Experimental Study of Isothermal Plate Uniformity for Blood Warmer Development using Geothermal Energy

J Hendrarsakti¹² and Y Ichsan¹

¹Faculty of Mechanical and Aerospace Engineering, ITB Jalan Ganeca No 10, Bandung, Indonesia
²Geothermal Master Program, ITB Jalan Ganeca No 10, Bandung, Indonesia

Abstract. This research was conducted to assess the direct use of geothermal energy for blood warmer. The heating plate was made from aluminium plates with dimensions of 100 x 200 mm and then fed from the hot water heater. Tests were conducted in the laboratory where geothermal source water is replaced with the heat generated from the heater. The hot water from the heater in the temperature range 55°C - 60°C flowed into vertical chamber. Setting the temperature of the hot water heater is done by changing the flow of hot water coming out of the heater. Results showed that the value of a standard deviation of plate temperature was about 0.42 °C, so it can be said isothermal accordance with design requirement and objective. The test data used for the analysis of the manufacture of the heating plate in the blood warmer to regulate the discharge of hot water at intervals of 21.47 mL/s to 24.8 mL/s to obtain a temperature of 37.20 °C – 40.15 °C. Geothermal energy has the potential for blood warmer because blood warmer is part of the energy cascade in a temperature range of 40°C to 60°C

1. Introduction
Indonesia has a tremendous opportunity in the field of geothermal energy. Potential reserves of geothermal energy in Indonesia amounted to 40% of the total reserves of geothermal energy worldwide, equivalent to 28,000 MWe [1]. Geothermal potential is spread from Aceh to Papua. To take advantage of this opportunity, it is necessary to conduct in-depth study so that the development of geothermal utilization for power generation is also balanced with an assessment of the direct utilization of geothermal fluid, such as for agriculture, fisheries, tourism and even for chemical processes.

Based on data from the Indonesia Ministry of Energy and Mineral Resources in 2010, the utilization of geothermal energy for electricity in Indonesia has reached 1189 MWe which are spread throughout Indonesia [1]. Direct use of application geothermal energy is still limited to the hot water bath used at tourist spots, such as Ciwidey, Cipanas, and Garut. In addition, the utilization of geothermal resources directly used for drying tea industry and aquaculture, but use is still limited.

This research was conducted as based Lindal diagram shown in Figure 1 that there is a potential source of geothermal heat at a temperature of 40 °C to 60 °C to heat the blood warmer. A blood warmer, itself is a device that is used to heat the blood during the blood transfusion process. In blood warmer, heater used consists of two vertical plates as one example is presented in Figure 2.

At the time of transfusion, blood preheated for blood stored in the refrigerator at a temperature of 1 °C - 6 °C in order to avoid lysis. Van Der Walt and Russell (2015) argued that ideally the blood is heated to body temperature, 37 °C, but at temperatures between 32 °C and 37 °C is still acceptable [3].
Heating the blood also may not exceed a certain temperature because it can result in either hemolysis damage or destruction of red blood cells due to disruption of membrane integrity of red blood cells and the release of hemoglobin [3].
The purpose of this research is to study and manufacture isothermal plate as the heating plate in the blood warmer. This research was carried out on a laboratory scale using a water heater in the form of heat generated from the heater. The current study was also to determine the geothermal potential as a source of heating in heating appliance blood.

2. Experimental Apparatus and Procedure
   2.1 Experimental Apparatus
   Tests were conducted on the chamber by flowing hot water from the heater as shown in Figure 3. In order the results of this test can be used in applications, the design requirement for blood warmer that must be met in this test are:
   1. Chamber positioned vertical to resemble blood warmer position.
   2. Aluminum plates with no coated with insulator was used to heat the blood.
   3. The temperature of the plate uniform with a standard deviation of less than 1 °C

   2.1. Experimental Procedure
   Tests were conducted to determine temperature distribution in the plate with a variety of a certain slope. Heater in Figure 4 is placed outside the room so that the exhaust gases can be neutralized by air. Furthermore, the hose is connected from the tap water supply to the heater. Then the system was put under the test plate to facilitate installation of the heater hoses from the heater to the plate. The procedures in the testing are as follows:
   1. The water pump is turned further water-supply valve to the heater is opened. Valve governing effluent water heater is closed. Heater is heated with a gas-fueled torch to the water in the heater reaches a certain temperature (about 55-60 °C).
   2. The next step is to organize the entry and exit discharge constant heater. To generate a constant flow of the heater valve that regulates water heater opened out with specific openings, simultaneously valve that regulates incoming water heater is also arranged so that the water level at heater remains constant.

