UNIVERSITI PUTRA MALAYSIA

DESIGN, FABRICATION, AND PERFORMANCE EVALUATION OF A HOT AIR HEATING SYSTEM FOR PROCESSING OF MALAYSIAN COCKLES (Anadara Granosa L.)

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DESIGN, FABRICATION, AND PERFORMANCE EVALUATION OF A HOT AIR HEATING SYSTEM FOR PROCESSING OF MALAYSIAN COCKLES
(Anadara Granosa L.)

BY

Iraj Yavari

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

July 2014

Dedicated To

To all my teachers and, my family members, especially

my beloved wife, Leila and my dear son, Nima

and my ever-encouraging parents for their

love, and my brothers and sisters

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

DESIGN, FABRICATION, AND PERFORMANCE EVALUATION OF A HOT AIR HEATING SYSTEM FOR PROCESSING OF MALAYSIAN COCKLES
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July 2014

Chairman: Associate Professor Johari Bin Endan, PhD. Ir
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Heat and the heating process are of the most widespread and the most important activities in the post-harvest operations for food products in the world. Such activities are usually expected to decrease the moisture content for crop preservation; the heating process is also used for modifying the mouthfeel of a product in order to raise the food's market values. Likewise, recovery and storage of the energy, environmental protection alongside the climate effect are considered as notable issues.

Nowadays different types of heating system such as the hot air heating machines are being used for heating the food products. Mostly, fossil fuel has been used by machines for this purpose, making the heat energy in the direct combustion. The heat from burning fuels is supplied directly by the airflow through the blower housing and harmful gases directed to enter the food chamber and the environment. , It must also kept in mind that in a direct in- line burner using natural gas, 3.5 lb. of water is add to the air for every cubic meter of natural gas consumed .

This action leaves undesirable and unintended effects on the product quality. Regarding these cases, such as non-constantity of the temperature in the compartment space of the products, lack of a precise temperature control, food contamination through contact with invisible gases from the burning fuel, more pollution and other environmental issues are among the disadvantages of these types of machines. Currently, the same actions are being used in Malaysia.

Therefore, a new hot air heating system was required for heating the food and it's products having high capacity and satisfactory heating quality with no damage to the food quality and the environment.

Air distribution in the machine reservoir and the flow rate were calibrated to achieve good results and outcomes in the construction phase as well as in the procedural steps to create the machine. To conserve energy, a closed circuit system and series was added to the machine.

In this research work first, the parts of the machine were designed using CATIA software then new heating system based on a hot water recirculation technique and effective air velocity has been fabricated.
An adjustable system was used to provide hot water with a high setting range of adjustment and high precision for different temperatures up to ninety degrees at the constant pressure.

In order to avoid energy losses and prevent pollution of the environment A Newly Developed and Extra-Enclosed System was designed, fabricated and add to the machine. For this purpose two extra devices of heat exchanger mounted on the machine, one located at the blower fan inlet and other situated at the air outlet final channel of machine. Both energy saving heat exchangers have been connected by connecting series and insulated tubes.

The new machine was tested in the Agricultural Process and Instrument Laboratory (APIL) of the faculty of engineering in UPM. The tests were performed based on the Randomized Complete Block Design (RCBD) experimental design was with three replications and the means were being compared using the Duncan's Multiple Range Test (DMRT). The parameters included the air temperature at three levels, the air velocity at three levels, and the hot air heting time duration at five levels. The data measured included the energy consumption, the opening force of the cockle shells, the moisture content, the cutting force, the compression force, the penetration force, the meat volume, the length, the height, the inflation, and the air and water temperature profiles. The Malaysian cockle (*Anadara Granosa L.)* was used as the experimental material.

