DEVELOPMENT OF VIRTUAL LABORATORY AS AN EDUCATIONAL/RESEARCH TOOL IN FOOD PROCESSING

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ABSTRACT

Personal computers (PC) and high level programming techniques have been developing so rapidly during last decade leading to new and exciting opportunities in the field of education. The purpose of this research was to develop food processing virtual labs as efficient teaching and study tools for food processing courses using user-friendly computer languages (VC++, MFC and OpenGL). A 3D graphic technique was employed in this study as a specific objective to generate 3D graphics in the visualization mode.

According to functionalities, virtual labs were designed for three basic simulations: (1) Calculation simulations, which perform various calculations related to food processing. These simulations help users to remember and understand the formula used in process calculations. Several simple concept calculations were included: conduction heat transfer in steady state through individual and composite slabs; two-component mass balance systems, Pearson rule applications; freezing and thawing time calculations; (2) Animation simulations, which are aimed to visualize processing scenarios for different physical phenomena or working principles. Included in these simulations were: conduction heat transfer through single and multiple walls under steady state; mixing processes involving two and three component systems and Pearson rule concept; freezing and thawing processes through slab, cylinder, and sphere, the three regular shapes; agitation thermal processing modes which include axial agitation and end-over-end agitation in rotational retort; (3) Virtual equipment simulations, which are aimed to dynamically simulate a real operating environment and to demonstrate equipment working principle, internal structure, and operating procedures. The simulated equipment include a horizontal retort used in thermal processing and a high pressure processing equipment used in non-thermal processing.

The food processing virtual labs provide a new way in teaching and learning, with

no risk, time or place limitations, and are cost effective. The simulated scenarios and equipment can be used as teaching tools in food processing courses, which provide an efficient way to the instructor/assistant. Instructor/assistant can dynamically and repeatedly demonstrate the operating process for the simulated equipment in a vivid and interested manner. Also students can get intuitive understanding by viewing these simulations. Computers are the waves of the future; however, traditional learning techniques should not be forgotten.

RÉSUMÉ

L'avènement des ordinateurs personnels et la progression rapide des techniques de programmation de haut niveau au cours de la dernière décennie ont mené à plusieurs applications basées sur l'informatique dans tous les domaines, entre autres la diététique. Ces succès ont ouvert également la porte à de nouvelles perspectives intéressantes dans le domaine de l'éducation.

Le but de ces travaux est de développer un laboratoire virtuel comme outils efficaces d'enseignement et d'apprentissage pour les concepts en transformations alimentaires, utilisant les langages informatiques conviviaux (VC ++, MFC et OpenGL). Ceux-ci incluent les simulations des procédés de calculs, la visualisation des concepts de transformations alimentaires et l'exploitation du matériel de transformations alimentaires. Une technique graphique tridimensionnelle (3 D) a été employée dans cette étude comme étant un objectif spécifique pour générer les graphiques 3D dans le mode de visualisation.

Selon les fonctionnalités choisies, les laboratoires virtuels ont conçu pour trois types de simulation de base : 1) simulations des calculs permettant d'exécuter les diverses opérations relatives aux transformations alimentaires. Ces simulations aident les usagers à se rappeler et à comprendre la formule utilisée dans le processus de calcul. Plusieurs concepts de calcul sont inclus, tels que : le transfert de chaleur par conduction en régime permanent à travers des dalles de forme parallélépipédique individuelles et composites; systèmes d'équilibre de la masse à deux composantes, applications de la loi de Pearson, calculs des temps requis pour le gel et dégel; (2) simulations d'animation visant à visualiser les scénarios de transformations pour différents phénomènes physiques ou principes de fonctionnement. Les simulations couvrent également le mécanisme de transfert de chaleur par conduction à travers une paroi simple ou multiple en régime permanent, les processus de mélange impliquant des systèmes à 2 composantes et le principe de la loi de Pearson, le

mécanisme de gel et de dégel à travers d'une dalle, d'un cylindre et d'une sphère qui sont les trois géométries les plus courantes, la transformation des modes d'agitation thermique incluant l'agitation axiale et celle de bout-sur-bout en forme de cornue rotationnelle, (3) Simulations du matériel en mode virtuel dont l'objectif est de simuler d'une façon dynamique un environnement réel d 'exploitation, de démontrer le principe de fonctionnement, la structure interne et les procédures d'exploitation. Les fonctions du matériel simulées incluent notamment la cornue horizontale utilisée dans le traitement thermique et le matériel à haute pression utilisé dans le traitement non-thermique.

Les scénarios et le matériel simulés sont des outils de base d'enseignement dans les cours de transformations alimentaires; le laboratoire virtuel fournit par conséquent à l'enseignant ou son assistant des outils efficaces pour décrire les concepts ou le phénomène clairement, de façon à faciliter la compréhension intuitive des usagers en regardant ces simulations. Les laboratoires virtuels en transformations alimentaires rendent les concepts ou phénomènes visibles et de ce fait, les cours ou les instructions seront plus efficaces et intéressants. Les interfaces conviviaux rendent l'apprentissage et l'opération faciles. Les graphiques 3D rendent possibles la visualisation de l'équipement, permettant de faire une description vivante et détaillée de leur caractéristique avec possibilité de le faire tourner sur lui-même et ce, de façon interactive, au lieu d'une démonstration classique à l'aide des photos, figures ou visites d'une usine-pilote de transformations.. Le mérite des graphiques 3D permet à l'usager d'examiner toutes les facettes de l'équipement virtuel au moyen d'une simple opération à l'aide de la souris.

Somme toute, le laboratoire virtuel en transformations alimentaires fournit une nouvelle approche dans l'enseignement et dans l'apprentissage, sans aucun risque, ni contrainte de temps et de lieu, et ce , de façon économique. L'informatique est la nouvelle voie de l'avenir, cependant on ne doit pas oublier complètement les méthodes d'apprentissage classiques .

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CHAPTER 1

INTRODUCTION

1.1 Motivation

In the late 1950s and early 1960s commercial computers were being developed (Merriam, 1999). The explosion in the use of computers began with 'Third Generation' computers (Wikipedia, 2004), and the use of computers is increasing in almost every field of endeavor. To the users in the field of food processing, the usage of the computers is not only limited to the traditional areas, for example, word processing, website or data exploring, controlling a food processing system, or various calculations, but has remarkably extended to various computer simulations.

Computer simulation is the discipline of simulating a model of an actual or theoretical physical system or phenomenon, executing the model on computers, and analyzing or predicting the execution output. The quality of simulations rely on both software and hardware computer techniques (Fishwick, 1994).

From the software point of view, the rapid development of modern programming languages enhances the possibilities and chances to develop more user friendly interactive interfaces. The interface of early computer simulations for food processing was not user-friendly (Chen, 2001). The modern computer programming languages, such as Java, C++, C, and Visual Basic, allow the users to develop much more complicated applications with user friendly interfaces.

The computer hardware technologies continue to evolve at a surprising rate, which greatly improves the image processing resolution and speed for computer simulations. The quality of image resolution depends on both the video card memory and the monitor resolution. The speed of image processing depends on graphics processors. Thus greater video card memory and faster graphics processors can result in more stunning and enjoyable visual effects when running simulations. The specifications of modern personal computers have been greatly increased compared with the computers used 10 years ago.

There are many advantages to using computer simulations in practice. They can provide quick and inexpensive testing of "what-if " scenarios (Chen, 2001). Simulations also supply a unique environment for exploring new concepts, for gaining and understanding the interplay between related complex phenomena, and for the construction of simplified working models topics under study.

The traditional educational method is facing the challenge of modern scientific techniques, and text based lectures for a course are somewhat inadequate for today's teachers and students. In order to increase the teaching and learning effectiveness in food processing courses, food processing virtual labs were targeted to be developed in this research according to the textbook used in the food processing course, and based on food processing principles and experiments. Most food processing simulations or animations have advantages in calculation and data analysis. Most of these simulations were two dimensional virtual labs, however, and for some phenomena and especially for food processing equipment, the two dimensional graphic mode had its limitations (Sun and Hu, 2002, Singh and Erdogdu, 2004, Gershenson *et al.*, 2000).

In order to solve this shortcoming, three dimensional techniques were applied in this project. The three dimensional technique shows its advantage by minimizing the constraint caused by the two dimensional techniques, and as well, the three dimensional visualization looks intuitive and vivid.

Some of food processing concepts and phenomena may not be explained easily and clearly by text depiction in the classroom, so we need to rely on figures or practical examples to make students understood easily. For the equipment or instruments used in food processing, not all of them can be explained easily (working principle or processing procedures), so we have to employ visualized graphics to demonstrate them. The internal structure of food processing equipment is not easily shown even in a real physical lab. Because of the risk, cost, time factors or some other reasons, some types of equipment may not be operated by students in a real pilot plant. All of these problems encourage us to develop a virtual lab for a food processing course, so that both instructors and students will be benefit from it.

1.2 Objectives

1.2.1 General Objectives

Based on the motivation of this research, the objective of this thesis research was to conceive an easy and fast way to benefit both teaching and learning in the food processing course. The general objectives for this research included:

- to develop educational tools for instructors, which are convenient for demonstrating the concepts, calculations, food processing phenomena, equipment interior structures and working principles.
- to help users to easily understand the concepts, and working principles of the food processing equipment etc.

For providing a better effect, the concepts were simulated and visualized as if they were being presented in a real pilot plant by including three dimensional graphic techniques. Visualized equipments could be operated manually or show the operation step by step automatically.

1.2.2 Specific Objectives

To fulfill the general objectives of this study, the specific objectives were to develop three types of simulations, which included:

1. Calculation simulation, which perform various calculations related to food processing. These simulations help users to remember and understand the formula used in process calculations. Several simple concept calculations were included: conduction heat transfer in steady state through individual and composite slabs; two component mass balance system and application of Pearson rule in mass balance; freezing and thawing time calculations;

2. Animation simulations, which are aimed to visualize the processing scenarios for different physical phenomena or working principles. These simulations were: conduction heat transfer through single and multiple walls under steady state; mixing processes involving a two component system and application of the Pearson rule in mass balance; phase change of freezing and thawing processes through slab, cylinder, and sphere, the three regular shapes; agitation of cans for rotary retort in food thermal processing which include two modes, axial agitation and end-over-end agitation;

3. Virtual equipment simulations, which are aimed to dynamically simulate a real operating environment and to demonstrate equipment working principles, internal structure, and operating procedures. The simulated equipment include horizontal retort used in thermal processing and high pressure processing equipment used in non-thermal processing.

1.3 Approach

We sequentially developed a set of simulations in this virtual lab according to the text book of Food Processing: Principles and Applications (Ramaswmy and Marcotte, 2003) by using computer techniques. The types of knowledge or techniques used for this research include:

- Food Processing Knowledge

  The fundamental knowledge includes: heat transfer in food processing, freezing and thawing processing, thermal processing and high pressure processing (Ramaswmy and Marcotte, 2003).

- 3D Techniques

  Some virtual labs have been developed in food processing; however, most of them focus on the animation and simulation in 2D or unreal 3D, for example, computer animations in food engineering developed by Dr. R. Paul Singh, University of California, Davis (Singh and Heldman, 2002). So the key point we have chosen in our research is to extend these applications to 3D. To obtain better 3D visualized objects, we used lighting, blending, color, material, viewing and some other techniques.

- Animation

  Animation is the technique using of computer graphics to generate a sequence of frames which, when passed before your eyes very quickly, produce the illusion of continuous motion (Fishwick, 1995). This technique is very useful to visualize food processing process into 3D animation.

- Programming Language

  In this study, we used C++ programming language and coded in Microsoft Visual C++ environment. The operating system is Windows 98 or above.

- Libraries

  Two classes of library are used in this research, they are Microsoft Foundation Class (MFC) and Graphic Library (OpenGL).

  Microsoft Foundation Class Library (MFC), is a standard set of classes that wraps around commonly used data types, windowing components, etc. MFC provides a framework on which applications can be developed for MS-Windows. MFC offers an exciting and powerful way to create Windows based applications. It is an acronym for The Microsoft Foundation Class Library which is an aggregation of classes (a generalized model or template that describes a collection of more specific items) that can be used in building software programs. It can generate a user-friendly interface as the main frame of visualization and simulation of calculation, and operating button generation.

OpenGL is a software interface to graphics hardware. This interface consists of about 250 distinct commands (about 200 in the core OpenGL and another 50 in the OpenGL utility library) that allows the developers to specify the objects and operations needed to produce interactive three dimensional application (Shreiner *et al.*, 1997).

This virtual lab developed is based on the 'waterfall' model procedures to achieve our objectives:

- Specification
  In this stage, we chose all food processing scenarios, food processing methods or equipments to be modelled, and defined their specifications, functionalities, requirements, and constraints to be developed in this virtual lab. We made sure that all the services supplied were helpful to both students and instructors in the food processing course.

- Design
  During this stage, based on the defined specifications, we decomposed the system into components, and designed interfaces between components and users, program structure, data structure, and the type of algorithms used. We had to guarantee that the virtual lab can really depict the phenomena as they are in practice. The virtual equipment must be interacted with and operated by users.

- Implementation
  The implementation stage is the process of converting a designed system into an executable system, implementing the relative functions using C++ language and compiling on Microsoft visual C++ environment. This process also includes debugging and testing the programs.

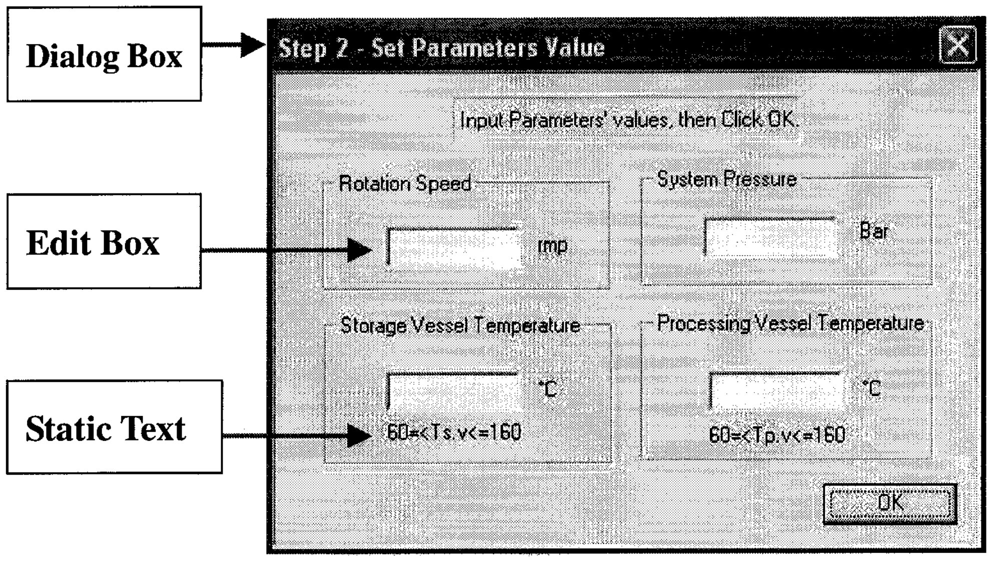


Figure 1.1 Definitions of Dialog Box, Edit Box and Static Text generated by MFC

1.4 Concepts

The basic concepts used in this Virtual Lab are illustrated in Figure 1.1.

1.4.1 Dialog Box

All the application developed in this research supply interactive screens to enter inputs and return outputs. All windows based GUIs (Graphical User Interface) definitely use dialogs for such user interactions.

1.4.2 Edit Box

The edit box is used to define variables for input or output data.

1.4.3 Static Text

The Static Text is used for description of a variable, unit of a parameter or a short text description in a Dialog Box.

1.5 Thesis Organization

This work is organized in the following sequence: In Chapter 2, we briefly review the types and their development history of computer simulations in food processing field. Then, in Chapter 3, we present the fundamental methodology used in this research. The detailed descriptions of the applications developed for this research are discussed in Chapter 4 and Chapter 5. The conclusions of this research and some suggestions for future work are presented in Chapter 5. The developed computer applications are stored in a CD accompanying the thesis.

CHAPTER 2

LITERATURE REVIEW

Over the past few years, computers have become vastly popular and a routine household item. But, not all functionalities of computer, high level computer languages supply a chance to develop some applications according to the user's expectations and desires. Virtual laboratory is one of the applications used as education tool in different scientific areas.

2.1 Concept of Virtual Laboratory

With the development of computer programming languages, the meaning of the computer for users is not only to handle text files with software of office, for example, Microsoft Office, but also allow users to design applications. Since those applications are designed to simulate the real world experiments by computer programming languages, therefore, we called them "computer simulation" or "virtual lab".

The virtual laboratory is an innovative program that lets the user interact with an entire simulated reality covering its principles using scientific research methods, specifically, i.e., virtual labs are used to simulate or visualize the calculations, scientific phenomena, experiments or the working principle of instruments in physical labs, and play a role as an assistant method to demonstrate simulated or visualized calculation, phenomena, experiment or the working principle of instrument clearly without going to the physical lab.

Computer simulation is the discipline of designing a model of an actual or theoretical physical system, executing the model on a digital computer, and analyzing the execution output. Simulation embodies the principle of "learning by doing' -

To understand reality and all of its complexity, we must build artificial objects and dynamically act out roles with them. Computer simulation is the electronic equivalent of this type of role playing and it serves to drive synthetic environments and virtual worlds.

The virtual lab can be run in two types of circumstances, one is to run it based on a network system. In this case, virtual lab can be available and interacted via internet. The other is CD-ROM format that the application of virtual lab is stored in CD. Depending on the designed aim of the operating system, users have to select a proper operating system, Windows, Linux or another one to run the application on it.

2.2 Why Use Virtual Laboratory as an Education Tool

Computers will be able to simulate the world as well as explain it. Creating or using a computer model can be a great educational tool. The advocates of simulation herald that it has great advances for education, it really supplies a new way in teaching and learning and will have a profound impact on teaching and learning scientific techniques in the coming years. Virtual labs lead us to a relatively new way in integrating the theory with practice.

Virtual labs are useful for pre-practice and post-analysis of experiments developed in a physical lab, and in some cases they can replace the physical lab itself (Gershenson *et al.*, 2000). Virtual labs also provide the users demonstrations, pre-lab work, and labs that otherwise could not be performed due to time constraints. It is possible for students to carry out experiments which might otherwise have been too dangerous, environmentally unfriendly, costly, or time-consuming. The interactive questioning from virtual labs is used to test a student's knowledge at every stage. The additional information available in the virtual lab really encourages students to learn about the scientific knowledge behind the experiment. It can also be a lot more fun than a traditional scientific practicum.

In a review of the first ten years of compulsory primary science, Harlen (1998) identified current concerns as: the teacher's role in constructivist learning, teachers' subject knowledge, the balance between process skills and science content, and the need for greater understanding and application of formative assessment. Simulations provide a unique environment for exploring new concepts, for gaining an understanding of the interplay between related complex phenomena, and for the construction of simplified working models of topics under study. Simulations are also an area in which computer technology is uniquely suited as the delivery mechanism for an educational experience. Therefore, the simulation technologies offer exciting opportunities for students to explore information, pursue their interests, experiment, and demonstrate what they have learned.

2.3 Current Status of Virtual Laboratory

Apart from an enduring interest in the use of simulation for military training, favorite early topics for such simulations in school and university classrooms included business management, political studies, geography and international relations (Widdison and Aikenhead, 1998). Virtual lab has been developed in many fields now, such as chemistry, physics, bioscience, biology, eduction, computer science, medicine and food science as well.

2.3.1 Virtual Laboratory Developed in the Food Processing Area

With the internet techniques development and wide use, some simulations and animations have been designed in food engineering and food processing area as well. This provides a new way for the teachers, students and researchers, and some have been commercialized.

A variety of simulations have been developed in the food processing area. These simulations include the Tomato processing plant (Starbird, 1990), drink manufacturering (Hardwick, 1992), food packages (Tanner *et al.*, 2002), the thermal destruction of Vitamin C in food pouches (Ghani *et al.*, 2002), a simple mathematical model (Simal *et al.*, 2003)) to simulate the drying curves of a meat-based product, Modeling and simulation of an oilseed meal desolventizing process (Cardarelli *et al.*, 2002).

In the food processing area, according to the different functionalities, we found that some different types of computer simulations were designed that include an analytical tool, an educational tool or both items of analysis and education combined. No matter which kind of application is designed, they all have their specific purposes.

2.3.2 Analytical Tool

The functions designed in early food processing simulations are simple and aimed to model an activity or process. Hardwick (Hardwick, 1992) developed a simulation of a single process for a complete food plant activity. A computer model of a UK based food and drink manufacturer is described in the work of Stratton and Sutton (Stratton and Sutton, 1992).

The finite element based simulation software (FIDAP) developed by Tattiyakul (Tattiyakul *et al.*, 2002) aimed to solve the governing mass, momentum and energy transport equations for heating the corn starch dispersion in a axially rotating can. In comparison to the experimental data, the simulated time-temperature profile was conservative and was in reasonable agreement.

A series of numerical simulations (Sun and Hu, 2002) using a computational fluid dynamics (CFD) code was carried out to predict core temperature and weight loss profiles of cooked meat during the vacuum cooling process. The CFD model allows the simultaneous prediction of unsteady heat and mass transfer, such as temperature distribution, weight loss and water content of the meats at vacuum pressure. The numerical simulation was verified by experiment with cooling cooked meat with cylindrical shape within an experimental vacuum cooler.

Computational fluid dynamics (CFD) is a simulation tool, which uses powerful computer and applied mathematics to model fluid flow situations for the prediction of heat, mass and momentum transfer and optimal design in industrial processes. It is only in recent years that CFD has been applied in the food processing industry. The paper of Xia and Sun, 2002 reviews the application of CFD in food processing industries including drying, sterilization, refrigeration and mixing. The advantages of using CFD are discussed and the future of CFD applications is also outlined.

A generalized mathematical model (Campanone *et al.*, 2002) was developed to simulate food refrigeration in air. The model takes into account surface water evaporation. It allows food physical properties to be considered as functions of temperature and/or composition, while providing means for including internal heat generation, composite materials (for instance, flesh and skin) and time-varying external temperature and humidity. Wetted surfaces and packaging can also be accounted for by the model, which can be used for spheres, infinite or finite cylinders, slabs. The numerical method was developed using the Crank-Nicolson scheme, and compared with exact analytical solutions as well as with experimental data on the refrigeration of various foods.

A numerical simulation (Sun and Hu, 2003) by using a computational fluid dynamics (CFD) code was carried out to predict heat and mass transfer during vacuum cooling of porous foods on the basis of mathematical models of unsteady heat and mass transfer. The simulations allow the simultaneous prediction of temperature distribution, weight loss and moisture content of the meats at low saturation pressure throughout the chilling process. The simulations are also capable of accounting for the effects of the dependent variables such as pressure, temperature, density and water content, thermal shrinkage, and anisotropy of the food. The model is verified by vacuum cooling of cooked meats with cylindrical shape within an experimental vacuum cooler. A data file for pressure history was created from the experimental pressure values, which were applied in the simulations as the boundary condition of the surface temperature.

A model (He and Li, 2003) was developed for predicting the temporal temperature and mass of spherical solid foods during vacuum cooling. He and Li discuss the effects of product thermophysical properties, convection heat transfer coefficient, latent heat of evaporation as well as vacuum environmental parameters that govern the heat and mass transfer of product. The temporal trends of total system pressure, product temperature such as surface temperature, center temperature, mass-average temperature, the mass of product were predicted. The model accounts for the change of temperature of solid product systematically during vacuum cooling by means of simulation. This paper also compares the results of the computer algorithm with experimental results taken from published literature.

Numerical simulations (Abdul *et al.*, 2002) were used to profile temperature, velocity vector and viable bacteria (*Bacillus stearothermophilus* spores) concentration in a three-dimensional pouch filled with beef-vegetable soup during thermal sterilization. The partial differential equations of the continuity, momentum and energy equations were solved numerically, together with an equation defining viable bacteria concentration, based on finite volume method of analysis. Saturated steam at $121°C$ was used as a heating medium, and the model liquid is assumed to have constant properties except for the viscosity (temperature dependent) and density (Boussinesq approximation). The simulations showed clearly the dependency of the concentration of live bacteria on both the temperature distribution and the flow pattern as sterilization proceeds. Experimental measurements are done to validate the bacteria concentration profiles. The experimental measurements were conducted at the Biotechnology Laboratory located at the Chemical and Materials Engineering Department, University of Auckland in New Zealand. The measured concentrations of *B. stearothermophilus* spores at different periods of heating were compared with those obtained from simulations, showing good agreements.

Computer simulation of thermal processing developed by Chen (Chen, 2001) provided multiple functionalities, such as process design, validation and optimization. Food processing virtual lab has been become a new way in gaining food processing knowledge and in research. As the very nature of teaching, where the teacher often puts a personal touch to the subject, means that a teacher may use some material developed by others, but not all. Variable retort temperature (VRT) thermal processing can be an effective technique used for improving the quality of canned foods and reduce the process time. In Chen's study, artificial intelligent techniques were applied to develop prediction models and search for optimal variable retort temperature processing conditions for conduction heated foods. A computer simulation program was used to gather data needed for training and testing of artificial neural network (ANN) models. Two VRT functions, sine and exponential, were used for modeling and optimization. ANN models were implemented to develop prediction models for VRT output variables: average quality retention (Qv), process time (Pt) and surface cook value (Fs). Genetic algorithms (GA) were coupled with trained neural network models to meet different optimization objectives: minimum Pt and Fs, under given constraints. The searching range of each independent variable was based on a sensitivity analysis of effects of function parameters on response variables. The best results for Qv, Pt and Fs under constant retort temperature (CRT) processing conditions were used as constraints. Test results indicated that coupled ANN GA models could be effectively used for describing the relationships between the operating variables and VRT function parameters, and for identifying optimal processing conditions. VRT processes reduced the process time by more than 20% and surface cook value by about 7 as compared to the best CRT process.

2.3.3 Education/Research Tool

The first simulation as an educational tool probably appeared to have been developed in 1960's on both sides of the Atlantic. Dr. R. Paul Singh, Professor at University of California (Davis, California), and his former students and associates developed the animations in food engineering based on *Introduction to Food Engineering* (Singh and Heldman, 2002). The purpose of these animations was to enhance the understanding of engineering concepts given in the text. The animations were published on the web site, and provide the lecture materials for typical courses taught at undergraduate and postgraduate levels to students or instructors engaged in learning and teaching food engineering. Animated graphics are provided to enhance learning of new concepts. They provide a distance learning tool, and students in school or those who want to review or update food engineering knowledge can experience it from anywhere and at anytime.

Recently, a book was published on *Virtual Experiments in Food Processing* (Singh and Erdogdu, 2004). In this book and the accompanying CD, they have drawn on results from over 30 years of research on selected computer applications in food processing to develop educational materials suitable for teaching. Seventeen virtual experiments were prepared that may be conducted using the software presented in the CD. The accompanying text provides detailed procedures required to conduct a given virtual experiment. These experiments may be used to augment existing laboratory courses, or as contents of a stand-alone virtual laboratory course in the food science curriculum. All virtual experiments selected in this book represent major food processes, and in each case an experiment is designed with four components which include:

1. A collection of multimedia materials including photographs, schematics and animations of process equipment presented to view industrial practice and laboratory procedures relevant to the experiment.

2. A process simulation that uses advanced mathematical models to predict physical, chemical or microbiological changes in the food due to the process. These mathematical models have been extensively validated with experimental data in published literature. Therefore, the predictions of the food processes are considered to be highly reliable. The user is shielded from the complexity

of the models, because of the consistent user-friendly input/output procedures that have been developed for each virtual experiment.

3. Critical thinking skills required in data analysis. Although the simulation programs may be enhanced to do all the analysis, this would minimize student's learning. Therefore, from each virtual experiment, a student obtains results in the form of spreadsheets. Students are then asked to analyze the data by making required plots, derive important parameters, conduct statistical analysis, and discuss key observations. This part is similar to what is normally done with data obtained from a real-life laboratory experiment.

4. Report writing. Online links to over 60 industrial web sites are provided. These links are included for students to conduct research for data analysis and report writing. Discussion questions are included to prompt students to make key observations while conducting experiments. These laboratories have allowed the students to take full advantage of the vast computational power of the modern personal computers and to improve their problem solving skills.

2.3.4 Example of Computer Simulations in Food Processing

Dr. C.R, Chen and Dr. H.S, Ramaswamy, McGill University, developed a comprehensive finite difference computer simulation program for thermal processing by using Microsoft Visual Basic in 2001 (Chen, 2001), which was employed to provide experimental data needed for the developing and testing of artificial neural networks (ANNs) model and genetic algorithms (GAs) optimization. This simulation could be used for simulating different aspects:

- different thermal processes: such as constant retort temperature (CRT) and variable retort temperature (VRT) thermal processing;
- different food types: solids, liquids, semi-liquids or liquids containing particulate;

- different purpose: design or validation.

From Figure 2.1, we can see the simulation with a friendly interface, the input data and output results parts were very clearly shown on the interface, and the profile of results assists the user to analyze and understand the output data easily and conveniently.

2.4 New Challenges in Development of Food Processing Virtual Lab

Traditional education method is facing the challenge of modern scientific techniques, the text based lecture for a course is becoming less suitable for today's teacher and students. In order to increase the teaching and learning efficiency in the food processing course, the food processing virtual lab is developed in this research according to the textbook used in the food processing course, and based on the food processing principles and experiments.

Following a review of computer simulations in the food processing field, we found that most simulations were limited in 2D graphics, and that as an education tool, only a few examples of simulation about fundamental knowledge were developed in the food processing field. In order to solve shortcomings of 2D graphics and help instructors to introduce the food processing scenarios and equipment much more easily and clearly in class, and provide to students a more direct and interesting lecture, this project offered a three dimensional computer simulation. Thus, both instructors and students can benefit from this virtual lab.

2.5 Summary of Literature Review

The new way to teach and obtain knowledge is via virtual labs. Although some virtual labs have been designed in the food processing area, there is place for further development in this area. For a student, the general and basic path to acquire

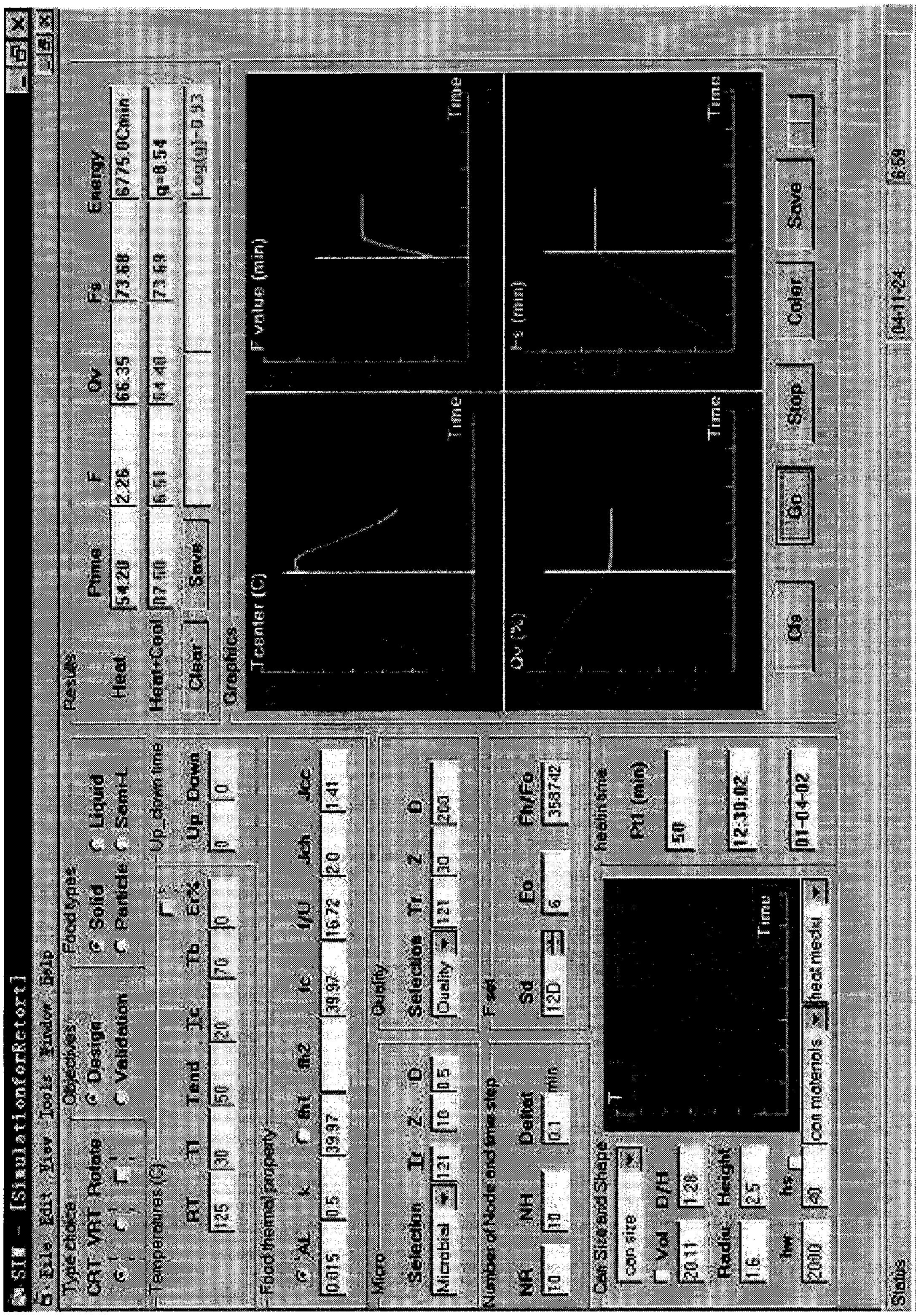


Figure 2.1 The interface of simulation by Chen and Ramaswamy (2001)

knowledge is still in class, and that reminds us of the importance of education. The food processing course is the core of the curriculum, yet most of the reviewed computer simulations in food processing were developed by researchers and focused on a specific processing method, so students may not benefit directly from these works. Therefore, the development of some more practical computer simulation is significant for both teaching and learning.

CHAPTER 3

BACKGROUND CONCEPTS FOR VIRTUAL LABORATORY DEVELOPMENT

3.1 Heat Transfer in Food Processing

Heat transfer is an operation that occurs repeatedly in the food industry. Whether it is cooking, baking, drying, sterilizing or freezing, heat transfer is part of the processing used in almost every food. An understanding of the principles that govern heat transfer is essential to an understanding of food processing.

Heat transfer is one of major theoretical foundations for food thermal processing. Here we only introduce two modes of heat transfer, conduction heat transfer and convection heat transfer.

3.1.1 Conduction Heat Transfer

The flow of heat by conduction occurs via collisions between atoms and molecules in the substance and the subsequent transfer of kinetic energy or through compacted particles without involving gross movement of particles. This is the common mode of heat transfer in solid material. Heat flows through thermally conductive materials by a process generally known as 'gradient transport'. Gradient heat transport depends on three quantities: the conductivity of the material, the cross-sectional area of the material, and the spatial gradient of temperature. The larger the conductivity, gradient, and/or cross-section, the faster the heat flows.

