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An Interactive Software to Simulate Thermal Processing of Foods*

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An interactive and graphics-oriented educational software was developed to assist in the teaching of thermal processing/sterilization of foods to food science students. The goal was to enhance the understanding of various parameters affecting the sterilization value. Critical thinking skills and problem-solving capabilities of students were also enhanced by simulating different scenarios as they would occur in the food manufacturing industry. The features of the software include data analysis, process simulation, and problem solving.

INTRODUCTION

FOOD processing extends the shelf-life of food products and ensures that the supply of food is sufficient, safe, and economically and nutritionally adequate. It also makes it possible to transport food to remote locations and to store it for long periods of time, and it makes a variety of foods available all through the year [1]. This provides an economical advantage and adds value to the product in the form of convenience for the consumer.

Thermal processing refers to the use of heat to preserve food products, and it is one of the most widely used preservation methods [2]. Heat destroys microorganisms and inactivates enzymes, and thus prevents food spoilage and health hazards caused by chemical changes and by microbial activity under normal storage conditions. A well-designed thermal process should also minimize the loss of nutrients by avoiding overheating of the food product.

Various degrees of food preservation can be attained by the use of heat. Blanching is used to inactivate natural food enzymes and is the mildest form of heat treatment, followed by pasteurization, where pathogenic microorganisms are destroyed. Commercial sterilization is a more severe heat treatment and refers to destruction of all pathogenic and toxin-forming microorganisms and other organisms that would grow under normal handling and storage conditions. Commercial sterilization is commonly referred to as canning in the food industry. Sterilization, or complete destruction of all microorganisms, is rarely used in the food industry, but is popular in the pharmaceutical and medical industry.

Food engineering is the application of engineering principles to processing and manufacture of food products. The Undergraduate Curriculum Minimum Standards adopted by the Institute of Food Technologists (IFT), USA, requires all food science curricula to include one course in principles of food engineering [3]. This introductory-level course includes fluid flow and heat transfer. However, in many instances students need more help in applying engineering principles to food-processing applications. Food engineering has been recognized by the IFT as one of the six food science research priorities for the 21st century [4].

A good understanding of thermal processing requires familiarity with food engineering (unsteady state heat transfer, numerical methods), microbiology (thermobacteriology and microbial destruction kinetics), and biochemistry (nutrient degradation reactions). Thermal processing instruction in a food science curriculum presents some challenges because of its interdisciplinary nature and its emphasis on food engineering.

A survey conducted in 1990 by the committee on education of the IFT found that only 65% of the respondents were pleased with the education received in engineering courses by food science undergraduates [5]. Instructors find it difficult to teach engineering related courses to food science students, in part because of students' limited background [6] and interest [5]. Thompson [7] identified the objectives of food engineering courses as to help students to develop logical problem-solving abilities, communicate intelligently with engineers, and to develop a basic knowledge of food-processing equipment and processes.

In many cases, students gather new information from lectures and readings, but this knowledge is not used spontaneously in the appropriate situations. Such information can be recalled if a student is specifically asked to do so, but it is inert or passive otherwise. To avoid this problem, it has been recommended that new information be acquired in the context of meaningful activities. When new knowledge is learned by solving actual

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problems or through case studies, it is perceived as a new tool rather than an arbitrary set of procedures [8].

In order to enable students to use the theoretical knowledge of thermal processing to solve problems in the food industry, they must be exposed to realistic problem-solving situations in class. This is best achieved with pilot plant experiments, which allow the students to observe the effect of different processing parameters on the thermal process delivered to the food product. These experiments, however, are very time consuming and only a limited number of parameters can be varied in a reasonable amount of time. Also, much time is needed to process the data obtained from such experiments before meaningful information can be extracted from them. It would be very useful for students to observe a wide set of situations within a short period of time.

Computer technology has been successfully used to teach students in many areas. Computer simulations expose students to a learning environment which presents information in a way that facilitates their future use in real situations [8]. A survey conducted in 1981 found that computers were underutilized in food science education [9]. An effort has been made in the last decade to improve the usage of computers in food science departments [6, 10, 11]. Computer literacy is still highlighted by the education committee of the IFT as one of the educational skills to be strengthened in food science curricula [3].

As part of an effort to improve the teaching of thermal processing of foods, a simulation software was designed. The objective of this software was to enhance the problem-solving capabilities of students by simulating different thermal processing conditions as they would occur in the food industry. Some of the features of the software include: (i) data analysis, where heating parameters and sterilization values are determined; (ii) process simulation, which allows the user to manipulate a set of input variables and observe their effect on the process delivered to the food product; and (iii) problem solving, allowing the instructor to specify special conditions, including process deviations, and requiring the student to confront the situation through logical reasoning.

