

# **UNIVERSITI PUTRA MALAYSIA**

# EXPERIMENTAL INVESTIGATION OF A VACUUM COOLING SYSTEM

# **ZHANG SI WEI**

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## EXPERIMENTAL INVESTIGATION OF A VACUUM COOLING SYSTEM

By

ZHANG SI WEI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science.

November 2009



## DEDICATION

Dedicate this thesis

To his teachers;

To his parents Mr. Zhang Yi Lin and Mrs. Jin Wei Hua

And

To all the help of his friends in Malaysia who had devoted their love and help



#### EXPERIMENTAL INVESTIGATION OF A VACUUM COOLING SYSTEM

By

#### Mr. ZHANG SI WEI

November 2009

#### Chairman: AHMAD SAMSURI MOKHTAR, PhD

#### Faculty: Engineering

The quality and safety of food are currently concerned by the world of population now. Usually, the surface temperature of horticultural crops, such as vegetables and fruits, remain high after harvesting. With the strong respiration, they continually release heat, so that the contented water keeps on evaporating and losing. Consequently, the deterioration will happen and get worse during this period. Therefore, several pre-cooling methods come up in succession, such as hydro-cooling, room cooling, forced air cooling and others. Apart from these methods, vacuum cooling is also an effective and a rapid evaporative pre-cooling method for porous and moisture foods to meet special cooling requirements. The basic principle of vacuum cooling consists of removing the latent heat of a product, which implies a rapid decrease in the temperature. Vacuum cooling can be used as an effective method for pre-cooling to prolong their shelf life or by preventing the influence of heat field. In previous research on this subject matter, the vacuum cooling method has been used in relation to food products. However, the cooling times from these research still has the challenge to improve. This could be due to the disposition of system equipment, the vacuum pump selection or the matching



between pumping speed and chamber volume. None of the studies conducted so far has referred to vacuum pump selection and the matching between pumping speed and chamber volume. A proper research investigation on this selection and matching could benefit the vacuum cooling method to improve upon the cooling times.

In this study, the selection of vacuum pump and the matching between pumping speed and chamber volume of vacuum cooling system are discussed and investigated in detail. A product of vacuum cooling system was designed without vapour condenser and operated by a single oil vacuum pump. Tests were carried out to investigate the effect of different vacuum levels, pumping speeds and temperatures on selected vegetables in the vacuum cooling process. Based on the discussion on the pressure, pumping speeds and temperatures, the results indicate that the vacuum cooling system can be operated without vapour condenser and by a single oil vacuum pump. The results also show that porous products pre-cooling using this method can be shortened in less than 4 min in this type of vacuum cooling system.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

#### KAJIAN EKSPERIMENTAL TERHADAP SISTEM PENYEJUKAN VAKUM

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Pada masa ini ,kualiti dan keselamatan makanan diambil perhatian oleh masyarakat dunia. Biasanya, suhu permukaan tanaman hortikultural, seperti sayur-sayuran dan buah-buahan, kekal tinggi selepas dituai. Dengan respiratori yang kuat, tanaman tersebut mengeluarkan haba secara berterusan, supaya kandungan air sentiasa segat. Akibatnya, kemerosotan terjadi dan bertambah teruk. Oleh itu, beberapa kaedah prapenyejukan berperingkat, seperti penyejukan dihasilkan secara hidro. penyejukan, bilik, penyejukan paksa air dan sebagainya. Selain kaedah ini, untuk memenuhi keperluan penyejukan yang khusus, penyejukan vakum juga berkesan dan merupakan kaedah prapenyejukan penyegatan yang cepat bagi makanan yang lembap dan poros. Prinsip asas penyejukan vakum mengandungi produk yang dapat mengeluarkan haba laten pendam yang menandakan kejatuhan suhu yang cepat. Penyejukan vakum digunakan sebagai kaedah yang efektif untuk prapenyejukan bagi melanjutkan tempoh simpan atau untuk mengelak pengaruh medan haba.



