ANALYSIS OF CHARACTERISTIC HEAT PIPE AS AN EFFICIENT COOLING HEAT TRANSFER DEVICE

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ABSTRACT

A heat pipe is a simple heat transfer device that can transport large quantities of heat with a very small difference in temperature between the hot ends to the other end. In this case study, the concept of the condensation process of heat pipe is applied in order to perform dehumidification process to remove extra moisture inside the air. The objective of this study is to compare the efficiency between the primary heat pipe in evacuated condition and the secondary heat pipe with water as the working fluid in order to perform the dehumidification process. The heat pipe device had been divided into 2 samples of specimens. First specimen of heat pipe using air whiles the other one used water as the working fluid. These two pipes were made without the wick but dealing with inclination of angle to see the performance of the heat pipe. These two heat pipes were built without the wick but dealing with inclination of angle to see the performance of the heat pipe. Both pipes were built by the total length of 400mm length and 8mm diameter using copper as the pipe material. Gravity pumping was used with the inclination angle to pump back the working fluid back to the evaporator section. The heat pipe was positioned at different angles of 0°, 30°, 60° and 90° with the horizontal. To achieve the objective of this study, both pipes were studied experimental and simulation to find the most efficiency between the primary heat pipe and the secondary heat pipe. The important parameter involves in the case study are the Merit Number, M and Heat Transfer Coefficient. After performing the experiments and simulation, the objective of this case study is achieved, which showed the secondary heat pipe is more efficient as a cooling heat transfer device.

ABSTRAK

Paip haba adalah alat ringkas pemindahan haba yang digunakan untuk memindahkan haba yang banyak dengan perbezaan kecil pada suhu di pangkal paip dengan di hujung paip. Dalam kajian kes ini, konsep kondensasi pada paip haba itu digunakan untuk *dehumidification* kandungan air di dalam udara. Objektif kajian ini ialah untuk membandingkan kecekapan paip haba primer yang mengandungi udara di dalamnya dengan paip haba sekunder yang mengandungi bendalir penggerak untuk menjalankan proses *dehumidification*. Paip haba tersebut dibahagikan kepada dua contoh spesimen. Spesimen pertama paip haba menggunakan udara manakala spesimen kedua menggunakan air sebagai bendalir penggerak. Kedua-dua paip ini dibina tanpa sumbu di dalamnya akan tetapi menggunakan perbezaan darjah untuk melihat keberkesanan medium dalam kedua-dua paip haba tersebut. Tarikan graviti digunakan melalui perubahan setiap darjah dengan tujuan untuk mengepam bendalir balik ke bahagian penyejatan. Kedua-dua paip ini diletakkan pada perbezaan darjah pada 0°, 30°, 60° dan 90° dalam keadaan melintang. Untuk mencapai objektif kajian ini, dua paip haba ini duji dengan melakukan eksperimentasi dan simulasi *CFD* untuk mencari kecekapan antara paip haba primer dan haba paip sekunder. *Parameter* penting yang berkaitan dalam kajian ini adalah seperti *Merit Number, M* dan juga *Heat Transfer Coefficient*. Setelah melakukan eksperimental dan simulasi *CFD* eksperimen berkaitan, objektif kajian ini tercapai dan hasilnya terbukti paip haba sekunder mempunyai kecekapan yang lebih berbanding dengan paip haba primer.

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LIST OF SYMBOL

FIGURE		TITLE
CFD	-	Computational Fluid Dynamics
ACT	-	Advanced Cooling Technologies
NASA	-	National Aerospace Agency
HPHE	-	Heat Pipe Heat Exchanger
USB	-	Universal Serial Bus
atm	-	Atmosphere
°C	-	Degree Celsius
T	-	Temperature
t	-	Time
W	-	Watts
M	-	Merit Number, M
K	-	Kelvin
ρ	-	Density of working fluid in liquid phase
σ	-	Surface tension of the working fluid
μ	-	Dynamic viscosity of working fluid in liquid phase
L	-	Length of the heat pipe
L_e	-	Length of evaporator section
L_a		Length of adiabatic section
L_c	-	Length of condenser section
m	-	Meter
mm	-	Millimeter
Re	-	Reynolds Number
V	-	Velocity, Average Velocity

c	-	Specific heat
k	-	Thermal conductivity
$\dot{Q}, \dot{q}$	-	Rate of internal heat generation
Φ	-	Dissipation function due to the viscous forces
D,d	-	Diameter
r	-	Radius
h	-	Heat transfer coefficients
H	-	Heights
π	-	Pi (radian)
Δ	-	Increment
$\dot{V}$	-	Volume flow rate
A_c	-	Cross sectional area
A_s	-	Heat transfer surface area
T_s	-	Temperature of the surface
T_∞	-	Temperature of the fluid sufficiently far from the surface
ml	-	Millilitre
l	-	Litre
gal	-	Gallons

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CHAPTER 1

INTRODUCTION

1.1 Introduction to Research

Heat Pipe

A heat pipe is a heat transfer mechanism that can transport large quantities of heat with a very small difference in temperature between the hot ends to the other end. In other words, it is a simple device that can quickly transfer heat from one point to another. They are often referred to as the "superconductors" of heat as they possess an extra ordinary heat transfer capacity and rate with almost no heat loss.

Basically, it consists of a sealed aluminum or copper container whose inner surfaces have a capillary wicking material. A heat pipe is similar to a thermosyphon. It differs from a thermosyphon by virtue of its ability to transport heat against gravity by an evaporation-condensation cycle with the help of porous capillaries that form the wick. The wick provides the capillary driving force to return the condensate to the evaporator. The quality and type of wick usually determines the performance of the heat pipe, for this is the heart of the product. Different types of wicks are used depending on the application for which the heat pipe is being used.