FUNDAMENTALS OF THERMAL PROCESSING

Thermal processing refers to the use of heat for inactivation of microorganisms and enzymes present in foods, to increase their shelf life. At the same time, the thermal process should minimize the nutritional loss and deterioration in the quality of food products. To achieve this, it is necessary to determine what microorganisms and deteriorative enzymes are present in the product, and how resistant they are to heat treatment. It is also important to know the rate of thermal degradation of the nutrients and other quality attributes of the food product. This information is used to calculate the temperature and the duration of the thermal process. Then, the heat transfer characteristics of the food product and the container need to be determined. The best thermal process can be determined from the heat transfer data as one which will reduce the microbial population and deteriorative enzymes to an acceptable level, while retaining the highest nutritive value and quality [1].

Commercial sterilization of foods is a severe thermal process, and utilizes a high temperature under pressure. These conditions are achieved with the use of industrial pressure cookers called retorts. Many different types of retorts are in use in the food industry. The food is sealed in a container (can, pouch or jar) and is heated in a retort. Steam or water is used to heat the food product, and then the containers are rapidly cooled to avoid overheating of the product. The temperature and duration of this heat treatment is chosen to reduce the microbial population to such an extent that the probability of a non-sterile container is less than 10^{-9} [12].

The most commonly used types of retort are still and agitating retorts. Still retorts operate in a batch mode. Food containers are loaded into the retort and heated. At the end of the process, the containers are cooled with water, and then the retort is opened, and the containers are unloaded. Agitating retorts have been developed for both batch and continuous operation. They agitate the containers and thus enhance heat transfer to the foods by forced convection inside the containers.

Microbial destruction by heat

The rate of destruction of microorganisms by heat can be assumed to be proportional to the surviving population [2]. If the logarithm of the number of microorganisms surviving at a constant temperature is plotted against time, the plot, in most cases, is linear. A useful parameter, called the *D* value (decimal reduction time), is calculated from this plot, as the time required for the microbial population to decrease one logarithmic cycle at a constant temperature. The *D* value can also be shown to be related to the rate constant of microbial destruction (k) as shown in equation (1) [13].

$$k = \frac{2.303}{D} \quad (1)$$

When temperature is increased, the rate of microbial destruction also increases. Therefore, *D* values decrease with an increase in temperature. If the logarithms of the *D* values are plotted against temperature, the plot is again linear in most cases. The increase in temperature needed to reduce the *D* value by one logarithmic cycle is called the *z* value. The *z* value can be related to the energy of activation for the rate constant of microbial destruction by [13]:

$$E_a = \frac{2.303\,RTT_1}{z} \qquad (2)$$

where

$T1$ = reference temperature (K)
R = gas constant (1.987 cal/mol D)
E_a = energy of activation {cal/mol)

The D and z values are measures of the thermal resistance of microorganisms, and are used to calculate the time–temperature treatment required to preserve a product.

To design a food sterilization process, a conservatively large population of the most heat-resistant microorganism known to exist in the particular food product is assumed to be present. Then, the time–temperature treatment needed to reduce the population of this microorganism to an acceptable level is calculated. The thermal process delivered to the food product should be such that every particle of food receives at least this specified time–temperature treatment.

The time required to destroy a specific microorganism from an initial population, N_0, to a final population, N_f, at a constant temperature, T, is called the F_T value (sterilization value at temperature T), and can be calculated using equation (3) [14]:

$$F = D(\log N_0 - \log N_f) \qquad (3)$$

Under normal processing conditions, the temperature is not constant. In this case, an equivalent F value at a reference temperature (T_{ref}) can be calculated as [15]:

$$F^z_{Tref} = \int_{t_a}^{t_b} 10^{-\left(\frac{T_{ref} - T(t)}{z}\right)} dt \qquad (4)$$

where

F^z_{Tref} = F value at a reference temperature T_{ref} for a microorganism characterized by a z value (min)
t_a = initial time (min)
t_b = final time (min)
$T(t)$ = product temperature as a function of time (°C)

The expression under the integral in equation (4) is called 'lethality rate'. When the F value is calculated at 121°C and the z value is 10°C, the F value is denoted by F_0. Thermal processes for many products are available in the literature and handbooks in terms of their F_0 values [16].

Heat penetration parameters

During thermal processing of foods within containers (such as cans and jars), temperature is not uniform throughout the container. To ensure that all the food particles within the container are sterilized, it is necessary to determine the position within the container that has the slowest heating rate. This is called the 'cold spot'. The thermal process delivered to a food product has to ensure that the cold spot within each container receives the minimum sterilization value. In foods that heat by conduction, the cold spot is located at the geometric center of the container, whereas the cold spot is located below the geometric center in convection heating foods.

