# AN INTERACTIVE FISH FREEZING MODEL COMPARED WITH COMMERCIAL EXPERIENCE

by Edward Kolbe

Departments of Bioresource Engineering and Food Science and Technology
Oregon State University

## 1. INTRODUCTION AND OBJECTIVES

The U.S. west coast seafood industry has seen substantial growth in recent years, as processing capability has rapidly developed to handle the off-shore catch once taken by foreign fleets. New technology is being developed and imported to utilize the vast quantities of pollock, cod, arrowtooth flounder, salmon, and others in Alaska, and Pacific whiting in the lower U.S. west coast states. Much of this processed catch is frozen. At the same time, a growing number of processors, many of them small fish plants or aquaculture enterprises, seek to develop specialized “value added” products from traditional species that were once landed and shipped with minimum processing and handling. Many of these new products are also frozen.

The process of freezing has an important influence on product quality and plant efficiency. Products must be left in the freezer long enough for the core temperature to approach that of the storage or shipment container. On the other hand, excessive freeze time wastes energy, slows production rate, risks excessive dehydration, and possibly diminishes quality due to low temperatures that will later increase in storage/ shipment /1,2/.

Processors and engineers need to know how a number of factors like product thickness, air velocities, or plate freezer suction pressures will influence freezing times. Research during the last ten years has produced some very useful analytical models which predict freezing times of food products. Examples include the work of Cleland and Earle /3,4/, Pham /5/ and many others. These closed form models present predictions that are within 10% when geometries and thermal properties are well described and boundary conditions are relatively constant /3/.

But industrial conditions are seldom so ideal, and industry personnel and technical advisors generally are not trained to recognize heat transfer coefficients and product thermal properties appropriate to the application of these models. An ongoing project in our food engineering Extension program has been to place analytical freezing models in a framework that will be useable by industry. Our objectives for this model are that it uses input information that a fish plan operator knows; reasonably predicts freezing times in the fish plant under a range of conditions; serves as an educational tool to highlight critical influences in the freezing process. This article describes the current status of this project.

## 2. MODEL DEVELOPMENT

The program is written in QuickBASIC (Version 4.5; Microsoft Corporation) as a series of modules, or sub-programs, which are carefully documented to allow continued upgrading by new programmers. The compiled program will run on any IBM compatible computer. When run, the operator is faced with a series of selections from on-screen menus, summarized by the following sections.

### Units

Either IP (inch-pound, or English units) or SI units can be selected.

### Program Task

Three options are currently open to the technical user. The first two present either a review of the thermal properties currently on file for a range of fish species, or allow an upgrade of data as new values become available. The third option is to compute freeze times.

### Process

The user selects the freezing process by air blast, brine, or plate. Air blast or brine requires knowledge of package configuration or shape (block, sphere, or finite cylinder) and appropriate dimensions needed to calculate shape factors used in the analytical model /3/. Currently, whole or H&G fish like cod or Pollock are treated as cylinders; flat fish as blocks. The program's calculation of a convection coefficient in brine freezing assumes normal flow over cylinders and uses an empirical equation of McAdams as reported by Mohsenin /6/:

$$Nu\text{-}Pr_{.33}[.35 + 0.56(Re)_{.52}]$$

where Nusselt (Nu) and Reynolds (Re) numbers are based on minimum product dimension. Convection coefficients in air blast result from empirical equations selected when the user chooses three different velocity options. Horizontal velocity over products on solid shelves calls for a linear relationship suggested by Pham /7/: $h = 4.0 + 6.8\,v$

where h = convection coefficient, W/mC
v = velocity, m/s

The cases of horizontal velocity and downward vertical velocity over products on wire belting use nondimensional relationships determined by Flores and Mascheroni /8/:

$$\mathrm{Nu} = 7.891\ \mathrm{Re}_{.}^{328}\ \text{(horizontal)}\quad \mathrm{Nu} = .326\ \mathrm{Re}_{.}^{640}\ \text{(vertical)}$$

where Nusselt and Reynolds numbers are based upon a minimum width (not thickness) of product lying on the belt.