1.2 Background of the Study

The range of its application is extremely wide and enormous. Some of the fields in which it is extensively used nowadays are listed below:

a) Electronics:

All electronic components, from microprocessors to high end power converters generate heat and rejection of this heat is necessary for their optimum and reliable operation. As electronic design allows higher throughput in smaller packages, dissipating the heat load becomes a critical design factor. Many of today's electronic devices require cooling beyond the capability of standard metallic heat sinks. Heat pipes offer a high efficiency, passive, compact heat-transfer solution and are rapidly becoming a main stream thermal management tool.

b) Aerospace:

Low weight penalty, zero maintenance and reliability have made heat pipes very attractive components in the area of spacecraft cooling and temperature stabilization. Structural isothermalization is an important problem as regards orbiting astronomy experiments due to the possible warping from solar heating. Heat pipes are also being used to dissipate heat generated electronic components in satellites.

c) Heat exchangers:

Increases in the cost of energy have promoted new methods of conserving energy in industrial applications. Due to their high heat transfer capabilities with no external power requirements heat pipes are being used in heat exchangers for various applications.

d) Medicine and human body temperature control:

One of the newest applications with great potential for growth is the use of heat pipes related to human physiology. A surgical probe incorporating a cryogenic heat pipe is used to destroy tumors in the human body. The cryoprobe is a hand-held device with a reservoir of liquid nitrogen and a 12-inch heat pipe extension, which is maintained at approximately 77K for nearly one-half hour. Another application to human with significant growth potential concerns the control of body temperature for benefits such as prevention of frostbites.

1.3 Problem Statement

The dehumidification is a process that needs to be done to remove extra moisture inside the air. To perform the process, heat pipe is used by applying the concept of condensation. The main problem of the research is to concentrate on the application of the condensation concept especially inside the heat pipe in order to perform dehumidification process.

1.4 Objectives of the Study

The main purposes of the research are: -

1. To compare the efficiency between the primary heat pipe in evacuated condition (no working fluid), and the secondary heat pipe (also in evacuated condition) with water as the working fluid, in order to perform the dehumidification process through experimental study.

2. To models and simulation of both heat pipes by using ANSYS CFD, as to gain the results in the heat transfer process from the temperature contour and measuring the temperature of adiabatic and condenser section.

1.5 Scopes of the Study

From the background of the study, the range of its application is extremely wide and enormous. By referring to the topic interest, the application of heat pipe is focused on solar thermal collector, which is the pipe is designed according to the specification standard usage from the laboratory studies. In this application, the function of heat pipe can be transferred more on the large quantities of heat without ignoring it as a solar thermal collector. But, in order to prove the function of heat pipe in cooling system, it can be demonstrated both in the experimental and CFD simulation study.

As usual, any research has its own limitation. Even though, the heat pipe section are divided into several sections such as evaporator, adiabatic and condenser sections, but the study only concentrated and considered upon the condition of adiabatic and without adiabatic at D1, D2 and D3 section of the pipe. The methodologies of the research design are divided into 2 categories which are the experiment method and the analysis CFD method. In the experimental study, the parameter involve is the calculation of Merit Number, M. Meanwhile, the parameter involve in CFD simulation is the convection of Heat Transfer Coefficient (which is the condition of without adiabatic) in order to measure the temperature of D1, D2 and D3 section of the pipes.

1.6 Thesis Outline

To accomplish this study, it is beginning with literature research from sources of books and journals to get the information of the case study. Then, the experimental equipments can be set-up to proceed. In addition, for the CFD analysis, it can be done regarding to the parameter study from the experiment. Next, all these data are required and useful at the end of the research study. For the recommendations or suggestions, an observation and discussion from the results is needed before any conclusion can be made. Figure 1.1 shows the flow process of the case study.

Through the research study, several chapters of the thesis are divided into five chapters. The thesis outlines of each chapter are specified and shown as follows:

- Chapter 1 expresses the background of the study, problem statement, objectives, and scopes of the study. Brief general concepts of heat pipe along with the various types of applications are described.
- Chapter 2 consists of an overview of the published work that is relevant to the research study. It is also presents the details definition of heat pipe, the types of heat pipe, construction, operation, operating limits of heat pipe and the applications in the industry.
- Chapter 3 describes the design and construction of heat pipe that is used in this case study. Besides, the apparatus or instrumentation that will be used in the experiment was described in details and various methods are used while collecting data. Furthermore, it is also includes with the step of analysis in CFD that dealing with the boundary conditions of heat pipe.
- Chapter 4 presents the results of the study on heat pipe design and characteristics. It comprises the statistical result obtained from the experiment and the CFD analysis result.
- Chapter 5 concludes the current work done, ties the result of the study to theory and practice, and suggestions for improvement and future work.

