DESIGN OF THERMAL CAUTERY DEVICE

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DECLARATION

I hereby declare that the work reported in this thesis is the result of my own investigation and that no part of the thesis has been plagiarized from external sources. Materials taken from other sources are duly acknowledgement by giving explicit references.

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ABSTRAK

REKA BENTUK ALAT LECUHAN HABA

Lecuhan adalah teknik yang dilakukan dengan pembakaran sebahagian tisu bagi tujuan menutup luka. Ini mengurangkan pendarahan dengan memusnahkan beberapa tisu untuk mengurangkan risiko kecederaan yang lain. Lecuhan haba menggunakan haba untuk memotong tisu, dan bukannya seperti pemotongan yang biasa dilakukan dengan menggunakan pisau.

Pengukuran suhu wayar pemotong alat lecuhan haba yang sedia ada dibuat untuk mengetahui suhu wayar pemanas dan ini dibandingkan dengan nilai yang diperoleh daripada simulasi Analisis Unsur Terhingga (FEA) menggunakan perisian ANSYS. Suhu tertinggi diukur menggunakan kamera ultra merah adalah 620°C dan suhu yang diperoleh daripada simulasi menggunakan haba terjana dalaman ialah 678°C memberikan ralat 9.4%. Kajian reka bentuk dilakukan untuk meningkatkan keselamatan alat lecuhan haba yang sedia ada. Kekurangan utama alat sedia ada ialah risiko bahagian panas daripada wayar pemotong yang terdedah dan boleh mencederakan pesakit dan pakar bedah. Dengan mengambil ciri-ciri reka bentuk yang selamat daripada alat lecuhan ultrasonic Ligasure™ dari Covidien Medtronic, maka reka bentuk baharu alat bedah lecuhan haba dapat dihasilkan.

Dalam reka bentuk yang baharu ini, wayar pemotong haba adalah terselindung sepenuhnya bagi mengelakkan kemalangan akibat sentuhan yang tidak sengaja dan butang notis pemanasan disediakan supaya pakar bedah boleh mengesahkan pemotongan akan dilakukan dan pemanasan dalam tempoh 5 saat diperlukan untuk menyediakan wayar pemotongan 620°C. Selepas suis dibuka, tiada lagi pemanasan dilakukan bagi mengelakkan pemanasan secara tidak sengaja. Sistem tuil pula akan membantu meningkatkan ketepatan dan mengurangkan pertukaran alat semasa pembedahan. Penambahbaikan reka bentuk alat lecuhan haba dari segi keselamatan ini boleh membantu dalam mengurangkan kemalangan dan kecederaan akibat peralatan elektrik semasa pembedahan.

ABSTRACT

DESIGN OF THERMAL CAUTERY DEVICE

Cauterization is a technique whereby a portion of tissues is burnt off for the purpose of closing the wound. It mitigates bleeding by destroying some tissues to reduce the risk of other possible injuries. Thermal cauterization uses heat for cutting of vessels, unlike the regular cutting with knife.

Temperature measurement of the existing thermal cautery device is carried out to obtain the temperature of the heating element. The temperature is then verified with the results obtained from the Finite Element Analysis (FEA) by using the ANSYS software. The highest temperature measured by the thermal infrared camera is 620 °C while the result obtained from the simulation is 678 °C. This gives a percentage error of 9.4%. The design study of the thermal cautery device is required in order to improve the overall safety aspects of the device. The existing thermal cautery device lacks in protection and has exposed heated parts which could injure both patients and surgeons. By implying the safety features of LigaSure™ small jaw instrument from Covidien Medtronic, a new design of the thermal cautery device is proposed.

In this proposed design of the thermal cautery device, the heating element is completely hidden when it is not in used, thus reducing the possibilities of accidental injuries. A heating notification switch is included to ensure the surgeon about the cutting. Total time of 5 seconds are needed to prepare the heating element to temperature of 620 °C. After the switch is released, there would be no more heating of the heating element to avoid any accidental errors. The first order lever system would help to increase the precision and reduce the exchange of instruments during surgeries. The improvement of the design of thermal cautery device in term of safety could help reduce accidents and injuries due to electrical devices.

CHAPTER 1: INTRODUCTION

1.1 Background study

There are many surgical techniques involve in a single surgery. Each technique requires the use of different instruments depending on its function. Cauterization is one of the widely used medical techniques during surgery. It is the burning of a part of a body to discard or shut off a part of it. It destroys some tissue in order to stop bleeding and damage. It is also used to minimize other possible injury, such as infections when antibiotics are not available. It could be done by thermal or chemical means for burning off the tissue.

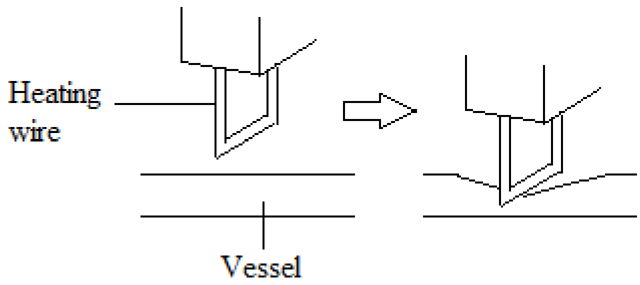

Figure 1.1 Thermal cauterization performed on vessel.

Traditional thermal cautery utilizes heat in the form of direct current to perform coagulation. This method uproot the possibility of alternate site burns that could occur with electrosurgery (World Precision Instruments, n.d.). The heated wire tip is the only part that comes in contact with the tissue and current does not enter the patient's body. It is used in minor surgical conditions such as dermatological and plastic surgery (World Precision Instruments, n.d.). This technique could provide sufficient heating of the bleeding site without producing excessive heat penetration. It actually heats up the bleeding site at a high temperature for an extremely short period of time (Auth et al., 1987). The temperature of the heating wire that is made of Nichrome 80 and Kanthal A-1 could go as high as 1204°C (Bovie Medical Corporation, n.d.).

The heating element of the thermal cautery device manipulates the process of resistive, or Joule heating in electricity. As electric current passes through the element, it encounters resistance, thus resulting in heating of the element. The process is dependent on the current passing through the element. Resistance wire is used as the heating element in the current thermal cautery device. It is a type of wire that is used for making electrical resistors (which are used to control the amount of current in a circuit). It must have a high resistivity of around of 1.45 Ω mm^2/m to make it possible to use a shorter wire (Kanthal, n.d.).

