UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A PILOT SCALE HIGH PRESSURE FOOD PROCESSING SYSTEM

WAEL MOHAMED ABDALLA ELAMIN

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DEVELOPMENT OF A PILOT SCALE HIGH PRESSURE FOOD PROCESSING SYSTEM

By

WAEL MOHAMED ABDALLA ELAMIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

January 2016
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Dedication

I believe that what I become depends on what my father teaches me at odd moments.

This work is dedicated to my father

Mohamed Abdalla Elamin.

the best teacher and friend I ever had

May Allah bless and forgive him and reward him the Jannah
Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Doctor of Philosophy

DEVELOPMENT OF A PILOT SCALE HIGH PRESSURE FOOD PROCESSING SYSTEM

By

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January 2016

Chair : Associate Professor Johari Bin Endan, PhD
Faculty : Engineering

High-Pressure Processing (HPP) is a non-thermal widely recognized pasteurization method to inactivate microorganisms and enzymes to prolong product shelf life instead of the conventional thermal preservation. However, unlike thermal methods, it can maintain the quality and keep the original nutrients, vitamins, flavor, and appearance as well. Such technology can be introduced to the country, to replace the current traditional methods of processing of many local food products. Although, high pressure processing has gained the interest of many manufacturers in the food industry, the cost of HPP equipment is considered high, and therefore, there are voices calling for new equipment.

The groundwork of this effort is to design, develop, and test of pilot-scale high-pressure food processing equipment that serve both small businesses and as a laboratory unit. The fabricated system comprises two pressurizing systems as well as two pressure vessels and their connections.

Experimental work and testing of the fabricated machine was extensively done and further testing of different processing pressures on different types of local food, allocating the quality attributes and improvement were also made. It seeks the better understanding of work of a pilot plant unit, both in its ability to reduce microorganisms and to find the effect of changes in the physical and quality attributes of treated food, namely Oil Palm fruit, Durian mash, Blood Cockles, Shrimps and Mud Crabs.

The testing of this HPP machine resulted in some significant contributions, findings, and observation and valuable discussions were conducted. A significant shelf life resulted in the Oil Palm fruit with an extension up to one year with 310 MPa of pressure. Blood Cockles, Shrimps and Mud Crab improved their separation and sensory quality at 345 MPa, while Durian mash and Blood Cockles’ microbial safeties were enhanced. HPP has reduced the microbial load of Durian mash from $5.9 \times 10^4$ to $4.8 \times 10^2$ CFU/g, whereas in the case of Blood Cockles the initial microbial load of $5.7 \times 10^4$ CFU/g was totally inactivated by 240 MPa of pressure and above. This work offers insight into upcoming areas of research opportunity particularly in the local food industry.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

REKABENTUK, PEMBINAAN DAN UJIAN SEBUAH SISTEM PEMPROSESAN MAKANAN TEKANAN TINGGI SKALA PILOT

Oleh

WAEL MOHAMED ABDALLA ELAMIN

Januari 2016

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Fakulti : Kejuruteraan

Pemprosesan tekanan tinggi (HPP) adalah satu kaedah pempasteuran bukan haba diiktiraf secara meluas untuk membuluh mikroorganisma dan enzim untuk memanjangkan jangka hayat produk dan bukannya pemeliharaan haba tradisional. Walau bagaimanapun, tidak seperti kaedah haba, ia boleh mengekalkan kualiti dan asal nutrien, vitamin, rasa, dan rupa juga. Teknologi seperti ini boleh diperkenalkan di negara ini, untuk menggantikan kaedah tradisional semasa pemprosesan banyak produk makanan tempatan. Walaupun, pemprosesan tekanan tinggi telah mendapat minat ramai pengeluar dalam industri makanan, kos peralatan HPP dianggap tinggi, dan oleh itu, ada suara-suara memanggil peralatan baru.

Asas usaha ini adalah untuk mereka bentuk, membangun, dan ujian tekanan tinggi peralatan pemprosesan makanan berskala kecil yang berkhidmat untuk kedua-dua perniagaan kecil dan sebagai unit makmal. Sistem yang direka terdiri daripada dua sistem menekan serta dua kepuk tekanan dan sambungan mereka.

Kerja uji kaji dan ujian mesin fabrikasi telah dilakukan secara intensif dan ujian lanjut tekanan pemprosesan yang berbeza pada pelbagai jenis makanan tempatan juga dibuat. Ia bertujuan untuk memahami dengan lebih baik kerja-kerja unit kilang perintis, baik dalam keupayaan untuk mengurangkan mikroorganisma dan mencari kesan perubahan dalam sifat-sifat fizikal dan kualiti makanan dirawat, iaitu buah-buahan Kelapa Sawit, Isi durian, Kerang Darah, Udang dan yang Ketam Lumpur.