The results revealed that the best and lowest cockle's opening force [N] belonged to the hot air heating parameters (air velocity: 2 m/s, air temperature: 70 °C) in the first hours of process, [M=(111±6.4) $\times 10^{-2}$][N]. For the volume of the cockle's, the best result was observed at (air velocity: 2 m/s, air temperature: 70 °C) in the first hours of the air heating time [M =(3.47± 0.19)] [cm^3]. Results also showed that the lowest ΔMC- % happened at (air velocity:1 m/s, air temperature: 50 °C) after 1hour (M=0. 26%± 0.01). The best treatment on the cutting stress (τ, N/m^2) was at the air parameter of (air velocity: 1 m/s, air temperature: 60 °C) in the first hours of the experiment [M= (1.08±0.02) $\times 10^5$] [N/ m^2]. The lowest penetration force [N], was also observed for the air parameter of (air velocity:1m/s, air temperature: 50 °C) in the first hours of time duration [M=(52± 0.58) $\times 10^{-2}$] [N]. The lowest compression stress (σ, N/m^2) was observed for the air parameter of (air velocity: 1 m/s, air temperature: 50 °C) in the first hours [M=(0.7887± 0.004) $\times 10^5$][N/m^2]. For the boiling experiment, it was found that the opened cockle, the cutting stress, the penetration force, and the compression stress increased significantly by having an increase in the boiling time. In this test, by increasing the boiling time, the cockle's volume decreased significantly and the lowest volume was for 15 min of boiling [M= (2.033± 0.033)] [cm^3].

This result showed that the volume increased in air heating system and shrinkage was M=1.186±0.09 compared to two traditional systems, volume decreased in boiling system (M=0.966±0.042) [cm^3] and in steaming was M=(1.042±0.067)[cm^3] which showed a little increase in volume.

For the steaming condition, a similar behavior happened with the boiling process with the difference that the cutting stress for more than 6 min was significantly different from the control.

The result of the lump system analysis on the cockles indicated that the center temperature of the cockle in the air heating system, steaming, and boiling methods after 35, 7 and 4 minutes respectively reached a thermal equilibrium state with the surrounding environment temperature. Furthermore, by using the Matlab fitting application and an exponential function, three different heating processes were formalized by equation $\theta(t) = Ce^{-mt}$ finding the coefficients, *C* and *m* with 95% , confidence bounds (*C*= 41.63, *m*= 0.002792, R^2= 0. 8453), (*C*=76.09, *m*= 0.02206, R^2=0.902) and (*C*= 74.44, *m*= 0.014, R^2= 0.9993) respectively for the air heating, boiling, and steaming processes.

Utilizing the data logger output and control volume testing on the machine indicated that 25% of the energy leaving the exhaust compartment of the machine has been returned to the product by using the extra system mounted on the machine.

As a result, after having compared the machine treatments and the traditional experiments by considering the expenditure of the production and the product quality, the new technique with treatment of (air velocity: 2 m/s, air temperature: 70 °C and first hour of air heating time) has been presented as the best method in this research work.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

REKABENTUK, FABRIKESI DAN PENILAIAN PRESTASI BAGI SISTEM PERMANASAN UDARA PANAS BAGI KERANG MALAYSIA
(Anadara Granosa L.)

Oleh

IRAJ YAVARI

July 2014

Pengerusi: Assosiat Profesor Johari Bin Endan, PhD. Ir
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Haba dan proses pemanasan adalah salah satu aktiviti yang paling penting dalam operasi lepas-tuaian bagi produk pertanian di seluruh dunia. Selalunya, ia akan mengurangkan kelembapan bagi penyimpanan tanaman; ia juga mampu mengubah rasa produk dan meningkatkan nilai pasarannya. Selain itu, pemulihan dan penyimpanan tenaga, perlindungan alam sekitar serta perubahan iklim adalah isu yang besar.

Kini, pelbagi jenis sistem pemanasan seperti mesin pengering digunakan untuk pengeringan tanaman pertanian. Kebanyakannya, bahan api fosil digunakan dalam mesin untuk tujuan ini. Bahan api fosil menjana tenaga melalui pembakaran langsung. Haba daripada bahan api terbakar dibekalkan secara langsung dengan aliran udara yang melalui rumah tiupan dan gas berbahaya diarahkan ke ruang tanaman dan alam sekitar.
Tindakan ini meninggalkan kesan buruk kepada kualiti produk. Mengenai perkara seperti perbezaan suhu dalam ruang tanaman, kekurangan kawalan suhu yang tepat, pencemaran tanaman melalui gas yang tidak dapat dilihat akibat pembakaran bahan api, pencemaran dan isu-isu alam sekitar adalah antara kelemahan mesin jenis ini. Pada masa ini cara yang sama telah digunakan di Malaysia.

