

UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A PILOT SCALE HIGH PRESSURE FOOD PROCESSING SYSTEM

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DEVELOPMENT OF A PILOT SCALE HIGH PRESSURE FOOD PROCESSING SYSTEM



By

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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 5.9×10^4 to 4.8×10^2 CFU/g, whereas in the case of Blood Cockles the initial microbial load of 5.7×10^4 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

Pengerusi : Profesor Johari Bin Endan, PhD Fakulti : Kejuruteraan

Pemprosesan tekanan tinggi (HPP) adalah satu kaedah pempasteuran bukan haba diiktiraf secara meluas untuk membunuh 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.

Ujian mesin HPP ini menyebabkan beberapa sumbangan yang ketara, penemuan dan pemerhatian dan perbincangan yang berharga. Secara ringkas, tekanan tinggi telah menyebabkan lanjutan hayat untuk buah Kelapa Sawit. Kerang Darah, Udang dan Ketam Lumpur bertambah baik perpisahan mereka dan kualiti deria, manakala Isi Durian dan Kerang Darah dipertingkatkan keselamatan mikrob mereka. Kerja ini telah membuka peluang penyelidikan untuk masa hadapan bagi industri makanan tempatan.

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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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TABLE OF CONTENTS

		Page
ABST	RACT	i
ABST	RAK	ii
ACKN	NOWLEDGEMENTS	iii
APPR	OVAL	iv
DECL	LARATION	vi
LIST	OF TABLES	xi
LIST	OF FIGURES	xii
LIST	OF ABBREVIATIONS	XV
CHAP	PTER	
		1
1		1
	1.1 Background	
	1.2 Problem Statement	2
	1.3 Aim of the Study	3
	1.4 Objectives of the study	3
	1.5 Scope of the study	4 5
	1.0 Thesis Outlines	5
2	LITERATURE REVIEW	6
	2.1 Introduction	6
	2.2 Quality and Markets of the Selected Local Food Products	6
	2.2.1 Tropical Foods Market	6
	2.2.2 Seafood Market	8
	2.3 Food Preservation and Consumers' Demand	9
	2.3.1 Methods of Food Preservation	9
	2.3.2 High Pressure Processing and Consumers' Demand	11
	2.4 High Pressure Processing Technology	12
	2.4.1 History of High Pressure Processing	13
	2.4.2 Principles and Basics of High Pressure Processing	14
	2.4.3 Effects of HPP on Food Attributes	15
	2.4.4 High Pressure Processing of Food	17
	2.5 High Pressure Equipment	17
	2.5.1 History of HP Equipment in Food Processing	17
	2.5.2 Components of High Pressure Processing System	19
	2.5.3 HPP Equipment Installation Modes	29
	2.5.4 Commercial HPP Application and Equipment	31
	2.6 Operation of HPP Systems	37
	2.6.1 HPP Operating Systems	37
	2.6.2 Cycle Time	42
	2.6.3 Packaging Materials	43
	2.7 Economics of HPP	44
	2.8 Conclusion	45