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I am grateful to many people for making this project possible. I would like to express my heartfelt gratitude to my friends in Sudan and UPM for their constant support and encouragement.
I certify that a Thesis Examination Committee has met on 26 January 2016 to conduct the final examination of Wael Mohamed Abdalla Elamin on his thesis entitled "Development of a Pilot Scale High Pressure Food Processing System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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<td>TPA</td>
<td>Texture Profile Analysis</td>
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<tr>
<td>TBC</td>
<td>Total Bacterial Counts</td>
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<tr>
<td>CFU</td>
<td>Colony Forming Unit</td>
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</table>
CHAPTER 1

INTRODUCTION

1.1 Background

Demands for minimally processed and high-quality food have increased in the last decades (Reineke, 2012). Consumers are becoming more aware of their food selection and are demanding better quality foods. This has eventually led to numerous developments of preservation methods in order to produce suitable new products capable of achieving the safety of food to meet the consumers' demands (Linnemann et al., 1999).

The primary goal of most traditional preservation methods (e.g., thermal processing) is to preserve food against microorganisms, and is achieved through excessive use of the process. These kinds of processes usually result in a decrease in the food value and properties.

Non-thermal Processing is considered as an emerging technology consisting of several food processing methods, which include, power ultrasonic, pulsed electric field, magnetic field, intense light pulses, irradiation, chemical, biochemical, hurdle technology and, of course, high-pressure processing (Cardello, 2003). Among the other emerging technologies, high pressure processing (HPP) has the most positive utility and greater acceptance by consumers (Cardello et al., 2007).

The high-pressure food processing technology has been established as a preservation method of pasteurization, which is an alternative to traditional thermal processes to obtain the microbiological safety of food products. Unlike the thermal method, HPP avoids unpleasant changes in food's sensory, flavor, nutritional, physical and chemical properties (Téllez-Luis et al., 2001; Fonberg-Broczek et al., 2005; Torres and Velazquez, 2005; Welti-Chanes et al., 2006; Torres et al., 2009; Campus, 2010; Bermúdez-Aguirre and Barbosa-Cánovas, 2011; Mújica-Paz et al., 2011).

The traditional thermal processing of food causes some reactions that lead to undesirable changes in the food properties and quality. However, the quality deterioration is much less with non-thermal processing (Benet, 2005; Jaeger et al., 2010).

HPP is the process of applying uniform high pressures to the food product from all sides for a given treatment time so that the product will retain its initial shape after the process. This process will not cause any physical damage if the treated product is not porous.
High-pressure technology has been used in the oil and gas industry for a long time. It has also been employed in the large-scale production of ceramic, steel components and in other fields. Because of the commercial success and advantage of inactivating the microorganisms and enzymes and producing high-quality food, HPP has been increasingly used in the food production industry. The HPP equipment and products have been in the markets since the 1990’s, and its technique has now effectively been used in Japan, the United States and Europe for many years. The industrial application of HPP has been increasing for the last decades resulting in more HPP equipment installations.

It is widely accepted and established that HPP is an environmental process and it can maintain the fresh like qualities of foods superior to the traditional heat processing. Still, it is not widely adopted yet (Toepfl et al., 2006; Grauwet et al., 2012; Chakraborty et al., 2014; Georget et al., 2015). There are some difficulties obstructing the entrance of HPP technology into the food industry in Malaysia and many other countries. It can be summarized in two main points:

1. The main reason is the high capital cost of the technology, which starts at 0.5 million United States dollars and upward depending on the equipment size and capacity (Koutchma, 2014a). The costs can be high for many food manufacturers around the globe to purchase and start their HPP business.
2. The second obstruction, which prevents the early entrance of the technology, is the consumers themselves, and their choice and orientation for food. Consumers have poor knowledge levels coupled with high levels of doubt towards the majority of food process innovations (Bredahl et al., 1998; da Costa et al., 2000).

Recently, consumers have changed their behavior towards their food acceptance. According to Szakály et al. (2012), there is a relationship between lifestyle, health and behavior, and the preference for food products. Consumers are becoming more aware of the value of food for their health and hence, are demanding freshness, clear labels and minimal chemical additives in processed food (Rollin et al., 2011). The advantage of HPP in this matter can help to introduce the technology to the country. Reducing the capital cost and operating cost of HPP equipment will open the gate for many food processors in the country to invest in the promising technology. It will also lead to improving efficiency through the mechanization in the production of local products in the Malaysian food industry, particularly, in the matter of the processing and preservation of local products.