Dalam kajian lepas, kaedah penyejukan vakum telah digunakan dalam penghasilan produk makanan. Walau bagaimanapun, tempoh penyejukan yang diperoleh daripada kajian ini masih perlu diperbaiki. Perkara ini terjadi akibat pelupusan sistem peralatan, pemilihan pam vakum atau pemadanan antara kelajuan pam dan jumlah ruang. Tiada kajian yang dijalankan setakat ini yang merujuk kepada pemilihan pam vakum dan pemadanan antara kelajuan pam dan jumlah ruang. Kajian sebenar yang berkaitan dengan pemilihan dan pemadanan akan memberi manfaat kepada kaedah penyejukan vakum bagi memperbaiki tempoh penyejukan.

Pemilihan pam vakum dan keserasian antra halaju pam dan isipadu kebuk sistem penyejukan vakum telah dibincangkan dan diselidik dengan teliti di dalam pembelajaran ini. Sebuah produk iaitu sistem penyejukan vakum telah direka tanpa kondensasi wap dan dioperasikan oleh satu pam minyak vakum. Pemeriksaan telah dijalankan untuk menyelidik kesan mempelbagaikan tahap vakum, halaju pam, dan suhu untuk sayuran terpilih di dalam proses penyejukan vakum. Berdasarkan perbincangan tentang tekanan, halaju pam, dan suhu, keputusan menunjukkan bahawa sistem penyejukan vakum boleh dioperasikan tanpa kondensasi wap dan digerakkan oleh sebuah pam minyak vakum. Keputusan juga menunjukkan bahawa pra-penyejukan produk berliang mampu dipendekkan menggunakan kaedah sistem penyejukan vakum ini. Dapatan kajian juga menunjukkan bahawa prapenyejukan produk poros yang menggunakan kaedah ini dapat disingkatkan kepada kurang daripada 4 minit sekiranya sistem penyejukan vakum ini digunakan.



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I certify that an Examination Committee met on November 11th 2009 to conduct the final examination of Mr. Zhang Si Wei on his Master of Science thesis entitled "Experimental Investigation of a Vacuum Cooling System" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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### DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

ZHANG SI WEI

Date: 08 August 2009



### TABLE OF CONTENTS

### Page

DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	Х
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
LIST OF ABBREVATIONS	xvii
LIST OF SYMBOLS	xviii

### CHAPTER

1	INTRODUCTION		1
	1.1	Background	1
	1.2	Problem Statement	10
	1.3	Research Hypothesis	11
	1.4	Objectives	12
	1.5	Organization of Thesis	13
2	LI	TERATURE REVIEW	15
	2.1	Introduction to Vacuum	15
		2.1.1 The Definition of Vacuum	16
		2.1.2 Vacuum Classification	17
	2.2	Introduction to Vacuum Cooling Method	19
		2.2.1 Principles of Vacuum Cooling	20
		2.2.2 Mathematical Model	23
		2.2.3 Advantages and Disadvantages of Vacuum Cooling	24
		2.2.4 Applications	28
		2.2.5 Refrigeration of Fruits and Vegetables	29
		2.2.6 Factors Affecting Cooling Rates	30
	2.3	Summary	33
3	VAC	CUUM COOLING SYSTEM DESIGN	35
	3.1	Overview	35
	3.2	Technology Specification	35
	3.3	Vacuum Cooling System	36
		3.3.1 Basic Vacuum System	36
		3.3.2 General Considerations for Design	37
	3.4	Materials for Vacuum Chamber	38
		3.4.1 Materials for Vacuum Chamber	38
		3.4.2 Vacuum Chamber Design	48
		3.4.3 Vacuum pump	58



4 <b>EX</b>		PERIMENTAL SETUP	70
	4.1	Experimental Equipment and Manipulation	71
	4.2	Circuit and Control of Vacuum Cooling System	75
	4.3	Materials and Methods	79
5	RES	SULTS AND DISCUSSIONS	83
	5.1	Vacuum Cooling System	83
		5.1.1 Pumping Speed	84
		5.1.2 Virtual Leaks	90
	5.2	Experimental Work	92
		5.2.1 Vacuum Cooling of Water	93
		5.2.2 Analysis of Vacuum Cooling Process of Different	96
		vegetables	
		5.2.3 Uncertainty Analysis	116
		5.2.4 Summary	118
6	CO	NCLUSIONS AND RECOMMENDATIONS	119
	6.1	Conclusions	119
	6.2	Recommendations for Future Research Works	121
REFEREN	ICES		123
APPENDI	CES		129
BIODATA	OF S	FUDENT	166