Oleh itu, mesin pemanas udara panas yang diperlukan bagi memanaskan produk pertanian perlu mempunyai kapasiti yang tinggi dan kualiti pemanasan yang memuaskan, serta tidak membawa kerosakan kepada kualiti tanaman dan alam sekitar. Dalam kajian ini, mesin pemanasan baru berdasarkan teknik edaran air panas dan halaju udara yang berkesan telah direka, dirumuskan dan dinilai.

Mesin teknik baru, telah diuji dalam (APIL) fakulti kejuruteraan UPM. Ujian telah dijalankan berdasarkan (RCBD) reka bentuk eksperimen dengan tiga replikasi dan dibanding menggunakan (DMRT). Parameter termasuk suhu udara pada tiga

peringkat, halaju udara pada tiga peringkat dan tempoh masa pada lima peringkat. Data yang diukur ialah penggunaan tenaga, tenaga pembukaan, kelembapan, daya permotongan, daya mampatan, daya penembusan, isipadu daging, panjang, tinggi, inflasi, dan profil suhu udara dan air bagi setiap keadaan telah ditafsirkan. Kerang darah Malaysia (Anadara granosa L.) telah digunakan sebagai bahan eksperimen.

Keputusan menunjukkan bahawa kuasa pembukaan kerang terendah adalah berdasarkan parameter pemanasan udara (2 m/s, 70 °C) dalam jam pertama [M=(111±6.4) $\times 10^{-2}$][N]. Untuk isipadu kerang, keputusan terbaik yang diperhatikan adalah pada 2 m/s, 70°C dalam jam pertama [M =(3.47± 0.19)] [cm^3]. Keputusan juga menunjukkan bahawa DMC yang paling rendah berlaku pada 1m/s, 50 °C selepas 1 jam (M=0.26±0.01). Cara terbaik untuk daya pemotongan (τ, kg/cm2) adalah pada parameter udara 1m/s, 60 °C pada jam pertama eksperimen [M= (1.08±0.02) $\times 10^5$] [N/ m^2]. Kuasa penembusan terendah [N] diperhatikan pada parameter udara 1m/s dan 50°C dalam jam pertama [M=(52± 0.58) $\times 10^{-2}$] [N]. Daya mampatan terendah (σ,N/m^2) diperhatikan untuk parameter udara 1 m/s, 50 °C dalam jam pertama [M=(0.7887± 0.004) $\times 10^5$][N/m^2]. Untuk experimen pendidihan: kerang yang bukan, daya pemotongan, daya penembusan dan daya perbandingan meningkat secara ketara dengan peningkatan dalam masa pendidihan dalam ujian ini. Isipadu kerang menurun dengan ketara semasa masa pendidihan meningkat dengan isipadu terendah selama 15 min mendidih [M= (2.033± 0.033)] [cm^3]. Untuk keadaan pengukusan, tingkah laku yang serupa juga berlaku pada proses pendidihan dengan perbezaan bahawa daya pemotongan selama lebih daripada 6 min adalah jauh berbeza daripada kawalan.

Hasil analisis sistem ketulan pada kerang yang menunjukkan bahawa suhu pusat kerang dalam pemanasan udara, pengukusan dan kaedah mendidih selepas 35, 7 dan 4 minit masing-masing telah mencapai keadaan keseimbangan haba dengan suhu sekitar alam sekitar. Tambahan pula, dengan menggunakan Matlab fungsi penyesuaian dan eksponen, tiga proses pemanasan yang berbeza dibentuk melaui persamaan dan mendapati pekali, C dan m dengan 95 %, sempadan keyakinan(**C**= 41.63, m= 0.002792, R^2= 0. 8453), (**C**=76.09, m= 0.02206, R^2=0.902) and (**C**= 74.44, m= 0.014, R^2= 0.9993) masing-masing untuk pemanasan udara, merebus dan pengukusan.

