes to assure that the necessary day-to-day cleaning and sanitizing operations are completed. A plant can have well designed, easily cleanable equipment, sanitizers, and employees who are willing to do what is necessary to maintain the equipment, but if management does not accept the responsibility to assure vigorously maintained sanitation practices, then the entire processing operation will be jeopardized.

Some of the problems I have observed in the hot dip method as practiced in some of the southern states may also apply to the steam shucking operation. The first problem that comes to mind was the varying length of time oysters were left in the hot dip tank. The processing time changed with such variables as the size and quantity of oysters in each basket, the quantity of mud on the shell-stock, and the area where the oysters were harvested. Another problem was that too many oysters were placed on the shucking bench at one time and the shuckers could not keep up with the heat shocking process. As a result, the oysters closed up and became difficult for the shuckers to open. This defeated the hot dip process.

I see several potential problems that may be associated with the development of the steam shucking operation. I present them for your consideration. When oysters are steam-shucked, is the product raw or cooked? If it is cooked, it no longer falls under the NSSP. Another problem, relating back to the discussion of purchasing shell-stock that comes from unapproved areas is, what is the effect of steam heating on viruses? This question should be addressed in the future.

Washwater disposal may create a problem. The plant must meet the EPA requirements for waste water discharge. Depending on the amount of mud on the shell-stock considerable amounts of solids could be released to receiving streams or waste treatment systems.

The final problem relates to the possible need to develop specific guidelines to cover steam shucking operations. The Food and Drug Administration must look at the total industry on a nationwide basis. The industry in Virginia may be able to do things exceptionally well in a steam shucking operation. But what about a small plant in the Gulf Coast or in New England? Is it reasonable to expect these plants could or would need to meet the standards established here in Virginia? I think this could be a significant problem, particularly in the development of the types of equipment, control systems and how intricate the control system should be.

In conclusion, as we look at the prospect of going into a new technology for the oyster industry, I believe that we must look at its development in general terms in order to permit as much diversification as possible within the economics of the industry. At the same time, we need to look at the steam shucking operation in terms of what is feasible as far as the regulation and the maintenance of sanitation within the plant. The primary concern of FDA, state health departments, and the industry must be the production of a safe product. I am sure that no one is more interested in that than the industry itself. The goal that needs to be reached is the development of the best procedures for steam shucking that will produce a safe and wholesome product on a financially sound basis.

## Equipment and Design

Frank Huang and William H. Mashburn

I. Purpose.

Heat treatment is designed to relax the adductor muscles of the oyster and cause partial gapping of the shell, thus facilitating the subsequent hand shucking operation. In the systems presently used by the Virginia seafood industry, live steam is injected into a tunnel through which the oysters are transported on either a monorail or conveyor belt system, as described by Huang (1980). However, the basic functional requirements for the system must be clarified, and the need determined for improvements or construction of a new line for optimal operation.

II. Functional Requirements.

Four basic functional requirements in a production design for the heat treatment of oysters are listed below.

A. Temperature.

Research has indicated that raising the temperature of oysters causes relaxation of the adductor muscles. However, high heat can severely reduce both the yield and the quality of oysters. It has been suggested that 120°F is the maximum internal temperature of the oyster which does not cause appreciable ill effects (Goldmintz et al. 1978; Huang 1980).

In order to minimize bacterial growth, the time allowed for heating and maintaining elevated temperatures should be carefully controlled. The shorter the time the oysters remain warm, the lower their bacterial count. Therefore, rapid chilling of the shucked oysters is recommended.

B. Investment and Operation Cost.

Generally, oyster shuckers are paid at the same rate per gallon or weight of meat they shuck. The economic payback of a heat treatment system for the plant owner then must come from increased production rather than reduced labor cost. Therefore, it is necessary that both investment and operational cost be kept to a minimum. Investment can be minimized by proper sizing and careful selection of materials, whereas operational cost can be reduced by efficient management.

Generally speaking, the product cost is made up of three components: labor, material, and energy. For the last two years, the cost of energy has been rising at a faster rate than the cost of the other two. A prudent manager should give special attention to the energy component. To be energy-conservative the steam tunnel system should have good insulation in the outer shell of the tunnel and suitable means of containing the steam within the tunnel. The design should also be such that the heat source provides a maximum heat transfer to the oyster with a minimum loss to the transport system. Reducing heat losses not only conserves energy but also provides more uniform heating throughout the tunnel, producing a more desirable product.

Versatility and flexibility of a system to handle more than one product line can sometimes prove to be important. Due to the seasonality of the oyster industry, possible changes in use and/or expansion of the oyster plant should be considered. Adapting the existing facility for a new process usually means a reduction on capital investment. In modifying a processing line, one also needs to evaluate the efficiency of the operation.

C. Cleaning, Repair and Maintenance.

Routine cleaning and sanitizing is necessary to ensure good product quality and to meet the health inspection requirements in a food processing plant.

An easy access to the transport system and the tunnel interior greatly facilitates the operation. Furthermore, it expedites repairs and maintenance, improving reliability by decreasing down time.

D. Environmental Concerns.

The operation system must conform to the food and health authorities' requirements as well as the Environmental Protection Agency's regulations, with respect to corrosion, lubrication, boiler water treatment, high humidity, noise, effluent and solid waste disposal. These are the concerns that also exist in the conventional hand-shucking operation.

III. Developing a Functional System.

In developing a functional system, decisions must be made concerning various components of the overall system. These components are discussed in detail below.

A. Heating Methods.

The hot water dip method was reported by Pringle (1961) and Russel et al. (1964) and used in the industry to raise the oyster temperature in order to achieve gapping. However, using live steam appears to have the advantage over using hot water in several respects: (1) it greatly reduces water usage and the resultant effluent; (2) it decreases potential for contamination caused by the dip water leaching into the gapped oysters; (3) it applies more intense heat on the oyster directly in a shorter time, and; (4) it prevents energy loss due to dirty hot water disposal.

Some other energy sources, such as electric resistance, radiant heat, open flame, microwave, and laser beam, have also been tested. The microwave and the laser beam have a high initial investment cost. In addition, since they are energy-intensive tools, it is hardly possible to control precisely the temperature of individual oysters, which are irregular in size and shape, on a mass production line. Neither microwave nor laser beam appears to have commercial value for oyster heat shock at the present time.

Open flame has been used commercially for clam and oyster shucking. However, its effect tends to be too rapid and its heat too high to allow easy control. It also causes excessive moisture depletion in the oysters. To prevent the oyster meat from dehydrating, direct flame heating, other "dry" heat utilizing electric heating elements, or radiant heat from hot water and steam should be supplemented with a controlled high-humidity environment. Among various radiant heat sources, electric resistance has the advantage of low initial capital cost, ease of temperature control, and low maintenance. Its operational cost, however, may be higher than that of steam or hot water.

Using a closed steam supply system alleviates the need for large amounts of feed water to replenish the boiler, and thus reduces the cost of boiler water treatment. Additionally, because the condensate does not come in direct contact with the oysters, chemicals used in the water treatment may not be restricted by the food regulations. In a closed supply system, live steam is not injected and released in a steam tunnel; thus problems associated with high humidity in the working area are alleviated.

An energy source should be selected with specific constraints of individual plants in mind. Factors to be considered include: the availability and price of the energy source, the cost of installation and maintenance, the existing facilities and plant layout, desired precision in temperature control, and the qualifications of the production supervising personnel.

B. Tunnel Structure.

1. Materials. Because of the marine environment and sanitation requirements, all metals used in the steam tunnel system must be corrosion-resistant. This

may be accomplished by using a corrosion-resistant base material or a coated metal.

Stainless steel is the best material from the standpoint of corrosion-resistance but is expensive and difficult to work with. Aluminum is much less expensive and easier to machine, and if the proper alloy is selected, it meets the requirements of corrosion resistance. Alloys best suited for the marine environment are 5052 and 6061.

If a low carbon corrosive steel is used, it can be coated with chromium, cadmium, or zinc. Chromium is the most durable and the most expensive. Cadmium is preferred to zinc.

When plywood is used to construct a steam tunnel, moisture- and corrosion-resistant coating, lamination, plastic, or metal sheet must be applied on the surface which comes in contact with the steam. The plywood structure is cheaper to build but not as durable or sanitary as the metal ones.

2. Insulation. Insulation should be selected to meet the relatively high-temperature and high-humidity requirements. Foam polystyrene has been used in steam tunnels but suffers from having relatively high moisture permeability, relatively low mechanical strength, a high burning rate, a low maximum recommended service temperature of $176^{\circ}F$, and a softening temperature of $194^{\circ}F$. Spray-on polyurethane foams and foam glass are more suitable for use in steam tunnels.

3. Steam Pipes. Copper or galvanized pipes 1 to 1½ inches in diameter can be used to carry the steam. Holes 1/8 to 3/16 of an inch in diameter may be drilled on pipes to inject steam into the tunnel. These holes should be located so as to provide an even distribution of steam. More holes per unit length should be made near the entrance end than at the exit of the tunnel. A gradually decreasing number of steam injection holes from the entrance towards

the exit is desirable for good steam utilization. Exposed steam pipes that are not used for heating purposes should be insulated to conserve energy.

4. Shape and size of tunnel. Continuous steam tunnels in rectangular, triangular, and tubular shapes have been built by the industry over the years. In most cases, the tunnel has been constructed to fit the existing facilities. From an engineering standpoint, a tunnel should be designed to meet the regulatory requirements and to provide efficient heat transfer and energy utilization at a minimum cost. A tubular metal construction may be easier to work with, but leaves various amounts of unused space depending on the type of the transport system employed. In a triangular tunnel, it is difficult to clean the debris collected. The rectangular tunnel is particularly suited for use with a belt conveyor. Regardless of shape, a well-designed tunnel should leave little room for waste.

"Steam boxes" have also been used for oyster steam shucking in batch productions. Their efficiency is generally low and temperature control unreliable. The use of a pressurized tunnel for the operation, which has been suggested by some people, allows total containment of the steam but requires pressure locks.

The size of the tunnel should be determined primarily by the production volume desired, the available space for the installation, general conditions of the raw oysters (e.g., clean or muddy, thick-shelled or thin-shelled, fat or lean, large or small, warm or cold), tunnel temperature, heating time duration, and dimension and speed of the conveyor system. In general, it can be calculated by using the formula:

$$P = \frac{V}{\ell} \times \frac{L}{T} \times 60$$

where,

P = desired production volume, bushel/hr,

$V$ = 1 bushel of oysters = $w.t.\ell$,

$w$ = width of conveyor belt, ft,

$t$ = thickness of oysters on belt, ft,

$\ell$ = the length a bushel of oysters spreads at constant w and t, ft,

$L$ = tunnel length, ft,

$T$ = time duration of each oyster in steam tunnel, min., and

$\upsilon = L/T$ = conveyor speed, ft/min.

Since P is a projected quantity (bushel/hour), V is equivalent to one bushel of oysters in question; $\ell$ can be obtained by measuring the spread of one bushel of oysters; and the length of the tunnel can be obtained as $L = \frac{P\ell T}{60}$.

Because the size and shape of raw oysters may vary in each lot, either the production (P) must be altered or the heating time (T) has to be adjusted according to $T = \frac{60L}{P\ell}$. In the latter case, when the heating time is changed, the tunnel temperature must be proportionally increased or decreased in order to allow the same amount of thermal energy to be received by the oysters. By the same token, whenever a new stock is used, the heating time and temperature should be altered to compensate for variations in thermal properties of the shell-stock. The time-temperature relationship should be determined in a laboratory to facilitate accurate control prior to production.

If a shorter tunnel is desired, and all other conditions remain the same, the tunnel and the belt must be widened. Increasing the number of layers of oysters on the belt is not recommended because it causes poor heat distribution among the oysters due to slow heat penetration.

Example: $L = \frac{P\ell T}{60} = \frac{60x5.5x2}{60}$ = 11 ft. long tunnel, when

$w$ = 2 ft,

$t$ = 3 in. (no more than 2 layers of oysters on belt),

$V$ = 1 bushel,

$\ell$ = 5.5 ft,

P = 60 bushel/hr, and

T = 2 min. at a tunnel temperature of 180$^{o}$F.

Conveyor belt length needed: 2x11 = 22 ft.

5. Others. The steam tunnel can be suspended from the ceiling or placed on the floor. It can also be made portable in order to give flexibility in shifting production lines. A tunnel installed with a slight slant is recommended to allow drainage and steam ventilation. Double flexible curtains, air curtains, water curtains, airlocks, or pressure locks should be installed to reduce heat losses caused by escaping steam during the transfer of oysters in and out of the tunnel. It is strongly recommended that a part of the steam tunnel be easily removable for cleaning, repairs, and maintenance.

C. Transport System.

Several transport systems can be used in the oyster steam shucking operation, including monorail, belt, and screw-type conveyors. Some oyster packers Virginia already had monorails carrying the oyster shell-stock in baskets to the working station. When they adopted the steam shucking process, they simply added a steam tunnel at one point in the monorail system. In this operation, raw oysters are filled into the baskets and transported through the tunnel and onto the shucking table. Individual workers unload the baskets, form a pile of heat-treated oysters on the table in front of them, and proceed shucking. The monorail continuously moves through the line unless stopped by shutting off the driving mechanism. The greatest disadvantage of the monorail system lies in uneven heat distribution due to poor heat penetration in the baskets. This drawback may be improved by re-designing the basket and the steam injection pattern. Another inherent shortcoming of the monorail system is the heat loss occurring from the constant heating-up and cooling-down of the baskets as they are moved in and out of the tunnel.

Flat-belt conveyors are employed widely in food processing plants to transport goods. They are available in a variety of materials for different purposes. A steel wire mesh belt is the most efficient for heating the oysters on the belt. It allows heat to distribute evenly among one or two layers of oysters placed on it. It also allows debris to fall through. The belt conveyor facilitates controlling the heating temperature and belt speed; thus, the danger of overcooking the oysters is greatly reduced. As shown in Figure 1, the belt conveyor may be entirely concealed inside the tunnel to eliminate heat loss caused by the heat-and-cool cycle.

The belt conveyor transport system is found to have one disadvantage. Workers at the beginning of a shucking line tend to select large oysters and leave the smaller and odd-shaped ones to those at the end of the line. This problem could be solved by designating personnel to distribute the oysters to the shuckers along the line. If the incentive wage system is replaced by hourly payment, the problem will naturally be alleviated.

Although only a few are being used at present, screw conveyors can be rather efficient system to heat and transport oysters. The outer tube of the screw conveyor may be steam-jacketed and insulated to contain the heat. The screw may be equipped with a hollow shaft to pass live steam to heat the oysters. The major disadvantages of this system are a high noise level, susceptibility to jamming, and excessive wear of the system caused by shell particles and other debris.

In most cases, a transport system has moving parts which need frequent lubrication. Because of the likelihood of the lubricant coming in contact with oysters, it is required that only food grade lubricants be used for this purpose. The tunnel temperature should also be included in the order specifications.

D. Temperature and Time Control.

The heating temperature and time duration to relax the oyster's adductor muscles, but not to cook them, are critical in maintaining product quality and rendering a maximum yield. One can use variable speed drive in the transport system to manipulate the heating time and apply temperature-sensing devices to manually or automatically regulate the steam inlet and thus the tunnel temperature.

Sensor probes should be located at several places throughout the tunnel to monitor the tunnel temperature. A check on the oyster body temperature after the heat treatment also is recommended to ensure correct heating conditions. Shucked oyster meat must be chilled rapidly to discourage microbial growth. The product temperature should be checked periodically so that corrections can be made immediately.

In selecting a temperature-sensing device, one should consider the accuracy, recording capability, ease of reading and installation as well as the cost. Mercury thermometers are generally accurate and inexpensive. Digital readout temperature sensors are easy to read but costly.

An automatic steam valve control governed by the temperature sensors can be easily installed. But a by-pass should be provided so that, when oysters are not being sent through the tunnel, steam can be saved by shutting off the valve.

E. Ventilation.

When the tunnel is not totally enclosed, steam escapes. Even in an air-tight condition, the heat-treated oysters coming out of the tunnel will disperse water vapor. This excess moisture in the air will cause high humidity and condensation problems in the working area.

To avoid high humidity and condensation, some means of ventilation must be provided. A collecting hood may be installed to vent the escaped steam outdoors and, if necessary, a fan can be added to draw out the moist air. A slanted ceiling and a sloped floor help prevent dripping and facilitate drainage. By using thermopane glass, condensation on the windows can be greatly reduced. Because condensation occurring in the tunnel may pose a health hazard, the tunnel should have a slanted roof and good drainage.

During this era of energy shortage, every possible effort should be made to conserve energy. Recovery of heat from the exhausted steam from the tunnel should be considered, so long as it is economically feasible.

IV. An Optimal Functional Design.

Figures V-1 and V-2 show two designs that attempt to optimize the required functions described above. The shell of the tunnel is sheet aluminum 5052 alloy made into a sandwich with two inches of polyurethane as insulation.

In order to reduce heat loss from the transport system, Design A (Fig. V-1) uses a conveyor with a wire belt totally enclosed in the heat tunnel. Oysters are placed on the conveyor equipped with a spreader which levels them out to one or two layers. They are then dropped down a chute through a double airlock door onto the conveyor within the steam tunnel. They travel through the tunnel, drop off the end through a second double airlock door onto another conveyor or to wire baskets for transporting to the individual work stations. The conveyor motor is located outside the tunnel so that it is not subject to high heat and humidity.

The steam is injected upward from underneath the belt and/or downward from above the belt carrying the oysters. More holes are drilled in the steam pipes at the entrance to allow maximum use of the steam. The number of holes on the pipes gradually decreases toward the exit end. Three thermometers are inserted in the tunnel at different locations. The top or the bottom of the tunnel is made with hinges on one side and butterfly bolts and nuts on the other. A rubber gasket is used around the junction between the moveable part and the main body to give a tight seal when closed.

Design B (Fig. V-2) reduces the size and total internal space of the tunnel by placing the belt sprockets and return portion outside the tunnel structure. The total internal space is 27 cubic feet as compared to 42 cubic feet in Design A. This reduction in space should improve heat utilization and efficiency. However, Design B does lose more heat through the belt, which is exposed to ambient temperature on its return, and requires a longer belt, 30 feet as compared to 22 feet in Design A.

References

Goldmintz, D., R. C. Ernst, and J. Rasekh. 1978. Development of a Pasteurized Oyster Product. National Marine Fisheries Service, Southeast Fisheries Center, NOAA, Charleston Laboratory, Charleston, SC 29412.

Huang, F. 1980. Case study on oyster steam shucking - yield, efficiency, and quality. Presented at the Engineering and Economics of Oyster Steam Shucking Process. May 22-23, 1980. Hampton, VA.

Pringle, S. B. 1961. The "Hot-Dip" or "Shock" method of opening oysters. Proceedings Shellfish Sanitation Workshop, Nov. 23-30. U. S. Department of Health, Education and Welfare, Public Health Service, Washington, DC.

Russel, R. T., R. J. Hammerstrom, S. B. Pringle, and M. Walsh. 1964. Studies of the "Heat Shock" process for oysters. Proceedings Shellfish Sanitation Workshop, Nov. 17-19.

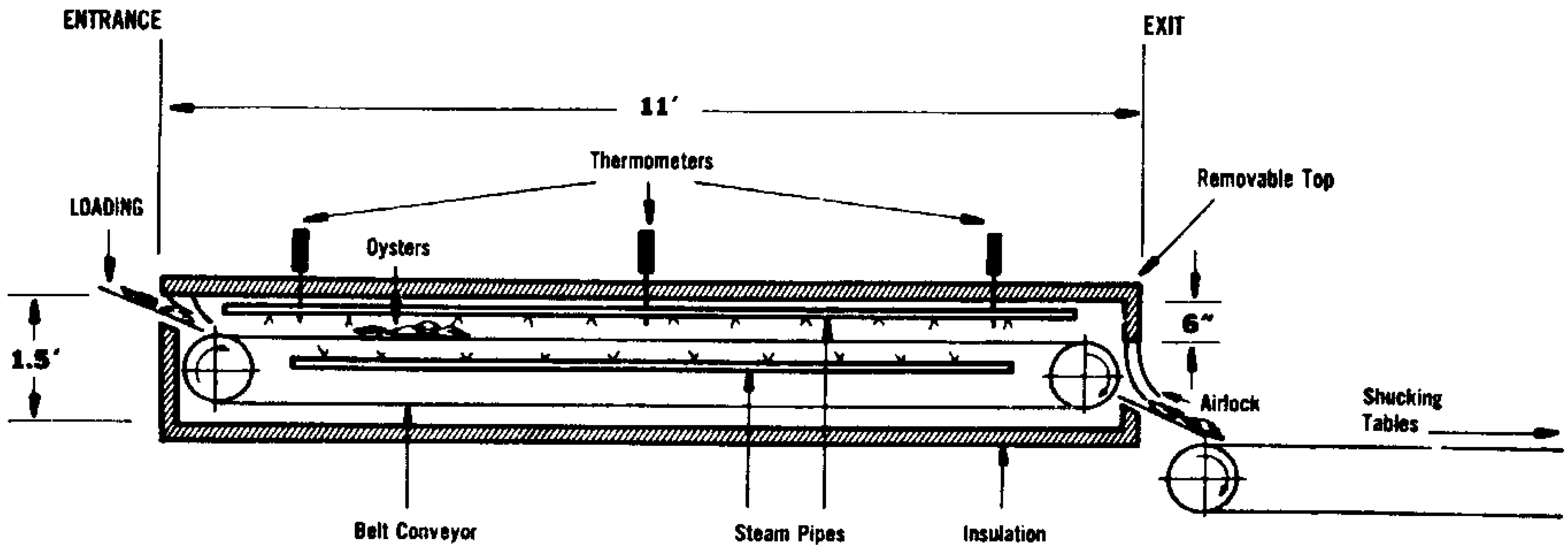



Figure 1. Steam Tunnel Design A.

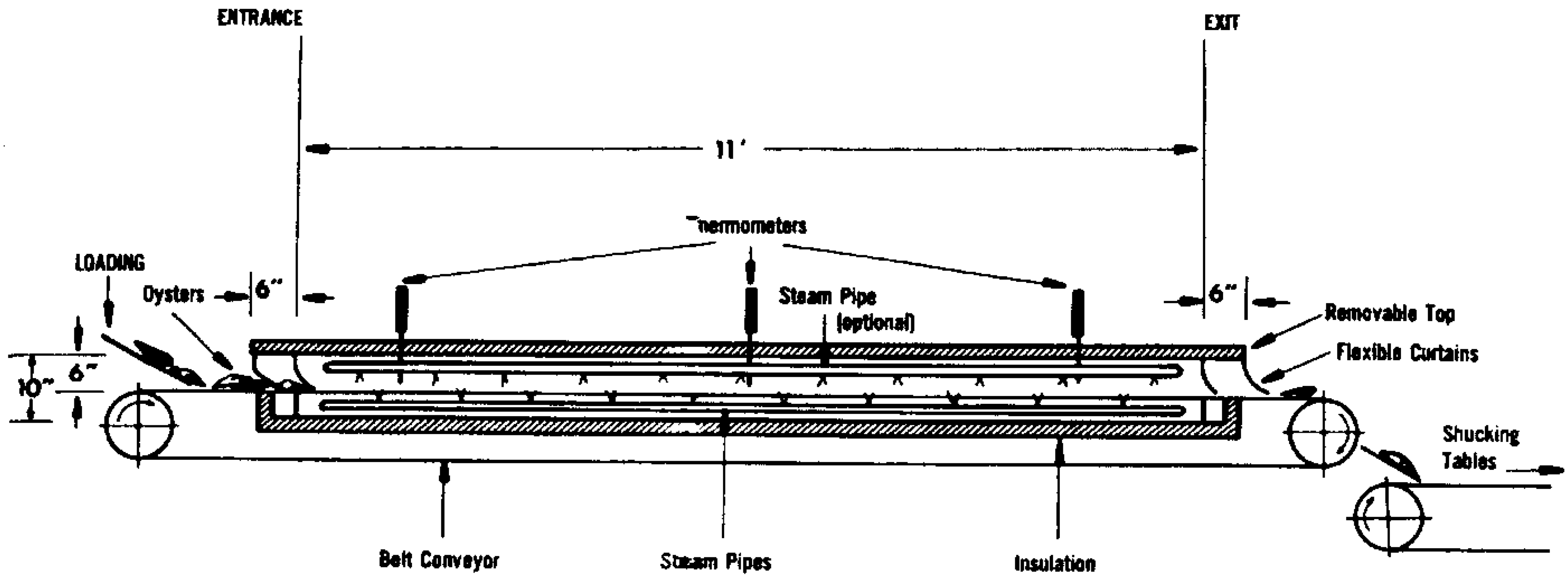



Figure 2. Steam Tunnel Design B.

# Steam Generation -

# Boiler Selection, Boiler Maintenance, Water Quality and Tests

Frank Huang, William H. Mashburn, and J. Kenneth Riggins

## I. INTRODUCTION

A boiler is a pressure vessel that generates steam by heating water, using electricity or some other fuel. Efficient boiler operations involve correct operation and maintenance procedures that become even more important when large quantities of steam are generated and consumed. Food processing plants utilizing steam for can sterilization, retort cooking, pressurized cleaning, or other direct heating purposes require a constant supply of live steam and thus a continuous supply of water to replenish water lost as steam. Improper water quality can reduce boiler efficiency tremendously because the impurities cause scale to be deposited on the heating surface. For example, a quarter-inch scale deposit increases fuel consumption by 25 percent (Fig. 1). Boiler efficiency is also reduced, and energy wasted, when fuel combustion is not adequately controlled.

Proper operation and maintenance procedures are also good safety practices. Most boilers operate above atmospheric pressure and could be dangerous if improperly operated or maintained. For this reason, the American Boiler Manufacturers Association and the American Society of Mechanical Engineers have established standards and codes for boiler construction. States and insurance companies have also set stringent specifications and requirements for boiler operations. A well-designed and constructed boiler does not guarantee safety, however. If the boiler is neglected, scale and corrosion accumulations or faulty valves and gauges may cause hazardous conditions within the boiler; also, erroneous operating procedures can cause safety as well as mechanical problems.

## II. BASIC BOILER ELEMENTS AND TYPES OF BOILERS

A boiler consists of two basic parts: a heat source and a vessel in which boiling water generates steam for heating and cooking. Surfaces in the vessel that water and steam contact are called <u>watersides</u>, and surfaces contacting the heating source are called <u>firesides</u>.

As shown in Figure 2, a boiler receives feed-water from a well or municipal source combined with the return steam condensate.

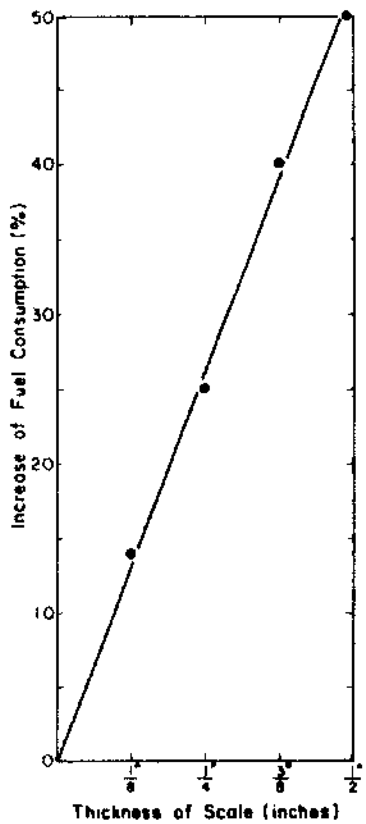



Figure 1. Effect of the thickness of scale on the boiler's fuel consumption.