In thermal processing, the heating of food products is commonly described by a two-parameter equation:

$$\log(T_r - T) = \log[j_h(T_r - T_0)] - \frac{t}{f_h} \qquad (5)$$

where

T_r = constant heating medium temperature (°C)
T = product temperature (°C)
j_h = experimentally determined heat lag parameter (dimensionless)
T_0 = initial product temperature (°C)
f_h = experimentally determined heating rate parameter (min)
t = time (min)

Similarly, cooling is represented as:

$$\log(T - T_c) = \log[j_c(T_0 - T_c)] - \frac{t}{f_c} \qquad (6)$$

where

T_c = cooling medium temperature (°C)
j_c = experimentally determined cooling lag parameter (dimensionless)
f_c = experimentally determined cooling rate parameter (min)

The f and j parameters are called the 'heat penetration parameters' and are determined experimentally from the time–temperature data at the cold spot of a food product, while it is being processed under the same conditions as during commercial production. A plot of $\log(T_r - T)$ against time is generally linear, with the exception of the initial portion. The f_h parameter is defined as the inverse negative slope of this plot in its linear portion. The deviation from linearity at the initial portion of the curve is taken into account via the j_h parameter, as defined in equation (7):

$$j_h = \frac{T_r - T_0'}{T_r - T_0} \qquad (7)$$

where T_0' is the product temperature computed at the intercept of the straight portion of the heating section with the vertical axis.

The heat penetration parameters for cooling, f_c and j_c, are determined similarly from the plot of $\log(T - T_c)$ against time. The heat penetration parameters can be used to calculate the time required to achieve a specific temperature at the cold spot during thermal processing. These heat penetration parameters, along with the D and z values, are used in thermal process design and quality control.

The sequence of events to establish a thermal

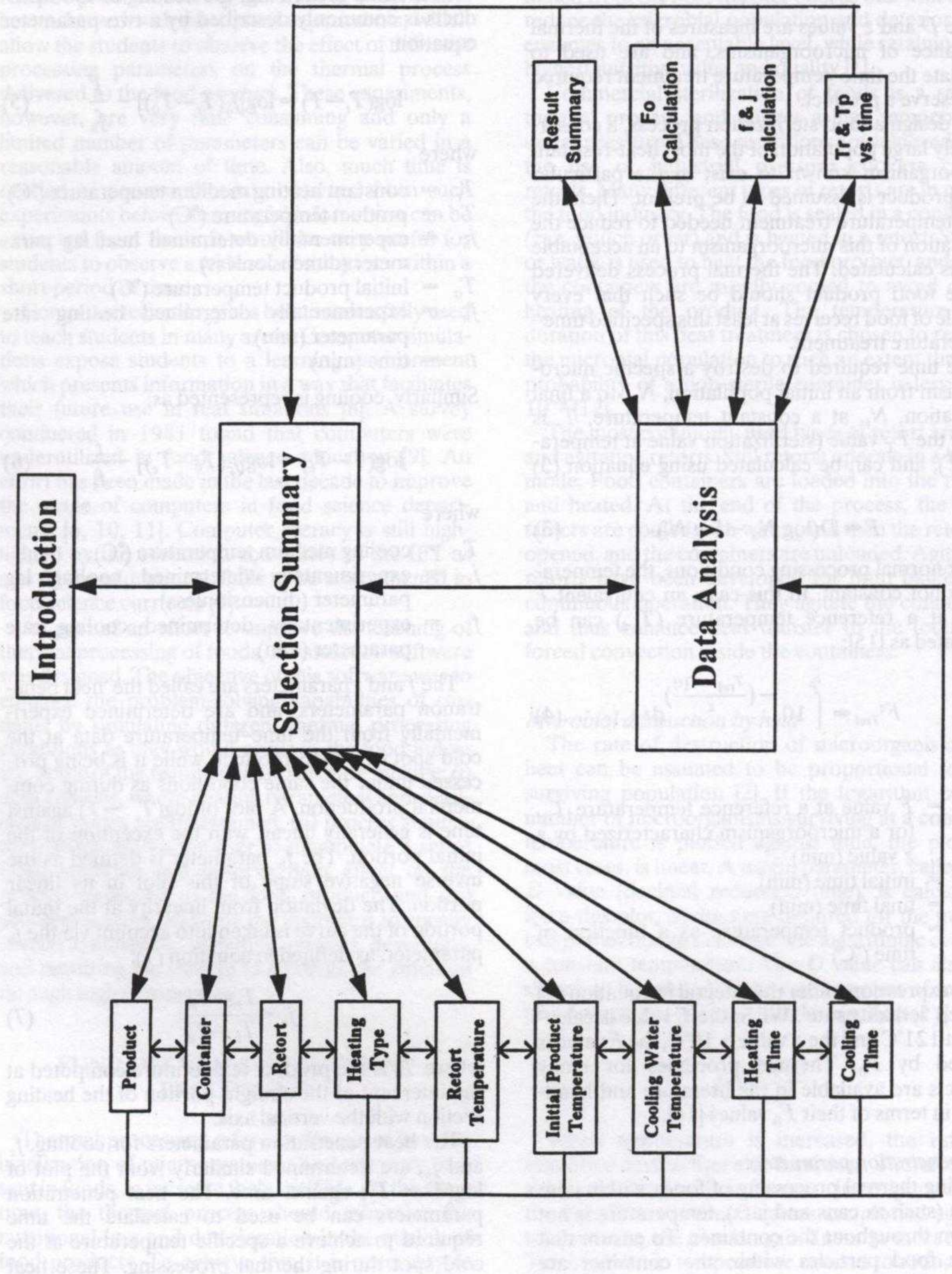

Fig. 1. Flowchart for the thermal processing program.