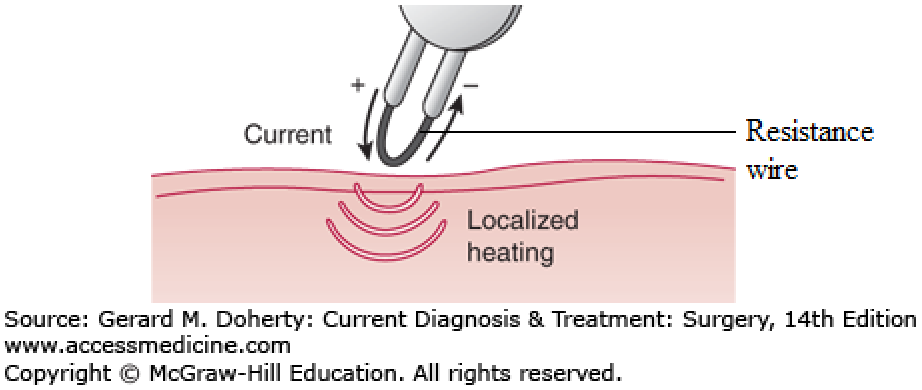

Figure 1.2 Heat produced at the resistance wire.

Resistance wire could be easily found in toasters and hair dryers, furnaces for industrial heating, floor heating, and roof heating. For many thermal cautery device, Kanthal thermocouple wire is used (Bovie Medical Corporation, n.d.). It has a high melting point of 5000 °C. The oxidation process of the resistance wire is significantly accelerated in the presence of water vapour (Götlind et al., 2007).

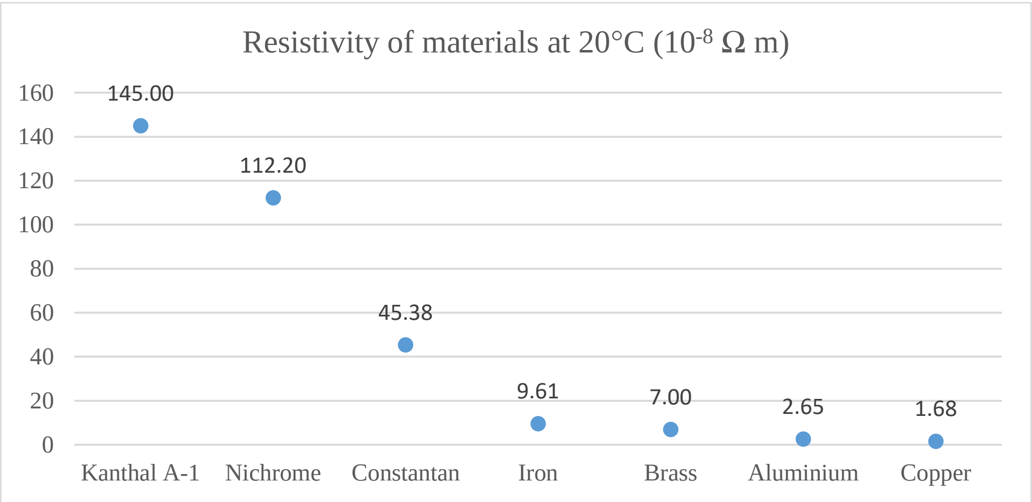

Figure 1.3 Comparison of resistivity of materials at 20°C (10^{-8} Ω m)

Figure 1.3 shows that Kanthal A-1 has the highest resistivity of 145.00 x 10^{-8} Ω m. Meanwhile, common materials such as Copper and Aluminium have low resistivity of 1.68 x 10^{-8} Ω m and 2.65 x 10^{-8} Ω m respectively. As electric current passes through the element, the resistance encountered results in heating of the element. The higher the resistivity of the material, the higher the capabilities of the element to heat up. The Kanthal wire is capable of reaching a high temperature of 1400°C (Kanthal, n.d.). The temperature is too high to be handled by human and would result in a severe burnt if not cautious enough. The thermal cautery device in its present form is lacking in term of its safety aspects. It has an exposed heating wire that could harm its users. Even though the current device is provided with a cap, it is still vulnerable to mistakes. Some protections must be considered to protect both the surgeons and patients.

1.2 Problem statement

The current design of the thermal cautery device has exposed heated parts which could injure both patients and surgeons. The design lacks protection and could not be used alone without being assisted with other instruments, such as forceps and thus consumes more time.

1.3 Motivation of the work

The current design of the thermal cautery device exposes the heating element directly to its users. This same design has been used since 2012 with not much safety implied. The analysis of thermal cautery on living tissues has not been reported in the literature.

1.4 Objectives

In this research, two objectives are set to be achieved:

- To carry out the finite element analysis of the heated part and verifying it with the experimental results of the thermal cautery device.
- To propose a design by which the safety features of the thermal cautery device can be improved.

1.5 Scope

An existing thermal cautery device is used as the baseline design. Finite element analysis will be carried out using internal heat generation model. The heating element will be based on the Kanthal heating wire. Validation of the model will be done by comparing the data obtained from the Fluke Infrared Thermal Camera with the Finite Element Analysis (FEA) model from ANSYS of the same design. The analysis will then be applied onto the proposed design

1.6 Thesis outlines

This thesis is divided into five chapters; introduction, literature review, methodology, results and discussion, and conclusion. Chapter One consists of background study, problem statement, motivation of work, objectives and scope of the research. Chapter Two describes a comprehensive literatures on the thermal cautery device over the past years. Chapter Three presents the theory and methodology of current work and the results are discussed in Chapter Four. Finally, Chapter Five describes the conclusion of this research and recommendation for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview

In this chapter, two main topics are presented as below:

- The risk of thermal device
- The evolution of thermal cautery device

2.2 The risk of thermal cautery

Often, when a new technology is introduced, there will be a hefty manual guide provided. However, even with a complete manual guide, mistakes could never be avoided. There are close to 40 000 burns recorded that are caused by electrical surgical devices every year (Brunt, 2002). These mistakes could have probably been avoided if the design of the device itself requires no understanding at all. In other words, the device should be design in accordance to mistake-proofing, also known as Poka-yoke. It is a term and an approach, which refers to the avoidance of accidental errors (Shingo, 1986). Mistake-proofing could be divided into few categories. These are mistake prevention, mistake detection, preventing the influence of mistakes, and mistake-proofing in the work environment (Tsuda, 1993). Mistake prevention should be the priority as it is meant to prevent mistakes from occurring.