![Diagram of the experimental apparatus](image)

**Figure 3.** System apparatus used in this study.
3. If the water flow in the range of 12.00 to 13.33 mL/s (when measured in the range of 18-20 seconds) with a water temperature of 55-60 °C then the next step drain the hot water from the heater to the isothermal plate system.

4. The hot water flows using a hydraulic hose isolated 0.5 inch diameter. Hoses connected with niple on a test system plate. Valve that regulates the water out on a plate covered with a test system thus hot water will fill the test system until it reaches a certain volume then marked on the glass. To maintain the volume of hot water in the system test plate to remain constant as described in Figure 5, then the flow of water entering the system plate must be equal to the flow of water out of the system test plate. It is thus necessary setting the valve on the test plate system manually. Hot water coming out of the test plate system is accommodated in a container before being discarded. Temperature readings on the plate in Figure 6 that are not insulated using a digital thermometer at eight different points. Before testing each thermometer calibrated beforehand with the mercury thermometer by inserting thermometer on water in order to obtain a correction factor for each digital thermometer. Digital thermometer readings done by making a video starts when the water flow out of the system constant test plate with a duration of five to eight-minute video.

![Figure 4. Heater used for the study.](image)

![Figure 5. Position chamber with testing plate](image)

![Figure 6. Testing plate with temperature sensors](image)
3. Results and Discussion

3.1 Temperature Distribution on the Plate
Temperature measurement performed at eight different points with position sensors as shown in Figure 7 to determine the temperature distribution in the plate. This is necessary because blood plate warmer temperatures should be uniform (design requirement).

The sensor is placed on a square plate with dimensions of 4 cm x 4 cm as shown in Figure 7. Selection of a square-shaped plate as a square is a symmetrical shape so as to facilitate analysis of the influence of symmetry of the position sensor plate temperature uniformity. The distance between the point of the sensor is 1.5 cm so that the sensor number 1, 3, 6, and 7 are not exactly on the edge of the plate, but the position of the sensor is 0.5 cm from the edge of the plate. Table 1 shows the temperature distribution plate with a standard deviation of 0.42 °C, thus the temperature distribution in the plate can be said to be isothermal.

Table 1. Temperature distribution (°C) on plate

| T1  | T2  | T3  | T4  | T5  | T6  | T7  | T8  | Tmax | Tmin | Tavg | St Deviation |
|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|--------------|
| 50.10 | 50.40 | 50.10 | 50.30 | 49.10 | 49.70 | 49.70 | 50.10 | 50.40 | 49.10 | 49.93 | 0.42          |

3.2 Effect of Water Flow rate Against Plates Temperature
Figure 8 shows the relationship between the discharges of hot water that flowed from the heater to the average temperature of plate by Equation (1). This test result is useful for designing blood warmer. Hot water comes from geothermal arranged debits resulting in a certain temperature on the plate. Determination of the hot water discharge that can be streamed using Equation (1) flow test results from the heater. Equation 1 is useful for determining the flow of hot water to be flowed into the chamber to get a certain temperature on the plate.

\[ T = 63.906e^{-0.025Q} \]  

Figure 7. Sensor position on plate

Figure 8. The influence of hot water flow rate to plate temperature.
3.3 Designing Blood Warmer
In designing the heating plate in the blood warmer, the data needed are type of plate material, plate dimensions, the effective area of the heating plate, the upper and lower temperature limits the heating plate, and the discharge of blood flow in the hose. The heating plate to heat the blood during transfusion be modeled referring to the heating plate designed of Biegler Protherm II in Figure 9 [5].