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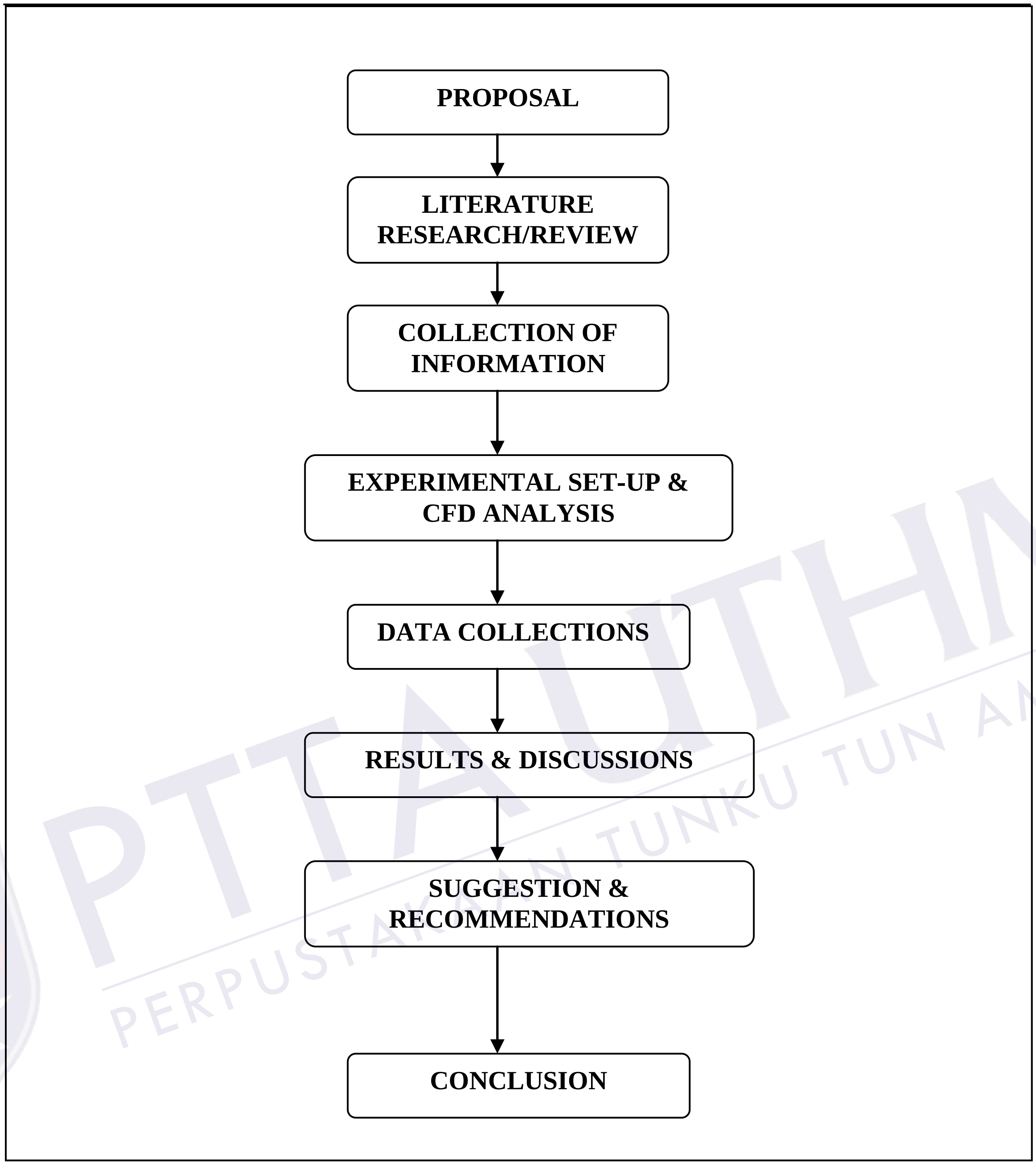

Figure 1.1: The flow process of the research study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Heat pipe is a simple heat transfer device that acts by transferring heat from evaporation section to the condensation section. Besides, the heat pipe mechanism is using the natural convection to absorb heat from evaporator sector and release the heat at the condenser sector which the latent heat of vaporization is utilised with a corresponding small temperature different. The heat transport inside the heat pipe is known to operate by evaporating a liquid at the heat input section (evaporator) and condensing the vapour at the heat rejection section (condenser). The heat pipe operations are running efficiently throughout the heat transport inside the working fluid that circulates either by capillary action or gravitational pull. The build up materials of heat pipes are usually constructed using copper, nickel, stainless steel and molybdenum containers. Meanwhile, the working fluids which act like a heat transport are usually using water, cesium, sodium, lithium, bismuth and any other relevant types of liquid. The main advantage by using a heat pipe is that large quantities of heat can be transported through a small cross-sectional area over a considerable distance with no additional power input to the system. Therefore, heat pipes can easily be found from the applications which are includes in a wide variety of areas such as energy conversion system, cooling of nuclear and isotope reactor, cooling of electronic equipment, and high performance space application [1].

2.2 Heat Pipe Analysis Characteristics

The analysis of heat pipe can be observed and investigated from the research finding of the characteristics in the heat transfer as the main subject. For examples, one of the heat pipe types, the thermosyphon, and a research had been done to study the heat transfer characteristics in two-phased closed thermosyphon to the fill charge ratio were investigated. The authors concluded that, the heat transfer coefficient of the evaporator section showed a trend that increased with the power used in the experimental investigation [2].

Furthermore, there is also another sample of the investigation of thermosyphon that are used in the application of solar water heater systems. But, in the investigation, the important parameters used such as the time (hour) and the temperature (°C) had been listed down. The study represents an experimental performance comparison between single-phased and two-phased closed system thermosyphon solar water heating systems. The performances of the systems were investigated under the field conditions in Konya, Turkey. The research conclusion is the two-phased system is more efficient than the other. In this case, the two-phased system is using the R-134a as the working fluid, while the single-phased system is using water as the working fluid. It shows that, with the proper selection of the working fluid and the selection of material, it can useful to be efficient in cooling condition. The details explanation of the suitable parameter design of heat pipe will be further discussed later on in the next chapter [3].

Next, the investigations are also comes up with the analysis study in CFD. A subject of Heat Pipe Heat Exchanger (HPHE) had been selected to be studied and analyzed, using simulation and CFD analysis techniques to obtain the results. This research paper concentrates on the investigation of the cause of the increase of the thermal efficiency of HPHE at the section of evaporator and condenser. To solve the process that consists of transport phenomena, the authors are using the CFD principles of the model entered in FLUENT (CFD solver program) by using finite volumes to solve. Moreover, it is also the important to recognize inlet flow conditions (physical specifications), that comprises with temperature (K), mass rate (kg/s), viscosity (kg/m.s), density (kg/m³) and heat conduction (W/m.K.). Besides, the authors' also using k-ε turbulence model is used to simulate this CFD problem [4].

2.3 Description of Heat Pipe

The heat pipe descriptions are including with the structure, design and the construction of the heat pipe itself. Each items of heat pipe will be discussed later on the next following sub-chapter. Basically, a typical heat pipe consists of a seal pipe at both ends that had been made up from a material such as copper or aluminium. Inside the pipe, it is filled with a fraction of a percent by volume of working fluid that is chose to match the operating temperature with the suitable types of materials. Even though inside of the heat pipe filled with working fluid, it is sealed by the types of vacuum conditions. Therefore, a vacuum pump is used to remove all air from the empty heat pipe before filling it with the working fluid.