Penggunakan keputusan Logger data, dan kawalan nilai pada mesin menunjukkan bahawa 25% daripada tenaga yang meninggalkan petak ekzos mesin, dengan menggunakan penjimatan tenaga dalam teknik ini, telah kembali ke produk.

Hasilnya, selepas dibandingkan antara mesin rawatan dan eksperimen tradisional daripada segi perbelanjaan pengeluaran dan kualiti produk, teknik baru dengan sebatian rawatan (2 m/s, 70 °C dan 1 jam) telah dibentangkan sebagai kaedah terbaik dalam kajian ini.

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I certify that a Thesis Examination Committee has met on 24th July 2014 to conduct the final examination of IRAJ YAVARI on his thesis entitled “Design, Fabrication and Performance Evaluation of a Hot Air Heating System for Processing of Malaysian Cockles (*Anadara Granosa L*.)” 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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LIST OF ABBREVIATIONS

ANOVA	Analysis Of Variance
DMRT	Duncan's Multiple Range Test
CRD	Completely Randomized Design
RCBD	Randomized Complete Block Design
LSD	Least Significant Difference test
SD	Standard Deviation
Df	Degree of Freedom
CV	Coefficient of Variation
SAS	Statistical Analysis System
d.b.	Dry Basis (moisture content)
w.b.	Wet Basis (moisture content)
APIL	Agricultural Process and Instrument Laboratory
FE	Faculty of Engineering
V_s	Volume of sample [cm^3]
V_{wafs}	Volume of water after falling the sample [cm^3]
V_{wbfs}	Volume of water before falling the sample [cm^3]
Pr	Prandtl Number
G	Mas Velocity
D_h	Hydraulic diameter
h_a	Heat Transfer Coefficients Air Side
h_w	Heat Transfer Coefficients Water Side
U_a	Overall Heat Transfer
Q	Total Heat Transfer rate
$\mathcal{E}$	Effectvnes, percent
$\mathcal{E}$_NTU	Method for Heat Exchanger analyses
η	The fin efficiency
B	Ratio heat transfer area for the fin to the total area
MHEWI	Main Heat Exchanger Water Inlet
MHEWO	Main Heat Exchanger, Water Outlet
MHEAI	Main Heat Exchanger Air Inlet
MHEAO	Main Heat Exchanger Air Outlet
SHEWI	Secondary Heat Exchanger, Water Inlet
SHEWO	Secondary Heat Exchanger, Water Outlet
SHEAI	Secondary Heat Exchanger Air Inlet
SHEAO	Secondary Exchanger Air Outlet
EHEWI	Exhaust Heat Exchanger, Water Inlet
EHEWO	Exhaust Heat Exchanger, Water Outlet
EHEAI	Exhaust Heat Exchanger Air Inlet
EHEAO	Exhaust Heat Exchanger Air Outlet
FHEWI	Fan Heat Exchanger, Water Inlet
FHEWO	Fan Heat Exchanger, Water Outlet
FHEAI	Fan Heat Exchanger Air Inlet
FHEAO	Fan Heat Exchanger Air Outlet

ΔMC	Moisture Changes [%]
V	Air velocity [m/s]
T	Temprature [°C]
t	Time [min}
L	Length [mm]
H	Height [mm]
I	Inflation [mm]
h	hour
cfm	Cubic foot per minute
ns	Not Significant
Re	Reynolds Number
St	Stanton Number
M	Mean of Data
$\dot{Q}$	Rat of Heat Transfer
$\dot{m}$	Mass flow Rat
q	Heat Transfer Per Unit Mass
m	Mass
z	Elevation
t	Time (h)
T1,T2,T3	Air Temperature
V1,2,3	Air Velocity
W	Total Work
$\dot{W}$	Rat of Work
h	Specific Enthalpy
H	Total Enthalpy
k	Specific Heat Ratio
F	Force
E_{ff}	Conversion efficiency (%)
K	Equilibrium Constant
RM	Malaisyan Ringit

CHAPTER 1

GENERAL INTROUCTION

1.1 Background of the study

Cockle *(Anadara Granosa L.)* is one of the important aquatic products and crustaceans in Malaysia. With an annual production of over 100,000 tons per year, their place in the export industry today is of particular importance in the country's national income Narasimham, 1968. Also, it plays an important role in job creation of harvest, transportation, processing and other manufacturing steps to reach the consumer market (Narasimham, 1968 and Shahidi, 1998).

