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TAJUK: **THERMAL OPTIMIZATION OF ICE CREAM MAKING PROCESS: COMPARISON BETWEEN R134A AND R404A REFRIGERANTS**

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Taman Scientex,

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Faculty of Manufacturing Engineering

THERMAL OPTIMIZATION OF ICE CREAM MAKING PROCESS: COMPARISON BETWEEN R134A AND R404A REFRIGERANTS

Mohd Azreen Bin Azmi

Master of Manufacturing Engineering (Industrial Engineering)

2019

DECLARATION

I declare that this thesis entitled “Thermal Optimization of Ice Cream Making Process: Comparison Between R134a And R404a Refrigerants” is the result of my own research except as cited in the references. The thesis has not been accepted for any master degree and is not concurrently submitted in candidature of any other master degree.

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Date :

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Manufacturing Engineering (Industrial Engineering).

Signature :

Supervisor Name : Profesor Madya Dr. Md Nizam Bin Abd. Rahman

Date :

DEDICATION

A special dedication to :

My beloved father and mother,

Azmi Bin Abd Rahman and Azizah Binti Mohd Yasin

My lovely spouse, Nazahiah Binti Salleh

For their great support, pray, love and care

Also to all lecturer,

Thank you very much to my Master Project's supervisor,

PM. Dr. Md Nizam Bin Abd. Rahman

For the good support and tolerate in this thesis.

To all my best friend,

Thanks for all your support and cares,

Give support to me,

In order to successfully graduate

"Alhamdulillah"

ABSTRACT

Refrigerant is a medium or working substance in a cooling and refrigeration system that run through all the inner parts of the refrigerator. The use of the right refrigerant in the system is important because it can help to shorten the ice cream processing time and increase the production capacity. The system optimization will help to ensure the system is working in an optimal condition with minimal energy loss. At the same time the selection of appropriate refrigerant can improve the efficiency of the refrigeration system, hence reduce the power consumption. The objectives of this project are to redesign and fabricate the ice-cream making machine as the test rig of this project and to identify which of the two refrigerants (R134a and R404a) is better in term of cooling rate for ice cream making process. The experiments to compare performance of those refrigerants were conducted using a test rig, design and built using standard refrigeration system components for ice cream machine. The data collected were time taken to reach the ice-cream freezing temperature (-8° C) and temperature reading during the freezing process for every 10 minutes interval for one hour. The experiments were replicated three times. Performance of the two refrigerants was compared using t-test and paired t-test analysis utilizing Minitab software. The t-test results indicated that statistically refrigerant R404a reached the freezing time in shorter time compared to that of R134a. The paired t-test also indicated that the refrigerant R404a's temperature readings during the freezing process is statistically lower than that of R134a's.

ABSTRAK

Bahan penyejuk merupakan satu medium atau bahan kerja di dalam sistem penyamanan dan penyejukan yang melalui bahagian-bahagian dalam sistem penyejukan. Pemilihan bahan penyejuk yang tepat untuk sistem adalah penting kerana ia membantu dalam memendekkan proses penyediaan aiskrim dan meningkatkan kadar penghasilan aiskrim. Sistem yang optimum akan memastikan sistem bekerja di dalam keadaan optima di mana kadar kehilangan tenaga berlaku adalah minima. Dalam masa yang sama, pemilihan bahan penyejuk yang tepat dapat meningkatkan kecekapan sistem penyejukan sekaligus mengurangkan penggunaan tenaga. Objektif projek ini adalah untuk merekabentuk semula dan membina sebuah mesin membuat aiskrim sebagai rig ujian untuk mengenalpasti mana antara dua jenis penyejuk (R134a dan R404a) lebih baik dari segi kadar penyejukkan dalam proses penyediaan aiskrim. Ujikaji-ujikaji untuk membandingkan prestasi bahan-bahan penyejuk tersebut dijalankan menggunakan rig ujian yang direkabentuk menggunakan komponen-komponen asas bagi sistem penyejukan bagi sebuah mesin pembuat aiskrim. Data-data yang diambil adalah masa yang diambil untuk mencapai suhu beku aiskrin (-8^{o}C) dan bacaan suhu pada setiap 10 minit selama satu jam. Ujikaji ini diulang sebanyak tiga kali. Prestasi setiap bahan penyejuk telah dibandingkan melalui analisa t-test dan paired t-test menggunakan perisian Minitab. Keputusan dari analisa t-test menunjukkan bahawa secara statistiknya, penyejuk jenis R404a mencapai suhu beku dalam masa yang lebih singkat berbanding R134a. Analisa paired t-test juga menunjukkan bahawa bacaan suhu bagi penyejuk R404a semasa proses pembekuan adalah secara statistiknya lebih rendah dari R134a.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variant
CAGR	Compound Anal Growth Rate
CFC	Chlorine - Florin - Carbon
COP	Coefficient of Performance
DoE	Design of Experiment
GWP	Global Warming Potential
HC	Hydrogen - Carbon
HCFC	Hydrogen - Chlorine - Florin - Carbon
HFC	Hydrogen - Florin - Carbon
ODP	Ozone Depletion Potential
FPL	Fixed Position Layout