Inside the heat pipe's walls, it is built either with an optional wick structure or without the wick structure. For the typical heat pipe using wick structure, it is exerting the capillary pressure which acts on the condensed liquid to wick so that it can circulate back to the heated end (evaporator section). Meanwhile, if a typical heat pipe without a wick structure, it is using the natural gravitational pull types or some other source of acceleration which is sufficient to overcome surface tension. Then, it can cause the condensed liquid flow back again to the heated end, same as the heating process as in heat pipe with wick structure.

Finally, the description of a heat pipe is typically has high conductance that can transfers heat from a source by means of cyclic evaporation and condensation of a working fluid. Then, it uses the latent heat of vaporization of the working fluid to transfer heat. Moreover, the heat pipe contains no mechanical moving parts and also does not require any external energy to be function. But, for the same load, a heat pipe has a very low temperature drop due to its high efficiency. However, unlike a metal conductor, a heat pipe has a limit on the amount of heat it can transfer.

2.4 The construction of a heat pipe

Basically, it is relying on the selection, design consideration, the working fluid and the material to construct the model. These are the important elements that can contribute to the successful of the analysis of the heat pipe specimen. It is not only a basic concept, but also depends on the previous information that had been investigated from the researchers around the world. Each of the elements that relevant to the case study had been included for reference and also for further review in the future.

In addition, according to the Thermacore Inc®, it had been also classified into 3 elements which are, a vacuum tight, sealed containment shell or vessel, working fluid and capillary wick structure. These elements are working together to transfer heat more efficiently and evenly. Moreover, the element of wick structure lines the inner surface of the heat pipe shell and is saturated with the working fluid. The wick provides the structure to develop the capillary action for the liquid returning from the condenser (heat output/sink) to the evaporator (heat input/source). Furthermore, since the heat pipe contains a vacuum, the working fluid will boil and take up latent heat at well below its boiling point at atmospheric pressure. For example, the working fluid such as water, for instance, will boil at just above 273° K (0°C) and start to effectively transfer latent heat at this low temperature.

2.4.1 Heat pipe design consideration

Before constructing the sample, there is some of the consideration that had to be made before the specimen can be proceeding into the study. Mostly, heat pipes are being used very often in particular applications when conventional cooling methods are not suitable. Only when the need for heat pipe arises, the most appropriate heat pipe consideration needs to be chosen. Even though, it is not an easy task, and the following consideration needs to be clarify.

1) Selection of the pipe material, wick structure and working fluid.

a. The determination the working fluid that appropriate in the case study.

Previously, referring to the scope of the study, the selection of the working fluid are to be considered such as water for the secondary pipe specimen, while the primary pipe specimen type only contains with air. The purpose of the different elements choice of the working fluid is to compare the results at the end of the analysis whether in the experimental condition and also in the CFD condition [5].

b. Selection of the pipe material that compatible to the working fluid.

For the selection of the pipe material [5], it should be compatible to the usage of the working fluid. It is also can be referred to the sample tested for the last 50 years ago by Los Alamos Scientific Laboratory.

c. Selection of the wick structure for the operating orientation.

In the (c) selection, the wick structure for the operating orientation can be ignoring because the case study is to be considered to be dealing with the inclination angles of pipe. In addition, the fact is, on earth, the heat pipe is slightly inclined to let the condensed water flow back to the heat source because of gravitational force. However, in space condition, the inside of the heat pipe has a wick system that assures the water, as the working fluid will flow back to the heat source. It is as the same with the sample that had been built by NASA for the first prototype. In figure 2.1 (a) and 2.1 (b) shows the different operation of working fluid in heat pipe such as using gravity pumping and also wick pumping.

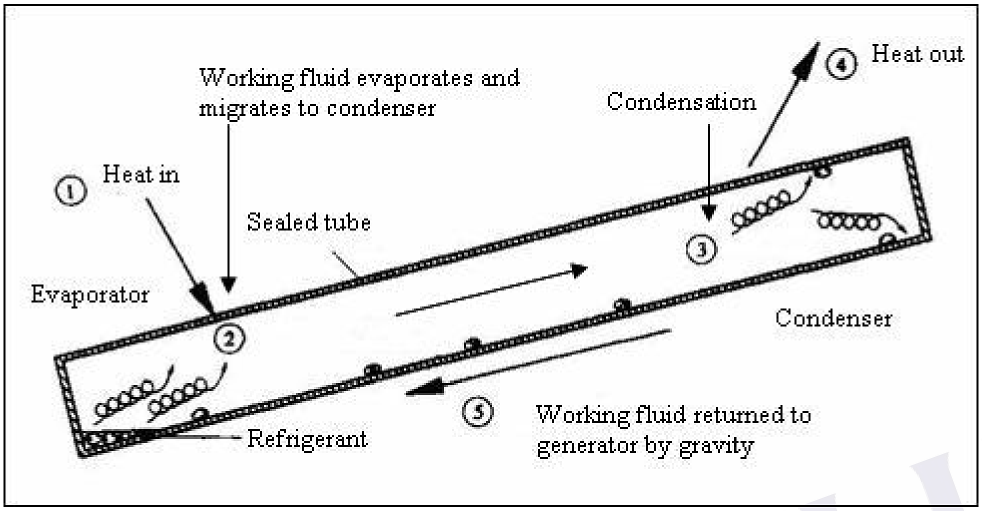

Figure 2.1 (a) Heat pipe using gravity pumping [6]