Cockle meat as a protein source is considerable in the diet of many important food groups are low- income cockle role in the diet of pregnant women is of very high importance Narasimham, 1968. Cockles filter one third of the salt-water, which comes into estuaries, also they are as a food for different species of birds plays an important role. Cockle is prepared in different ways in the meat market. According to (Liewa, et al.,1998) In Malaysia, the cockle is popular as an ingredient in several types of local foods. Distribution can be fresh, canned, frozen, or cooked and direct sales and consumption in restaurants are ways through which the consumer's desired method is achieved.

Heating methods of boiling and steaming cockle are traditional methods which are used to separate the meat from the shells. The results may include meat shrinkage, reduce quality and meat marketable (Haniza, 2010). Design have been with regard to content, and not forgetting the environment and nature friendly methods, such as normal heat as hot air heating, indirect water heating systems based on heat transfer. This machine solves all the problems caused by boiling and steaming on the food but also improves its quality.

The physical and mechanical properties of Malaysia cockle were investigated and the design and construction of configurable machine fully adjustable to produce hot air heating system started. At first, the parts were designed by Catia software (Cozzens, 2002). Air distribution in the machine reservoir and flow rate were done to get good results to achieve satisfactory outcomes in the construction phase as well as in the procedural steps to make the machine.

Heat transfer in cockle meat, time and transfer rate are quality factors that have a direct effect on the texture of the meat since heat transfer in cockle meat and reaching thermal equilibrium state in the heating process is important. The foundation of this study was to investigate the changes in body temperature of cockle to reach the equilibrium temperature , the three conditions were analyzed by the Lumped system analysis method (Necati,1985) .They include air heating method, boiling and steaming of the cockle. These methods were tested and compared.

Energy is considered as one of the pillars of life. Humans have always been searching to find a way to convert, transfer, and utilize the energy. One of the most important forms of the energy is heat. Actually, the heat change into other types of energy has made significant advances in various fields of human life including the heat transfer which is a significant sector of the human industry (Sukhatme, 2005). The heat transfer has a role in various industries including the food process industries, automotive, aerospace and electronics. Furthermore, it is one of the essential mechanisms in the design considerations and system performance.

A precise temperature control needed during the operation, reduction of fuel consumption and energy conservation, preservation of physicochemical features of food and thus reduction of soil and air pollution are among the significant objectives of this research. Nowadays different types of hot air heating system are used for heating the food products ranging from seeds to the meat. Most fuels used in this machines are fossil fuels and the heat energy is from their direct combustion (Pierre B.1998).

The heat from burning fuels is supplied directly by the airflow through the fan chamber and directly enters the foods. Moreover, the amount of moisture in the food is discharged as the heating process of the foods is along with the direct contact of the produced heat and harmful gases. This action leaves undesirable and unintended effects on the physicochemical properties of the products (Pierre B.1998). Some of the drawbacks of these types of machines include non-constantity of the temperature in the food products compartment space, having no accurate temperature control, contaminating the crop by contacting invisible gases resulted from burning the fuel, more pollution, as well as other environmental issues (Benny,1985.Sylvester ,1989 and Pierre 1998). Irrespective of related shortages, the proposed design for the dryer machine has the subsequent merits:

In this machine, the thermal energy from the hot water is used for heating the food. The main energy source for heating is the hot water, not the heat from the fossil fuels. By using this method, not only the direct contact with harmful gases is cut but also a precise temperature control is maintained resulting in fuel storage. Constant hot water from the water heater is pumped into a close circuit including the heat exchangers.
The heated water is divided after exiting the water heater and passes through the heat exchanger tubes to release its heat with the help of the air circulation and heat converters around the ambient atmosphere of the products; meanwhile, it returns to the water heater to renew its heat energy. In other words, the heat transfer from the hot water results in energy storage, less fuel consumption, and reduced environmental pollution.