## LIST OF TABLES

Table		Page
1.1	Available cooling methods	4
2.1	Vacuum in space	16
2.2	Variation of Parameters with Pressure	17
2.3	Definition of different vacuum levels	19
2.4	Boiling point of water at different pressure	21
2.5	Some vegetables susceptible to chilling injury and the lowest safe	
	storage temperature	30
4.1	Physical characteristics of the products	81
5.1	Statistics of vacuum cooling process of different vegetables and fruits	112
5.2	Suitability of different vegetables and fruits in vacuum cooling process	114



## LIST OF FIGURES

Figure		Page
2.1	Schematic diagram of the physical model of the vacuum cooling of liquid	23
3.1	Vacuum cooling system equipment	37
3.2	Vacuum cooling system connections	38
3.3	Photon stimulation desorption yield reduction with accumulated beam dose for stainless steel, aluminum and copper	45
3.4	Diagram of vacuum pump safety factor K	66
3.5	Pumping speed of ideal system	67
4.1	Schematic diagram of vacuum cooling system	73
4.2	Diagram of Pressure and output	74
4.3	Ideal diagram of Pressure and DC current	74
4.4	Schematic View of control panel	75
4.5	Wiring diagram	76
4.6	Circuit diagram	77
4.7	Flow chart of the overall experimental work	82
5.1	Experimental results of vacuum speed in the first test	86
5.2	Experimental results of vacuum speed in the second test	87
5.3	Experimental results of pressure and DC current diagram in the first test	87
5.4	Experimental results of pressure and DC current diagram in the second test	88
5.5	Experimental results of outgassing	88



5.6	Experimental results of water in vacuum cooling T-t diagram	93
5.7	Experimental results of water in vacuum cooling P-t diagram	94
5.8	Time of water in vacuum cooling to reach vacuum	94
5.9	Experimental results of cabbage in vacuum cooling T-t diagram	96
5.10	Experimental results of cabbage in vacuum cooling P-t diagram	97
5.11	Experimental results of Greengrocery in vacuum cooling T-t diagram	97
5.12	Experimental results of Greengrocery in vacuum cooling P-t diagram	98
5.13	Experimental results of lettuce in vacuum cooling T-t diagram	98
5.14	Experimental results of lettuce in vacuum cooling P-t diagram	99
5.15	Experimental results of cauliflower in vacuum cooling T-t diagram	99
5.16	Experimental results of cauliflower in vacuum cooling P-t diagram	100
5.17	Experimental results of green pepper in vacuum cooling T-t diagram	100
5.18	Experimental results of green pepper in vacuum cooling P-t diagram	101
5.19	Experimental results of balsam pear in vacuum cooling T-t diagram	101
5.20	Experimental results of balsam pear in vacuum cooling P-t diagram	102
5.21	Experimental results of eggplant in vacuum cooling T-t diagram	102
5.22	Experimental results of eggplant in vacuum cooling P-t diagram	103
5.23	Experimental results of eggplant without pericarp in vacuum cooling T-t diagram	103



5.24	Experimental results of eggplant without pericarp in vacuum cooling P-t diagram	104
5.25	Experimental results of cucumber in vacuum cooling T-t diagram	104
5.26	Experimental results of cucumber in vacuum cooling P-t diagram	105
5.27	Experimental results of cucumber without pericarp in vacuum cooling T-t diagram	105
5.28	Experimental results of cucumber without pericarp in vacuum cooling P-t diagram	106
5.29	Experimental results of onion in vacuum cooling T-t diagram	106
5.30	Experimental results of onion in vacuum cooling P-t diagram	107
5.31	Experimental results of onion without pericarp in vacuum cooling T-t diagram	107
5.32	Experimental results of onion without pericarp in vacuum cooling P-t diagram	108
5.33	Experimental results of tomato in vacuum cooling T-t diagram	108
5.34	Experimental results of tomato in vacuum cooling P-t diagram	109
5.35	Experimental results of apple in vacuum cooling T-t diagram	109
5.36	Experimental results of apple in vacuum cooling P-t diagram	110
5.37	Experimental results of products in vacuum cooling T-t diagram	111
5.38	Figure 5.37 Experimental results of products in $\triangle T$	111
5.39	Comparison of vacuum cooling of different vegetables and fruits	113