The rising costs and medical errors are two major concerns in healthcare. The reduction of medical errors leads to significant cost reductions (Grout and Toussaint, 2010). This is one of the reasons that encourages researchers to keep on developing better instruments that to avoid errors. Cost reductions in healthcare could also mean that the medical benefit could be reached out to bigger audience. The large sum of money could also be used in research for health advancement and finding of cure.

Figure 2.1 The heating element is directly exposed to users (Baron and Reznik, 2012).

A normal and healthy person has its cells function at 37°C. As the cell reaches 50°C, cell death could happen within minutes if no action is taken immediately. At temperature of 90°C, there would be instant cell death. Cellular vaporization would occur at the temperature of 100°C. Cauterization purposely takes advantage of this knowledge. It heats up the resistance wire beyond the cellular vaporization to discard or shut off a part of the vessel. The temperature of resistance wire of Kanthal A-1 type could go as high as 1400°C (Kanthal, n.d.).

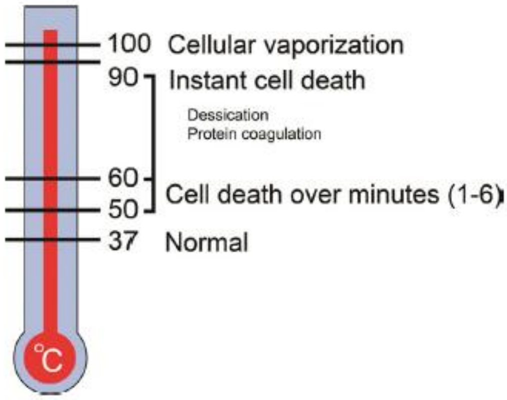

Figure 2.2 Effect of temperature on cells and tissue (Jones et al., 2015)

In medical field, the most important principle is to do no harm. With this in mind, it is important to know about what not to do rather than what to do. Mistakes made by human are hardly predictable. However, with a little help from a proper device, these unnecessary and avoidable injuries could be prevented.

2.3 The evolution of thermal cautery device

The current available heating element uses metal wire to direct heat. Referring to Figure 2.3, the thermal cauterizing forceps device incorporates a pair of ceramic heater elements mounted within the tips of the tines of a forceps (Herzon, 2001). It is used to grasp tissue or blood vessels and apply heat to effect cauterization, unlike the usual thermal cautery device available in the market. This way, the cauterization is only applied on the exact spot as desired. The cautery device has undergone many improvisations over the time, from the forceps instrument which incorporates a battery and control electronics to a handheld disposable design. Further improvement is done by connecting it to an external power source.

The choice of heating elements play a vital role in the success of the proposed design. Kanthal wire is capable of generating heat up to temperatures of over 1400°C (Kanthal, n.d.). This heat capacity and temperature of operating range of 650° to 700°C can easily cauterize medium and large blood vessels (Herzon, 2001).

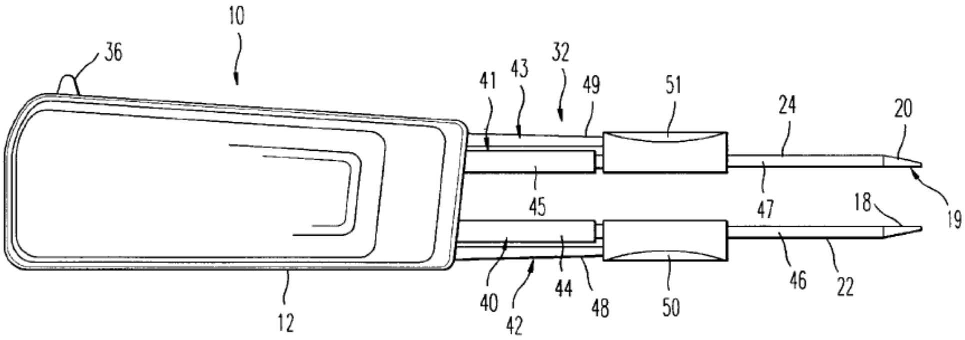

Figure 2.3 Thermal cautery surgical forceps as proposed by Herzon.

Referring to Figure 2.4, further improvement is done on the heating capabilities of the thermal cautery device by the addition of a thermally conductive plate proximate the resistive heating element used in those devices (McGaffigan and Echeverry, 2006). It is important that the heating element heats up within a short period of time as the open wound are more prone to bacterial infections. This could save much time for the surgeons to conclude operations. The high heat generated by the heating wire, combined with light pressure exerted on the body tissue, results in division at line. In comparison, the extent of heat affected zone in the body tissue, when conductive plate is added results in more secure seal of the tissue (McGaffigan and Echeverry, 2006). The plate increases the amount of heat energy that can be delivered to the tissue prior to cutting the tissue. This somehow increases the size of the seal (the amount of tissue that is sealed) and the wholeness of the seal. It also supports tissue sealing in the thermally conductive plate area and tissue cutting in the heating area.

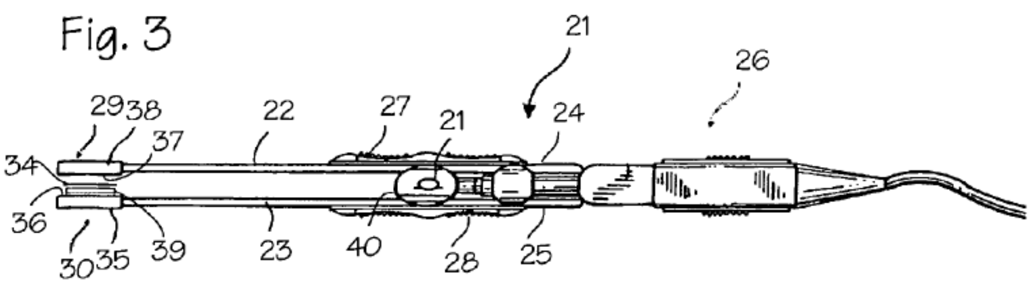

Figure 2.4 Forceps embodiment of thermal cautery device (McGaffigan and Echeverry, 2006).

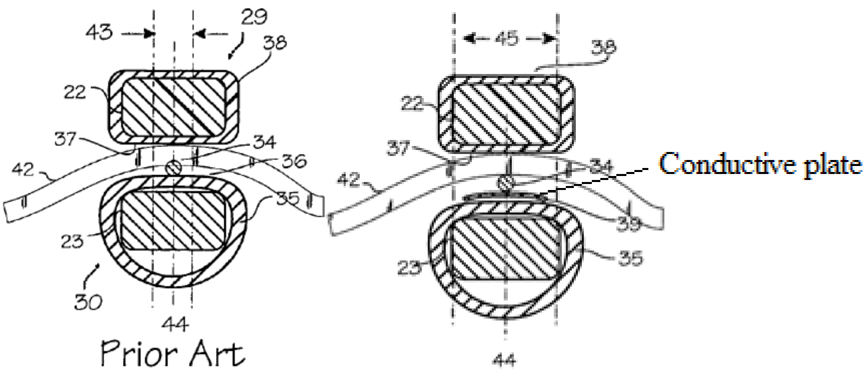

Figure 2.5 Figure on the left is the prior art. Figure on the right shows that a conductive plate is added for purposed of sealing (McGaffigan and Echeverry, 2006).