Since changes in temperature are less, the food products are less affected by the environmental temperature fluctuations. Furthermore, a quality crop with its original physical and chemical features will be produced for the warehouse and storage to provide a constant temperature and to improve and accelerate the transfer of heat. To provide a constant temperature, as well as improving and accelerating the heat transfer of the heat exchangers and transferring the evaporated moisture to outdoor, a centrifugal blower was used.

Finally the foods of the air velocity, air temperature and flow rate of water within the system at different levels will be carried out on the moisture content of the material, its physical and mechanical properties also texture, and food quality in completely randomized block design in three replication. The results of the evaluation parameters of the machines and their effects on the food and crop characteristic have been statistically analyzed using RCBD. Furthermore, the means of the measured characteristic of cockle have been compared using the Duncan's multiple range tests.

1.2 Statement of the Problem

Heating is one of the most important process operations for the food products which is mostly expected to reduce the moisture content for the food conservation. For some, food product such as cockle *(Anadara Granosa L.)*, and so on, the heating is used not only for conservation purposes, but also for modifying the tastes and flavors in order to increase their market values. Nowadays, different types of hot air heating system are used for different products. Mostly, fuel is used by the machines for air heating the food products (Benny1985, Steffen 1989 and Pierre 1998). The fossil fuel makes the heat energy in the direct combustion (Pierre 1998). The heat from the burning fuels is supplied directly by the airflow through the fan chamber and directed to enter the foods (Pierre 1998). The amount of the moisture content in the foods is discharged during the heating process of the products, along with the direct contact of producing heat and harmful gases (Pierre 1998). This action leaves undesirable and unintended effects on the physicochemical properties of the foods (Pierre 1998).

Cases such as non-constantity of the temperature in the compartment space of the products, lack of precise temperature control, food contamination through contact with invisible gases from burning fuel, more pollution and other environmental issues are considered as the drawbacks of these types of machines.

Existing problems of the current trial hot air heating system can clearly demonstrate the requirement of a specific food and crop heating machine. Therefore, a heating system must able to dry the material without damage having a high capacity and satisfactory heating quality, which is more suitable for agriculture industry. In this thesis, considering the fact that there is no suitable dryer for food product, an attempt is made to design and develop a wide range food and crop heating machine.
Then a precise temperature control is needed during the operation, reduction of fuel consumption and energy conservation, preservation of texture features of products and thus reduction of soil and air pollution are among significant objectives of this research.

1.3 Contributions

The main contribution of this research is to improve the existing air heating methods to reduce the energy consumption, minimize the environmental pollution, and enhance the quality of the cockle *(Anadaea Granosa L.).*

1.4 Objective

General Objective

- To design, fabricate and evaluate the performance of an efficient hot air heating method.

Specific Objectives

- To save energy and reduce environmental pollution by decreasing the fossil fuel consumption by way of applying hot water heat recirculation
- To provide a closed system for heating the food material independent from the open air conditions.
- To provide a precise temperature control and uniform temperature in the chamber of the product.
- To study the effect of the different heating system on texture and physical characteristics of the cockles
- To compare the texture and physical characteristics, of the cockles between the traditional methods and the new dryer machine

1.5 Scope of Study

This study focuses on two important aspects of food processing:
1. designing, development, and evaluation of a new hot air heating system for energy issues with extra mounted system on a newly and fabricated machine.
2. Food quality

1.6 The Research Framework

The summary of the general steps taken in this thesis are shown in Figure1.1.

