Analysis of macro channel heat exchanger for fever relief cool cap using thermoelectric

C Y Goh¹, M N Y Rahman¹, Z M Razlan¹,*, S A Bakar¹, W K Wan¹, I Zunaidi², A Harun³, M S M Hashim¹, M K Faizi¹, I Ibrahim¹, N S Kamarrudin¹ and M S Muhamad Azmi¹

¹School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis Malaysia
²Faculty of Technology, University of Sunderland, St Peter's Campus, Sunderland, SR6 0DD, United Kingdom
³School of Microelectronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis Malaysia

*Corresponding author: zuradzman@unimap.edu.my

Abstract. Fever is happened when the human having infection or other illness which the body temperature is higher than normal body temperature. The heat load released during the fever cause the uncomfortable condition to the human. Thermoelectric is used in the design of heat exchanger to provide cooling by using electricity which reliefs the fever uncomfortable. The thermal comfort zone for human and the analysis of the heat load from the human head surface are determined. The analysis focuses on the fever teenagers aged range from 15 to 25. The range of the thermal comfort zone is from 20 ° C to 25 ° C whereas the range for the total heat load from the head surface is from 10.56 W to 16.39 W. The findings from the analysis will be used in the design of heat exchanger that suites the requirement from the analysis result. The fluid flow effect of the working fluid and thermal effect of the heat exchanger are simulated by ANSYS Fluent. In addition, the different types of Peltier plate and fluid as well as the different materials of heat exchanger and tube have applied into heat exchanger design model for observing the effect of the fluid flow in heat exchanger. Using ANSYS Fluent, the temperature contours are compared and found that the combination of alumina Al₂O₃ nanofluid, copper heat exchanger have better performance due to high heat transfer rate while the tube materials show no effect. The best performance of cooling in the design of the heat exchanger is proposed. These design criteria include the selection of the material of heat exchanger, tube and fluid as well as the selection of the device such as Peltier plate, battery, cooler fan and pump.

1. Introduction
The range for human normal body temperature is between 36.5 °C and 37.5 °C, which the condition that over the range will be known as fever. Fever is happened when the human having infection or other illness, the thermostat in human body readjusts which results fever to fight the infections. However, a high body temperature more than 39.5 °C will result some serious consequences such as hyperthermia and heat stroke that may cause the brain damage or even cause death to the human beings. Thermoelectric uses the new technology to generate electricity by using a temperature difference and to provide heating or cooling by using electricity. Thermoelectric is used in medical...
profession to reduce human high fever body temperature [1]. It is believed that the design of the heat exchanger cooling systems can relieve the fever uncomfortable and release the heat load from head surface to achieve thermal comfort by using thermoelectric. In the medical field, the thermoelectric Peltier elements are used in the cooling of living tissues [2].

The aims of this research are to study the human body behaviour on heat and to analyse the heat load on the human head surface. At the same time, the aims are to do heat transfer analysis in heat exchanger and propose the design of heat exchanger that suites the requirement. The analysis focuses on the fever teenagers aged range from 15 to 25 and focuses on the human head surface. The design of the heat exchanger is focused on the parameters such as the types and the materials of the parts. The analysis is done on the fluid flow effect and thermal effect of the heat exchanger which are simulated by ANSYS Fluent.

2. Methodology

2.1. Analysis of heat load on head surface

A group of the teenagers who aged from 15 to 25 and who had a fever are picked to record their measurement data. The measurement data needed are mass, height and the fever temperature. These measurement data help to determine a range of the heat load from the head surface. The measurement data is aimed to collect from 10 male teenagers and 10 female teenagers. The mass of the teenagers is measured by using a weight scale while the height of the teenagers is measured by using wall mounted height rods. Furthermore, the fever temperature of the teenagers is measured by using body non-contact infrared thermometer. Below are the formulae used in the analysis.

\[
\dot{Q}_{\text{rad}} = \varepsilon \sigma A_s (T_s^4 - T_{\text{sur}}^4), \quad (1)
\]

\[
A_s = 0.202 \, h^{0.425} \, T^{0.725}, \quad (2)
\]

\[
\dot{Q}_{\text{cond}} = k A \frac{\Delta T}{\Delta x}, \quad (3)
\]

\[
\dot{Q}_{\text{latent}} = \dot{m}_{\text{vapor}} h_{\text{fg}}, \quad (4)
\]

2.2. The model of the heat exchanger

The brief idea of the design is presented in the schematic diagram in Figure 1. In the model, the heat is absorbed by the heat exchanger from the human head surface. The working fluid inside the heat exchanger transfer the heat by working fluid through the function of the pump which generates the mass flow. The heat is then passed to the water tank and the heat is absorbed by the Peltier plate. Heat is released through the hot side of the Peltier plate by the use of a heat sink and a fan. A real and more detailed of the whole model of the heat exchanger is displayed in the Figure 2. A power source is used to provide current to the Peltier plate, fan and pump. Furthermore, a microcontroller is used to control the performance of the Peltier plate, fan and pump by limiting or controlling the current direct to them.