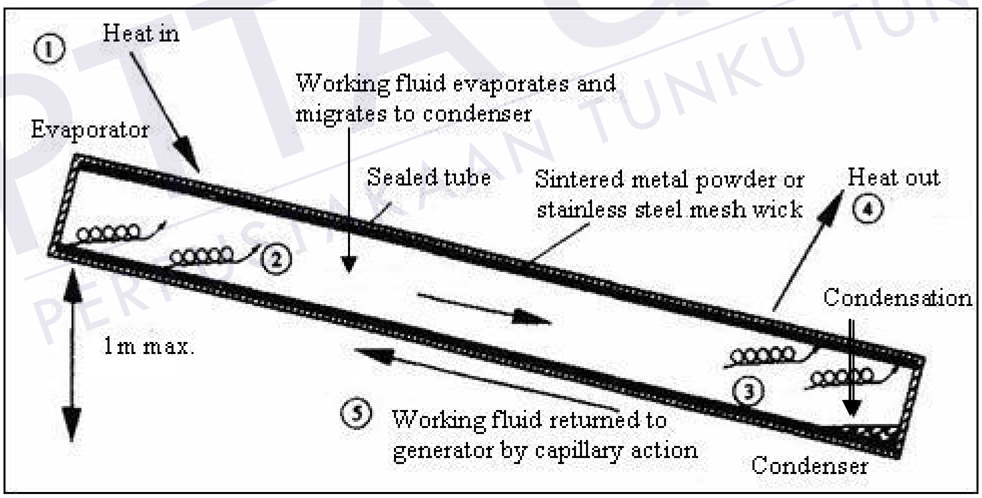

Figure 2.1 (b) Heat pipe using wick pumping [6]

2) Determination of the length, size and shape of the heat pipe.

To meet the objective study in comparing the efficiency of the primary and the secondary heat pipe, the selection consideration is the conventional heat pipe, as shown in Figure 2.2. This is because the conventional shape is the most convenience and reliable to meet the objective. Finally, the length and the size of heat pipe are described in details in parameter study of heat pipe in the next chapter.

2.4.2 Heat pipe selection

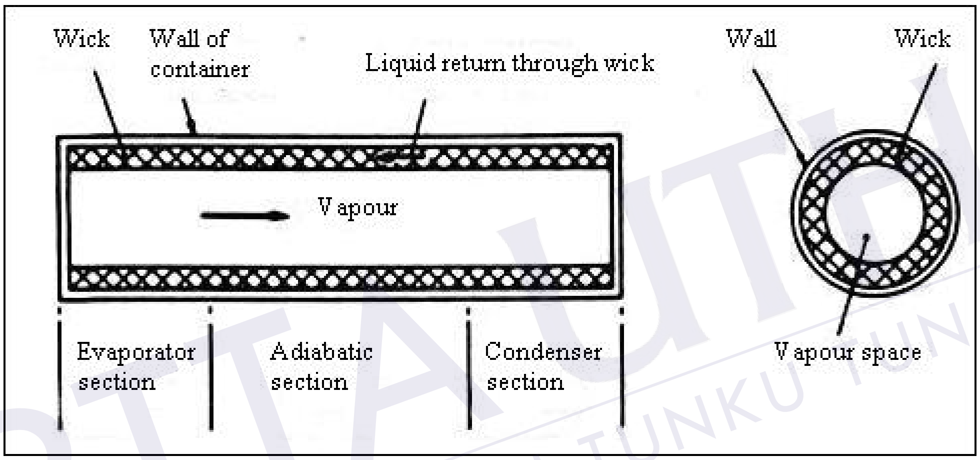

Figure 2.2: The conventional of heat pipe diagram [7]

Figure 2.2 shows the diagram of heat pipe as the main subject in the case study. The conventional of heat pipe design are divided into three sections. The first section is the evaporator section where the heat is absorbed from the heat source. Meanwhile, the second section is the adiabatic section where the liquid turns into a vapour and runs through the third section. Finally, the third section is the condenser section where vapour condenses back to liquid and rejects heat. These three sections are very important for the heat pipe elements and conditions, but the main focus is at the adiabatic and condenser section for further analysis study.

2.4.3 Working fluid

As previously described in other resources from the researchers field of heat pipe works, heat is transfer via the evaporation and condensation of a working fluid. The fluid selected for use in the heat pipe must not react chemically with the heat pipe envelope material and, in turn, the environment to which it will expose must not damage the heat pipe envelope material. For example, heat pipe in electronic cooling applications, the best working fluid, from the thermal performance and operating life aspects, is water. Water exhibits incomparable thermal performance characteristics and is the most demonstrated heat pipe working fluid in the world. Table 2.1 on the next page shows typical operating characteristics of heat pipes. For reference, different working fluids with different temperature range and measured heat flux. Each of working fluid depends on the types of applications with the suitable vessel material [8].

Table 2.1: Typical operating characteristics of heat pipes [5]

Temperature Range (°C)	Working Fluid	Vessel Material	Measured axial[8] heat flux (kW/cm^2)	Measured surface[8] heat flux (W/cm^2)
-200 to -80	Liquid Nitrogen	Stainless Steel	0.067 @ -163°C	1.01 @ -163°C
-70 to +60	Liquid Ammonia	Nickel, Aluminum, Stainless Steel	0.295	2.95
-45 to +120	Methanol	Copper, Nickel, Stainless Steel	0.45 @ 100°C[X]	75.5 @ 100°C
+5 to +230	Water	Copper, Nickel	0.67 @ 200°C	146@ 170°C
+190 to +550	Mercury* +0.02% Magnesium +0.001%	Stainless Steel	25.1 @ 360°C*	181 @ 750°C
+400 to +800	Potassium *	Nickel, Stainless Steel	5.6 @ 750°C	181 @ 750°C
+500 to +900	Sodium *	Nickel, Stainless Steel	9.3 @ 850°C	224 @ 760°C
+900 to +1,500	Lithium *	Niobium +1% Zirconium	2.0 @ 1250°C	207 @ 1250°C
1,500 + 2,000	Silver*	Tantalum +5% Tungsten	4.1	413

2.4.4 Material

The heat pipe material must be chemically inert with the working fluid. Any chemical reaction will result in a by-product of noncondensible gas. Noncondensible gas is a gas from chemical or petroleum processing units (such as distillation columns or steam ejectors) that is not easily condensed by cooling that consists mostly of nitrogen, light hydrocarbons, carbon dioxide, or other gaseous materials. So, the gases will collect in the condenser end of the heat pipe, swept there by the following vapour, and obstruct a portion of the available heat dissipation area. This in turn degrades of heat pipes efficiency. In addition, a corrosive reaction between the envelope and the working fluid would lead to a failure of the heat pipe's vacuum integrity thereby causing the heat pipe to fail. The best way is, by using water as the working fluid, the suitable heat pipe material should be a copper. A copper-water heat pipe is the most demonstrated heat pipe material combination in the world. Millions of units have been building with this system and literally, millions of units per year are currently produce. For example, Thermacore Management Solution Company from United States had testing the material system that been demonstrated in excess of 180,000 hours of operation with no sign of thermal degradation [8].