A low-resistivity material could dissipate enough power from a relatively low current. It is possible only by making the material extremely thin so that the resistance of the probe is high (Auth et al., 1987). However, a probe having an extremely thin shell does not have sufficient strength to withstand clinical use. A probe having a relatively thick shell of a higher resistivity or semiconductive material would be capable of dissipating enough power at acceptably low currents (Auth et al., 1987).

Figure 2.6 refers to the latest design of the thermal cautery device found in the operation theatre that is of disposable type. It consist of a housing, a cautery tip, and a removable power source. An actuator acts as a switch to selectively complete the circuit between the cautery tip and the removable power source. The design has exposed heated parts and could injure both surgeons and patients during surgery. Even though the device is made disposable per usage for its hygienic issues, cost is a concern. The idea of having a thermal cautery device that is reusable but at the same time could maintain its hygienic standards could have reduce the cost of the total operations.

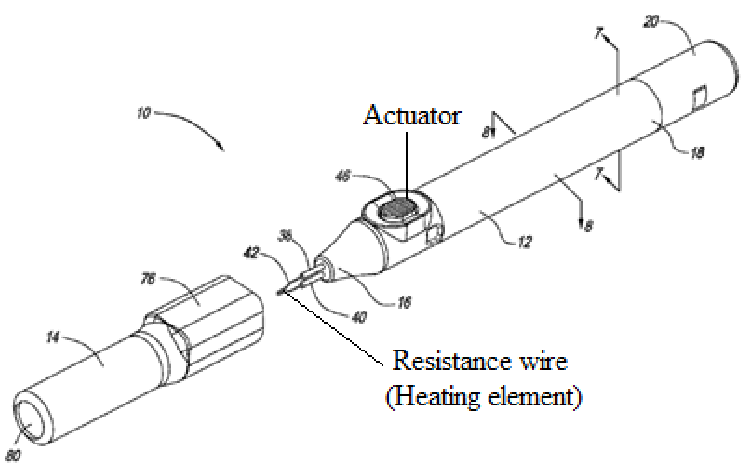

Figure 2.6 The design of the Hand-held Cautery Device (Baron and Reznik, 2012).

In the case of the thermal cautery device, the heating elements of the ones available are all directly exposed. A better option would be to have a covered heating element when it is not in used. The current ones used in the operation theatre has not yet used the application of the first order of the lever system (scissor-like system). It does not only uses a minimal force, but could also restrain the force applied. The combination of sealing and cutting help to reduce the exchange of instruments and thus reduces the cutting operation time.

2.4 Summary

From the literatures, it can be summarized that there are two knowledge gaps which can be used to be filled in this research:

- All the thermal cautery device developed exposes the heating element directly to its users.
- There is no thermal cautery device developed by applying the first order lever system yet.

CHAPTER 3: THEORY AND METHODOLOGY

3.1 Overview

In this chapter, a detail specification and description of the thermal cautery device, power input calculation and finite element analysis of the experimental modal are presented. The development of the proposed thermal cautery device the validation technique are also presented.

3.2 The different modes of heat transfer

By definition, heat is the energy that flows from the higher level of temperature to the lower (without any work being performed), whenever there is a temperature gradient.

Conduction

Heat conduction is a diffusive transport of thermal energy. Heat spontaneously flows from a hotter to a colder body. The heat flow is within and through the body itself. The heat transfer rate per unit area is proportional to the normal temperature gradient (Dickson, 1977),

$$\frac{q_x}{A} \sim \frac{\partial T}{\partial x}$$

When the proportionality is inserted,

$$q_x = -kA\frac{\partial T}{\partial x}$$

where q_x heat-transfer is rate and $\partial T/\partial x$ is the temperature gradient in the direction of the heat flow. The positive constant k is the thermal conductivity of the material, and the minus sign is inserted so the second principle of thermodynamics that heat must flow down the temperature gradient will be satisfied.

Convection

Convection is heat exchange between a moving fluid (gas or liquid) and an adjoining wall. Depending on the temperature proportions, heat is delivered to the wall ($T_\infty > T_w$) or taken away from it ($T_\infty < T_w$). Forced convection is when the current of the fluid is held up by a pump or blower. Even without the technical aids, a flow may emerge due to density differences in the fluid, which are brought forth on their part by temperature or concentration gradients (free convection). The forced convection usually clearly exceeds the free one.

$$q = hA(T_w - T_\infty)$$

The heat transfer rate is related to the overall temperature difference between the wall and fluid and the surface area A. An analytical calculation of the convection heat transfer coefficient h may be made for some systems. For some complex systems, it must be determined experimentally.

Radiation

Heat could also be transferred through regions where a perfect vacuum exists through heat transfer mechanism of radiation. Thermal radiation is electromagnetic radiation that is propagated as a result of temperature difference. An ideal thermal radiator, also known as a blackbody, will emit energy at a rate proportional to the fourth power of the absolute temperature of the body and directly proportional to its surface area. Thus,

$$q_{emitted} = \sigma A T^4$$

3.2.1 Conduction with internal heat generation

Conduction in systems with internal energy generation can take place under transient conditions. The thermal differential energy balance equation describing the conduction of heat in a solid undergoing internal heat generation can be expressed as the most general form of the differential thermal energy balance equation is

$$\frac{\partial H}{\partial t} = -\nabla \cdot \boldsymbol{q} + g(\boldsymbol{r}, t)$$

and is called the heat equation. Where h is the enthalpy, q is the heat flux, and g is the voluminic rate of internal energy generation. Under steady state conditions,

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot k\nabla T + g(\boldsymbol{r}, t)$$

ρ is the density, C_p is the specific heat, k is the thermal conductivity, and T is the temperature. While the steady state equation becomes

$$\nabla \cdot k\nabla T + g(\boldsymbol{r}, t) = 0$$

3.3 Baseline design specifications

3.3.1 The LigaSure™ small jaw instrument

The LigaSure™ small jaw instrument is used as a baseline design of this project. However, it does not use resistance wire as its mitigation mechanism. Instead, it seals the vessel before it is cut by the built-in blade. It applies the first order lever system and provides an integrated cutting mechanism independent of sealing, leaving the critical cutting decisions in the hands of the surgeon. It also seals and cuts vessels up to and including 7 mm in diameter without dissection or isolation. From Figure 3.2, the combination of sealing and cutting by the built-in blade helps to reduce the exchange of instruments and thus reduces the cutting operation time.