3	DESIGN, SELECTION, CONSTRUCTION AND TESTING OF THE		
	SYS	ГЕМ	46
	3.1	Introduction	46
	3.2	Mechanical Design Process	46
		3.2.1 Stages of the Design Process	47
		3.2.2 Conceptual Design	48
		3.2.3 Design Considerations	50
		3.2.4 Selection Requirement	50
		3.2.5 Computer Aided Design	50
		3.2.6 Determination or the Shape and Dimensions	50
	3.3	System Configuration	51
		3.3.1 Main Pressure vessel	53
		3.3.2 High Pressure Pumping System	58
		3.3.3 Manual Operated Pressure Generation system	62
		3.3.4 Connection of the Machine Components	65
		3.3.5 Pressure Transmitting Fluid	66
		3.3.6 Thermodynamic Effect of the System	66
	3.4	Modelling of the Machine Structure	66
	3.5	Construction Stages	68
		3.5.1 System Specifications	68
		3.5.2 Selection of Materials	69
		3.5.3 Frame Structure	71
		3.5.4 System Size	72
	3.6	Operation of the System	73
		3.6.1 Supplementary Tools of Line Production	74
		3.6.2 Operation of the High Pressure Pumping System	76
		3.6.3 Operation of the Manual Operated Pressure Generation system	80
	3.7	Machine Performance	81
		3.7.1 Machine Performance Evaluation Test	81
		3.7.2 Products Experimental Test	81
		3.7.3 Statistical Analysis	90
	3.8	Maintenance of the System	90
	3.9	Cost Analysis	90
		3.9.1 Acquisition Cost	90
		3.9.2 Maintenance Cost	91
		393 Operation cost	91
		394 Total Cost	92
	3.10	Safety Aspects of the System	93
	3.11	Conclusions	93
	0.11		20
4	RESI	ULTS AND DESCUSSION	95
	4.1	Introduction	95
	4.2	Results of Machine Performance Evaluation Test	95
	4.3	Results of Products Experimental Test	96
		4.3.1 Experiment 1: Effect of HPP on Blood Cockles	96
		4.3.2 Experiment 2: Effect of HPP on Storage Time of Palm Oil Ernits	104
		4.3.3 Experiment 3: Effect of HPP on Sensory and Physical Attributes of Shrimps and Mud Crabs	107
		4.3.4 Experiment 4: Effect of HPP on Safety Attributes of Durian's Mash	109

	4.4	Summary	111
5	SUM	IMARY, CONCLUSION AND RECOMMENDATIONS FOR	
	FUT	URE RESEARCH	112
	5.1	Conclusion	112
	5.2	Study limitations	113
	5.3	Recommendations	114
RE	FEREN	ICES	115
AP]	PENDI	CES	133
BIC	DATA	OF STUDENT	166
LIS	T OF P	UBLICATIONS	167



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LIST OF TABLES

Table		Page
2.1	Major traditional food preservation technologies	10
2.2	The trends of consumers' requirement and food industry reactions	11
2.3	Effect of High Pressure Processing on healthy beverages	16
2.4	Adiabatic heat of compression in various food systems	27
2.5	Actual and predicted compression heating values of certain mixtures	27
2.6	Main suppliers of HPP equipment and services in the industry, and their key contributions to the market	35
3.1	Specifications of low-cost, high-pressure unit	69
3.2	The mechanical properties of the 4340 Alloy Steel	69
3.3	The mechanical properties of the 316 stainless steel	70
3.4	Mechanical properties of AISI 1045 cold drawn steel	70
3.5	The list of connecting tubes, valves, fittings, and hoses used in the machine	71
3.6	Definitions of selected evaluation parameters in TPA test	85
3.7	Total costs per run of the system	92
4.1	Performance evaluation of the system, representing each pressure level, come up time, and number of repetitions	95
4.2	Total bacterial counts of untreated samples (N_0) and the HPP samples treated with a different level of pressure	103
4.3	The results of the Durian mash microbial test following the HPP treatments	110

G

LIST OF FIGURES

Figure		Раде
1.1	The scope of the study	4
2.1	Reported aquaculture production in Malaysia from 1950	9
2.2	Isostatic pressing concept in HPP	15
2.3	First high pressure food processing equipment	18
2.4	A self-seal packing used in high-pressure vessel	19
2.5	Schematic of a dual closing system of the high-pressure vessel, with a connection at the bottom	20
2.6	General types of thread used in power screw	20
2.7	Possible reduction in pressure vessels wall thickness achieved by	21
2.8	Different methods of manufacturing of Pressure Vessels	21
2.9	Methods of reinforcing a thick walled cylinder	22
2.10	Stress loads during and after autofrettage	23
2.11	Shrink fit inner and outer shell during fabricating	24
2.12	Wire winding process during fabrication of a pressure vessel	25
2.13	Pressure generation techniques	28
2.14	Horizontal layout of a pressure vessel	29
2.15	Rotary layout concept of the pressure vessels	30
2.16	Vertical layout concept of a pressure vessel	31
2.17	Total number of HPP industrial machines in production until mid- 2014 and worldwide HPP food production in 2014	32
2.18	Typical HPP operation phases	32
2.19	High-pressure system for processing packaged foods	38
2.20	Continuous high-pressure processing system	39
2.21	Semi-continuous high-pressure processing system	40
2.22	High Pressure vessel in semi-continuous operations concept	41
2.23	Multi-vessels arrangement for semi-continuous high-pressure	42
2.24	Cycle time profile during a typical HPP treatment applied to food.	43
3.1	The design process	47
3.2	General configuration of high-pressure processing structure frame	52
3.3	The pre-tensioned wire-winding concept of pressure vessel	
2.4	construction	53
3.4	Thick cylinder subjected to internal pressures	54
3.5	Wire wounded cylinder subjected to internal pressures	54
3.6	Main removable cap consists of two parts, the screw and closure	57
3.7	K4-24-60 pressure vessel	58 50
3.8	I ne automatic HPP pumping system cabinet	59 50
3.9	Main components of the air driven hydraulic pump	59