A boiler system can be either closed or open. In the closed system, steam is employed as an indirect heating agent; the steam pipes do not have openings outside the boiler (Fig. 3). Thus, the steam condensate is recycled to the boiler for steam generation. Steam jacket kettles and space heaters are good examples of this arrangement.

An open system employs steam as a direct heating agent. In this case, steam condensate will not return to the boiler (Fig. 4). Consequently, a constant water flow will be necessary to make up for water losses. Retort cooking and sterilization in food processing are examples of this system.

Efficient steam generation requires as much water as possible to be brought in close contact to the heating source. To meet this requirement, boilers are con-

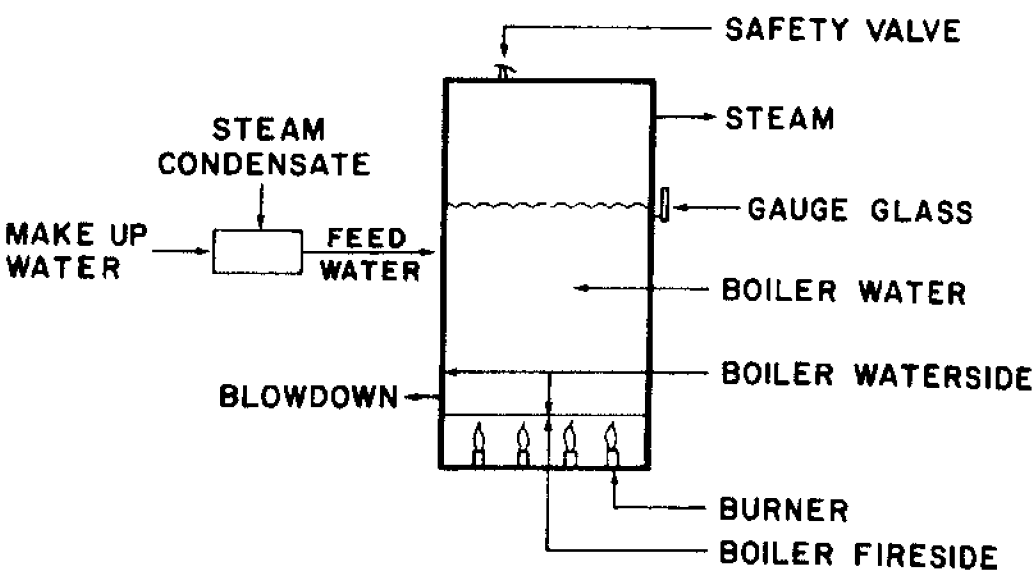



Figure 2. Basic elements of a boiler.

structed with either watertubes or firetubes (Fig. 5). In both cases tubes passing through the boiler provide efficient heat transfer. A watertube boiler allows water to flow inside the tubes, whereas a firetube boiler directs the heating agent through the tubes. A watertube boiler generally consists of a water and steam reservoir drum and has large capacities with high steam pressures. A firetube boiler is often built with additional passes to maximize heat usage. Boilers may be designed for horizontal installation, or, to save space, vertical construction.

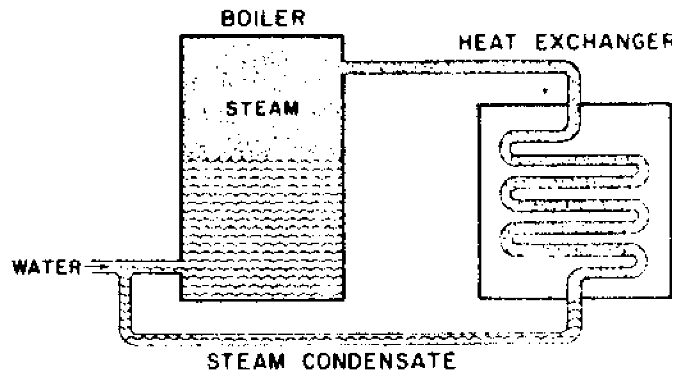



Figure 3. A closed steam supply system.

Some boilers use electricity rather than fuel. In this case, heat is generated between metal electrodes submerged in the boiler water. Since an electric current will continue to flow only when water is present, the water level automatically controls heating in the boiler. There are also smaller steam generators that simply use electric heat elements for their source of thermal energy.

Boilers may be rated according to their horsepower, heating surface, evaporation capacity, or equivalent direct radiation. Boiler horsepower is equivalent to the evaporation of 34.5 lb of water per hour at 212°F (33,472 Btu/hr). Evaporation capacity is expressed in lb steam/hr at specified steam conditions. The heating surface is the total square footage on the fireside of the tubes. Equivalent direct radiation (EDR) is 242 Btu/hr-ft$^2$ for steam boilers.

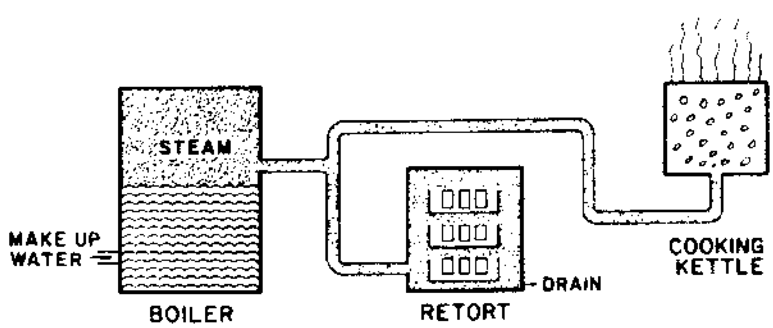



Figure 4. An open steam supply system.

## III. WATER QUALITY

This section deals with the basic principles, problems, and treatment of boiler water. Methods are discussed for determining water quality, water treatment, and correct operation procedures to reduce effects of impurities in water.

Boiler water is used to generate steam or to transfer heat. Its quality is of vital importance to the efficiency and safety of the boiler. Good boiler water is free from impurities that may cause detrimental effects within the boiler. Several tests can be made to determine water quality, including pH, acidity, alkalinity, odor, color, turbidity, total solids, total dissolved solids, dissolved gases, hardness, chlorine content, etc. Fortunately, in many cases, depending on the specific situation, not all tests are necessary.

### A. pH, Acidity, Alkalinity

The pH represents the intensity of the acid or alkaline condition (hydrogen ion concentration) of water. It can be easily determined using a pH meter. Electrodes are inserted into the sample and the pH value is read on the meter. Since the water temperature affects the reading, a correction must be made on each measurement. Normally, pH 7.0 is the neutral point. A value lower than 7 indicates acidity (like vinegar), and a value greater than 7 indicates alkalinity (for example, soapy water). To measure the total amount of acid or alkali in a sample, employ a titration method using an alkali or acid solution of known concentration.

The proper pH of feed water for boilers ranges from 7.5 to 9.5, and that of blowdown water from 10.2 to 11.5. Improper pH induces corrosion. As corrosion continues, metal thickness is reduced, resulting in greater boiler stresses and unsafe operating conditions. If a steel boiler is subjected to long exposure to highly alkaline waters, caustic embrittlement can occur. In such cases, cracks develop below the water line and under rivets, welds, and seams.

Boiler water is considered acidic when its pH is below 8.5. The acidity is a result of dissolved carbon dioxide and/or dissolved minerals and organic acids. Normally, municipal water has a pH between 6 and 7. Thus, for boiler use, city water is usually too caustic and requires adjusting by addition of caustic soda or by installation of a de-aerator.

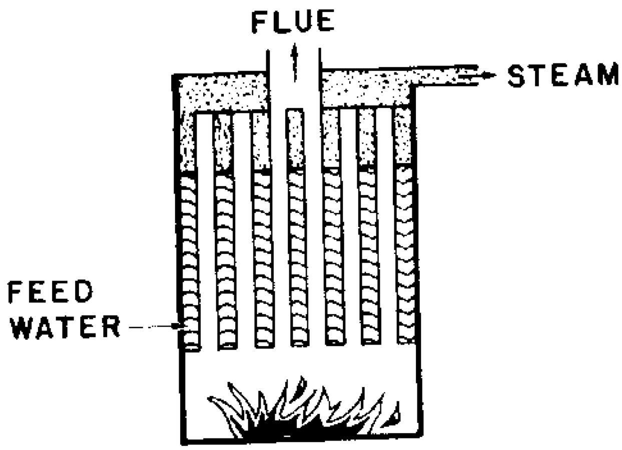



Figure 5A. A firetube boiler.

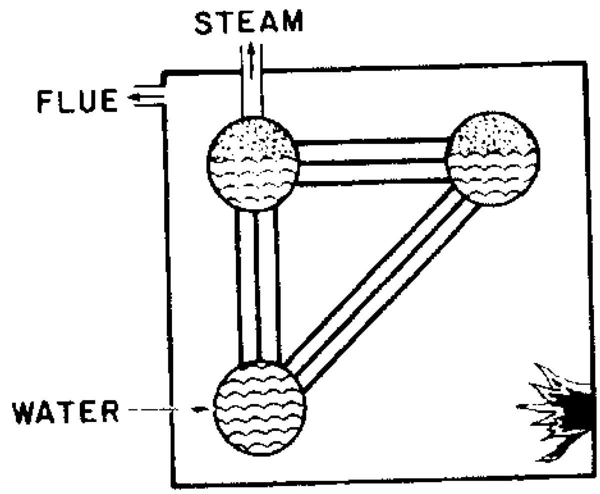



Figure 5B. A watertube boiler.

Boiler efficiency is determined by comparing the output heat (steam) to the input heat (fuel). In order to achieve high efficiency, a boiler should be designed to minimize heat losses. In addition, proper care and maintenance must be exercised routinely so that high efficiency may be sustained and operational safety warranted.

A boiler that is 'clean' and 'tight' is one that is properly operated and maintained. Feed water quality is most important in maintaining boiler cleanliness. Water of undesirable quality can cause scale formation, corrosion, carryover ( continual discharge of slag in the steam), and caustic embrittlement (the development of cracks in the boiler system). Proper fuel-air mixing is also important. Poor fuel adjustments cause soot and ash deposits to accumulate on the firesides, reducing efficiency and increasing operation costs. Correct operation procedures can greatly reduce these problems.

A 'tight' boiler is free from water, steam, or air leaks. Periodic inspection and repair of faulty valves, gauges, steam pipes, etc. through the entire boiler system is necessary to ensure tightness. A routine maintenance schedule provides opportunities in both cleaning and repairing. A tight boiler provides maximum efficiency, long boiler life, and better safety conditions.

B. Dissolved Gases

As mentioned above, dissolved carbon dioxide can lower the pH in water, causing corrosion. Corrosion also takes place when oxygen is present in the boiler water. Corrosive reactions accelerate at the elevated temperatures at which boilers normally operate; if uncorrected, localized pitting or cracking can eventually rupture boiler tubes. When rusty water shows in the gauge glass, it is a sure sign of corrosion in the system.

To remove dissolved gases in boiler water, a de-aerator can be installed on the feed water line. Sodium chromate, sodium sulphite, or hydrazine can also be used to control corrosion. Sodium sulphite and hydrazine react with the oxygen in water and eliminate oxygen.

C. Odor, Color, Turbidity

Normal boiler water should not have odor, discoloration, or turbidity problems. Excessive amounts of suspended matter which either diffuse or interfere with the passage of light cause turbidity and give color to the water. Filtration or sedimentation can usually eliminate the suspended solids in water.

D. Total Solids and Hardness

Total solids include dissolved and undissolved solids that are separated by filtration. Undissolved solids are usually referred to as suspended matter. Because the amount of suspended solids in most water supplies is relatively small, it is rarely a concern for boiler maintenance. On the other hand, total dissolved solids is an important test, which can be determined by either evaporating a water sample and drying the residue or by means of a conductivity meter.

Among the dissolved solids, sulfates, chlorides, and carbonates of calcium and magnesium are notorious for their tendency to form boiler scale. Their presence is indicated by the concentration of calcium carbonate in a water sample. It is called degree of hardness. Carbonate hardness can precipitate with prolonged boiling, and therefore is termed temporary hardness. Noncarbonate hardness, formerly called permanent hardness, does not precipitate from water by physical means.

Total dissolved solids range from 20 to 1,000 milligrams per liter (mg/l) in potable waters and increase with hardness. The necessity to reduce or totally eliminate these dissolved solids prior to feeding water into the boiler cannot be overemphasized. Scale formed on the heating surface, due to the presence of the dissolved solids, has the same effect as insulation: it retards the flow of heat, lowers fuel efficiency, and permits overheating of the firesides.

The procedure to eliminate hardness in water is commonly known as softening. It can be done by addition of phosphates, polyphosphates, or lime, or by application of ion-exchange resins or reverse osmosis techniques. When chemicals are used to precipitate the hard-water salts, certain organic compounds may be added to keep the insoluble matter in suspension as a sludge to be flushed out periodically. When the resins and reverse osmosis units are applied, they can be regenerated by passing strong salt solutions through them, or they can be cleaned for further use.

In addition, blowdowns of the boiler water from the drain valve can remove the loose sludge settled on the bottom and also reduce the concentration of scale-forming substances. Scale formation is thus discouraged. Continuous blowdown can be achieved by installing automatic control devices. However, considerable hot water is lost through this practice. A system designed to recover the water and thermal energy lost in blowdown should be considered.

Undissolved substances, such as grease, scale particles, and dirt in boiler water can cause foaming and carryover problems in the system. Foaming is the existence of a layer of froth and suds on the water's surface in the boiler drum. When foaming is severe, boiler water, scale particles, corrosion, oil, grease, or dirt can be discharged with steam into pipes (that is, carryover). Deposits of the carried-over substances and dissolved solids in water may settle in the steam piping and valves, causing a loss of efficiency or a blockage to steam passage. To remedy carryover and foaming problems, the total solids concentration in boiler water must be reduced to, and maintained at, a minimum level. Mild cases of carryover can be limited by installing a mechanical separating device in the drum.

Occasionally, undesirable contaminations can be brought from the boiler into steam piping by a sudden carryover of boiler water. This priming problem may be due to a sudden change in demand for steam, or a surging or spouting in the drum. It can result in shocks and water-hammer in the steam lines. Because priming and foaming represent undesirable and often dangerous conditions, immediate investigation and correction is necessary.

E. Other Tests

For specific purposes, tests to determine metal ions, phosphate, sulfite, sulfate, nitrate, grease, etc. can also be conducted to evaluate water quality. They are not normally considered routine procedures in testing boiler water.

The chloride content is used as an index in determining sea water intrusion and also as a tracer for pollution of wells. Chloride concentration generally increases as the mineral concentration increases. Thus, in boiler maintenance, chloride concentration can be used to determine the need for and frequency of blowdown.

F. Sampling, Testing and Reporting

A complete boiler water analysis should include samples of makeup water, feed water, and blowdown from each boiler in a plant. Clean containers should be used to collect samples. Water should be filled to container volume and containers should be closed air-tight, if possible, to avoid contamination with air or dirt. Since the water can be dangerously hot, care should be taken in collecting pressurized boiler water from the blowdown drain valve. It is preferable that the sample be taken just before or at the time of blowdown. The samples should be cooled and tested immediately.

Detailed testing methods and result reporting can be found in the Annual Book of ASTM Standards (American Society of Testing and Materials),

Table 1. ASTM Tests Most Frequently Used for Boiler Water Analysis.

| Test | ASTM Method |
|---|---|
| Acidity and alkalinity | D 1884 |
| Carbon dioxide | D 513 |
| Chloride ion | D 512 |
| Dissolved oxygen | D 888 |
| Electrical conductivity | D 1125 |
| Hardness | D 1126 |
| Hydroxide | D 514 |
| Nitrate | D 992 |
| Phosphate | D 515 |
| Reporting | D 596 |
| Sampling water | D 3370 |
| Sulfate | D 516 |
| Sulfite | D 1339 |

under section D for water analysis. Table 1 lists some ASTM tests and procedures.

The chemical tests which may be used for prevention or control of specific boiler problems are tabulated in Table 2.

Table 2. Chemical Tests Used in Controlling Boiler Problems.

| Test | Boiler Problems | | | |
|---|---|---|---|---|
| | Scale | Corrosion | Embrittlement | Carryover |
| Makeup water: | | | | |
| Acidity/alkalinity | -- | x | -- | -- |
| Hardness | x | -- | -- | -- |
| Feedwater: | | | | |
| Acidity/alkalinity | x | x | -- | -- |
| Hardness | x | -- | -- | -- |
| Boiler water: | | | | |
| Acidity/alkalinity | x | x | -- | -- |
| Hydroxide | x | x | x | x |
| Nitrate | -- | -- | x | -- |
| Phosphate | x | -- | x | -- |
| Sulfite | -- | x | -- | -- |

IV. FIRESIDE MAINTENANCE

Boiler inefficiency can also result from improper operating procedures and poorly maintained firesides. Problems that can develop include either excess or deficient combustion air, fouled and inefficient heating surfaces, and faulty burners.

A. Excess or Deficient Combustion Air

A certain amount of air is required to completely burn the fuel. If excessive air is used, energy is wasted in heating up the excess air and discharging it into the flue. Figure 6 shows the relationship between the percent theoretical air required for combustion and the fuel efficiency. When air is supplied in excess (beyond 100% of required air for complete combustion), the fuel efficiency falls below its maximum possible level.

On the other hand, if the combustion air is insufficient, the efficiency is greatly reduced. The fuel efficiency can be improved considerably by simply increasing the supply of air for combustion from 50 percent to 100 percent of the amount required for a complete combustion, as shown in Figure 6. Because fuel does not burn completely without sufficient air, a deficient air supply not only causes a severe loss of fuel efficiency but also constitutes a safety hazard. The residuals of an incompletely combusted fuel such as soot or ash may deposit on the heating surface, causing overheating. Or they may escape the flue as smoke and pollutants.

To assure complete use of fuel, a properly controlled combustion should allow 10 to 20 percent excess air. This control can be achieved by using a forced draft system to regulate the air-fuel ratio. To determine if a correct adjustment has been achieved, test the flue gas using Orsat analysis or an oxygen indicator.

B. Fouled Heating Surface

A fouled heating surface reduces heat transfer from the combustion gases to the water. The major symptom of this problem is increased flue-gas temperature. Unfortunately, a number of conditions tend to obscure this indicator. For example, deficient combustion air and fouled or eroded burners tend to decrease flue-gas temperature. This decrease could offset the increases due to a fouled heat transfer surface. In addition, priming, foaming, and carryover can cause excess water in the discharge steam line, increasing the flue-gas temperature. Thus, it is important to insure that these latter conditions do not exist before using flue-gas temperature as an indicator of heat-transfer surface fouling. If this precaution is taken, the change with time of the flue-gas temperature indicates the amount of fouling. Of course, the flue-gas temperature should be approximately equal to the design value specified by the manufacturer. Any deviation from normal flue-gas temperature

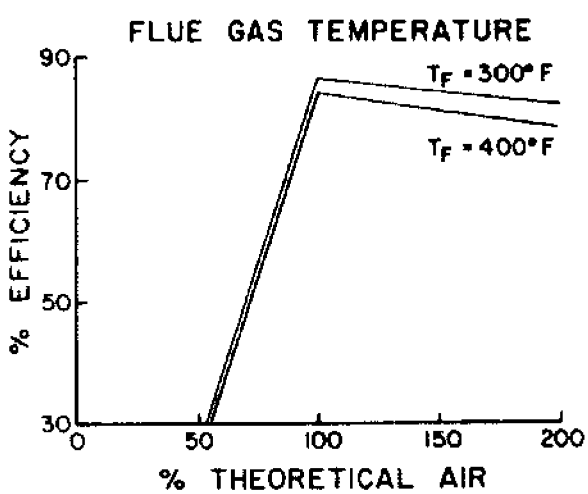



Figure 6. The fuel efficiency as affected by the amounts of air supplied for combustion in a boiler.

(assuming proper combustion air burner operation, etc.) indicates fouling.

A visual inspection of the boiler tube surfaces will reveal fouling if present. This fouling includes corrosion and scale formation on the waterside as well as the deposit buildup and corrosion on the fireside. Such fouling directly affects the heat transfer, which can be monitored by the installation of chordal thermocouple tubes in the tube wall. Periodic checks of tube metal temperatures can signal the buildup of harmful deposits. When necessary, internal cleaning can be performed to avoid overheating damage.

C. Insufficient Heating Surface

Insufficient heating surface limits the amount of energy transfer between the hot gases and water, resulting in a high flue-gas temperature. The flue-gas temperature should be compared to the minimum allowable temperature (approximately 230°F for natural gas and 290°F for fuel oil) as specified for a particular boiler. Any flue-gas temperature in excess of this minimum value may indicate insufficient heat transfer surface. Additional heat surface can be installed in the form of an air preheater or economizer. The installation cost can be paid off in less than one year for any boiler with a designed flue-gas temperature exceeding 400-425°F.

D. Faulty Burners

A number of problems can occur with burners -- including fouling, improper design, and material degradation. The result of any of these conditions will be poor fuel-air mixing and subsequent incomplete combustion. Thus, extremely large amounts of air compared with the theoretical requirement will be needed to allow complete combustion of the fuel. When a reasonable amount of excess air is used, the Orsat analysis will indicate significant amounts of carbon monoxide and unburned fuel if the burner is faulty.

Periodic cleaning to free the burners from foreign matter and carbon residues minimizes fouling. Pilot burners, ignition equipment, and other parts should be inspected to insure proper flame performance.

## V. OTHER SOURCES OF DEFICIENCIES AND ENERGY LOSSES

### A. Leaks

Since a boiler is a pressure vessel, it should be tight -- that is, free of leakage. Routinely checking the steam pressure, investigating abnormal water loss, and looking for leaking tubes are maintenance practices recommended to ensure a tight boiler.

Unless an automatic recorder is used, frequent checking of steam pressure is a sure way of knowing about any abnormal pressure drops or increases in a boiler before it is too late. For this reason, dependable pressure gauges are necessary. They should be checked routinely and old, worn out or faulty ones should be replaced.

Due to a buildup of corrosive deposits around the bottom of the valve, a safety valve may fail to open at the set pressure. It may leak or even cause safety hazards.

Water losses can be determined by the water level observed at the gauge glass and/or the amount of makeup water used in a period of time. In general, a boiler used for a closed system, in which all steam returns as condensate, should not lose more than three inches of water per month. Otherwise, there probably is a leak in the system.

Leaking tubes cause abnormal water loss. An unusual 'hiss' or a sudden demand for feedwater without a corresponding increase in load may indicate a leak. One leaking tube could mean more faulty tubes. Therefore, a thorough inspection of the boiler should take place as soon as possible.

Steam leakage from faulty valves and joints on the discharge steam pipes and worn gaskets on cooking vessels can also cause considerable heat loss. These leaks are generally apparent and should be corrected immediately.

### B. Lack of Proper Insulation

Without proper insulation, heat can escape through the boiler shell, from the walls of steam pipes, or from cooking vessels such as retorts. An uninsulated retort may lose more than twice the energy needed to operate it.

Losses due to uninsulated steam pipe may seem insignificant, but they do, in fact, represent a relatively high energy loss. Figure 7 shows the expected yearly heat loss of variously sized (diameter) steam pipes. And the heat loss per foot of uninsulated hot water pipe is indicated in Figure 8.

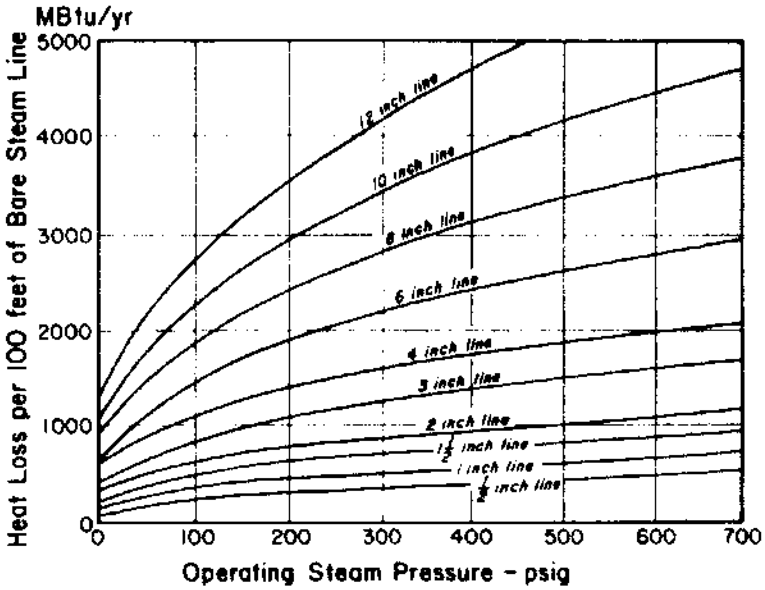



Figure 7. Yearly heat loss from bare steam lines.
*(From Dyer et al. 1977)*

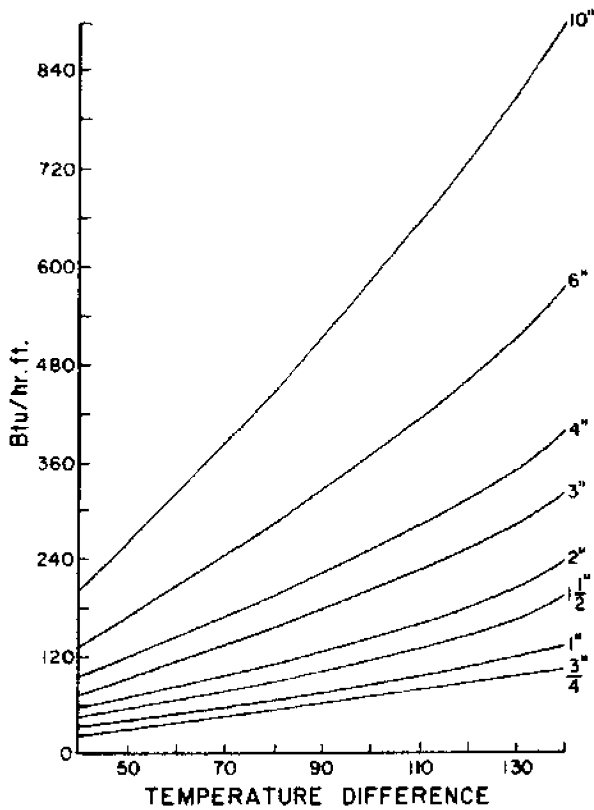



Figure 8. Heat loss of uninsulated hot water lines.
*(From Dyer et al. 1977)*

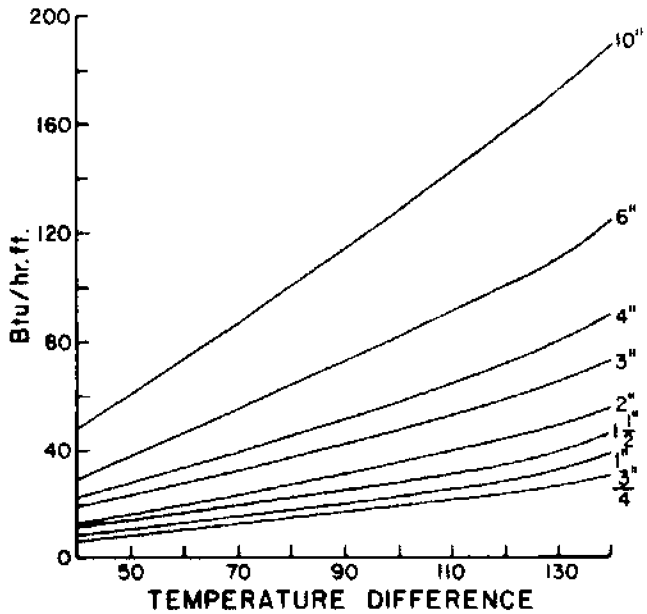



Figure 9. Heat loss of insulated hot water lines.
*(From Dyer et al. 1977)*

C. Improper Operational Practices

Operational procedures and specifications recommended by the manufacturer should be closely followed to avoid various difficulties and hazards. Priming may occur if the water level in the boiler is too high. Great energy losses may occur if blowdown is too frequent or the flue-gas temperature is maintained too high. Stress or waste may result if a boiler is utilized over or under its capacity. Problems can get bigger and more difficult to solve, if routine checkups are ignored.

