UNIVERSITI PUTRA MALAYSIA

EXPERIMENTAL INVESTIGATION OF A VACUUM COOLING SYSTEM

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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.

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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

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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

Oleh

MR. ZHANG SI WEI

November 2009

Pengerusi: AHMAD SAMSURI MOKHTAR, PhD

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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 dihasilkan secara berperingkat, seperti penyejukan 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 feel proud to express that all the help my family members gave me, guidance and inspiration throughout this work. Their sacrifice and love made this thesis a great success in my carrier. Last but not the least, my appreciation and thanks to all around my surroundings especially to Mr. Helmi Ramdhaney, Mr. Soo Chee Wah, and all my country people in UPM, for their help and co-operation during my struggle in the MSc. pursuit.

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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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date: 11 February 2010

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

LIST OF TABLES

LIST OF FIGURES

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

A	Gas–Liquid Interface Area (m^2)
c_{pf}	Specific Heat Capacity of Cooled Liquid ($J.kg^{-1}.K^{-1}$)
C_1	Corrosion Capacity ($mm.s.a^{-1}$)
D_i	Chamber's Inner Diameter (m)
D_o	Chamber's Outer Diameter (m)
k_c	Mass Transfer Coefficient ($m.s^{-1}$)
K	Safety Factor
Ka	Corrosion Speed ($mm.a^{-1}$)
M_f	Mass of Cooled Liquild (kg)
$\dot{M}_p$	Mass Flow of Liquid Vapours ($kg.s^{-1}$)
n	Mass Flux ($kg.s^{-1}.m^{-2}$)
n_b	Intension Limit Safety Factor
n_s	Yield Limit Safety Factor
p_c	Atmospheric Pressure (Pa)
p_m	Maximum Pressure (Pa)
P_1	Original Pressure (Pa)
P_2	Required Vacuum Pressure (Pa)
q_z	Total Heat Flow Rate ($W.m^{-2}$)
Q	Gas Load (liter $torr.s^{-1}$)
Q_h	Quantity of Heat (J)
t	Time (s)

□t	Time difference (s)
T	Temperature (°C or K)
R	Gas constant ($J.mol^{-1}.K^{-1}$)
S	Pumping Speed ($m^3.h^{-1}$)
S_t	Ideal Pumping Speed ($m^3.h^{-1}$)
T_e	Ambient Temperature (°C or K)
T_f	Temperature of Cooled Liquid (°C or K)
T_{f0}	Initial Temperature of Cooled Liquid (°C or K)
T_s	Saturation Temperature (°C or K)
V	Volume of Vacuum Chamber (m^3)
V_w	Volume of Liquid Vapours above the Cooled Liquid (m^3)
z	Coordinate (m)
α	Heat Transfer Coefficient ($W.m^{-2}.K^{-1}$)
φ	Welding Coefficient
δ	Minimum Thickness of Chamber (m)
δ_Γ	Film Thickness (m)
λ	Thermal Conductivity of Cooled Liquid ($W.m^{-1}.K^{-1}$)
$[\sigma]$	Allowable Stress (Pa)
σ_b	Intension Limit (Pa)
σ_s	Yield Limit (Pa)
ρ_f	Density of Cooled Liquid ($kg.m^{-3}$)

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.

Table 1.1 Available cooling methods

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

(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).