

**LOW POWER HEATER DESIGN ON
FLEXIBLE PRINTED CIRCUIT BOARD
FOR INCUBATOR APPLICATION**

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**LOW POWER HEATER DESIGN ON FLEXIBLE PRINTED CIRCUIT
BOARD FOR INCUBATOR APPLICATION**

by

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LIST OF ABBREVIATIONS

FPC	Flexible Printed Circuit
PC	Personal Computer
LCD	Liquid Crystal Display
PCM	Phase Change Material
SOI	Silicon on Insulator
AFM	Atomic Force Microscopy
UV	Ultraviolet
LED	Light Emitting Diode
PVC	Polyvinyl Chloride
RTD	Resistance Temperature Detector
IDE	Integrated Development Environment
ANOVA	Analysis of Variance
PWM	Pulse Width Modulation

LIST OF SYMBOLS

R	Resistance, Ω
R_o	Initial Resistance, Ω
ΔR	Difference of Resistance, Ω
α	Temperature Coefficient of Resistance, / $^{\circ}\text{C}$
V	Voltage, V
I	Current, A
ρ	Resistivity, Ωm
T_i	Initial temperature, $^{\circ}\text{C}$
T_f	Final temperature, $^{\circ}\text{C}$
T_{wall}	Wall temperature, $^{\circ}\text{C}$
T_{heater}	Heater temperature, $^{\circ}\text{C}$
ΔT	Difference of temperature, $^{\circ}\text{C}$
cm	Centimeter
μ	Micrometer
W	Watt
Q	Heat Energy, J
c	Specific Heat Capacity, J/gK
θ	Temperature increment, $^{\circ}\text{C}$
P	Power, W
t	Time, s
m	Mass, g
h	Heat transfer coefficient, $\text{W}/\text{m}^2\text{K}$
s	Width, m
d	Thickness, m

l	Length, m
A	Area, m^2
D	Density, kg/m^3
D_{copper}	Density of copper, kg/m^3
V	Volume, m^3
R_{series}	Series resistance, Ω
R_{parallel}	Parallel resistance, Ω
H_0	Null hypothesis, Ω
H_1	Alternate hypothesis, Ω
μ	Mean
α	Threshold value
t_{on}	Time taken during heating, s
t_{off}	Time taken during cooling, s
$t_{\text{switching}}$	Switching time
P_{on}	Power on, W
$\%P$	Percentage of power, %

REKA BENTUK PEMANAS KUASA RENDAH DI ATAS PAPAN LITAR TEKAP FLEKSIBEL BAGI APLIKASI INKUBATOR

ABSTRAK

Inkubator adalah peralatan yang digunakan untuk membina dan mengekalkan persekitaran yang stabil bagi bayi, telur, haiwan, sel dan organisma hidup. Kebiasaannya, inkubator yang digunakan dalam saiz yang besar, berat dan menggunakan kuasa yang tinggi. Oleh sebab itu, pemanas fleksibel yang nipis dan ringan dicadangkan untuk merekabentuk inkubator yang ringan dan cekap tenaga. Walaubagaimanapun, pemanas fleksibel hanya terdapat dalam sambungan sesiri yang mungkin menyebabkan penggunaan kuasa yang tinggi. Oleh itu, pemanas fleksibel dalam konfigurasi selari dikaji dalam projek ini. Pemanas direka menggunakan perisian Ansys dan dimensi untuk pemanas tersebut ialah 1.62m (panjang), 0.33m (lebar) dan 35 μ m (tebal). Pemanas difabrikasi di Teknologi QDOS Sdn Bhd. Tiga ujian dijalankan iaitu; 1) Ujian fungsi pemanas tunggal, pemanas sesiri dan pemanasan selari, 2) Ujian pemanas sesiri dan selari dengan dan tanpa kipas dalam inkubator, 3) Pemanas sesiri dan selari dengan dan tanpa kipas menggunakan sistem kawalan bertukar dalam inkubator. Mikropengawal yang digunakan dalam projek ini ialah Arduino Uno. Keputusan menunjukkan semasa proses pemanasan, pemanas sesiri dengan kipas dan selari dengan kipas boleh mengurangkan kuasa sebanyak 12.5% dan 13.8% berbanding dengan pemanas sesiri tanpa kipas dan pemanas selari tanpa kipas. Keputusan juga menunjukkan pemanas sesiri tanpa kipas dan pemanas selari tanpa kipas dapat mengurangkan tenaga sebanyak 6.37% dan 16.9% semasa proses penyejukan. Oleh itu, bagi proses penyejukan, pemanas tanpa kipas adalah lebih baik daripada pemanas dengan kipas. Dalam ujian ketiga, keputusan menunjukkan bahawa pemanas selari dengan kipas semasa proses pemanasan dan pemanas selari tanpa kipas semasa proses penyejukan menggunakan sistem kawalan bertukar dapat