2.5 Heat Pipe Operation

The operation of heat pipe is depends on the each section. These sections are the evaporator, adiabatic and condenser as in Figure 2.5. The description of the heat pipe operation is based on the physical principles [8]. At a specific pressure conditions, two physical principles will be occurred.

1. The first physical principles are, at a certain specific temperature, a liquid will vaporize or turns to be vapor that will be condense. The vapor can only be condense when the temperature at the level of saturation [8]

2. The second physical principles are, the amount of heat absorbed as a unit mass of liquid vaporizes is equal to the amount of heat rejected at that vapor condenses. It can

be also be conclude that, the amount of heat absorbed at the heat supply at the evaporator section actually is equal to the heat rejected at the section of the condenser.

The operation of heat pipe can also happen when during the capillary effect [8]. The capillary effect is the result that occurs from the capillary pressure that moves a liquid (working fluid) in the wick inside the pipe against the gravitational field. It shows that, the capillary effect will be operates by using the wick pumping in the heat pipe to operates. See in Figure 2.4.

Moreover, the observation of the movement of a fluid along the channel flows through the direction from the evaporator section to the condenser section can cause the effects in decreasing the pressure. This axial variation of pressure is illustrated in Figure 2.3

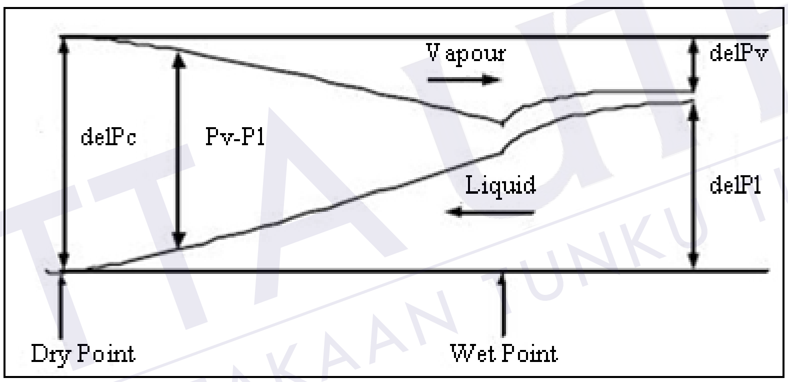

Figure 2.3: Pressure variation along a heat pipe [7]

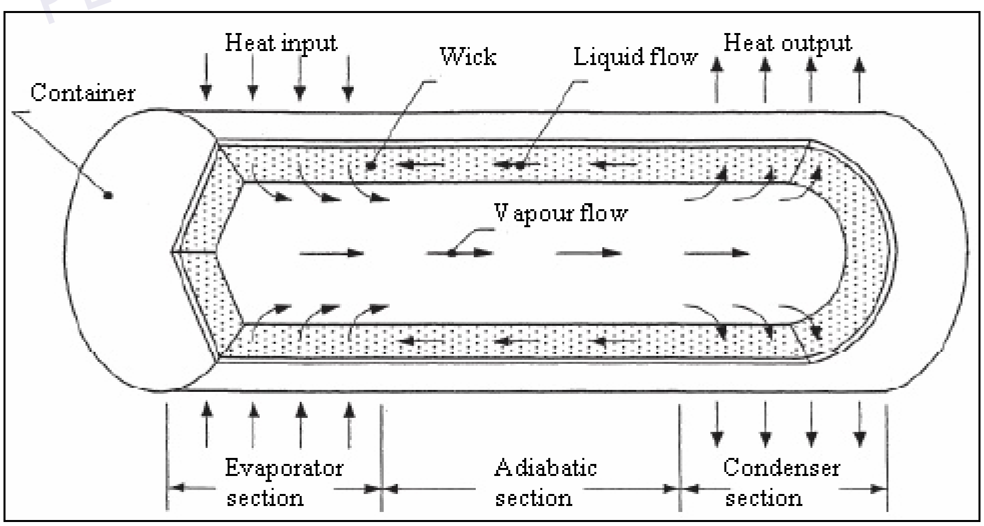

Figure 2.4: Schematic view and the main regions the heat pipe [4]

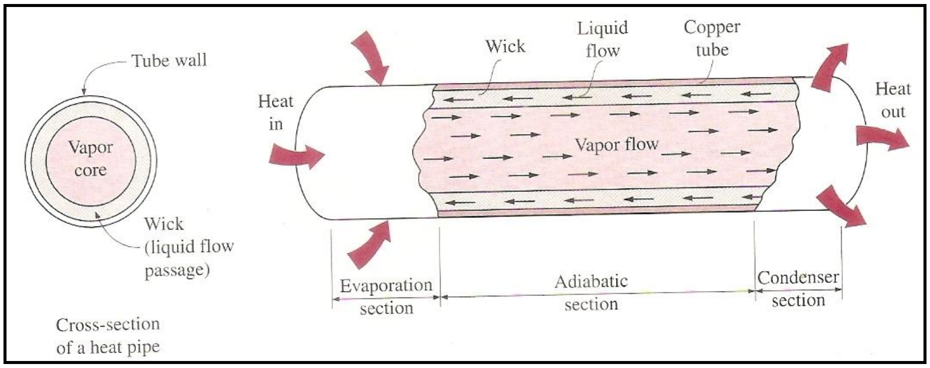

Figure 2.5: Schematic and operation of a heat pipe [8]

2.6 Heat Pipe Application in Solar Thermal Collector

There are 5 major usages of heat pipe application such as in electronics, aerospace, heat exchangers, medicine and human body temperature control. Even though there are various research studies, solar heating is also another example for the application of heat pipes which is widely used nowadays. By the year of 2010 onwards, from the global warming and environmental issues, the heat pipe solar collector is the best solution of the renewable energy that can be applied to our daily activities [9].