process in the food industry is: (i) develop/formulate the product (composition, packaging), (ii) conduct heat penetration studies, and (iii) determine the sterilization value for different time–temperature combinations. The thermal process should be optimized for minimum quality degradation for a given microbial destruction. The software simulates this sequence of events. Inoculated pack studies need to be conducted to validate the thermal process before marketing the product.

THERMAL PROCESSING SIMULATION SOFTWARE

Software development

The software, called 'Micro World', was developed using ToolBook, a software development program which works within the Windows environment for IBM and compatible computers. As a Windows-based program, ToolBook is graphics oriented and supports the use of a mouse, pull-down menus and dialogue boxes.

A software designed in ToolBook is structured in what is called a 'book', which is divided into 'pages'. Each page may contain many different objects, such as graphics, buttons and text for example, which can be programmed to perform specific functions when the user points or clicks at them with the mouse. Each book, page, and object has a script written in ToolBook's own programming language called 'OpenScript'. Software development using ToolBook requires considerable time and effort to design and develop the different components of a book, but it results in a package that is visually pleasant, efficient from a computational point of view, and user friendly. Many students are already familiar with the Windows platform used by ToolBook, and this makes it very natural for them to use the features of Micro World. Even for users with little or no experience with the Windows environment, the program is relatively easy to use.

Flowsheet for the program and navigation

The different pages of the program are grouped into four sections: introduction, data input, data analysis and results. When the user starts the program, the first page that appears is the Introduction. The Introduction page outlines the objectives of the program, and offers some initial instructions. From the Introduction, the other pages can be accessed as shown in the flowchart for the program (Fig. 1). Navigation is achieved in the program by using the buttons located at the bottom of the screen in each page (Fig. 2). These buttons allow

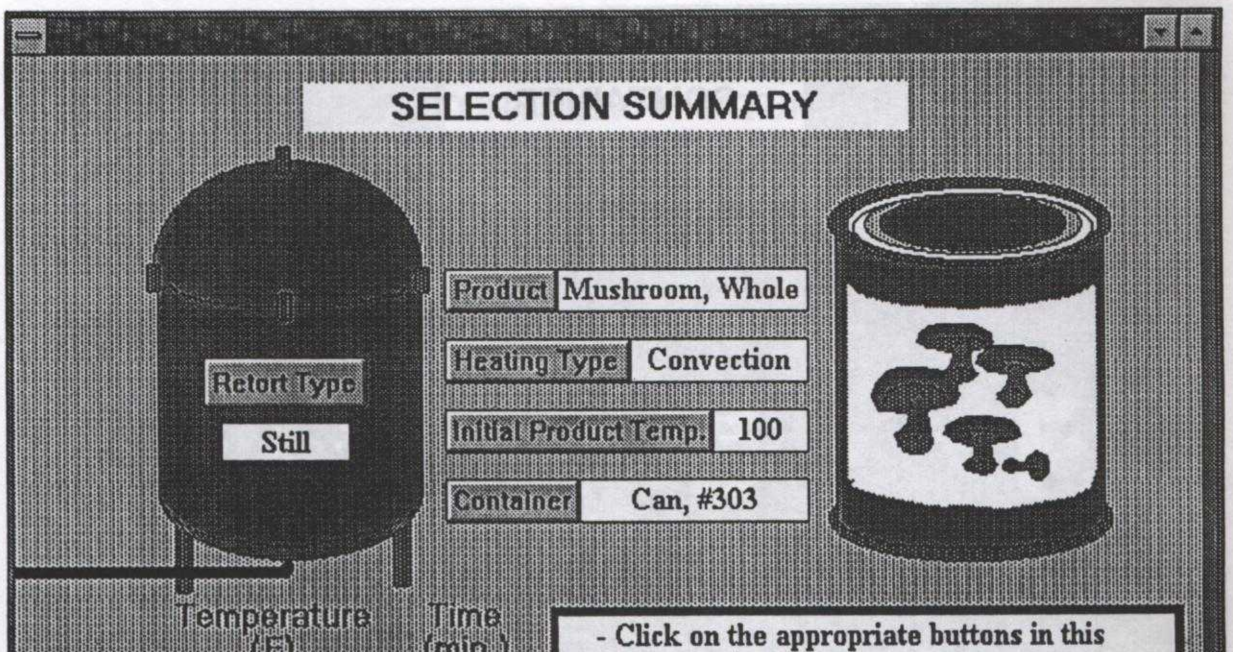

Fig. 2. Selection Summary page.

immediate access to the next or the previous page, and to the Selection Summary and Data Analysis Menu pages.