mengurangkan kuasa sebanyak 48.66% berbanding pemanas lain. Kesimpulannya, pemanas selari yang dicadangkan menggunakan kuasa yang lebih rendah dan sesuai untuk aplikasi inkubator.

LOW POWER HEATER DESIGN ON FLEXIBLE PRINTED CIRCUIT BOARD FOR INCUBATOR APPLICATION

ABSTRACT

Incubator is equipment used to grow and maintain a stable environment for infants, eggs, animals, cell and living organism. Conventionally, the incubators are commonly bulky, heavy and high power consumption. Therefore, a flexible heater is proposed to design a light-weight and power efficient incubator. However, flexible heater is only available in series connection, which may cause high power consumption in incubator. Therefore, flexible heater in parallel configuration is studied in this project. The heater is designed using Ansys software and dimensions for the heater is 1.62m (length), 0.33m (width) and 35 μ m (thickness). The heater is fabricated at QDOS Technology Sdn Bhd. Three tests are conducted which are; 1) Functionality test of single heater, series heater and parallel heater, 2) Series and parallel heater with and without fan test in the incubator, 3) Series and parallel heater with and without fan test using switching control system in incubator. Microcontroller is used in this project. Results show that for heating process, series heater with fan and parallel heater with fan can save more power by 12.5% and 13.8% compared to series heater without fan and parallel heater without fan. Results also show that the series heater without fan and parallel heater without fan can reduce power by 6.37% and 16.9% during cooling process. Therefore, for cooling process, heater without fan is better than heater with fan. In the third test, results show that by using switching control the parallel heater with fan at heating stage and the parallel heater without fan at cooling stage can reduce power by 48.66% compared to other heaters. As a conclusion parallel heater consumes less power and suitable for incubator application.

CHAPTER ONE

INTRODUCTION

1.1 Research Background

An incubator is a device used to grow and provide humidity, temperature and oxygen for infants, eggs, animals, cell and living organism. The simplest incubator consists of boxes or container with an adjustable heater and the most commonly used temperature for bacteria and mammalian cells is approximately 37°C. Incubators are usually run on electricity with size ranging from small table top unit to room-size.

The history of incubator started in late of 18th century when the first published description of incubator was written by Denuce. In 1883, a French obstetrician Stephane Tarnier invented the first infant incubator to warm numerous premature infants in Paris's Maternite' hospital. This incubator was made using hot water reservoir attached to an external heating source. This hot water bottles were replaced manually every 3 hours. In 1891, Alexandre Lion was invented more sophisticated incubator than Tarnier. He designed an infant incubator with a large metal apparatus equipped with a thermostat and an independent forced ventilation system. Then, a Chicago obstetrician Joseph B. Dee Lee was created a transport service using portable incubator to pick up the premature new-born in Chicago in 1990 (Baker, 2000). Dee Lee's invention encouraged Julius Hess developed the first electrical heated bed surrounded by metal jacket containing hot water (Ehsan, et al. 2011). Since then, there are many more types of incubator came out such as manually controlled incubator, servo-controlled incubator, open box-type incubator, close type incubator and portable incubator.