The solar thermal collectors and its application are linked within the analysis of the environmental problem that can lead to the usage of sources from the renewable energy [10]. It comes with the usage of solar thermal collectors that had been used the radiation energy from the sun. The main function of the solar thermal collectors is to absorbed heat radiation from the sun and converts it to electricity. In addition, the information includes with the brief description of various types of collectors such as flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel len, parabolic dish and helistat field collectors.

From the various types of the solar thermal collector that had been listed [10], one of the company in Canada, Solar Supply Canada Inc.® mention that the evacuated solar collector is the main application of heat pipe technology. The main component of the solar thermal collector which is the evacuated tube solar collector will be discussed on the next sub-chapter.

2.6.1 Evacuated Tube Solar Collector

Solar Supply Canada Inc.® mentioned that, each evacuated tube collector contains up to 30 individual glass tubes, each with an absorber plate bonded to a heat pipe. The sample of evacuated solar collector is as shown in Figure 2.6. They are surrounded by two glass tubes that hold a vacuum between the two tubes. The pipe transfers the heat efficiently to a condenser through the top of the tube. The condensers are clamped to heat exchange blocks in a well-insulated manifold. The special absorber coating absorbs more than 92% of the arriving radiation but radiates less than 8% back to the environment as the circulation of heat transfer process.

For the heat transfer process, it can be transferred from the absorber to the fluid circuit which is performed by the heat pipe. A heat pipe condition is in a closed system, evacuated and charged with a small amount of glycol before it is sealed for the usage in the solar collector. The main function of the absorber is to impart heat to this glycol (another type of working fluid used), which can cause it to evaporate. Meanwhile, the steam rises to the upper end of the heat pipe where it transfers heat to the fluid circuit via a metallic conduction bridge. Being in a dry connection, the working fluid in the heating circuit does not flow through the collector. The heat transfer process in the evacuated solar thermal collector shown in Figure 2.8.

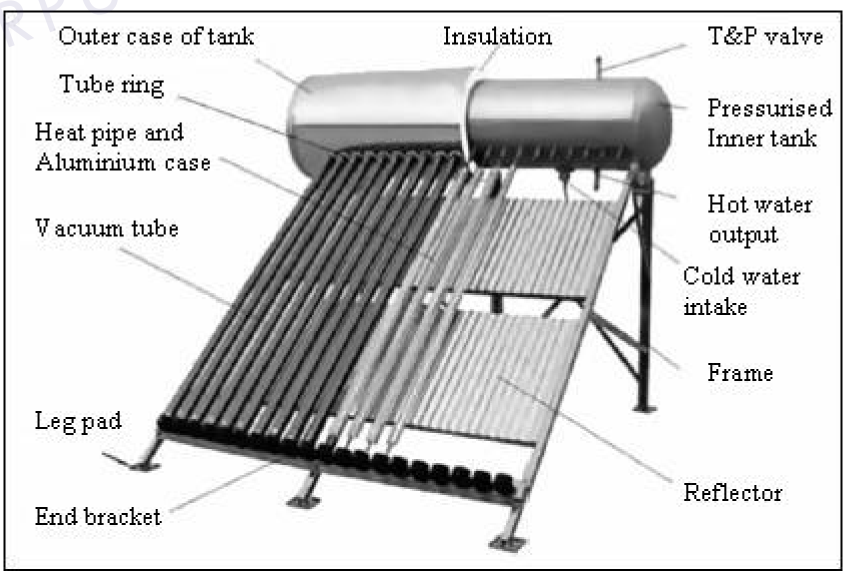

Figure 2.6 Evacuated Solar Collector (with heat pipe technology) [11]

Moreover, in Figure 2.7 shows the glass tube contains with the absorber and heat pipe which are mounted and sealed inside it whereby it carry the function in cutting the heat losses via conduction and convection. Besides, within the condition of stable vacuum, it can assure that, the collector can performed at low outside temperatures and also protects the absorber against the environment.

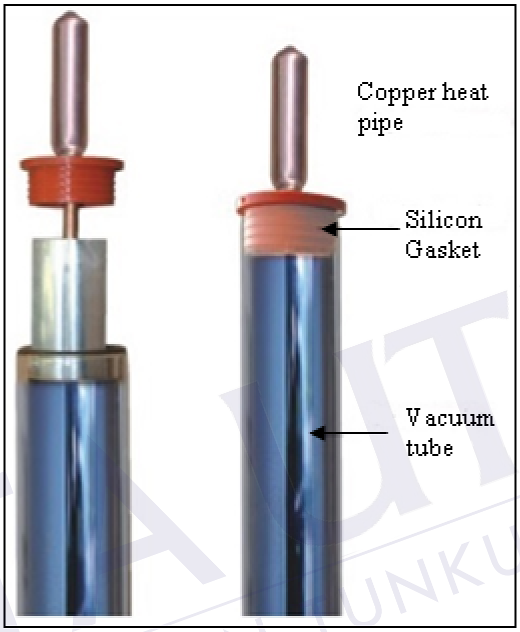

Figure 2.7: Glass tube of evacuated tube collector

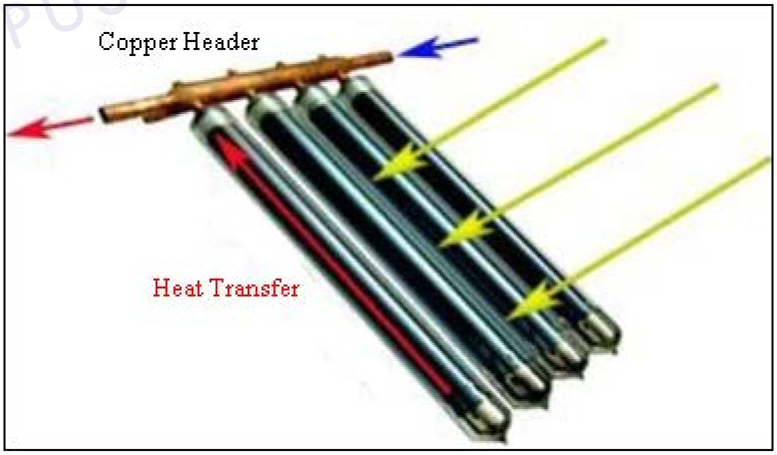

Figure 2.8: Heat transfer process in evacuated tube solar collector

Table 2.2 shows the specification of evacuated tube solar collector. Solar Supply Canada Inc.® comes up with the details specification standard in building the tube. Based from Table 2.2, it can gives out an idea on the operation of the tube that operates within the certain parameter standard in order to do the heat transfer process.