Use of the plate freeze option requires the package to be in a block form. The program currently assumes saturated refrigerant (R-717, 502, or 22) flow in the plates. Heat sink temperature results from empirical equations for saturated refrigerants /9/ after the user identifies suction pressure (or vacuum) at the beginning and end of the approximate freeze period. An “effective” heat transfer coefficient,

$$h - 200 \frac{W}{m_{2}C}$$

has been assumed from experience and from previous guidelines /10/.

In all cases, the program will then calculate an overall heat transfer coefficient, U, which combines the resistance of the convection film with that of packaging materials and thicknesses input by the user. Material options currently include solid cardboard, corrugated cardboard, polyethylene film. in plate freezers, an extra 1 mm layer of cardboard is suggested to account for the insulation of voids found in certain packages like H&G fish. This procedure is related to that reported by Pham /7/.

**Species**

Menu options currently include cod, hake, salmon, tuna, dungeness crab, and pink shrimp, although specific property data for all of these is not yet in place. For each species, the program will consult a data file for the thermal properties required to calculate a freezing time. If it encounters none available for that property, it will assume a value or calculate the appropriate property from an assumed empirical relationship as follows:

1) Moisture content = 80% (wet basis)
2) Unfreezable moisture fraction = 15% (wet basis)
3) Specific heats of unfrozen and frozen tissue calculated by Siebers equations as reported by Toledo /11/
4) Initial freezing point = -2.2º C
5) Latent heat = 334 kJ/kg x (freezable moisture), where (freezable moisture) = (moisture content) - (unfreezable moisture)
6) Thermal conductivity of frozen product, from Sweat /12/
7) Total enthalpy change to -10º C, is calculated as a sum of latent heat plus sensible heat above and below the initial freeze point.

From experience, the user then enters an initial and final estimated medium temperature (or refrigerant pressure, in the case of plate freezers) and an estimated time constant indicating how rapidly the ambient condition is expected to fall. Freezing time then results from a summation of fractions as suggested by Loeffen et al. /13/ and Pham /14/.

## 3. MONITORING FREEZER PERFORMANCE

Our effort to monitor freezing times and existing commercial equipment performance has included plants in Oregon and Alaska. Kolbe and Cooper /15/ have described details of the Alaska experience in a recent contract report.

**Instrumentation**

Temperature monitoring equipment included two systems. The first, a series of thermocouples attached to a datalogger (Model 21Y, Campbell Scientific, Logan, UT)

which could be programmed to record and save readings in memory. The system, as described by Kolbe and Schnekenburger /16/ is housed in a heated insulated box which was typically placed inside a blast freezer or cold room to minimize the required length of wires and the risk of damage during routine plant operations. The logger was most suitable for stationary systems such as blast and manually-loaded plate freezers.
The second temperature monitoring system included small self-contained temperature recorders (Control-One Inc., Greenwich, CT). Each of these supported a single thermistor sensor mounted either internally or in an external probe which we built for these tests. Small in size (approximately 90 x 110 x 27 mm), these recorders are potted in epoxy and are therefore quite rugged. They could be programmed to record and save temperatures at a range of sampling rates; their portability made them most suitable to evaluate performance of spiral freezers and automatic plate freezers, and to record situations (such as fish glazing, case-up, and transport) in which product is moved from one operation to another.

Blast freezer performance is strongly dependent upon air velocity and its uniform distribution. A hot wire anemometer velocity probe (Model 1440, Kurz Instruments, Inc., Carmel Valley, CA) calibrated for low temperature enabled us to manually measure air velocities and distribution. The meter was packed in an insulated carrying case to maintain the proper operating temperature; an electronic damping feature enabled a slow response which tended to smooth the signal and avoid responses to high velocity turbulence. The “wire” in the probe was also quite rugged and proved suitable for industrial applications (Kolbe and Cooper /15/).

### Freeze Times

Sensors placed in the core (or estimated thermal center) of a variety of products recorded temperature vs-time. In a few cases, the sensors were not at the “last point to freeze” as evidenced by the shape of the freezing curves, and an estimate of actual freeze time was made from the plot.