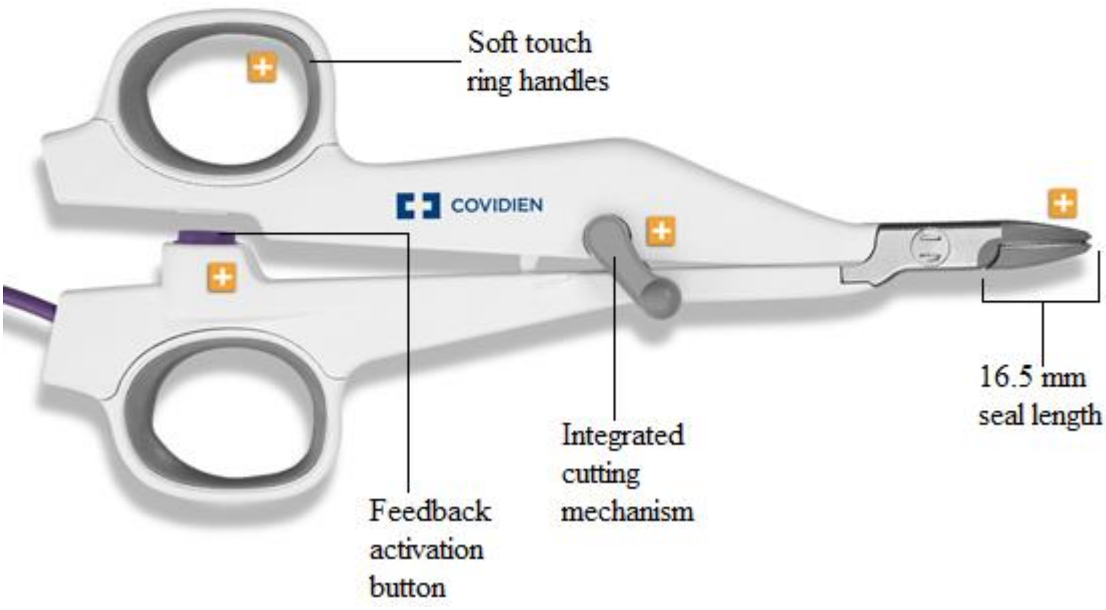

Figure 3.1 The LigaSure™ Small Jaw Instrument (Medtronic, n.d.).

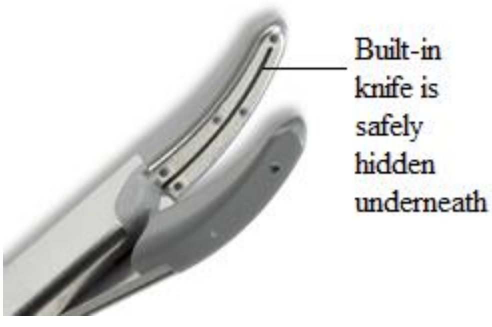

Figure 3.2 The built-in blade of the integrated cutting mechanism is safely hidden underneath when it is not in used (Medtronic, n.d.).

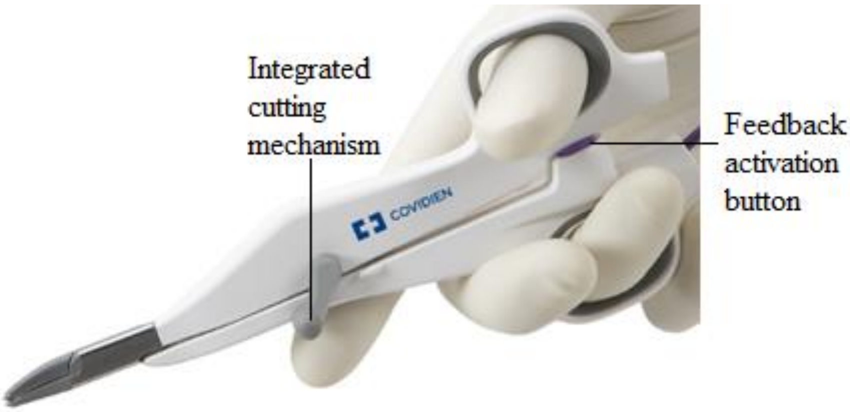

Figure 3.3 The integrated cutting mechanism is in-line with user's index finger. This makes cutting a lot easier and precise. The feedback activation button will be activated only if the handles are pressed together (Medtronic, n.d.).

Table 3.1 Physical Characteristics of LigaSure™ Small Jaw Instrument

Length	18.8 cm (7.4 in)
Jaw Design	28 Degrees
Seal Length	16.5 mm
Cut Length	14.7 mm

As for the proposed design of the thermal cautery device, by adding the first order lever system to its design, it may help the surgeon to use less instruments and increase the precision during the cautery operation. The current thermal cautery device could not be used alone and must be assisted with other instruments such as forceps for grasping of the soon-to-be cut vessel. By applying the lever system, it actually provides a combination of force and energy to create vessel fusion. This way, it would result in a more consistent and tidy cutting.

Figure 3.4 Thermal cauterization is performed on a vessel in an open surgery by using Hand-held Cautery Device by Baron. The heated part is exposed and usage of supplementary tool is a must. Retrieved from http://www.brazjurol.com.br/

3.3.2 Kanthal resistance wire properties

Kanthal A-1 is a ferritic iron-chromium-aluminium alloy (FeCrAl alloy) for use at temperatures up to 1400°C (2550°F) (Kanthal, n.d.). The alloy is characterized by high resistivity and very good oxidation resistance. Applications for Kanthal A-1 are electrical heating elements in high temperature furnaces for heat treatment, ceramics, glass, steel, and electronics industries. For heating, resistance wire must be stable in air when hot. Kanthal alloy forms a protective layer of aluminium oxide (alumina). Aluminium oxide is an electrical insulator but has a relatively high thermal conductivity; special techniques may be required to make good electrical connections.

Figure 3.5 Kanthal A-1 wire. Retrieved from www.kanthal.com

Table 3.2 Physical properties of Kanthal A-1 wire (Kanthal, n.d.)