Conductive heat transfer is the mode of heat transfer of energy that takes place at a molecular level. Conduction takes place when a temperature gradient exists in a solid (or stationary fluid) medium. Energy is transferred from the more energetic to the less energetic molecules when neighboring molecules collide. Conductive heat flow occurs in the direction of decreasing temperature because higher temperature are associated with higher molecular energy.

The amount of heat transferred by conduction under steady state conditions can be determined using Fourier's Law:

$$q = -kA\frac{dT}{dL} \tag{3.1}$$

where

q - heat transfer rate (W)

A - area of heat transfer (m^2)

dT - temperature gradient $(°C)$

dL - a unit thickness (m)

k - thermal conductivity $(W/[m°C])$

3.1.2 Convection Heat Transfer

Heat energy transferred between a surface and a moving fluid at different temperatures is known as convection. Convective heat transfer may take the form of either forced or assisted convection or natural or free convection.

- forced or assisted convection
  Forced convection occurs when a fluid flow is induced by an external force, such as a pump, fan or a mixer.
- natural or free convection
  Natural convection is caused by buoyancy forces due to density differences caused by temperature variations in the fluid. At heating the density change

in the boundary layer will cause the fluid to rise and be replaced by cooler fluid that also will heat and rise. This continues phenomena is called free or natural convection.

Steady state convection heat transfer is governed by Newton's Law:

$$q = hA(Ts - T) \tag{3.2}$$

where

q - heat transfer rate (W)

h - surface heat transfer coefficient $(W/[^\circ Cm^2])$

A - area of heat transfer (m^2)

Ts - surface temperature $(^\circ C)$

T - fluid temperature $(^\circ C)$

3.2 Applications of Mass Balance

Mass balance is widely applied in many applications, such as mixing, blending, concentration, cooking, intermediate moisture foods, and drying, etc.

3.2.1 Law of Conservation of Mass

The law of conservation of mass states that mass can neither be created nor destroyed. The principle of a mass balance is that the total mass of the materials entering a process must equal the total leaving the process. That is to say, mass in is equal to mass out, or mass in minus mass out is equal to mass accumulated, or raw materials is equal to products plus wastes and stored materials. Material and energy balances are very important in the food industry. Material balances are fundamental to the control of processing, particularly in the control of yields of the products. The law of conservation of mass leads to what is called a mass or a material balance.

3.2.2 Calculations of Two Components Mass Balance System

Suppose, component A (mass is m_a (kg)) is to be mixed with component B (mass is m_b (kg)) to get component C (mass is m_p (kg)). Solids percentage in each component are $x_a\%$, $y_b\%$, and $z_p\%$ separately. For this two components mass balance system, the flow sheet or process block diagram is shown in Figure (3.1).

If there are no chemical changes occurring in a process, the law of conservation of mass will apply to each component. So that for each component, mass entering the system is equal to mass exiting the system plus mass stored in the plant. If any four variables are given, we can get the other two unknown variables by solving equations (3.3) and (3.4)

$$m_a + m_b = m_p \tag{3.3}$$

$$x_a * m_a + x_b * m_b = z_p * m_z \tag{3.4}$$

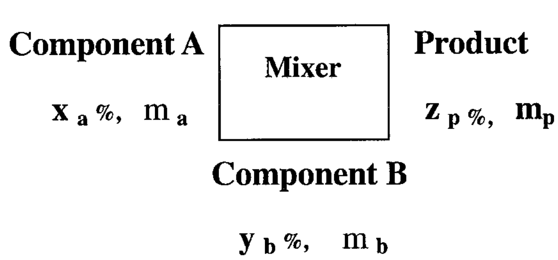


Figure 3.1 Mass balance application - Two components system flow sheet

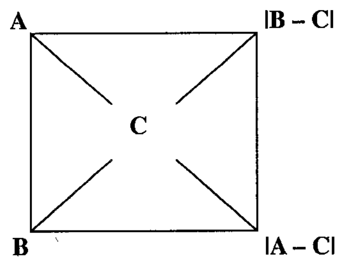


Figure 3.2 Pearson Square schematic

3.2.3 Pearson Rule

The Pearson Rule is usually applied in confectionary industry. It is suitable to be used for only two ingredients which are to be mixed, and it can be considered as the two components mass balance system which was mentioned above as well. The Pearson Rule can be called The Pearson square or box method of balancing rations, and has been used for many years. The Pearson square is a simple method as shown in Figure (3.2). Different numbers concentrations of ingredients are placed in four vertex points and central point of quadrilateral. A, B and C values in the Figure (3.2) are known, other two values , $|B-C|$ and $|A-C|$ are absolute values obtained from A, B and C. The more important number, the number that appears in the middle of the square, represents the desired concentration of the achieve component in the mixture .

Once the known percentage of each component are placed it on the right vertex, the rule is mixture of $|B-C|$ parts of A plus $|A-C|$ parts of B gives $|A-B|$ as parts of C. If the total product quantity is defined as m_{total} (kg), quantity of component A is m_A (kg) and quantity of component B is m_B (kg), then,

$$m_A = \frac{|B-C|}{|B-C|+|A-C|} m_{total} \tag{3.5}$$

$$m_B = \frac{|A-C|}{|B-C|+|A-C|} m_{total} \tag{3.6}$$

3.3 Thermal Processing Equipment

Thermal processing has a long history in food processing since 1810. The principle of thermal processing is to proportion the heat to foods in hermetically sealed containers. In some ways, retorting has come a long way since the days of its inception. Yet, essentially the process has remained the same. The underlying concept – heating foods prone to microbial spoilage in hermetically sealed containers to extend the shelf life – remains the operating principle which defines as well as limits the process. Although formulation plays an important role in these products, it is the process that ultimately affects the finished product quality. Three factors must be in delicate balance in order to design a retorted product: safety, quality and economics.

3.3.1 Retorts in Thermal Processing

Thermal processing is defined as the combination of temperature and time required to eliminate a desired number of microorganisms from a food product. Heat sterilization of food in containers is an old technology largely attributed to the work of Nicholas Appert in the 1800s (Lopez, 1987). The application of heat processes to containers requires not only the ability to heat and cool the container contents efficiently but also the ability to do so while minimizing the stresses imposed upon the container. This controlled application of heat and pressure is the function of the modern sterilizing retort.

The equipment that is employed in food thermal processing for packaged foods is a retort. The retort can be vertical or horizontal both are common. The main types of retorts used in the manufacture include: Batch retorts, such as saturated steam retorts, full water immersion retorts, steam/air retorts, raining water/sprayed water retorts, crateless retorts, batch rotary retorts,continuous retorts, such as hydrostatic retorts, hydrolock retorts, reel and spiral retorts.

The batch retorts heated with water under pressure are designed vertical or horizontal. These types of retorts are most frequently used for processing glass container, because if the glass containers is processed in pure steam, there will be the risk of thermal shock breakage. The products which are packed in aluminium cans are sterilized by using these types of retort widely. The layout of a typical vertical saturated steam retort is given in Figure (3.3). Understanding the key features of this traditional retort system will give the required insight to the features of more modern systems.

With continuous retorts, containers are passed through a mechanical inlet port into a pressurized chamber containing steam where they are processed before passing through an outlet port into either another pressurized shell or an open water reservoir for cooling. The motion of the cans through the retort causes some forced agitation which improves the rate of heat transfer.

In steam/air Retorts, the containers are processed under pressure in a system which relies on forced circulation for the continuous mixing of the steam with the air. Inadequate mixing can result in the formation of cold spots which could lead to under-processing spoilage. As with water filled retorts, this system is suitable for retortable pouches which require a counterbalancing overpressure to prevent their rupture.

The procedures of retort operation typically involve the following:

1. Place the cans inside the crate, car or basket

   Place cans inside the basket, crate or car according to the capacity of basket, cage or car, and any dividers used between layers of containers must be perforated sufficiently to allow heat to penetrate the load.

2. Put the cage or car into the retort

   This second step of operation of a retort is to load the containers into the retort. This involves portioning the crate, car or basket. The sides and base of

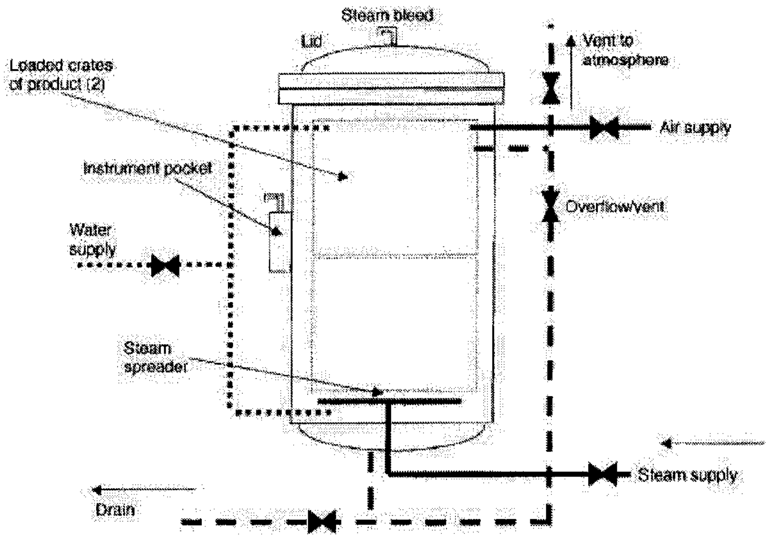


Figure 3.3 The layouts of a typical saturated steam vertical retort

the crates must be perforated sufficiently so that all products can be supplied enough heat penetration.

3. Close the lid and secure all the bolts

   Make sure the lid is closed completely, and all bolts are secured to prevent any risks during processing.

4. Introducing of heat medium

   When the heat medium goes in, the vent and drain vales are kept open so that the water from the condensing steam and all the air can be removed from the retort. The efficiency of the venting process can be monitored by measuring of the bulk temperature of the retort, the time required for removing the air being determined experimentally. When the temperature reaches the preselected level, the vent is closed.

5. Processing process

   The processing time is counted after come up time.

6. Cooling process

   Once the desired hold period has been completed, the processing is finished, and then the retort is cooled. The start of the cooling phase is most critical for ensuring the container integrity of the processed containers. If at the start of cooling the supply of steam is turned off and the pressure allowed to drop quickly, then the internal pressure can be sufficient to cause permanent damage to the containers. In order to overcome container damage, the steam pressure can be replaced with a supply of compressed air at the same, or a slightly higher pressure, the internal pressure of the can is balanced by the external air pressure.

7. Finish of the process

   Once the cooling process is complete, the door or lid is opened and the crates unloaded. The retort is then ready for the next cycle.

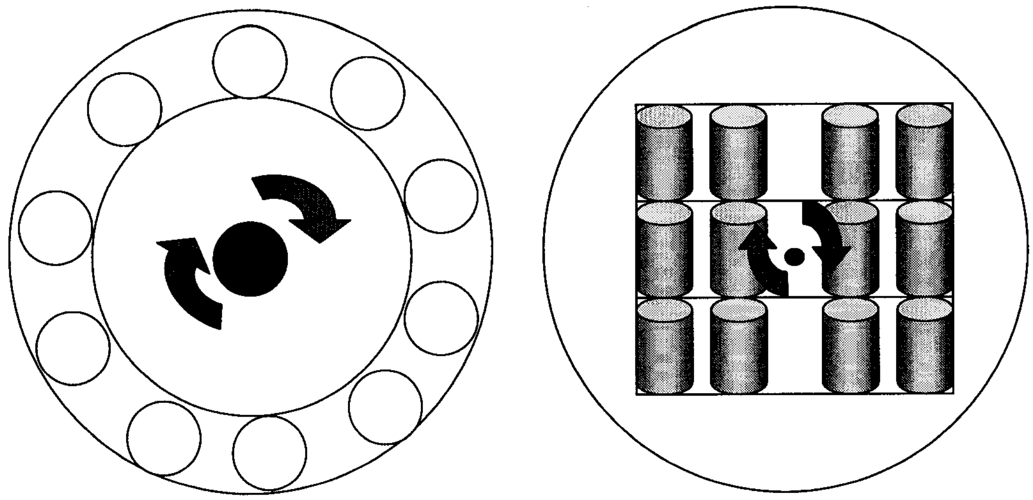
While this is the typical operation of the retort, the details for different retorts may vary.

3.3.2 Agitation of Cans for Rotary Retort

Rotational batch retort systems are designed to rotate (or oscillate) entire baskets of product during processing. The rotary retort provides several advantages compared with still retort, especially, improved quality, and may reduce the processing time by up to 80%. A tremendous advantage over the still retort is in processing viscous foods in large containers. Two modes of agitation can be employed, these are referred to as "axial", in which a can spins on its own long axis, or "end-over-end" in which the can is tipped over. The patterns of axial and end over end rotation are illustrated as Figure 3.4(a) and Figure 3.4(b).

An important factor in the effectiveness of agitation in bringing about product heating is the size of the headspace which plays a big part in the mixing process.

In axial agitation, the cans rotate axially as described in the Figure 3.4(a), the cans agitate along with reel during the processing. For approximately the one third of



(a) Schematic of axial agitation of cans for rotary retort

(b) Schematic of end-over-end agitation of cans for rotary retort

Figure 3.4 Schematic of agitation of cans for rotary retort in thermal processing

the rotation, the cans will be contact with shell and as result experience counter spin. This is because there exists a gap between the can and the inner wall of the sample shell, the can will drop down against the inner wall of the sample shell, and because of the friction force between the can and sample shell, the can rotates itself. That enhances the mixing and heat transfer rate during the processing.

End-over-end agitation refers to rotation of sealed cans around a circle in a vertical plane as described in Figure 3.4(b). Mixing is largely due to the movement of the headspace during agitation and to be effective there must be a sufficiently large headspace inside the can. A small headspace may lead to under processing. The end over end rotation will result in different efficiency for mixing the contents of cans and heat penetration. With lower speed agitation, the solids of contents of the cans move along the inner wall of the can. Movement and mixing are limited, which may not improve the heat penetration. If the rotation speed is in optimal, the contents of cans move randomly inside the cans and have a good mixing. With the higher speed, the contents of the cans may stay in a fixed position inside the can because of the centrifugal force, hence high speed is not the right choice for improving the heat penetration, so the best one is an optimal speed.

Agitation is useful for products which are too viscous to heat or cool by natural convection. The retort agitates the cans during processing in order to increase the rate of heat penetration into the cans. Container agitation may provide faster rates of heat penetration to the container coldspot as compared to still cooks. However, while this is true for some containers, it may not be so for all containers within a load and caution must be exercised to identify the slowest heating containers. Critical factors in these retorts include: headspace, product consistency, solids to liquid ratio, initial temperature, container size, rotational speed and radius of rotation.

3.4 Food Freezing and Thawing Processing

3.4.1 Freezing Processing

Food freezing is the unit operation in which the temperature of a food is reduced below its freezing point and a proportion of water undergoes a change in state to form ice crystals. Since freezing preservation can result in a high-quality product for consumption, therefore, the preservation of food by freezing has become a major industry in some countries. For example, the annual per capita consumption of frozen vegetables in the United State increased from 20 to 38 kg between 1970 and 1999 (Singh and Heldman, 2002). During the freezing, sensible heat is first removed to lower the temperature of a food to the freezing point. Most foods contained a large proportion of water, which has a high specific heat (4200 $Jkg^{-1}K^{-1}$) and a high laten heat of crystallization (335 $kJkg^{-1}$). A substantial amount of energy is therefore needed to remove latent heat, form ice crystals and hence to freeze foods. There is a smaller amount of latent heat present in other components of food (for example fats), for removing this kind of latent heat, a relatively small amount of heat needed for crystallization to take place.

The major commercially frozen foods are as follows:

- fruits (strawberries, orange, raspberries, blackberries), either whole or pureed, or as juice concentrates
- vegetables (peas, green bean, sweetcorn, spinach, sprout and potatoes)
- fish fillets and seafoods (cod, shrimp and crab meat) including fish fingers, fish cakes or prepared dishes with an accompanying sauce
- meats (beef, lamb, poultry) as carcasses boxed joints or cubes and meat products (sausage, reformed steaks)
- baked goods (bread, cakes, fruits or meat pies)
- prepared foods (pizzas,deserts, ice cream).

3.4.1.1 Calculation of Freezing Time

Freezing time is the most important factor in making a high quality frozen food. It is difficult to define the freezing time precisely. During freezing processes, heat is conducted from the interior of a food to the surface and removed by the freezing medium. Some factors influence the heat transfer rate:

- the thermal conductivity
- the area of food available for heat transfer
- the distance that heat must travel through
- the temperature difference between food and freezing medium
- the insulating effect of boundary film of air surrounding food
- packaging, if present, is an additional barrier to heat flow.

Freezing time has been defined in several ways (Ramaswmy and Marcotte, 2003):

1. it is defined as the total time taken from the start of the freezing to the finish.
2. it is defined as the time taken by the food from its initial temperature to reach a target temperature of $-10°C$ or $-18°C$.
3. it is defined as the time interval from when the food reached $0°C$ to the time when it reached $-10°C$ or $-18°C$.
4. it is defined as the time taken to cross the zone of maximum ice crystal formation, i.e., $-1°C$ to $-5°C$. This definition somewhat is similar to 3.

3.4.1.2 Plank's Model for Calculation of Freezing Time

When freezing a food product to a given temperature, it is often difficult to make accurate predictions about the required time. This is due to uncertainty about the exact composition of the food product and the thermal properties of its components. Several models have been developed (Ramaswmy and Marcotte, 2003), Plank's model (1913) is one of the earliest models for predicting freezing times, it is useful for describing and estimating only the phase change period of the freezing process.

Plank's model developed based on the assumptions of follows:

1. the product to be frozen is " free" water
2. the freezing point of the product is $0°C$
3. the freezing process is initiated with the product at $0°C$ (as water) and terminated when water is converted to ice at $0°C$
4. all the heat removed is in the form of latent heat
5. the model is based on the rate of progression of the ice front from the surface and is terminated when the ice front reaches the midpoint level if frozen from both sides or when it reached the other side, when frozen from one side.

Making these assumptions, freezing rates for bodies of simple shapes can be calculated. As an example of the method, the time taken to freeze to the center of a slab whose length and breadth are large compared with the thickness, will be calculated.

Rates of heat transfer are equal from either side of the slab. Assume that at time t (s), freezing has penetrated a distance of x (m); the slab is divided into two halves (each with thickness $d/2$ (m)), the surface area of cross section is A (m^2), the temperature of the freezing medium is T_a $(°C)$, and the surface temperature of the food is T_s $(°C)$. Associate heat transfer coefficient is h $(W/[°Cm^2])$, product initially freezing point is T_f $(°C)$, thermal conductivity of frozen and unfrozen product is k_f $(W/[°Cm])$ and k_u $(W/[°Cm])$ respectively. The schematic of a slab freezing process is shown in Figure (3.5).

The freezing process has three scenarios:

1. Heat transfer from the freezing medium to the product - convection heat transfer, the equation is:

$$q = -hA(T_a - T_s) \tag{3.7}$$

2. The propagation of the heat through the frozen material - conduction heat transfer, the equation is:

$$q = -k_f A \frac{(T_s - T_f)}{x} \tag{3.8}$$

3. The liberation of laten heat at the ice front, the equation is:

$$q = -A\rho_f(\frac{dx}{dt})L \tag{3.9}$$

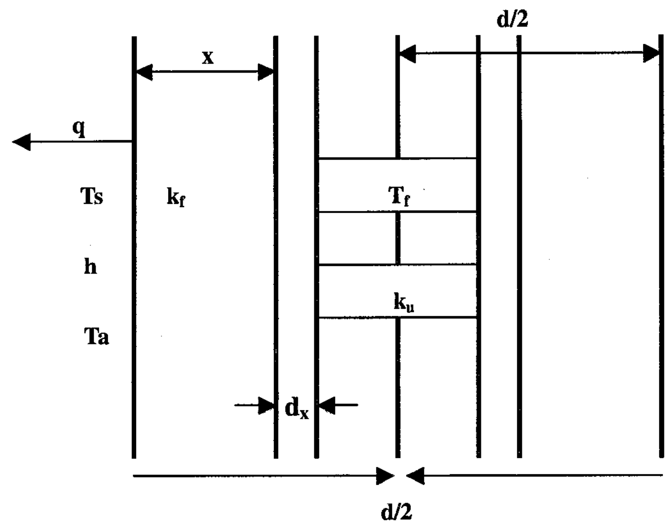


Figure 3.5 Schematic of a slab freezing process

after solving these three equations, we get:

$$(\frac{1}{h} - \frac{x}{k_f})dx = [\frac{(T_f - T_a)}{L\rho}]dt \tag{3.10}$$

to get the freezing time, from $x = 0$ to $x = d/2$ and $t = 0$ to $t = t_f$, the integration of Eqn. (3.10) is:

$$\int_{x=0}^{x=\frac{d}{2}} [\frac{x}{h} + \frac{x^2}{2}k_f]dx = \int_{t=0}^{t=t_f} [\frac{T_f - T_a}{L_\rho}]tdt \tag{3.11}$$

simplifying the equation (3.11), we get

$$t_f = [\frac{\rho_f L}{(T_f - T_a)}][\frac{d}{2} + \frac{d^2}{8k_f}] \tag{3.12}$$

Equation (3.12) applies to an infinite slab by the assumption, therefore, the general form of Plank's equation is:

$$t_f = [\frac{\rho_f L}{(T_f - T_a)}][P\frac{d}{h} + R\frac{d^2}{k_f}] \tag{3.13}$$

for an infinite slab, d is the thickness, for a cylinder or spherical shape, d is the diameter.

P and R are used to account for the influence of product shape, with $P = \frac{1}{2}$ and $R = \frac{1}{8}$ for infinite plate; $P = \frac{1}{4}$ and $R = \frac{1}{16}$ for infinite cylinder; and $P = \frac{1}{6}$ and $R = \frac{1}{24}$ for sphere.

3.4.1.3 Phase Change of Freezing and Thawing Processing

The three phases are solid, liquid and gas. A change of phase occurs when a substance passes from one phase state to another. The freezing point is the point at which the substance passes from a liquid to a solid.

As the water within the food product changes from liquid to solid, the freezing process of the food product results in a phase change during the freezing process. Prefreezing, phase change and postfreezing are three distinct periods in a food undergoing freezing. The phase change period happens after prefreezing and the temperature of water decreases to the freezing point as sensible heat is removed. The temperature remains at the freezing point until a complete phase change occurs as the laten heat of fusion is removed from liquid to solid ice. Figure (3.6) shows the temperature change during freezing and thawing of food.

The calculation of freezing time with Plank's equation is relatively simple. This equation describes only the phase change period of the freezing process.

3.4.2 Thawing Processing

When food is thawing in air or water, the surface ice of the food melts to form a layer of water. Water has lower conductivity and lower diffusivity than ice, so this layer of water reduces the rate at which heat is conducted to the frozen interior. This insulating effect increases as the layer of thawed food grows thicker. Therefore,

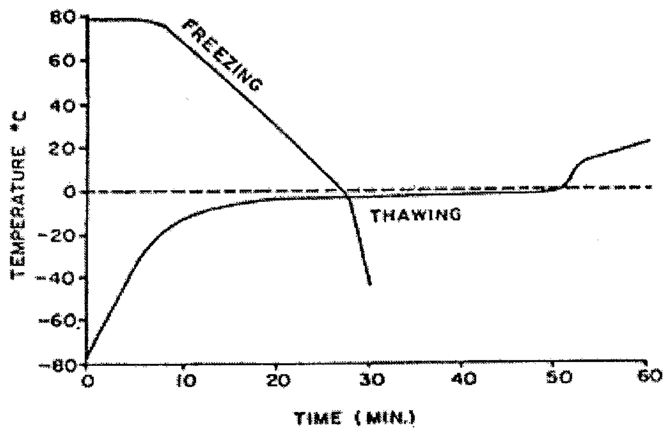


Figure 3.6 Temperature change during freezing vs thawing of food

thawing is a substantially longer process than freezing when temperature differences and other conditions are similar.

There are three ways to safely thaw food: in the refrigerator; in cold, frequently changed water; or in the microwave.

- Refrigerator Thawing
  This is the preferred method of thawing, but it is the slowest method. Small food items may defrost overnight in the refrigerator, but most foods require a day or two. For large foods, such as a turkey, allow one day for each 5 pounds of weight.

- Cold-Water Thawing
  This method is faster than refrigerator thawing, but it requires more attention. Food should be placed in a leakproof plastic bag and immersed in cold water. Make sure the bag doesn't leak, as bacteria from the air or surrounding environment could be introduced into the food. Also, food tissues absorb water that would result in watery, less-than-high-quality food. Change the water frequently, but at least every 30 minutes. After thawing, refrigerate the food until ready for use, or cook it immediately.

- Microwave Thawing

Use this method to defrost food only when you plan to cook it immediately. Some areas of the food may become warm and begin to cook during microwaving. Microwave thawing does not destroy bacteria, so the food still needs to be thoroughly cooked.

3.4.3 Calculation of Thawing Time

Thawing from a mathematical view point is just the reverse of freezing. Hence by just reversing the properties and conditions of freezing to match that of thawing, the Plank equation for thawing time model can be easily written as:

$$t_{th} = [\frac{\rho_u L}{T_a - T_f}][P\frac{d}{h} + \frac{Rd^2}{k_u}] \tag{3.14}$$

For most purposes, the Plank equation is used substituting or exchanging different constants to account for the various geometries of different food products.

3.5 High Pressure Processing

High pressure as a food preservation method was first used in milk production in 1899 (Hite, 1899). Although such research continued at intervals in the years following Hite and his coworkers' pioneering efforts, the big resurgence of interest in commercial high-pressure preservation treatment of food occurred in the 1980s. In the following years, high pressure was not introduced to food preservation and processing (Knorr, 1995), probably because of technical difficulties associated with pressure processing units and packaging materials (Ludikhuyze *et al.*, 2001).

During the last decade, high pressure gained renewed interest in the area of food preservation and processing, and high pressure processed products are commercially available in US, European, and Japanese markets, such as fruit smoothies, guacamole, ready meals with meat and vegetables, oysters, ham, chicken strips, fruit juices, and salsa in the United State.

The high pressure technique applied in food has shown advantages in inactivation of vegetative microorganisms and spoilage enzymes with minimized loss in quality attributes such as color, flavor and nutritional value. But bacterial spores cannot be reduced by high pressure alone without combination with other preservation techniques, in particular mild temperature elevation.

Some computer simulations were designed for high pressure as well, for example, CFD computer simulation of high pressure cooling process for pork (Chen *et al.*, 2004). The study demonstrated that the CFD modelling technique was an effective tool for simulation of the cooling process, which can be used for observations of transient temperature distribution in both the food being processed and in the equipment, extract some thermal properties, and also can become a tool for process designs of associated equipment and product processing (Chen *et al.*, 2004).

3.5.1 Principle of High Pressure Processing

High Pressure Processing (HPP) is a method of food processing where food is subjected to elevated pressures (up to 87,000 pounds per square inch or approximately 6,000 atmospheres), with or without the addition of heat, to achieve microbial inactivation or to alter the food attributes in order to achieve consumer-desired qualities. Most vegetative bacteria can be inactivated at pressures above 60,000 pounds per square inch. HPP retains food quality, maintains natural freshness, and extends microbiological shelf life. The process is also known as high hydrostatic pressure processing (HPP) and ultra high-pressure processing (UHP). Compared to thermal processing, HPP results in foods with fresher taste, and better appearance, texture and nutrition. High pressure processing can be conducted at ambient or refrigerated temperatures, thereby eliminating thermally induced cooked off-flavors. The technology is especially beneficial for heat sensitive products.

3.5.2 Equipment and Process of High Pressure Processing

The main components of a high pressure system are:

- Sample vessel
- Sample vessel lid
- Lid lock
- A pump
- A medium vessel

In a typical HPP process, the product is packaged in a flexible container (usually a pouch or plastic bottle) and is loaded into a high pressure chamber filled with a pressure-transmitting (hydraulic) fluid. The hydraulic fluid (normally water) in the chamber is pressurized with a pump, and this pressure is transmitted through the package into the food itself. Pressure is applied for a specific time, usually 3 to 5 minutes. The processed product is then removed and stored/distributed in the conventional manner. Because the pressure is transmitted uniformly (in all directions simultaneously), food retains its shape, even at extreme pressures. And because no heat is needed, the sensory characteristics of the food are retained without compromising microbial safety.

3.6 Computer 3D Techniques

3.6.1 Transformation Techniques

To correctly display an object, we used five types of transformations. Let v be the coordinate for a vertex, and each vertex always has four coordinates (x, y, z, w). The transformed vertex v' is accomplished by multiplying the old coordinates for a vertex

v and the transformation matrix, M. M is a 4 x 4 transformation matrix, and it is varied for different transformations, i.e. translation, rotation, scaling, perspective projection and orthographic projection.

$$v' = Mv \tag{3.15}$$

3.6.1.1 Translation

By multiplying translate matrix, an object moves by the given $x-$, $y-$, $x-$values.

$$M = \begin{bmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & y \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.16}$$

3.6.1.2 Rotation

By multiplying rotation matrix, an object rotates with an angle of a degree in a counterclockwise direction about the ray from point $(0, 0, 0)$. The matrix for rotating a degree about X-axis:

$$M = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cosa & -sina & 0 \\ 0 & sina & cosa & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.17}$$

The matrix for rotating a degree about Y-axis:

$$M = \begin{bmatrix} cosa & 0 & sina & 0 \\ 0 & 1 & 0 & 0 \\ -sina & 0 & cosa & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.18}$$

The matrix for rotating a degree about Z-axis:

$$M = \begin{bmatrix} cosa & -sina & 0 & 0 \\ sina & cosa & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.19}$$

3.6.1.3 Scaling

By multiplying scaling matrix, an object stretches, shrinks by the given $x-$, $y-$, $x-$values along each axis.

$$M = \begin{bmatrix} x & 0 & 0 & 0 \\ 0 & y & 0 & 0 \\ 0 & 0 & z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.20}$$

3.6.1.4 Perspective Projection

This projection makes objects appear to converge in the distance, that means, objects farther away appear smaller. The matrix is given below:

$$M = \begin{bmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & \frac{-(f+n)}{f-n} & \frac{-2fb}{f-n} \\ 0 & 0 & -1 & 0 \end{bmatrix} \tag{3.21}$$

3.6.1.5 Orthographic Projection

Objects are directly mapped on to the screen without affecting their relative sizes. The relative projective matrix is:

$$M = \begin{bmatrix} \frac{2}{r-l} & 0 & 0 & \frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & \frac{t+b}{t-b} \\ 0 & 0 & \frac{-2}{f-n} & \frac{f+n}{f-n} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.22}$$

3.6.2 Viewing Techniques

3.6.2.1 Color

The human eye perceives color through certain cells in the retina, called "cone cells", or just "cones". The three basic kinds of cone cells are red, green and blue. A computer-graphics monitor emulates visible colors by lighting pixels with a combination of red, green ,and blue light in proportions that excite the red-, green-, and blue-sensitive cones in the retina. In this Virtual Lab, we display a particular color using RGB (red, green, blue) packed color system.

3.6.2.2 Lighting

Different light may cause physical surfaces to have different properties. Some are shiny and preferentially reflect light in certain directions, while others scatter incoming light equally in all directions. The types of light used in this Virtual Lab include:

1. Ambient

   When the light is scattered by the environment, this light is called ambient. It seems that light comes from all directions.

2. Diffuse

   When the light comes from one direction, it is called diffuse.

3. Specular

   When light is reflected or bounces off from the surface of a particular object,it is called specular.

4. Emissive

   When the light is simulated or originates from materials, it is called emissive light.

3.6.2.3 Depth Buffer

It is very important to draw the objects that are closer to the viewing position and to eliminate objects obscured by others nearer to the eye. Depth buffer enables us only to display the visible part of the object(s) which is not obscured by something else.

3.6.2.4 Blending

It is a technique to display the objects in a translucent manner on screen.

3.7 Summary

This Section provides the basic background of concepts involved in selected food processing applications and computer applications. Actual details, design and operation of the euipment used for food processing may differ from the virtual equipment viewpoint and those will be developed in Chapter 5.

CHAPTER 4

VISUALIZATION OF FOOD PROCESSING SCENARIOS

4.1 Introduction

Heat transfer, mass balance, freezing and thawing process, and agitation of cans for rotary retort are some foundational unit operations in food processing. In order to teach or learn these concepts in a food processing course or research, the computer simulations of those food processing scenarios were developed in our research. The first objective of this project is to develop a virtual lab to simulate the calculations of heat transfer, mass balance and freezing and thawing processes. The second is to visualize the heat transfer process, mixing of mass balance, the phase change of freezing and thawing process, and two modes of agitation of cans for rotary retort in thermal processing. This will make the phenomena much more intuitive and vivid when shown in the class, and help students to understand concepts and phenomena easily, and as well evoke the interest of the students during the study. The 3D graphics make the visualized objects be more vivid and similar to real objects.

4.2 Design Methodology

4.2.1 Designing of Main Interface of Simulation

The main interface of simulation includes three parts illustrated as in Figure 4.1.

- Tool Bar Area
  This part includes three buttons which are File, method selection and Help buttons.

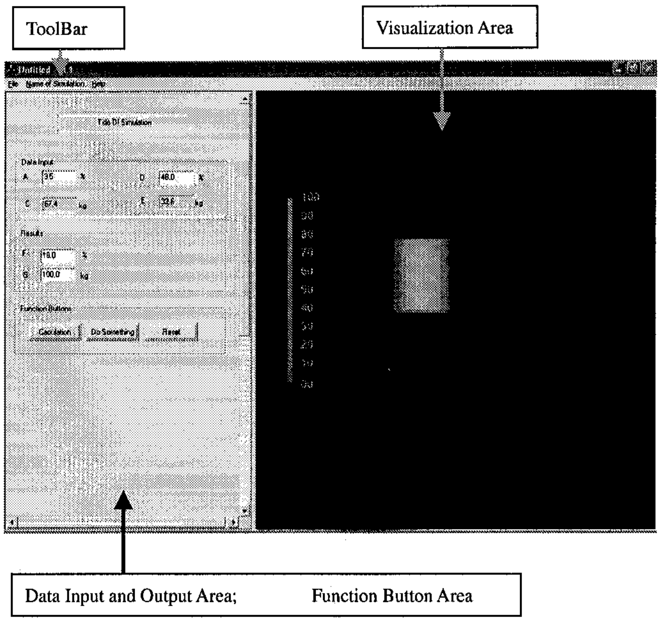


Figure 4.1 The form of the main interface of the virtual lab

- Data Input and Output area and Functional Buttons Area

  This area includes data input, data output or results and functional buttons for calculating the results or controlling the graphics of visualized objects.

- Visualization Area

  This area is used for displaying static or animated graphics, which are controlled by the buttons in the tool bar area or the functional button area.

4.2.2 Designing of Heat Transfer Simulation

The design methodology of heat transfer simulation includes three major items which are listed as follows:

- **Selection of food processing scenario**

  Conduction heat transfer in steady state through a slab.