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Thermal efficiency is a dimensionless performance measure of a device of system that uses thermal energy to operate (MAN, 2017). Internal combustion engine, steam engine, steam turbine, boiler and refrigerator are the equipment that directly depends on thermal efficiency. For a heat engine, thermal efficiency is the fraction of the energy added by heat as primary energy which is converted to net work. In the case of refrigeration, thermal efficiency is the ratio of net heat output for heating or removal for cooling, to the energy input (known as coefficient of performance).

Thermal efficiency concept has been used widely in many ways. As for this study, the focus is in the ice cream making process using ice cream rolling maker. It is a unit of ice cream maker which used a common components and basic cooling system to produce ice cream. In this study, the effects of different refrigerants on the ice cream making process will be studied. The focus is how different type of refrigerants affect the rate of freezing time for the ice cream.

Currently, most of the refrigeration systems using lower Global Warming Potential (GWP) refrigerants may not perform optimally with various loads because of the different thermodynamic properties of the refrigerants which would affect the optimum operation of the heat pumps. In order to select what refrigerant to use, it is important that their

performance range is characterized and aligned with the demands of the refrigeration system so as to achieve energy efficiency for overall operation.

1.2 Problem statement

Patel and Banerjee (2017), stated that ice cream is a sweetened frozen food typically eaten as a snack or dessert and was considered as a food for enjoyment, rather than a basic food. It is usually made from dairy products, such as milk and cream, and often combined with other fruits or other ingredients and flavors. In Malaysia, ice cream can be categorized as a popular dessert for all ages especially children. We can buy ice cream easily at any time.

Ice cream also become a source of additional income to small traders which sells their handmade ice cream during ceremony or occasions. Some of them, sells their ice cream in the booth at several places such as *pasar malam*. The quantity of ice cream can be produced is limited since the ice cream making process needs times to ensure the ice cream is ready to be served. At peak time, the ice cream needs to be produced quickly to fulfil the demand of the customers. Meaning that the time taken to produce the ice cream must be accelerated.

The major issue for these ice cream makers is the time taken for ice cream to completely freezes and according to Trgo *et al*., (1999), the freezing point of ice cream is -8^{o}C. Sometimes, the customer needs to wait to have and ice cream but not all customers willing to waste their time just for a cone of ice cream. So, there is a lost of sales happened. If the time of ice cream making process can be reduced, so the quantity of ice cream produced automatically can be improved and the sales as well.

By improving the process of making ice cream, the benefits are :

- Shorten the time of making ice cream

- Improve the number of cycle of making ice cream
- Increase the productivity

Currently, there are not many research has been done on how different type of refrigerant affect the ice cream hardening process especially for ice cream rolling machine. Most of the published studies focused on function of additives and stabilizers in ice cream hardening process and freezer's system optimization for a mass production. Therefore, this study will focus on how different type of refrigerants will affected the ice cream hardening process.

1.3 Objectives of Study

The objectives of this study are:

i. To re-design an ice cream making machine as the experimental rig for this study.

ii. To compare and characterize the performance of two refrigerants with the respect to the ice cream freezing time and rate of cooling by using Minitab software.

iii. To propose the better refrigerant that can be used to shorten the time taken to produced ice cream.

1.4 Scope and Limitation

This project will be focused on two environmentally friendly refrigerants (R134a and R410) and will be conducted using an ice cream roll machine which use standard cooling system like air conditioning and refrigerant system. The system has four

fundamental components which are compressor, condenser, expansion valve and evaporator (Rani *et al.*, 2017).

A standard refrigerant (R134a type) for ice cream making process will be used as a comparison to the proposed alternatives refrigerant. The comparison will be focused on the time taken to produce an ice cream and on how it will increase the amount of ice cream can be produced. The time taken to produce an ice cream is the time for the system achieve the ice cream's frozen temperature. The comparison will be evaluated using Minitab and some analysis.