Nowadays the portable incubator is important since people are moving all over the world. Hence, the design of the portable incubator should be rugged in casing, safe

for air travel, sensitive to temperature control and inexpensive (Charles, 1968). The portable incubator also should consume less power and not heavy. Unfortunately, the conventional incubators are often heavy, bulky and immobile (Walzik, et al. 2014).

The incubator consists of heater component, control system and power supply. Electrical heater is commonly used in the incubator. It converts electrical energy to heat energy through Joule Heating concept where the heat is produced due to the flow of current within the heater. There are many type of heater design where the design comes with specific application such as light bulb in chicken incubator and heating wire in infant incubator. The selection of the heater depends on the heater material, heater types, sheath material that surrounds the heater and the operating voltage of the heater. Example of heater types are strip, ring, rope and cable, cartridge, tubular, band, immersion, circulation, process air and duct, radiant, comfort, flexible, tote, and drum.

Today, flexible heater has become popular and available in market. The advantages of using flexible heater are it can be bent which can be designed in specific shape which makes it suitable for cylindrical devices. Flexible heater provides fast heat-up and cool down rates, uniform heat distribution and high watt densities (Radadia, 2008). The heat transfer of flexible heater is good due to direct bonding and heater's thin design. In incubator most of the heat is transferred through conduction and convection process inside the incubator. In heater, the heat is transferred through conduction process. When the adjacent atom or molecules in the heater vibrate and interact with the adjacent atoms or molecules, heat energy will be conducted to the neighbouring particles. This will make the whole heater become hot. Meanwhile, the heat from the heater is transferred to the surrounding incubator through convection process by movement of air inside the incubator.

1.2 Problem Statement

In the case that biological samples are cultured at different locations or there are no culture facilities available, the probes need to be transported to the laboratory which can cause delays or in the worst case failure of a planned experiment. Thus, making the incubator small, low power and transportable is a hugely advantage. Most incubators run on electricity and are rendered worthless in regions without electricity, or in those that suffer from electricity shortage. The challenge therefore is to design an energy efficient incubator that will run using low power of electricity. A portable incubator with low powered heater is addressed on these issues.

Heating rods and coils is widely used as a heating element in the incubator. However the drawbacks of the heating rods and the heating coils are bigger size and heavy. Flexible heater is one more available option for electrical heater. The flexible heater is a resistive heater which offers low cost, thin, lightweight, flexibility, minimum occupied space and high heating rates. However, the flexible heater may consume a lot of power because it is connected in series configuration and has high value of resistance of the heater. Since the power consumption is based on the resistance of the heater and the length of the heater will determine the resistance of the heater, so there is a possibility if the length is reduced then the power consumption can be decreased.

1.3 Research objectives

In this thesis, flexible heater in incubator application is studied. The performance of series and parallel flexible heater is investigated whether it can reduce the power consumption in incubator system. Besides, the effect of fan and switching control is studied in incubator application. Therefore, a low power portable incubator is developed

to test the flexible heater with fan and switching control system. Hence the following objectives have been set to solve the problems.

- i. To identify the performance of parallel flexible heater and series flexible heater for low power incubator application.
- ii. To investigate the effect of fan on the heater performance for incubator application.
- iii. To develop a low power portable incubator by using flexible heater with fan or without fan and switching control system.

1.4 Research Scope

The study is defined with a few requirements and specification which as listed as follows:

- (a) Engineering specification: Investigate the changes of heater's temperature and power from series and parallel heater with fan or without fan. Establish switching controller to investigate the power of series and parallel heater and implement the switching control system in incubator.
- (b) Hardware specification: A microcontroller PIC based system is developed to perform data acquisition for the development of incubator system and control the switching time for heater during heating and cooling.