Density (g/cm^3)	7.10
Electrical resistivity at 20 °C (mm^2/m)	1.45
Poisson's ratio	0.30

Table 3.3 Thermal conductivity of Kanthal A-1 resistance wire.

Temperature (°C)	50	600	800	1000	1200	1400
Thermal conductivity ($Wm^{-1}K^{-1}$)	11	20	22	26	27	35

Table 3.4 Specific heat capacity of Kanthal A-1 resistance wire.

Temperature (°C)	20	200	400	600	800	1000
Specific heat capacity ($kJ\ kg^{-1}\ K^{-1}$)	11	20	22	26	27	35

Table 3.5 Melting point and maximum continuous operating temperature in air of Kanthal A-1.

Melting point (°C)	1500
Max. continuous operating temperature in air (°C)	1400

3.4 Experiment on the existing thermal cautery device

Experimental data collection is carried out to obtain the parameters of the existing thermal cautery device. The maximum temperature achieved due to the internal heat generation is captured with an infrared camera of model FLUKE Ti27. This is important to make sure that the analysis done is within reasonable and acceptable range. The data collected are used in the ANSYS finite element analysis modelling.

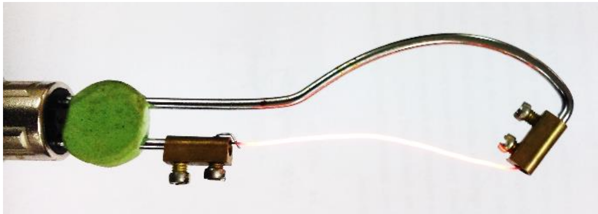

Figure 3.6 Thermal cautery device used for the experiment.

Figure 3.7 shows the experimental setup on the existing thermal cautery device. The apparatus that are used in this experiment are an infrared camera, a thermal cautery device, a voltmeter, a variable DC power supply and a clamp ammeter. The thermal cautery device is connected in series with the variable DC power supply. Then, the voltmeter is connected in parallel into the circuit. The clamp ammeter is attached across the wire to get the current reading.

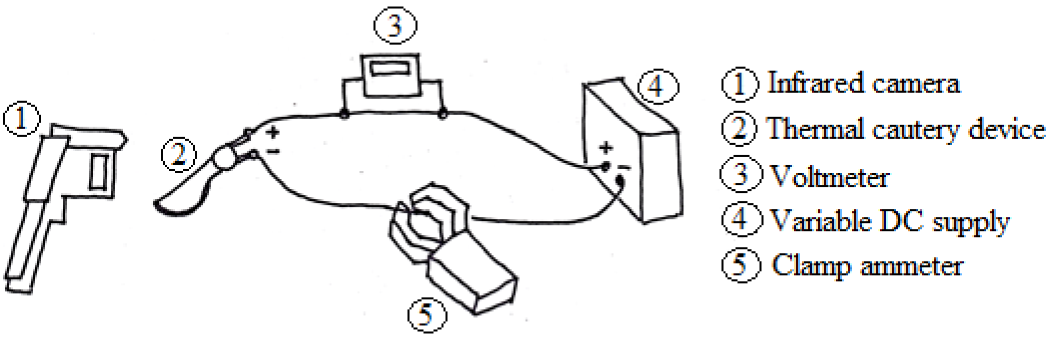

Figure 3.7 Experimental setup for determination of the voltage and current supply.

3.4.1 Determination of voltage and current

The voltage and current of the thermal cautery device is determined in order to find the power input for the internal heat generation of the heating element. The voltage is measured in a parallel manner by using a multimeter. Meanwhile, the current is measured in a series manner. It is measured by using the multimeter with the assistance of the AC/DC current clamp FLUKE i410.

Figure 3.8 The multimeter is used to measure the voltage and current.

Figure 3.9 The current is measured with the assistance the AC/DC current clamp FLUKE i410.

3.4.2 Determination of the maximum temperature

In order to make sure that the maximum temperature achieved by the ANSYS analysis is reliable, an experiment on a similar model is carried out. Infrared thermography (IRT) is a part of infrared imaging science. Thermographic cameras detect radiation in the long-infrared range of the electromagnetic spectrum and produce images of that radiation. The amount of radiation emitted by an object increases with temperature. Thus, this allows one to see variations in temperature. When viewed through a thermal imaging camera, warm objects stand out well against cooler backgrounds. The infrared image is captured by using the infrared camera of model FLUKE Ti27.

Figure 3.10 Infrared camera of model FLUKE Ti27.

Table 3.6 Temperature specification of FLUKE Ti27. Source: http://www.fluke.com/

Temperature	
Temperature measurement range (not calibrated below -10 °C)	-20 °C to +600 °C (-4 °F to +1112 °F)
Temperature measurement accuracy	± 2 °C or 2 % (at 25 °C nominal, whichever is greater)
On-screen emissivity correction	Yes
On-screen reflected background temperature compensation	Yes
On-screen transmission correction	Yes

An experiment with simple procedure is carried out in the Vibration Laboratory. The thermal cautery device is activated by continuously pressing the switch. The battery of the thermal cautery device is fully charged prior to usage with known voltage and current supply. The infrared camera is positioned close to the heating thermal cautery device. The infrared image would indicate a temperature rise and stops at its peak. The moment the maximum temperature is achieved, the infrared image is then captured. The image shows the temperature of the heating element, the associate parts, and the surrounding temperature.

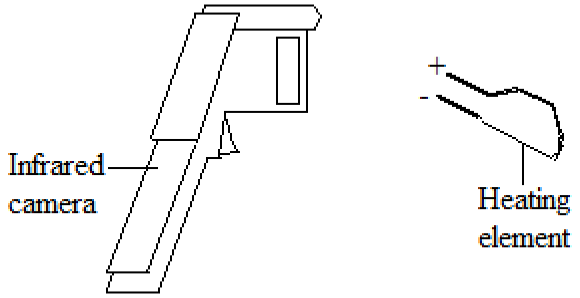

Figure 3.11 The maximum temperature achieved due to the heat generation at the heating element is captured through the infrared camera.

3.5 Heat transfer analysis of existing thermal cautery device

The thermal cautery device used for the experiment previously is modelled using SOLIDWORKS. The dimensions of the thermal cautery device is measured and applied onto the Computer Aided Design (CAD) model. The model is then imported into ANSYS to determine the heat transfer analysis of the existing thermal cautery device by using finite element method. The materials are assigned accordingly into the imported CAD model. Transient analysis is used for this analysis.