## LIST OF ABBREVIATIONS

HV	High vacuum	
ISS	International space station	
MV	Medium vacuum	
PRT	Platinum resistance thermometer	
RV	Rough vacuum	
UHV	Ultrahigh vacuum	



## LIST OF SYMBOLS

А	Gas-Liquid Interface Area (m <sup>2</sup> )	
$c_{pf}$	Specific Heat Capacity of Cooled Liquid (J.kg <sup>-1</sup> .K <sup>-1</sup> )	
C <sub>1</sub>	Corrosion Capacity (mm.s.a <sup>-1</sup> )	
D <sub>i</sub>	Chamber's Inner Diameter (m)	
Do	Chamber's Outer Diameter (m)	
k <sub>c</sub>	Mass Transfer Coefficient (m.s <sup>-1</sup> )	
Κ	Safety Factor	
Ka	Corrosion Speed (mm.a <sup>-1</sup> )	
$M_{\mathrm{f}}$	Mass of Cooled Liquild (kg)	
$\dot{M}_{p}$	Mass Flow of Liquid Vapours (kg.s <sup>-1</sup> )	
n	Mass Flux (kg.s <sup>-1</sup> .m <sup>-2</sup> )	
n <sub>b</sub>	Intension Limit Safety Factor	
n <sub>s</sub>	Yield Limit Safety Factor	
pc	Atmospheric Pressure (Pa)	
p <sub>m</sub>	Maximum Pressure (Pa)	
<b>P</b> <sub>1</sub>	Original Pressure (Pa)	
P <sub>2</sub>	Required Vacuum Pressure (Pa)	
qz	Total Heat Flow Rate (W.m <sup>-2</sup> )	
Q	Gas Load (liter torr.s <sup>-1</sup> )	
Q <sub>h</sub>	Quantity of Heat (J)	
t	Time (s)	



t	Time difference (s)	
Т	Temperature (°C or K)	
R	Gas constant (J.mol <sup>-1</sup> .K <sup>-1</sup> )	
S	Pumping Speed (m <sup>3</sup> .h <sup>-1</sup> )	
St	Ideal Pumping Speed (m <sup>3</sup> .h <sup>-1</sup> )	
Te	Ambient Temperature (°C or K)	
$T_{\rm f}$	Temperature of Cooled Liquid (°C or K)	
T <sub>f0</sub>	Initial Temperature of Cooled Liquid (°C or K)	
Ts	Saturation Temperature (°C or K)	
V	Volume of Vacuum Chamber (m <sup>3</sup> )	
$V_{\rm w}$	Volume of Liquid Vapours above the Cooled Liquid (m <sup>3</sup> )	
Z	Coordinate (m)	
α	Heat Transfer Coefficient (W.m <sup>-2</sup> .K <sup>-1</sup> )	
φ	Welding Coefficient	
δ	Minimum Thickness of Chamber (m)	
$\delta_{\Gamma}$	Film Thickness (m)	
λ	Thermal Conductivity of Cooled Liquid (W.m <sup>-1</sup> .K <sup>-1</sup> )	
[σ]	Allowable Stress (Pa)	
$\sigma_b$	Intension Limit (Pa)	
$\sigma_{s}$	Yield Limit (Pa)	
$ ho_{ m f}$	Density of Cooled Liquid (kg.m <sup>-3</sup> )	



## Chapter1

### Introduction

This chapter describes the research background, problem statement objectives, scopes of work for the study, the importance of the study and its development to the vacuum cooling system and the organization of the thesis.

#### 1.1 Background

Nowadays, people are extremely concerned of the cooling process. Pre-cooling has now become very important to keep food fresh. The cooling process is also used to hinder any microbiological action forming any toxin in the food. In the food processing industry, effective and efficient machines have to be used in order to perform the pre-cooling process. Besides the preservation temperature of food, a minimum cooling rate to reduce the temperature of food should be achieved during the cooling process in order to maintain the quality of the food in high conditions. This is followed by a sufficiently rapid cooling process to minimize the growth of any surviving pathogens. Several studies have observed



that the pre-cooling system is the most suitable choice for the food industry in order to keep food fresh.