Certain economical measures may be considered in order to conserve energy and reduce operating costs. For instance, cleaning the heating surfaces periodically, installing a forced-draft system, utilizing a preheater for feedwater and combustion air, adding heat recovery systems, and using accurate gauges or monitors can all contribute to the economical operation of the boiler.

VI. MAINTENANCE

Following are the routine maintenance schedules for heating boilers and hot water boilers as recommended by the American Society of Mechanical Engineers (ASME).

A. For Steam Boilers:

1. Daily (boiler in service). Observe operating pressures, water level, and general conditions and correct.

2. Weekly (boiler in service).

   a. Test low-water cutoff and/or water feeder. Blow down boiler if considerable makeup is used.

   b. Test water column or gauge glass.

   c. Observe condition of flame; correct if flame is smoky or if burner starts with a puff (for oil, observe daily).

   d. Check fuel supply (oil only).

   e. Observe operation of condensate or vacuum pump.

3. Monthly (boiler in service).

   a. Safety valve, try lever test.

   b. Test flame detection devices.

   c. Test limit controls.

   d. Test operating controls.

   e. Sludge blowdown where required.

   f. Check boiler room floor drains for proper functioning.

   g. Inspect fuel supply systems in boiler room area.

   h. Check condition of heating surfaces (for preheated oil installation, inspect more frequently; twice a month).

4. Annually.

   a. Internal and external inspection after thorough cleaning.

   b. Routine burner maintenance.

   c. Routine maintenance of condensate or vacuum return equipment.

   d. Routine maintenance of all combustion control equipment.

   e. Combustion and draft tests.

   f. Safety valve pop test.

   g. Slow drain test of low-water cutoff.

   h. Inspect gas piping for proper support and tightness.

   i. Inspect boiler room ventilation louvers and intake.

B. For Hot Water Boilers:

1. Daily (boiler in service). Observe operating pressures and temperature, and general conditions. Determine cause of any unusual noises or conditions and make necessary corrections.

2. Weekly (boiler in service).

   a. Observe condition of flame; correct if flame is smoky or if burner starts with a puff (for oil, observe daily).

b. Check fuel supply (oil only).

c. Observe operation of circulating pumps.

3. Monthly (boiler in service).

   a. Safety relief valve, try lever tests.

   b. Test flame detection devices.

   c. Test limit controls.

   d. Test operating controls.

   e. Check boiler room floor drain for proper functioning.

   f. Inspect fuel supply system in boiler room area.

   g. Check condition of heating surfaces (for preheated oil installation, inspect more frequently; twice a month).

   h. Perform combustion and draft tests (preheated oil only).

   i. Test low water fuel cutoff and/or water feeder if piping arrangement permits without draining considerable water from the boiler.

4. Annually.

   a. Internal and external inspection after thorough cleaning.

   b. Routine burner maintenance.

   c. Routine maintenance of circulating pump and expansion tank equipment.

   d. Routine maintenance of entire combustion control equipment.

   e. Combustion and draft tests.

   f. Safety relief valve(s) - pop test.

   g. Slow drain test of low water cutoff.

   h. Inspect gas piping for proper support and tightness.

   i. Inspect boiler room ventilation louvers and intake.

Maintenance and cleaning procedure for specific purposes or situations can also be found in the ASME Handbook, as well as your manufacturer's manual.

C. Chemical Treatments:

To clean the grease, scale, and corrosion deposit from the internal surfaces of the steam generator system, alkaline detergent solution may be applied to remove the oily matter, followed by acidic or basic solvent to dislodge other foreign materials. However, this type of cleaning is highly technical and should be supervised by qualified personnel.

The United States Food and Drug Administration and the Department of Agriculture have approved a list of chemicals which can be used for boiler water treatment. Only the approved chemicals may be used in an open system where steam may be in direct contact with food materials (Table 3).

## VII. BASIC CONSIDERATIONS IN BOILER SELECTION

In selecting an adequate boiler for plant operation, the following criteria should be considered:

A. Capacity, temperature and pressure
B. Future expansion
C. Fuel availability and economy
D. Initial cost of unit
E. Space requirement
F. Insurance policy

Table 3. FDA Approved Additives for Boiler Water Treatment*

| | |
|---|---|
| Acrylamide-sodium acrylate resin | Sodium metasilicate |
| Ammonium alginate | Sodium metabisulfite |
| Cobalt sulfate | Sodium nitrate |
| Lignosulfonic acid | Sodium phosphate |
| Monobutyl ethers of polyethylene-polypropylene glycol | Sodium polyacrylate |
| Polyethelene glycol | Sodium polymethacrylate |
| Polyoxypropylene glycol | Sodium silicate |
| Potassium carbonate | Sodium sulfate |
| Potassium tripolyphosphate | Sodium sulfite |
| Sodium acetate | Sodium tripolyphosphate |
| Sodium alginate | Tannin |
| Sodium aluminate | Tetrasodium EDTA |
| Sodium carbonate | Tetrasodium pyrophosphate |
| Sodium carboxymethylcellulose | Cyclohexylamine |
| Sodium glucoheptonate | Diethylaminoethanol |
| Sodium hexametaphosphate | Hydrazine |
| Sodium humate | Morpholine |
| Sodium hydroxide | Octadecylamine |
| Sodium lignosulfonate | Trisodium nitrilotriacetate |

* *For usage limitations, labelling requirements and other details, refer to the Code of Federal Regulations, Title 21 173.310.*

VIII. CONCLUSION

A properly maintained boiler can provide maximum efficiency with no abnormal safety hazards. Boiler care means the difference between saving and wasting. Do not let your boiler problems get ahead of you. A routine checkup allows an early warning so that you can correct boiler troubles early, eliminating excessive maintenance expenditures.

This manual provides basic information and draws processors' attention to the importance of boiler maintenance. It must, however, be emphasized that boiler services should always be supervised by trained experts or professionals because of the complications, the regulatory implications, and the potential dangers involved in many of the maintenance procedures.

IX. REFERENCES

ASME Boiler and Pressure Vessel Code - An American National Standard, 1974 (revised annually). Section 6: Recommended Rules of Care and Operation of Heating Boilers; Section 7: Recommended Rules for Care of Power Boilers. American Society of Mechanical Engineers. New York, New York 19917.

Annual Book of ASTM Standards, 1974 (revised annually). American Society for Testing and Materials. Philadelphia, Pennsylvania 19103.

Dyer, David, and Glennon Maples. 1978. Industrial-commercial-institutional boilers: Measuring and improving efficiency. Paper presented February 1-2, 1978, North Carolina State University, Division of Continuing Education.

Dyer, D.F., G. Maples, J. C. Maxwell, Jr., D. Pride, and W. G. Dickie, Jr. 1977. Measuring and improving the efficiency of boilers. Paper prepared for Federal Energy Administration, Washington, D.C. November, 1976. Contract No. FEA-CO-04-B0100-00. Revised.

# An Economic Design for an Oyster Shucking Production Line: A Comparative Study of Four Systems

Jose M. A. Tanchoco and Charles W. Coale, Jr.

## I. INTRODUCTION

The oyster industry has traditionally relied on highly-skilled labor-intensive methods for shucking oysters. In the past decade, however, this skilled labor pool has significantly declined. The addition of a steam bath process has been shown to improve the labor productivity of the shucking operation. A steam bath causes a slight opening in the shell. This opening enables the oyster shucker to extract the oyster meat from the shell more quickly than from oysters processed in the conventional method without the steam bath. In-plant observations of oyster shucking showed that where shell-stock was passed through a steam bath prior to the shucking operation, the shuckers increased their productivity by 20-35 percent. The simplified method brought about by the introduction of a steam bath reduces the skill level required of shuckers. This simplification coupled with the monetary incentives that come with increased labor productivity will reduce the unit cost of preparing fresh oysters for market and decrease the need for a more skilled work force.

The purpose of this paper is to evaluate a revised work station design incorporated into oyster shucking production systems and the corresponding economic analysis complementing the steam bath as a means to improve capital and labor productivity in the oyster industry.

Five factors that are critical to an effective operation of an oyster shucking/processing plant are examined. This is to insure that the potential for improved productivity with the introduction of the steam bath is compatible with the total system design which includes the shucking work station, the material handling method, and layout. Comparative cost analyses are then performed to demonstrate the relative economies of alternative production systems.

To realize the potential productivity gains with the introduction of the steam bath process, workable management plans, essential to implementation, are proposed. These plans are for:

a. oyster shell-stock procurement and handling,
b. regulation of shell stock flow in the system,

c. training and supervision of oyster shuckers,

d. preventive maintenance, and

e. sanitation and quality maintenance.

Objectives of the Study

The specific objectives of this study are the following:

1. To design an oyster shucking work station using principles of motion economy to improve processing efficiency.
2. To examine the effects on labor productivity of selected material handling methods.
3. To develop and compare alternative plant layouts for each handling method examined.
4. To examine the effects of introducing the steam bath process on labor and capital costs, savings, and productivity of alternative production systems.
5. To analyze and recommend a workable management plan for personnel and production line operations.

Each of these objectives is analyzed and discussed in separate sections of this paper.

## II. MATERIAL FLOW FOR OYSTER PROCESSING

There are a number of processing stages required in the conversion of shell-stock to edible products and oyster meat by-products utilizing the shells, as shown in Figure 1. Beginning from the harvesting stage and in some cases through a relaying operation, shell-stock is hauled to shucking houses for further processing. The principal products of the shucking operations in Virginia are the oyster meat and the shells themselves. Fresh, fresh frozen, and fresh frozen/breaded oyster meat products make up the largest percentage of Virginia's marketable products. The oyster shells are mainly replanted on oyster seed beds, and a smaller portion is utilized in the manufacture of poultry feed and lime. The oyster shucking operation indicated by the shaded area in Figure 1 is only a small part of the total system. Even for such a small segment of the total system, the amount of detailed requirements for an economic design of the oyster shucking subsystem is enormous and necessary.

In the following sections, industrial engineering principles were applied to derive an improved work station design and to provide alternative material handling methods and layout arrangements. Four material handling methods were analyzed:

1. a manual method complemented by skatewheel conveyors,
2. a manually operated pallet truck system,
3. a floor mounted horizontal belt conveyor system, and
4. an overhead monorail conveyor system using wire baskets.

A comparison of these four methods was made with and without a steam bath process incorporated prior to the actual shucking operation.

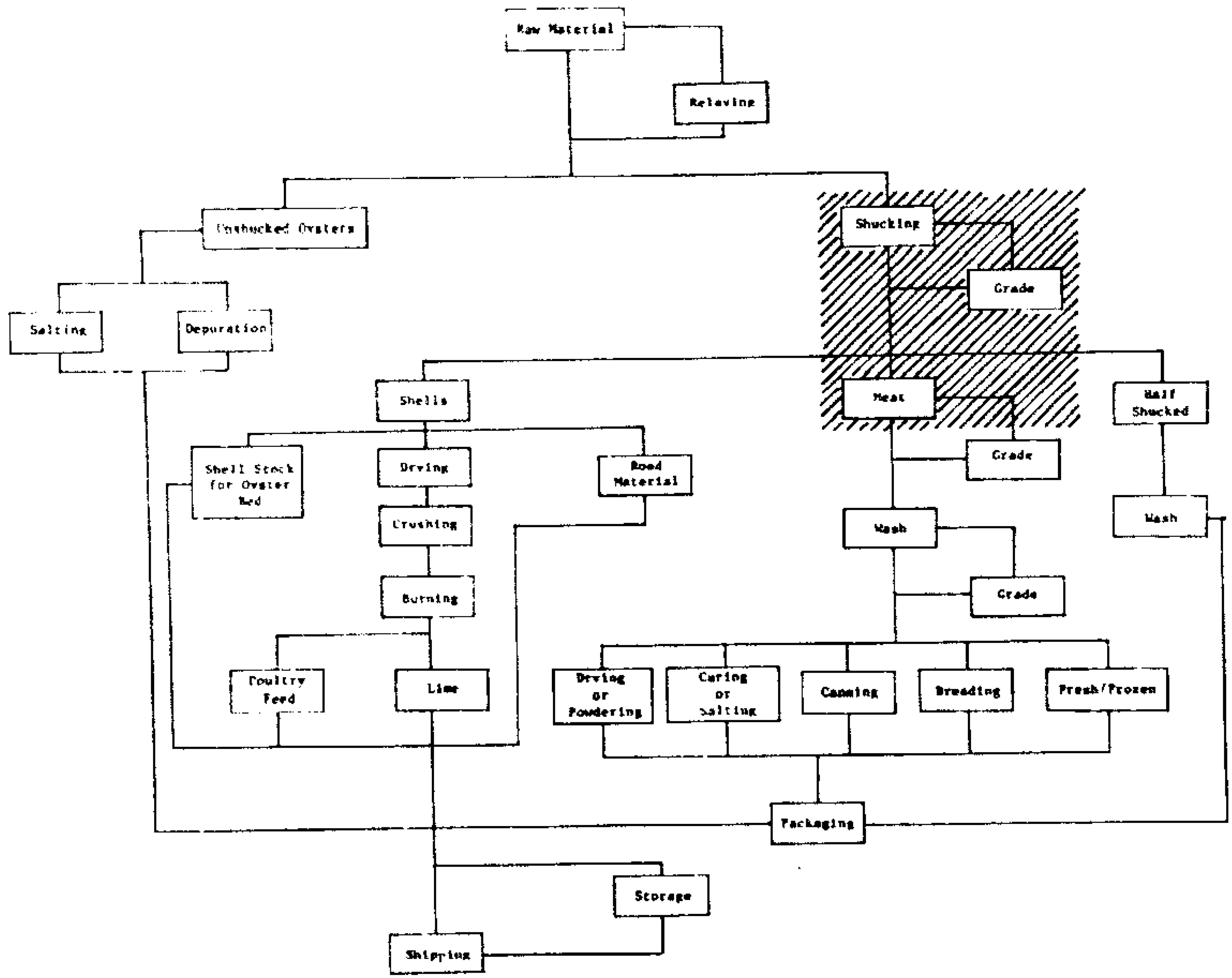


Figure 1. Oyster product process flow chart

## III. FACILITY DESIGN CONSIDERATIONS

### A. Design of the Work Station

The fundamental element in any production facility is the work station. A poorly designed work station results in a more fatigued shucker, causing wide variations in output rates. Such conditions cause sharp declines in productivity for the entire plant. Redesigning the work station is thus critical, since the current method of shucking in existing work stations violates many of the principles of motion economy. Labor-intensive operations performed in these work stations offer opportunities for improvement and significant cost reduction.

The design of work stations has been extensively studied particularly in the manufacturing (metal working) industry. Several principles, known as 'laws of motion economy,' have been developed as a result of these studies. The following principles were judged to be directly applicable to an effective design of a shucking work station:

a. fixed locations should be provided for all tools and materials,

b. gravity bins and drop delivery should be used,

c. all materials and tools should be located within an effective area in both the vertical and horizontal plane,

d. a comfortable chair should be provided for the operator and the height arranged so the work can be efficiently performed by the operator alternately standing and sitting,

e. proper illumination, ventilation, and temperature should be incorporated,

f. visual requirements of the work station should be considered so eye fixation demands are minimized,

g. rhythm is essential to the smooth and automatic performance of a shucker, and the work should be arranged to permit an easy and natural rhythm in the shucking operations, and

h. investigate the possibility of powered or semi-automatic tools.

The application of these principles in conjunction with the use of anthropometric data as shown in Figure 2 resulted in a recommended shucking work station illustrated in Figure 3. A prototype of this shucking table has been fabricated in the Manufacturing Process Laboratory of the Industrial Engineering and Operations Research Department at Virginia Polytechnic Institute and State University.

B. Material Handling Systems

Four material handling systems to transport shell-stock to the individual shucking work stations were considered: (a) the skatewheel conveyor handling system, (b) the pallet truck handling system, (c) the floor-mounted horizontal belt conveyor handling system, and (d) an overhead monorail conveyor handling system.

Operational characteristics of each system are first described. Determination of the areas required per shucker is then made for each system (Figures 4a, 5a, 6a, and 7a) and layout arrangements illustrated (Figures 4b, 5b, 6b, and 7b).

1. The Skatewheel Conveyor Handling System (Skatewheel Conveyor) -

Under this system, shell-stock is placed on containers which are loaded manually onto the skatewheel conveyor located in the aisles adjacent to the shucking work stations. The shucker has easy access to the containers. The shell-stock is then dumped into a bin on the work table and the empty containers are stacked at fixed locations along the aisle and returned via a dolly for refill. The skatewheel conveyor is utilized to facilitate the horizontal movement of shell-stock serving the same function as the wheelbarrow, a method currently used in several shucking houses.

For this system, the total area required for the shucking work station, the shucker space, the skatewheel conveyor, and personnel aisle is 16.67 square feet per shucker (see Figure 4a).

2. The Pallet Truck Handling System (Pallet Truck) - A pallet truck is a non-motorized lift truck of low to intermediate load carrying capacity. Its function is basically for the horizontal movement

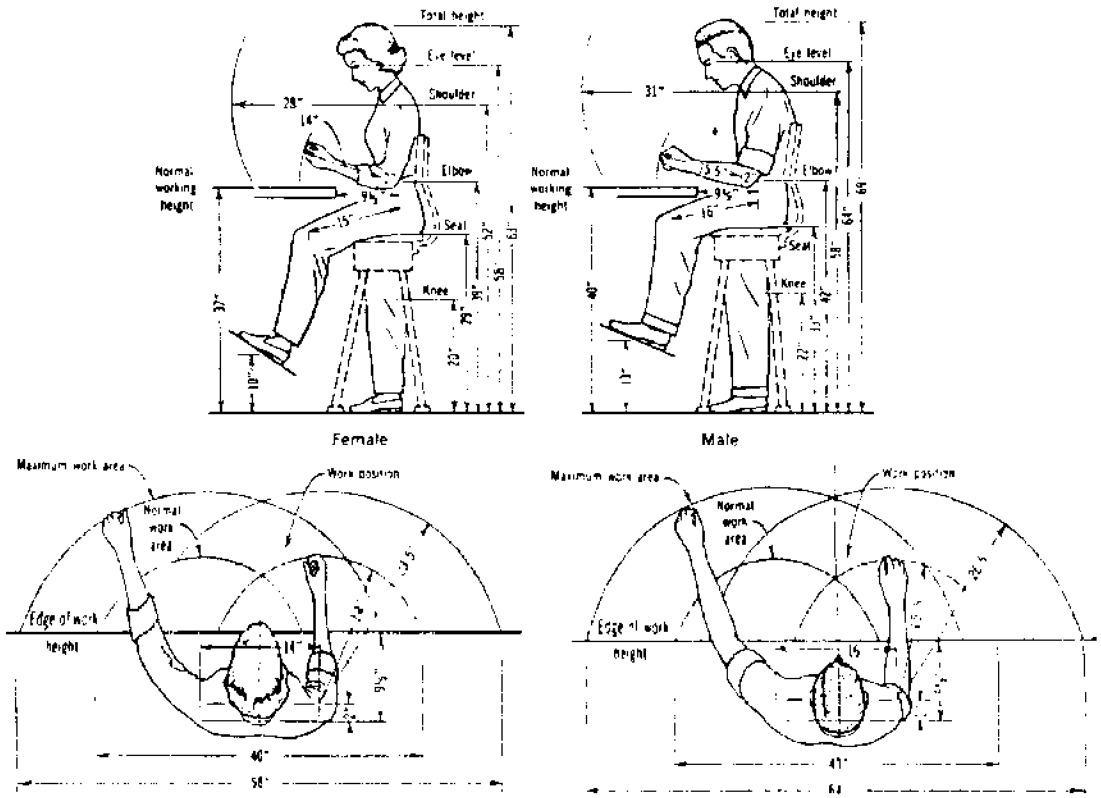



Figure 2. Anthropometric data for average male and female production workers, obtained from Motion and Time Study by Ralph M. Barnes, John Wiley and Sons, Inc., 1968.

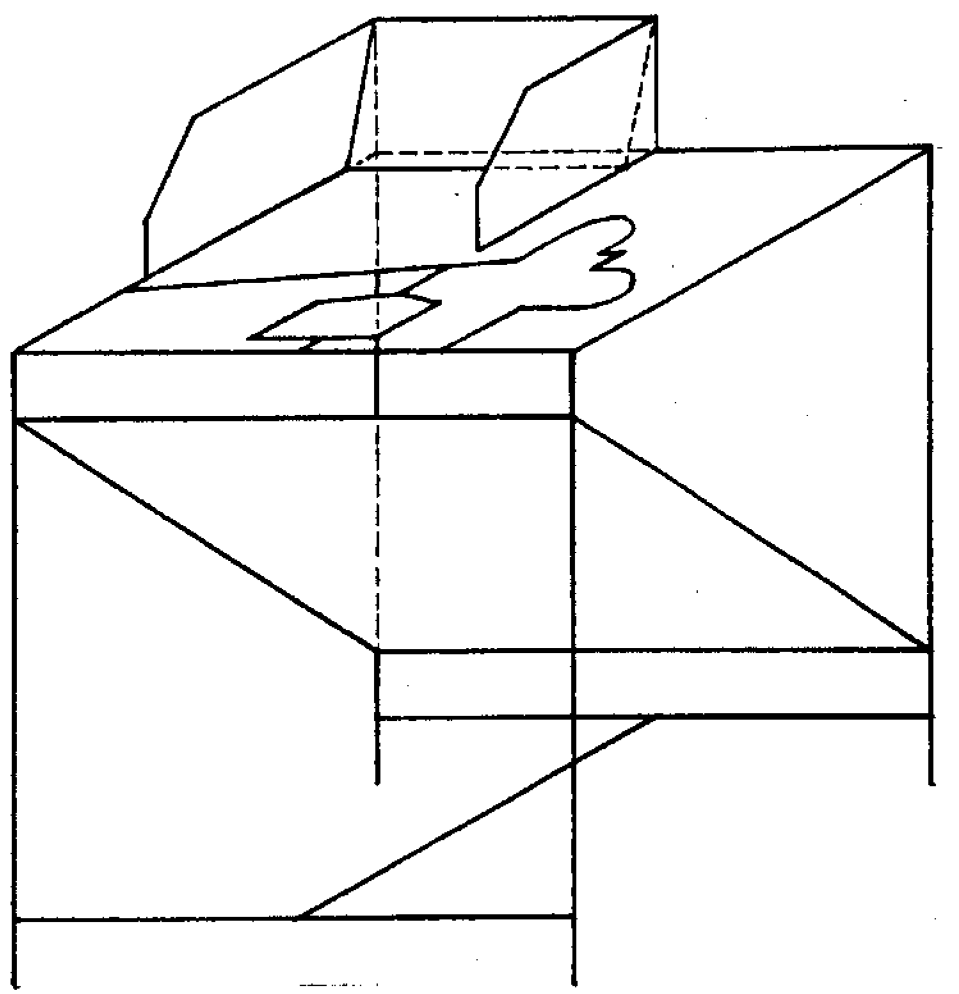
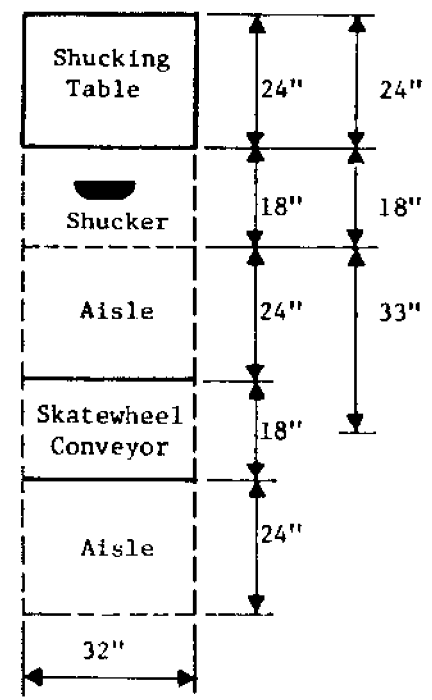


Figure 3. Drawing of prototype shucking work station




$$\text{Area/Shucker} = (32)(24+18+33)\ \text{in.}^2 = 16.67\ \text{ft.}^2$$

Figure 4a. Work station layout for skatewheel conveyor system.

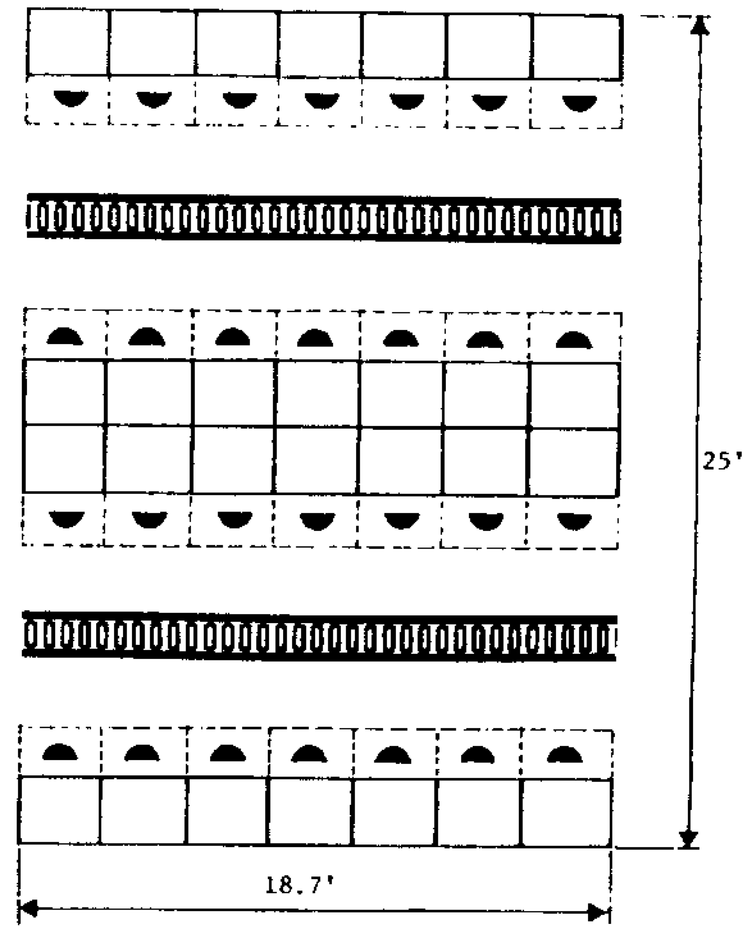


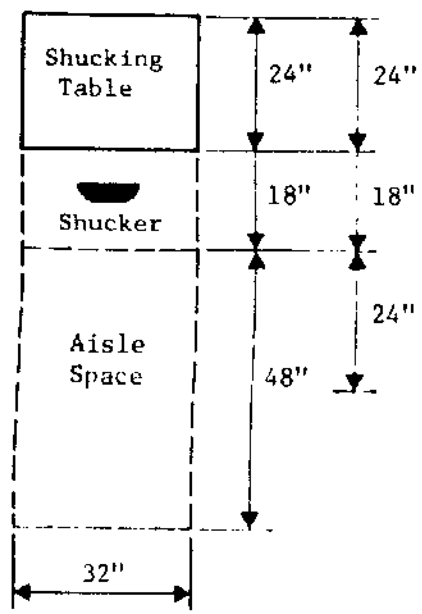

Figure 4b. Layout for skatewheel conveyor system based on an output of 250 gallons of oyster meat per day.

of materials over a wide area. As with other types of lift trucks, the fork is inserted under a pallet on top of which are the containers filled with the shell-stock. A number of shell-stock containers can be stacked on top of the pallet but limited by the weight capacity of the equipment or by the load bearing capacity of the container. The volume of oysters carried per load depends on the rate at which shuckers can complete the shucking of all the oysters in each container. One shell-stock handler is required by this method. This system needs a total area of 14.67 square feet per shucker inclusive of the aisle space required by both personnel and equipment (see Figure 5a).