Some pages allow access to other pages by clicking on a graphic or a button next to it. Also, conditions such as incomplete data or physically impossible values will cause the program to return to the Selection Summary page. This feature was designed to avoid system errors, which would take the user out of the book's environment, and into ToolBook's programming level. The program can be terminated by clicking on the Quit button.

Data input pages

Selection Summary. This page (Fig. 2) serves as a visual display of current selections, and allows instant access to each selection page. The user has the option of accessing each selection page from the Selection Summary, or proceeding in a sequential order by clicking the Forward button in each selection page. Also, the Data Analysis Menu page is accessible from the Selection Summary page.

Selection pages. The purpose of the selection pages is to input the values of variables. There are nine pages to select: product, container, retort type, heating type, retort temperature, cooling water temperature, initial product temperature, heating time and cooling time. From each selection page the user can access the next or previous page, the Selection Summary page, or the Data Analysis Menu page.

There are two types of selection pages. The first type uses graphical representations of the selections, such as drawings of the different containers, to make the selection (Fig. 3). The user clicks on boxes next to the graphics to select an option. Variables selected this way are: product, container, retort, and heating type. The second type of selection page uses a graphical representation of a numeric pad (Fig. 4) to input numerical values for retort temperature, cooling water temperature, initial product temperature, and heating and cooling time. Each selection page has an instruction box which explains how to make the selections.

Data analysis pages

All of the data analysis pages generate plots by using a mathematical model based on equations (5)–(7), and the settings selected by the user. The accuracy and resolution of the graphs were chosen to provide a good visual representation of the variables and to minimize the computation time needed to generate the plots. It is hoped that faster computations would encourage the students to try