- **Equations used in the simulation**

The thermal resistance, R_t ($°Cm^2/W$), can be calculated by the equation:

$$R_t = \frac{L}{k * A} \tag{4.1}$$

where

L - thickness of slab (m)

k - thermal conductivity ($W/[m°C]$)

A - area of the slab (m^2)

Conduction heat transfer rate (q) through a slab in steady state can be calculated through the following equation:

$$q = \frac{kA(T_2 - T_1)}{L} \tag{4.2}$$

where

q - heat transfer rate (W)

T_2 - T_1 - temperature difference ($°C$)

L - specific thickness (m)

The k and A are the same as in equation (4.1).

For any points between the thickness of a slab, the temperature, T_x ($°C$), at distance Δx is calculated by the equation:

$$T_x = \frac{T_2 - T_1}{L} \Delta x + T_1 \tag{4.3}$$

where

Δx - distance from the surface to any point within thickness of the slab (m)

- **Temperature represented in colors**

  The highest temperature is represented in red, the lowest is in blue.

4.2.3 Designing of Mass Balance Simulations

- **Selection of food processing scenario**

  The selected applications of mass balance are the two component mass balance system and the Pearson Rule.

- **Equations used in the simulation**

  - Two component system:

$$m_a + m_b = m_p \tag{4.4}$$

$$x_a * m_a + y_b * m_b = z_p * m_p \tag{4.5}$$

where

m_a - quantity of component A (kg)

m_b - quantity of component B (kg)

m_p - quantity of product (kg)

x_a - solids percentage of component A

y_b - solids percentage of component B

z_p - solids percentage of product

- Pearson Rule:

$$m_A = \frac{|C_B - C_C|}{|C_B - C_C| + |C_A - C_C|} m_{total} \tag{4.6}$$

$$m_B = \frac{|C_A - C_C|}{|C_B - C_C| + |C_A - C_C|} m_{total} \tag{4.7}$$

where

m_A - quantity of component A (kg)

m_B - quantity of component B (kg)

m_{total} - quantity of product (kg)

C_A - concentration of component A

C_B - concentration of component B

C_C - concentration of component C

- **Concentration represented in colors**

  The highest concentration (100%) is represented in green, and the lowest (0%) in red.

4.2.4 Designing of Freezing and Thawing Simulation

The freezing and thawing processing simulations include calculations of freezing and thawing time, and visualization of phase change of freezing and thawing processes.

- **Selection of food processing scenario**

  The freezing processing and thawing processing are selected in the simulation. Plank's method is employed for calculating the freezing time and thawing time. Three different shapes are selected for simulating both calculation and phase change, which include slab, cylinder and sphere.

- **Equations used in the simulation**

  The freezing time by Plank's method is:

$$t_f = [\frac{\rho_f L}{(T_f - T_a)}][P\frac{d}{h} + R\frac{d^2}{k_f}] \tag{4.8}$$

The thawing time by Plank's method is:

$$t_{th} = [\frac{\rho_u L}{(T_a - T_f)}][P\frac{d}{h} + R\frac{d^2}{k_u}] \tag{4.9}$$

where

t_f - freezing time (s)

t_{th} - thawing time (s)

ρ_f - density of frozen material (kg/m^3)

ρ_u - density of unfrozen material (kg/m^3)

L - latent heat (kJ/kg)

T_a - medium temperature $(°C)$

T_f - freezing point $(°C)$

d - thickness of slab (m)

k_f - thermal conductivity of frozen material $(W/[m°C])$

k_u - thermal conductivity of unfrozen material $(W/[m°C])$

P and R values for different shapes are list as follows:

slab: $P = 0.5$, $R = 0.125$

cylinder: $P = 0.25$, $R = 0.0625$

sphere: $P = 0.167$,$R = 0.0416$

- **Temperature represented in colors**

  The freezing phase is represented in blue, the thawing phase in red.

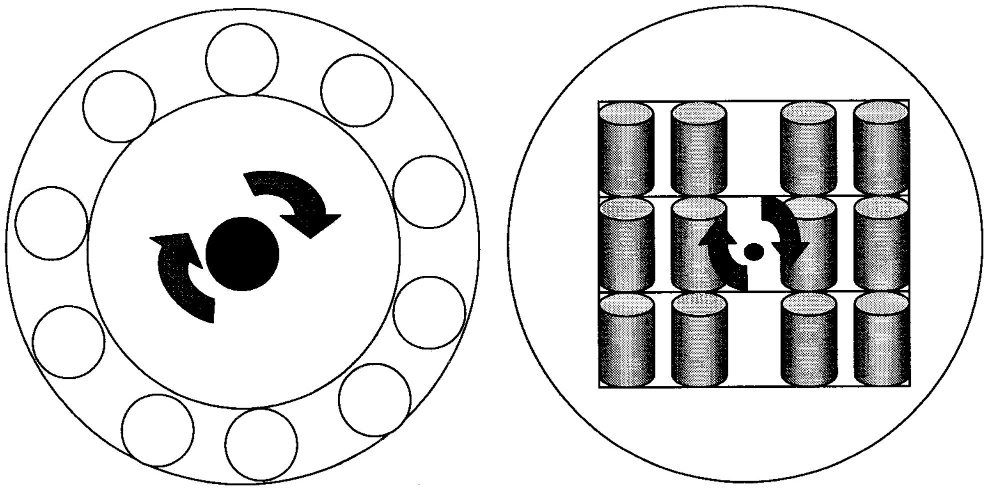
4.2.5 Designing of Simulation of Agitation of Cans

- **Selection of food processing scenario**

  Two modes of agitation of cans for rotary retort are selected in food thermal processing which are axial agitation and end-over-end agitation.

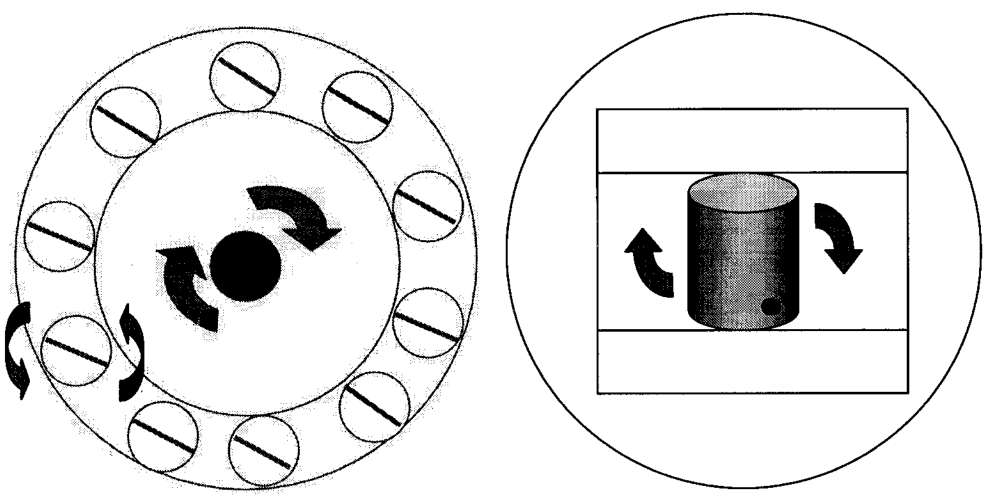
- **Designing of simulation of axial agitation**

  The schematic of axial agitation is shown as in Figure 4.2(a). According to the principle of this type of agitation, the cans in the simulation are drawn in 3D. In order to illustrate the principle clearly, the marks are drawn in red color on the top side of the cans so that the rotation of the cans can be seen easily, the designing schematic for the simulation of axial agitation shown in Figure 4.3(a).



(a) Schematic of axial agitation (b) Schematic of end-over-end agitation

Figure 4.2 Schematics of agitation of cans in thermal processing



(a) Designing schematic of axial agitation (b) Designing schematic of end-over-end agitation

Figure 4.3 Designing schematic of agitation of cans in thermal processing

- **Designing of simulation of end-over-end agitation**

  The schematic of end-over-end agitation is shown as Figure 4.2(b), the figure shows the principle of end-over-end agitation. The end-over-end agitation simulation is designed according to the working principle of end-over-end agitation, with some modifications in the simulation. These include: only one can is transparent; and a particle is drawn in the shape of a small sphere inside the can so that the user can observe the different effects when the rotation speeds are different. The speed of agitation is set at three speeds: low speed, intermediate speed and high speed. Three buttons are defined for controlling the three rotation speed.

4.3 Results and Discussions

4.3.1 Heat Transfer Simulation

For steady state conduction heat transfer, through equation 4.2, we can find that the heat transfer rate concerns with four factors, which are L, the thickness of slab; k, the thermal conductivity; A, the area of the slab and temperature difference ΔT. If the materials of slabs are different, their heat conductivities will be different; on the other hand, if two slabs made of the same material, k, the thermal conductivity is constant, in this condition, the heat transfer rate is effected by the other three factors. How to show the relationship among those factors in class within short time and with less calculations? The heat transfer simulation provides a quick and easy way to solve this problem. We use example 1 to show the developed result of conduction heat transfer simulation and the functionalities of this simple simulation.

Example 1:

A meat slab (1.0 m x 1.0 m x 0.1 m) is placed between two plates, one maintained at 100°C, and the other at 40°C; the thermal conductivity of the meat is 0.48 W/m°C. Calculate the rate of heat transfer under steady state conditions, and give *the temperature profile through the meat slab.*

The following results show the functionalities of heat transfer simulation based on the example 1.

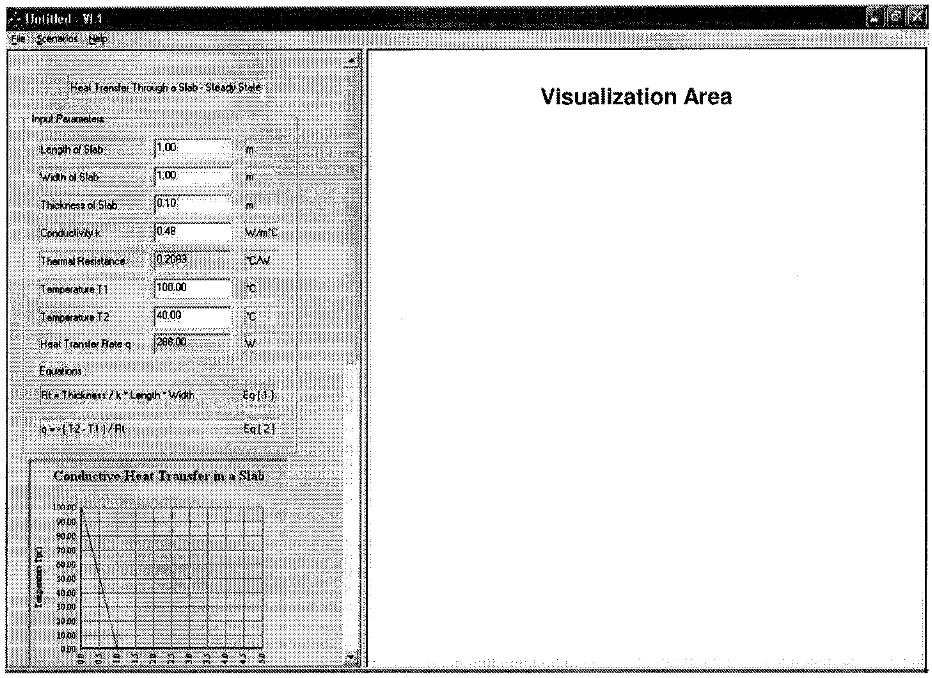
4.3.1.1 Calculation Interface of Heat Transfer Simulation

The four Figures 4.4(a), 4.4(b), 4.5(a) and 4.5(b) show the interfaces of simulation for conduction heat transfer through a slab under steady state conditions.

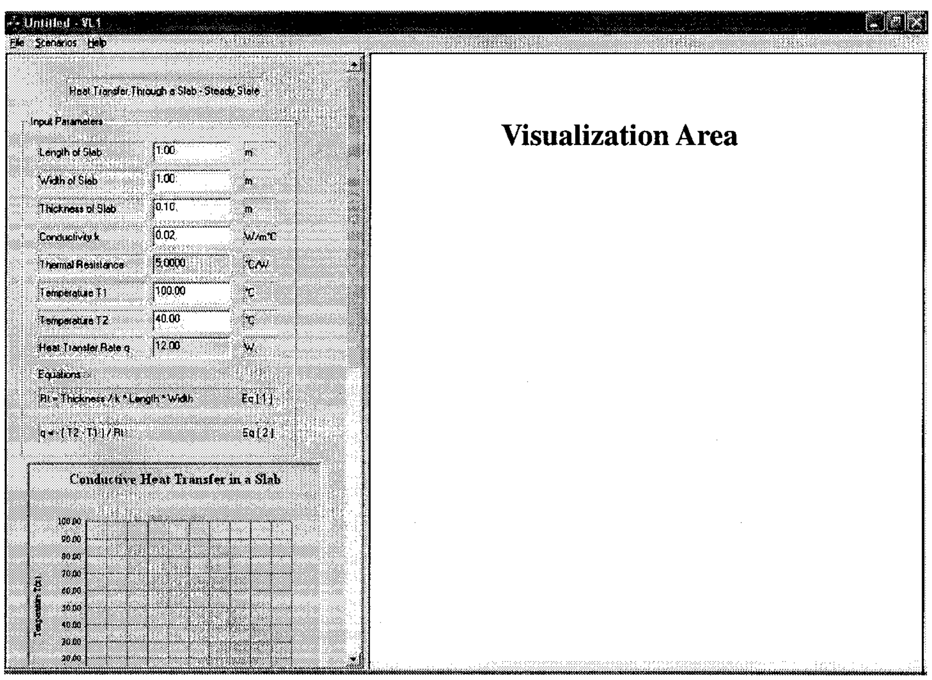
Figure 4.4(a) is the interface of input and output parameters: the length is 1.0 m, width is 1.0 m, thickness is 0.1 m and thermal conductivity is 0.48 W$/m°C$. When those four variables are put in, the result of thermal resistance is calculated by equation 4.1 which has been embedded in the program, and the value of thermal resistance will be displayed ($0.2083°C/W$). After inputting the temperature, T_1 ($100°C$) and T_2 ($40°C$), the heat transfer rate, q, is calculated automatically according to equation 4.2 and the resulting q value ($288W$) is displayed in its variable edit box.

When the user wants to know how the four factors effect the heat transfer rate, for example, if the user wants to show relationship between the conductivity of the slab and heat transfer rate, just modify the conductivity valve, then the new heat transfer rate will be obtained immediately. Figure 4.4(b) shows the result of heat transfer rate ($12.0W$) after the conductivity of the slab was changed to 0.02 $W/m°C$ as in an insulating material. This is easy and fast to demonstrate comparison of the slab heat transfer rates with insulting materials; no need to recalculate again, this advantage of simulation improves the efficient in the class and saves time as well. This also can be used to change any other factor and to see the change of heat transfer rate.

Figure 4.5(a) shows the coordinates, in which the x axis is the distance Δx, and the y axis is the temperature at Δx. The temperature profile is shown in this coordinate



(a) Result of calculation of conduction heat transfer rate



(b) Result of heat transfer rate after changing the conductivity of the slab

Figure 4.4 Interface of calculations of conduction heat transfer simulation system after the button $\boxed{\text{Temperature Profile}}$ is pressed, the temperature profile shows the linear line of the temperature with Δx.

Figure 4.5(a) shows the function buttons for controlling the visualization of the object in **Function Selection** frame. When the button $\boxed{\text{Show Visualization}}$ is pressed, the visualized slab will be shown in the visualization area.

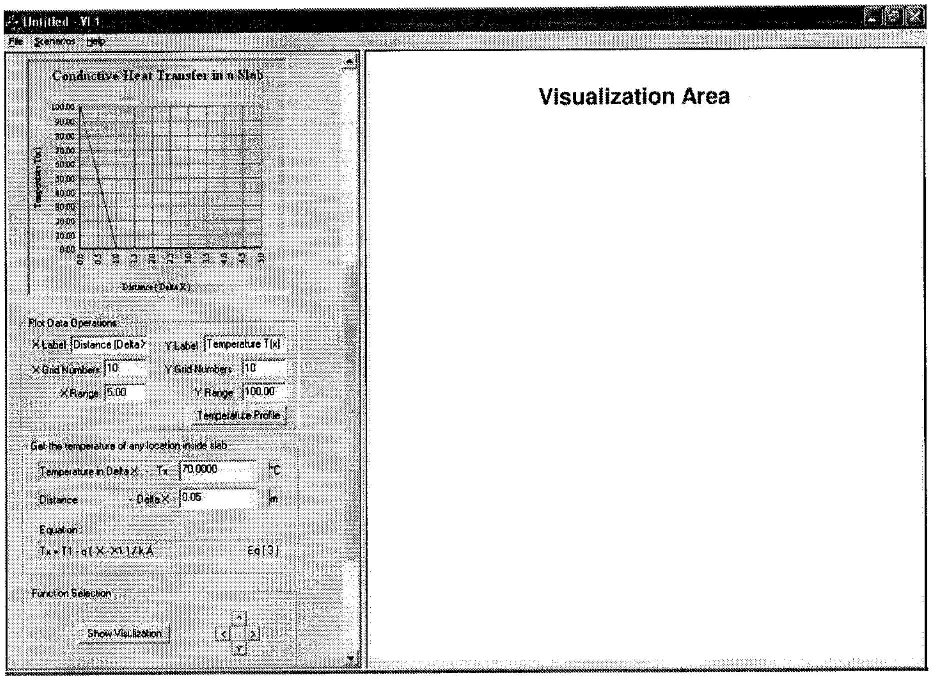
4.3.1.2 Visualization Interface of Heat Transfer Simulation

Figure 4.5(b) shows the result of visualization of conduction heat transfer through a slab in steady state. The red cuboid and blue cuboid represent the heat sources, the red the high temperature side, the blue the low temperature side. The middle cuboid represents the slab.

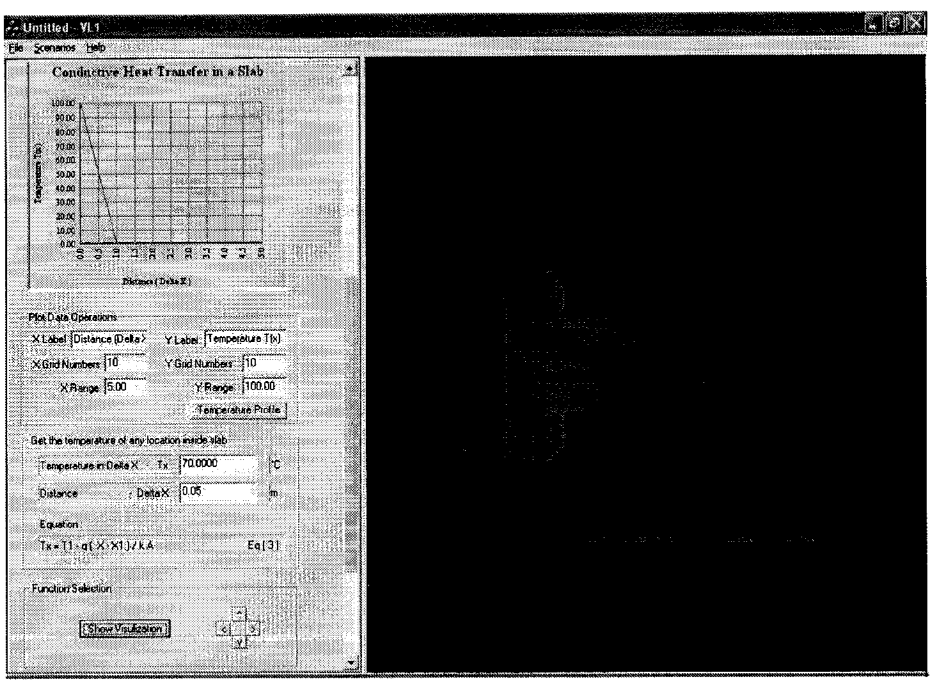
The slab is placed between the red cuboid and blue cuboid. The slab contacts directly the heat source to depict the heat transfer is only conduction, and not convection.

From the figure, we can observe that the color of slab is not a single color. The temperature distribution is represented in colors, the red becoming light gradually from the contact surface of the slab to the blue color side. That means the temperature drops steadily, and heat transfer is transferred from high temperature to low temperature. Since the temperature in the slab varies by location but does not change with time, this state is called steady state.

The visualization of temperature distribution in colors takes the place of the traditional way of drawing an oblique line with the high position resulting higher temperatures, and the low position representing lower temperatures. The visualization makes results more visual and distinct than the traditional method.



(a) Temperature profile and function buttons of conduction heat transfer simulation



(b) Visualization of phenomenon of conduction heat transfer through a slab

Figure 4.5 Results of function buttons and visualization of conduction heat transfer through a slab

4.3.2 Result of Mass Balance Simulation

Mass balance is the important application using in food processing as described in Chapter 3. For two component mass balance, we usually draw a process block diagram as shown in Figure 3.1, and write every components and concentration on block, then solve the equations to get the unknown values. If any parameters are changed, the instructors need to recalculate, this will cost much time in class. In order to make this process easy and spend less time in class, simple two component mass balance and the Pearson rule simulations were developed. Other examples can easily be developed using similar concepts.

Example 2 is used to show the developed result and the functionality of mass balance simulation.

Example 2:
A dairy manufactures wants to produce 100 kg batches of low fat cream product (fat 18%*) by blending milk (fat* 3.5%*) and double cream (fat* 48%*). What quantities of milk and double cream should be mixed?*

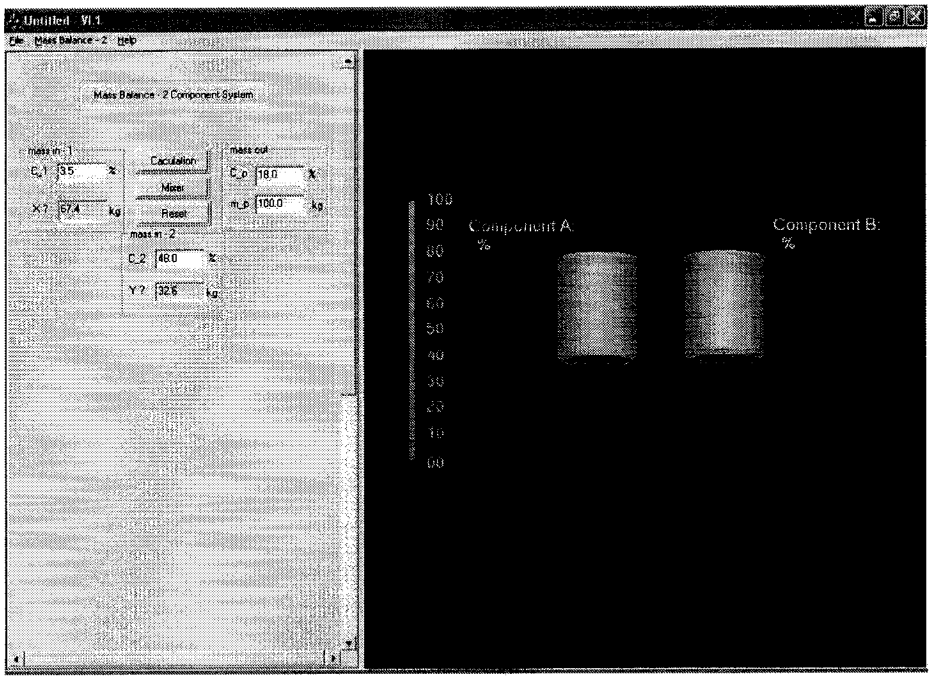
4.3.2.1 Simulation of the Two Component System of Mass Balance

Figure 4.6(a), 4.6(b), 4.7(a) and 4.7(b) show the interfaces of calculation and visualization of the two component system for mass balance.

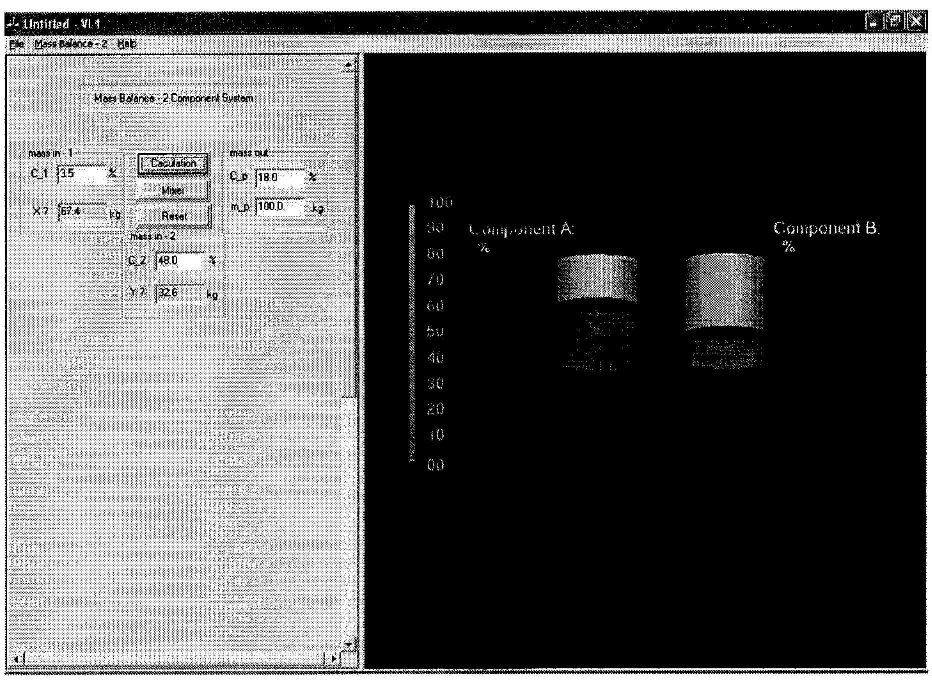
Figure 4.6(a) shows the result of the initial interface of simulation for the two component mass balance system.

From Figure 4.6(a), we can find that there are three frames which include two components of mass-in and one mass-out in data input and output area:

1. mass in-1: C_1 is mass percentage of concentration of component 1, $X?$ is unknown quantity of component 1;

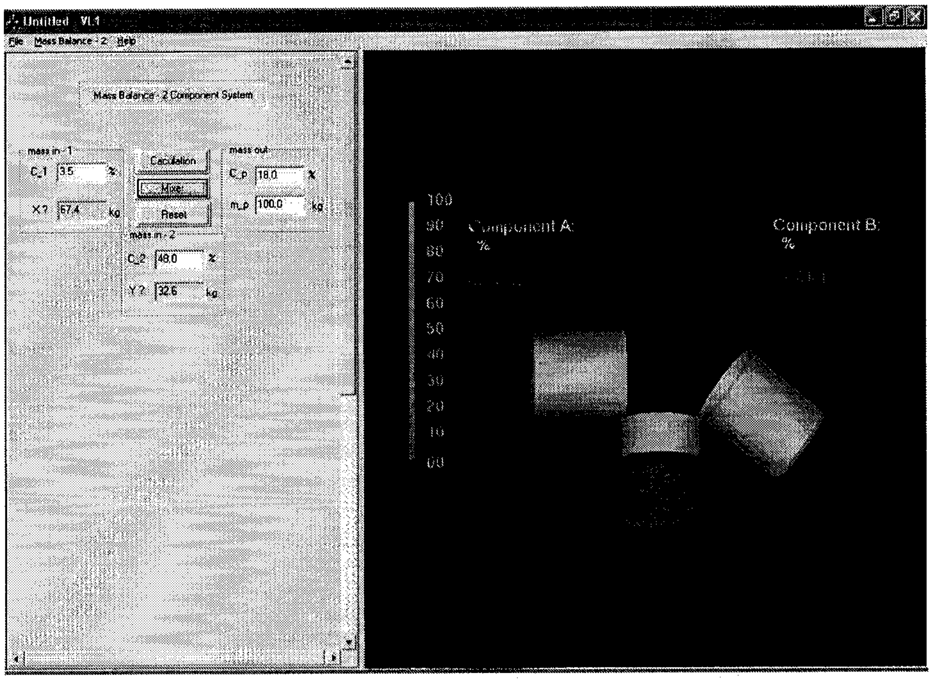


(a) Initial interface of simulation of the two components mass balance system

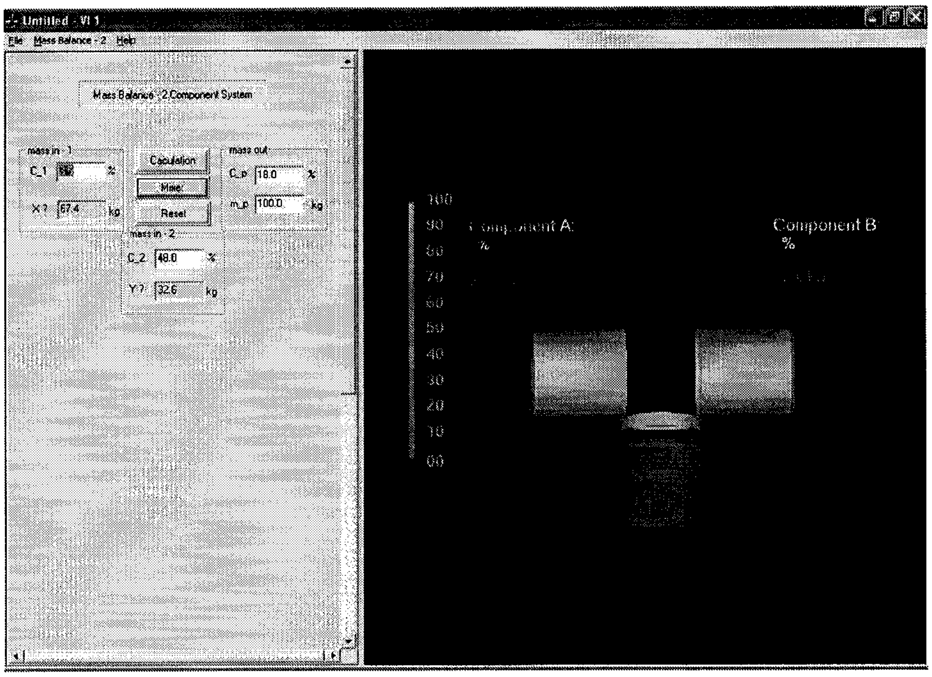


(b) Interface of simulating calculation of the two components system mass balance

Figure 4.6 Results of initial interface and output of calculation of the two component mass balance system



(a) Simulation of mixing process of the content in two containers



(b) simulation of final product after mixing two components

Figure 4.7 Results of simulation of mixing process of the two component mass balance system

2. mass in-2: C_2 is mass percentage of concentration of component 2, $Y?$ is unknown quantity of component 2;

3. mass out: C_p is mass percentage of concentration of mixed product, m_p is the total quantity of product.

The known parameters can be modified by the user, which include:

1. C_1: mass percentage of concentration of component 1 (milk, fat 3.5%);

2. C_2: mass percentage of concentration of component 2 (double cream, fat 48%);

3. C_p: mass percentage of concentration of mixed product (low fat cream, fat 18%);

4. m_p: the total quantity of product (100 kg).

The value of total quantity of product, m_p, must be less or equal to 100 kg.

The unknown parameters can not be input and modified by user, which include:

1. $X?$: the quantity of component 1 (milk);

2. $Y?$: the quantity of component 2 (double cream).

The three buttons are defined for calculation, performing mixing process and reset of the parameters. These buttons are $\boxed{\text{Calculation}}$, $\boxed{\text{Mixing}}$ and $\boxed{\text{Reset}}$. There are two empty containers shown in the visualization area.

Figure 4.6(b) shows the result after pressing the $\boxed{\text{Calculation}}$ button, the unknown values $X?$ (67.4 kg) and $Y?$ (32.6 kg) are obtained. At the same time, the quantity of component 1 ($X?$) and the quantity of component 2 ($Y?$) are shown in the

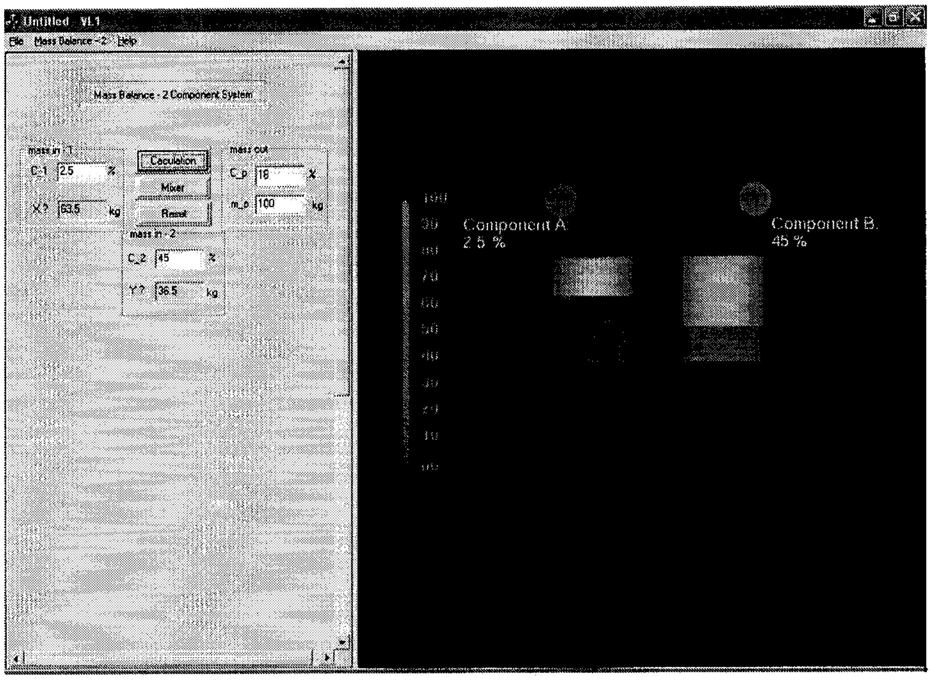


Figure 4.8 Result of calculation after changing two mass in components concentration values by using two component mass balance simulation

two containers by different colors in the visualization area, the colors referring the concentrations of the two components.

Figure 4.7(a) shows the mixing process. The two containers with component 1 and component 2 are pouring the contents into the product container. That indicates the two mass-in components are mixed.

Figure 4.7(b) shows the final product after mixing the two components. The color refers to the concentration of the final product, the amount of product is 100 *kg*. There is a criterion bar of concentration drawn aside of the containers as the reference for indicating concentration of each component. The visualization of mixing process is used to make the lecture much more vivid and interesting.

When we changed milk fat from 3.5% to 2.5%, and double cream fat from 48% to 45%, and press Calculation button again, the quantities of milk and double cream display in corresponding edit box ($X = 63.5$, $Y = 36.5$) immediately, no need to solve the equations and recalculate result on black board as traditional method during class. The simulation really save the time. The result is shown in Figure 4.8, other visualized results for this change are similar with the above four figures.

The $\boxed{\text{Reset}}$ button allows the user to reset the all known parameters and do another calculation and simulation of the mixing process.

4.3.2.2 Simulation of the Pearson Rule of Mass Balance

The Pearson Square is extensively used in confectionary industry and is often used to determine the amounts of different syrups that are needed to be mixed in order to achieve the desired solute concentration in the syrup. In order to omit drawing the Pearson Square schematic and simplify calculation, the simulation of the Pearson Rule was developed, we are going to use the example 3 to show the result and functionality of this simulation.