## 4. RESULTS

Products tested in blast freezers included whole or H&G (headed and gutted) salmon, cod, pollock, and sole and blocks of rough-packed fillets. Tests in plate freezers included blocks of surimi, mince and roughpacked filets, and packages of H&G whiting. Spiral freezer tests included pollock fillets in the size range of 70-180 gms. In the airblast cases, the measured velocity was used in the calculations. Table I compares measured freezing times with those predicted by the program.

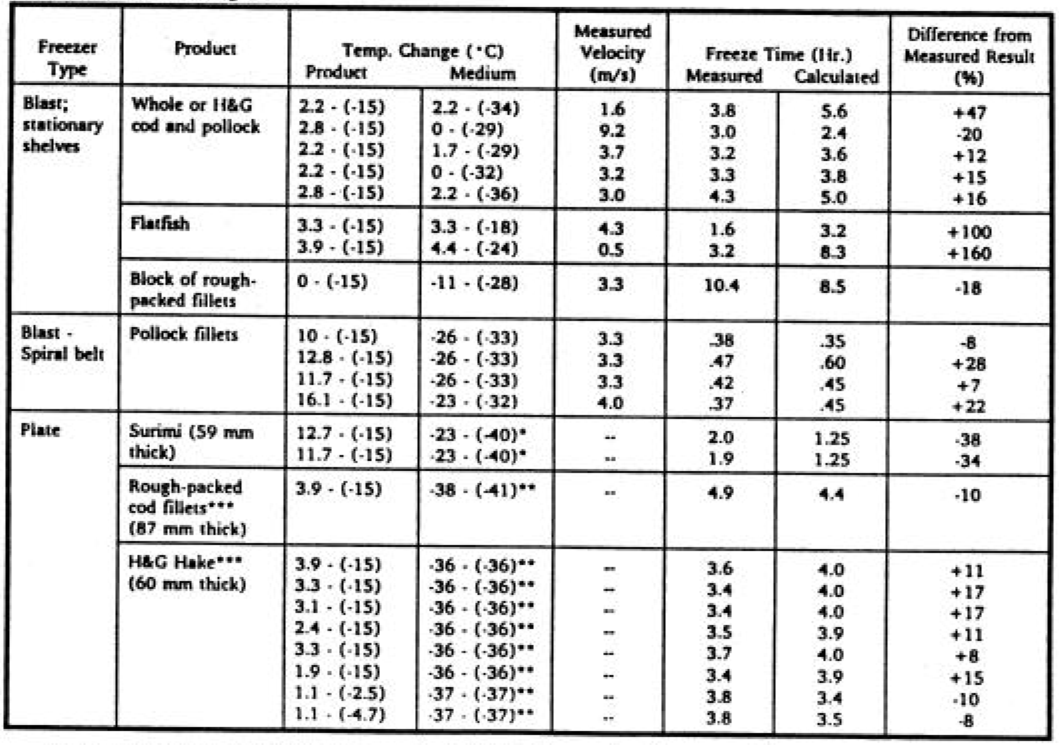
## 5. DISCUSSION

This paper describes progress toward developing a tool with which a seafood plant operator might evaluate factors influencing freezer performance. Such a general tool must handle a range of situations, thus it must also ignore, simplify, or generalize a number of input variables that prevent its accuracy from matching that found with controlled experiments. Such variables as local air velocities and temperatures, variation of convection coefficients over the product surface, shape factors describing actual whole fish, and others, cannot be accurately known or even measured under most industrial conditions.

The measurements shown in Table I included just those for which all relevant data was measured. With a few exceptions, it appears that an operator could have predicted freezing times roughly within 20%. Although no systematic sensitivity analysis has been done, experience indicates that the greatest uncertainty lies with calculation of a heat transfer coefficient, particularly with low Biot Number cases where surface film resistance controls. The blast frozen flatfish were laid directly on metal shelves in an area of highly variable flow velocities. Failure to consider the “fin effect” of the shelf, and the higher shape factor of a thin oval-shaped fish, both contributed to predications which greatly exceeded measurements. Two of the three plate freezer systems used old-style tube-in-sheet plates having also very uncertain surface coefficients.