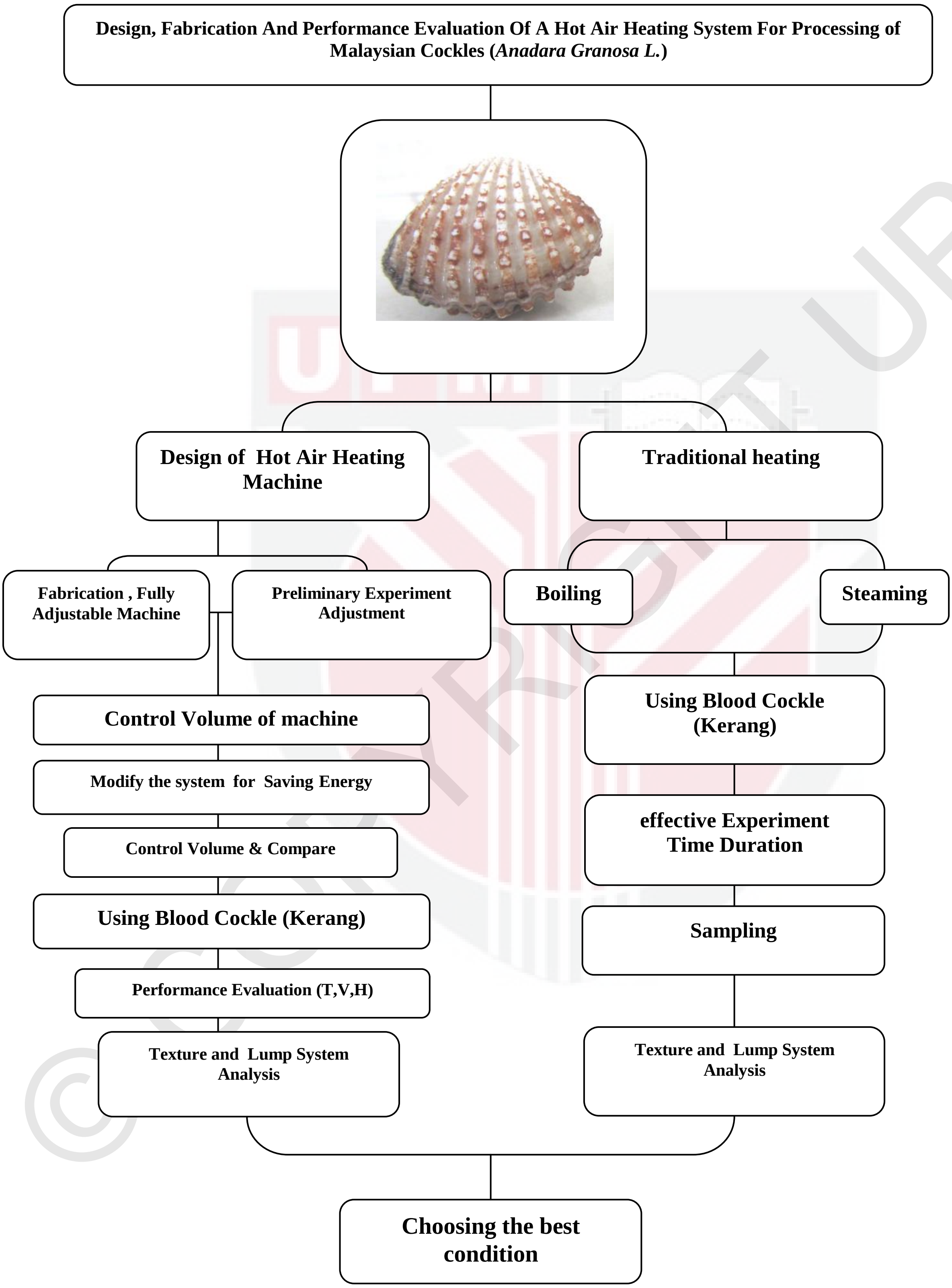

Figure 1.1. Framework of Study

1.7 Outline of the Thesis

The thesis will be organized as follows: Chapter one describes the overview of hot air heating system and objectives of the study. Related literatures will be reviewed and presented in Chapter two. The heat transfer characteristics and factors considered in the design and the development of the hot air heating system have been reported in Chapter three. Materials and methodology used in this research work for evaluation the hot air parameter of machine through the hot water heat transfer and testing of the material, has been illustrated in Chapter four. Comprehensive results has been presented and discussed accordingly in Chapter five. Conclusions have been drawn at the end of the study and lastly suggestions for future work has been illustrated and reported in Chapter six.

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