Due to data limitations, some assumptions used to design the plate. The assumptions used are:

1. Material aluminum plate \((k = 180 \text{ W/mK})\)
2. Heating plate dimensions 200 x 100 x 2 mm
3. The area of effective heating plate 80 x 160 mm
4. Based on data obtained from Biegler Protherm II plate temperature can be set at intervals of 37 ± 0.5 °C - 41 ± 0.5 °C
5. Steady state fluid conditions
6. Constant material properties

In Figure 10, dimensions shown in the schematic drawing of the plate, the effective area of the heating plate, the area of insulation, and water level inside the chamber. In Figure 10 the heating plate has dimensions of 10 cm x 20 cm with an effective heating area 8 cm x 16 cm and height of the water in the chamber is maintained at a height of 18 cm. A tube of blood will be positioned wrapped around the front of the plate surface area of effective heating.

3.4 Calculation of the hot water discharge temperature limits of the upper and lower plates
In designing the heating plate of blood warmer, the temperature of the upper and lower plates should be known. The purpose of calculating the temperature of the upper limit and lower limit on the plate is to determine the amount of discharge of hot water to be flowed into the chamber. The following step will be given calculation of discharge as the steps shown in Figure 11 so that the plate reaches a temperature of 37 ± 0.5 °C - 41 ± 0.5 °C.

![Figure 9. Biegler Protherm II [5].](image)

![Figure 10. Schematic of plate designed.](image)

Determination of the temperature upper limit and lower limit based on the blood warmer on the market, in this case refers to design of Biegler Protherm II. Calculation of the hot water discharge flow in chamber involves the calculation of the internal flow convection in the chamber. Thus in calculations involving dimensionless number Nusselt internal flow [6]. While the water temperature data inlet and outlet obtained from measurements of the temperature of the hot water heater.

A detailed explanation Figure 11 is described in the following steps:

1. The first step is to determine the hot water discharge \(Q\) flowing on the hot plate with the equation in Figure 8, \(T = 63.906e^{-0.025Q}\)
2. Determine the temperature of hot water coming out of the heater using equation $T = 69.39e^{-0.016Q}$. This equation shows the relationship discharge of hot water from the hot water heater with temperature.

3. Calculation of convection on the internal flow in the chamber.

4. Calculation of the outside temperature plate. The calculation result discharge hot water must flow into the chamber to reach temperatures lower limit ($37 \pm 0.5 ^\circ C$) plates are shown in Table 2. Outside temperature plate $T_{s,\text{out}} = 37.2 ^\circ C$ which is in the interval below the minimum limit of the desired temperature of the heating plate. Thus the discharge of hot water from the heater should be drained into the chamber was 24.80 mL/s.

The next step is to determine the hot water discharge in order to reach the upper limit temperature of $41 \pm 0.5 ^\circ C$. Calculations are performed the same as in the previous phase to obtain the results as shown in Table 3. The first line in Table 3 calculation $T_{s,\text{out}}$ with the use of debit from the equation in Figure 6. After the calculation, $T_{s,\text{out}} = 42.26 ^\circ C$ then there is a difference by 2.26 $^\circ C$ or 5.35% of the desired temperature is 40 $^\circ C$.

In the second line of iterations performed by determining the discharge current plate temperature = 40 to 5.35% x 40 = 37.86 $^\circ C$. By using step 2 was obtained debit of 20.91 mL/s. After calculation until at step 4 $T_{s,\text{out}}$ obtained results, $T_{s,\text{out}} = 40.56 ^\circ C$. There are differences in value by 1.38% from the desired temperature at 40 $^\circ C$. This value is outside the upper limit of the temperature interval desired plate so do one more iteration. The second iteration can be seen in the third row of Table 3. Determination of discharge is by Equation 1 when the temperature plate = 37.86 to 1.38% x 37.86 = 37.33 $^\circ C$. By using step 2 was obtained debit of 21.47 mL/s. After calculation until at step 4, $T_{s,\text{out}}$ obtained results, $T_{s,\text{out}} = 40.15 ^\circ C$. Thus it can be concluded that the discharge of hot water to be flowed into the chamber to get a plate temperature upper limit was 21.47 ml/s.