Table 2.2: Evacuated Tube Solar Collector Specifications

Stand	Metal gray
Tube headers	Available in 10-20-25-30 (25 tube standard)
Heat pipe technology	1.2 mm copper
Maximum working temperature	99 degrees Celsius
Maximum stagnation temperature	270 degrees Celsius
Maximum working pressure	10 Bars (145 psi)
Insulation layer	50 mm polyurethane
Quality certificate	ISO 9001:2000-CE
Testing certificate	DIN En12975-2:2006
Length	1800 mm
Outer tube diameter	58 mm
Inner tube diameter	47 mm
Glass thickness	1.6 mm
Thermal expansion	3.3x10-6°C
Material	Borosilicate Glass 3.3
Absorptive coating grading	Al-N/Al
Absorptance	>92% (AM 1.5)
Emittance	<8% (80°C)
Vacuum	P<5x10-3 Pa
Heat loss	<0.8W/(m^2°C)
Maximum strength	0.8 MPa

2.6.2 Heat pipe concept in evacuated tube solar collector

The heat transfer process in the evacuated tube is still the same with the heat pipe heat transfer process. The evacuated tube that contains with the heat pipe rapidly and efficiently transfers the captured thermal energy through the evacuated tube. Then, the thermal energy delivered to the manifold (header) as the liquid (working fluid) boils and rises. After the heat is removed from the heat pipe by the copper header, the liquid condenses and gravity returns it to the base of heat pipe. It really shows that, the heat pipe that contains in the evacuated tube solar collector, are not using the wick pumping, but only using the gravity pumping as in conventional heat pipe operation. Finally, after the liquid condenses and gravity pumping returns it to the base, the process is continually repeated over and over again during the operation in absorbing the thermal energy from the sun radiation energy as shown in Figure 2.8.

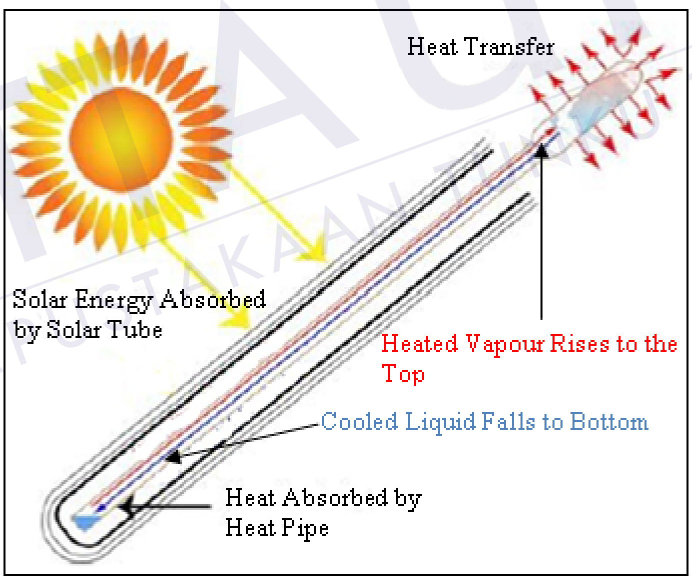

Figure 2.8: Heat pipe operates in an evacuated tube solar collector

The main function of the evacuated tube solar collector comes from the operation of heat pipe which is located inside the glass tube. Same as previous description, it is also a sealed hollow copper tube that contains a small amount of proprietary liquid, which under low pressure boils at a very low temperature. For the information, the liquid contained in the heat pipe boiling points only happens at 86 °F (30°C).

CHAPTER 3

METHODOLOGY

3.1 Introduction

The literature reviews had brought up some of the idea on designing the methodology to meet the purpose of research study. Some of the journals are dealing with the experimental study and some of it is dealing with CFD analysis. Nevertheless, there are not less in the journals selected that are using both methods (experimental and CFD analysis) to solve all the problem statements. According to the objectives of the study, a proper methodology design should be made in order to make sure that to get the successful and accurate results.

To meet the objectives, the method and design is focusing more on the qualitative data based from actual and simulation condition. An actual condition of heat transfer tends to be occurs when an experiment is conducted or even more in advanced techniques of experiments. Meanwhile, the simulation conditions can be used and apply after the physical parameters are recognized and correctly be inserted to the CFD modelling. The collection of data need to be compared and observed to shows that all the characteristics reliable to make the heat pipe best solution in cooling system. This can be further to discussed in the next chapter.

3.2 Research Design

The first stage is it is divided into 2 sections which are the literature review and the fabrication methods. The literature review section had gone through in the previous chapter which contains with the field of works that comprises from various sources of study. It is also includes with the information to suite the problem statement and purpose of study. Meanwhile, the fabrication methods are the steps to bring up the actual model and samples for the specimens in the parameter study. It can be used either in the experimental, or in the CFD analysis study for comparisons of the results.

Next is the further analysis study in CFD for comparison in experimental to obtain for both results. The important parameter studies in the experimental methods are the temperature, T (°C) and time, t (min.). These values can be presented into a graphical that be plotted based from the orientation angles for specimens. Finally, in the CFD analysis study, the physical parameters such as the temperature, T (°C) and heat transfer coefficients W/m^2.K are the important elements for the analysis. Besides, the analysis study also deals with the most common boundary conditions such as inlet, outlet and wall. These elements are further discussed. In the next pages, the research method and design had been simplified into Figure 3.1 Flow chart of project plan.

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