3.10	The diagram shows main control valves, air and pressurizing fluid	
0.11	lines of the automatic pumping system	60
3.11	Main filters of the system, the pressurizing medium filter and air lubricator	61
3.12	HVP-203 air compressor	61
3.13	Manual operated pressure generation system	62
3.14	Schematic of the main components of the manual pressurizer	63
3.15	Pressure piston vessel and cross-section of its main components	64
3.16	Main components of the automatic HPP pumping cabinet	65
3.17	High-pressure connections in the system	67
3.18	Modeling of high pressure processing system	68
3.19	High-pressure processing system during fabrication process	72
3.20	Typical high-pressure processing production processes	73
3.21	Flexible canisters for both solid and liquid food products	74
3.22	Vacuum-Sealed pouches for solid and liquid food products	74
3.23	Package handling tools	75
3.24	The operating process: step one	76
3.25	The operating process: step two	77
3.26	The operating process: step three	77
3.27	The operating process: step four	78
3.28	The operating process: step five	78
3.29	The operating process: step six	78
3.30	The operating process: step seven	79
3.31	The operating process: step eight	79
3.32	The operating process: step nine	79
3.33	Schematic of the control valves, fluid lines, and connection of the	
2.24	manual pumping system	80
3.34	Experimental design of Blood cockles' tests.	83
3.35	Experimental design for the Oil Palm fruit tests	87
3.36	Measuring of fresh samples	87
3.37	HPP treatment	88
3.38	Durian mash samples packed in flexible EVOH pouches, ready for	00
	HPP treatment	89
3.39	Durian mash samples at 4°C after HPP treatments ready for the	20
41	Total cycle times of each set pressure level	89 96
4.2	No. of shucked cockles after each HPP treatment level	97
4.3	Comparison between the HPP 345 MPa treated cockle shells and the	
	untreated hand-shucked shell	97
4.4	Effect of HPP on the appearance and volume of cockle meat treated at	00
15	345 MPa in comparison to untreated manually shucked cockles Mean L ₂ , a b-values of cockles' color following various HDP	98
т.Ј	treatments.	99

4.6	TPA test texture parameters of untreated and HPP-treated raw Cockle	101
17	Mold infaction in the control and the HPP treated samples during a	101
4.7	one-year storage period	105
4.8	Spread of mold infection on the Oil Palm HPP-treated and control	
	fruit during 12 months storage	105
4.9	Oil Palm 310 MPa treated fruit, 275 MPa treated fruit, and controlled	
	fruit after a one-week storage period in ambient temperature	106
4.10	Separation of the shrimp meat from the shell after a 345 MPa	
	treatment	107
4.11	Changes in the hardness and volume of the untreated samples, and	
	345 MPa processed sample meat	108
4.12	Separation of the meat from the shell in Mud crab after 345 MPa	108
	treatment	

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LIST OF ABBREVIATIONS

High Pressure Processing
Texture Profile Analysis
Total Bacterial Counts
Colony Forming Unit



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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.

- (b) 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.
- (c) 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

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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