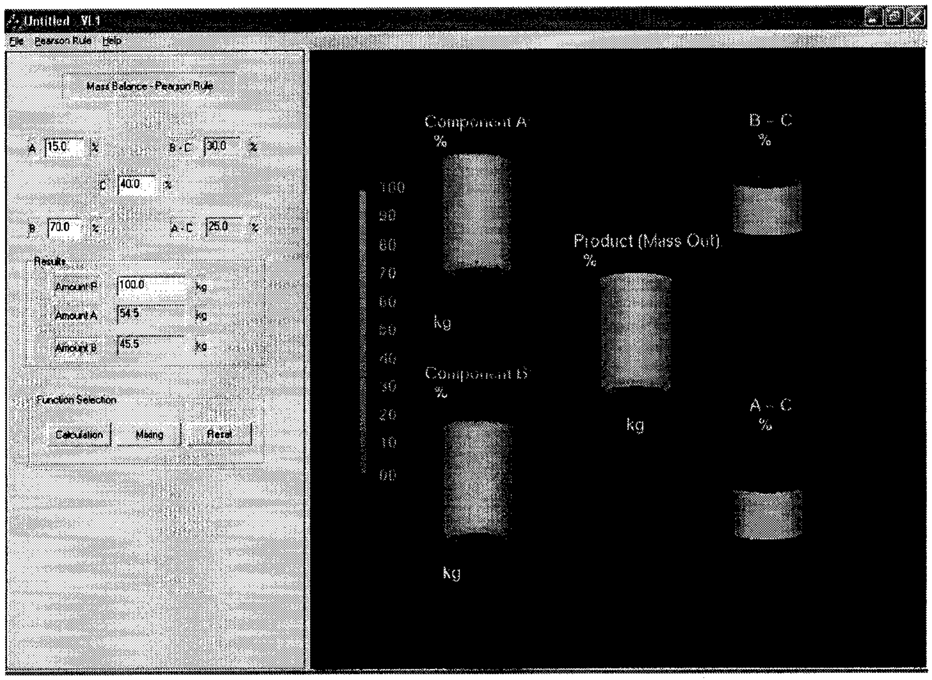
Example 3:

A fruit squash containing a total soluble solids content of $40°B$ *is to be prepared by mixing a fruit puree containing* 15% *soluble solids and a concentrated syrup of* $70°B$. *Calculate puree and syrup needed to be mixed to make* 100 kg *squash.*

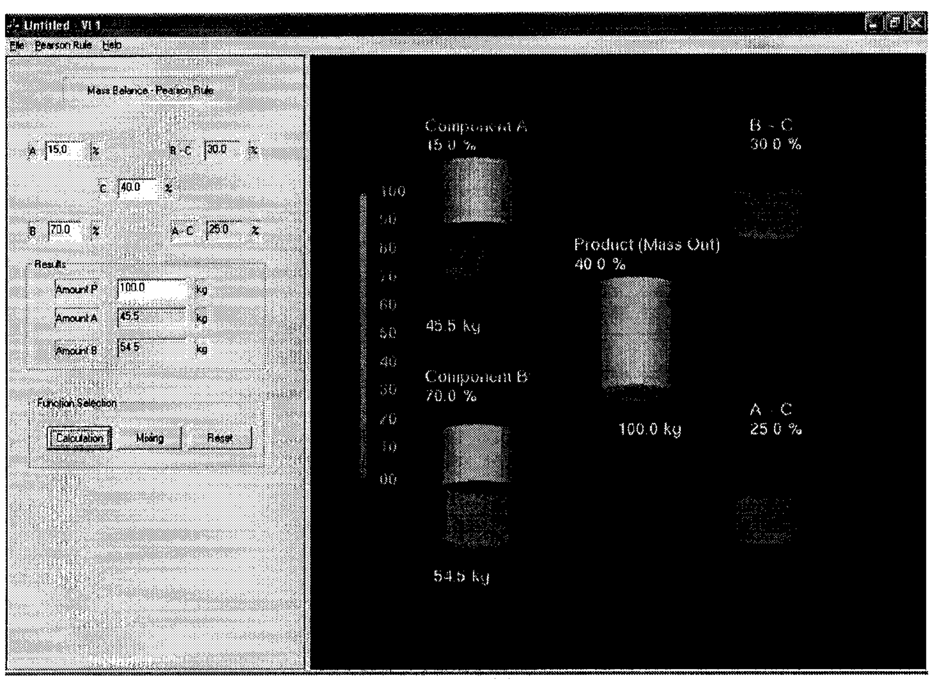
Figure 4.9(a), 4.9(b), 4.10(a) and 4.10(b) show results of simulation of the Pearson Rule in mass balance.

Figure 4.9(a) shows the initial interface of simulation of the Pearson Rule. The Pearson Square is developed in the data input and output area. A, B, $|B - C|$ and $|A - C|$ were defined as the four vertex points of the square, and C is in center of the square. The value in each vertex point represents the corresponding concentration in percentage.

There are another three edit boxes in the **Results** frame area, **Amount** A, **Amount** B and **Amount** P, which are the quantity of A, B and C as we defined three variables m_A, m_B and m_{total} respectively in equations 4.6 and 4.7.

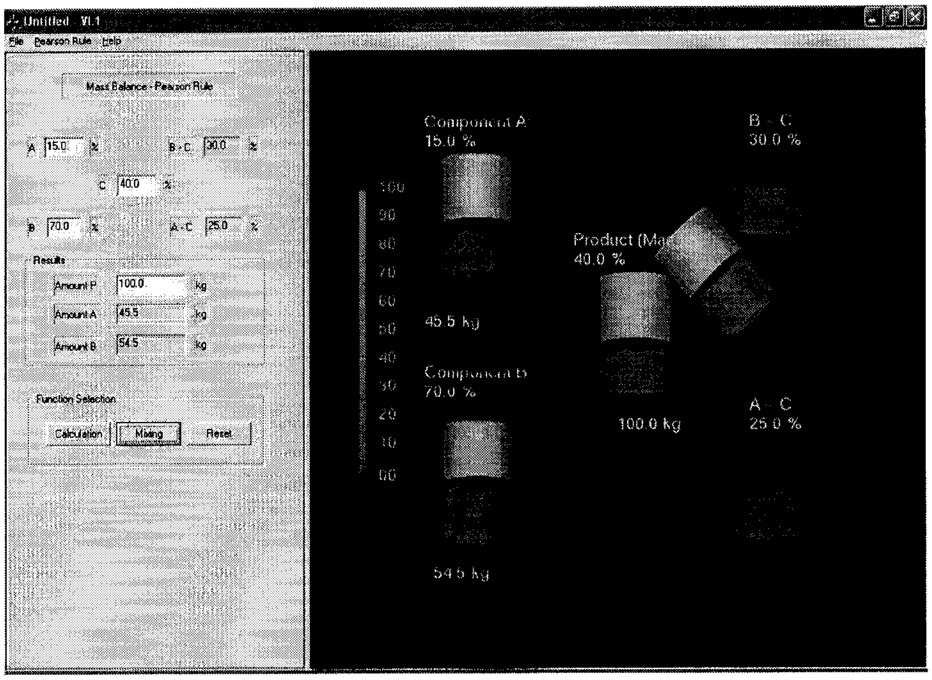


(a) Initial interface of simulation of the Pearson Rule

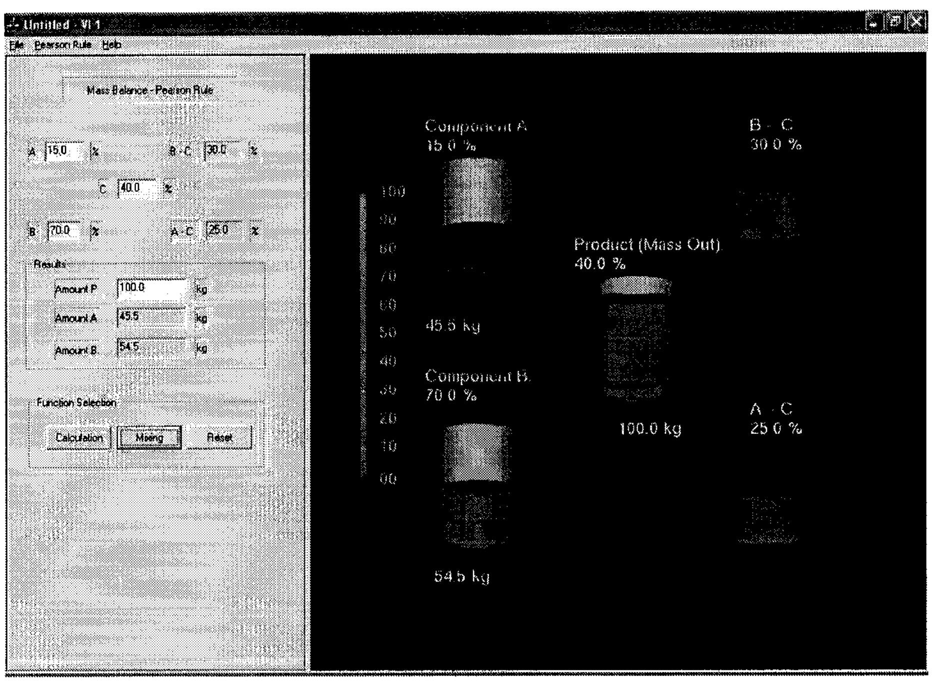


(b) Interface of simulation of calculation for the Pearson Rule

Figure 4.9 Results of initial interface and output of calculation for simulation of the Pearson Rule



(a) Simulation of mixing process of two components by using the Pearson Rule



(b) Visualization of final product after mixing process by using the Pearson Rule

Figure 4.10 Results of simulation of mixing process by applying the Pearson Rule in mass balance

The known parameters are $A = 15$, $B = 70$, $C = 40$ and **Amount** $P = 100$.

The unknown parameters are **Amount** A, **Amount** B.

Three function buttons are defined, which are:

1. $\boxed{\text{Calculation}}$: is used to calculate the result;
2. $\boxed{\text{Mixing}}$: is used to show the visualization of mixing process;
3. $\boxed{\text{Reset}}$: is used to reset all known parameters and to do another simulation of calculation and mixing process.

Three empty 3D containers are drawn for component A, component B and component C (Product) in the visualization area. There are another two 3D short cylinders drawn in corresponding places with the $|A - C|$, $|B - C|$ in the data area.

When the known parameters are input, the bottom colors of containers A , B and C are changed, and that represents the concentrations of A , B and C (Product).

When the $\boxed{\text{Calculation}}$ button is pressed, the **Amount** A (54.5) and **Amount** B (45.5) values are obtained by the equations 4.6 and 4.7 that have been embedded in the programs. In the meanwhile, the containers of A and B are filled the contents to different heights and in different colors, height representing the amount, and the color representing the concentration. This state of simulation is shown in Figure 4.9(b).

The criterion bar is drawn with two colors shown in Figure 4.9(a), green and red, the red represents the lowest (0%) concentration, the green the highest (100%). The concentration of components increases from the red color side to the green color side.

The mixing process is shown in Figure 4.10(a). When the $\boxed{\text{Mixing}}$ button is pressed, the mixing process starts, the two containers of A and B are pouring the contents into the container C (Product). After mixing, the color of the content in the

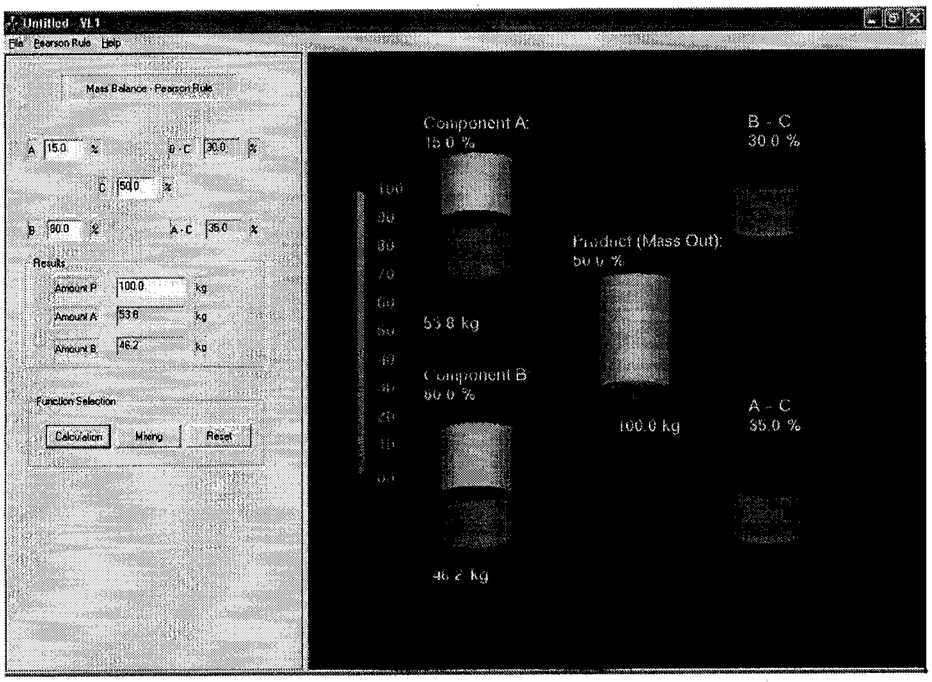


Figure 4.11 Result of calculation after changing concentrations of B and C

container C changed to the color of concentration of C. The final product is achieved, and the mixing process is finished. This state is shown in 4.10(b).

All known parameters can be modified according to the user's requirement. When any of them are changed, the results of the unknown parameters will be achieved by pressing Calculation button. Figure 4.11 shows the result of calculation after changing concentration of C to 50, and B to 70. The visualization of the mixing process is similar to above example. This functionality of the simulation provides a convenient way to explain the concept and application of the Pearson Square in the class.

4.3.3 Result of Freezing and Thawing Processing Simulation

The situation during freezing process is one of product cooling while in the case of thawing, it is product warming. In freezing process, heat is removed from water and thawing process heat is added to ice. Under comparable conditions, which process last longer? As we know, because thermal conductivity and thermal diffusivity of ice are much larger than that of water, the freezing process will be faster than the thawing process. How to explain this difference? The answer is to calculate the freezing time and thawing time by giving examples, this calculation may take much time. The freezing and thawing processing simulation can be used to solve this problem, we will use examples 4(a) and 4(b) to show the functionality and developed result of this simulation.

Example 4:

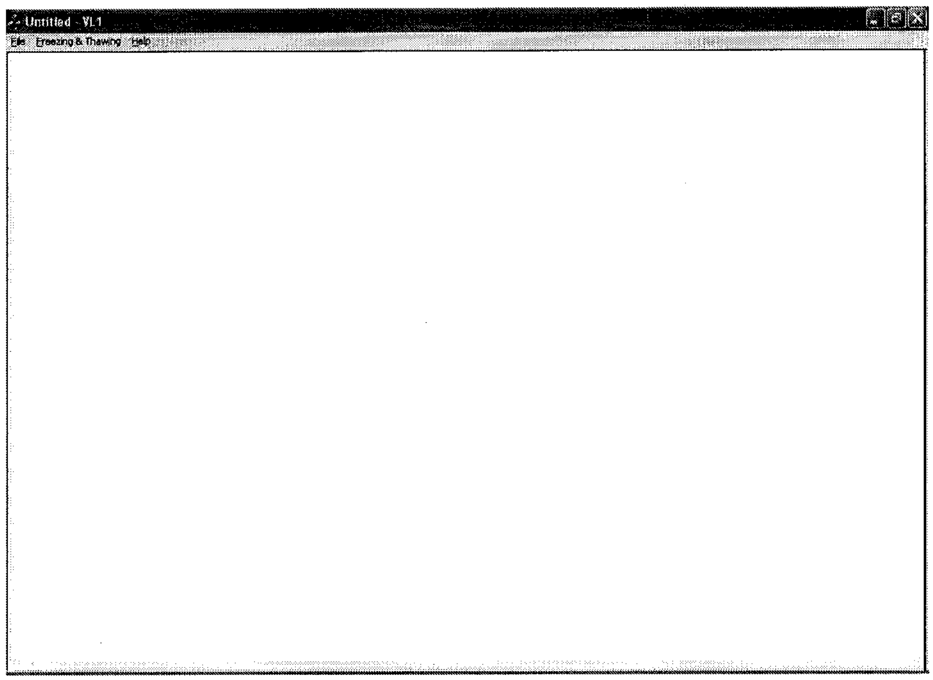
(a) 100 *kg meat (77% moisture) at an initial temperature of* 20°*C is to be frozen to* −20°*C. Assume that the initial freezing point is* −1°*C. Assume the density of the frozen product to be* 1100 kg/m^3 *and that the meat is frozen in* 10 *cm thick slabs in a plate freezer at* −40°*C. Further assume that latent heat is 258 kJ/kg, thermal conductivity of frozen meat is 1.9 W/m°C and the h value associated with the plate freezer is* 60 $W/m^{2\circ}C$. *Calculate the freezing time.*

(b) *In the reverse thawing process, the frozen meat at* −20°*C is placed in the plates maintained at* +40°*C (providing the same temperature differential). Assume density of unfrozen material to be* 1200 kJ/m^3, *thermal conductivity* 0.48 *W/m°C and same h and L values. Calculate the thawing time.*

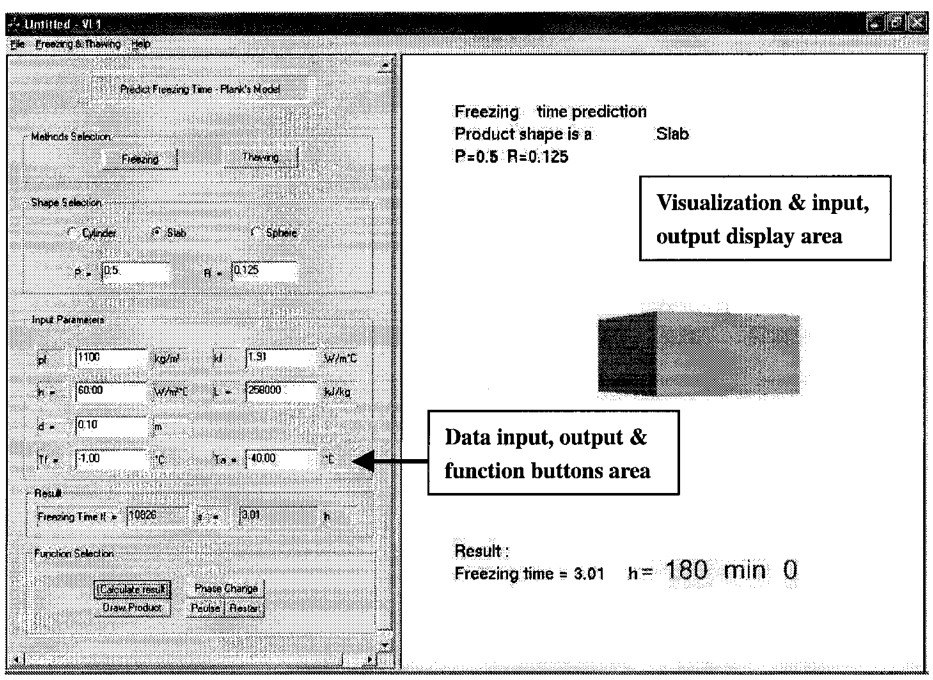
4.3.3.1 Main Interface of Freezing and Thawing Processing Virtual Lab

Figure 4.12(a) shows the initial main interface of simulation of freezing and thawing processing. There is a button in the toolbar of the frame, Freezing & Thawing, which tells the user that the simulation is performing freezing and thawing process. When the button is pressed, the whole interface is split into two areas as shown in Figure 4.12(b). The left hand side is for data input and output, and function buttons; the right hand side area is the visualization area for displaying the graphics.

The function buttons and all variables are designed in the data input and output



(a) Initial interface of freezing and thawing processing virtual lab



(b) Split interface of freezing and thawing processing virtual lab

Figure 4.12 Main interface of freezing and thawing processing virtual lab area. For each operation, the input parameters and output results can be displayed in the visualization area by the text format, so that the user can verify the selected method and the relative input values.

4.3.3.2 Functionalities of Freezing and Thawing Process Virtual Lab

- Method Selection:

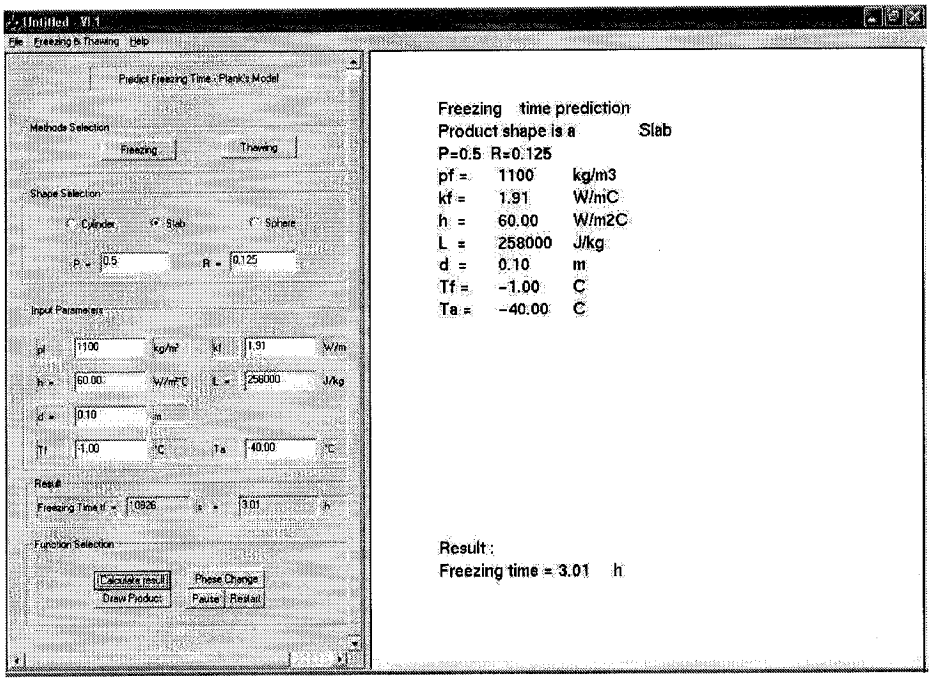
In this part, two buttons are defined for the selection of freezing method or thawing method. One button is named Freezing, and the other is Thawing. When one of them is pressed, the text for the selected method is displayed in the visualization area, and reminds the user which method is selected. Figure 4.13(a) and 4.13(b) show the examples for both freezing and thawing methods.

- Shape Selection:

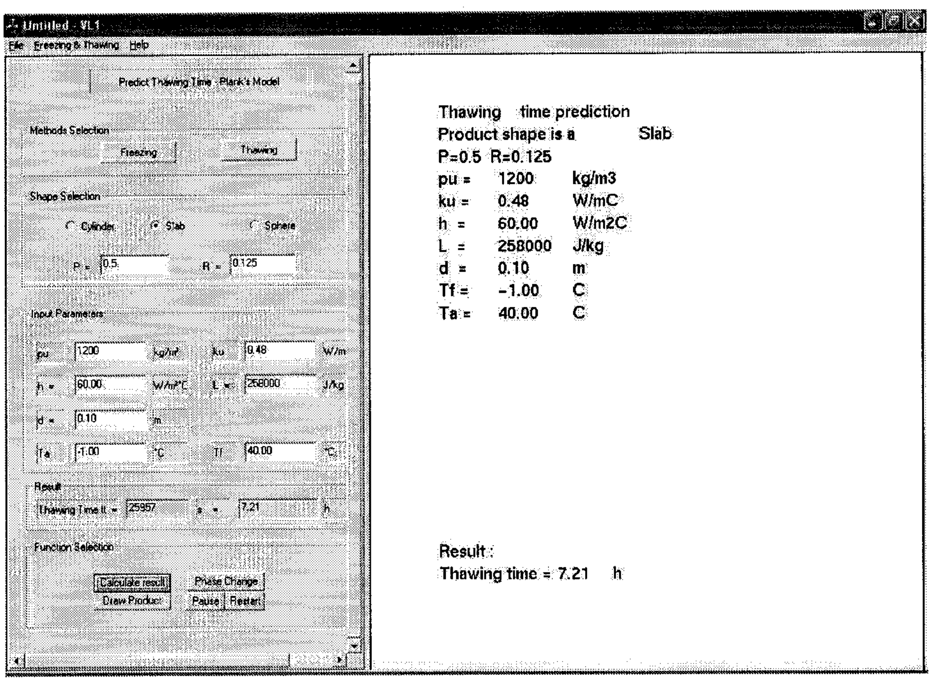
There are three types of shapes in this part for selection, slab, cylinder and sphere. The P and R values are set in this part as well. The Radio Button is used for shape selection so that the user can only select one of them each time. When the selected shape is a cylinder, the text of the shape is displayed as "The product shape is cylinder" at the top of the visualization area, and the corresponding P and R values are shown in their edit boxes automatically. The result of this part also is shown in Figure 4.13(a) and 4.13(b).

- Input and Output of Parameters:

The developed interface of input and output parameters part is shown in Figure 4.13(a) and 4.13(b). In the data input and output area, the description of some variables can be changed according to the method selected. The parameters defined include: ρ_f is the density of frozen product when the method is freezing process. It



(a) Interface of function buttons and result of calculation of freezing time



(b) Interface of function buttons and result of calculation of thawing time

Figure 4.13 Functionalities of freezing and thawing process virtual lab and calculation of freezing and thawing time will be changed to ρ_u when method is thawing process. k_f is the thermal conductivity for freezing, k_f will become to k_u when the method is thawing; h is the heat transfer coefficient; L is the latent heat; T_f is product freezing temperature; T_a is the temperature of the freezing medium; d is the thickness for an infinite slab, it is the diameter for an infinite cylinder or a sphere; t_f is the result of freezing time. When the button of thawing method is pressed, t_f will become t_{th}, which is the result of thawing time.

- Functional Buttons:

From the list number of figures we can find there are three buttons designed for calculating the freezing and thawing time, drawing the product and showing phase change, which are:

1. $\boxed{\text{Calculate Result}}$ button: is used to calculate the freezing or thawing time;
2. $\boxed{\text{Draw Product}}$ button: is used to draw the 3D objects, cylinder, slab or sphere;
3. $\boxed{\text{Show Phase Change}}$ button: is used to show the phase change for selected shape;
4. $\boxed{\text{Pause}}$ button: is used for stopping phase change (animation) temporally during the process of phase change;
5. $\boxed{\text{Restart}}$ button: is used for restarting the phase change after a pause.

4.3.3.3 Calculation of Freezing and Thawing Processing Time

When the method and shape are selected, after inputting the known parameters described in **Input and Output of Parameters**, then press the $\boxed{\text{Calculate Result}}$

button. The freezing or thawing processing time will be obtained and displayed in the corresponding edit boxes. The time unit is the hour.

Based on example 4, when we have these data, we calculate freezing time by substituting for all known variables in Plank's equation, we get:

$$t_f = [1100 * 25800/(-1-(-40))][0.5*(10/100)/60 + 0.125*(10/100)^2/1.91] \quad (4.10)$$

then, calculate the result of freezing time t_f. This really costs a lot of time to obtain the result, sometime the result may be inaccurate. For example, if the instructor wants to modify one of the parameters, and try to explain the effect of the modified parameter to the result, the instructor has to recalculate the result. But using this simulation can solve this "difficulty" easily. What the user need to do is modify the parameter, then press the Calculate Result button, the result will be obtained immediately.

Figure 4.13(a) shows the result of freezing time calculation based on example 4, freezing time is 3 hours. When the method is changed to thawing, the p_f=1100 changed to p_u=1200; k_f=1.91 changed to 0.48 and T_f changed to 40°C; just press Calculate Result button, the thawing time is obtained immediately, 7.21 hours, from the results, it is easy to see which process last longer time and save time.

4.3.3.4 Simulation of Freezing and Thawing Processing Phase Change

- Phase Change of Freezing Process through a Slab:

After calculating the freezing time, press the button Draw Product , and a slab is drawn in red color as shown in Figure 4.14. The value of freezing time is converted to minutes, **180 min**. When the button of Phase Change is pressed, the phase change is started, and we can see the blue color in the front surface from two sides, the top and bottom move to the middle of the front surface gradually. At the same

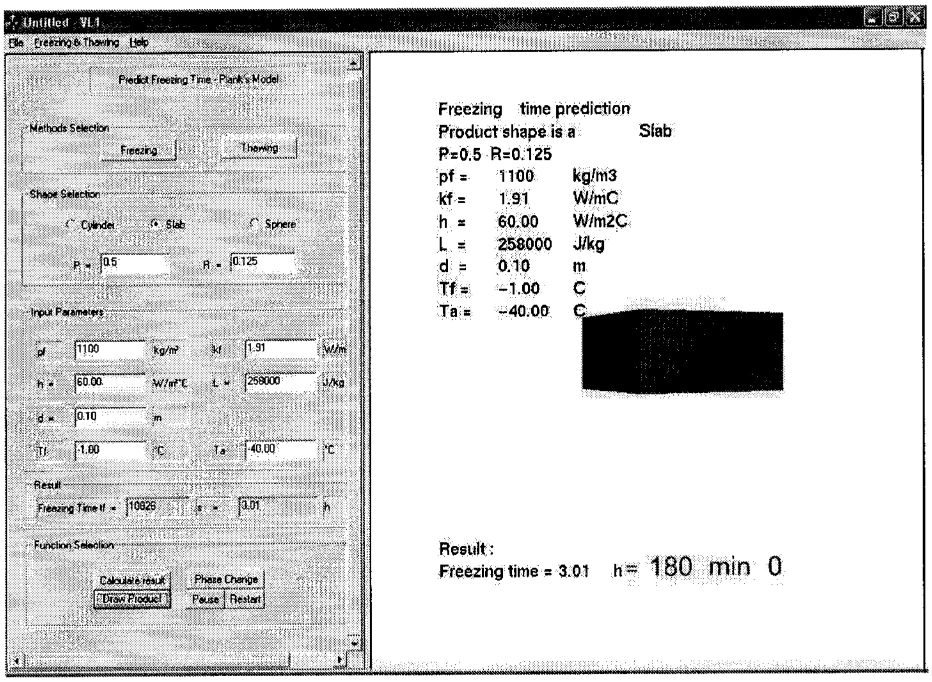
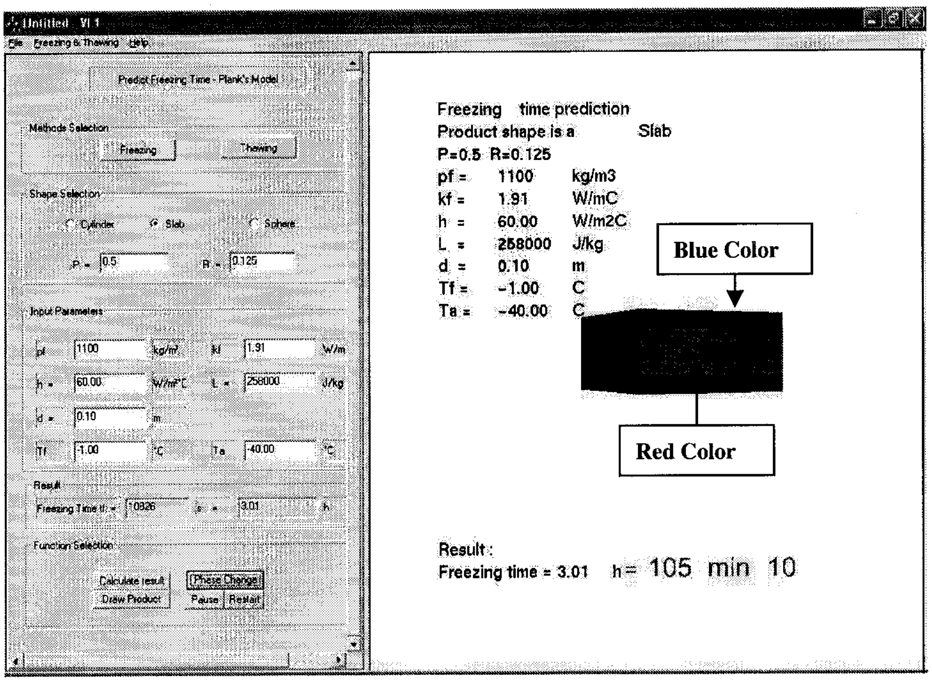


Figure 4.14 Interface of visualization of initial unfrozen state (red color) of the slab for freezing processing

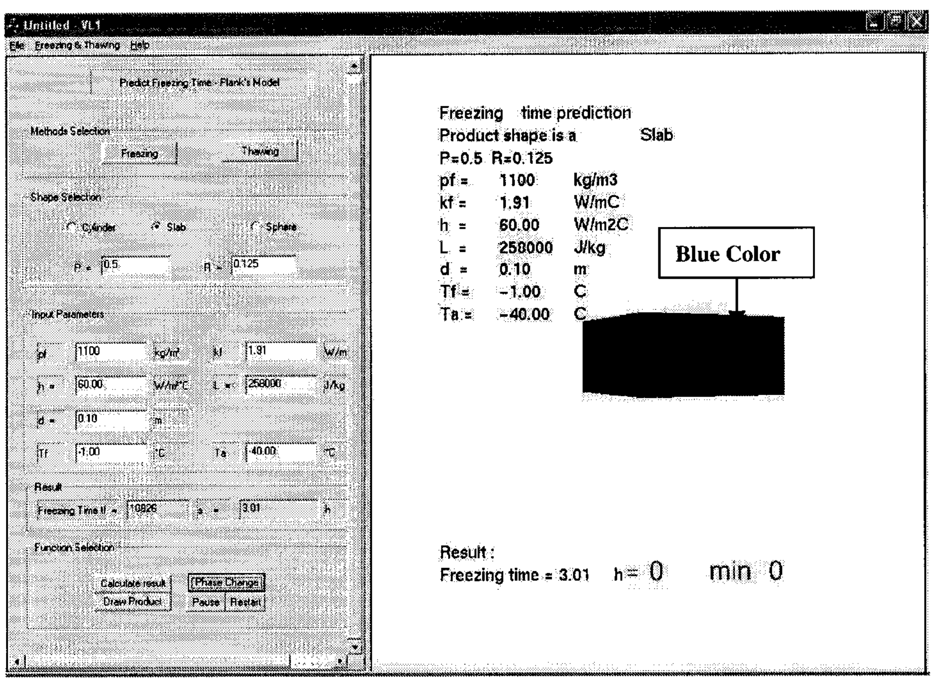
time, the freezing time in minutes keeps decreasing to display how much time left. Figure 4.15(a) shows this process. Finally, the two moving surfaces meet together, and the slab becomes blue as shown in Figure 4.15(b). The freezing time also goes to zero, meaning the freezing process is finished. The change of the width of this blue color represents the change of the frozen phase from the two sides which contact with freezer to the middle of the slab.