3. Floor-mounted Horizontal Belt Conveyor Handling System (Belt Conveyor) - A horizontal rubber-belted conveyor with an end-drive unit is sufficient for the purpose of delivering the shell-stock to each of the shucking work stations. The shell-stock is initially dumped on top of the moving belt conveyor and, as each shucker requires additional shell-stock, a diverter is activated to provide an adequate amount to fill the shell-stock bin on the shucking tables. The effective utilization of a belt conveyor system requires that the top strand of the conveyor belt is positioned at the same elevation as the top of the shell-stock bin. This positioning facilitates the delivery of shell-stock to the bins since gravity is utilized, but the "drop" distance should be minimized for maintenance of the product quality.

   An advantage of the belt conveyor handling method compared to the skatewheel conveyor and the pallet truck handling systems is the reduced effort involved in the continuous delivery of shell-stock to individual work stations. The area required per shucker under this method is identical to the pallet truck system, 16.67 square feet, inclusive of the conveyor equipment space, the operator work space, and a personnel aisle (see Figure 6a).

4. Overhead Monorail Conveyor System (Monorail Conveyor) - Under this method, shell-stock is loaded into containers from a feed hopper. At the work station, the shell-stock is either manually




$$\text{Area/Shucker} = (32)(24+18+24)\ \text{in.}^2$$
$$= 14.67\ \text{ft.}^2$$

Figure 5a. Work station layout for pallet truck system.

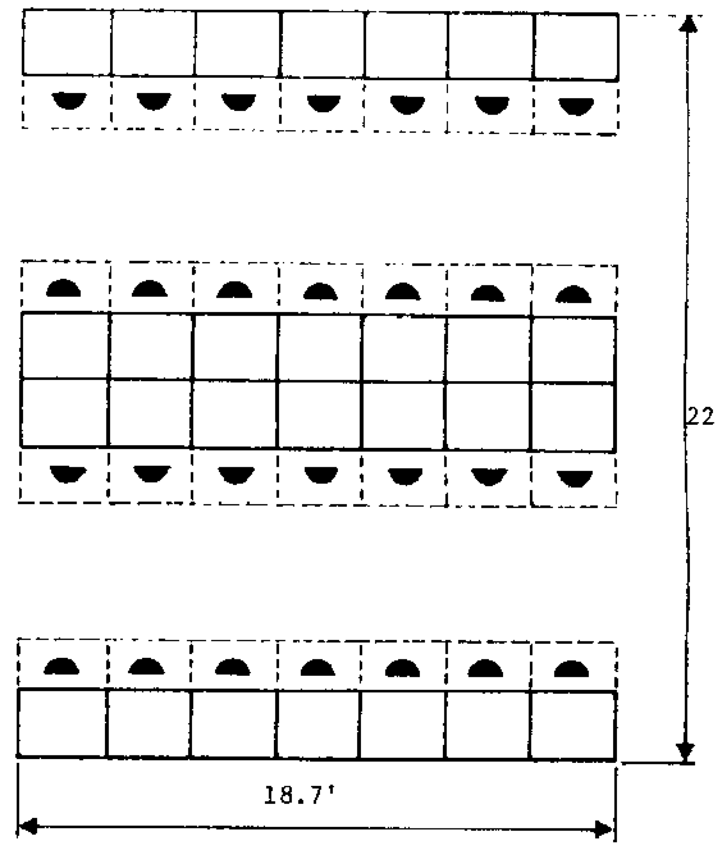
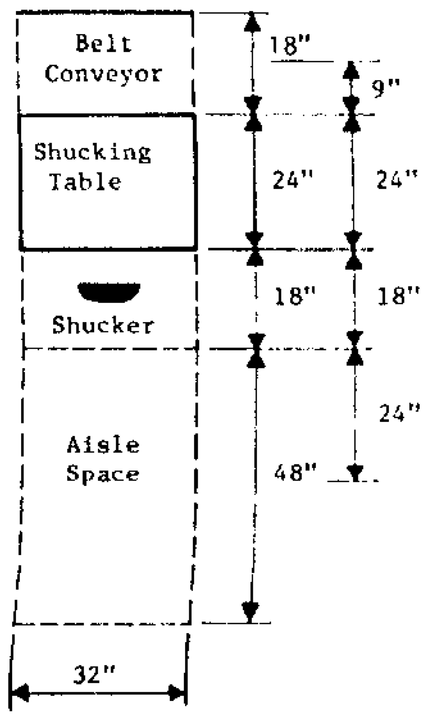



Figure 5b. Layout for pallet truck system based on an output of 250 gallons of oyster meat per day.




Area/Shucker = $(32)(9+24+18+24)\ \text{in.}^2$
$= 16.67\ \text{ft.}^2$

Figure 6a. Work station layout for belt conveyor system.

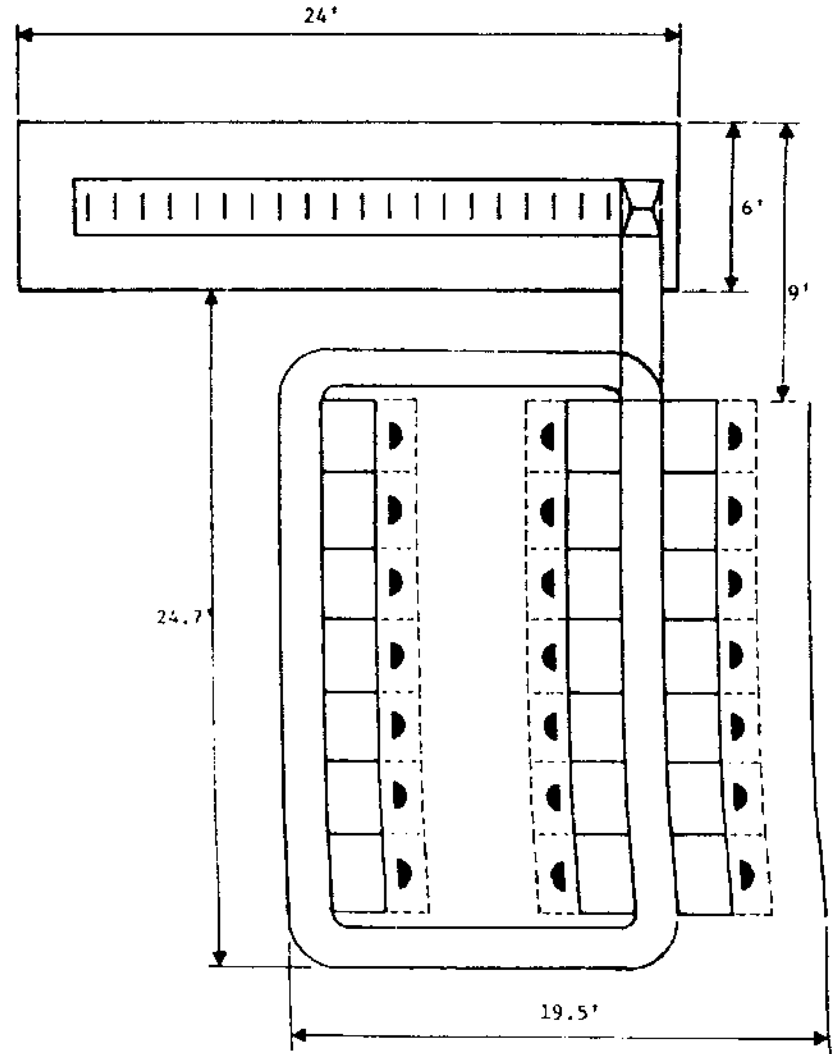



Figure 6b. Layout for conveyor system based on an output level of 250 gallons of oyster meat per day.

or mechanically dumped into the shell-stock bin at the work station. The basic principle involved in the use of this system is identical to the belt conveyor system. However, the transportation medium for the monorail system is a wire basket or an equivalent container. The container is connected to a continuously moving chain driven by a variable speed motor. A variable speed motor is needed to periodically adjust the conveyor speed to the shucking rate.

The total area required for each shucker using the monorail conveyor system is 14.67 square feet (see Figure 7a).

C. Introduction of Steam Bath

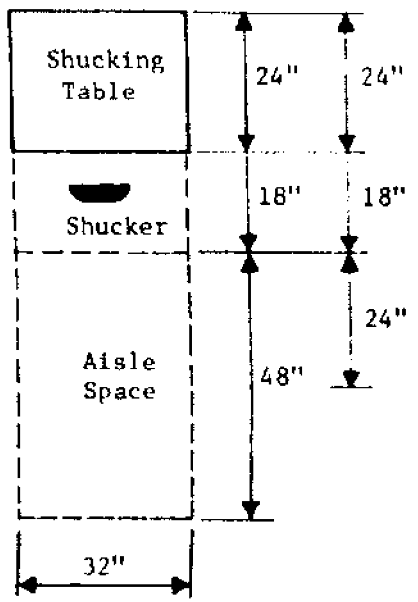
The preceding discussion focused entirely on the handling methods for the delivery of shell-stock to the shucking work stations where the oyster meat is separated from the shells. The application of steam to the shell-stock through a steam bath can now be discussed.

Without the benefit of the steam bath process, the average output rate at a single shucking work station is estimated at 1.13 gallons of oyster meat per hour. Subjecting the shell-stock through a steam bath process yields an output rate of approximately 1.50 gallons of oyster meat per hour, a 33-percent increase in output. Using these output rates, a table (see Table 1) was constructed showing the number of shuckers required at various levels of outputs ranging from 50 to 500 gallons of oyster meat per day. The total floor space area needed at each output level for the various material handling systems discussed earlier is contained in the same table.

D. Plant Layout Considerations

Based on the four handling systems previously discussed and the shell-stock processed with or without the steam bath, eight possible combinations of handling and processing systems could be designed. Of these eight systems, the following four constituted the more feasible alternatives:

I. Without Steam Bath
   A. Skatewheel Handling System
   B. Pallet Truck Handling System




Area/Shucker = $(32)(24+18+24)\ \text{in.}^2$

$= 14.67\ \text{ft.}^2$

Figure 7a. Work station layout for monorail conveyor system.

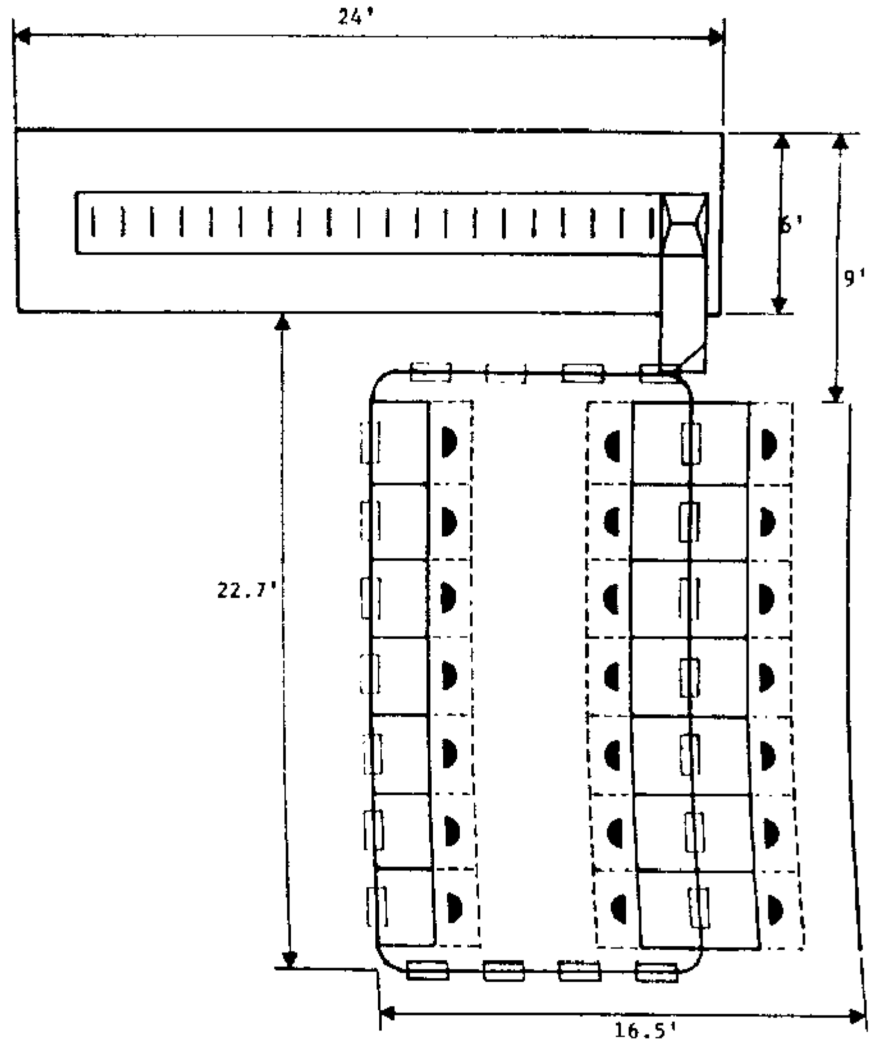



Figure 7b. Layout for overhead monorail conveyor system based on an output level of 250 gallons of oyster meat per day.

Table 1. Number of Shuckers and Area Requirements for Alternative Handling Systems Based on Various Levels of Output (gallons of oyster meat per day).

| Output (gallons/day) | Without Steam Bath[a] | | | | With Steam Bath[b] | | | |
|---|---|---|---|---|---|---|---|---|
| | No. of Shuckers | | Area Requirement ($ft.^2$) | | No. of Shuckers | | Area Requirement ($ft.^2$) | |
| | Actual | Rounded | Skatewheel | Pallet Truck | Actual | Rounded | Belt Conveyor | Monorail Conveyor |
| 50 | 5.53 | 6 | 100 | 88 | 4.16 | 5 | 84 | 74 |
| 100 | 11.06 | 12 | 200 | 176 | 8.33 | 9 | 150 | 132 |
| 150 | 16.59 | 17 | 284 | 250 | 12.50 | 13 | 217 | 191 |
| 200 | 22.12 | 23 | 384 | 338 | 16.67 | 17 | 284 | 250 |
| 250 | 27.65 | 28 | 467 | 411 | 20.83 | 21 | 350 | 308 |
| 300 | 33.19 | 34 | 567 | 499 | 25.00 | 25 | 417 | 367 |
| 350 | 38.72 | 39 | 651 | 573 | 29.16 | 30 | 500 | 440 |
| 400 | 44.25 | 45 | 751 | 661 | 33.33 | 34 | 567 | 499 |
| 450 | 49.73 | 50 | 834 | 734 | 37.50 | 38 | 634 | 558 |
| 500 | 55.31 | 56 | 935 | 822 | 41.67 | 42 | 700 | 616 |

a. Based on a shucking rate of 1.13 gallons/hour/shucker
b. Based on a shucking rate of 1.50 gallons/hour/shucker

II. With Steam Bath

A. Belt Conveyor Handling System

B. Monorail Conveyor Handling System

It is meaningless to discuss the physical layout arrangement of work stations and equipment without defining a desired plant output level. Consequently, an output level of 250 gallons of oyster meat per day were chosen and used as an average output per day of a typical oyster processing plant in Virginia. The total number of shucking work stations required for the four systems considered were 28, 28, 21, and 21 for systems IA, IB, IIA, and IIB, respectively. The corresponding layout arrangements for these four systems are contained in Figures 4b, 5b, 6b, and 7b. Note that, for Systems IIA and IIB (Belt Conveyor and Monorail Conveyor Systems, both with steam bath), a wire-mesh conveyor was used as the transporting device to carry the shell-stock through a steam bath process. The shell-stock was subsequently dumped into a chute feeding the main conveyor line. The layouts in Figures 4b, 5b, 6b, and 7b are the results of careful study and analysis. A minimal use of space was achieved in each of these layouts and flexibility in terms of expansion has been built in.

A summary of the various requirements (building, equipment, and personnel) are given in Table 2 for comparison. These figures formed the basis for the economic analysis.

Table 2. Comparison of Space Requirements for Four Alternate Handling Systems.*

| Description | Skatewheel | | Pallet Truck | | Belt Conveyor | | Monorail Conveyor | |
|---|---|---|---|---|---|---|---|---|
| | $Ft.^2$ | % | $Ft.^2$ | % | $Ft.^2$ | % | $Ft.^2$ | % |
| 1. Shucking Work Table | 149.33 | 32.0 | 149.33 | 36.4 | 112 | 18.9 | 112 | 23.0 |
| 2. Aisle | 149.33 | 32.0 | 149.33 | 36.4 | 150 | 25.3 | 145 | 29.7 |
| 3. Shuckers | 112 | 24.0 | 112 | 27.2 | 84 | 14.2 | 84 | 17.2 |
| 4. Material Handling | 56 | 12.0 | -- | -- | 102.5 | 17.3 | 3 | 0.6 |
| 5. Steam Tunnel | -- | -- | -- | -- | 144 | 24.3 | 144 | 29.5 |
| TOTAL | 466.66 | 100% | 410.66 | 100% | 592.5 | 100% | 488 | 100% |

*Basis: 250 gallons of oyster meat per day capacity.

## IV. ECONOMIC ASPECTS OF COMPARABLE OYSTER SHUCKING PRODUCTION SYSTEMS

Facilities and equipment were standardized for each of the four alternative production systems so that oyster shuckers may produce oyster meat of comparable quality. These systems were designed to produce 250 gallons of oyster meat per day. In-plant observations of oyster shucking showed that, where shell-stock was passed through a steam bath prior to the shucking operation, workers increased their shucking productivity by 20-35 percent over shucking operations without steam. Each production line varied in facility and equipment costs depending on the engineering organization of resources among the four production systems analyzed.

### A. Comparative Costs of Oyster Shucking Production Systems

The comparative costs for oyster shucking production systems described in this paper showed values for facilities, equipment, and labor utilization (see Table 3).

Comparative costs for each production line facility were allocated to floor space requirements for shucking tables, aisles, material handling equipment, oyster shucking personnel, and, when applicable, a steam tunnel. Equipment costs for each system were compared and allocated to oyster shucking work stations, conveyors, monorails, pallet truck, and steam tunnel. A comparison of labor productivity was also made.

Skatewheel Handling System - The costs of space for this production system were allocated to shucking work stations, aisles, personnel, and material handling equipment. The total facility cost for this production alternative amounted to $9,333.20. A high percentage of floor space costs in this system was assigned to shucking work stations (about 32 percent), the adjacent aisle space (about 32 percent), and the shuckers (about 24 percent). Eighty-eight percent of the space costs were devoted to the oyster shucker and his work station, and the remaining twelve percent to the skatewheel handling system utilized to supply shuckers with shell-stock. The equipment costs consisted of 28 shucking tables (about 89 percent) and a roller skatewheel conveyor (about 11 percent). In-plant observations showed that 28 shuckers were needed to operate at a capacity of 250 gallons of oyster meat per day.

Table 3. Comparative Costs for Alternative Oyster Shucking Production Lines (250 Gallon/Day Capacity).

| Resources | Production Line Alternatives | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Skatewheel | | Pallet Truck | | Belt Conveyor | | Overhead Monorail Conveyor | |
| | Dollars | (Percent) | Dollars | (Percent) | Dollars | (Percent) | Dollars | (Percent) |
| Building Space[1] | | | | | | | | |
| Shucking Work Station | 2,986.60 | (32) | 2,986.60 | (36) | 2,240.00 | (19) | 2,240.00 | (23) |
| Aisle | 2,986.60 | (32) | 2,986.60 | (36) | 3,000.00 | (26) | 2,900.00 | (30) |
| Oyster Shuckers | 2,240.00 | (24) | 2,240.00 | (28) | 1,680.00 | (14) | 1,680.00 | (17) |
| Material Handling | 1,120.00 | (12) | -- | -- | 2,050.00 | (17) | 60.00 | (1) |
| Steam Tunnel | -- | -- | -- | -- | 2,880.00 | (24) | 2,880.00 | (29) |
| Total | 9,333.20 | (100) | 8,213.20 | (100) | 11,850.00 | (100) | 9,760.00 | (100) |
| Equipment[2] | | | | | | | | |
| Shucking Work Station | 5,600.00 (a) | (89) | 5,600.00 (a) | (69) | 4,200.00 (b) | (31) | 4,200.00 (b) | (33) |
| Conveyor | | | | | | | | |
| Monorail | -- | | -- | | -- | | 1,593.00 | (12) |
| Belt | -- | | -- | | 3,175.00 | (24) | 1,180.00 | (9) |
| Roller | 675 | (11) | -- | | -- | | -- | |
| Pallet Truck | -- | | 2,500.00 | (31) | -- | | -- | |
| Steam Tunnel | -- | | -- | | 6,000.00 | (45) | 6,000.00 | (46) |
| Total | 6,275.00 | (100) | 8,100.00 | (100) | 13,375.00 | (100) | 12,973.00 | (100) |
| Shucking Labor Cost[3] (per year) | 748.00 | | 784.00 | | 588.00 | | 588.00 | |

1. Estimated at \$20.00 $Ft^2$
2. Estimated from John Wiltse, Modern Material Handling, February, 1979, pp. 60-61
   a) Based on 28 shuckers
   b) Based on 21 shuckers
3. Based on 8 hour work day

Pallet Truck Handling System - The cost of $8,213.20 of space in this system was allocated to shucking work station, aisles, and personnel. The major cost of building space in the line was assigned to the shucking work station (about 36 percent), aisles (about 36 percent), and personnel (about 28 percent). The pallet truck supplying shuckers with shell-stock utilized existing aisle space with a realized cost savings.

The equipment costs to make this system operational were allocated to shucking work stations and a pallet truck; about 69 percent to the shucking work station, and about 31 percent to the pallet truck. This production system utilized 28 shuckers to operate at its capacity.

Belt Conveyor Handling System - The facility costs for the belt conveyor system were designated for building space, shucking work stations, aisles, shuckers, material handling, and steam tunnel equipment. The cost for this alternative production system amounted to about $11,850.00. A relatively small cost for space was assigned to the shuckers' work stations (about 19 percent), for aisle space (about 26 percent), and for oyster shuckers (about 14 percent). A larger portion of costs was devoted to equipment spaces such as the steam tunnel (about 24 percent) and material handling space (about 17 percent).

The equipment costs in this alternative were allocated to shucking work stations (about 31 percent), belt conveyors (about 24 percent), and a steam tunnel (about 45 percent). This production system utilized 21 shuckers to operate at its capacity.

Monorail Conveyor Handling System - For this production system, the building costs and the costs of the steam tunnel and material handling equipment amounted to $9,760.00. It was broken down as follows: work stations (about 23 percent), aisle space (about 30 percent), shucker space (about 17 percent), conveyor space (about 1 percent), and steam tunnel (about 29 percent).

The equipment costs for the monorail system amounted to $12,973.00. They were divided among shucking work stations (about 33 percent), conveyor equipment (about 21 percent), and steam tunnel (about 46 percent). The reason the conveyor cost is high compared to the other equipment is the higher fixed cost of a short conveyor. This production system utilized 21 shuckers to operate at its capacity.

B. Comparative Cost Savings of Four Oyster Shucking Production Lines

The total and average costs of oyster shucking operations for the four production systems were estimated to determine whether any of these four designs offered significant cost savings to oyster processors (see Table 4). Facility, equipment, and labor costs were estimated on the basis of capital and labor productivity for the oyster shucking operations with and without the steam bath. Building costs were estimated on the basis of $20.00 per square foot. These values were applied to the analysis of each of the four production lines. Cost amortization schedules for building were based on a 30 year repayment period, an interest rate of 20 percent, and a repayment schedule based on 12 equal yearly payments. Equipment costs were estimated on the basis of industry and engineering data. Equipment costs were amortized on an 8 year repayment schedule, an interest rate of 20 percent, and 12 equal yearly payments. All four production systems were rated at an output capacity of 250 gallons of oyster meat per day to provide an equivalent basis for evaluation.

The Skatewheel Handling System - The total and average costs for operating the skatewheel system without a steam bath were the second highest of the methods studied. The total operating costs for the shucking operations amounted to $97,529.00 for producing approximately 30,000 gallons of oyster meat in a season (120-day period). The average operating costs per one gallon of oyster meat was $3.25.

The amortized costs of the building space were estimated at $1,871.52 or the second lowest of the four systems analyzed. Equipment costs, on a yearly payback schedule, amounted to $1,577.76, the lowest cost of the four systems. The total fixed costs for building space and equipment amounted to $3,449.28, the lowest value of the four.

Labor costs incurred in utilizing this production system amounted to $94,080.00 per season for the estimated 28 shuckers.

Table 4. Comparative Annual Cost-Savings for Four Oyster Shucking Production Line Methods (250 gallon/day output).

| Cost Item | Skatewheel | | Pallet Truck | | Belt Conveyor | | Monorail Conveyor | |
|---|---|---|---|---|---|---|---|---|
| | Amount | Rank | Amount | Rank | Amount | Rank | Amount | Rank |
| Building Space | $1,871.52 | (3)[1] | $1,646.88 | (4) | $2,376.24 | (1) | $1,957.08 | (2) |
| Equipment | 1,577.76 | (4) | 2,036.64 | (3) | 3,363.00 | (1) | 3,261.96 | (2) |
| Facility Cost[2] | 3,449.28 | (4) | 3,683.52 | (3) | 5,739.24 | (1) | 5,219.04 | (2) |
| Labor Cost[3] | 94,080.00 | (1) | 94,080.00 | (1) | 70,560.00 | (2) | 70,560.00 | (2) |
| Total Cost[4] | 97,529.28 | (2) | 97,763.52 | (1) | 76,299.24 | (3) | 75,779.04 | (4) |
| Cost per Gallon of Oyster Meat | 3.25 | (2) | 3.26 | (1) | 2.54 | (3) | 2.53 | (4) |
| Cost-Savings (%) | -- | | -- | | 22% | | 22% | |

1. Ranking of costs from highest (1) to lowest(4).
2. Amortized values.
3. Based on one season (120 days per year).
4. Based on 30,000 gallons of oyster meat.

The total cost (building, equipment, and labor) utilizing the skatewheel conveyor without a steam bath amounted to $97,529.00. This estimated cost figure does not include the cost of utilities -- heat, lights, and water. The average cost of the shucking operation per season amounted to $3.25 per gallon, which is the third highest cost of the four production systems studied.

Pallet Truck Handling System - The total and average costs for operating this system were the highest of the four production lines studied. The total cost amounted to $97,763.52 per season. The average cost was $3.26, the highest average cost for the four production systems.