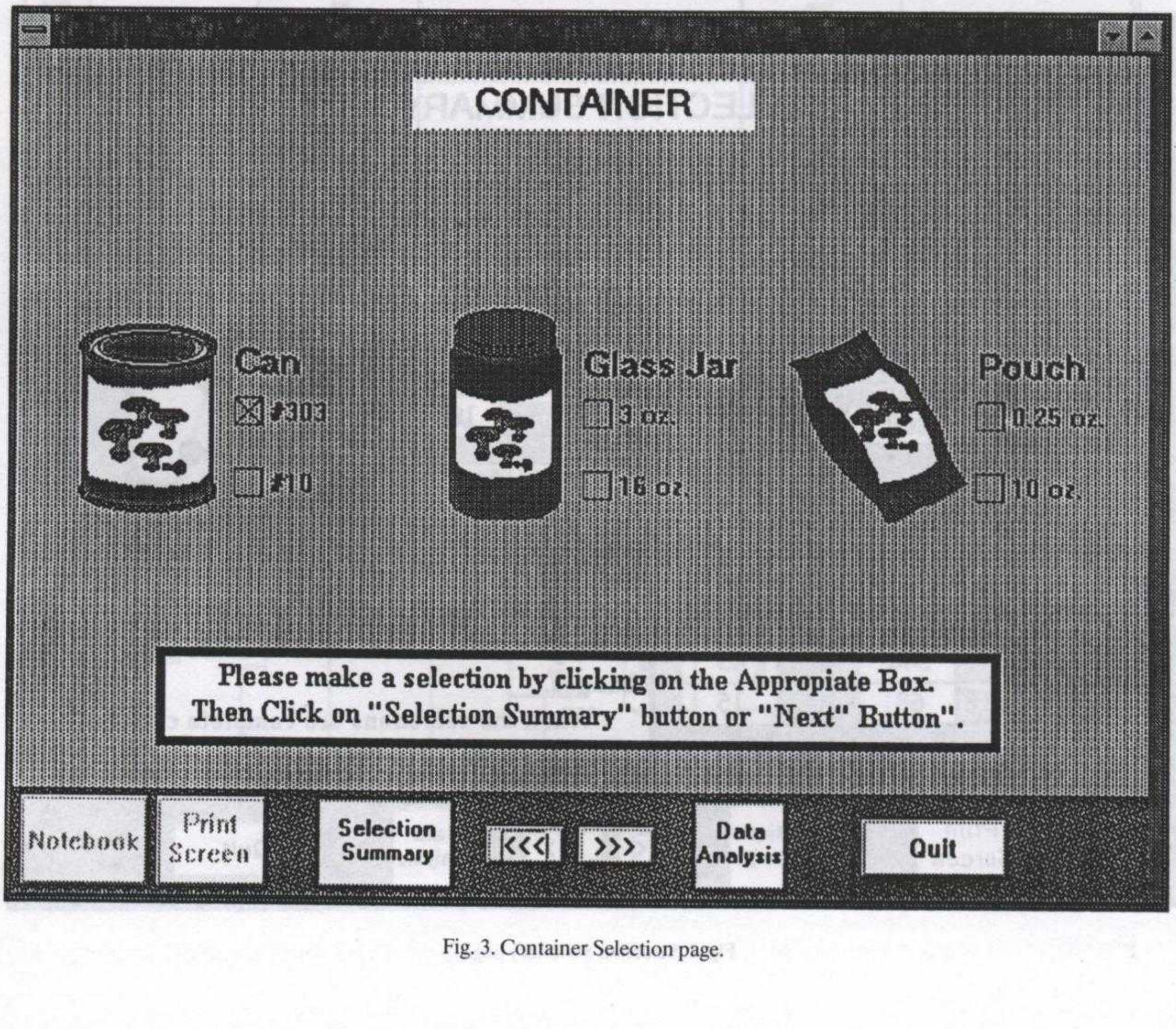

Fig. 3. Container Selection page.

many different settings in each session. Figure 5 shows one data analysis page.

Data Analysis Menu. The two main functions of this page are to ensure that the user selected a possible value for each of the variables, and to allow instant access to the graphics and results pages. If a set of variables is chosen which will cause a computation error, or if there are some settings missing, a message appears and the program automatically returns to the Selection Summary page.

Temperature vs.time page. This page uses the mathematical model to predict the temperature at the cold spot within the product during the simulated process. A similar model, assuming no lag for heating or cooling, was used to predict the retort temperature. The model uses the actual *f* and *j* parameters corresponding to the product and container from the literature, and the process settings previously selected by the user. A graph is generated with the values from the model, and maximum and final temperatures of the product are recorded for the results screen. Up to three graphs for three different sets of conditions can be overlaid so that the effect of different parameters can be examined in the same screen.

f and j calculation page. This page also uses the mathematical model to generate a logarithmic plot of the product temperature. Two separate plots for the heating and cooling sections of the process are shown in the same graph (Fig. 5). After the plots are generated, graphical analysis can be performed.

The students are then required to evaluate the *f* and *j* parameters using the Guide Line. The Guide Line is a graphic tool which can be manipulated using the mouse. When the Guide Line is aligned with the straight portions of the logarithmic plots, estimates of *f* and *j* for the heating and cooling sections are computed and recorded for the Results Summary page. Detailed instructions for the use of the Guide Line are provided to the user when this page is entered. Figure 5 shows the Guide Line with two handling circles being used to calculate the *f* and *j* values for the heating section of a process. The *f* and *j* calculation page also supports overlaying of up to three plots.

F_0 calculation page. In this screen the time–temperature data are used to compute lethality rate as a function of time. Numerical integration of the lethality–time data (equation 4) using the trapezoidal rule yields the F_0 value. The calculations are based on a reference retort temperature of 121°C