- Phase Change of Thawing Process through a Slab:

The simulation of phase change of the thawing process through a slab is similar to the freezing process phase change, the difference being that the initial color of slab is blue (that represents the frozen material). After the thawing process, the color of the slab becomes red. The major steps are shown in Figures 4.16, 4.17(a) and 4.17(b).



(a) In processing of phase change of freezing process for a slab



(b) Final result of phase change of freezing process for a slab

Figure 4.15 Interfaces of phase change of freezing process through a slab

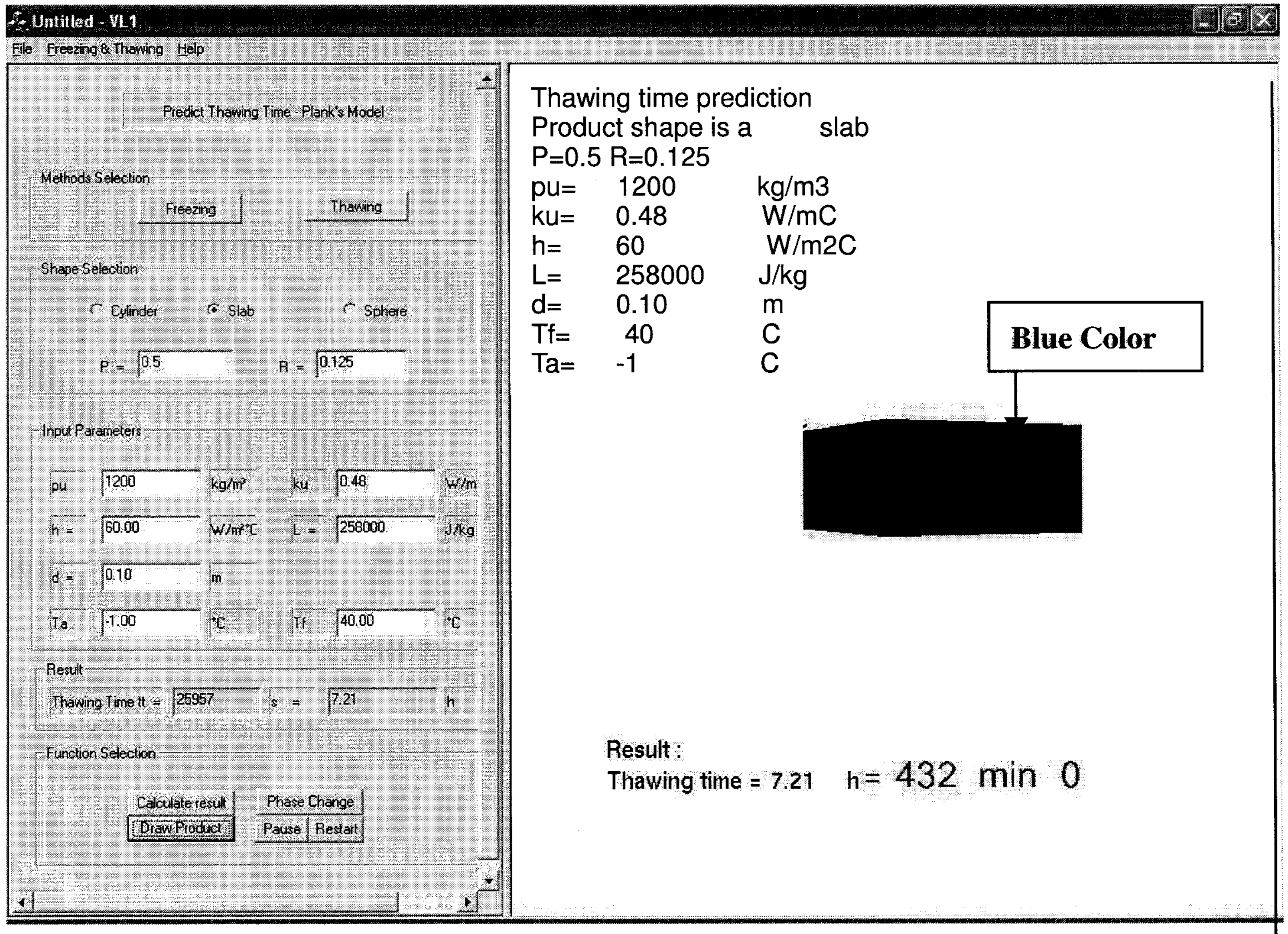
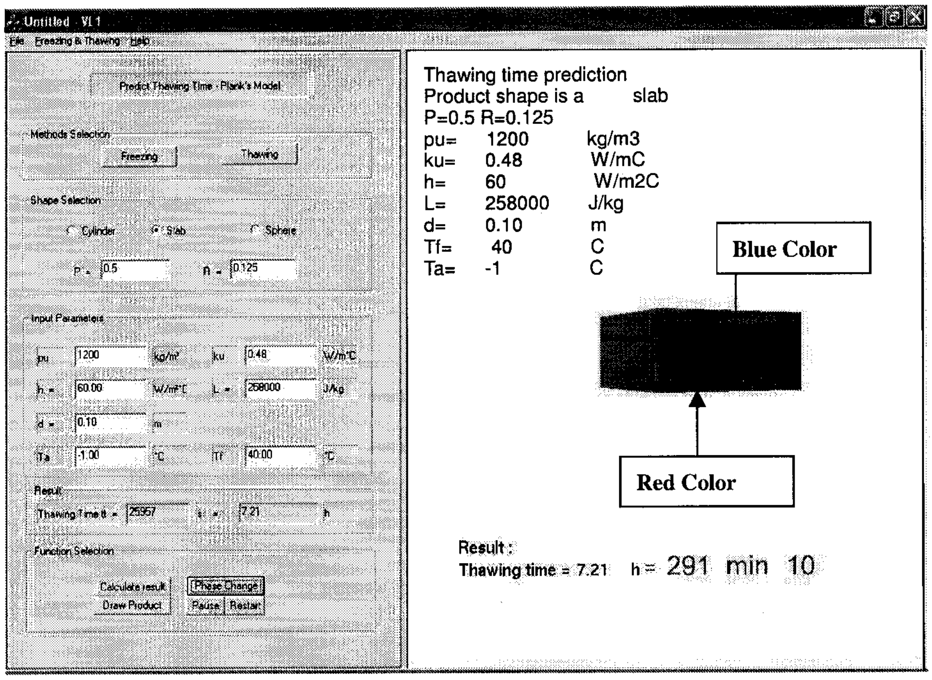
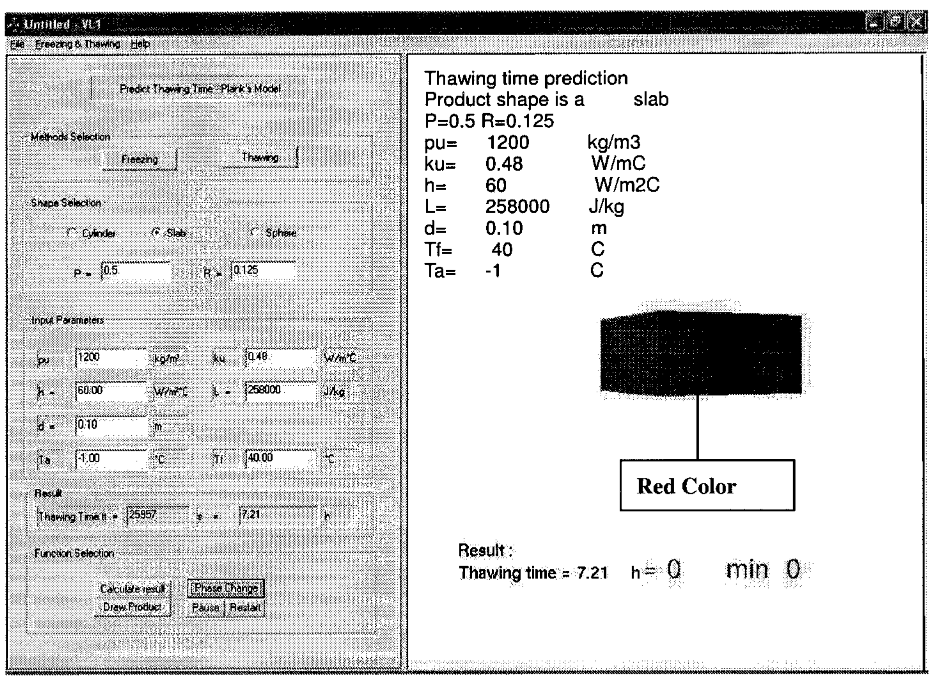


Figure 4.16 Interfaces of visualization of initial frozen state (blue color) of the slab

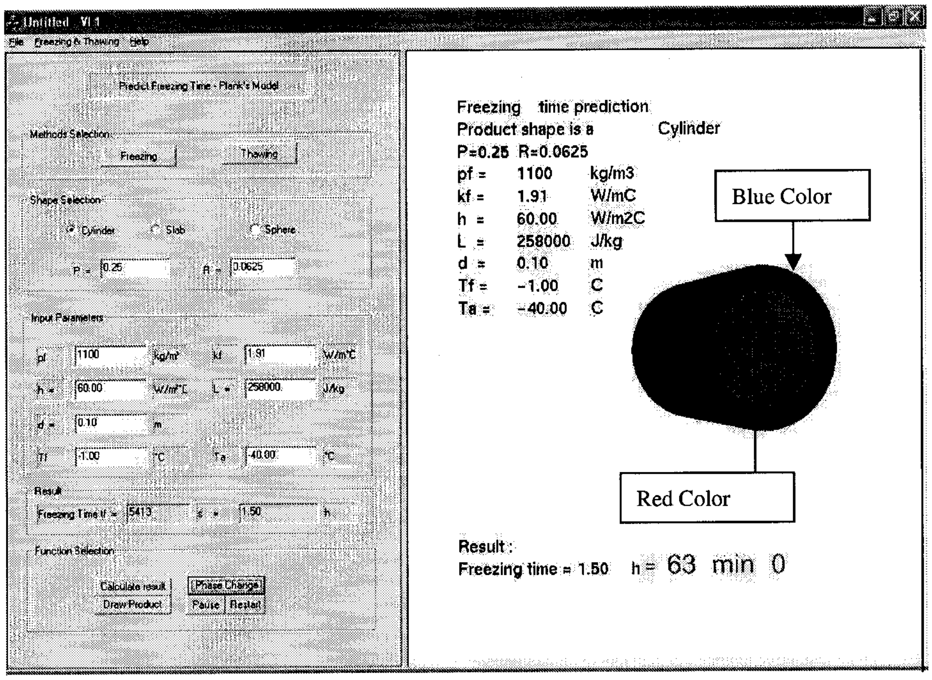


(a) In processing of phase change of thawing process for a slab

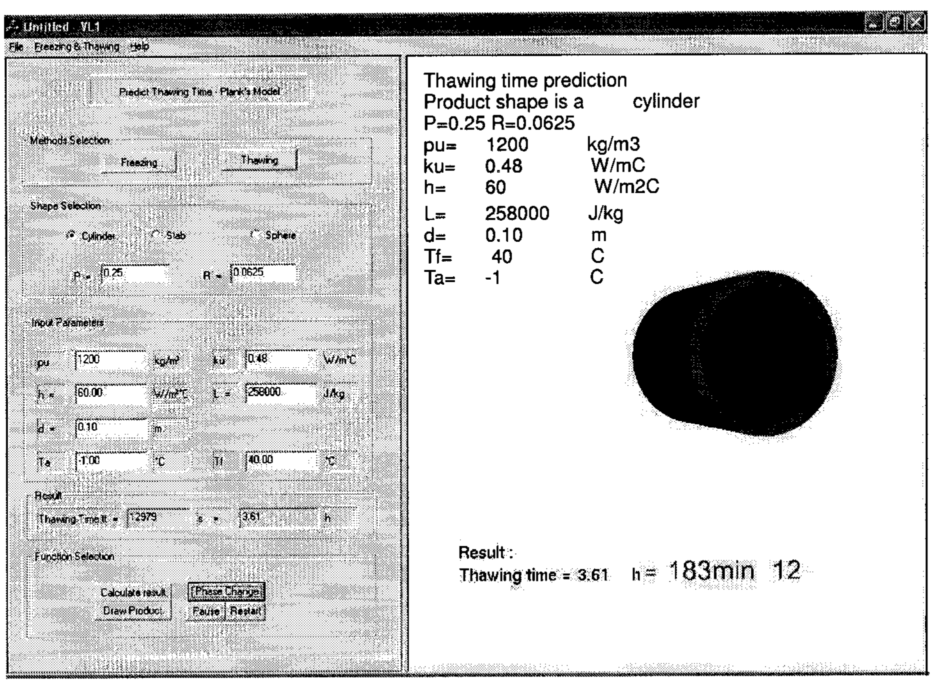


(b) Final result of phase change of thawing process for a slab

Figure 4.17 Interfaces of phase change of thawing process through a slab

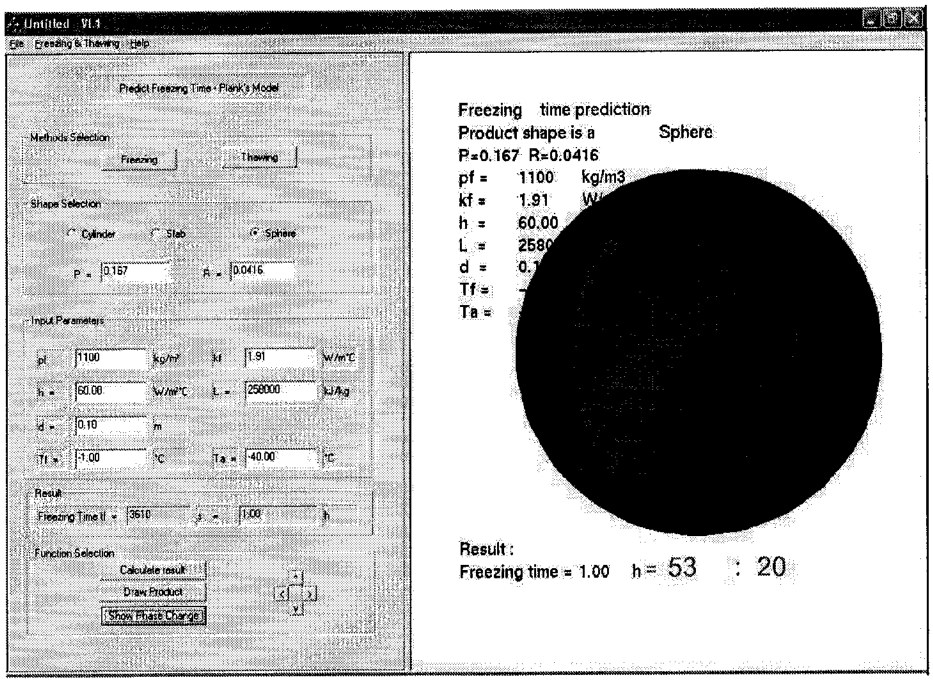


(a) Simulation of calculation and phase change of freezing process for a cylinder

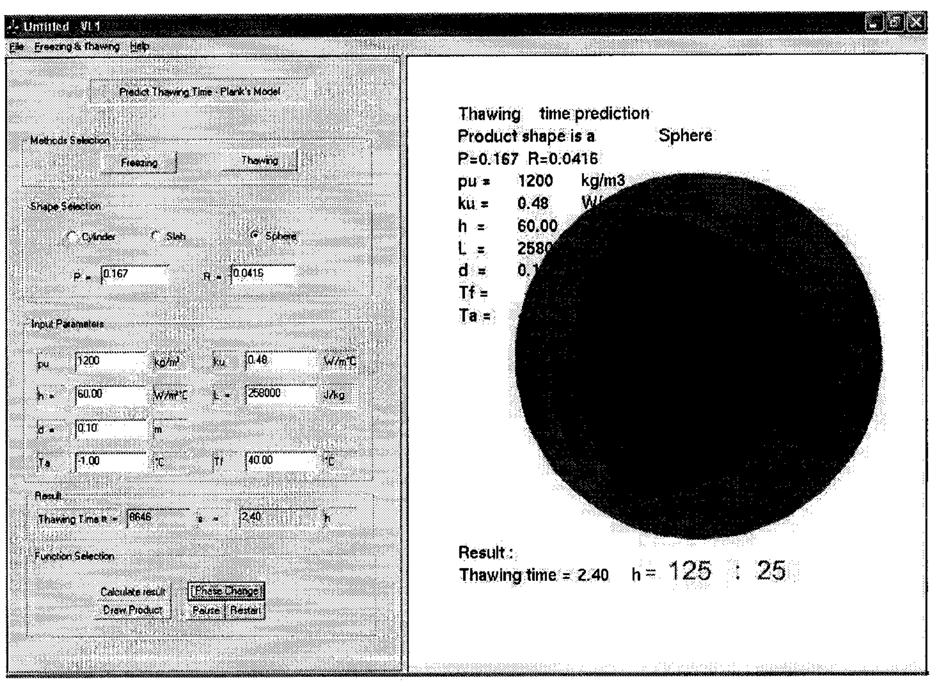


(b) Simulation of calculation and phase change of thawing processing through a cylinder

Figure 4.18 Results of simulation of calculation and phase change of freezing and thawing processing for a cylinder



(a) Simulation of calculation and phase change of freezing process for a sphere



(b) Simulation of calculation and phase change of thawing processing through a sphere

Figure 4.19 Results of simulation of calculation and phase change of freezing and thawing processing for a sphere

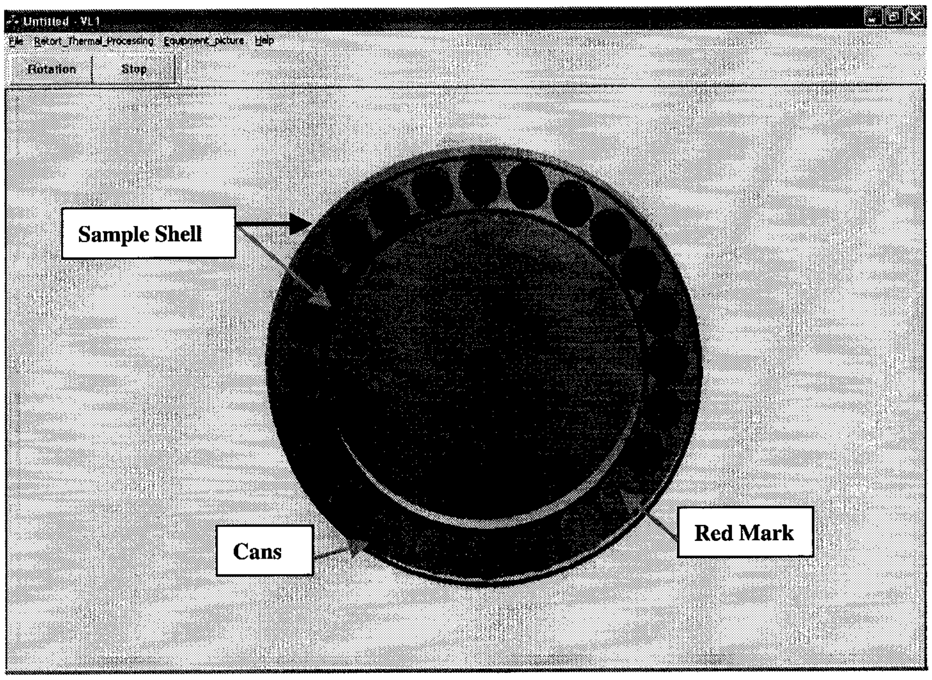
4.3.3.5 Results of Simulations of Freezing and Thawing Processing for a Cylinder and a Sphere

The simulations of calculations and visualizations of phase change for a cylinder and a sphere are similar with a slab, the difference is the shape of the product. Figure 4.18(a) and 4.18(b) show the results of simulation of calculation and phase change process for a cylinder. The results for sphere are shown in Figure 4.19(a) and 4.19(b).

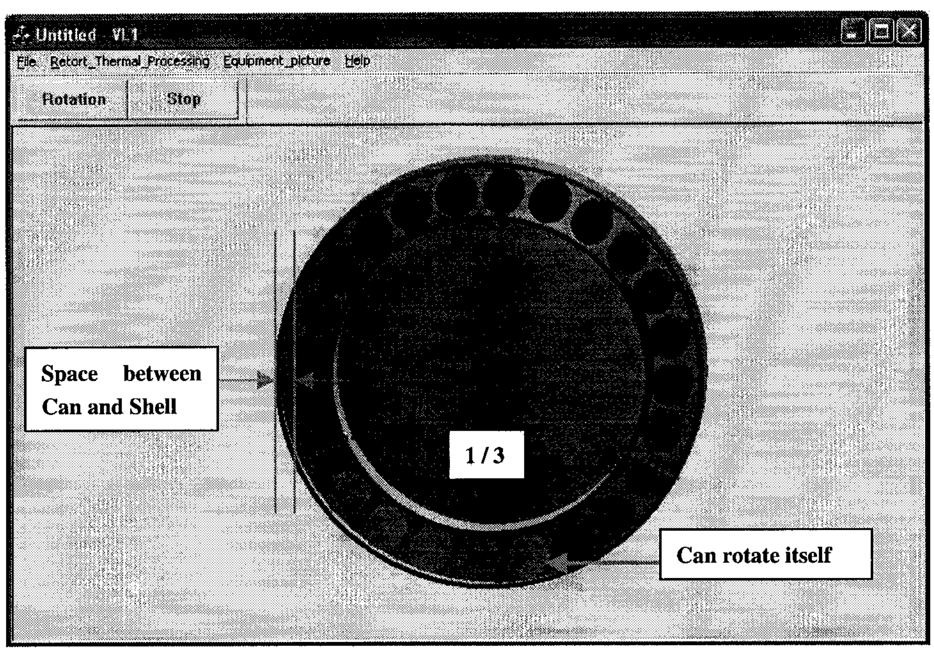
4.3.4 Result of Simulation of Axial Agitation

The result of visualization of axial agitation is shown in Figure 4.20(a). The outer layer is the retort shell, cans with red marks are the indicators to show the rotating cans. There are two buttons on the tool bar, one is $\boxed{\text{Rotation}}$. When it is pressed, the sample shell will be agitated. The other button is $\boxed{\text{Stop}}$ for stopping the rotation.

When the $\boxed{\text{Rotation}}$ button is pressed, the sample shell rotates, and the cans rotate with the shell. While the can rotated to the position marked as $\frac{1}{3}$ of shell as shown in Figure 4.20(b), because there is some space between the cans and the outer layer of the shell, the cans drops down against the inner edge of shell. Because of the force of friction between surfaces of cans and edge of shell, the cans rotated around themselves, with the agitation of the sample shell. When the cans position moves up, and cans have no contact with edge, they rotate with the shell again.



(a) Main interface of axial agitation simulation



(b) Interface of cans rotating itself along the inner edge of shell

Figure 4.20 Results of simulation of axial agitation

4.3.5 Result of Simulation of End-over-End Agitation

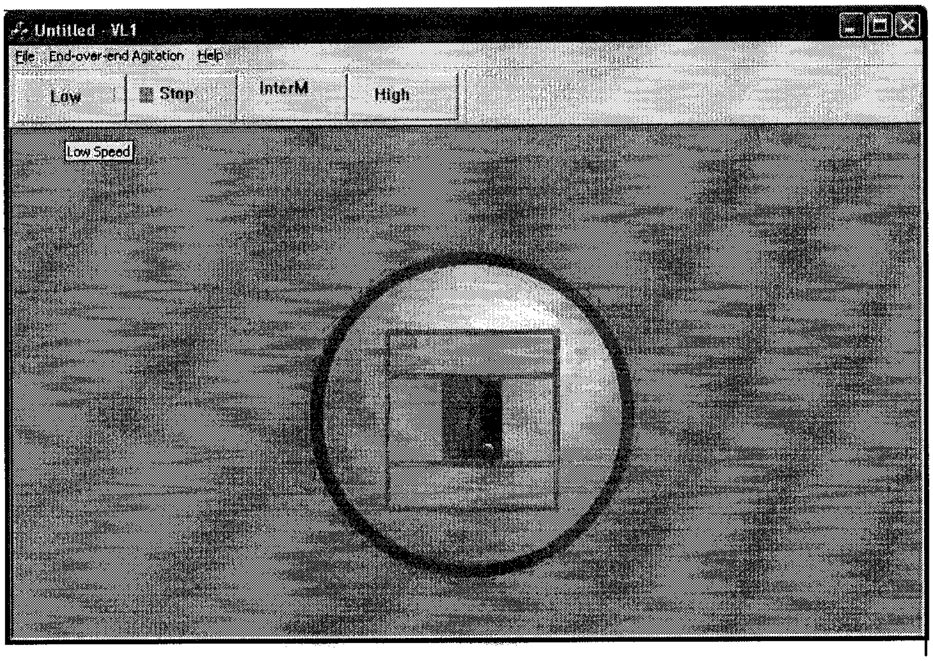
The result of main interface of end-over-end agitation simulation with a low rotating speed is shown in Figure 4.21(a). There are four major parts in the simulation: the sample shell, basket of sample, a can which is enlarged to be observed conveniently, and a particle inside the can. There are four buttons on the tool bar for operating the simulation, one is Low for low rotating speed of the can, the InterM is for intermediate rotating speed, High is for high rotating speed, and the Stop button is used for stopping the rotation.

The can is placed in the middle of basket (the worst case scenario). When the basket is rotating, the particle also moves inside the can, which explains why the end-over-end agitation can enhance the heat penetration during the processing. The rotating speed of the can may vary to achieve different efficiencies of heat penetration with different rotating speeds.

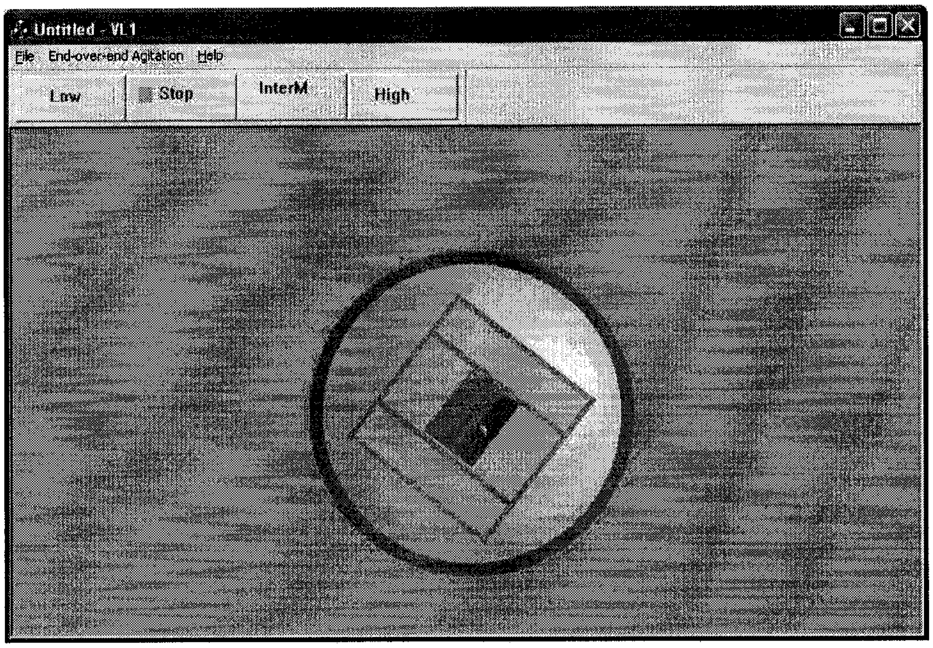
Figures 4.21(a) and 4.21(b) show the results of end-over-end agitation simulation with a low rotating speed. From these figures we can find that the paths of movement of the particle are along the inner wall of the can. That means the lower speed may have little effect on the heat transfer rate.

Figures 4.22(a) and 4.22(b) show the results of end-over-end agitation simulation at intermediate rotating speed. The particle moved randomly inside the can, therefore, this speed of rotation gives a good mixing of content in can, and enhances the heat transfer rate during processing.

Figures 4.23(a) and 4.23(b) show the results of end-over-end agitation simulation with a high rotating speed. Because the rotating speed is too fast, the particle may stick to any place on the inner wall of the cans. this speed of rotation makes almost no contribution to mixing of contents or heat penetration during the processing.

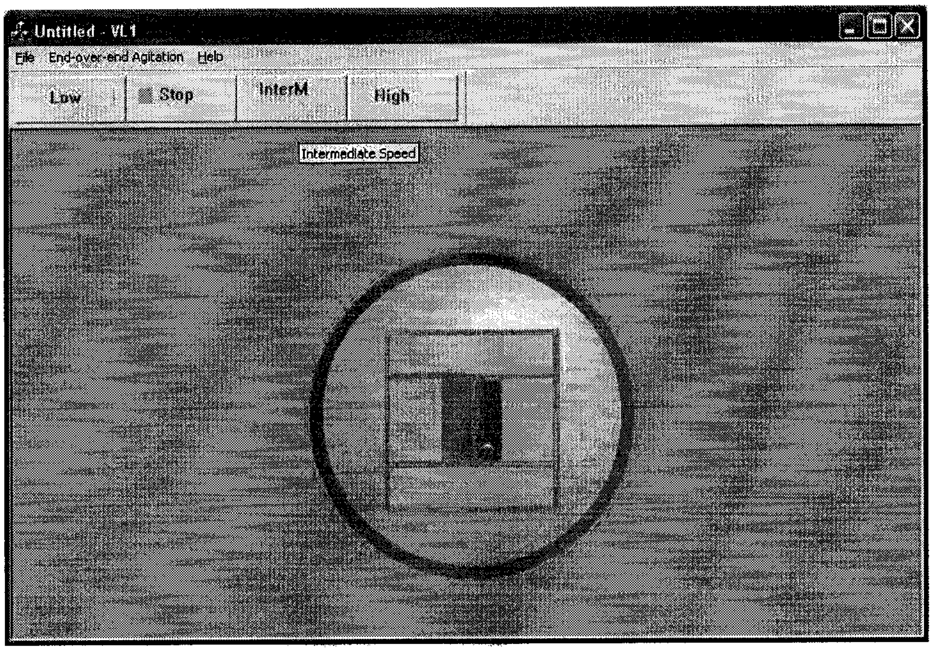


(a) Initial interface of simulation of end-over-end agitation at low rotating speed

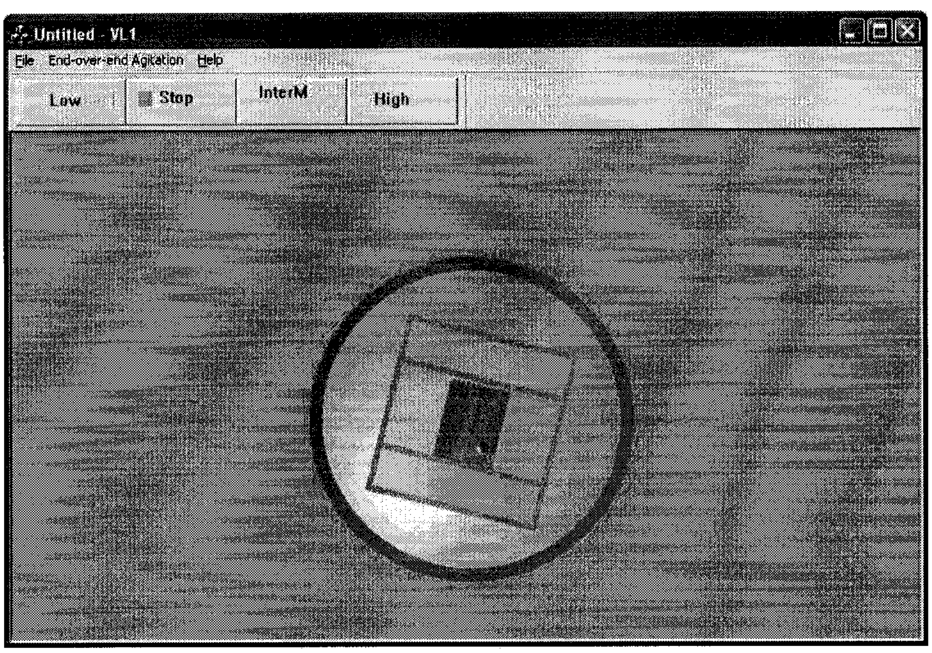


(b) Rotating process of simulation of end-over-end agitation at low rotating speed

Figure 4.21 Simulation of end-over-end agitation at low rotating speed

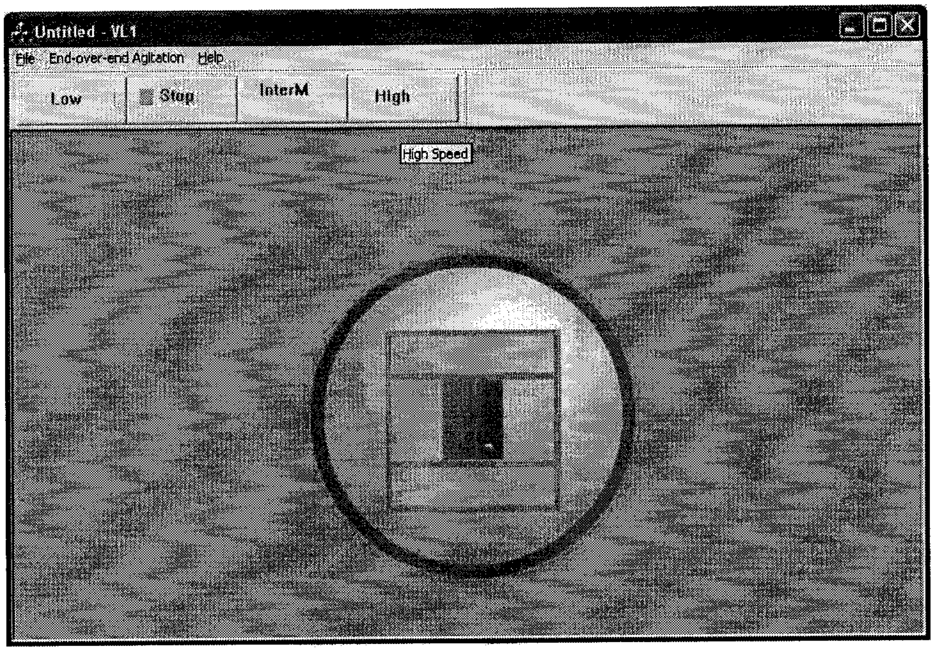


(a) Initial interface of simulation of end-over-end agitation at intermediate rotating speed

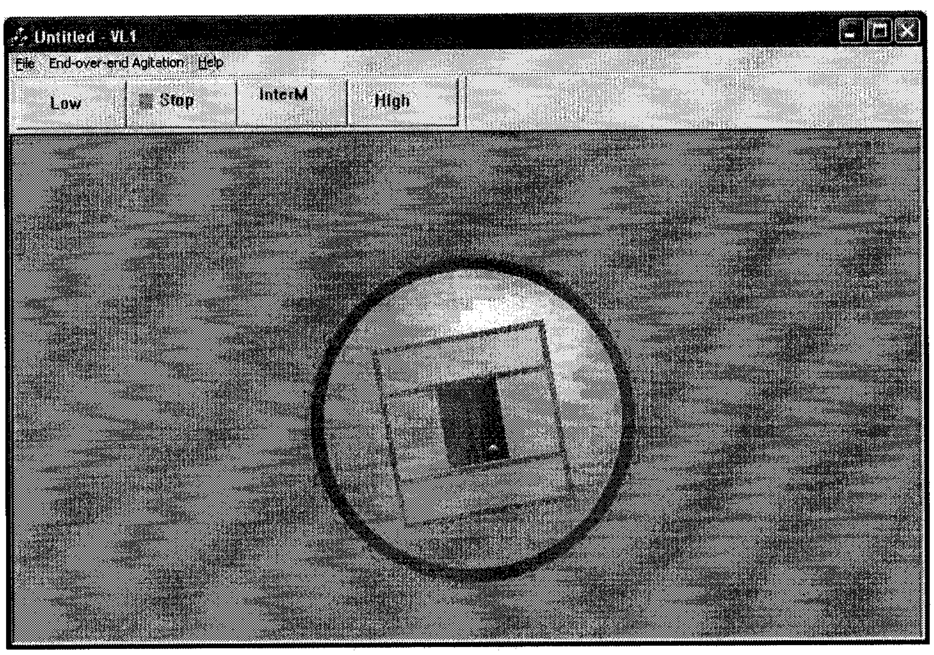


(b) Rotating process of simulation of end-over-end agitation at intermediate rotating speed

Figure 4.22 Simulation of end-over-end agitation at intermediate rotating speed



(a) Initial interface of simulation of end-over-end agitation at high rotating speed



(b) Rotating process of simulation of end-over-end agitation at high rotating speed

Figure 4.23 Simulation of end-over-end agitation at high rotating speed

4.4 Conclusions of Visualization of Food Processing Scenarios

The calculations and visualizations of food processing scenarios in conduction heat transfer, mass balance, freezing and thawing processing, and the agitation of cans for rotary retort in thermal processing were developed. Those virtual labs as an education tool make up for deficiencies, and decreased the limitations of static figures or pictures by traditional methods.