1.2 Problem Statement

There is no doubt that the marketability and demand for some of the local Malaysian edible products, such as palm oil, durian and seafood, are very high and significant to be consumed locally or even worldwide. Thermal pasteurization is commonly used to attain the microbial safety and prolong the shelf-life of these products. However, thermal processing causes quality degradation of treated food products.
High-pressure processing is a non-thermal food preservation method and can be considered as an alternative solution to this matter. In this technology, food is exposed to a high level of pressure, to attain microbial inactivation as well as to maintain the quality of the fresh product. The principal advantage of this processing is that it does not use heat. This will guarantee that the sensorial quality attributes and nutritional qualities of the raw food remain the same while attaining a clean and safe product (Cheftel and Culioli, 1997).

On the other hand, high-pressure food processing systems around the globe have some issues that prevent the fast spread and expansion of the technology, such as the high-cost, huge panel size and heavy weight of the equipment. This work was conducted to start introducing HPP equipment as well as its products commercially in Malaysia by designing and developing a novel HPP system. This system will reduce the total cost of the investment in HPP technology that is related to other commercial equipment, and will restrict the size and weight to the minimum.

The Malaysian food industry is full of different kinds of food products; it will be great to gain a benefit of these already examined and published studies with HPP to be transferred and reflected in the industry, and also to conduct new research towards local products. Some local food products, which included Malaysian blood cockles, Malaysian shrimps and mud crabs, Oil palm fruit, and Durian mash, were selected upon their importance in the Malaysian market and to be treated as novel products that were never HPP tested. The introduction and enabling the transfer of this advanced technology can significantly reduce the operation cost of the processed unit and increase the productivity, which will reflect positively and help the food industry in the country.

1.3 Aim of the Study

The main aim of this study was to design, develop and test a pilot-scale high-pressure processing system that includes two pressurizing systems, one automatic and one manually operated system; both of them were batch designs. The first system, which is the main system, can generate pressure automatically into a pressure vessel by means of two air driven pumps. The second system uses the direct compression method to test the specimen by means of a piston derived by a manual pressurizer that is designed to generate high pressures. The developed system will minimize the total cost, and reduce the size and weight to the minimum in comparison to other commercial units. Also, it was used to investigate the effect of high-pressure processing on different quality attributes of the selected local food products.

1.4 Objectives of the Study

The specific objectives can be described as follows:

(a) To design and develop a low cost pilot-scale high-pressure processing system for preservation and pasteurization of local food products, and also to achieve the size and weight maximum reduction.
To compare the economics of the developed system with the commercial scale units, and to evaluate the performance of the system at different pressure levels from 67 MPa up to 410 MPa the maximum.

To test the developed prototype unit with the selected local food products, which include Malaysian blood cockles, Malaysian shrimps and mud crabs, Oil palm fruits and Durian mash. Also, to determine the different quality attributes and improvement of the treated products, and to compare it to the conventional methods.

1.5 Scope of the study

In this work, the authors have designed and fabricated a HPP machine for food processing, which is able to solve almost all the problems mentioned in the problem statement section. This thesis illustrates the design process of a pilot-scale high-pressure processing system. It also includes some complementary investigations for the development and testing of the machine to fulfil the objectives of the thesis. Figure 1.1 shows the diagram that describes the three main scopes of this study.

![Figure 1.1. The scope of the study](image)

The focus of this thesis has been directed at cost reduction while achieving the maximum possible efficiency of the currently existing machines. The design has been achieved based on the required functions to accomplish the relevant operations, such as loading, unloading and handling of the products, as well as employing the specifications of the current types of systems taking into account their imperfections, such as pressure vessel position, pumps used, safety factors and efficiency.

In this study, a review of various HPP equipment technologies, components and operating mechanisms were made bearing in mind the chronological order of reports and publications. An interactive logical study and necessary calculations have been developed for designing the machine structure in this study. This work presents the steps and overall components of the design of the machine structure in the conceptual and fundamental design phase. This processing system was built to enable harvested food conversion into the useful, high-quality products.
By developing the design to fulfil the necessities of the operating process, the cost and weight were able to be significantly reduced. This has created an opportunity that qualifies the machine to have its competitive advantage. Testing the machine guaranteed its reliability and provided the required information about the system performance.

1.6 Thesis Outline

In this study, the work is divided into five chapters beginning with an introduction, followed by the second chapter, which is a literature review devoted to HPP equipment. The literature review defines the technology, components and mechanisms of operation, viewing, chronologically, the publications of HPP equipment and its applications.

The third chapter covers the design and the selection criteria of the HPP pilot plant system components from scratch until its final form. This chapter discusses the crucial design formulas and drawings used in the design of the main parts of the HPP system. This chapter also covers the construction processes beginning with the conceptual design and going through all the design requirements.

In chapter four, the experimental work and testing of the fabricated machine is presented and discussed for further examination of different processing pressures on various types of food. This chapter seeks the better understanding of the work of the pilot plant.

The final chapter summarizes the significant contribution and findings of this work, and lists several conclusions and recommendations upon what was achieved in the study. It also offers insight into future areas of research opportunities and speculates how such areas might best be explored.
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