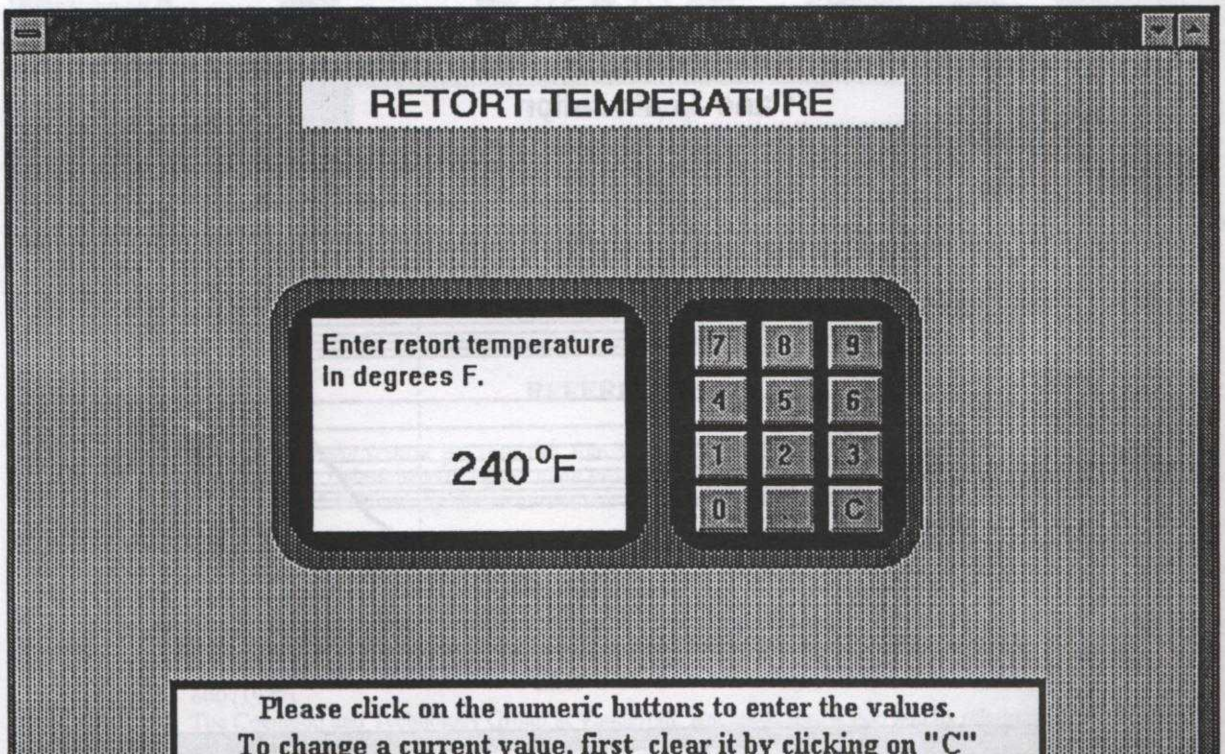

Fig. 4 Retort Temperature Input page.

and a z value of 10°C. A display on the bottom of the page indicates accumulated lethality (F_0) during the computations. The final value of the F_0 for the simulated process is recorded for the Results page. As with the other two graphics screens, the F_0 calculation page allows the overlaying of three plots.

Results page

The Results page contains a report of all the current variable settings and the results from the simulated thermal process. This page also provides the user with messages warning about incorrect settings or wrong selections or estimates. Additional information can be obtained by clicking the messages with the mouse. Figure 6 shows the Results page, with a message about the incorrect setting for cooling water temperature.

PROGRAM EVALUATION

In spring 1993, students taking the thermal processing course were asked to evaluate this program. In general, the students agreed that the program was user friendly and information was clearly presented. More than half of the students thought that the program helped them to understand better the variables which impact the sterilization value. Students also were asked to suggest improvements to the program. Their suggestions were carefully evaluated, and some of them were implemented in the current version.

CONCLUSIONS

The study of thermal processing involves concepts from engineering, microbiology and biochemistry. This presents difficulties in teaching this food engineering course to food science students, in part because of the interdisciplinary nature of the subject matter. An educational software was developed to complement the instruction of thermal processing for food science students. By modifying the value of different input variables, and observing their impact on the sterilization value, students learn to apply the theoretical knowledge of thermal processing to practical situations. This program can also enhance the problem-solving capabilities of the students through realistic simulation of food sterilization processes. Students evaluated the program, and