The amortized value of building space was estimated at $1,646.88. Building space cost for this system was the lowest of the four systems analyzed. Equipment costs, based on the amortized schedules, amounted to $2,036.64, the second lowest figure of the four systems. The total cost for building space and equipment amounted to $3,683.52. This was the second lowest cost of the four production lines in the study.

Labor costs incurred for a seasonal output of oyster meat amounted to $94,080.00. As in the skatewheel handling system, 28 shuckers were needed to operate this system.

The total cost for this production line operation amounted to $97,763.52, exclusive of utility cost. The average cost amounted to $3.26. This was the highest operating cost for any of the four systems studied. Although the comparative cost analysis showed the pallet truck system to offer the lowest cost of construction and equipment, its operating costs were calculated to be the highest of the four production lines. However, there appears to be no significant difference between the operational costs of the skatewheel and the pallet truck handling systems without a steam bath. The decision to select either of these production systems should be based on factors other than costs.

Belt Conveyor Handling System - The total and average costs for operating this system were significantly lower than the skatewheel and pallet truck systems. This production line introduced into the shucking process a steam bath which treats shell-stock prior to delivery to the shucking work station. The total operating costs for the horizontal belt conveyor system amounted to $76,299.24 for producing approximately 30,000 gallons of oyster meat in a 120-day season. The average cost of this yearly operation amounted to approximately $2.54. There appears to be clearly significant reductions in cost by introducing the steam bath into the shucking process.

The yearly amortized cost for building space was estimated at $2,376.24, equipment at $3,363.00, for a total amount of $5,739.24. For the belt conveyor system, building space is the most expensive of the four systems studied.

Labor costs incurred in operating this production line amounted to $70,560.00 per season. Twenty-one oyster shuckers were required to operate this system at its capacity.

The total cost of operating a conveyor belt system with a steam bath amounted to $76,229.24. This estimated cost figure did not include the cost of utilities -- heat, lights, water, and steam. The cost of operating this system should be higher than stated because the cost of steam which was not accounted for should slightly increase the overall operating cost. The average cost at its rated capacity for one season was $2.54 per gallon. This was the second lowest cost of the four production systems studied. The difference in the operational cost between this system and the skatewheel and the pallet truck systems without steam appeared to be significant. The decision to select this method over the first two methods could be based on reduced costs. Other operational factors also favor the selection of this system.

Monorail Conveyor Handling System - The total and average costs for operating this system were about the same as the belt conveyor system, but were significantly lower than the skatewheel and the pallet truck systems. This production line featured a steam bath as did the belt conveyor system.

The total operating cost for the overhead monorail conveyor amounted to $75,779.04 per season, and the average cost was about $2.53. This was the lowest average operating cost of the four systems.

The amortized cost of building space was estimated at $1,957.08 or the second highest annual cost of the four systems. Equipment costs, based on an eight year payback, amounted to $3,261.96, the second highest cost of the four systems. Total cost for building space and equipment amounted to $5,219.04, or the second highest value of any system.

Labor costs incurred in operating this production line at its capacity amounted to $70,560.00 per season utilizing 21 shuckers.

Total cost for operating this system amounted to $75,779.04. This estimated cost figure did not include the cost of utilities -- heat, light, water, and steam. The cost of operating this oyster shucking production system should be higher than the stated average cost since the unaccounted cost of steam would increase the average cost slightly. The average cost of this system amounted to $2.52 per gallon of oyster meat. This was the lowest average cost of the four production systems studied.

There was a significant difference in the average cost between the monorail conveyor system and the skatewheel or the pallet truck handling systems, and the decision to select this production method over the skatewheel or pallet truck handling systems should be on reduced operating costs or other operational factors. However, the decision to select the monorail conveyor system over the horizontal belt conveyor system should be made primarily on non-cost factors since no significant cost difference appeared in the analysis.

C. Summary of Comparative Costs and Savings for the Four Production Systems

The building costs for the four production systems varied between $8,213.00 and $11,850.00. The lowest cost facility was the pallet truck handling system. The total cost of this system was lower because the supply of shell-stock to oyster shuckers was provided in the existing aisle space. The highest cost for building space was in the belt conveyor system. Although space for personnel was reduced because of the layout design, greater space was needed for the support systems related to equipment specified for conveyors and steam tunnel.

The equipment showed greater variation in price among the four systems. The least expensive production line was the skatewheel handling system. The equipment specified for this system was valued at approximately 50 percent of the cost of a belt conveyor system. The belt conveyor system required the most expensive equipment of the four systems studied.

The total facility (building and equipment) cost for the skatewheel handling system was the least expensive of the four. The most expensive system was the horizontal belt conveyor system. Lowest cost systems do not necessarily yield the lowest operating cost. This concept is examined in greater detail next.

There were significant differences in the operating costs among the four production systems studied. The operating costs were significantly lower in these systems in which a steam bath treated the shell-stock prior to shucking. The skatewheel and pallet truck handling systems incurred the highest average operating costs of $3.26 and $3.25 per gallon of oyster meat, respectively. The lowest average operating costs per gallon of shucked oyster meat were obtained from the belt and monorail conveyor systems which showed an average cost of $2.54 and $2.52, respectively.

The average cost savings derived from the belt and monorail conveyors with the steam bath clearly showed a significant advantage over the skatewheel and pallet truck handling systems without a steam bath. The steam bath, utilized as a gaping method for opening the oysters, is an important component of the more productive systems. The cost reduction potential offered by the two conveyor systems -- belt and monorail -- provide significant incentives to oyster processors for their installation and operations in the shucking operations of the industry.

The management decision of whether to select a belt or monorail conveyor rested with production factors of shell-stock procurement and handling, in-plant shell-stock flow, labor management, preventative maintenance, and sanitation and quality maintenance.

## V. COMPARABLE LABOR SAVINGS FOR PRODUCTION LINES WITH AND WITHOUT A STEAM BATH

Labor productivity gains were significant for those systems incorporating a steam bath in the production line at comparable output levels. This increase in labor productivity reduced the number of shuckers and the building space and equipment needed to produce at comparable output levels.

A sample of oyster processors showed that processing plant output in Virginia averaged about 250 gallons of oyster meat per day. Twenty-eight shuckers were required to produce this output level in the operations without a steam treatment and 21 shuckers in production systems with a steam bath (Table 5). The labor savings realized from the reduction in the number of shuckers from 28 to 21 amounted to $19,520.00 for a 120-day period, a 22 percent decrease.

The absolute labor savings increased as the scale of plant increased with more shuckers added to the production lines utilizing a steam bath (Table 5). At each level, a plant was also operated by a labor force of about 25 percent less shuckers in systems with a steam bath.

## VI. A MANAGEMENT PLAN FOR REALIZING POTENTIAL PRODUCTIVITY GAINS FROM ALTERNATIVE OYSTER SHUCKING SYSTEMS

A management plan for realizing potential productivity gains from the four oyster shucking systems studied included subordinate plans for maintaining adequate shell-stock for the system to operate at plant capacity, maintaining optimum flow rates of shell-stock to oyster shuckers, assigning, supervising, and training an adequate labor pool of oyster shuckers, maintaining the operating effectiveness of the engineering plant, and implementing a quality maintenance and sanitation program.

The systems described in the four production designs fell in two basic work-oriented categories -- with and without a steam bath application. Those engineering designs featuring a steam bath application included a floor-mounted horizontal belt and an overhead monorail conveyor systems, and those systems operating without a steam bath application included the skatewheel and pallet truck handling systems. The systems were labeled 'With Steam Bath Process' or 'Without Steam Bath Process.'

Table 5. Comparative Labor Savings in the Application of the Four Production Lines for Shucking Shell Oysters.

| Oyster Meat Output (Gallons/day) | Skatewheel and Pallet Truck Systems: No. of Shuckers | Dollars/ hour | Dollars/ year | Belt and Monorail Conveyor Systems: No. of Shuckers | Dollars/ hour[1] | Dollars/ year[2] | Difference Between two Types of Systems: No. of Shuckers | Dollars/ hour | Dollars/ year | (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 6 | 21 | 20,160 | 5 | 17.5 | 16,800 | 1 | 3.5 | 3,360 | (17) |
| 100 | 12 | 42 | 40,320 | 9 | 31.5 | 30,240 | 3 | 10.5 | 10,080 | (25) |
| 150 | 17 | 59.5 | 57,120 | 13 | 45.5 | 43,680 | 4 | 14.0 | 13,440 | (24) |
| 200 | 23 | 80.5 | 77,280 | 17 | 59.5 | 57,120 | 6 | 21.0 | 20,160 | (26) |
| 250 | 28 | 98 | 90,080 | 21 | 73.5 | 70,560 | 7 | 24.5 | 19,520 | (22) |
| 300 | 34 | 119 | 114,240 | 25 | 87.5 | 84,000 | 9 | 31.5 | 30,240 | (26) |
| 350 | 39 | 136.5 | 131,040 | 30 | 105 | 100,800 | 9 | 31.5 | 30,240 | (23) |
| 400 | 45 | 157.5 | 151,200 | 34 | 119 | 114,240 | 11 | 38.5 | 36,960 | (24) |
| 450 | 50 | 175 | 168,000 | 38 | 133 | 127,680 | 12 | 42.0 | 40,320 | (24) |
| 500 | 56 | 196 | 188,160 | 42 | 147 | 141,120 | 14 | 49.0 | 47,040 | (25) |

1. Hourly labor rate = $3.50/8 hour work day
2. Yearly labor rate = $3.50 x Number of shuckers x 8 hour work day x 120 day season

With Steam Bath Process - A critical time-period for managing this system is the interval when the shell-stock is treated in a steam bath to cause a slight opening of the oyster shell. This opening allows the shucker to extract the oyster meat from the shell more easily. However, shell-stock should be treated in a steam bath cycle only long enough for the oyster to open its shell, but not any longer. A prolonged exposure of the shell-stock to steam tends to cook the oyster meat thereby reducing its quality as a fresh oyster product.

Without a Steam Bath Process - A management plan for implementing oyster shucking systems does not differ significantly from the work methods currently applied in the oyster industry. The material handling systems supporting the shucking methods without a steam bath treatment differs only slightly from the manual or mechanized delivery systems utilized in oyster processing plants.

A. A Management Plan with a Steam Bath

Productivity gains expected from passing the shell-stock through a steam bath were 20 to 35 percent over the productivity of the systems not utilizing a steam bath. The production lines illustrated in this analysis featuring a steam bath showed an estimated average gain in labor productivity of about 24 percent, regardless of output rates.

An overall management plan for realizing potential productivity gains from a steam bath consisted of a shell-stock procurement and handling plan, a plan for regulating in-plant shell-stock flow, a plan for supervising and training oyster shuckers, an engineering design and preventive maintenance plan, and a quality maintenance and sanitation program. Each subordinate plan noted should be integrated into a master management plan to insure productivity gains from the steam bath systems.

A Shell-Stock Procurement and Handling Plan - A steam bath treatment for shell-stock simplified the method of shucking. The new shucking method reduced body fatigue of the shuckers and enabled them to work for longer daily time periods resulting in higher output rates. A plan should insure that additional quantities of shell-stock are available to support extended working hours should two work shifts be feasible.

A steam bath treatment also changed the handling methods of shell-stock being supplied to shuckers. Smaller quantities were loaded on the conveyor and in baskets for the monorail for a steam bath treatment. This handling procedure probably requires more effort by the worker in the shell-stock room to keep shuckers adequately supplied.

These two demands focus attention on a management plan that calls for an adequate supply of shell-stock and a well-trained handler supplying shuckers with shell-stock.

A Plan for Regulating Shell-Stock Flow in Steam Bath Systems- A key variable for realizing maximum labor productivity from a steam bath treatment is time. The importance of time is illustrated by the following example. The shell-stock is conveyed through a steam bath at a defined rate. Once the shell-stock exits the steam bath, it is moved continuously or in batches to the shucking work stations. The delay between the time the shell-stock exits the steam bath and the time the oyster meat is removed from the shell should be minimized. The in-plant shell-stock flow rate should be regulated so that a small volume of shell-stock is waiting to be shucked. The shucking work station was designed for steam-treated shell-stock to move toward the shucker in the order that it exits the steam bath. Excessive time delays may cause the oysters to close their shells together, causing a loss in worker productivity. A cooking effect may also take place should the shell-stock remain unshucked due to the high temperature of the shell. Shucking the shell-stock immediately after the steaming process reduces this undesirable effect.

The two material handling systems (belt and monorail conveyors) reduced the time delay by their design and application. The floor-mounted horizontal belt conveyor system had the capability to handle oysters continuously. The shuckers could keep only enough shell-stock to shuck in a reasonable time period without an extra volume being piled up in the work station holding bin. As the shell-stock came off of the conveyor, the inclined panel at the back of the bin allowed the shell-stock to be pushed toward the shucker producing "first in" and "first out" effect. This procedure insures the quality of the oyster meat because of its rapid transit through the production line.

The overhead monorail conveyor, on the other hand, operated on the concept of a batch process. This system transported the shell-stock in a wire basket containing about 1/2 bushel of shell-stock. As these baskets were conveyed in front of a shucker, the entire shell-stock was dumped into the bin on top of the work table. In this procedure, delays in shucking might have occurred that were not present in a belt conveyor handling system. The batch process supplied more shell-stock and the order of shucking might not always result in a "first in" and "first out" flow.

Observations showed that shucking work stations near the steam bath were highly preferred by the shuckers. Aggressive shuckers tended to position themselves near the entrance of the tunnel for access to freshly steamed shell-stock. The flow of shell-stock to work stations had to be controlled to minimize the delay in conveying shell-stock from the steam bath to the shucking station.

In order to effectively maintain the flow of shell-stock to the shuckers, a management plan must include an appropriate plant layout, an adequate supply of shell-stock, and a shucking force trained and supervised in fundamental work methods.

A Plan for Supervising and Training Oyster Shuckers - The production lines containing a steam bath changed the oyster shucking work method slightly. The most important aspect of the modified work method was to reduce the delay time between the steam bath and the shucking of the oyster from the shell. Oyster shuckers should be trained and supervised in the steps of the modified work methods. This training and supervision should insure that the potential productivity gains are realized through the modified work method, and that the quality of the oyster meat is maintained.

The steam process should enlarge the labor pool available to the industry because of the reduced skill level needed to perform the oyster shucking operation. This should enable the processing industry to increase the daily hours of operation should it become necessary to increase oyster meat output.

An Engineering and Preventive Maintenance Plan - Management must incorporate an effective engineering design for the potential productivity gains to be realized through the application of the steam bath to shucking operations. The principles of motion economy and material handling must be used in designing a production system.

Prototype designs of four production systems were illustrated. The proposed systems minimized construction and operating costs because they made effective use of building space. The design of the shucking work station incorporated the principles of motion economy which minimized the motion(s) of the shuckers during the shucking operation. These principles included the application of gravity flow designs to the storage bins for shell-stock and minimization of the reaching and moving functions of the shucker's body in picking up shell-stock, removing the oyster meat, depositing the oyster meat into cans, and discarding the oyster shell. Caution should be exercised when utilizing the gravity flow methods. Oysters may lose weight and quality if dropped excessive distances in a modified work routine.

These modified shucking work methods and work station designs contributed to potential productivity gains. However, the gains may not be realized unless a complementary preventive maintenance program is implemented. The two systems utilizing a steam bath -- the belt and the monorail conveyors -- consisted of many mechanical parts of which a certain failure rate might be expected. A qualified maintenance worker should be employed to repair any breakdowns in the system. To complement a maintenance worker, an adequate supply of spare parts should be inventoried for potential repair needs.

A Quality Maintenance and Sanitation Program - The shelf life in the market place of oyster meat depends on an effective in-plant quality maintenance and sanitation plan. A plan should include handling procedures for shell-stock (temperature maintenance) and for oyster meat (shucking, blowing, and packing procedures). A cleaning and sanitizing program should be developed for the shell-stock holding room, the steam bath (tunnel), the shucking work stations and shucking room, and the conveyor system. Particular attention should be directed to a regular cleaning cycle of the steam tunnel, the shucking work stations, and the conveyor systems. The overhead monorail conveyor requires minimal cleaning and sanitizing. There is a cost/quality trade-off in the batch process with a monorail delivery system in that it is easy to clean because the machine is not in touch with the shell-stock conveyed through the system. As for the belt conveyor system, the flow of shell-stock is continuous but the down time for cleaning is greater.

B. A Management Plan Without a Steam Bath

Productivity gains of production systems without a steam bath were expected to equal output of traditional oyster shucking systems, or at rates of 20 to 35 percent less than systems with a steam bath.

An overall management plan for operating an oyster production system without steam treatment was much more simplified than a steam bath system. Management plans supporting these systems consisted of a shell-stock procurement and handling plan, a plan for supervising and training oyster shuckers, an engineering and material handling plan, and a quality maintenance and sanitation plan.

A Shell-Stock Procurement and Handling Plan - A procurement and handling plan for shell-stock in production lines without a steam bath closely paralleled manual or mechanized industry practices. Shell-stock handlers supplied shell-stock to oyster shuckers by a skatewheel conveyor or a pallet truck. These handlers delivered several bushels of shell-stock to each work station at a time. Their major concern was keeping an adequate supply of shell-stock in front of the shuckers.

A Plan for Training and Supervising Oyster Shuckers - Oyster shuckers working on production lines without steam treatment faced a task of shucking oyster meat from a tightly closed shell-stock. Training methods for these shuckers focused on the application of traditional work methods in the use of oyster mallets and knives and the related motions in the shucking process. A principal duty of the supervisor was to monitor the discarded shell-stock to insure shuckers were not throwing away the smaller oyster shell-stock and reducing the shell-stock yield and marketable oyster meat as a result.

An Engineering and Material Handling Plan - The engineering plan in this set of systems focused on an effective design of a shucking work station and its associated material handling system. Relatively little coordination was needed to supply the oyster shuckers with shell-stock.

A Quality Maintenance and Sanitation Program - A plan comparable to the steam bath system was needed to prolong shelf life of oyster meat. The principal difference was the absence of the conveyor system and its more frequent cleaning and sanitizing needs.

C. Summary of the Management Plan

The management plan for production systems featuring a steam bath was much more complicated than that for systems without a steam bath and required greater attention to detail. The duties expected of management to operate the steam bath systems were greater in number and were more complex in nature. This situation indicated that the size of management staff and its competence should be improved to effectively manage a steam bath system. The benefits derived from the installation of a steam bath appeared to justify this trade-off to be made.

## An Evaluation of the Heat Transfer Capability of Two Virginia Oyster Steam Tunnels

J. Kenneth Riggins

### A. INTRODUCTION

As the steam tunnel becomes more widely used in the oyster industry, it becomes increasingly important to establish certain criteria to assist in its proper design and operation. This chapter investigates the oyster meat temperature and tunnel air temperature as a function of oyster travel time in two Virginia steam tunnels. This relationship is important in that it can be used to provide an indication of the tunnel to oyster heat transfer capability. Since design considerations and operational procedures must insure maximum heat transfer between the tunnel and oysters, the results gained from this investigation should enhance the future development of the oyster steam tunnel.

### B. TUNNEL DESCRIPTION

The basic features of the conveyor type steam tunnel tested in this study are shown in Figure VIII-1.

#### 1. Tunnel #1

Oysters are dumped from a hopper located at the entrance and conveyed through the tunnel on a steel chain link belt driven by a variable speed motor. A layer of oysters 3 inches thick is maintained on the belt while steaming.

The tunnel is constructed with a top and two sides. No bottom is used. The inside surfaces are boiler plate steel and outside surfaces

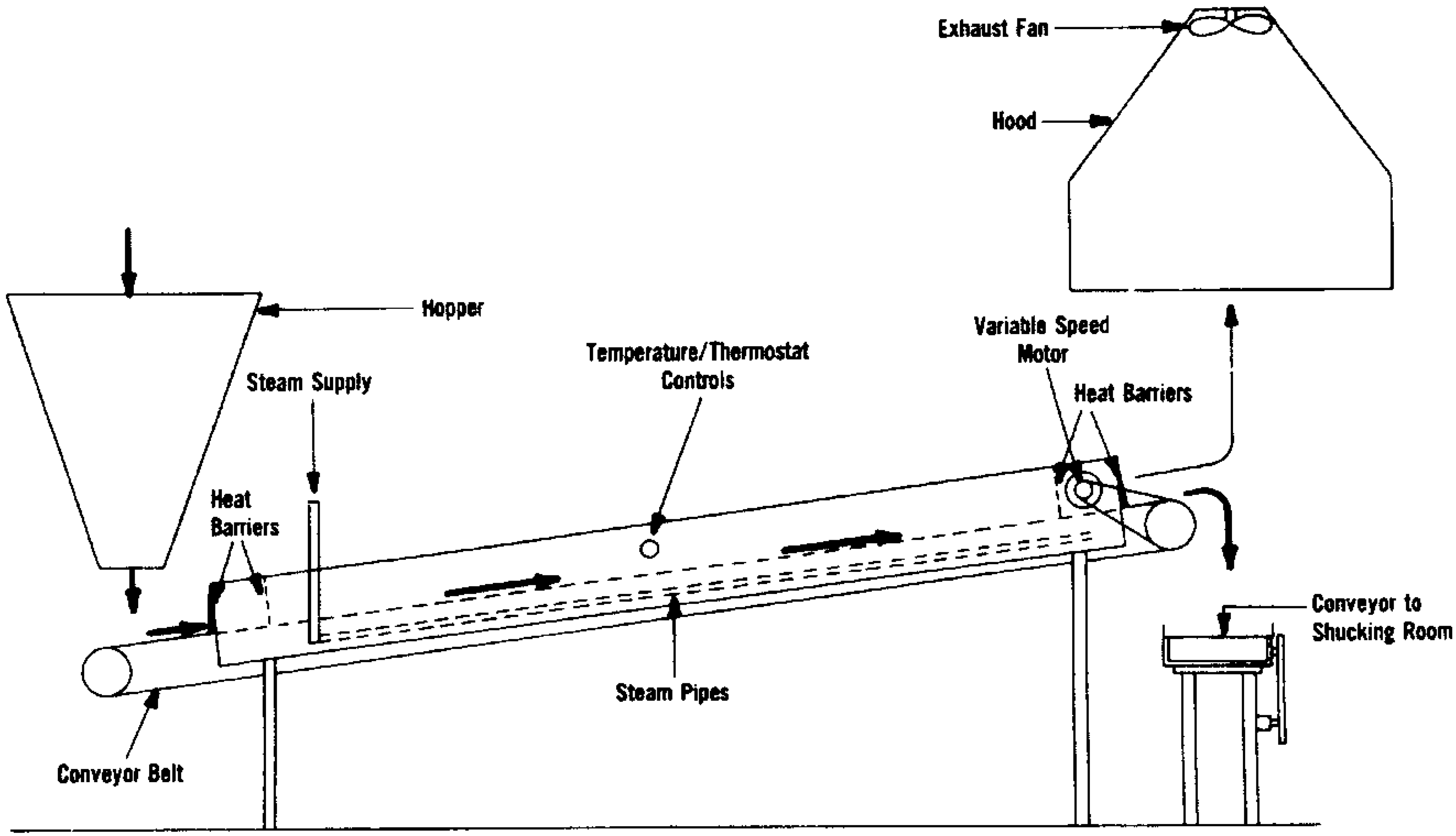



Figure VIII - 1. Oyster Steam Tunnel

are plywood. Tunnel dimensions are: length, 12 ft; width, 36 in; depth, 12.5 in. No insulation is used.

In order to reduce steam loss through the end openings, two heat barriers are located at each end of the tunnel. The force of the oysters striking the barriers causes them to swing open to allow passage of the oysters.

Steam is supplied near the entrance to a header supplying four pipes 1 inch in diameter running the length of the tunnel. Since these pipes are located beneath the oysters, the injection holes are oriented upward so that steam can be directed on the oysters on the conveyor belt above. The tunnel air temperature is maintained at about 185° F.

The tunnel is inclined 7.5° to achieve natural flow of steam through the tunnel. A hooded exhaust fan at the exit vents steam from the building.

2. Tunnel #2

Oysters are hand shoveled approximately 3 inches deep on to a steel chain link belt operated by a variable speed motor.

The tunnel is completely enclosed on all four sides and is constructed with stainless steel surfaces inside and boiler plate steel outside. Tunnel dimensions are: length, 12 ft; width, 26 in; depth, 13.75 in. No insulation is used.

Steam is supplied to the tunnel near the mid section. Two pipes perforated with holes carry the steam through the tunnel. Since these pipes run along the inside bottom of the tunnel, the steam injection holes are directed upward. The tunnel thermostat is set at 185° F.

A 9° incline of the tunnel and a hooded exhaust fan allows the flow and ventilation of steam through the tunnel and out the building. One heat barrier at each end is used to prevent steam from escaping too rapidly.

## C. TEST PROCEDURE

Oyster meat temperature and tunnel air temperature were recorded on a data logger (Monitor Labs Model 9300, Monitor Labs, Inc. San Diego, CA 92131). Temperatures were measured by copper-constantan thermocouples.

After each test oyster was washed, a 3/16-inch hole was drilled through each shell. Through this hole a thermocouple was inserted into the oyster meat. A loop of the thermocouple wire was fastened with a rubber band to the oyster shell to prevent dislodging of the thermocouple from the oyster. A heat resistant putty compound placed around the drilled hole prevented outside heat from entering the oyster at this point.

Experimental and production tests were conducted on each tunnel. In the experimental tests, only test oysters were conveyed through the tunnel. In the production tests, test oysters were mixed in with a normal batch of production oysters. This procedure was used so that the effect of the oyster layer thickness could be determined.

The tests (observations) were plotted as a function of time and are shown in Figures VIII-2 and VIII-3 for tunnel #1 and Figures VIII-7 and VIII-8 for tunnel #2. Each data point represents the average meat temperature at a given time of three oysters equally spaced across the conveyor belt. Each observation is a plot of the average meat temperature at each time interval in the tunnel. An average observation was plotted for each set of observations.