The advanced computer 3D techniques provide a method to simulate the object as it is in the real world, and supply an intuitive image.

The simulated calculations and animations help instructors to save time in preparing the lectures, and describe the concepts and phenomena clearly. The interest of user also can be evoked by the simulations and animations. They can use these simulations to review the information before or after class.

CHAPTER 5

VISUALIZATION OF EQUIPMENT AND WORKING PRINCIPLE IN FOOD PROCESSING

5.1 Introduction

Thermal technologies have been applied in food processing for many years, and have become the core of food preservation. Nicholas Appert (Lopez, 1987) made a large contribution to heat sterilization (canning) of food in the 1800s. Since then, the application of heat processes to containers (canning) have developed into a substantial industry. Although some other new food processing techniques have been applied in food preservation nowadays, thermal processing still remains a major commercial food preservation method for providing shelf stable food commodities to consumers worldwide. Much of the food consumed each year is preserved by packaging it in hermetically sealed containers in a process known as canning.

Canning aims to produce a product which is free of pathogens and all micro-organisms which might spoil the food in the container, to produce a heat stable product. Canning is a severe heat process. Traditional canning involves packaging the food, then sterilizing both food and package at temperatures at around 115 to 125$°C$ for low acid foods (pH is greater than 4.5) or at about 100$°C$ for high acid foods (pH is less than 4.5).

The application of heat processes to containers not only requires the ability to heat and cool the container contents efficiently but also the ability to do so while minimizing the stresses imposed upon the container. This controlled application of heat and pressure is the function of the modern sterilizing retort. Therefore, the retort became the key equipment for accomplishing the above requirements .

The retorts are classified as either vertical or horizontal, depending on the position of the long axis. A vertical retort loads the vessel of products from the top, a horizontal retort loads from the end. A typical vertical retort is shown in Figure 5.1 and horizontal retort is shown in Figure 5.2.

STOCK R & D retorts are made by STOCK , an American food and pharmaceutical processors company, the company supplies retorts and associated equipment to food and pharmaceutical processors. These retorts are multi-purpose units, capable of simulating virtually all commercial retort equipment. They are capable of running small batches of just a few containers but can be validated to provide test market or small production volumes as well.

Water immersion thermal processing has been used in the United States since its introduction by STOCK in the mid 1970's. First developed in the early 1950's, water immersion processing is the most prevalent style of overpressure process in use today. New packaging technologies, along with new food products with more heat sensitivity have driven the demand for better thermal processing techniques. Water immersion rotary retorts provide a faster rate of both heating and cooling. The mixing which occurs in "end over end" rotation, also allows for high temperature, short time processing which produces much better quality product.

Figure 5.2 shows the horizontal retort made by STOCK company. This retort is used in our pilot plant for researchers in food thermal processing field, and is utilized to demonstrate to the students who take the food processing courses by instructors or lab teaching assistants.

The traditional way for a new user to learn the operation of the retort was to read the equipment operation menu, or to be taught by a skilled operator. The instructors who teach food processing courses may use pictures or figures to introduce the retort or other food processing equipment to students in class, or arrange a visit to the pilot plant for equipment demonstration. Sometimes it is really not convenient for both instructors and students, so the virtual equipment provides a new and easy

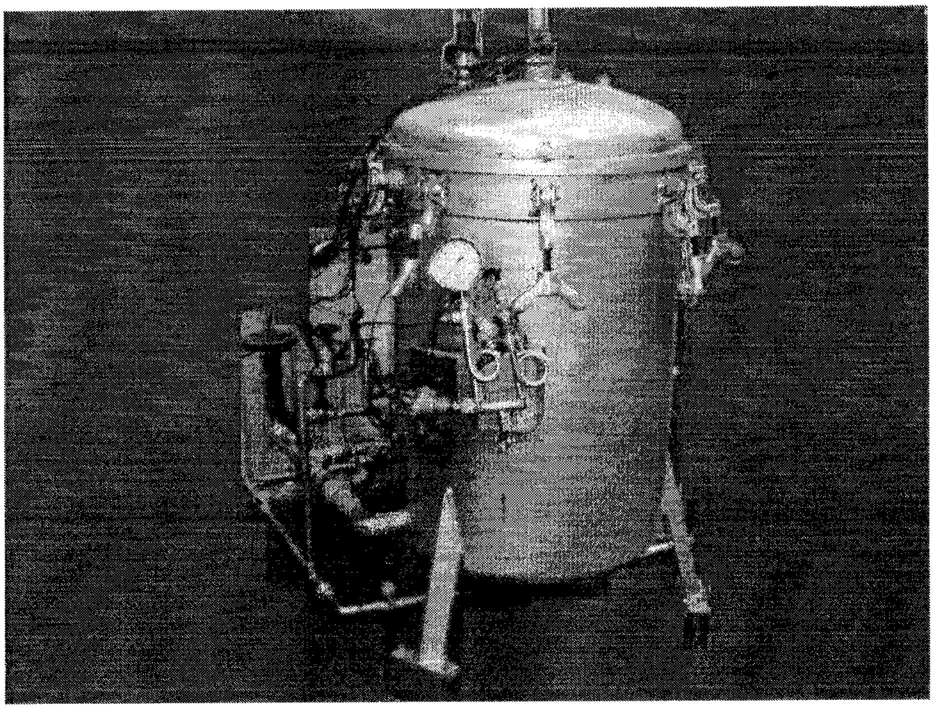


Figure 5.1 Picture of vertical retort

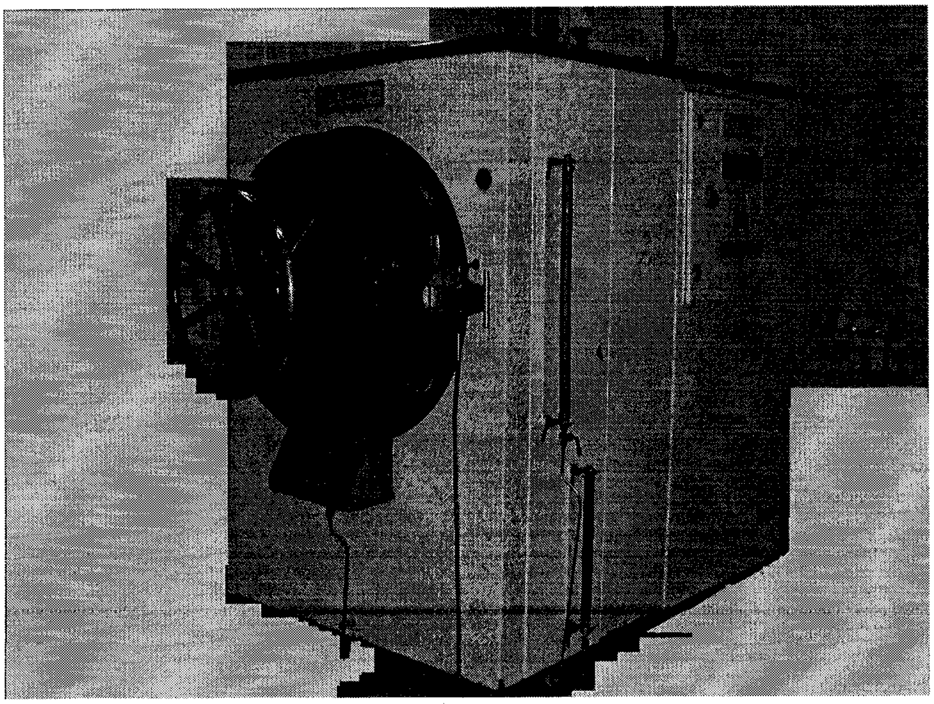


Figure 5.2 Picture of horizontal retort

way to achieve the same effect without going to the pilot plant.

5.2 Methodology

5.2.1 Procedure of Designing the Selected Food Processing Equipment

The designing flow chart is shown in Figure 5.3. The first step is to select the food processing equipment which will be visualized. The second procedure for visualization is to understand the whole equipment structure both outside and inside by reading and consulting the user manual of the equipment, and identify the position of each component of the equipment and its functionality. The third step is coding or programming, that means to develop the application using the selected computer languages. The last step is to test the application of the virtual equipment. If passed, the final product is delivered, otherwise, user go back to the programming source code and debug, then test again until the application runs properly.

5.2.2 Selection of Food Processing Equipment

The selected food processing equipment in this project include:

1. Horizontal Retort
2. High Pressure Processing Equipment

5.2.3 Structure of Food Thermal Processing Equipment

The thermal processing equipment selected is the horizontal retort as in Figure 5.2.

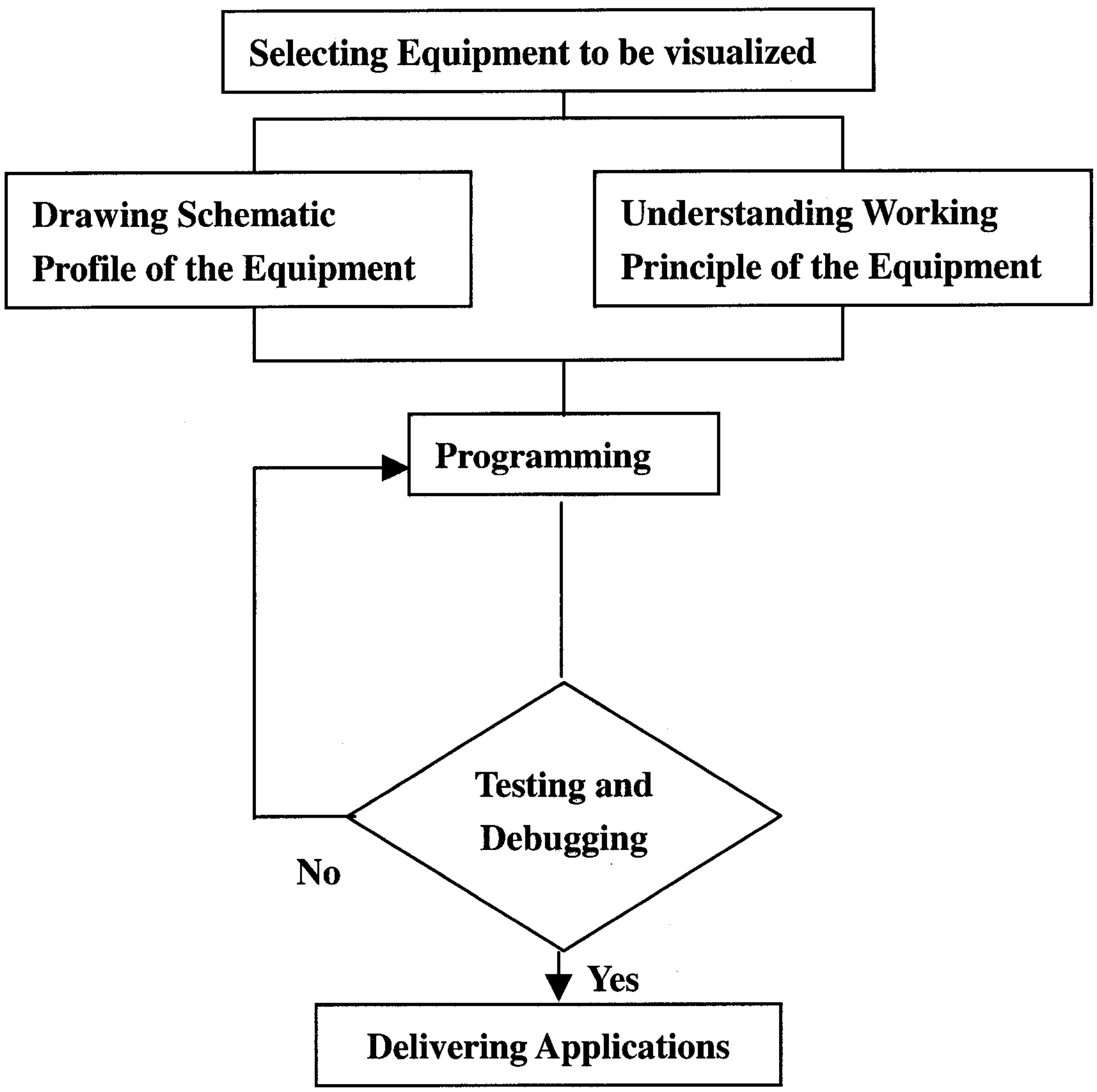


Figure 5.3 The flow chart of designing and visualizing the virtual equipment

5.2.3.1 Thermal Processing Equipment - Horizontal Retort

Target of Visualization:

The retort made by STOCK is available in our pilot plant and usually is provided for students who take food processing course or researchers whose research project is closely related to the thermal processing area with this equipment. The schematic of the STOCK retort is shown in Figure 5.4. This retort was chosen to be visualized in this project.

Structure of Horizontal Retort:

In order to visualize this horizontal retort, refer to Figure 5.5. We have to group it into several parts according to its structure and functionality.

- Drums (or Vessels):
  There are two vessels in the horizontal retort, the upper vessel is called the processing vessel, the lower one is called the storage vessel.
- Lid of retort:
  There is a lid in the front of the processing vessel.
- Basket of samples:
  There is a basket inside the processing vessel for canned samples. It is a rotary component.
- Water Levels:
  Two water levels are used to indicate the water quantity in the storage vessel and processing vessel.
- Entrance of mediums:
  There are three separate entrances for cold water, steam and air.

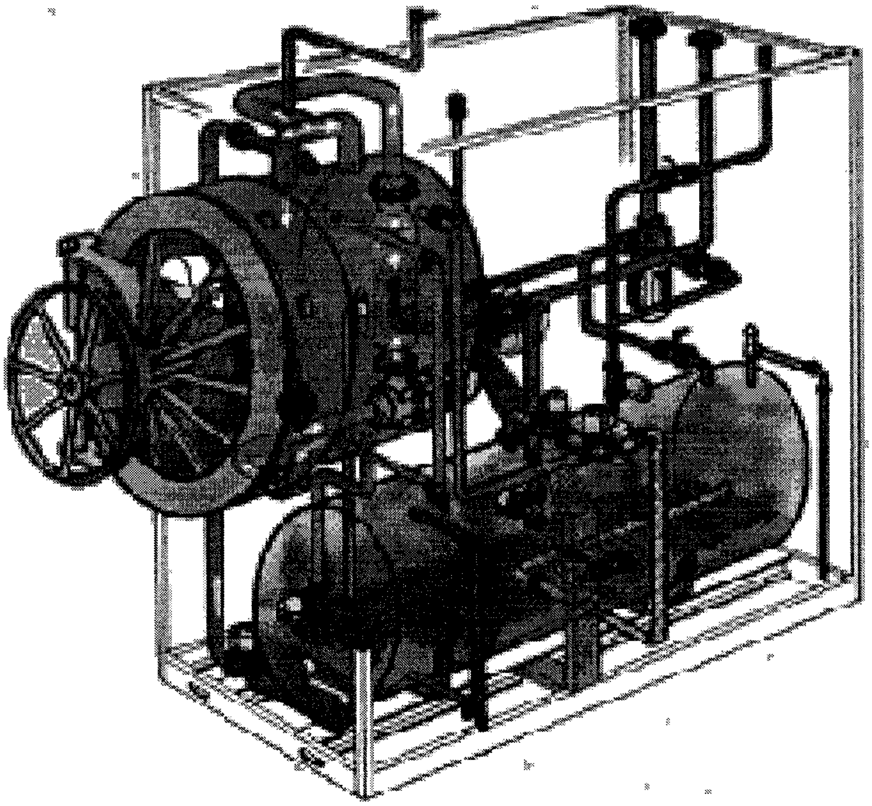


Figure 5.4 Schematic of horizontal retort (STOCK America Inc.)

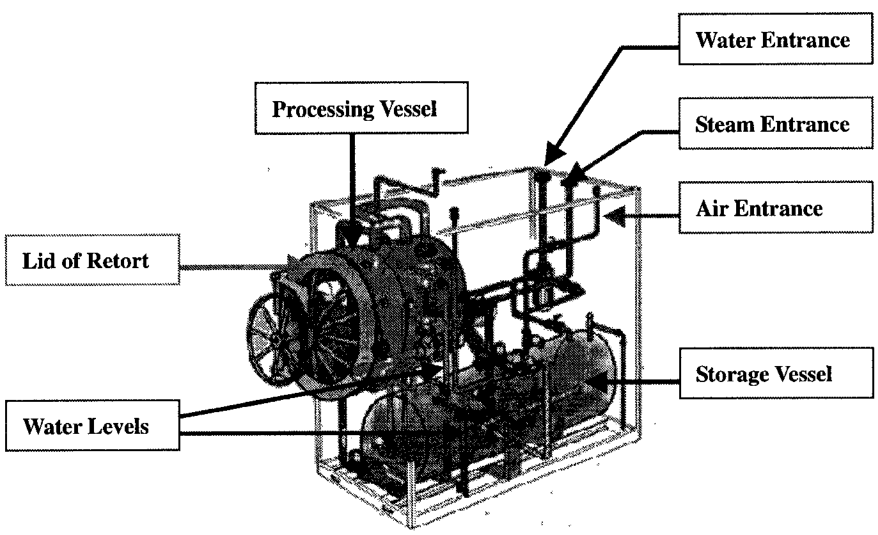


Figure 5.5 The structure of horizontal retort (STOCK America Inc.)

- Control Panel:

  There are different gauges and control buttons in the control panel, such as the temperature gauge of the storage vessel, the temperature gauge of the processing vessel, the gauge of rotating speed, the system pressure gauge and 18 control keys for controlling the equipment.

- Valves:

  There are several different valves used to control water, steam and pressure.

5.2.4 High Pressure Processing Equipment

Figure 5.6 shows the picture of high pressure equipment used in studying food high pressure processing. The main components composing this high pressure equipment are: sample chamber, lid of sample chamber, lid lock, medium chamber, and pressure pump.

5.2.5 Computer Language Used in This Project

Microsoft Foundation Class (MFC) was used to develop the interface of the virtual lab. OpenGL was used to visualize the equipment and generate the 3D graphic.

5.3 Results of Visualization of Food Processing Equipment

The selected equipment, retort for thermal processing and high pressure processing equipment, have been simulated and visualized by using computer graphical languages. The results of the developed virtual equipment are shown as follows.

Figure 5.6 The picture of food high pressure processing equipment

5.3.1 Result of Visualization of Horizontal Retort

5.3.1.1 Main Interface of Virtual Horizontal Retort

According to the real horizontal retort structure and its components, the horizontal retort was visualized by computer languages, MFC and OpenGL. Figure 5.7 shows the result of developed virtual horizontal retort. There are six areas on the main interface: Toolbar, Gauges, Description of condition of functional buttons, Text display area for each operating step, Temperature Profile and Visualized retort. The details of functions and descriptions of each area are given as follows.

1. Toolbar:

   From the toolbar area in Figure 5.7, twenty functional buttons were defined. The first 18 buttons were exactly designed according to the keys of the control panel in the real horizontal retort. The next two buttons were defined for

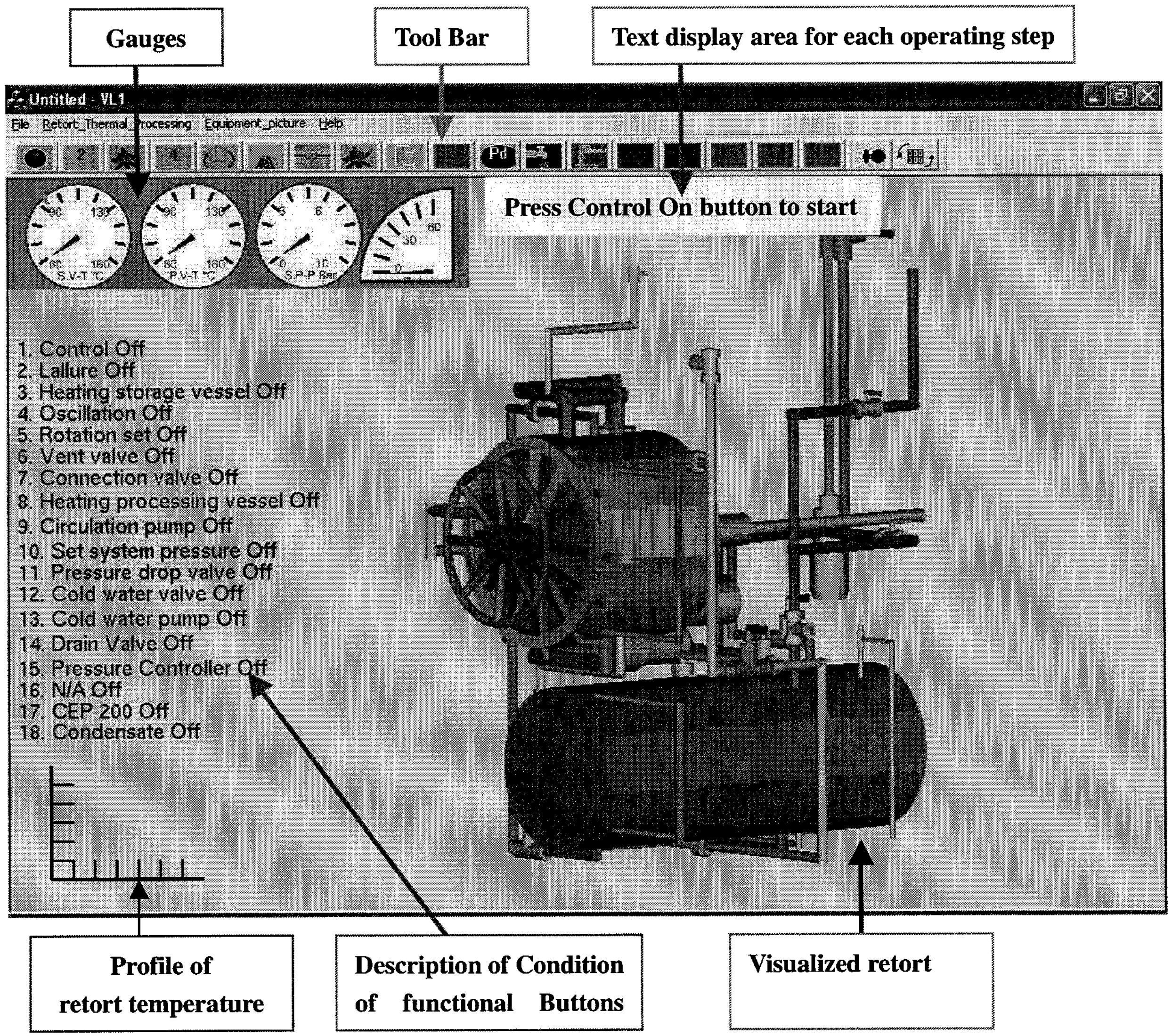


Figure 5.7 Main interface of visualized horizontal retort

control the virtual retort lid and rotating the sample basket. The 19th button is used to open or close the lid of the retort so that the sample basket can be shown any at time by clicking this button. The 20th button is used to rotate the sample basket. Figure 5.8 showed results of opening lid and rotation of the sample basket, while the 19th button and 20th button were clicked with mouse. The description of each button can be displayed in a small window by moving the mouse arrow on each button, see Figure 5.8.

2. Gauges:

   There are two temperature gauges at the left top of the main interface. The first gauge is the temperature gauge of the storage vessel, the second is the temperature gauge of the processing vessel.

   When the condition of Heat Storage Vessel button is in ON, that means the water in the storage vessel (S.V) is heated, and the hand of gauge moves gradually with the temperature of water in the storage vessel increasing until it reaches the temperature which has been predefined. During the cooling process, the hand of the gauge will drop down to minimum temperature of the gauge again.

   The temperature gauge of the processing vessel (P.V) is similar to the temperature gauge of the storage vessel. When the connection valve between the storage vessel and the processing vessel is opened, the temperature of water in the processing vessel will be increased, and the hand of temperature gauge of the processing vessel will move until it reaches the processing temperature which has been predefined.

   The third gauge is the system pressure gauge which can display the system pressure while operating the retort. When the System Pressure button is turned on, the gauge will display the system pressure which is predefined before this step.

   When the rotating rate of sample basket is set, the fourth meter will display the value of rotation rate.

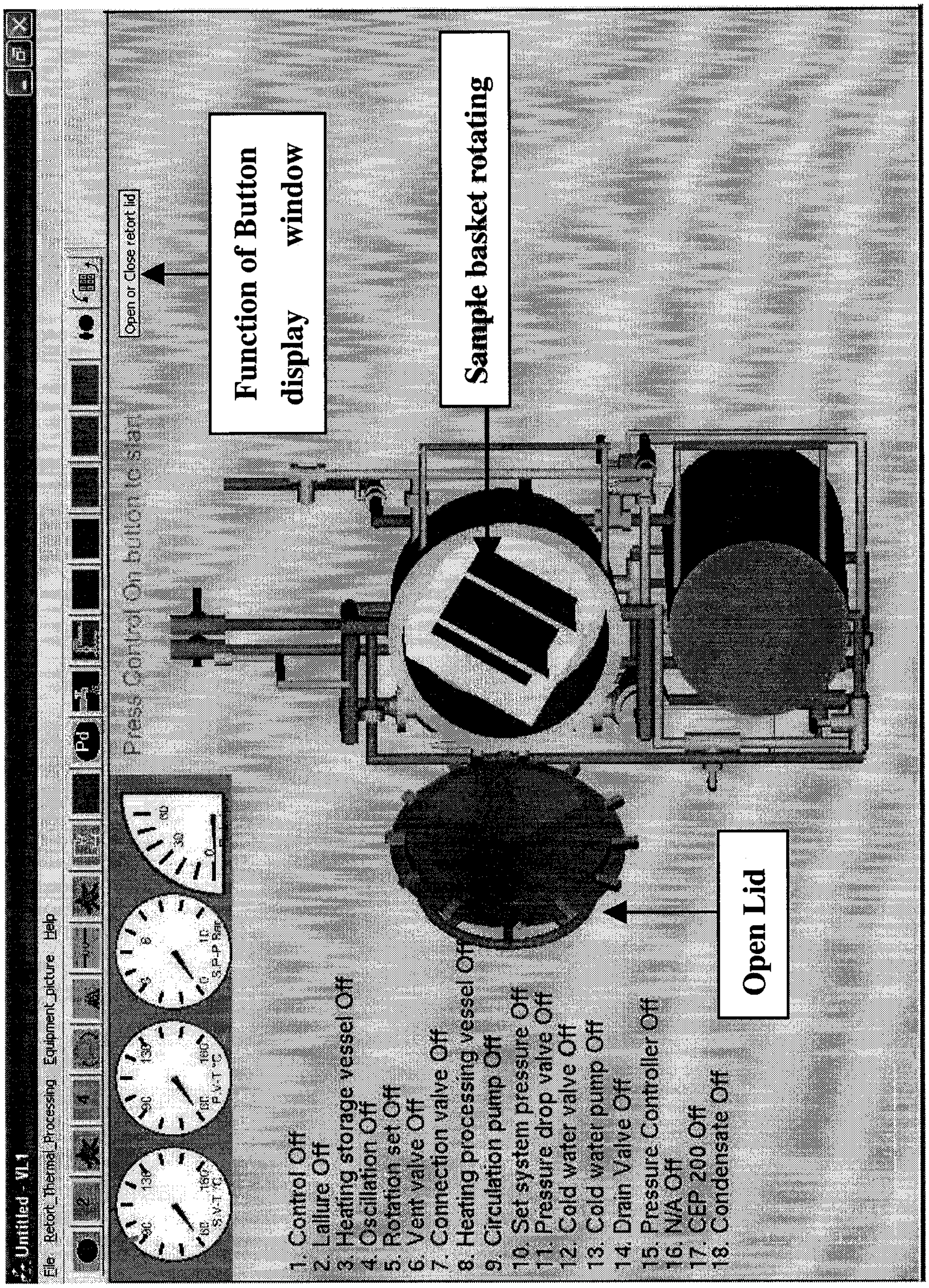


Figure 5.8 The text display for the button function of virtual horizontal retort

All details of functions for these four gauges will be described in the results of working principle part.

3. Description of Condition for functional buttons:

   This area is developed for displaying the condition of each button in the text so that the user can know the status of each button during operation. When the button is turned on, the text color will become green, otherwise it is red.

4. Text display area for each operating step:

   This area is utilized to display the text for each operating procedure, this function can help the user to understand what is happening during any change inside of the retort.

5. Profile of retort temperature:

   The coordinate is designed for showing the profile of the retort temperature. The temperature profile will be changed dynamically when the retort temperature is changed.

6. Visualized retort:

   This area is used to generate 3D graphics of the virtual horizontal retort. When the operation button is pressed, the virtual retort will rotate to a proper location so that the user can see clearly what happens inside of the virtual retort during each step.

5.3.1.2 Working Principles and Operation Procedures

The virtual horizontal retort was designed as the real retort in the physical lab. As described above, the lid of retort can be opened and the sample basket can rotate. The virtual retort is easy to operate, and the text display area, works as the helper to tell the user how to act and know what is going on.

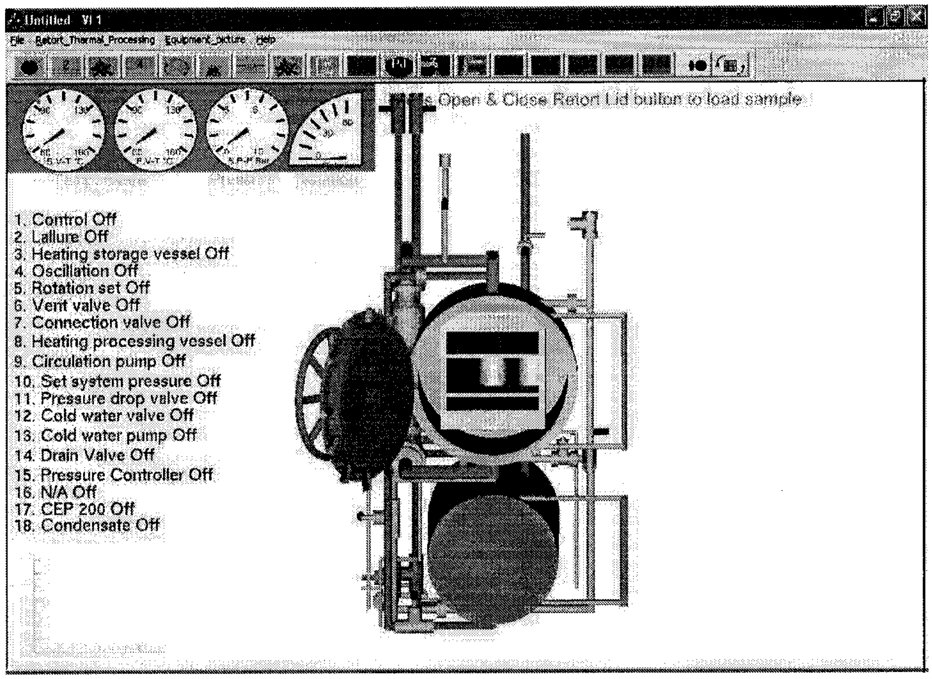
The button $\boxed{\text{Control On/Off}}$ for turning on the power located at the first position in the toolbar area. The function of this button is the same as to turn on the power in the real retort, and the following operation will continue automatically. The major operating procedures are listed as follows.

1. Load sample:
   The result of the initial interface is shown in Figure 5.9(a). The text hints in text display area "Press Open & Close Retort Lid button to load sample" indicates the user to start the simulation, and the sample will be loaded into the sample basket automatically once $\boxed{\text{Open \& Close Retort Lid button}}$ button is pressed, which is located at the 19th position in the toolbar area. Then, the operation hints in the text display area will remind the user to press $\boxed{\text{Control On/Off}}$ button to continue the operation.

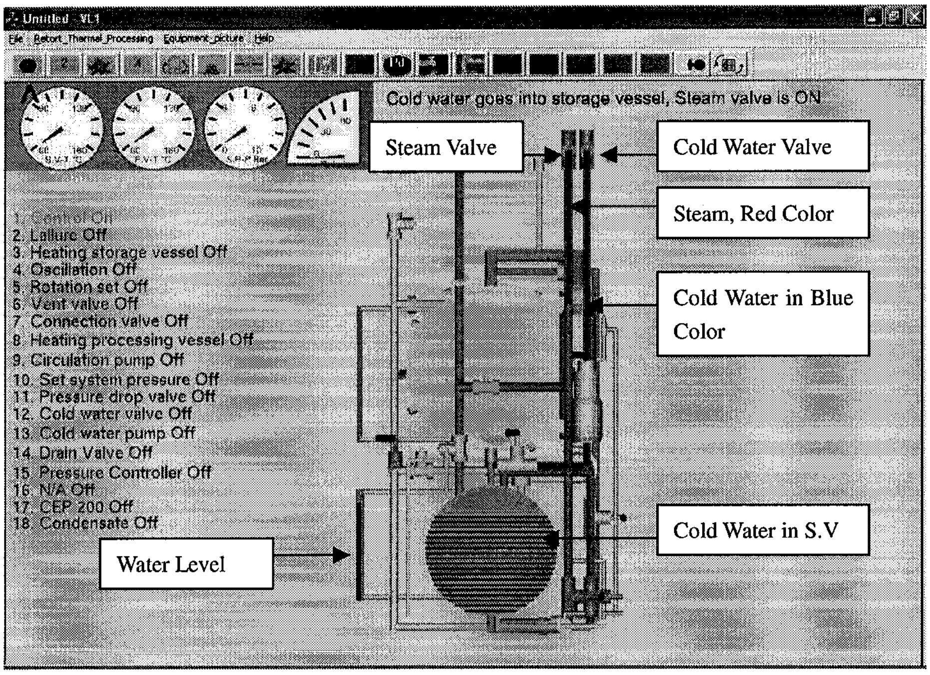
2. Cold water and steam valve turn on:
   The Figure 5.9(b) shows the situation with the cold water valve opened. Cold water enters and goes to the storage vessel. The cold water flows inside the tube expressed in blue color, and the water level of the storage vessel rises as cold water goes into the storage vessel. The blue lines in storage vessel indicate quantity of water in the storage vessel. The other valve is the steam valve next to the cold water valve. When this valve is opened, the steam goes into the steam tube which is represented by red color.

