A DEVELOPMENT OF PORTABLE FLUID WARMER FOR SURGICAL HYPOTHERMIA PATIENTS

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ABSTRACT

This research designs and develops Intravenous of fluid warmer device for surgical patients in order to prevent hypothermia and the risk of infection caused by chills. It makes the heart work harder. This may cause myocardial hypoxia and heart failure. According to hypothermia, it found that the warm liquid can help prevent hypothermia, but fluid warmer has big dimension and expensive. Therefore, development of portable fluid warmer for the surgical patients was proposed. This proposed prototype takes more long warming up time than commercial device for 3 minute, but the cost of prototype is much lower than commercial device, and the dimension is also reduced. The result at 20ºC of room temperature shows that heater can conserve the temperature with 6.50 of percent error and 0.42 of standard deviation. Moreover, the saline temperature after warming has 0.68 of percentage error and 0.64 of standard deviation.

Keywords: hypothermia, fluid warmer, intravenous fluid, surgical.

1. INTRODUCTION

Normally, human body operates efficiently in equilibrium condition. It tries to conserve to equilibrium condition when some conditions are changed such as pressure and temperature. Temperature is one of the most important vital signs that human body needs to conserve to equilibrium. Normally, human body operates finely at 37 °C approximately. The enzymes also work normally at this temperature [1]. If body temperature cannot conserve to equilibrium condition, it will affect to other systems inside the body. For example, when human body absorbs more heat, it causes hyperthermia which is increasing of body temperature due to failed thermoregulation. On the other hand, when human body dissipates heat more heat than it absorbs, it causes hypothermia, body core temperature below 35.0 °C [2].

In surgery, the unsuitable temperature has many effects to human body. T.N. Ajish and P. Govindan found that thermal occuring by bone drilling surgery can cause thermal necrosis [3]. Therefore, in surgery, human body temperature is very important parameter that need to control.

According to surgery room, the room temperature is set to 20-22 ºC in order to prevent microorganism growing [4]. Therefore, patient may have hypothermia condition during the operation. According to hypothermia, patient has shivering condition [5] that need more oxygen for 400-500% [6]. This condition can cause myocardial infarction (MI) [7], Arrhythmia [8], slow anesthetic recovery [9], bleeding disorder [10] and slow trauma recovery [11]. The body temperature control can reduce these accidences caused by hypothermia [12]. Therefore, in surgery, it is very necessary to control the patient body temperature in order to prevent hypothermia.

One of the causes of hypothermia is intravenous fluid such as blood and saline. normally, intravenous fluid is warmed before use in surgical room. since temperature in surgical room is low, heat of intravenous fluid transfers to environment until equilibrium according to heat transfer theory. The cold intravenous fluid causes hypothermia to patient.

There are many commercial fluid warmers now, but they have big size and are not convenient to use in some surgical rooms that have small area, many tools and many devices. Moreover, the commercial has very high price. Some primary hospitals cannot purchase with their budget.

In this paper, a proposed prototype of portable fluid warmer for surgical patient is designed and constructed. In the experiment, the environment of surgical room was set in order to test the performance in real condition. The saline was used in this experiment as case study.

2. BASIC CONCEPT

This paper, consist of three basic concepts that relates to the prototype: temperature control and thermodynamics of liquid. Each concept will be described in this section.

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2.1 Temperature control

In engineering, they are many ways to control the temperature such as On/Off control, proportion control and PID control that can be found in heater devices. On/Off control is one the simplest techniques to control the temperature. For On/Off control, the system is on when the temperature is below the set point, and off above set point. In proportion control, it decreases the average power that is supplied to the heater as the temperature approaches set point. It can slow down the heater to protect overshoot problem. For PID control, the controller is used to provides proportional control.

2.2 Thermodynamics of Liquid

There are many types of fluid heat transfer having different temperature. In industry, the exchange between targeted fluid and other material needs heat exchanger designed for each type of fluid [13]. The heat exchanger can be divided by flow characteristics and heating devices [14], [15].

According to calculate the rate of heat transfer, the overall heat transfer coefficient (U) is the important parameter that can be calculated using the following equation

$$Q = UA\Delta T \tag{1}$$

when Q is the rate of heat transfer (W)
U is overall heat transfer coefficient (W/m^2 ºC)
A is heat transfer area (m^2)
ΔT is temperature difference (ºC)

J. Taborek, G. F. Hewitt, and N. Afgan [16] calculated the heat transfer efficiency of heat exchanger using the following equation.