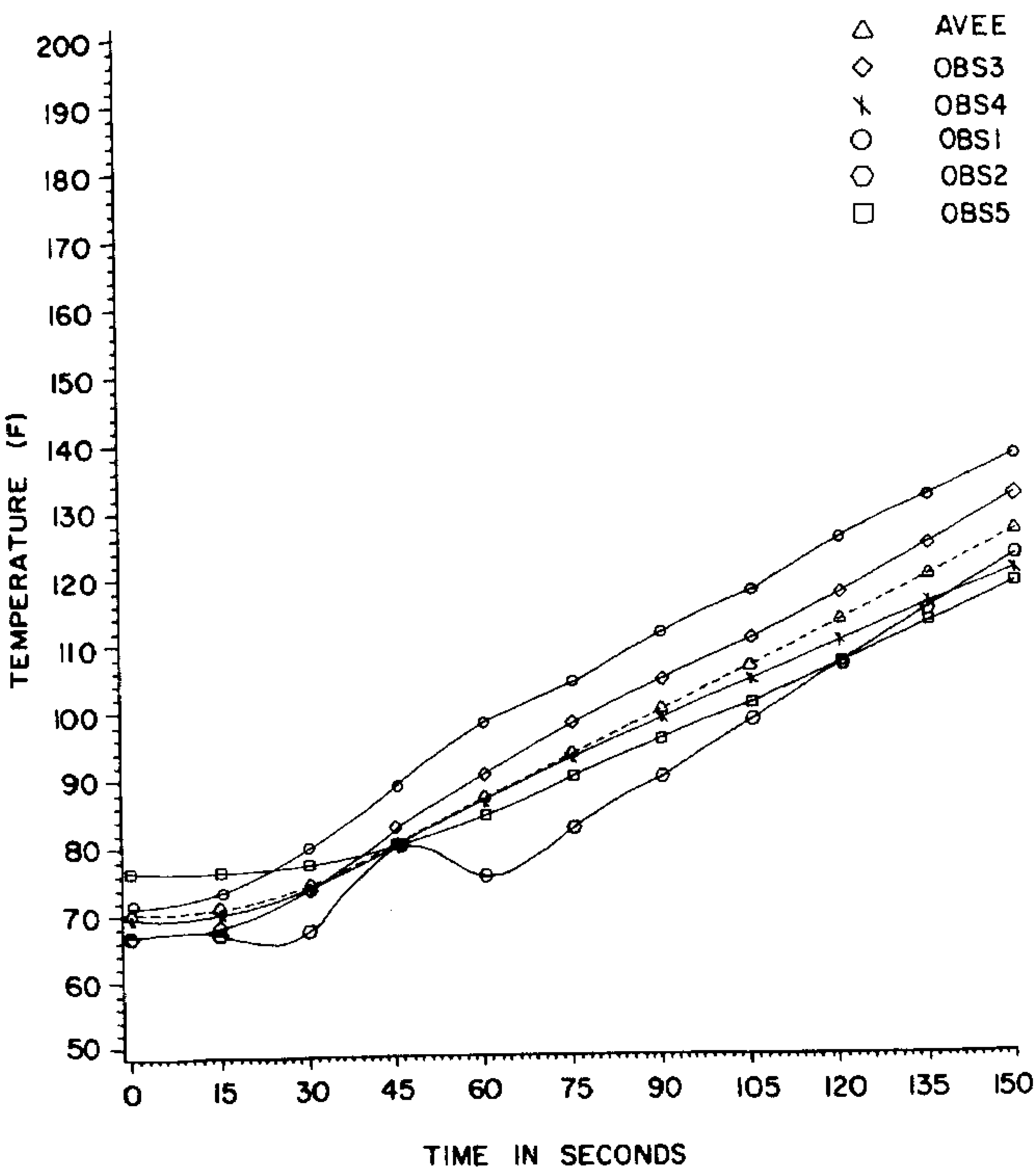



Figure 2. Experimental oyster meat temperature versus time (Tunnel #1)

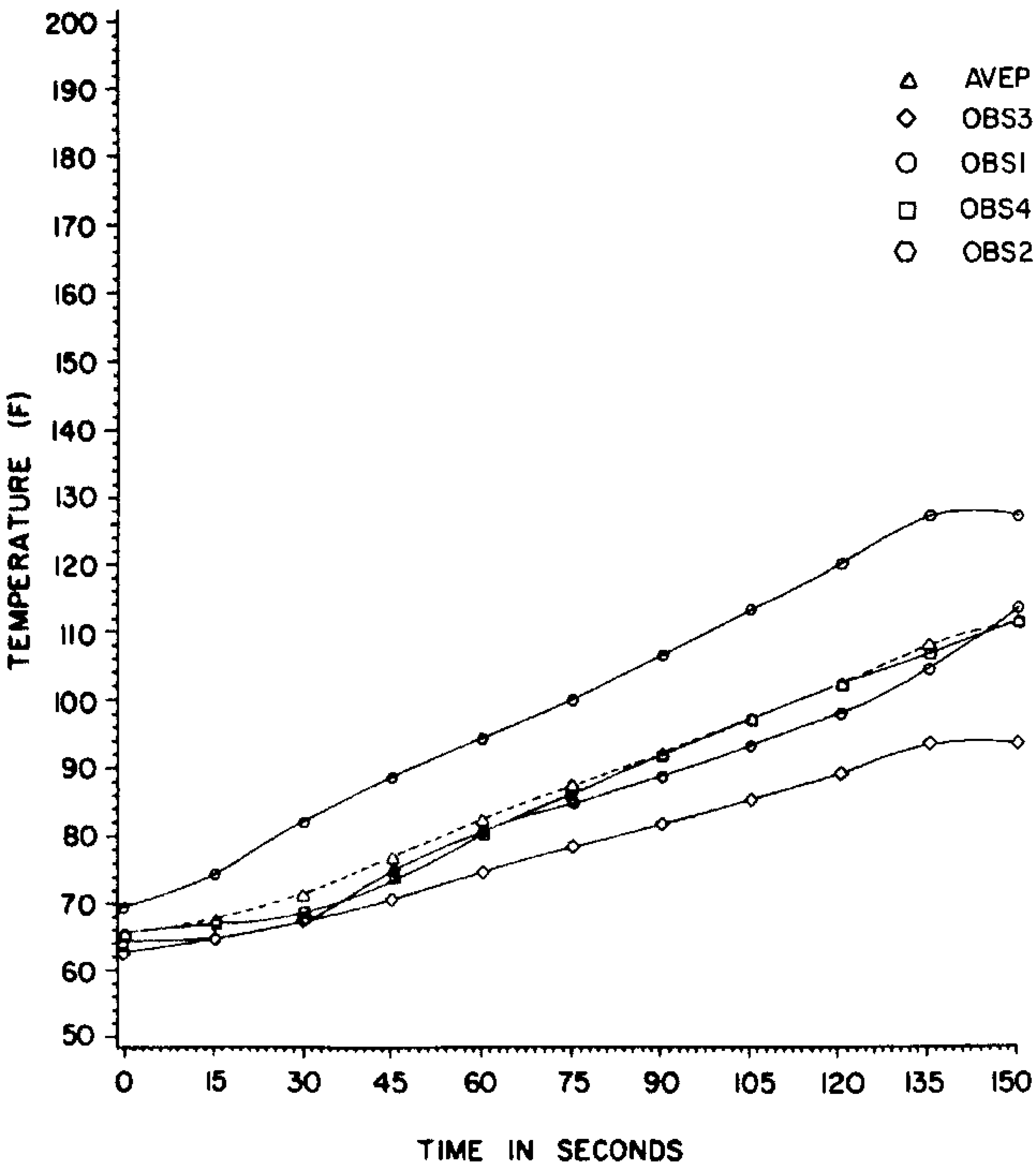



Figure 3. Production oyster meat temperature versus time (Tunnel #1)

The tunnel air temperature was recorded by fastening a thermocouple on the outside of an oyster's shell and conveying it with the three test oysters. With tunnel #1 this was done in only one production observation (Fig. VIII-4) and with tunnel #2, in all four production observations (Fig. VIII-9).

Figures VIII-5 and VIII-10 are plots of the average experimental and production meat temperature and the average tunnel air temperature for tunnel #1 and #2 respectively.

Average tunnel and oyster meat temperatures are recorded in Tables 1 and 2. Temperatures were recorded every 15 seconds in tunnel #1 and every 5 seconds in tunnel #2.

Table 1. Oyster and tunnel temperatures for tunnel #1

| Time (sec) | Tunnel °F | Oyster (production) °F | Oyster (experimental) °F |
|---|---|---|---|
| 0 | 67.8 | 65.4 | 70.4 |
| 15 | 124.1 | 67.6 | 71.1 |
| 30 | 136.2 | 71.2 | 74.5 |
| 45 | 161.5 | 76.6 | 80.5 |
| 60 | 166.2 | 82.3 | 87.2 |
| 75 | 166.2 | 87.1 | 93.6 |
| 90 | 170.5 | 91.8 | 100.2 |
| 105 | 177.6 | 96.9 | 106.5 |
| 120 | 183.0 | 102.0 | 113.3 |
| 135 | 189.0 | 107.5 | 119.9 |
| 150 | 196.9 | 110.9 | 126.3 |

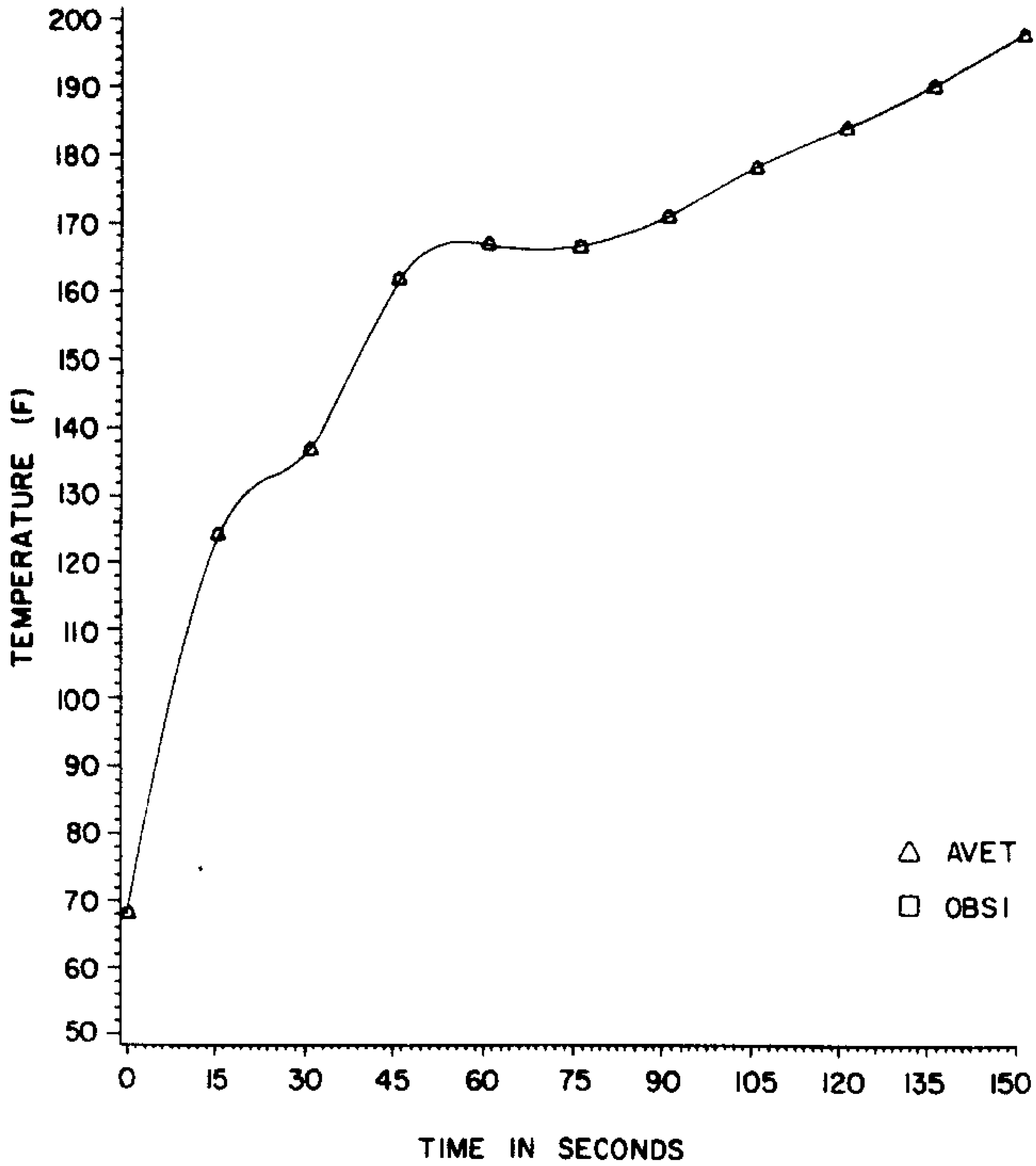



Figure 4. Steam tunnel air temperature versus time (Tunnel #1)

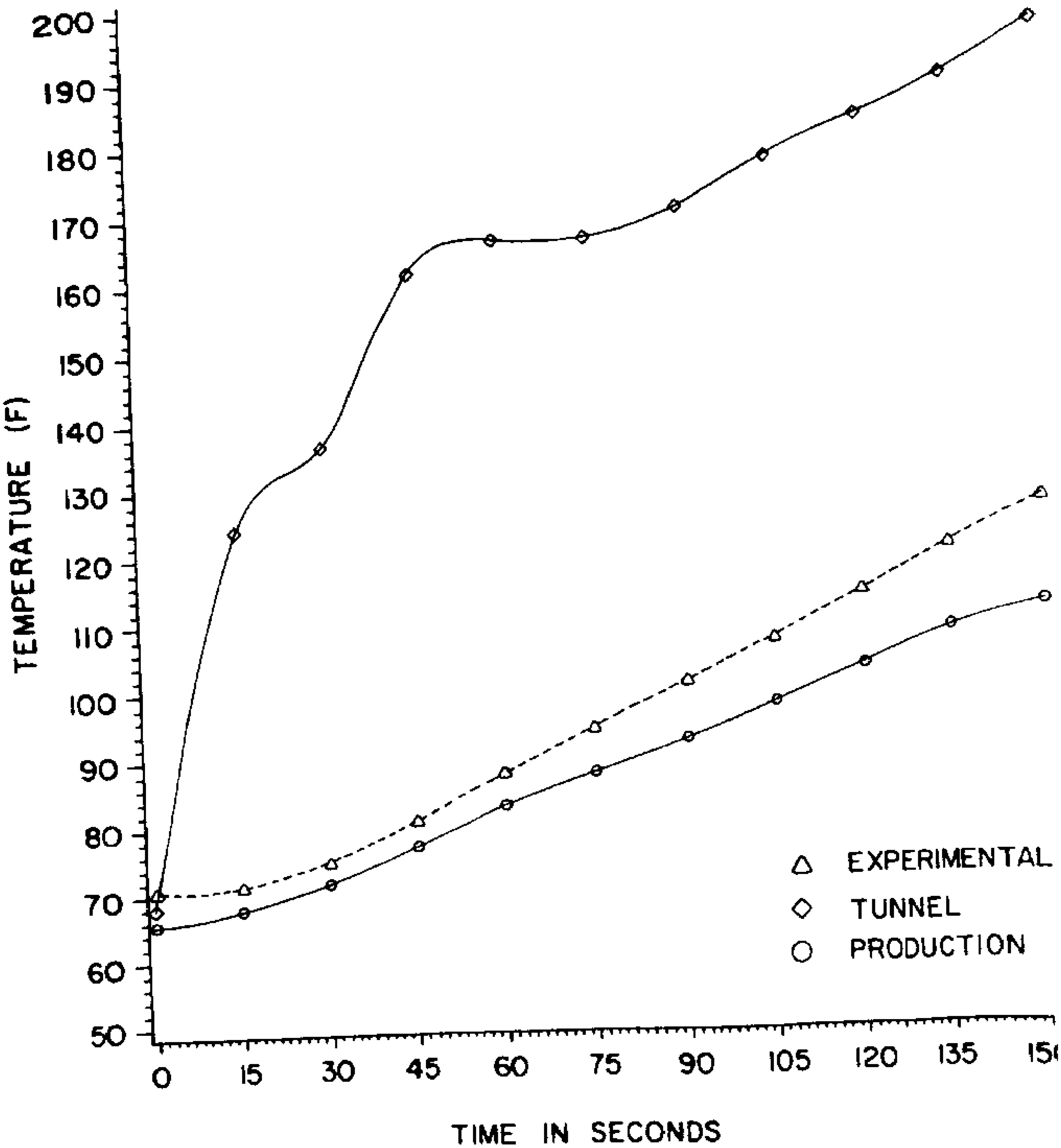



Figure 5. Average heating time compared (Tunnel #1)

Table 2. Oyster and tunnel temperatures for tunnel #2

| Time (sec) | Tunnel °F | Oyster (production) °F | Oyster (experimental) °F |
|---|---|---|---|
| 0 | 76.2 | 62.4 | 56.3 |
| 5 | 97.1 | 62.7 | 56.4 |
| 10 | 113.6 | 63.3 | 56.9 |
| 15 | 122.0 | 64.4 | 57.8 |
| 20 | 127.6 | 65.7 | 59.2 |
| 25 | 135.7 | 67.0 | 60.8 |
| 30 | 139.5 | 68.4 | 62.8 |
| 35 | 145.8 | 69.9 | 64.8 |
| 40 | 150.8 | 71.4 | 67.0 |
| 45 | 156.8 | 73.0 | 69.8 |
| 50 | 162.7 | 74.9 | 72.9 |
| 55 | 167.2 | 76.7 | 76.2 |
| 60 | 171.1 | 80.4 | 80.5 |
| 65 | 173.9 | 83.9 | 85.1 |
| 70 | 176.1 | 87.9 | 89.5 |
| 75 | 179.2 | 92.3 | 93.6 |
| 80 | 180.6 | 96.7 | 97.6 |
| 85 | 181.9 | 100.8 | 101.6 |
| 90 | 183.7 | 104.5 | 105.4 |
| 95 | 184.0 | 107.9 | 109.4 |
| 100 | 184.9 | 111.0 | 113.3 |
| 105 | 184.6 | 113.7 | 117.3 |
| 110 | 185.4 | 116.3 | 120.7 |
| 115 | 185.5 | 118.8 | 123.7 |
| 120 | 184.9 | 120.9 | 126.7 |
| 125 | 185.5 | 122.8 | 129.5 |
| 130 | 185.1 | 124.4 | 132.4 |
| 135 | 184.9 | 125.9 | 135.1 |

## D. RESULTS AND DISCUSSION

### 1. Initial Oyster Meat Temperature

The initial oyster temperatures varied by over 14° F depending on storeroom temperatures. Since an accurate evaluation of the heat transfer performance of the steam tunnels should reflect the use of equal starting temperatures for the oysters, an average starting temperature was used in all meat temperature tests. The average (62.38° F was determined by averaging all initial meat temperatures. Using 62.38° F as the initial meat temperature, the average tunnel and meat temperatures for both tunnels are plotted in Figure VIII-12.

### 2. Regression Equations

Linear and non linear regression analysis on observation averages yielded the following prediction equations where x is the independent variable representing tunnel travel time.

a. Tunnel #1

1). Experimental meat temperature, $°F = .398x + 65.04$

2). Production meat temperature, $°F = .321x + 63.14$

3). Tunnel air temperature, $°F = 87.98 + 1.586x - .0062x^2$

b. Tunnel #2

1). Experimental meat temperature,

$$°F = 56.94 - .1369x + .0119x^2 - .000049x^3$$

2). Production meat temperature,

$$°F = 64.39 - .2353x + .012x^2 - .00005x^3$$

3). Tunnel air temperature,

$$°F = 90.45 + 1.855x - .0088x^2$$

To reflect equal starting temperatures, the regression equations were modified with 62.38° F as the starting temperature for all meat temperature tests.

a. Tunnel #1

1). Experimental meat temperature, $^{o}F = .398x + 62.38$

2). Production meat temperature, $^{o}F = .321x + 62.38$

b. Tunnel #2

1). Experimental meat temperature,

$$^{o}F = 62.38 - .1369x + .0119x^2 - .000049x^3$$

2). Production meat temperature,

$$^{o}F = 62.38 - .2353x + .012x^2 - .00005x^3$$

The F and t-tests on the regression variances and estimated co-efficients were significant at the .0001 level and all $R^2$ values were greater than .98. The regression curves for these equations appear in Figure VIII-6 for tunnel #1 and Figure VIII-11 for tunnel #2. Figure VIII-13 shows the regression curves using the actual starting temperatures and Figure VIII-14 shows the curves using equal starting temperatures.

3. Tunnel Air Temperature

The tunnel air temperature in both tunnels follows a similar trend (Figs. VIII-12 and VIII-13). Tunnel #2, however, heats slightly more than tunnel #1 near its mid section. Higher temperatures near the mid section of tunnel #2 are probably due to the steam supply which is located at this point. In tunnel #1, steam is supplied near the entrance.

4. Oyster Meat Temperature

a. Experimental tests versus production tests

Experimental meat temperatures are greater than production meat

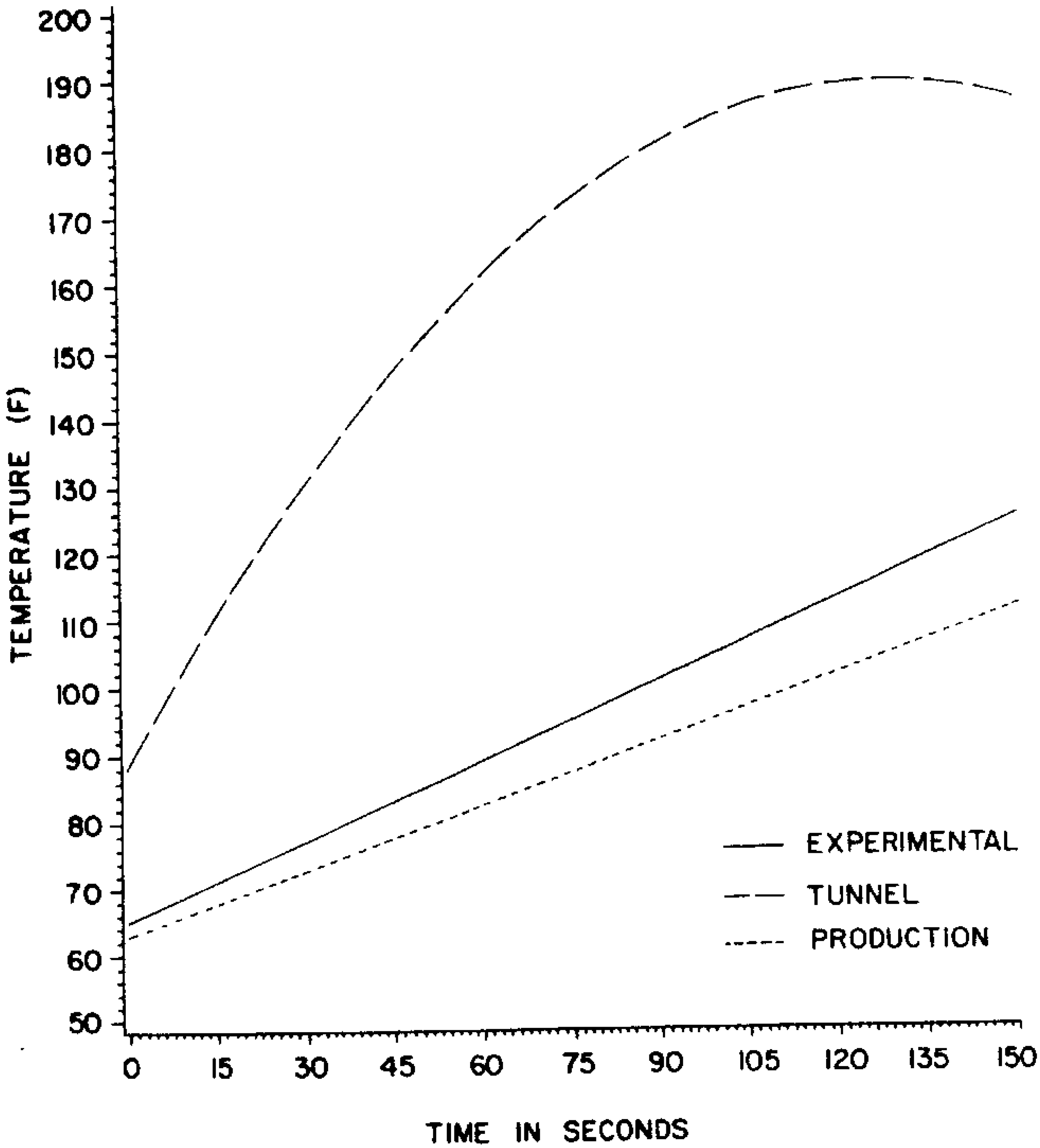



Figure 6. Prediciton curves (Tunnel #1)

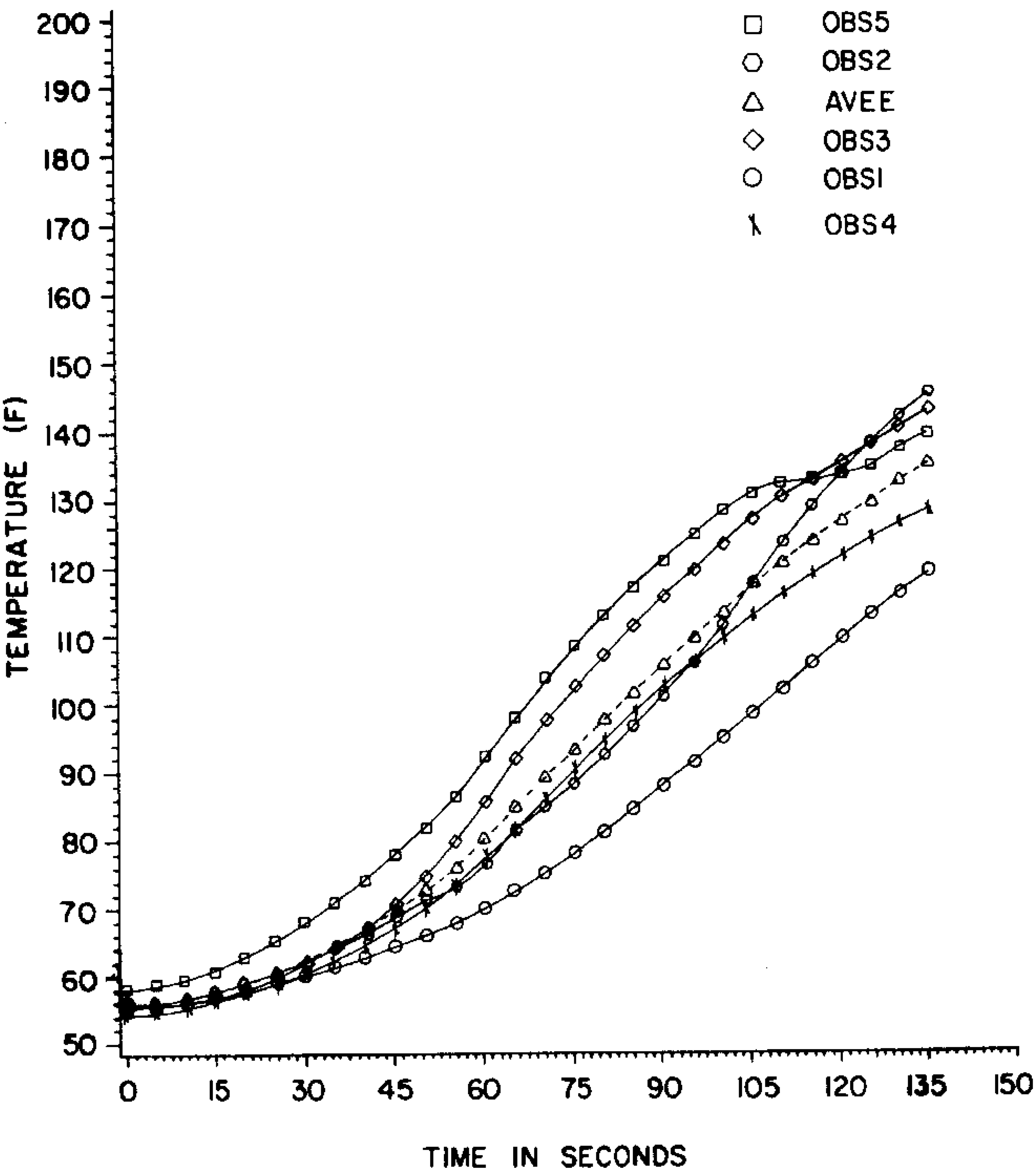



Figure 7. Experimental oyster meat temperature versus time (Tunnel #1)