Discharge calculations that have been done on the heater can also be done on a geothermal heat source at temperatures 50 $^\circ C$ - 60 $^\circ C$. By using the hot water temperature data on the geothermal heat source, then the discharge must flow into blood warmer can be known.
Figure 11. Flowchart diagram calculation of outer plate temperature

Table 2. Calculation of the lower limit temperature of plates

| Debit (mL/s) | \( \dot{m} \) (kg/s) | \( T_{m,i} \) (°C) | \( T_{m,o} \) (°C) | \( T_{m,\bar{}} \) (°C) | \( T_{s,in} \) (°C) | \( Re_D \) | \( \overline{Nu} \) | \( \dot{h} \) (W/m²K) | \( T_{s,out} \) (°C) |
|--------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| 24.80        | 0.025               | 46.65               | 41.90               | 44.27               | 37.30               | 513.64              | 14.61               | 92.60               | 37.20               |

Table 3. Calculation of the upper limit temperature of plates

| Debit (mL/s) | \( \dot{m} \) (kg/s) | \( T_{m,i} \) (°C) | \( T_{m,o} \) (°C) | \( T_{m,\bar{}} \) (°C) | \( T_{s,in} \) (°C) | \( Re_D \) | \( \overline{Nu} \) | \( \dot{h} \) (W/m²K) | \( T_{s,out} \) (°C) |
|--------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| 18.71        | 0.018               | 51.43               | 46.70               | 49.00               | 42.30               | 421.58              | 12.49               | 79.87               | 42.26               |
| 20.91        | 0.020               | 49.66               | 44.90               | 47.28               | 40.60               | 456.79              | 13.29               | 84.76               | 40.56               |
| 21.47        | 0.021               | 49.21               | 44.50               | 46.85               | 40.20               | 465.56              | 13.49               | 85.94               | 40.15               |
3.5 Calculation of blood flow

Another calculation needs to be done to design the blood warmer is debit of blood in the hose at plate. It is necessary to know the time of the blood reaches body temperature.

The blood before transfusion prior stored at a temperature of 1 °C to 6 °C, therefore it must be heated in order to reach body temperature. Setting the blood flow is important to know the blood of warm-up time at the plate until it reaches body temperature when the blood out of the blood warmer.

In this calculation using the following assumptions:
1. Steady state
2. Constant properties
3. The outside temperature of hose equal to the temperature of the plate
4. The outer surface of the plate is well isolated

A Blood hose with a length of 60 cm wound on the heating plate would produce 10 pieces windings. The heating plate is set at a temperature of 41 °C. Calculation of blood flow and related temperatures can be conducted using Equations (2)-(6).

\[ \tilde{h}A_s \Delta T_{L,M} = \dot{m}c_p \Delta T \]  
\[ \Delta T_m = \frac{\Delta T_i - \Delta T_o}{\ln(\frac{\Delta T_i}{\Delta T_o})} \]  
\[ A_s = \pi D_o L \]  
\[ \Delta T = T_{m,o} - T_{m,i} \]  

Blood convection coefficient calculated by Equation (6)

\[ \overline{Nu_D} = 3.66 \quad (Ts \text{ constan}) \]

The time it takes the blood to reach temperatures of 37 °C can be calculated by Equation (7)

\[ t = \frac{\text{Volume of blood}}{\text{Debit}} = \frac{\pi D_i^2 L}{4 Q_b} \]

Data calculations of blood flows are as follows:
1. Surface temperature of hose is constant, \( T_s = 41 °C \)
2. The temperature of blood into the chamber, \( T_{m,i} = 6 °C \)
3. Temperature blood out chamber, \( T_{m,o} = 37 °C \)
4. The diameter of the blood hose, \( D_i = 6 \text{ mm} \)
5. The outer diameter of the blood hose, \( D_o = 9 \text{ mm} \)
6. The length of the blood hose, \( L = 60 \text{ cm} \)
7. Blood properties \( k = 0.52 \text{ W/m K} ; \; c_p = 3617 \text{ J/kg K} ; \; \rho = 1060 \text{ kg/m}^3 \) [7]