Nevertheless, results indicate that the current program supplies a rough prediction of freezing times. It also supports evaluation of freezing time trade-offs against operating conditions such as medium temperature and variability, packaging material, and product shape and size. Development will continue to improve both the program’s accuracy and usefulness. Immediate next steps are to share the model with users who can direct changes to improve useability. Example changes will be to have the program select whole fish thickness from correlations with species and weight, upgrade shape factors for whole or H&G fish, add more messages to inform the operator. An example would be to report the effect on freezing time if air velocity is varied by 10% — a built-in “sensitivity” message. it appears that the new area of “expert systems” analysis would serve as a useful framework in which to place this
model.

Table I. Calculated Freezing Times



| Freezer Type | Product | Temp. Change (°C) Product | Medium | Measured Velocity (m/s) | Freeze Time (Hr.) Measured | Calculated | Difference from Measured Result (%) |
|---|---|---|---|---|---|---|---|
| Blast; stationary shelves | Whole or H&G cod and pollock | 2.2 - (-15) | 2.2 - (-34) | 1.6 | 3.8 | 5.6 | +47 |
| | | 2.8 - (-15) | 0 - (-29) | 9.2 | 3.0 | 2.4 | -20 |
| | | 2.2 - (-15) | 1.7 - (-29) | 3.7 | 3.2 | 3.6 | +12 |
| | | 2.2 - (-15) | 0 - (-32) | 3.2 | 3.3 | 3.8 | +15 |
| | | 2.8 - (-15) | 2.2 - (-36) | 3.0 | 4.3 | 5.0 | +16 |
| | Flatfish | 3.3 - (-15) | 3.3 - (-18) | 4.3 | 1.6 | 3.2 | +100 |
| | | 3.9 - (-15) | 4.4 - (-24) | 0.5 | 3.2 | 8.3 | +160 |
| | Block of rough-packed fillets | 0 - (-15) | -11 - (-28) | 3.3 | 10.4 | 8.5 | -18 |
| Blast - Spiral belt | Pollock fillets | 10 - (-15) | -26 - (-33) | 3.3 | .38 | .35 | -8 |
| | | 12.8 - (-15) | -26 - (-33) | 3.3 | .47 | .60 | +28 |
| | | 11.7 - (-15) | -26 - (-33) | 3.3 | .42 | .45 | +7 |
| | | 16.1 - (-15) | -23 - (-32) | 4.0 | .37 | .45 | +22 |
| Plate | Surimi (59 mm thick) | 12.7 - (-15) | -23 - (-40)* | -- | 2.0 | 1.25 | -38 |
| | | 11.7 - (-15) | -23 - (-40)* | -- | 1.9 | 1.25 | -34 |
| | Rough-packed cod fillets*** (87 mm thick) | 3.9 - (-15) | -38 - (-41)** | -- | 4.9 | 4.4 | -10 |
| | H&G Hake*** (60 mm thick) | 3.9 - (-15) | -36 - (-36)** | -- | 3.6 | 4.0 | +11 |
| | | 3.3 - (-15) | -36 - (-36)** | -- | 3.4 | 4.0 | +17 |
| | | 3.1 - (-15) | -36 - (-36)** | -- | 3.4 | 4.0 | +17 |
| | | 2.4 - (-15) | -36 - (-36)** | -- | 3.5 | 3.9 | +11 |
| | | 3.3 - (-15) | -36 - (-36)** | -- | 3.7 | 4.0 | +8 |
| | | 1.9 - (-15) | -36 - (-36)** | -- | 3.4 | 3.9 | +15 |
| | | 1.1 - (-2.5) | -37 - (-37)** | -- | 3.8 | 3.4 | -10 |
| | | 1.1 - (-4.7) | -37 - (-37)** | -- | 3.8 | 3.5 | -8 |

*Direct expansion (R-502); **Flooded ammonia (R-717); ***Assumed voids accounted for by 1 mm cardboard insulation.

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