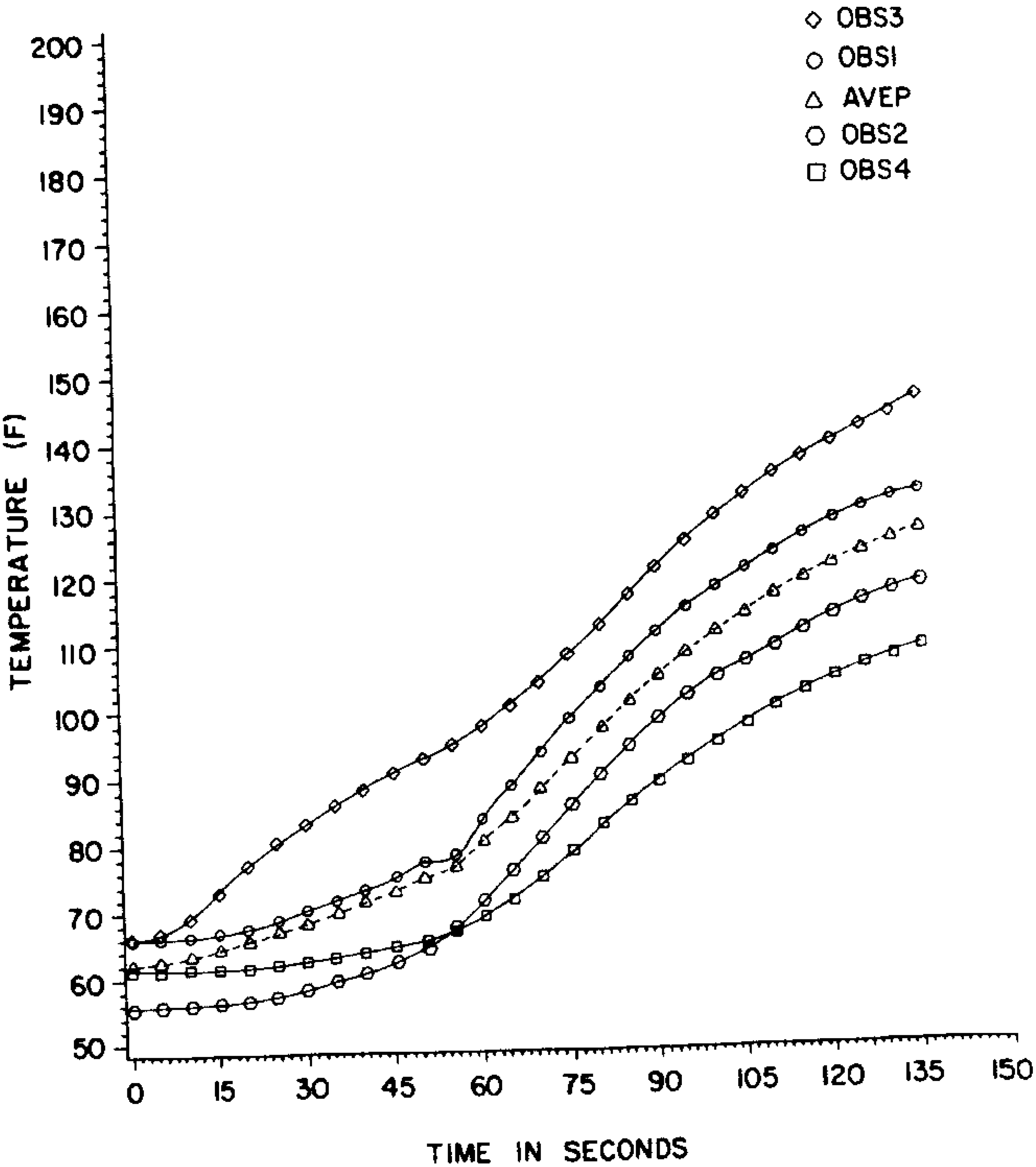



Figure 8. Production oyster meat temperature versus time (Tunnel #2)

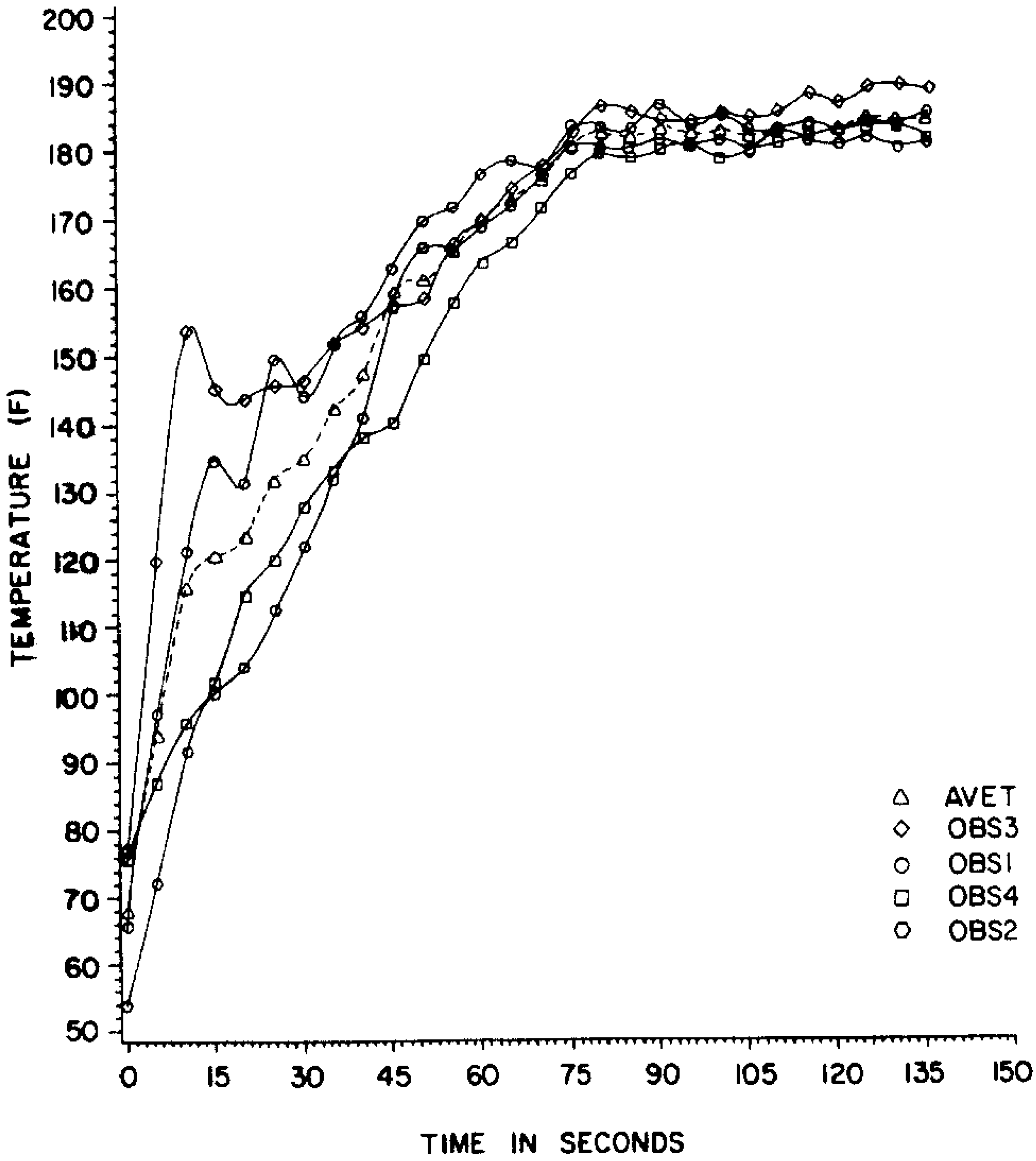



Figure 9. Steam tunnel air temperature versus time (Tunnel #2)

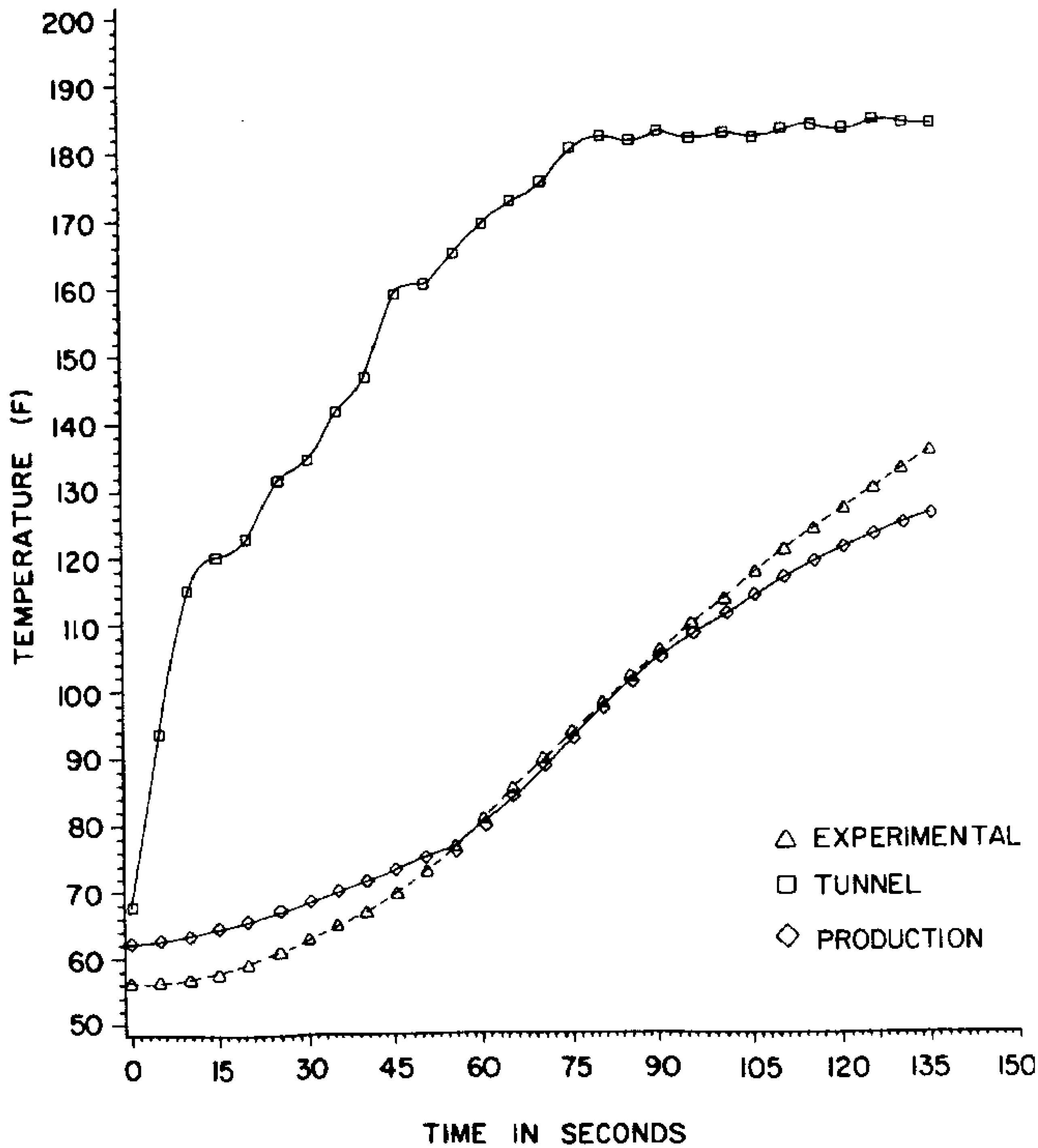



Figure 10. Average heating times compared (Tunnel #2)

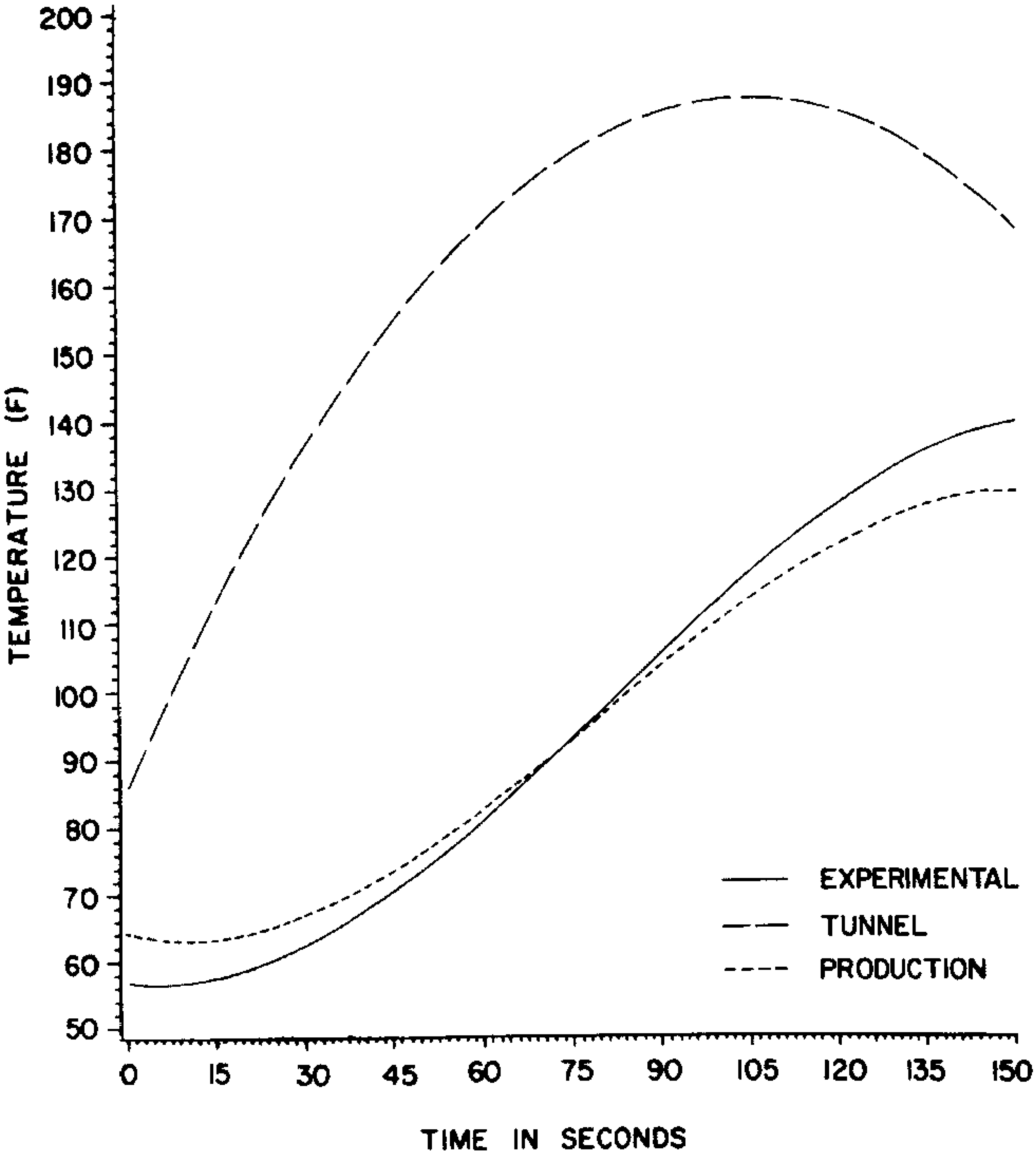



Figure 11. Prediction curves (Tunnel #2)

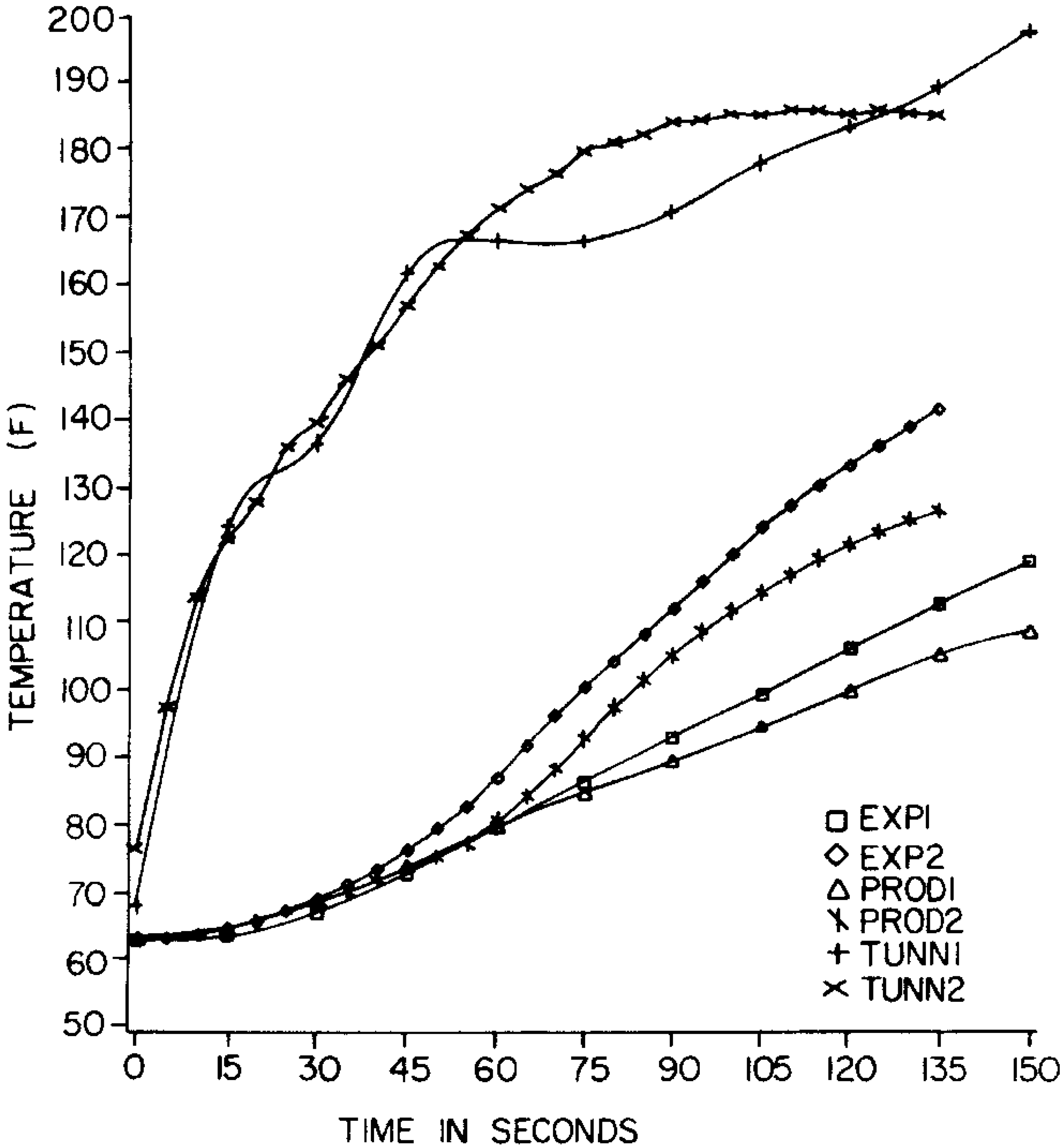



Figure 12. Plot of average tunnel and meat temperatures at same starting temperatures for tunnel #1 and tunnel #2

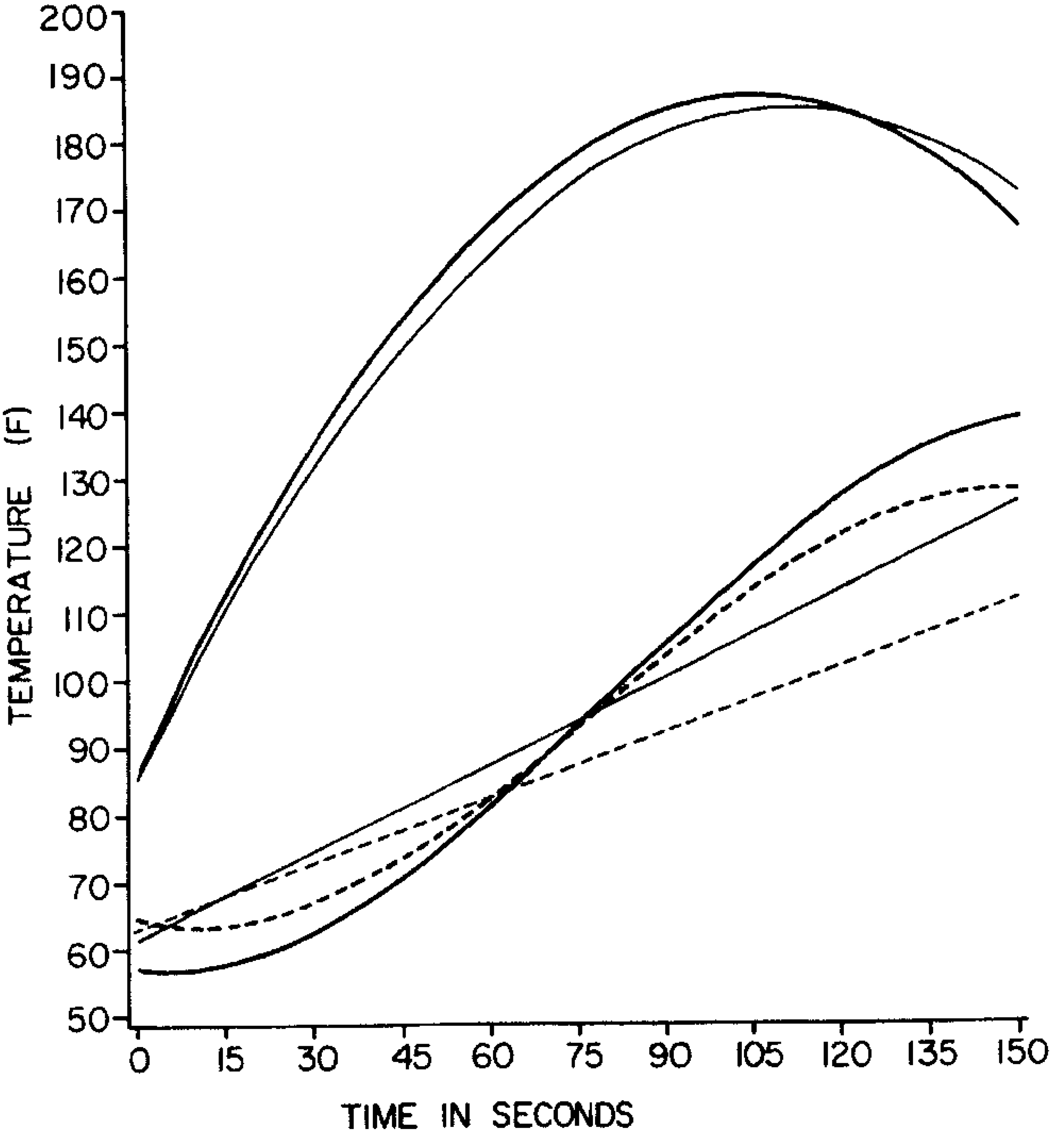



Figure 13. Prediction curves at actual starting temperatures for tunnel #1 and tunnel #2

temperatures in tunnel #1 (Fig. VIII-5). This is expected since surrounding oysters in the production tests prevent the higher heat transfer possible in the experimental tests.

In tunnel #2 the experimental meat temperature curve is initially lower than the production meat temperature curve (Fig. VIII-10). By comparing starting temperatures in Figure VIII-10 it can be seen that the experimental oysters are approximately $6^{\circ}$ F colder than the production oysters, accounting for this discrepancy. Upon heating the oysters, the experimental temperature moves rapidly upward and finishes higher than the production temperature.

h. Oysters in tunnel #1 versus oysters in tunnel #2

Oysters in tunnel #2 leave the tunnel at higher temperatures than those in tunnel #1. The characteristic wave in the meat temperature curve of tunnel #2 (Fig. VIII-13) shows the effect of supplying steam near the mid section. If steam had been supplied near the entrance, the sharp increase in meat temperature near the mid section would be more uniformly spread across the travel time, appearing similar to the linear relationship of tunnel #1.

5. Heat Transfer Efficiency

In order to provide a general indication of the heat transfer (H.T.) efficiency of each tunnel, an expression based on the ratio of the area under the modified meat temperature curve to the area under the tunnel air temperature curve is used. This ratio represents the percentage of available tunnel heat effectively penetrating the oyster and heating the inside meat. The relationship is expressed as:

$$\text{H. T. Efficiency} = \frac{\int_a^b (\text{Oyster Meat Temperature})dx}{\int_a^b (\text{Tunnel Air Temperature})dx}$$

Where dx represents the incremental change in oyster travel time through the tunnel, and a and b refer to the beginning and ending of the oyster travel time. For tunnel #1 the travel time is 150 seconds and for tunnel #2 it is 135 seconds. The base temperature of 62.38° F is subtracted from both the oyster meat and tunnel air temperature equations.

a. Tunnel #1

1) H. T. efficiency (production) =

$$\frac{100 \int_0^{150} (.321x)dx}{\int_0^{150} (25.6 + 1.586x - .0062x^2)dx} = 24.55\%$$

2) H. T. efficiency (experimental) =

$$\frac{100 \int_0^{150} (.398x)dx}{\int_0^{150} (25.6 + 1.586x - .0062x^2)dx} = 30.44$$

b. Tunnel #2

1) H. T. efficiency (production) =

$$\frac{100 \int_0^{135} (-.2353x + .012x^2 - .00005x^3)dx}{\int_0^{135} (28.07 + 1.855x - .0088x^2)dx} = 26.31\%$$

2) H. T. efficiency (experimental) =

$$\frac{100 \int_0^{135} (-.1369x + .0119x^2 - .000049x^3)dx}{\int_0^{135} (28.07 + 1.855x - .0088x^3)dx} = 32.97\%$$

6. Tunnel Travel Time

Research has indicated that the oyster meat temperature should not exceed 120° F to maintain optimum product quality. The time required to bring the oyster meat to 120° F is determined by using the meat temperature regression equations.

a. Tunnel #1

1) Production Time

$.321x + 62.38 = 120° F$

$x = 180 \text{ sec.} = 3.00 \text{ min.}$

2) Experimental Time

$.398x + 62.38 = 120° F$

$x = 145 \text{ sec.} = 2.42 \text{ min.}$

b. Tunnel #2

1) Production Time

$62.38 - .2353x + .012x^2 - .00005x^3 = 120° F$

$x = 117 \text{ sec.} = 1.95 \text{ min.}$

2) Experimental Time

$62.38 - .1369x + .0119x^2 - .000049x^3 = 120° F$

$x = 102 \text{ sec.} = 1.70 \text{ min.}$

The tunnel travel times calculated from the regression equations are longer than the time calculated by Mashburn (see section V). Since the tunnel travel time calculated by Mashburn (1.66 min.) is based on a constant temperature difference of 130° F (180° F - 50° F) between meat and tunnel temperature, the heat penetration rate of 289 BTU/hr does not account for the changing temperature difference between the tunnel and oyster meat. In reality, as the regression curves demonstrate, the heat flow is constantly changing since this temperature difference is continually changing. Thus, 289 BTU/hr is expected to be too high since a constant 130° F temperature difference between oysters and tunnel will not be achieved under normal operation procedures.

7. Average Heat Penetration Rate and Thermal Conductance of Oysters

With the conveyor system, the number of oyster layers on the conveyor belt affects the heat penetration and thermal conductance of the oysters. Oysters stacked several layers deep will tend to have a lower heat penetration rate and thermal conductance than oysters stacked in a single layer. In order to observe this variation due to layering, an average heat penetration rate and thermal conductance are calculated for both production (multi-layer) and experimental (single layer) tests.