Efficiency ($\boldsymbol{\eta}$) = *(heat power absorbed / heat power emitted) x 100* (2)

According to human blood, it consists of water with 90% closing to water. Therefore, the overall heat transfer coefficient of water can be used in this research.

3. PROTOTYPE DESIGN

This research started from study the technology of conventional fluid warmer in surgical room in order to define its parameter such as heating temperature, heating rate, device material including cost.

The prototype was designed and divided into 4 parts which are power supply unit, processing unit, heating unit and temperature measurement unit. The diagram of prototype design is shown as follows:

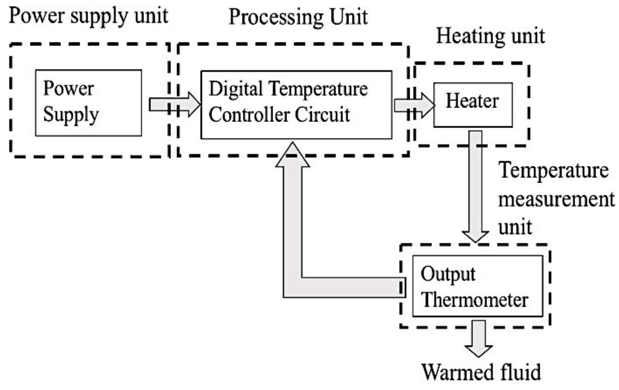

Figure 1. Diagram of fluid warmer prototype

According to Figure 1, the system starts from power supply unit. In this research, the 9V, 2A DC adaptor power is used to supply all parts of this system. The processing unit is used to control heater after receives temperature data from measurement unit. The heating unit uses brass that has 111 W/m.K of thermal conductivity and robust to corrosion. A digital thermometer measures the fluid after warming and sends temperature data back to processing unit in order to adjust the heater power for suitable fluid temperature.

The prototype of portable fluid warmer is shown in Figure 2.

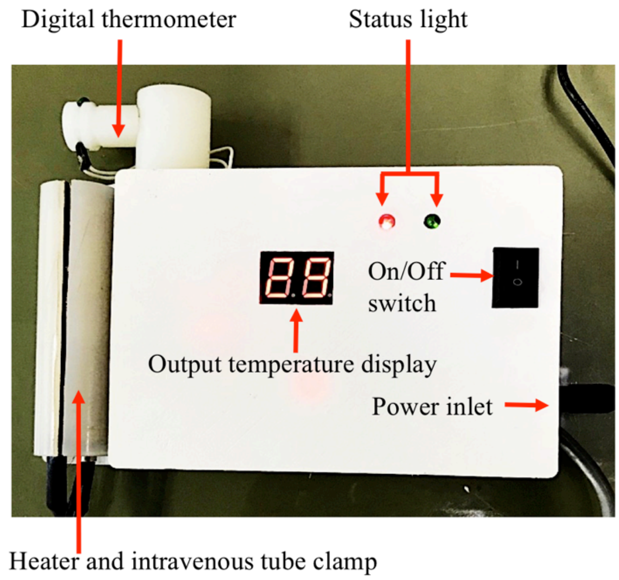

Figure 2. Components of fluid warmer prototype

According to Figure 2, the prototype of fluid warmer was designed to compact size, and it can grip with surgical bed in order to facilitate doctor or surgical team. The dimension of designed prototype is 18x1x2.5 cm.

Moreover, the prototype was designed for uncomplicated use that has only one switch. The prototype works automatically after switches On.

4. EXPERIMENTS

The prototype of fluid warmer was experimented in order to evaluate its performance. The experiment condition was set as a surgical room which has 20ºC of room temperature [4] in order to study effect of room temperature reacting to fluid warmer working.

The experiment was divided into 3 sections which are heating rate of fluid warmer prototype, temperature holding of fluid warmer prototype and temperature of saline after warming.

In evaluation, this research need to test the accuracy and performance of the designed prototype evaluated by warming time starting from initial temperature (20ºC) to targeted temperature. The accuracy of prototype can be found by percentage error calculated as follows:

$$Percentage\ Error = \frac{|E\text{-}S|}{S} \times 100\% \quad (3)$$

where S is standard physical quantity
E is the physical quantity as same as S.