3. Dialogue for setting parameters:
   After opening the cold water valve and the steam valve, the cold water fill the storage vessel, and then a dialogue is launched out as Figure 5.10(a). This dialogue is used to define the parameters for the processing which include temperature of storage vessel, temperature of processing vessel, system pressure and rotating rate. The values of those parameters were initialized, but can be modified as well, when the user clicks OK with the mouse. The setting parameters will be shown at the bottom of interface screen as in Figure 5.10(b).

4. Temperature gauge for displaying storage vessel temperature:
   There is a gauge shown at the bottom of the left-hand side in Figure 5.10(b),



(a) Initial interface of virtual horizontal retort and process of loading sample



(b) The results of simulating the cold water and steam flow into the retort system

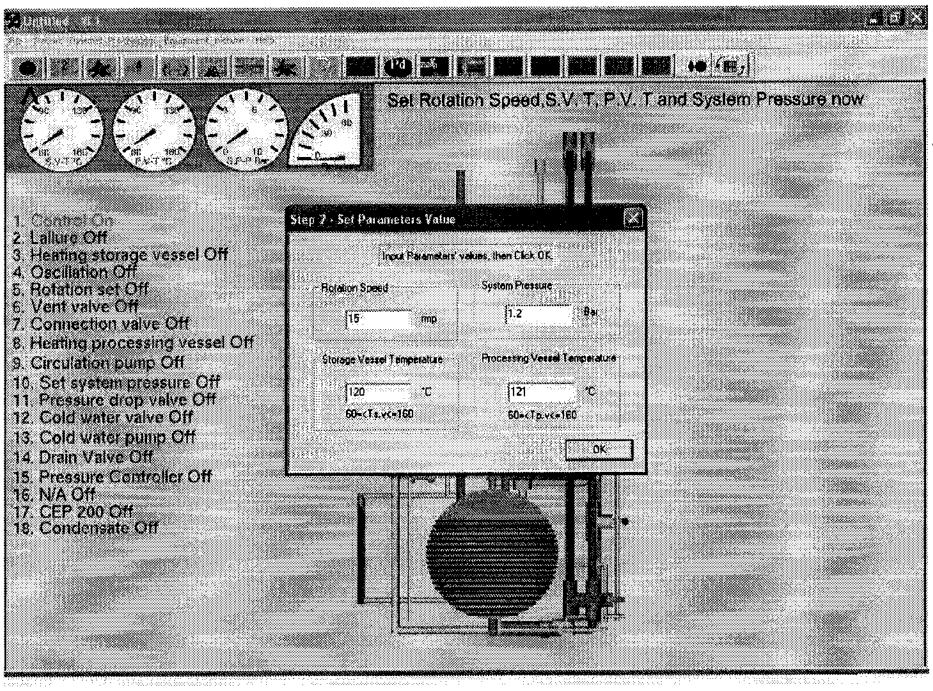
Figure 5.9 The results of loading sample and simulating to turn on the cold water and steam valve, the water and steam flow into retort system in different color which is the enlarged storage vessel gauge. While heating the water of the storage vessel, the temperature change displayed in this gauge, it synchronized with the storage vessel gauge at the top of the application interface. The purpose of this will show this step of the operation much more clearly.

5. Setting of rotation rate of the sample basket:
   When the rotation rate of the sample basket is set as described in step 3, the lid of the retort becomes transparent. This characteristic makes the change inside the retort sample shell become visible while the sample basket is rotating. This specific characteristic is shown in Figure 5.11.

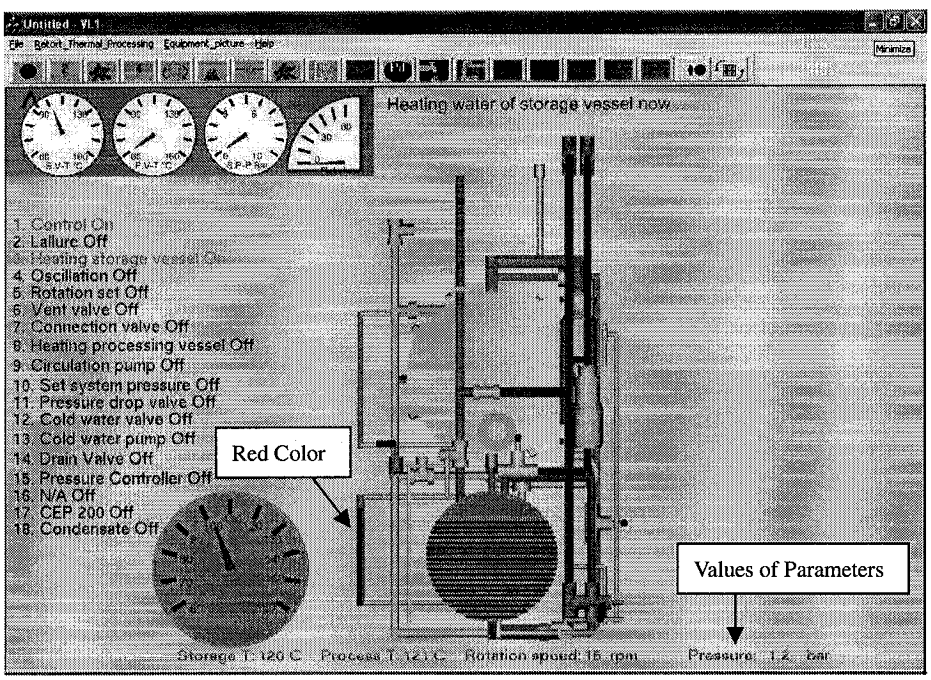
6. Processing vessel and Retort Temperature profile:
   When the temperature of the storage vessel reaches the predefined temperature, the Connection valve between the storage vessel and the processing vessel opens, and the heated water goes into the processing vessel. This process is shown in Figure 5.12(a). The retort profile also shows the result. When the Circulation Pump is ON, the circulation of water in the processing vessel is expressed by a red moving short cylinder (see Figure 5.12(b)). The retort profile indicates that the retort temperature is increasing now, and the temperature gauge of the processing vessel shows the same result.

7. Processing process and Processing time:
   Figure 5.13 shows the result of processing process of the virtual horizontal retort. The timer is launched out to count the processing time. The processing time is also shown in the retort temperature profile, which is the time when the temperature becomes constant.

8. Cooling process and drain water:
   After finishing processing, the next step is the cooling process. The cold water goes into the processing vessel, and spare water flows back to the storage vessel. This process is shown in Figure 5.14(a). When the temperature drops down to initial temperature, the drain valve is opened and the water in the processing vessel is drained out. This is shown in Figure 5.14(b).



(a) The result of setting system and processing parameters



(b) The result of simulating temperature gauge change while heating the water in storage vessel

Figure 5.10 The results of simulating to set system and processing parameters and the storage vessel temperature gauge change while heat storage vessel

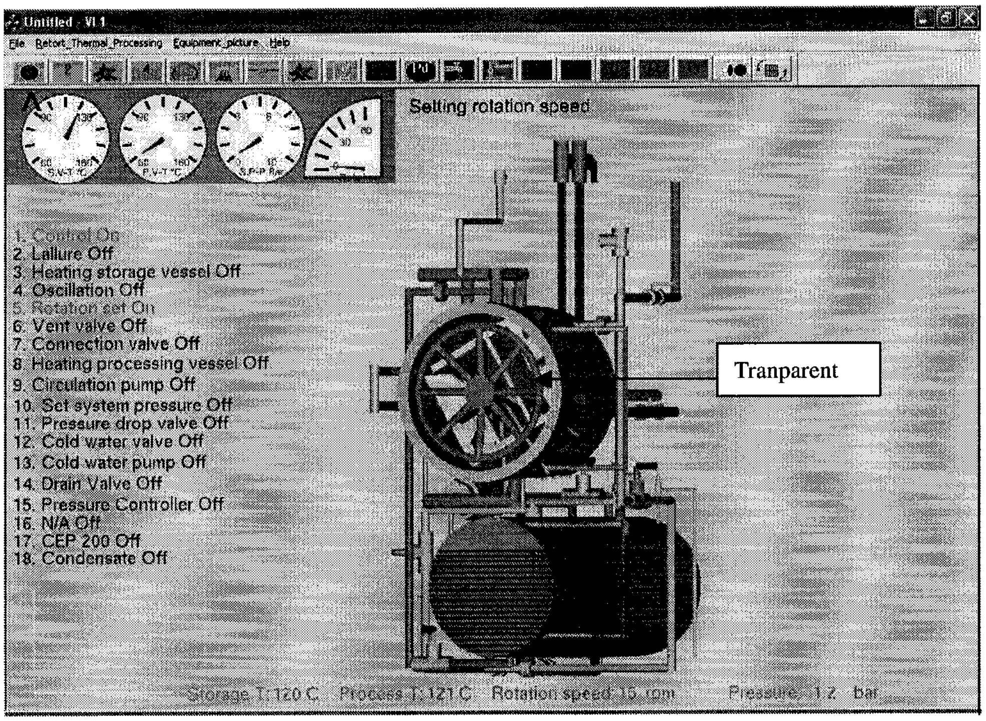


Figure 5.11 The results of setting rotation rate and transparent of retort lid

9. End of virtual processing:

   When the simulation of the retort processing is completed, there is a hint in the text display area to indicate user to press the Control On/Off button. This step is similar to turning off the power of the retort.

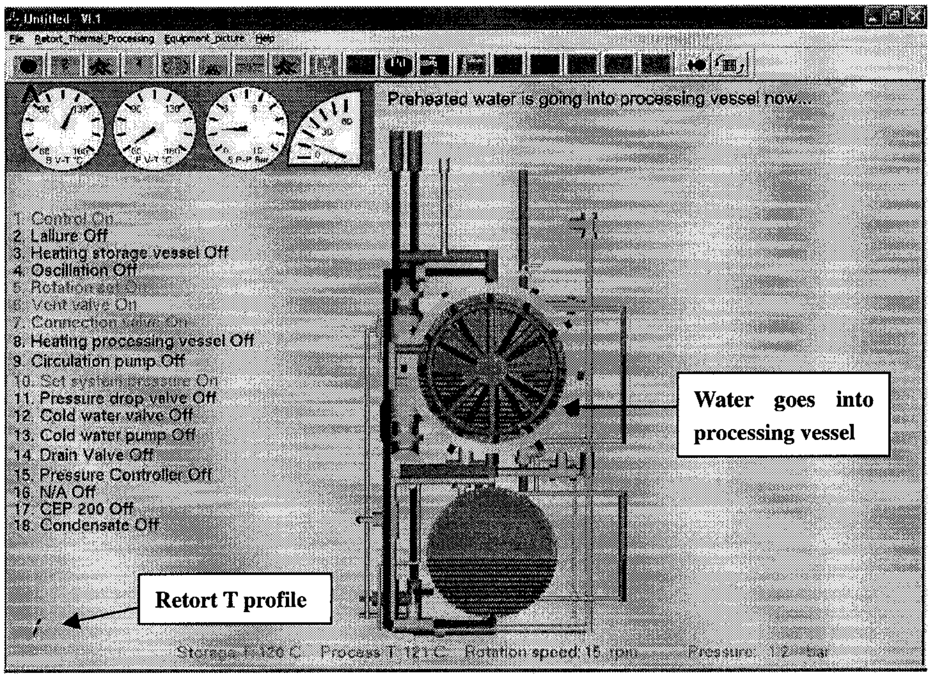
10. Unload sample:

    This procedure is similar to the first step, press Open & Close Retort Lid button, then the sample is moved out from the sample basket. The simulation is completely finished.

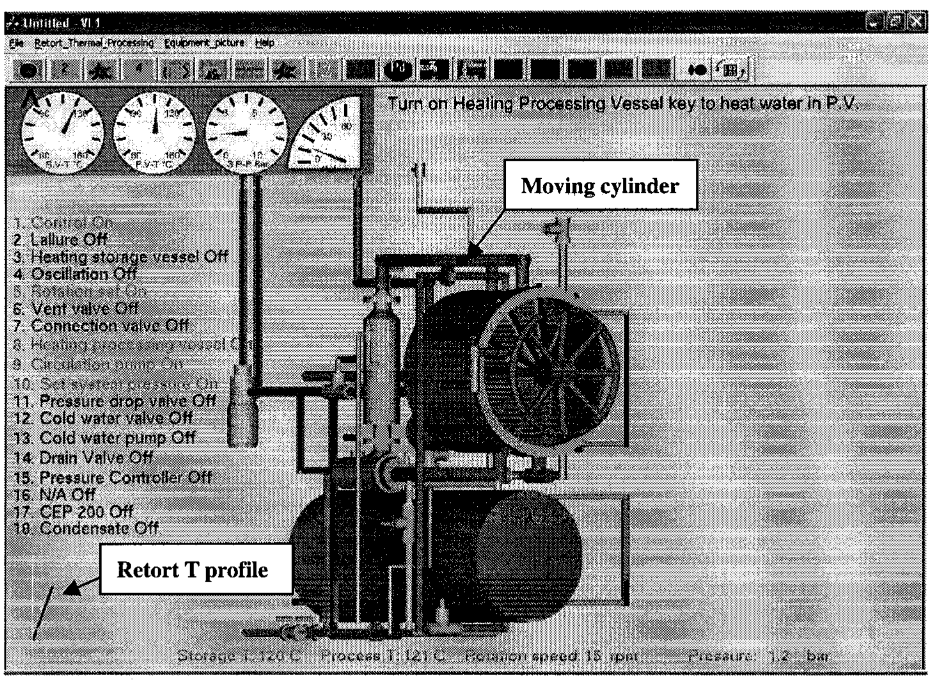
5.3.1.3 Differences and Specific Characteristics

Rotatability of visualized object:

Since the object (the horizontal retort), is visualized in three dimensional technique, the visualized 3D object has different appearance and character compared with the two dimensional simulation. The virtual retort can be



(a) The result of water goes into processing vessel



(b) The result of retort temperature profile and circulating water

Figure 5.12 The results of heated water from storage vessel to processing vessel, retort profile and circulation pump turns on

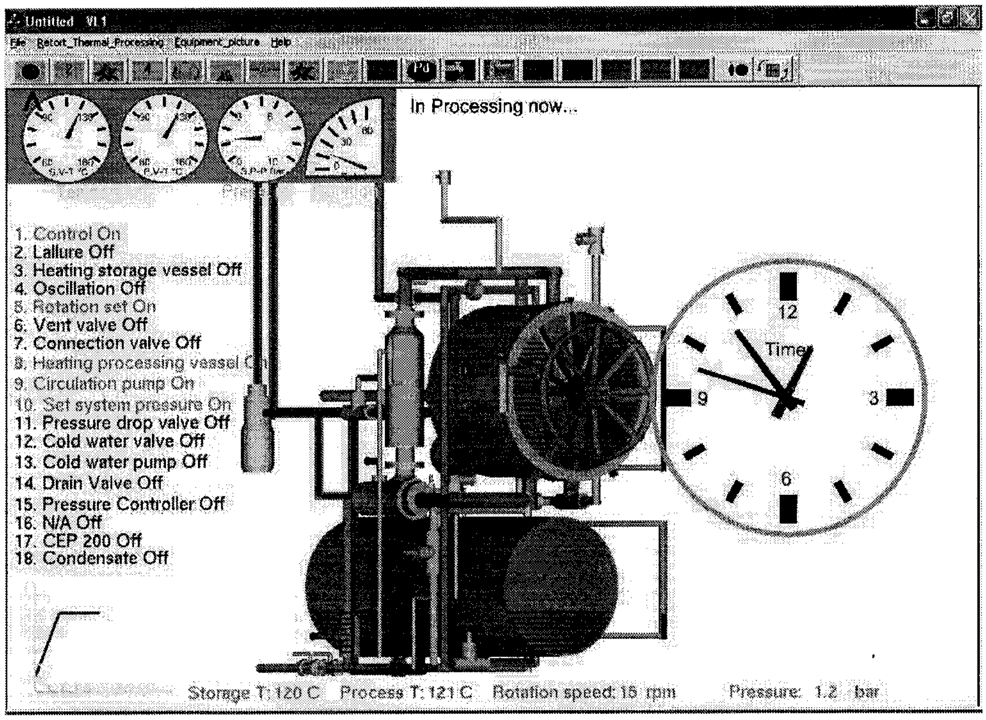


Figure 5.13 The results of processing process and use of timer to count the processing time

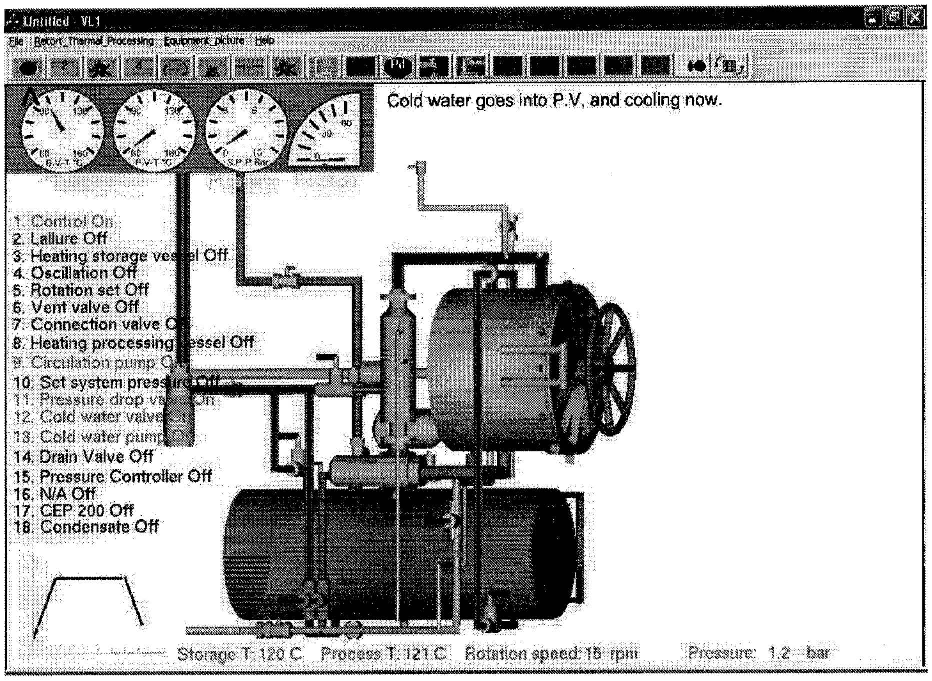
rotated randomly by pressing down the left button of mouse and moving the virtual horizontal retort in any direction. Figures 5.15(a), 5.15(b), 5.16(a) and 5.16(b) show the results of viewing the virtual horizontal retort from different directions: facade, top, bottom, back and side respectively. Here we only present the results obtained from four different view points. In fact, the user can view from any direction.

Transparency of visualized object:

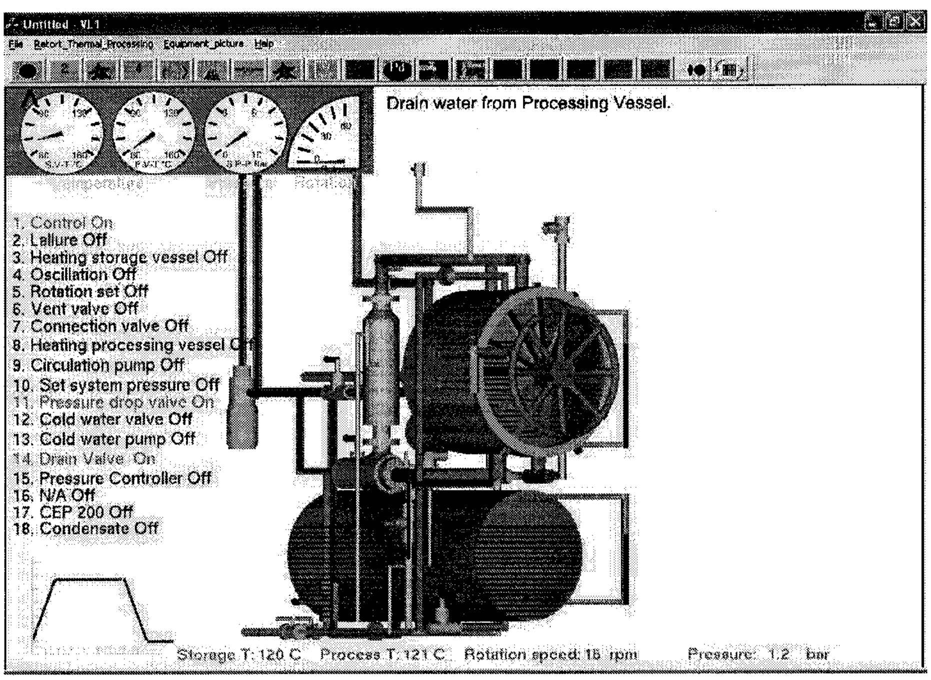
In order to observe the internal change of tube or sample shell, "Blend" function is utilized in this project to make the object become transparent, so that the flowing water inside of the tube can be observed. Also the rotating sample basket can be seen as well when the rotation rate is defined . This is shown in Figure 5.11.

Simulation Dynamically:

The virtual horizontal retort simulation provides a dynamic 3D image, such

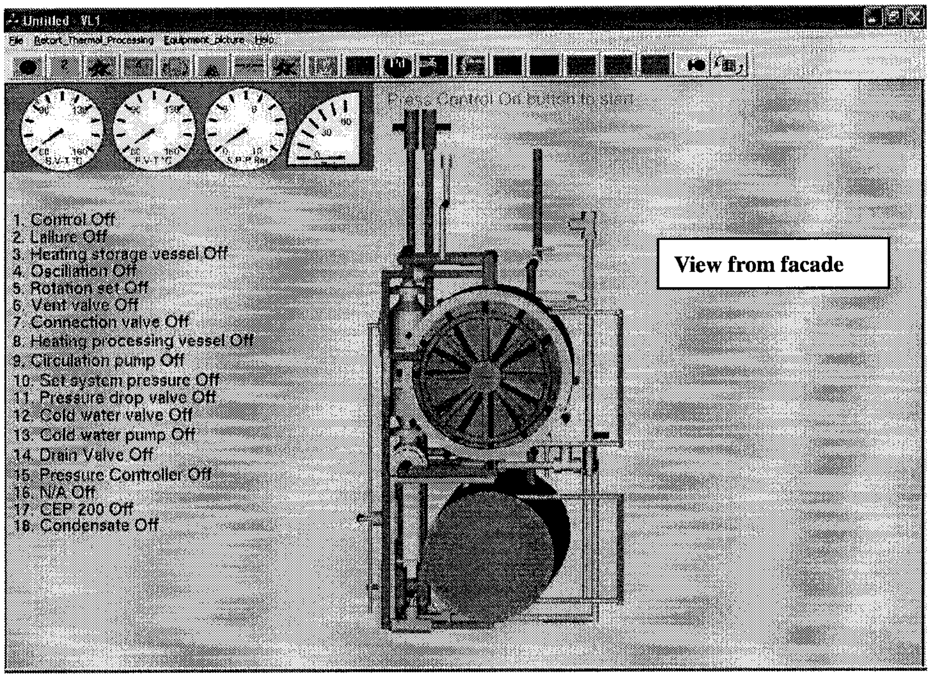


(a) The result of cold water goes into processing vessel for cooling

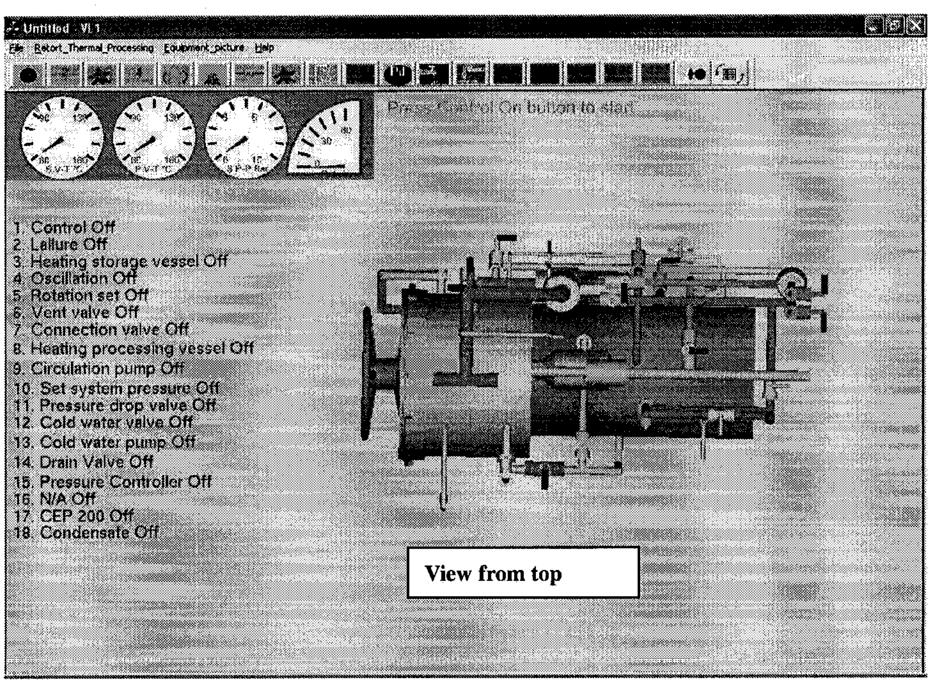


(b) The result of draining water from processing vessel

Figure 5.14 The results of cooling process and drain out the water from processing vessel

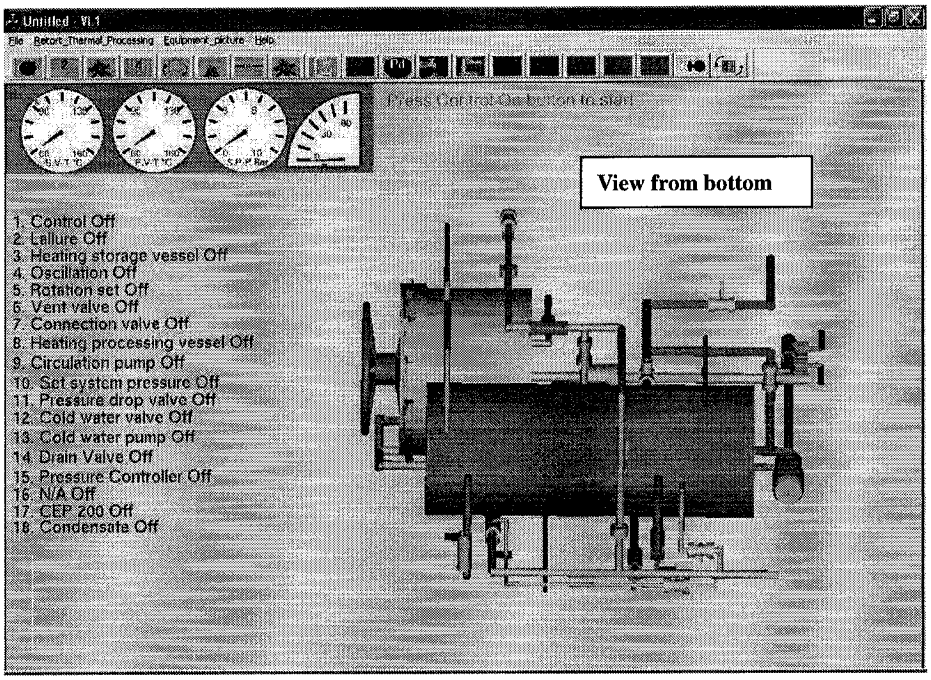


(a) Rotate the virtual retort and view from facade

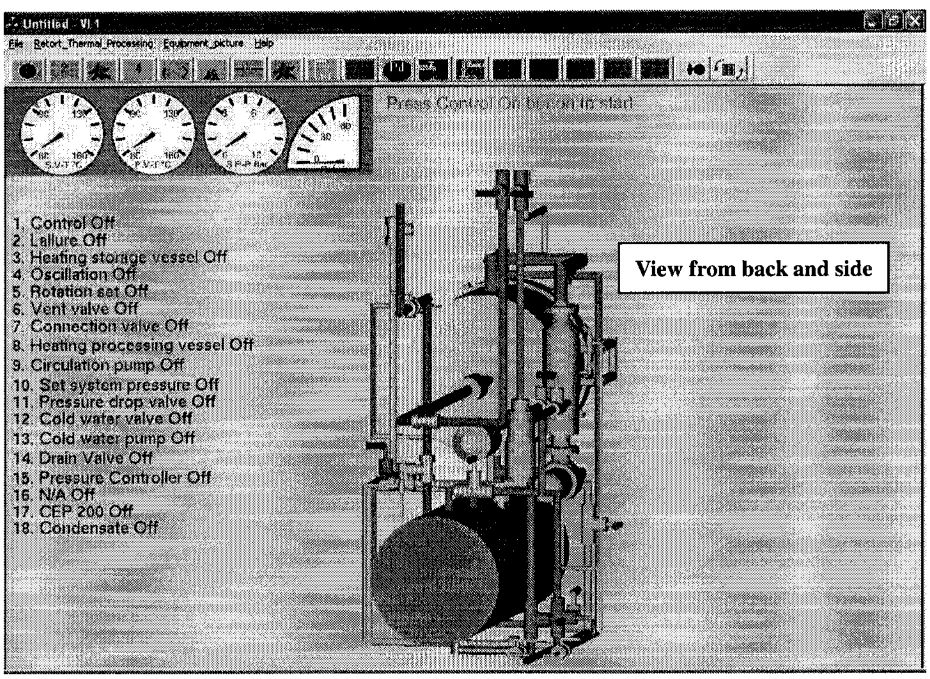


(b) Rotate the virtual retort and view from top

Figure 5.15 Specific characteristics of 3D simulation - rotating and viewing in any different directions - 1



(a) Rotate the virtual retort and view from bottom



(b) Rotate the virtual retort and view from back and side

Figure 5.16 Specific characteristics of 3D simulation - rotating and viewing in any different directions - 2 as, water or steam flowing inside the tube, the valve opening or closing. These are lifelike and dramatic.

5.3.2 Result of Visualization of High Pressure Processing (HPP) Equipment

5.3.2.1 Main Interface of Virtual HPP Equipment

The main interface of virtual high pressure processing equipment is shown in Figure 5.17. In order to show the working principle in a clearer manner, the virtual HPP equipment does not include the outer shell. We only visualize the major components of the high pressure equipment. The purpose is to introduce the high pressure working principle easily and clearly in class by the instructor, or to review of the working principle after class by the students.

The main interface (shown in Figure 5.17) includes the sample chamber, lid of sample chamber, lid lock, pressure pump and medium chamber. The medium in the medium chamber is represented in blue color.

The temperature bar is placed at the bottom of the interface, and is drawn in blue and red colors at the two ends of the bar. The blue side represents low temperature, and the red side represents high temperature. Those two components in the virtual high pressure processing equipment are shown in Figure 5.18.