Methods to keep food fresh and to prolong their shelf lives have been an important investigation. Horticultural crops contents field heat which is also called respiration heat after harvesting, and it can cause deterioration of some of them. Therefore, it is desirable to remove this field heat as quickly as possible after harvesting. As a guide, much deterioration can occur in one hour at 25°C, nevertheless they only occur in a week at 1°C. Based on these radical facts which highlight the necessity for pre-cooling (Brosnan and Sun, 2001).

The concept of pre-cooling is to remove the field heat from vegetables immediately after harvesting; before they are transported to the market or conserved in a cold storage. The definition of pre-cooling points out that it is likely the most important of all the operations used in the maintenance of desirable, fresh and salable products. Based on this statement, a rapid cooling is represented as the key to successful storage of vegetables and other horticultural crops (Gao et al., 2003). The temperature of the vegetables will be reduced quickly in a few minutes or a few hours, so that the vegetables can remain fresh. Pre-cooling is highly recommended and often required by processors. It is well



suited to farmers if there exists a pre-cooling place not too far from the market, which can provide them the cooling facilities. In order to facilitate the rapid cooling of foods, there are a variety of pre-cooling techniques available for use in the horticultural industry. The principal of these pre-cooling methods and advantages and disadvantages are shown in Table 1.1.



Method	Description	Advantages/Disadvantages
Room Cooling	-Placing field temperature	-Large refrigeration and
	(warm) containers of produce	storage space
	in a cold room.	-Need a proper design of
	-Containers are stacked	cooling room and refrigeration
	individually so that cold air	equipment
	from the ceiling blows over	-Slow process
	or around the produce to	-Suitable for small amount of
	contact all surfaces of the	goods
	containers.	
Forced-Air	-Similar to room cooling	-Higher cost operation
Cooling	-Force cold air through	-suitable for large amount of
	produce containers and its	goods
	content	
Hydro-Cooling	-Uses water as coolant	-Suitable for water tolerant
	-Produce is submerged or	goods
	drenched with ice water	-Using disinfectant in water
		-require sanitation and daily
De alva e a Laire e	Used to east some meduce	More even an aire vector to lorent
Package Icing	-Used to cool some produce	-More expensive water tolerant
	shipping containers	containers required
<b>F</b>		<b>y</b> •
Evaporative	-Dry air is drawn through	-Inexpensive
Cooling	moist padding or a fine mist	-Suitable for low humidity area
	of water, then through vented	-Best for warm season crops
0	containers of produce.	
Sources of	-Goods immersed in clean	-ineed very clean water, free
Cold water	water	nollutents
		large amount of water needed
Vaanna	Water eveneration process	-large amount of water needed
Cooling	- water evaporation process	-Quick cooling
Cooling		distribution
		-Suitable for small and large
		amount of goods
		-Dependent of the porosity of
		product
		product

# Table 1.1 Available cooling methods

(Yang, 1982 and Ma et al., 2007)



The advantages and disadvantages of these methods show how and why the vacuum cooling system stands out as a new method for keeping food fresh in the food safety area. The vacuum cooling system can overcome the disadvantages of these conventional methods with its quick cooling, uniform temperature distribution and suitability for small and large products. In particular, vacuum cooling has been used as an effective pre-cooling process to remove field heat and thus to extend shelf life and improve quality for many types of horticultural and floricultural products, such as lettuce (Haas and Gur, 1987) and cut flowers (Sun and Brosnan, 1999). Vacuum cooling has also been successfully applied in food processing procedures, such as the processing of liquid foods and baked foods (Houska et al., 1996) in order to reduce the cooling time and to improve the cooling efficiency. Through the advantages of a fast cooling process which reduces high temperature effects and minimizes the time during pre-cooling process, recent studies have suggested that the vacuum cooling system had been applied instead of other pre-cooling methods due to its energy saving performance. For example, The United States Space Shuttle returned due to the food system which was without freezers and refrigerators. This is because of the short duration of planned mission and the lack of storage room and electrical power on the orbiter (Perchonok and Bourland, 2002).