With Equation (2), blood convection coefficient can be found to be \( \tilde{h} = 317.2 \text{ W/m}^2\text{K} \). Calculation of mass rate of blood through the hose obtained using Equation (2) \( \dot{m} = 4.57 \times 10^4 \text{ kg/s} \). Thus obtained blood flow through the hose at \( Q_b = \dot{m} / \rho = 4.31 \times 10^{-4} \text{ m}^3/\text{s} = 0.43 \text{ mL/s} = 25.8 \text{ mL/min} \). The time for the blood takes to reach temperatures of 37 °C by Equation (7) is about 39 seconds. Setting the blood flow in order to reach the debit at 25.8 mL/s was conducted by turning the hose clamp the blood. Blood flow calculation results are shown in Table 4.

Step calculations of hot water discharge and the discharge of blood can be applied to the use of geothermal directly on a small stream and a temperature between 50-60 °C. However, considering that the geothermal heat source generates heat that is unstable will require further studies regarding the stability of the temperature so as to produce a uniform temperature on the plate.

**Table 4. Blood flow calculation**
4. Conclusions
Based on the studies that have been done, it can be concluded as follows:
1. Blood Warmer can be application use of geothermal direct use.
2. Configure the plate at an angle of 0° can be used as a heating plate in the blood which can produce a warmer temperature of 37.20 °C - 40.15 °C by regulating the discharge of hot water from the heater of 21.47 mL/s - 24.80 mL/s.
3. To reach 37 °C, the blood flow in the discharge of 28.30 mL/min and heating takes 39 seconds.

5. Nomenclature
\( \bar{h} \) = average coefficient of blood convection (W/m²K)
\( A_s \) = Surface area of blood tube (m²)
\( \Delta T_{LM} \) = Logarithmic mean temperature (K)
\( m \) = Mass rate of blood (kg/s)
\( c_p \) = Heat capacitance of blood (J/kgK)
\( T_s \) = Temperature surface (°C)
\( T_{m,i} \) = Temperature inlet (°C)
\( T_{m,o} \) = Temperature outlet (°C)
\( \bar{T_m} \) = Temperature average between inlet and outlet (°C)
\( \Delta T_i \) = Difference temperature between temperature surface and inlet (K)
\( \Delta T_o \) = Difference temperature between temperature surface and outlet (K)
\( T_{o,\text{out}} \) = Outside temperature of plate (°C)
\( T \) = Plate temperature
\( \bar{N}_{H_D} \) = Nusselt number for blood in the hose
\( \text{Re}_D \) = Reynolds number for water in the chamber
\( Q \) = a discharge of hot water that flowed into the chamber.
\( Q_b \) = Flowrate of blood (mL/s)
\( L \) = Length of blood tube (m)
\( D_i \) = Inner diameter of blood tube (m)
\( D_o \) = Outer diameter of blood tube (m)
\( t \) = Total time the blood flows on the plate (s)

References
[1] http://www.esdm.go.id/berita/55-siaran-pers/3021-pengembangan-energi-panas-bumi-di-indonesia.html accessed on 26/01/2016
[2] http://www.nova.org.au/technology-future/feeling-heat-geothermal-energy accessed on 2/02/2016
[3] T Poder, W Nonkani, and E Leponkouo, (2015), “Blood Warming and Hemolysis: A Systematic Review With Meta-Analysis”, Transfusion medicine Reviews, 29, p. 172 – 180
[4] F Anugrah, (2015), “Design, Manufacture and Testing Heater Capacity 2 Bar”, Undergraduate Thesis, ITB
[5] http://www.cedar.wales.nhs.uk/sitesplus/documents/1091/CEP10014%20IV%20fluid%20warmers%20MR.pdf accessed on 27/11/2015
[6] F Incropera & D Dewitt, (2011), “Introduction To Heat Transfer 6th Edition”, New York.
[7] http://www.itis.ethz.ch/virtual-population/tissue-properties/database/heat-capacity/ accessed on 26/02/2016

[8] J Cutnell and K Johnson, (1998), “Physics, Fourth Edition”, Wiley, p: 308