5.3.2.2 Functions of Virtual HPP Equipment

From Figure 5.17 we can find some functional buttons which are designed in this simulation. There are five buttons on the toolbar. The first is the Start button for starting the simulation of working principle of high pressure processing, the second button is Set P, t button, **P** represents processing pressure, **t** represents processing time. When this button is clicked, user can use it to set pressure and time. The

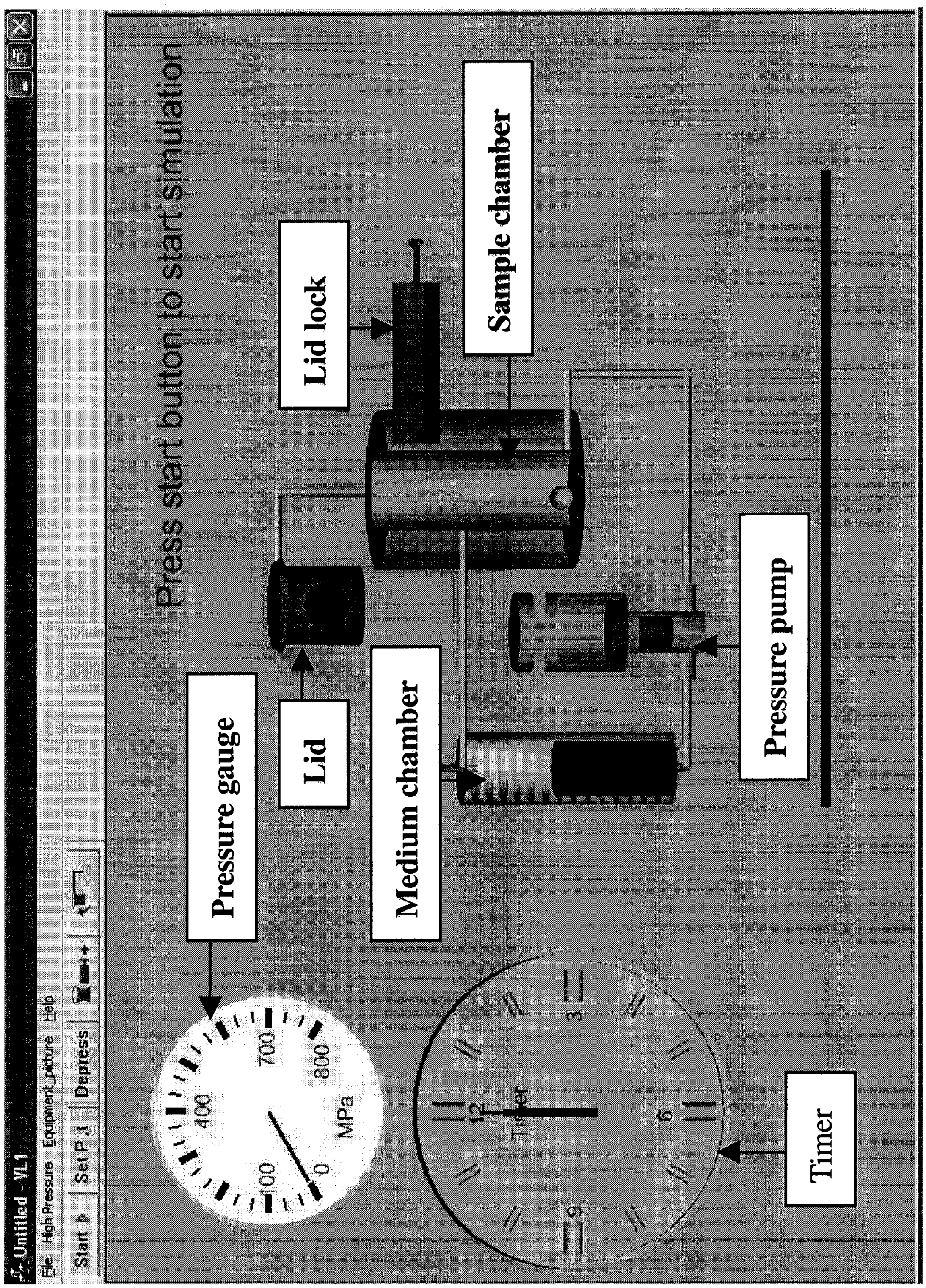


Figure 5.17 Results of main interface of virtual high pressure processing equipment and sample is loaded into sample chamber

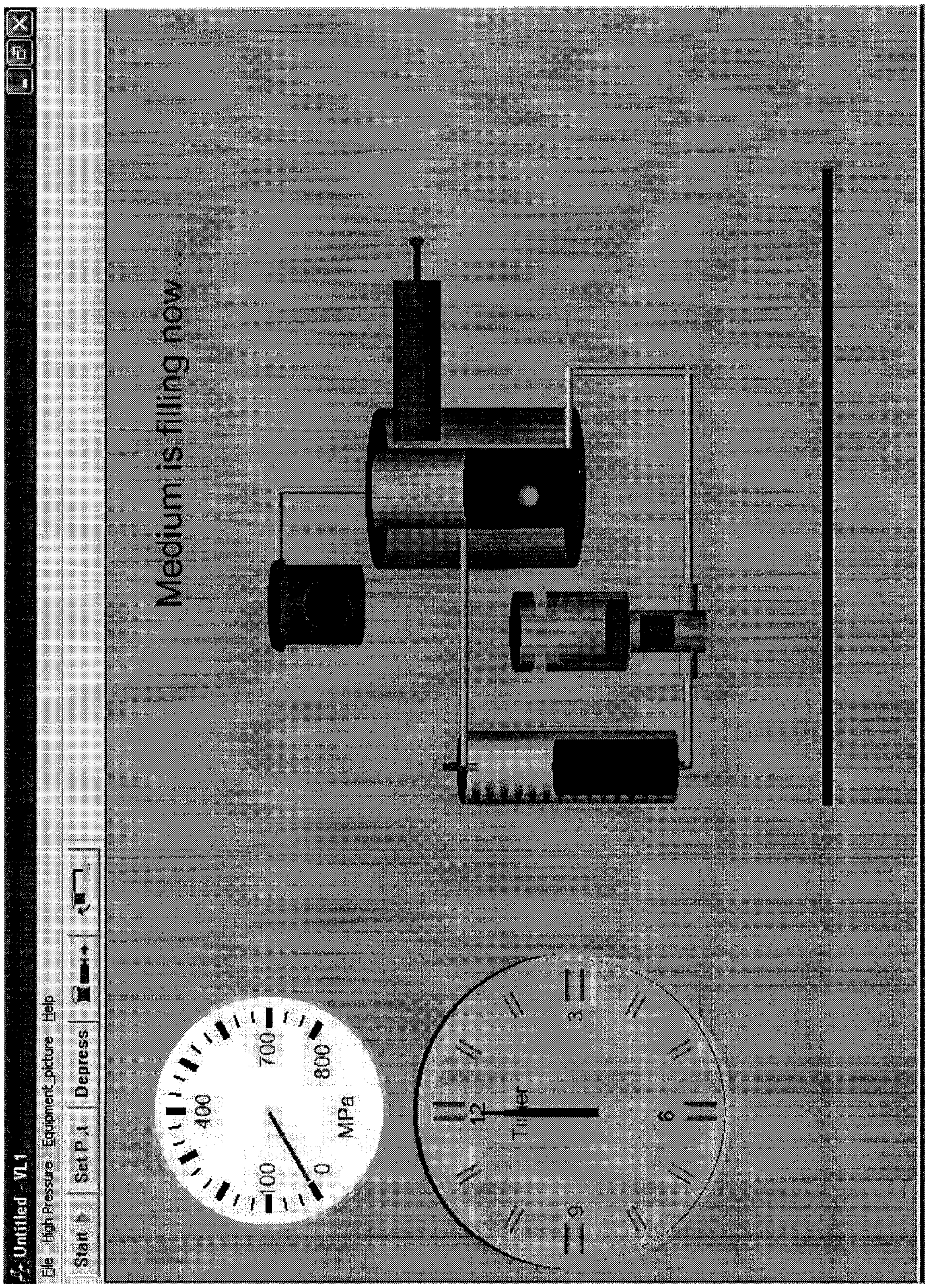


Figure 5.18 Result of sample in chamber and temperature bar in virtual high pressure equipment

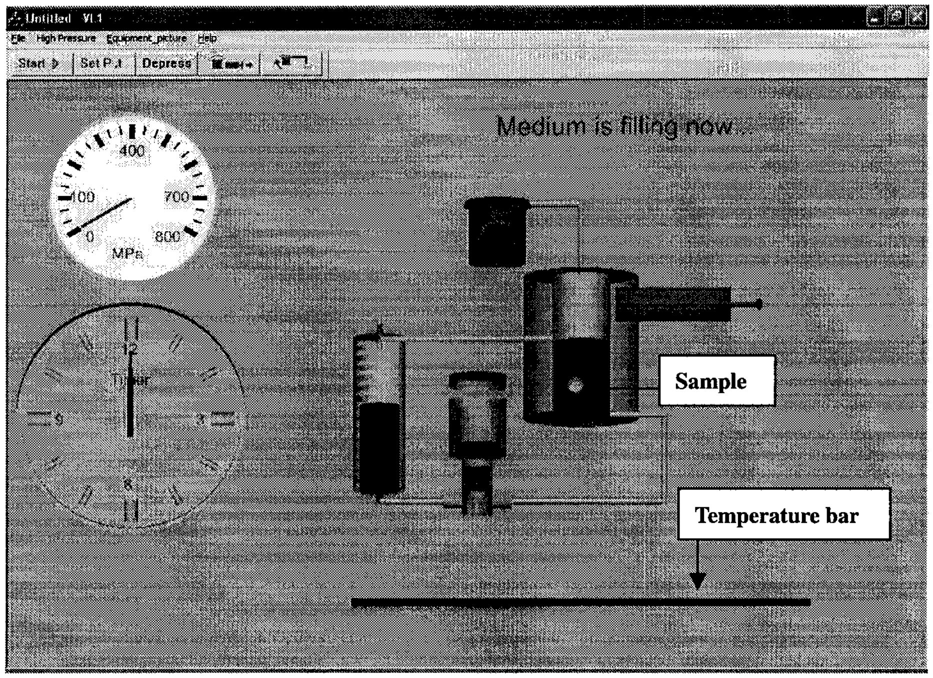
third one is $\boxed{\text{Depressure}}$ button for depressurizing when processing is complete. The fourth button is for withdrawing the lid lock and the fifth one is to open the lid after processing.

5.3.2.3 Demonstrating Process of Working Principle of Virtual HPP Equipment

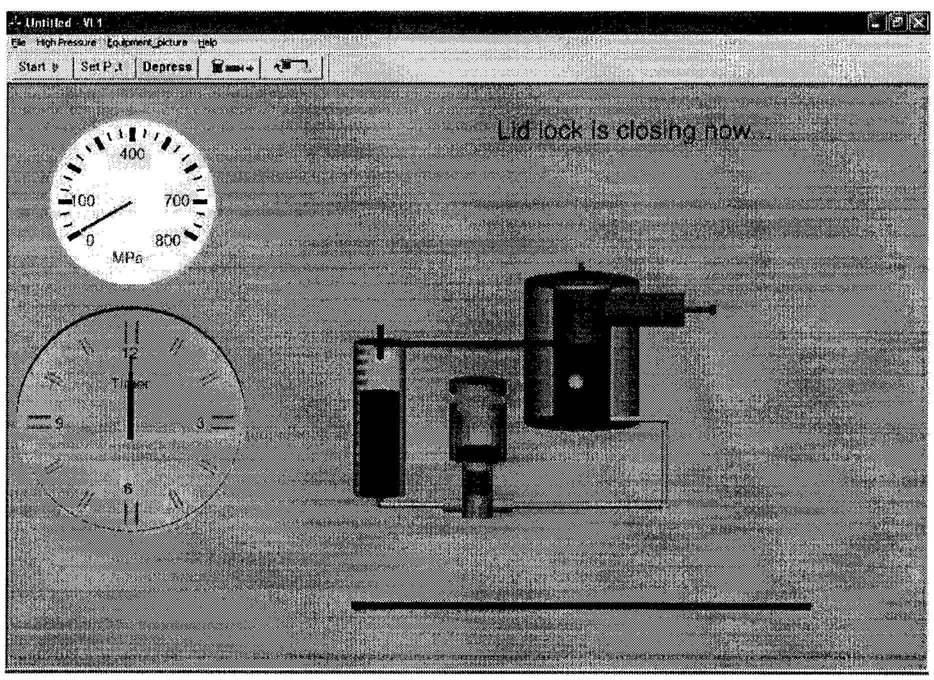
The virtual high pressure processing equipment is developed to show the operating procedure automatically. When the $\boxed{\text{Start}}$ button is clicked by the mouse pointer, the first step is to load sample, the small cube move into the sample chamber as shown in Figure 5.17. Then, the medium (blue color) in chamber will increase from the bottom of the sample chamber. That means the medium is filling the sample chamber. The second step is to put the packaged sample into the sample chamber, then close the lid and lid lock. These steps are shown in Figure 5.19(a) and Figure 5.19(b).

The third step is setting pressure and processing time by clicking $\boxed{\text{Set P, t}}$ button. After clicking the $\boxed{\text{Set P, t}}$ button, a dialogue is launched out as shown in Figure 5.21. There are two edit boxes for input values, one is pressure and the other is processing time. The values can be changed or use default values which are 300Kpa and 1 minute respectively. After setting these two parameters, click **OK**, and the pressure pump starts to work: the piston of pump starts to move for pumping, and the pressure increases in the sample chamber. The pressure change is displayed in the pressure gauge and the color of medium in the sample chamber is changed gradually from blue to red. Figure 5.20 illustrates this.

When the pressure reaches the setting pressure, the timer counts the time until the process is finished. Figure 5.22 shows this. In Figure 5.22, the pressure gauge displays that the setting pressure is 300KPa, and the timer displays that the time is 55 seconds which means that the processing time has passed 55 seconds.



(a) Result of medium filling process of HPP simulation



(b) Result of lid closing of HPP simulation

Figure 5.19 Results of medium filling and lid closing processes for operating the virtual HPP equipment

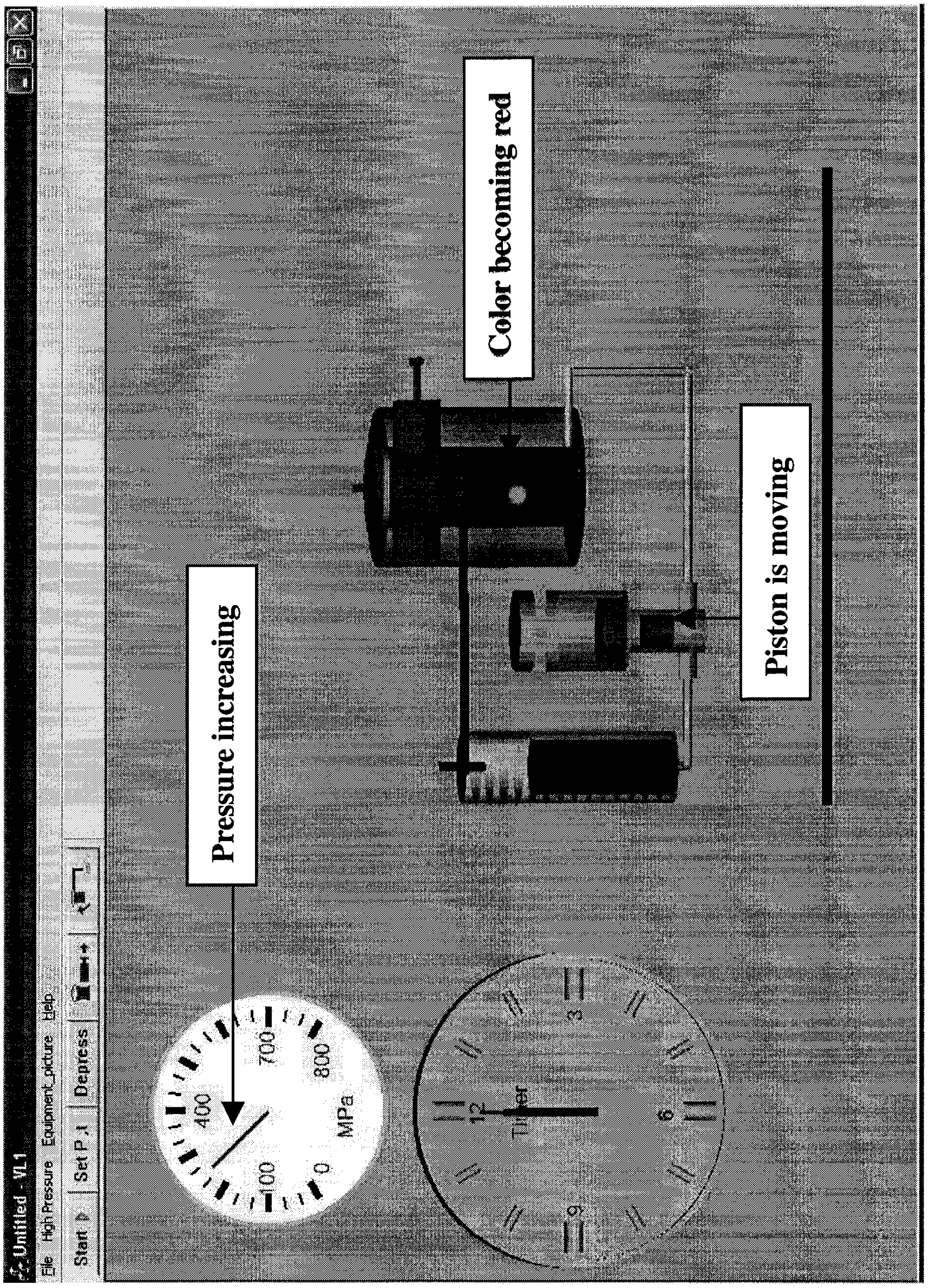


Figure 5.20 Result of interface of working process of pump and increasing pressure for operating virtual HPP equipment

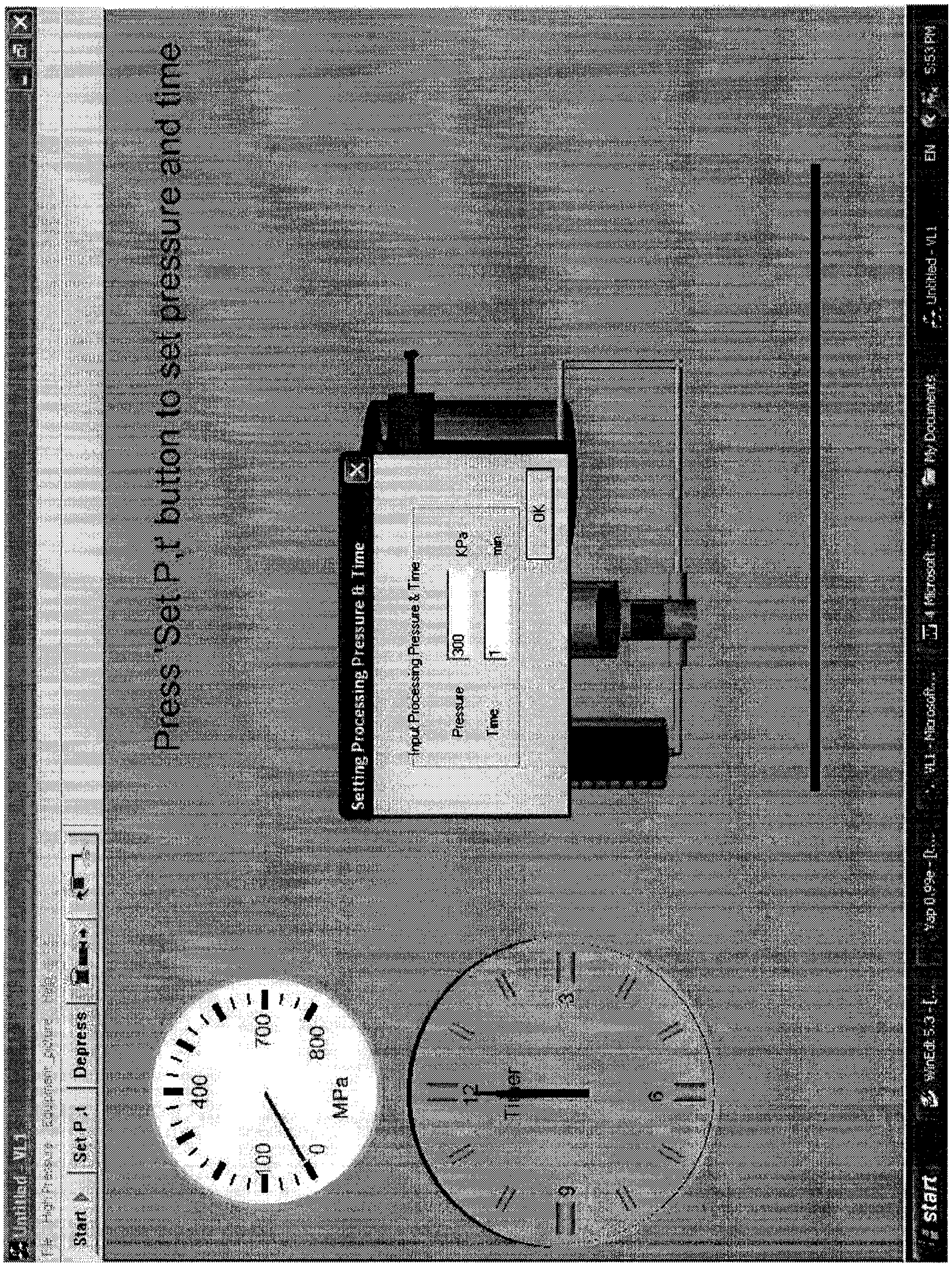


Figure 5.21 Result of interface of setting pressure and processing time for operating virtual HPP equipment

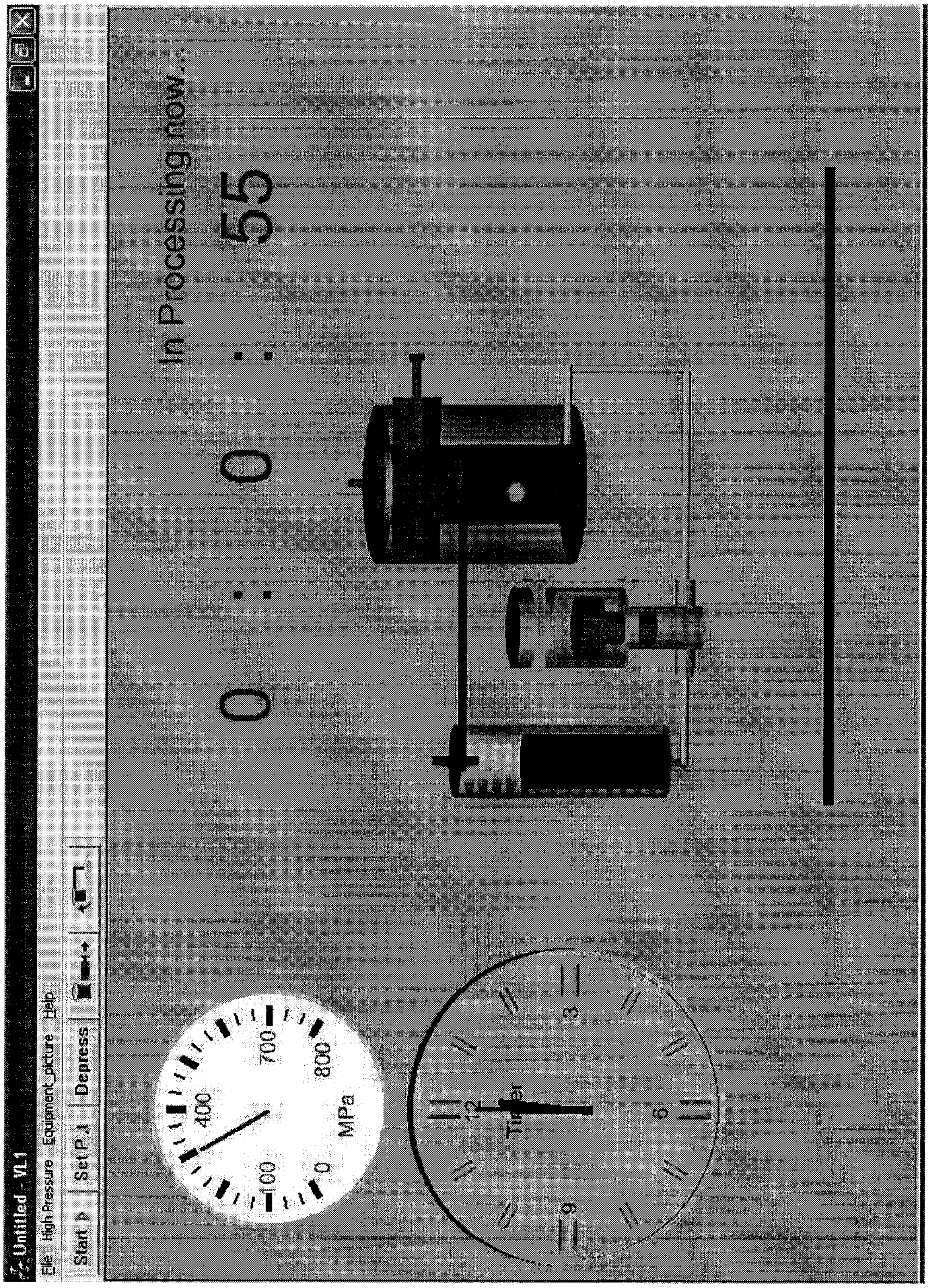


Figure 5.22 Result of interface of displaying processing time for operating virtual HPP equipment

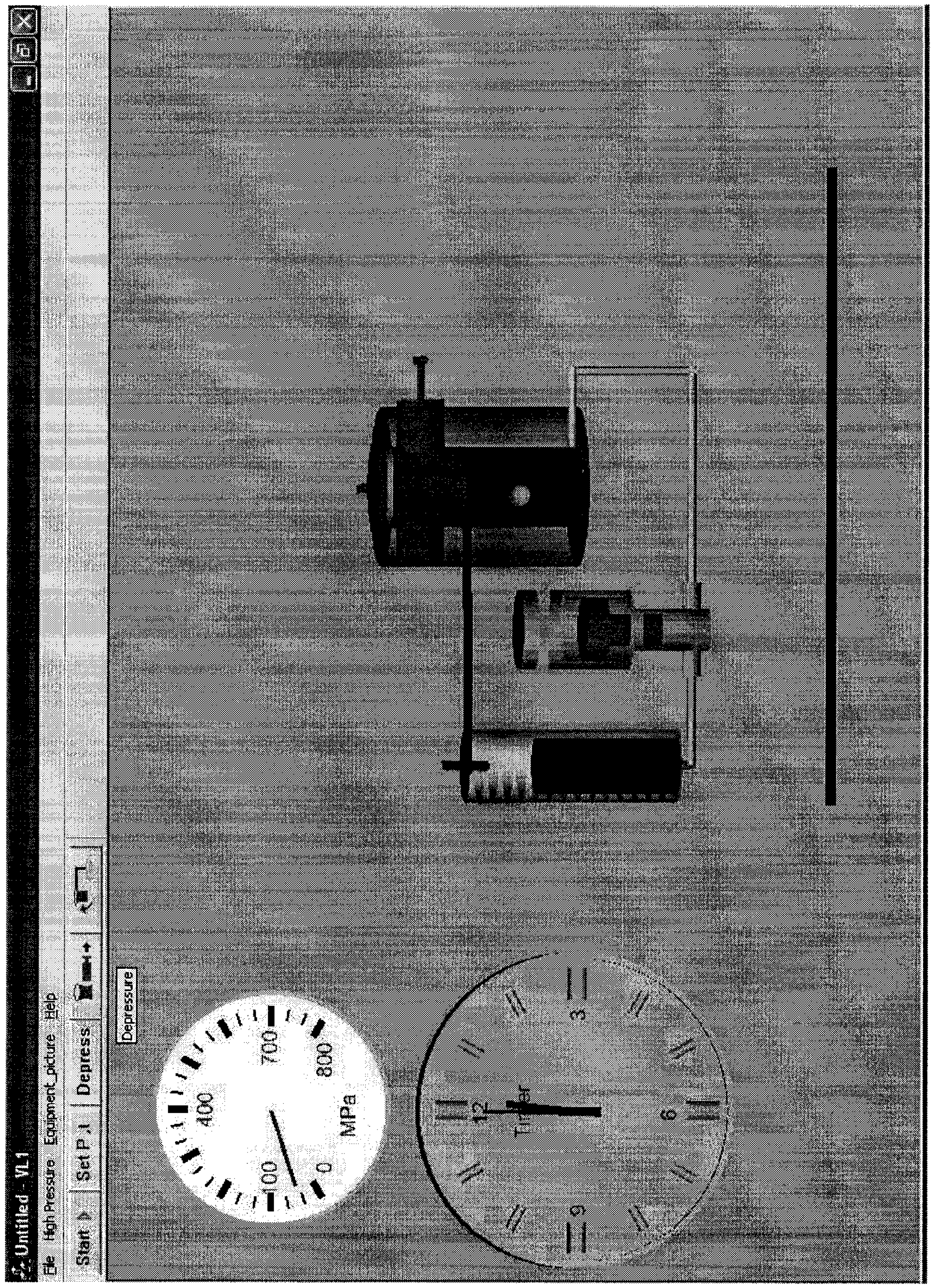


Figure 5.23 Result of interface of depressurization for operating virtual HPP equipment

When the processing is finished, next step is depressurization. Click the Depressure button, and then the pressure starts to drop down. This scenario is shown in Figure 5.23. The pressure gauge displays the pressure, and the medium color in the sample chamber becomes blue again, meaning that the pressure is depressurizing.

The final three steps are to unlock the lid lock and to open the lid of the sample chamber, then unload the sample from sample chamber. Those three steps are similar to closing lid, lid lock operation and loading sample, but in an opposite direction.

During the operation process, in order to tell the user which procedure is being carried out at that moment, we define the text description at top area of main interface for describing each step of the operations.

5.4 Conclusions

Two major types of food processing equipment were developed by using 3D computer techniques, which included a horizontal retort and a high pressure equipment. The virtual equipment is similar to the real equipment operating in the real world, and the working principles of these equipment are shown more clearly than possible in traditional ways. The principal advantages of the virtual equipment: easy to learn and no risk, no cost.

CHAPTER 6

SUMMARY AND RECOMMENDATION FOR FUTURE STUDY

6.1 Summary of Development of Food Processing Virtual Lab

The food processing virtual lab has been developed with computer languages, VC++, MFC and OpenGL.

The simulations for several food processing scenarios were developed in this research. The calculation simulations provide the user fast, accurate and easy way to teach or learn new food concepts. Since the parameters are changeable in the simulations, the user can use these simulations to compare the results by changing the values of different variables.

The food processing virtual equipment has been developed in thermal processing and high pressure processing, and include retort utilized in thermal processing and high pressure equipment . The developed 3D virtual equipment provides vivid images as real equipment in physical labs. As an educational tool in the food processing area, the 3D virtual equipment can be used to improve or take the place of traditional methods, for example, showing the related photos, pictures or going to the pilot plant.

The virtual food processing equipments can be rotated in any angle. The rotatable functionality is a major merit of the 3D virtual equipment, and allows the user to observe the virtual food processing equipment from any viewpoint. It supplies a very convenient way for instructors or students to grasp the internal structure and every part of the equipment. This function can be accomplished by simple action - left press the mouse on the virtual food processing equipment, then move the mouse until get to the right place where the user desires to observe.

The multi-functions of virtual equipment shows its practical value in showing and learning operation of equipment. The virtual horizontal retort is a good example of this characteristic. The buttons are set on the tool bar of the main frame, the first 18 buttons designed as the keys on the operating panel in the real horizontal retort. The sequence and functions of the buttons in the virtual horizontal retort are arranged the same as the real keys in real retort. The function description of each button can be displayed in a small window which shows the function and name of the button by moving the mouse on the button. The virtual equipment also supplies an active, dramatic, and new way for instructors and students in teaching and learning, rather than bald and uninteresting. The virtual equipment provides no risk, and no place or time limitation.

Computers are the wave of the future, but traditional learning techniques should not be forgotten. A student needs to interact physically with the real equipment and practice the theory in the real world and not learn everything from computers.

6.2 Future Study Suggestions

This project is focused on the visualization of equipment, and the operation of virtual equipment. Simulations developed by Chen (Chen, 2001), emphasized on calculation and prediction. Here, we suggest to combine these two kinds of computer simulations and integrating them to produce a complete food processing virtual lab. The user can make a food product or do an experiment from the sample preparation and loading of equipment, and setting processing parameters (selecting a processing model), operating the virtual equipments, get the final product and analyze the results. This is a comprehensive and complete virtual laboratory design and is much more practical for instructors, students and researchers in the food processing field.

REFERENCES

ABDUL, G., FARID, M. and CHEN, X. (2002). Numerical simulation of transient temperature and velocity profiles in a horizontal can during sterilization using computational fluid dynamics. *Journal of Food Engineering, 51(1): 77-83.*

CAMPANONE, L., GINER, S. and MASCHERONI, R. (2002). Generalized model for the simulation of food refrigeration. Development and validation of the predictive numerical method. *International Journal of Refrigeration, 25(7): 975–984.*

CARDARELLI, D., CRAPISTE, G. and MATTEA, M. (2002). Modelling and simulation of an oilseed meal desolventizing process. *Journal of Food Engineering, 52(2): 127–133.*

CHEN, C. (2001). *Application of Computer Simulation and Artificial Intelligence Technologies for Modelling and Optimization of Food Thermal Processing.* PhD. Thesis, McGill University, Montreal, PQ, Canada.

CHEN, C., ZHU, S., RAMASWAMY, H., MARCOTTE, M. and LEBAIL, A. (2004). CFD computer simulation of high pressure cooling process for pork. *IFT Annual Meeting and Food Expo.* IFT, Las Vegas, Nevada, USA, July 12-16.

FISHWICK, P. (1994). *Simulation Model Design and Execution: Building Digital Worlds.* Prentice Hall PTR Upper Saddle River, NJ, USA, First Edition, pp. 11-17.

FISHWICK, P. (1995). Computer simulation: The art and science of digital world construction. *http://www.cis.ufl.edu/ fishwick/.*

GERSHENSON, C., GONALEZ, P. and NEGRETE, J. (2000). Thinking adaptive: Towards a behaviours virtual laboratory. In Meyer et. al. (eds.) SAB 2000 Proceedings Supplement. Paris, France. ISAB Press, Massachusetts, USA.

GHANI, A., FARID, M. and CHEN, X. (2002). Theoretical and experimental investigation of the thermal destruction of vitamin C in food pouches. *Computers and Electronics in Agriculture, 34(1-3): 129–143.*

HARDWICK, R. (1992). Computer modelling/simulation in the food industry. *Institution of Chemical Engineers Symposium Series, 126: 507–510.*

HE, S. and LI, Y. (2003). Theoretical simulation of vacuum cooling of spherical foods. *Applied Thermal Engineering, 23(12): 1489–1501.*

HITE, B. H. (1899). The effects of pressure in the preservation of milk. *T. W. Va. Agric. Exp. Stn. Bull., 58: 15–35.*

KNORR, D. (1995). *Hydrostatic pressure treatment of food: Microbiology. In: New and Emerging Technologies for Food Preservation*, Blackie Academic & Professional, Glasgow, Scotland. pp. 159–170.

LOPEZ, A. (1987). *A Complete course in canning and related processes*, The Canning Trade Inc., Baltimore, Maryland.

LUDIKHUYZE, L., LOE, V., INDRAWATI, A. and HENDRICKX, M. (2001). *Thermal Technologies in Food Processing*, Editor: Philip Richardson, Campden and Chorleywood Food Research Association. Woodhead Publishing, Chipping Campden, UK, Chapter 14, pp. 266–268.

MERRIAM, D. (1999). Reminiscences of the editor of the kansas geological survey computer contributions, 1966-1970 & a byte. *Computers & Geosciences, 25: 321–344.*

RAMASWMY, H. and MARCOTTE, M. (2003). *Principles and Applications: Food Processing, Lecture Notes for the Food Processing Course.* McGill University, Montreal, PQ, Canada.

SHREINER, D., DAVIS, T., WOO, M. and NEIDER, J. (1997). *OpenGL Programming Guide: The Official Guide to Learning OpenGL.* Silicon Graphics Inc. Menlo Park, California, USA, Version 1.1, pp. 91-247.

SIMAL, S., FEMENIA, A., GARCIAPASCUAL, P. and ROSSELLO, C. (2003). Simulation of the drying curves of a meat-based product: Effect of the external resistance to mass transfer. *Journal of Food Engineering, 58(2): 193–199.*

SINGH, P. and ERDOGDU, E. (2004). *Virtual Experiments in Food Processing.* RAR Press, Davis, California, USA. pp. 19–20.

SINGH, R. and HELDMAN, D. (2002). *Introduction to Food Engineering.* Academic Press, London, UK. pp. 55–60.

STARBIRD, S. (1990). Metamodel specification for a tomato processing plant. *Journal of the Operational Research Society, 41(3): 229–240.*

STRATTON, V. and SUTTON, A. (1992). Modelling the business. *Institution of Chemical Engineers Symposium Series, 126: 487–492.*

SUN, D. and HU, Z. (2002). CFD predicting the effects of various parameters on core temperature and weight loss profiles of cooked meat during vacuum cooling. *Computers and Electronics in Agriculture, 34(1-3): 111-127.*

SUN, D. and HU, Z. (2003). CFD simulation of coupled heat and mass transfer through porous foods during vacuum cooling process. *International Journal of Refrigeration, 26(1): 19–27.*

TANNER, D., CLELAND, A. and OPARA, L. (2002). A generalized mathematical modelling methodology for the design of horticulture food packages exposed to refrigerated conditions: Part 2. heat transfer modelling and testing. *International Journal of Refrigeration, 25(1): 43–53.*

TATTIYAKUL, J., RAO, M. and DATTA, A. (2002). Heat transfer to a canned corn starch dispersion under intermittent agitation. *Journal of Food Engineering, 54(4): 321–329.*

WIDDISON, R. and AIKENHEAD, M. (1998). Computer simulation in legal education. *International Journal of Law and Information Technology, 5: 279–307.*

WIKIPEDIA (2004). History of computing hardware (1960s - present). *http://en.wikipedia.org/wiki.*

XIA, B. and SUN, D. (2002). Applications of computational fluid dynamics (cfd) in the food industry: A review. *Computers and Electronics in Agriculture, 34(1-3): 5–24.*