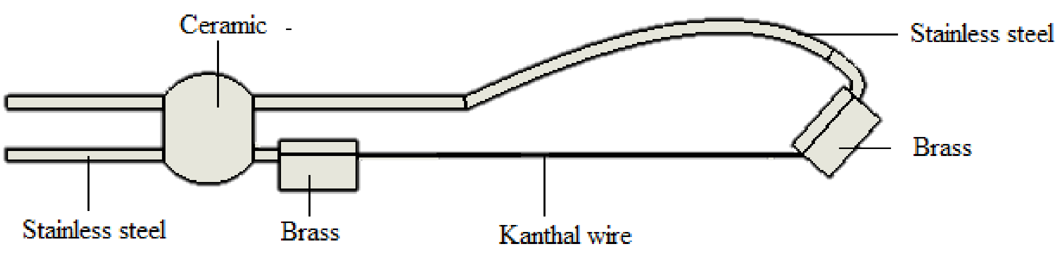

Figure 3.12 The design that is used for ANSYS simulation.

Table 3.7 Properties of materials. Source: http://www.ansys.com/

Materials	Density (kg m^{-3})	Thermal conductivity (W m^{-1} °C^{-1})
Ceramic	4900	4.5
Stainless steel	8055	13.8
Brass	8600	111.0

* Kanthal wire properties are included in sub-chapter *3.3.2 Kanthal resistance wire properties*.

3.6 Proposed design of thermal cautery device

The LigaSure™ small jaw instrument as shown in Figure 3.1 is taken as the baseline design. This is considered as a good adaptation of the existing thermal cautery device that has exposed heated parts with the combination of features of which may resulted in thermal cautery device with improved safety features. The design process is presented using a morphological chart to generate multiple ideas in an analytical and systematic form.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Overview

In this chapter, the results obtained from the experiment for thermal cautery device are presented. The heat transfer analysis from the ANSYS simulation will be verified with the results obtained from the experiment for thermal cautery device. The design process of the proposed thermal cautery device with improved safety features are presented and discussed.

4.2 Model validation

In this section, the results obtained from the experiment will be used to validate heat transfer analysis obtained from ANSYS simulation.

4.2.1 Internal heat generation of the heating element

Two experiments are carried out on the existing thermal cautery device. The first one is to find the voltage and current supply of the device. Second, it is to determine the maximum temperature achieved by the heating element due to internal heat generation.

Table 4.1 Voltage and current as measured by the multimeter.

Voltage, V	4.50 V
Current, I	7.60 A

Electric power, P is the rate at which electrical energy is transferred by an electric circuit. It is the result of voltage, *V* and current, *I*. Thus, the power input is

$$P = VI$$

$$= 34.20\ W$$

The battery of the thermal cautery device gives a power input of 34.20 W. With this result, it is now possible to calculate the internal heat generation on the heating element. The dimensions of the heating element is measured and the cross-sectional area and volume of the heating element is calculated. The internal heat generation is calculated by dividing the power input by the battery with the volume of the heating element.

Table 4.2 Set of parameters for the heating element (Kanthal wire).

Diameter of wire, D	0.45 mm
Length of wire, L	77 mm

The cross-sectional area, *A* of the heating element,

$$A = \pi D$$

$$= 2 \times 10^{-17} mm^2$$

The volume, *V* of the heating element,

$$V = AL$$

$$= 1.22513 \times 10^{-8}\, m^3$$

Thus, internal heat generation

$$Internal\ heat\ generation = \frac{Power}{Volume}$$

$$= 2.7916 \times 10^9\, W/m^3$$

The internal heat generation by the heating element is 2.7916 x 10^9 W/m^3.

4.2.2 Maximum temperature achieved by heating element

The internal heat generation by the heating element is observed. The heat generated from the middle of the heating element and spreads outward. Thus, it is expected that the highest temperature achieved is at the middle part. Referring to Figure 4.1, the highest temperature is achieved at the heating element. The colour distinction is obvious between the heating element and its surrounding area. The colour range for the temperature is located on the right side of the image. The lowest range of the colour that is black in colour indicates the lowest temperature captured by the infrared image. The highest range of the colour that is white in colour indicates the highest temperature captured by the infrared image. The value that is located next to the middle part of the colour range is the temperature where the cursor is indicated to. The heating element is of a bright colour range from orange to light yellow. Meanwhile, the surrounding temperature is of dark colour. The information at the bottom of the image are the emissivity correction value, reflected background temperature compensation value and transmission correction percentage. From Figure 4.1, the temperature of the neighbouring element is not much affected with the heat generation by the heating element. This is because the colour of the neighbouring element falls below the dark range.

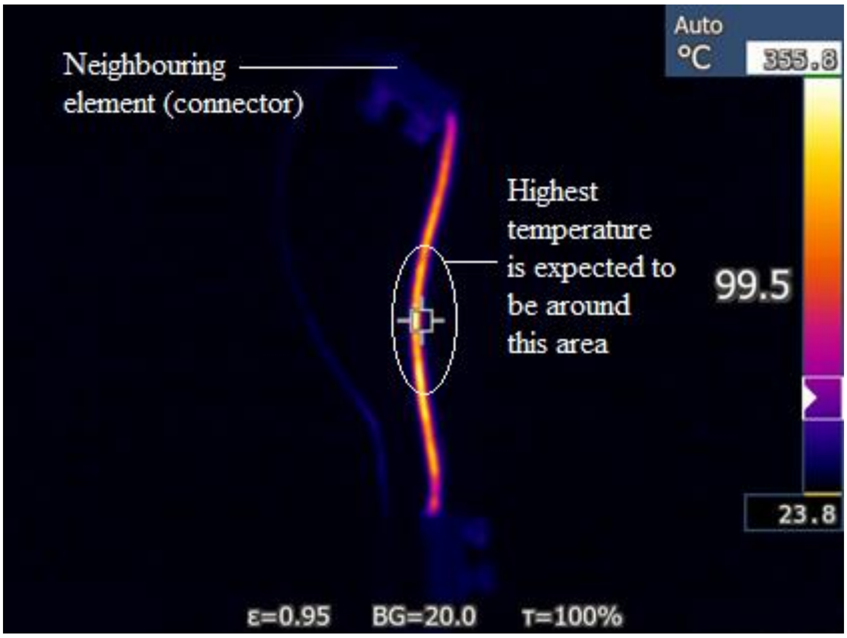

Figure 4.1 The infrared image shows that the heat generated does not affected much on the temperature rise of the other parts of the device.