1.5 Significance of Study

The aim of this study is to find an alternative refrigerant which can be used to replace the current refrigerant in ice cream making process. The alternatives refrigerant selected must have an effect to the ice cream making process especially in reducing the time taken to completely achieve the ice cream's frozen temperature.

By improving process, the production flow can be shortened and will be more effective and practical. The time shorten, the productivity increased, so demand can be fulfilled as soon as possible. As for the seller, the increasing of production will directly give an impact to their sales and the customers will no longer have to wait to get the ice cream.

Not only that, refrigeration system has the potential to improve thermal optimization at lower energy costs. Therefore, evaluating the performance of a refrigeration system working with the current alternatives refrigerants presents an excellent opportunity to expand the market and promotes the use of energy saving systems.

1.6 Project Report Organization

The summary for each chapter of the report for this project are as follow:

a) Chapter I: Introduction

This chapter consist a background of study and it comprises of introduction, problem statements, objectives of study, scope and limitation and project report organization.

b) Chapter II: Literature Review

This chapter is based on literature reviews on related topics for this study. Mainly the literature reviews are from books, journals, articles and internet.

c) Chapter III: Research Methodology

This chapter explain the methodologies used to carry out this study.

d) Chapter IV: Results

This chapter is about data collected and the preliminary analysis on several data.

e) Chapter IV: Discussions

This chapter focuses on analyzing collected data and discussing the findings. Various suitable techniques and methodologies are used in analyzing the data gathered appropriate with the information needed and the type data collected. Analysis and discussion in this chapter is carried out with regards to fulfilling the objectives of the research.

f) Chapter VI: Conclusion and Recommendations

This chapter is about the conclusions and recommendation for this further improvement of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

This chapter will discuss about the ice cream making process, cooling system design, refrigerants, simulation and the advantages using simulation in layout arrangement. It will give an idea on the techniques and tools which will be used in this study. All the information for this study are from journals, books, case study, report, scholarly articles and the other reliable sources.

2.2 Ice Cream

Ice cream may be defined as a frozen dairy product made by suitable blending processing of ice cream and other milk product together with sugar and flavour with or without stabilizer or colour and with the incorporation of air during freezing process (Sukumar,1980). Maryam and Mostafa (2011) defined ice cream as a complex food consists of small air cells dispersed in a partially frozen, continuous aqueous phase. Its desired quality is achieved by both proper processing and formulation. Stabilizers are substances that, despite their low usage level in ice cream mix, aeration improvement, cryoprotection and control of meltdown.

Ice cream starting to freeze when the mixture of ice cream reaches its freezing point. Freezing is a phase transition in which liquid turns into a solid when its temperature

is lowered below its freezing point. As other liquid, ice cream freeze by crystallization, formation of crystalline solid from the uniform liquid.

This situation complies with the first-order thermodynamic phase transition, which means that as long as solid and liquid coexist, the temperature of the whole system remains very nearly equal to the melting point due to slow removal of heat when in contact with air, which is a poor heat conductor. Because of the latent heat of fusion, the freezing is greatly slowed down and the temperature will not drop anymore once the freezing starts but will continue dropping once it finishes.

Khaliduzzaman *et al.*, (2012) proved that the freezing point for different mixture ice creams is between -2^{0}C to -4^{0}C while Budiaman and Fennema (1987) found that crystallization temperature is between -3^{0}C to -5^{0}C. The freezing points might be different because of the content of the mixture, but generally below than 0^{0}C. Trgo *et al.*, (1999) has derive information on the technological influences on the ice crystallization in ice cream during the sensitive temperature range from the freezing point to -8^{0}C. Murtaza *et al.*, (2004) stated the ice cream was frozen at temperature of -1^{o}C to -9^{o}C along with the whipping of iar into the mix by agitation in hand operated ice cream freezer or machine.

Table 2.1 : Freezing point of ice cream mixes (Khaliduzzaman, 2012)

Mix	Fat %	Total Solid %	Cane Sugar %	Honey %	Freezing Point
1	13. 27	35.28	14.0	0	-2.06^{0}C
2	13.42	36.45	10.5	4.5	-2.57^{0}C
3	13.19	36.70	7.0	9.0	-2.95^{0}C
4	13.20	36.44	3.5	13.5	-3.11^{0}C
5	12.90	36.42	0	18.0	-3.47^{0}C

It can be simplify that temperature is one of the important factors in ice cream making process. If the time to reach freezing point can be shortened, the production of ice cream also can be increased.