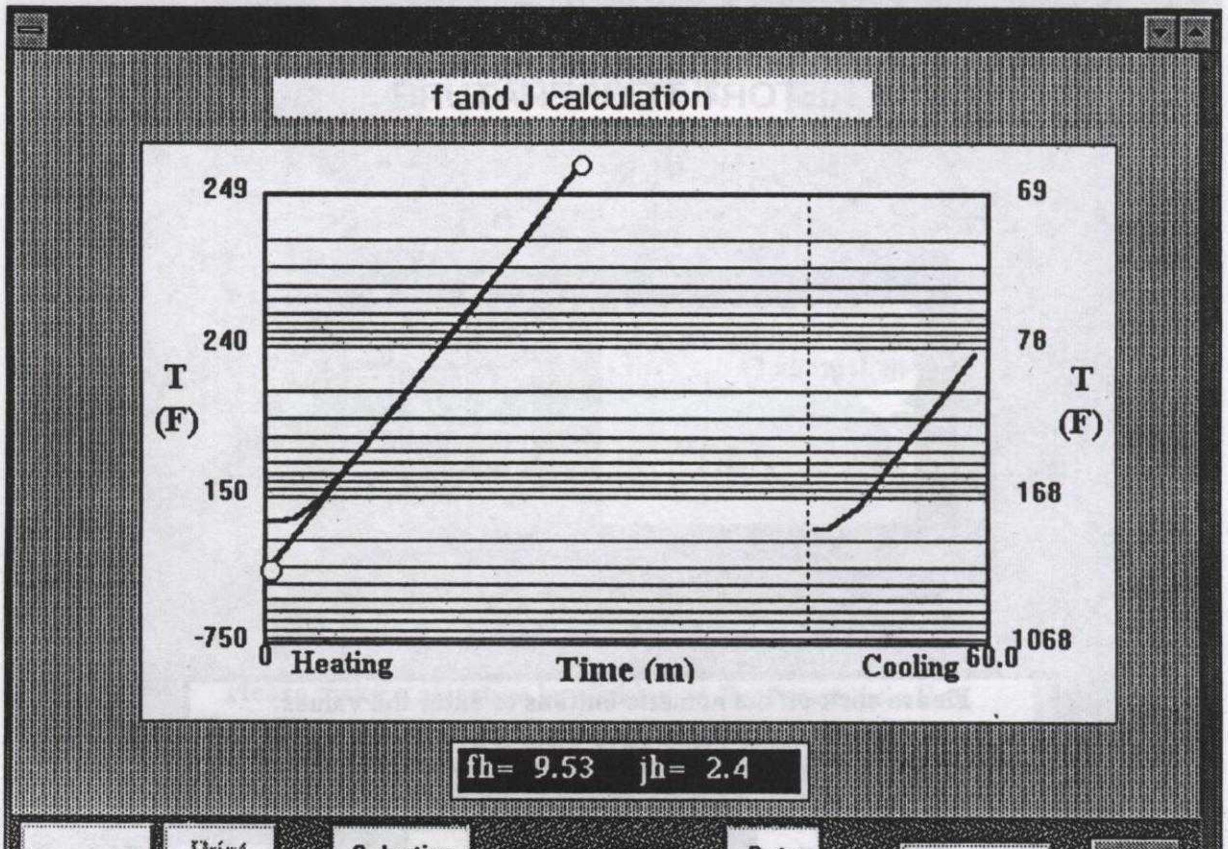

Fig. 5. *f* and *j* calculation page.

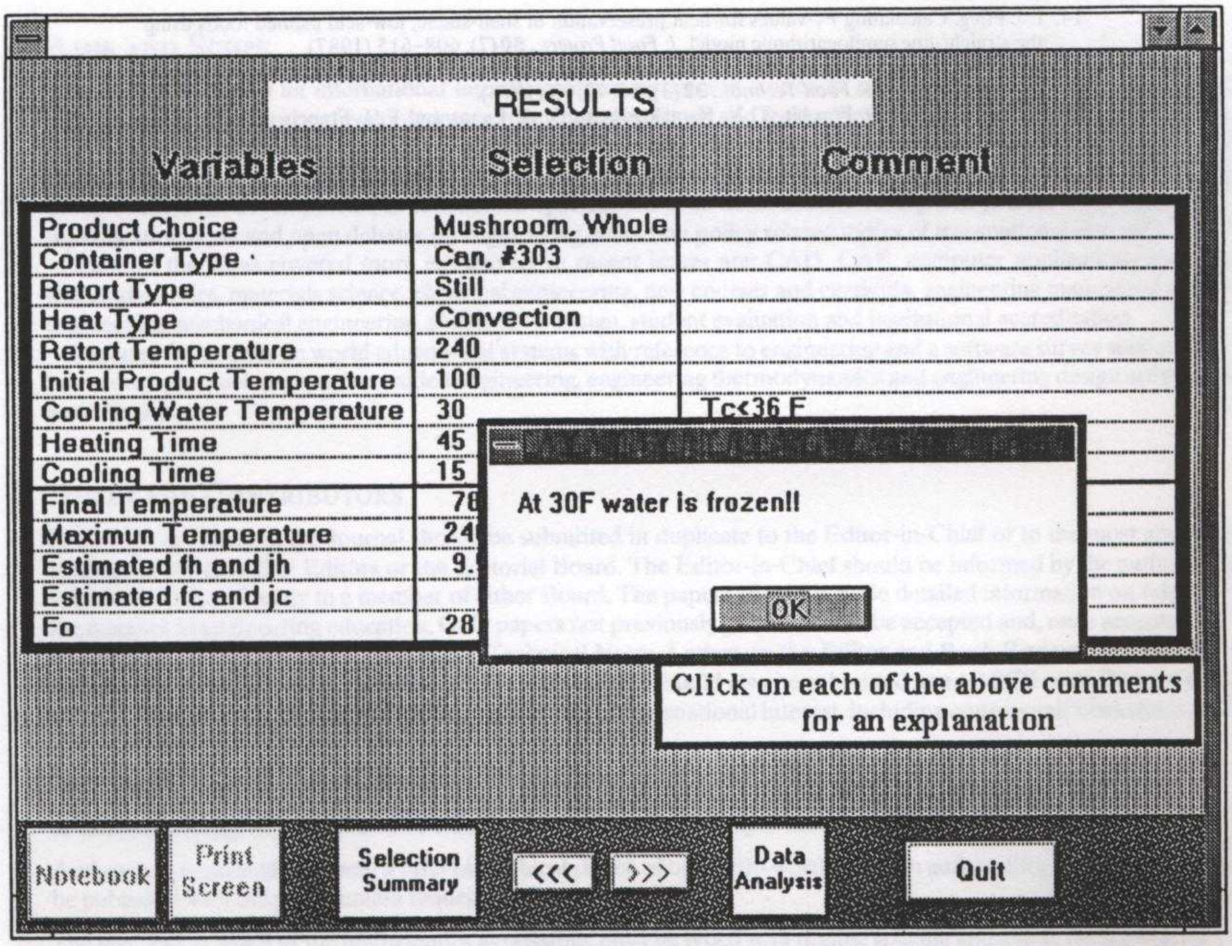

Fig. 6. Results page.

generally found it to be user friendly and appropriate for enhancing their understanding of thermal processing.

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