- (c) Test specification: Evaluate the performance of series and parallel heater in incubator in terms of temperature, time and power. Performance of series and parallel heater with switching control and fan is also analysed.

1.5 Thesis layout

The thesis is organised into five chapters. The first chapter discusses on the background of incubator and problems faced by researchers in conventional incubator. The overview of flexible heater application as an alternative to the existing heater used in incubator is also briefly explained. This chapter also discussed on problem statements, research objectives, research scope and thesis layout.

Chapter 2 explains on literature review whereby it describes the research and studies of different types of heaters use in various applications. The application of flexible heater, resistivity, power consumption, types of heaters connections, heat transfer in incubator and temperature range and control is discussed in detail in this chapter.

The third chapter discusses on work flow of the project. The work flow described and illustrated by a flow chart and block diagram. A detail explanation of design of heater, fabrication of heater steps is presented in this chapter. Preliminary test on electrical characteristics of heater is further discussed. It is followed by development of incubator, testing and data collection. This chapter is concluded in summary.

Chapter 4 explains about results and discussion from the test. The chapter is divided into introduction, functionality test, parallel and series configuration test and switching control test in incubator. The results of temperature and power are studied and compared for all types of heaters. The explanation also consists of data collection and graphical analysis.

Finally, Chapter 5 describes in detail on the conclusion of the research, research contribution and the suggestions for future works.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The previous chapter demonstrated that the incubator plays a major role providing an appropriate environment for infants, eggs, animals, cell and living organism. This device is designed to maintain humidity, carbon dioxide and the temperature within it. Incubators require accurate temperature regulation (Tisa, 2012). The most important part of the incubator is a heater. The heater produces heat and helps regulate temperature. It is used for raising and maintaining the temperature of the air surrounding the incubator. There are many types of heaters such as a Phase Change Material (PCM) heater, lamp or light bulb heater, heating wire heater and flexible printed circuit heater. The details of each heater are discussed from Sections 2.1.1 to 2.1.3.

2.1.1 Phase Change Material

A Phase Change Material (PCM) heater uses materials such as water and metal balls that are incorporated into a container that can store and release heat through the changing of a liquid phase to solid phase or vice versa. For a PCM heated incubator, the amount of heat released largely depends on the temperature gradient between the PCM melting/solidifying points and environmental temperature. The advantages of a PCM heated incubator are that it is simple, safe and inexpensive. However, there are noticeable drawbacks. A PCM overheats and becomes increasingly unreliable as the material degrades through repeated cycles of heating. Besides, the time taken to release absorbed

heat is too long which takes place over 1 to 2 hours depending on the ambient temperature (Mishra, et al. 2015).

2.1.2 Lamp & Light Bulb

The attempts to incorporate an electrical heater such as an incandescent lamp or light bulb in portable incubators are not new. One of the earliest documented applications of an electrically heated cell culture portable incubator was in 1968 (Charles, 1968). Two incandescent lamps acting as the heating element are placed in the incubator with a fan and thermo-regulator. The heaters are connected in parallel and require a minimum of 10 W battery to maintain a temperature of 37° C within the incubator at an ambient temperature of 5° C. Other types of incubators have used an electrical heater using a lamp and light bulb, such as egg incubator (Adid, 2008; Adegbulugbe, et al. 2013) and infant incubator (Singh, 2006; Mittal et al. 2015). However, the net weight of a cell culture incubator introduced by Charles (1968) is 14.6 kg which is still heavy to carry during transportation.

2.1.3 Heating Wire

Another type of electrical heater used in incubators is heating wire. In 1978, a portable neonate incubator was invented by Durie (1978). He used a heating wire that is bonded to the inner kernel of the incubator wall. The product's name is the Maxcell Mini CO₂ Incubator and was designed by a company N-Biotek. The incubator design involved an electric heating wire with a maximum AC voltage of 220 V to cover the six sides of the chamber. The three parts of the heating section are controlled and calibrated individually by three temperature sensors (Durie, 1978). However, this product is not