Although the heat penetration rate changes in response to changing temperature conditions between the tunnel and oyster, an average rate can be expressed from the following equation:

$$q \text{ average} = \frac{1}{a} \int_0^a AC\,(T_1 - T_2)\,dx \quad \text{where,}$$

q average = average heat penetration rate (BTU/hr)

A = surface area of oyster = 10 $in^2$ (.0694 $ft^2$)

C = thermal conductance (BTU/hr · $ft^2$ · °F)

$T_2$ = modified meat temperature equation (°F)

$T_1$ = tunnel air temperature equation (°F)

a = time in tunnel (sec)

In order to solve for C, another expression for q average is necessary. Since 8 BTU is required to bring oyster meat from 50° F to 120° F and the tunnel travel time to heat oyster meat to 120° F has previously been calculated (see section V), q average can be expressed as,

$$q \text{ average} = \frac{8 \text{ BTU}}{\text{time required to heat to } 120° \text{ F}}$$

Solving for q average and substituting it into the original equation, C can be determined. Thus,

$$C = \frac{q \text{ average}}{\frac{1}{a} \int_0^a A\,(T_1 - T_2)\,dx}$$

a. Tunnel #1

1) Production oysters

$$q \text{ average} = \frac{8 \text{ BTU}}{3.00 \text{ min.}} \times \frac{60 \text{ min.}}{\text{hr}} = 160.00 \text{ BTU/hr}$$

$$C = \frac{160.00 \text{ BTU/hr}}{\frac{.0694 \text{ ft}^2}{180} \int_0^{180} (25.6 + 1.256x - .0062x^2)dx, \ ^\circ F}$$

$$C = 31.80 \text{ BTU/hr} \cdot \text{ft}^2 \cdot {}^\circ F$$

2) Experimental oysters

$$q \text{ average} = \frac{8 \text{ BTU}}{2.42 \text{ min.}} \times \frac{60 \text{ min.}}{\text{hr}} = 198.35 \text{ BTU/hr}$$

$$C = \frac{198.35 \text{ BTU/hr}}{\frac{.0694 \text{ ft}^2}{145} \int_0^{145} (25.6 + 1.188x - .0062x^2)dx, \ ^\circ F}$$

$$C = 41.86 \text{ BTU/hr} \cdot \text{ft}^2 \cdot {}^\circ F$$

b. Tunnel #2

1) Production Oysters

$$q \text{ average} = \frac{8 \text{ BTU}}{1.95 \text{ min.}} \times \frac{60 \text{ min.}}{\text{hr}} = 246.15 \text{ BTU/hr}$$

$$C = \frac{246.15 \text{ BTU/hr}}{\frac{.0694 \text{ ft}^2}{117} \int_0^{117} (28.07 + 2.09x - .0208x^2 + .00005x^3)dx, \ ^\circ F}$$

$$C = 47.01 \text{ BTU/hr} \cdot \text{ft}^2 \cdot {}^\circ F$$

2) Experimental Oysters

$$q \text{ average} = \frac{8 \text{ BTU}}{1.70 \text{ min.}} \times \frac{60 \text{ min.}}{\text{hr}} = 282.35 \text{ BTU/hr}$$

$$C = \frac{282.35 \text{ BTU/hr}}{\frac{.0694 \text{ ft}^2}{102} \int_0^{102} (28.07 + 1.992x - .0207x^2 + .000049x^3)dx, \ ^\circ F}$$

$$C = 57.40 \text{ BTU/hr} \cdot \text{ft}^2 \cdot {}^\circ F$$

Table 3. COMPARISON CHART

| | Tunnel #1 | | Tunnel #2 | |
|---|---|---|---|---|
| | Production | Experimental | Production | Experimental |
| Heat transfer efficiency (%) | 24.55 | 30.44 | 26.31 | 32.97 |
| Time to heat meat to 120° F (min.) | 3.00 | 2.42 | 1.95 | 1.70 |
| Heat penetration rate through oysters (BTU/hr) | 160.00 | 193.35 | 246.15 | 282.35 |
| Conductance through oysters (BTU/hr · $ft^2$ · °F) | 31.80 | 41.86 | 47.01 | 57.40 |

8. Comparison of Tunnels

Table 3 shows a comparison of both tunnels. Comparing production and experimental results of each tunnel, oysters heat more rapidly in tunnel #2 compared to tunnel #1 and consequently require less steaming time. Also the heat penetration rate and thermal conductance values are significantly higher in tunnel #2. These higher values indicate the greater capability of tunnel #2 to handle larger volumes of oysters in a given time period or to steam a given quantity of oysters more rapidly.

The heat transfer efficiencies of both tunnels are similar. However, by introducing the steam supply at the entrance of tunnel #2, the heat transfer efficiency would be expected to improve since oysters would be exposed to a given quantity of steam for a longer time period. This would also decrease the required tunnel travel time and increase the heat penetration rate and thermal conductance of the oysters.

9. Design and Operation Considerations

The following design and operation considerations are suggested in order to maximize the steam tunnel performance. These suggestions will improve the efficiency of the steaming process by increasing heat transfer between the tunnel and oysters.

a. Design Considerations

1) Locate the steam supply near the entrance of the tunnel.

2) Steam oysters from bottom and top. Steam pipes running above and beneath the conveyor belt could be supplied with steam from two headers, one above and the other beneath the belt.

3) Enclose and insulate the tunnel on all sides. Also insulate

all exterior steam lines.

4) Use flexible heat barriers made from rubber or plastic. If necessary, use several at each end to prevent excessive amounts of steam from escaping the tunnel.

5) Incline tunnel to allow steam to move slowly to exit end. Do not incline more than necessary. A 4° to 5° angle should be sufficient.

6) Correctly size exhaust fan. An oversized fan will draw steam from the tunnel and an undersized fan will not vent steam adequately.

7) As an alternative to venting steam, use this waste steam to preheat oysters prior to steaming.

b. Operation Considerations

1) Wash oysters before steaming. Mud and debris on the oysters reduce the heat transfer between the tunnel and oysters.

2) Maintain a minimum oyster layer thickness on the conveyor belt.

3) If oysters are consistently oversteamed, lower the tunnel air temperature rather than increase the conveyor belt speed. If oysters are consistently understeamed, decrease the conveyor belt speed rather than increase the tunnel air temperature.

4) Periodically disconnect and check tunnel temperature gauges. Replace if the condition or accuracy of the gauge is questionable.

## E. SUMMARY

The following items were accomplished in this study:

1. Data from two Virginia oyster steam tunnels were compiled and used to calculate tunnel air temperature and oyster meat temperature prediction equations for multilayer and single layer oysters on a conveyor belt.
2. A method was developed to determine the heat transfer capability of the oyster steam tunnel by calculating:
   a. heat transfer efficiency between tunnel and oysters,
   b. time needed to reach a 120° F meat temperature,
   c. heat penetration rate of oysters,
   d. thermal conductance of oysters.
3. Both steam tunnels were compared based on their heat transfer capabilities.
4. Design and operation procedures were suggested to improve the heat transfer capability of the steam tunnel.

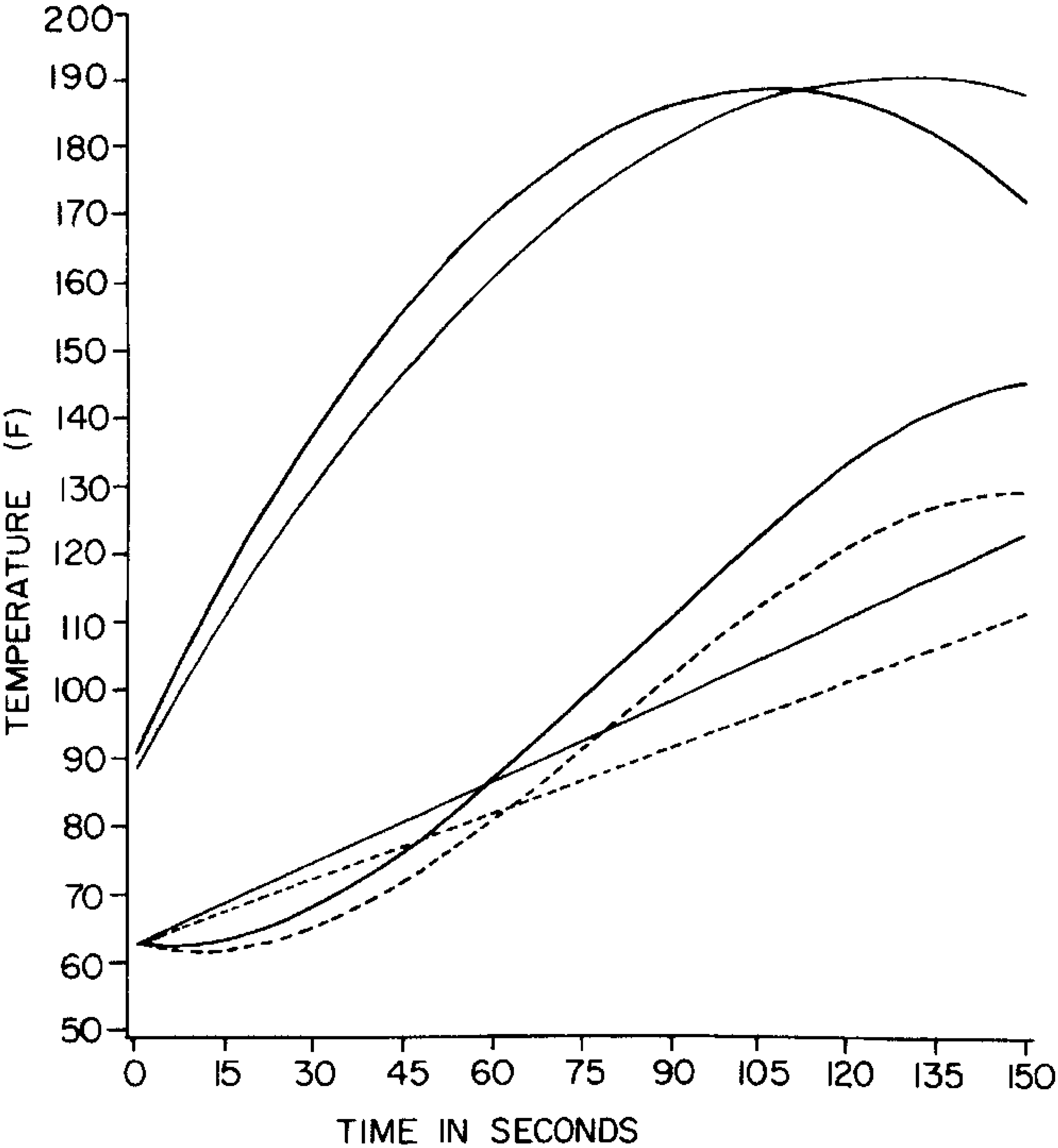



Figure 14. Prediction curves at same starting temperature for tunnel #1 and tunnel #2

## REFERENCES

1. Mashburn, W. H. 1980. Equipment and design in: Engineering and Economics of the Oyster Steam Shucking Process. Department of Food Science and Technology, Seafood Processing Research and Extension Unit, VPI & SU.

## Comments from the Industry

### A. Bill Morgan

The first efforts of steam shocking were done by J. W. "Buster" Ferguson. The method was originally started to increase production. The tunnel by J. W. Ferguson was built as inexpensively as possible because it was an experimental model. Having great success with this apparatus and after many alterations, he later built a more permanent and more sanitary model of stainless steel.

W. F. Morgan & Sons, Inc. built an aluminum model about three months after Ferguson's first tunnel. This one was intended to be permanent so considerable cost was involved. With a new high pressure boiler and all other equipment, the cost came to $18,000. The next venture of this type was a conveyor belt system by Tommy Shackleford.

Both the Ferguson and Morgan tunnels have baskets on a track system running through the tunnel. The belt system by Shackleford has a mesh belt which allows a more even steam heat to penetrate the oysters. The only drawback in this type of system is the assembly line of employees. The employees standing closest to the tunnel will have first pick of the largest and most open oysters, leaving the smaller oysters for shuckers at the end of the line.

In each case, however, production was increased by as much as 35%. There are many factors involved with this operation with which we are still unfamiliar. Absorption of the oyster liquor is one of these factors. The oyster upon being heated has a tendency to absorb its own liquor in the shell. This gives the oyster a much better flavor.

We also know that there is less yield after blowing steamed oysters than with conventionally shucked oysters. There are many unknowns involved in modernizing a food processing industry and we wish to involve as many agencies and universities as we can to help. Hopefully the steam shock method will be the first step in the development of automatic shucking machinery.

We in the industry would like to thank Frank Huang and the rest of the VPI team for their help and support in our efforts to promote our industry.

## B. J. W. Ferguson

I have been given an opportunity to make a few remarks for this workshop put together by the Virginia Tech Sea Grant Advisory Program and the National Fisheries Institute. My name is J. W. Ferguson, Sr., and I am associated with the J. W. Ferguson Seafood Co., Inc., at Remlik, Virginia. In 1974 I became concerned about the oyster processing industry and began looking for some way out of the problem facing the industry. The industry was facing a very serious problem with minimum wage and inflation. People were leaving the industry and going to better paying jobs, and we couldn't blame them. Because of the increase in the cost of living, they could not make it on their present salary.

I had looked at all kinds of devices to try to shuck oysters, but had found none that were practical. Because of the size and shape of the oyster, there was nothing that would do the job commercially. It was then that I began to explore the use of a steam tunnel. I would like to say at this point that I appreciate the cooperation given me by Mr. Cloyde Wiley and the Virginia Health Department. In the summer of 1977, I built a steam tunnel with the help of my employees. This tunnel was only 17 feet long and triangular shape with a monorail conveyor. The tunnel was built so the conveyor would pass through the center of the tunnel. We used this tunnel for two years and in the summer of 1979 we built a new tunnel.

The new tunnel is made of stainless steel and is round, 20 foot long, 30 inches in diameter. It is also covered on the outside with three-inch-thick insulation. We maintain the temperature of 185-190°F (85-88°C) in the center and a 170-175° (77-79°C) at each end. We are using a 20 Hp high pressure Columbian boiler. The conveyor drive has an adjustable motor, and we set the speed so the oyster will stay in the tunnel for two minutes. If the oysters are large and the shell thick, we expose them to steam for two and a half minutes.

When the oyster meats are taken out of the shell, they are dropped into ice and ice water, until they are received at the skimmer window. I can't say this process will keep red oysters off the market, but I can say we haven't had any trouble with oysters we have shucked using the steam tunnel in the past three years. VPI has made evaluations of the temperature inside the tunnel, and I believe that the oyster meat temperature ranges from 110 to 120°F (43 to 49°C) when it leaves the tunnel.

Now I want to talk about the economics of shucking oysters. First, we had the cost of oil for the boiler and the cost of the tunnel, but we increased our production by about 35%. It meant that our overhead cost per gallon was sufficiently reduced to offset the cost of the tunnel and oil. Here I'd like to say that the extra oysters that we are shucking with the tunnel reduced the overhead cost to only $1.02 per gallon. Normally the overhead on shucked oysters is about $1.25 per gallon. You can see that the increased production has lowered the overhead cost per gallon. We were shucking 300 gallons per day previously, and now we are shucking 400 gallons per day. Our payroll for shuckers has increased from $975 to $1,500 per day. Our employees who were earning $20 per day now earn $28-30 per day. Some shuckers make as much as $50 for a 7½-hour day. Now we can meet pretty much the minimum wage which is $3.10 an hour. Our employees are making up to $6.00 an hour.

I was the first to build a steam tunnel and while I was building the tunnel, I tried to encourage others in the industry to try the same, knowing the industry was in trouble and must try and find a way to decrease the cost of shucking oysters, and increase the volume of production, because the more volume you have, the less cost per unit.

QUESTION: According to your experience, are oysters of poor quality more affected by the treatment of steam than the fatter oysters as far as yield and the final product quality are concerned?

ANSWER: When oysters are poor and only produce 4½ pints or less per bushel, there is nothing you can do to improve the quality once they are shucked. However, I don't find poor quality oysters to be of poorer quality once they have been steam treated.

QUESTION: What is the regular yield for the regular oyster?

ANSWER: Oysters that are shucking fair-to-good would yield from 5½ to 7½ pints per bushel.

QUESTION: Why did you change from a galvanized wire-mesh basket to a stainless steel one?

ANSWER: I recommend using stainless steel for the baskets because it is hard to keep galvanized baskets clean, for the steam corrodes galvanized ones.

QUESTION: How do your workers make out on their wages with steam shucking?

ANSWER: We are paying $3.25/gallon by weight, the same price per gallon as without the steam treatment, and the shuckers are earning about 35% more per 7½ hour day. For example, some shuckers have been working for us for over 25 years and their average pay was from $17 to $20 per day. With the steam treatment their average pay is from $28 to $32/day. All this is because it is much easier to get the knife into the oyster after the steam treatment.

QUESTION: Does that mean that it is easier to train the workers?

ANSWER: Yes, you can take a person who has never shucked an oyster, and within two weeks, he can make the average of what the house is making.

QUESTION: What kind of insulation do you use in your tunnel?

ANSWER: Polyurethane, 3 inches thick, and the insulation for the whole tunnel and the ends costs about $500.

QUESTION: How about the exhaust system, do you have some kind of system in the tunnel to take care of high humidity and the steam that escapes from the tunnel?

ANSWER: We are using a 20-foot stainless steel tunnel round in shape and 30 inches in diameter, with a hood at each end which is raised about 16 inches above the tunnel to trap excess steam and exhaust steam.

QUESTION: You don't experience any problem with high humidity in the shucking area?

ANSWER: No, we don't, because we are exhausting just about all of the steam and the heat with exhaust fans to the outside of the building.

QUESTION: Does the boiler that you are using have the proper capacity for the operation? What would you recommend?

ANSWER: I would recommend boilers with no less than a 20 Hp capacity, although I don't use my boiler for anything else but the steam tunnel. If you are using the boiler for anything else like heating the building, then you need a larger boiler. A 20 Hp boiler will suffice if it is only going to be used for the steam tunnel.

QUESTION: How many shuckers can the tunnel serve?

ANSWER: Up to 50 shuckers without any problem. If you add more shuckers, then you have to have a longer tunnel. If you want to increase the number of shuckers to 70, I recommend at least a 30-foot tunnel, so that the speed would be increased by a third but the oysters would be exposed to the steam for the same length of time.

QUESTION: What is your estimate for the total cost of the tunnel?

ANSWER: The complete cost shouldn't be over $5,000. I used my own men to install the tunnel; I had it built away from the plant; I bought stainless steel sheets wholesale and had them welded together. It is a good heavy gauge, though I don't know the exact gauge. I can get the information easily and have it available. The sheets were 4 x 10 ft and were rolled, spotwelded and then welded together to make a 20-ft round cylinder. That cost $2,000 and $500 for the insulation. My investment was about $2,500, but I did a lot of the work with my own crew.

QUESTION: How is your fuel cost after starting steam shucking operations as compared to before?

ANSWER: For a 5-day week we are using about $160 worth of fuel, but I feel that the extra production of 500 gallons per week, with the same manpower and the same equipment and building, cuts the cost. Normally the overhead cost per gallon is $1.25, but these 500 extra gallons that we are shucking with the steam treatment are only costing an overhead of about 32¢, so I think it is a good investment.

QUESTION: You already had the boiler and the monorail in your plant before using the steam shucking process?

ANSWER: We have been using the monorail for about 18 years. We built the tunnel around the monorail conveyor, so that the conveyor goes right through the tunnel. If I were building a new plant, I would probably have different ideas about how to steam treat the oysters. For instance, you would conserve your steam by using a flat belt conveyor to run the oysters through the tunnel, because the opening would be much smaller. After oysters come out of the tunnel, you can distribute them to the shuckers in any fashion you want to.

QUESTION: Does the origin of the shell-stock affect the heating time and the quality of the product?

ANSWER: No, I haven't found it so. We shucked some oysters all the way from Texas to Delaware, and some of the oysters have a thick shell, so you slow your belt down to keep them in the tunnel longer. And you run thin shell oysters through faster. I found 2 to 2½ minutes will take care of any oyster you run across in an operation.

QUESTION: So you do vary your heating time according to the size or thickness of the shell of the oysters?

ANSWER: Yes, if you don't give them enough steam, they are going to be hard to open. But you can't afford to give them too much steam, so you'd better be on a minimum side instead of on a maximum side. Otherwise you will dehydrate the oysters and you come up a loser. We never allow the oysters to go through the tunnel more than once.

QUESTION: How does the shelf-life of a steam shucked oyster compare to a regular shucked oyster?

ANSWER: Shelf-life of the steam shucked oyster is longer by at least 7 days.

QUESTION: Is there any quality improvement on the steam shucked product?

ANSWER: We found the quality has improved in taste and in color. You have a more standard color and an improved taste. We haven't had any problem with red or pink oysters.

QUESTION: Do you think it is better to use steam shucked oysters for a breaded product and why?

ANSWER: We have been breading oysters for 20 years and learned a lot about the right kind of oysters to use. An oyster that is firm and solid handles a lot better in the breading operation, and we find that the steam treatment does not tear the oyster as badly as regular shucking. Because of the steam treatment, the shucker doesn't have to dig in the knife and the meat does not get damaged, and it is a lot more plump.

QUESTION: What about cleaning the steam tunnel?

ANSWER: We have a rig attached to the side of the tunnel which uses high pressure water. And we use a detergent and a sanitizer. We rinse it down thoroughly first, then use the detergent and the sanitizer, wash it well and then rinse it again with water.

QUESTION: What are the workers' opinions about the steam tunnel?

ANSWER: We have more shuckers now than we had before we installed the steam tunnel. We find that younger people are more interested now. We have some young people in the plant just out of school. They came here and are doing quite well. It usually takes them about a week to ten days to learn how to shuck if they never had any experience with shucking oysters. After 10 days they increase their pay about one dollar a day. They normally start out making $10 a day, and after a week they get $12 to $14 a day, and thereafter up to $25 a day. From then on, it depends on how hard they want to make more money.

Cloyde Wiley's Comment:

I would like to relate an incident that occurred several years ago regarding the steam tunnel oyster processing system in the state of Virginia. While visiting the J. W. Ferguson plant in Remlik, Virginia, in the late summer of 1977, Captain Buster explained to me his ideas for developing the system utilizing steam for the opening of oysters. He went into great detail explaining his ideas and how he intended to construct a tunnel system in order to make the shucking of oysters easier and thereby increase the capability of non-experienced or less-experienced workers. Captain Buster stated he had been thinking about utilizing steam for this purpose for a long time and would like to construct a system in his plant to give a trial. After much discussion we concluded that it seemed like a good idea and that the State Health Department would work with him in trying to develop such a system.

Later I asked Captain Buster if he planned to patent his idea or charge a royalty for this system, should it be successful. Captain Buster thought a minute and replied: "No, if the system works, I don't want any reward for whatever I am able to contribute to the seafood industry. If the system is successful, I would like to see the shellfish industry use it to its fullest capability. If it is of any benefit to the industry, or helps foster it in any way and will help keep it viable and alive, then that will be reward enough." Consequently, I consider Mr. Ferguson the father of the steam tunnel oyster processing system in the state of Virginia. I think we all owe him a debt of gratitude for his contribution to the industry. I recommend that we give him a round of applause to express our appreciation for what he has contributed to this industry......

J. W. Ferguson's Response:

Mr. Cloyde Wiley, the Director of the Shellfish Sanitation Department, and his department have worked with us on the steam shucking processing of oysters, and his comments were very encouraging. I would like to say that I appreciate the nice things that Mr. Wiley said about me with reference to the steam tunnel and the possibility of maybe having it patented. I didn't have any desire to capitalize on something that I felt I owed the industry. The oyster industry has been very good to me. I began working with oysters when I was only 18 years old, and now, I am past 72 and have been working with oysters just about all the time. I have managed to raise a family and buy a home and have a little money in the bank. So I feel that the very least I could do is to contribute something to the industry that may be helpful in the years to come. The industry needs contributions of this type and I have been more than happy to give it. I would like to say further that, if people desire any information from my experience or about the tunnel that I am using, then I would be happy to invite them to come in and take a look. And I will try to help them in any way that I can, answering any questions that they may have.

C. Tommy Shackelford

Basically the reason we started our steam tunnel is that, at the time, we were producing a lot of shell oysters in this area and we did not have experienced shuckers for that kind of oysters. Shell oysters were not uniform in size, shape or otherwise. Then we learned that, in Carolina, they used heat to open the oysters partially to make them easier to shuck. In Carolina they use a hot water bath, so we looked at first for a hot water bath for our plant. But the Health Department frowned on hot water baths, so we had to look for another method, which was steam. We did not have anything to start with, such as an overhead dolly system that a lot of other oyster plants already had. We started from scratch.

By trial and error, we settled on steam and the conveyor method. We like it because it is a clean method approved by the Health Department. As for the labor problem, out of the 24 shuckers that I now have, only about 12 had been shuckers before. We did not have skilled oyster shuckers in this area to run a fresh oyster shucking plant. Most of my shuckers are young mothers who start at 7:30 in the morning which gives them time to get the children ready for school. And they quit at 2:30 so that they are home before the children return. This steam method was ideal for us, because there is no machine available that will shuck oysters.

The conveyor we use was converted from an old one used to run clams on. I will eventually replace this old conveyor with a new stainless steel one. I will make a lot of modifications on the system because I have gained more knowledge thanks to the studies done by Virginia Tech scientists. These studies show that the tunnel could be smaller and the steam could be injected at a different area than where I have it now, to make it more efficient. The tunnel should be insulated, which would be a great help. All in all there are various things that can be done to improve the present system. My advice for anyone starting out is not to make their tunnel like mine but to go with the modifications and suggestions of the people that did the studies on steam tunnels.

At the beginning of our adventure with the steam tunnel, we ran into a problem: the shuckers at the beginning of the line would take the larger oysters and leave the smaller ones for the shuckers further down the line. We eliminated this problem by putting a man on the line to rake the oysters to the shuckers. That way they shuck what is put in front of them, and they have no choice as to size and shape.

## Discussion and Evaluation

Roy E. Martin

Steam shocking of oysters for faster and easier shucking holds great promise for the oyster industry. But in order for this new method to be thoroughly efficient and widely accepted, more research needs to be done. Some of the questions that must be answered in the future are:

1. Once the oysters are steam-treated, how long can you hold them before the adductor muscles begin to tighten up again?
2. What is the minimum internal temperature of the oyster for its muscle relaxation to occur?
3. What are the bacterial levels of the mud prior to heating?
4. Investigations should be evaluated with regard to seasonal variabilities.
5. Comparison of bacterial counts of hand-shucked oysters and those of steam-shucked oysters.
6. Microbiological speciation to determine bacterial populations.
7. Design the system to reduce foreign matter loading before the entrance to the tunnel.
8. What effect does high temperature have on the viruses?
9. Need for a better definition of what is considered raw and cooked oysters.
10. When oysters are considered poor, what happens to product yield?

This work was sponsored by the Office of Sea Grant, NOAA, U. S. Department of Commerce, under Grant No. NA81AA-D-00025 and the Virginia Sea Grant Program. The U. S. Government is authorized to produce and distribute reprints for governmental purposes, notwithstanding any copyright that may appear hereon.

Virginia Tech does not discriminate against employees, students, or applicants on the basis of race, sex, handicap, age veteran status, national origin, religion, or political affiliation. Anyone having questions concerning discrimination should contact the Equal Employment/ Affirmative Action Office.