2.2.1 Ice Cream in Malaysia

Ice cream is one of the favourite dessert in Malaysia. Based on the report prepared by Canadean (2015), generally, Malaysian consumes three categories of ice cream which are :

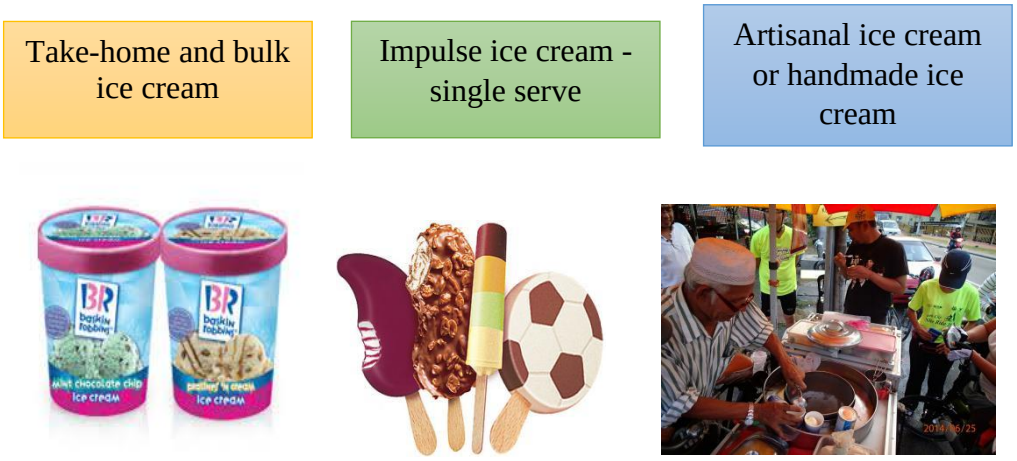

Figure 2.1 : Ice cream categories

The definition of ice cream categories are as in Table 2.2 below :

Table 2.2 : Category definitions (Canadean, 2015)

CATEGORY	DEFINITION
Artisanal Ice Cream	Manufactured by small local producers for sale on the premises. Also includes branded gourmet ice cream and includes both on and off trade consumption.
Impulse Ice Cream - Single Serve	Includes single-serve ice cream tubs, packaged cones (e.g. Cornetto), ice cream sandwiches and chocolate-coated ice cream (e.g. Magnum). Includes all on-trade and off-trade consumption.
Take-Home & Bulk Ice Cream	Sold for take-home and bulk consumption. Includes multiple-serving ice cream tube (e.g. Haagen-Dazs) and ice ream cakes (e.g. Vienetta). Includes all on-trade and off-trade consumption.

2.2.2 Artisanal Ice Cream

Market Watch 2012 : The Malaysia Food Industry (AHK, 2012), stated that ice cream production in Malaysia in year 2009 and 2010 is about 44.1 and 45.2 million liters. Based on the finding from the report on the ice cream market in Malaysia, done by Canadean (2015), an artisanal ice cream is most popular ice cream category. It can be seen easily in Malaysian daily life, in the booth at shopping complex, *pasar tani*, *pasar malam*, carnival, wedding ceremony and many more. It is just like a part of a Malaysian culture.

It is reported that in 2014, the artisanal or handmade ice cream is the largest category by value in on trade sales and is forecast to register a highest Compound Anal Growth Rate (CAGR) of 5.6% during 2014 - 2019 (Canadean, 2015).

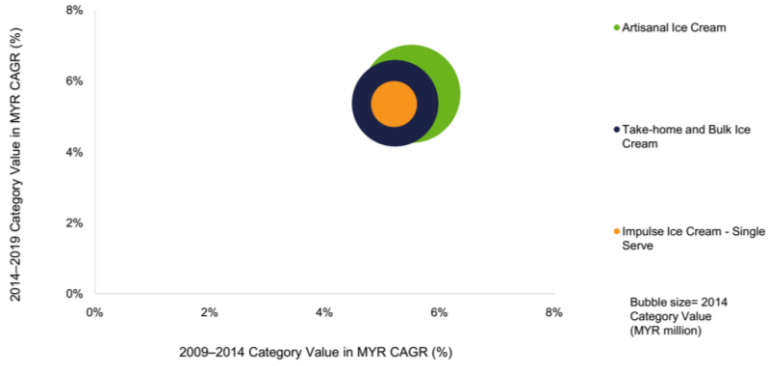

Figure 2.2 : Market value of categories in the ice cream market - on trade

(Canadean, 2015)

In Malaysia, the market for artisanal ice cream is very encouraging and one of the trending now is ice cream roll.

2.3 Refrigeration System Design

Refrigeration is a process in which work is done to remove heat from one location to another. It has many applications including but limited to household refrigerators, industrial freezers, cryogenics, air conditioning and heat pumps. In order to satisfy the