The statistical analysis of this research uses average ($\bar{X}$) and standard deviation (δ) when N is number of measurements and X_i data of measurement. Therefore, $\bar{X}$ can be found using following equation.

$$\bar{X} = \frac{\sum X_i}{N} \quad (4)$$

The sample standard deviation (δ) can inform the accuracy of measurement. If sample standard deviation has low value, the measured information has high accuracy. The sample standard deviation can be found using following equation.

$$\delta = \sqrt{\frac{\sum (X_i\text{-}\bar{X})^2}{N\text{-}1}} \quad (5)$$

5. RESULTS

The experiment is to test the efficiency of the proposed prototype. It can be divided into 3 sections which are heating rate of fluid warmer prototype, temperature holding of fluid warmer prototype and temperature of saline after warming.

5.1 Heating rate of fluid warmer prototype

Since fluid warmer always operates in surgical room which has low room temperature (20-22 ºC or 20-23 ºC) [4][5], heat generating is hard to perform because the prototype need to compensate the low room temperature. Therefore, the important factor that affects to prototype efficiency is heat generating rate.

According to heat conduction theory, the phenomenon of heat energy between contacted objects transfers from high temperature object to low temperature object until equilibrium that all contacted objects has the same temperature.

In surgical room, normally the intravenous fluid in surgical room lose their heat to room environment. Since the surgery takes long time, the intravenous fluid loses their heat to room environment until it has the same temperature. In this experiment, the saline used as case study and room temperature were set to 20ºC as initial temperature. Therefore, the generated heat from proposed prototype need to generate at least 54ºC in order to transfer to saline to get equilibrium at 37ºC which is human body temperature.

In this section, the results of heat generating rate from the proposed prototype that starts to heat the 20ºC of saline in 20ºC of room temperature are shown as follows:

Time (minute)	Temperature at contacted point (ºC)
0	20.0
0.5	25.2
1.0	28.3
1.5	30.4
2.0	33.2
2.5	35.3
3.0	37.7
3.5	39.3
4.0	42.4
4.5	48.5
5.0	57.3

Figure 3. The results of heating rate of proposed prototype

According to Figure 3, it can be shown in graph as follows:

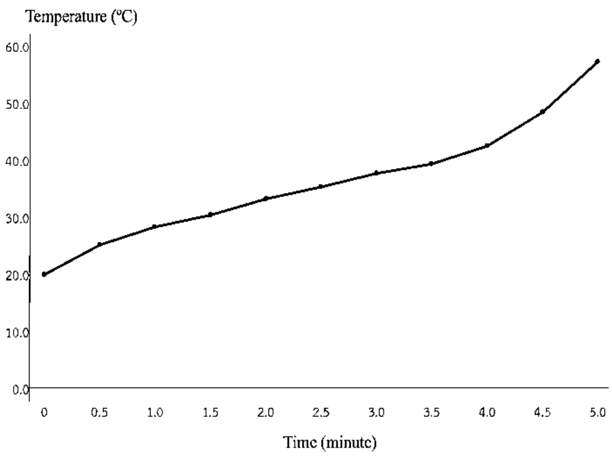

Figure 4. Heating rate graph

According to the results, the heating rate of proposed prototype shows that the prototype can generate the temperature at contact point between heater and intravenous tube from 20ºC to 57.3ºC within 5 minutes. Since the prototype need to generate at least 54ºC in order to transfer to saline to get equilibrium at 37ºC, the proposed prototype need to warm up at least 4.5 minutes before use.

5.2 Temperature holding of fluid warmer prototype

The fluid warmer need to have temperature control function in order to damage the intravenous fluid. For example, in blood warming, human blood cannot gain temperature more than 42ºC because the erythrocytes are boiled at this temperature. Theoretically, the heater should generate at least 54ºC in order to transfer to 20ºC intravenous fluid to get 37 ºC.

In this experiment, the environment was set to 20ºC like surgical room, and the prototype operated 1 hour continuously. The heater temperature was measured every 5 minutes. The results were compared to theoretical value which is 54 ºC. The results were shown as follows:

Time (minutes)	Temperature (ºC)	Percent Error
5	57.1	5.74
10	57.6	6.67
15	58.2	7.78
20	57.8	7.04
25	57.5	6.48
30	57.3	6.11
35	56.7	5.00
40	57.2	5.93
45	57.6	6.67
50	58.1	7.59
55	57.7	6.85
60	57.3	6.11
Average	57.51	6.50
S.D.	0.42	

Figure 5. Result of temperature holding of fluid warmer prototype for 1 hour

According to Figure 5, it can be shown in graph as follows:

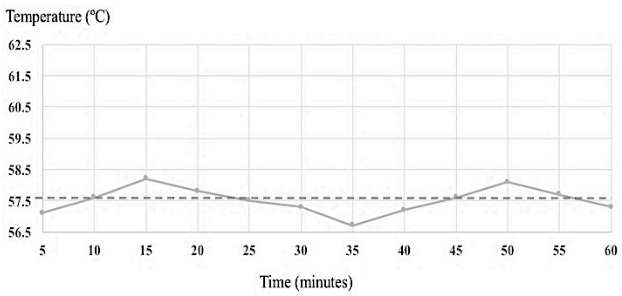

Figure 6. Graph of prototype temperature holding (dot line is average value)

5.3 Temperature of saline after warming

In this experiment, the prototype was experimented with saline in real condition. The room temperature was set to 20ºC. Saline has 50 milliliter/hour of flow rate which is the average of intravenous fluid injection. The prototype operated 1 hour continuously. The saline temperature after heated was measured every 5 minutes The result was shown as follows:

Time (minutes)	Temperature (ºC)	Percent Error
5	37.1	0.27
10	37.3	0.81
15	38.4	3.78
20	37.3	0.81
25	37.2	0.54
30	36.3	1.89
35	36.3	1.89
40	37.0	0.00
45	37.9	2.43
50	38.0	2.70
55	37.5	1.35
60	36.7	0.81
Average	37.25	0.68
S.D.	0.64	

Figure 7. Result of saline after heated by prototype

According to Figure 7, it can be shown in graph as follows:

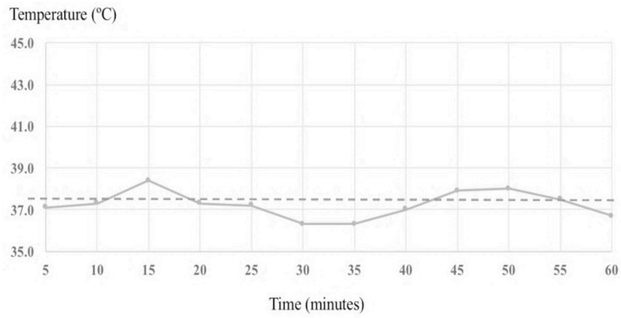

Figure 8. Graph of saline temperature after heated (dot line is average value)

6. DISCUSSION

A development of portable fluid warmer used for surgical patient who has hypothermia condition. Since surgical room has low temperature (20-22 ºC) [4], patient sometime causes hypothermia because of cold intravenous fluid. Therefore, this research tried to warm and hold the intravenous fluid through the operation.

According to Figure 3, the prototype was designed to generate heat rapidly. The heater can rise the temperature from 20ºC (surgical room temperature) to 57.3ºC within 5 minutes. Therefore, the prototype need to warmup for 5 minutes approximately. Since the commercial fluid warmer need to warmup for 2 minutes, the prototype need to improve heater system to reduce warming time in the future.

According to Figure 5, the prototype was tested to conserve the temperature in surgical room condition for 1 hour. The prototype was set to generate at 54ºC, but the results showed 56-57ºC approximately. This error came from rapid heat generating that the controller cannot have real time control. This problem can be solved by use performance heater and controller, but the cost also goes higher.

Moreover, according to Figure 7, the 20 ºC saline which has 50 milliliters/hour of flow rate was tested in real condition in order to find the output temperature of saline after warming. The results closed to human body temperature which is 37ºC. Although, heater generate heat more than setting, the results still closed to desired temperature. It was not theoretical because the generated heat loses in some factors such as gap between saline tube and heater, saline tube, and environment. Therefore, the relation between real condition and generated heat should be studied in the future.

This prototype was designed to have low cost, work automatically, use easily and have small size (18x11x2.5 cm.) in order to use in surgical room conveniently. Moreover, it can install with surgical bed.

7. CONCLUSION

This research designs and develops Intravenous of fluid warmer device for surgical patients in order to prevent hypothermia and the risk of infection caused by chills while operating. The prototype was designed to have low cost, small size, use easily and work automatically. The experiment divided into 3 sections which are heating rate of fluid warmer prototype, temperature holding of fluid warmer prototype and temperature of saline after warming.

The result shows that the prototype has 6.50 percent error in generating temperature occurring from controller and heater. In real condition, the relation between generated heat and surgical environment need to be studied.

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