As thermal images are actually a visual display of the amount of infrared energy emitted, transmitted, and reflected by an object, it is difficult to get an accurate temperature of an object using this method since there are multiple sources of the infrared energy. Thermal imaging camera performs algorithms to interpret data and build an image. Even though the image only gives an approximation of the temperature at which the object is operating, the camera is actually using a multiple sources of data on the areas surrounding the object to determine the value rather than detecting the actual temperature. Thus, in order to limit the set of source of data for the camera, the camera is brought as close as possible to the object.

Figure 4.2 is the image whereby the camera is brought to a closer distance. The maximum temperature as captured by the infrared image is 620.0 °C. The temperature is expected to be somewhere at the heating element. The high temperature is made possible because of the high resistivity of the heating element. This same type of heating element is used for making electrical resistors which are made to control the amount of current in a circuit. This is possible with the knowledge of Joule heating. It is the process whereby the path of an electric current through a conductor produces heat due to the high resistivity of the element. Joule heating affects the whole electric conductor, in this case the heating element.

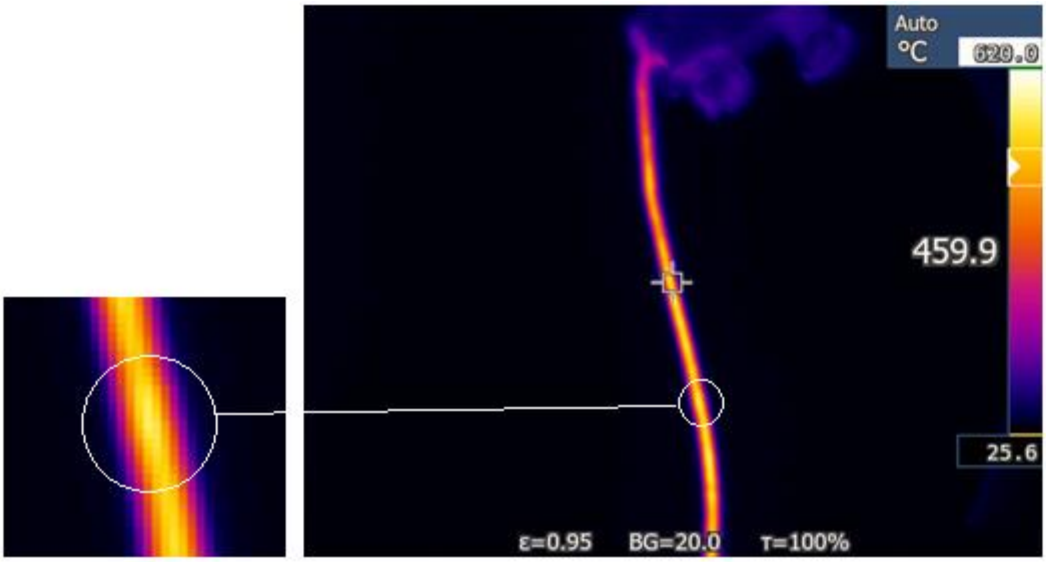

Figure 4.2 The highest temperature achieved by internal heat generation of the heating wire is 620.0 °C.

4.2.3 Heat transfer analysis of existing thermal cautery device

The thermal cautery device that has its data collected earlier is modelled in the SOLIDWORKS. It is then imported to ANSYS software for heat transfer analysis. The dimensions of the model is based from the measurements of the thermal cautery device. The ambient temperature is set to 30 °C. The conditions of convections and radiations are applied onto the model of the thermal cautery device. As for convections, the temperature dependent setting is imported from the ANSYS library with simplified case of stagnant air as its reference. This gives the convection value of 5 W/m^2 °C. The internal heat generations is 2.7916×10^9 W/m^3 as from the calculations earlier.

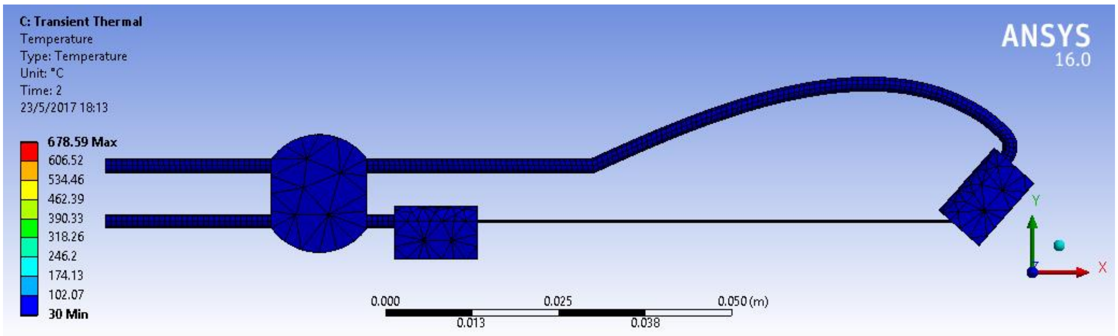

Figure 4.3 The heat transfer analysis as modelled in ANSYS.

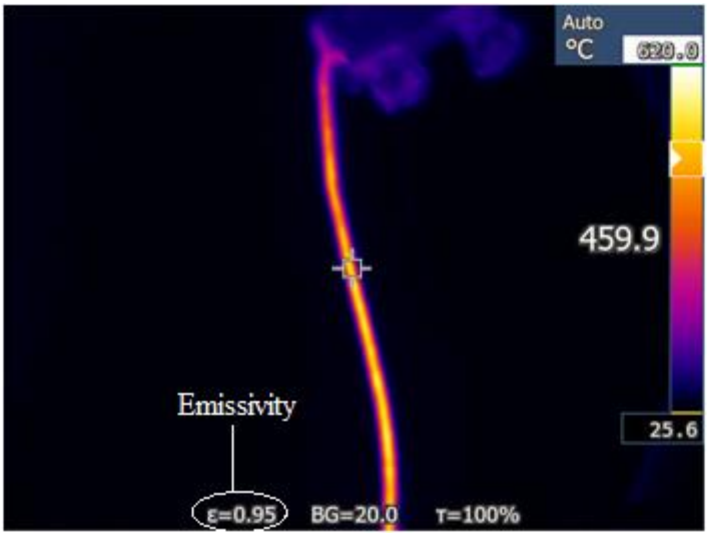

Figure 4.4 The value of the emissivity is obtained from the infrared image of the heating element.

Figure 4.5 shows that the highest temperature of the heating wire is 678.6 °C. The temperature is slightly higher from the experimental results. This could be due to the oxidation process that has already taken place at the heating element. Plus, the convection applied into the model is of the simplified case of stagnant air.