2.3. Analysis and design of the heat exchanger

The model of the heat exchanger is used for thermal analysis in the ANSYS Fluent. The fluid flow and thermal analysis is done by changing the parameters to determine the highest heat transfer rate and the best performance for the design. The parameters concerned are the types of Peltier plate and fluid as well as the materials of heat exchanger and tube. There are five types of Peltier plates such as TM 71-1.0-3.0, TM 127-1.0-3.0, TM 71-1.0-4.0, TM 31-1.0-6.0 and TM 71-1.0-6.0 are considered in the design. The fluids considered are water and alumina nanofluid Al₂O₃ [3], [4]. For heat exchanger materials considered are aluminium and copper whereas for tube materials considered are plasticized polyvinyl chloride (PVC-P), polypropylene and the silicone rubber.
3. Result and Discussion

3.1. Study of human body behaviour on heat
The topic for the human body behaviour on heat is studied and is explained in mechanical definition. A constant human core body temperature between 36.5 °C to 37.5 °C must be maintained, which the purpose is to prevent the high temperature damages the body systems; if above the temperature is called fever. Heat generation and heat dissipation are the types of heat transfer in human body. These heat transfer in human body is done by metabolic heat production, heat conduction, heat convection, heat radiation and evaporation.

In addition, the important part for the human body behaviour on heat is the thermal comfort for human which is the individual satisfaction thermal environment condition. A range from 20 °C to 25 °C is the thermal comfort range for human [5]. A lower than or higher than the range temperature will cause discomfort for the human. This range of thermal preferences is used as the preferable temperature in the design of heat exchanger for the human fever relief.

3.2. Determination of the heat load on the head surface
The data measurements for the 20 fever teenagers who aged range from 15 to 25. The heat load by conduction, radiation and evaporation are calculated and they are summed up to the total heat load from the head surface. The evaporation heat is assumed to be the same for all the teenagers. From the study, the range for the total heat load from the head surface is from 10.56 W to 16.39 W.

| Minimum Heat Load | Maximum Heat Load |
|-------------------|-------------------|
| Male              | 13.26 W           | 16.39 W           |
| Female            | 10.56 W           | 14.37 W           |

3.3. Thermal analysis of heat exchanger
The model of the heat exchanger is cut into symmetry since the both left side and right side are the same. By cutting the model into symmetry, the analysis will be easier and faster. Outside the model is the case for the cooling system, while inside the model is the fluid domain which will be determined the flow and the heat transfer rate.

There are total of 12 conditions by different materials, such as heat exchanger (aluminum or copper), tube (PVC-P, polypropylene or silicone rubber) and fluid (water or alumina nanofluid). The
boundary condition is set to the temperature of heat is 38 °C and the temperature of cooling is 5 °C. The tube materials show no effect on the heat transfer rate. For the heat exchanger materials show a little effect whereas the different fluid shows significant effect. Figure 3 shows the significant effect on the fluid flow and heat transfer rate by changing the working fluid and the heat exchanger materials.

![Figure 3. Temperature Contour](a) Water and Aluminium Heat Exchanger, (b) Water and Copper Heat Exchanger, (c) Nanofluid and Aluminium Heat Exchanger, (d) Nanofluid and Copper Heat Exchanger]

3.4. Design of the heat exchanger

The design will consider Lithium Polymer (LiPo) battery pack or Power bank to provide power source to power the Peltier plate. When using the LiPo battery pack, the current is set to have 20 W of heat absorbed in Peltier plate, whereas the current in power bank is 2.1 A which determines the Peltier plate that has at least 20 W of cooling. Table 2 and Table 3 show the results of suitable Peltier plate.

### Table 2. Values of Heat Load Absorbed by Peltier Plate using LiPo Battery Pack

| Part Number | I (A) | V (V) | Q̇ (W) | Ṗ (W) |
|-------------|-------|-------|-------|-------|
| TM 127-1.0-3.0 | 2.0 | 10.0 | 20.0 | 20.00 |
| TM 71-1.0-4.0 | 3.9 | 8.2 | 16.0 | 31.98 |
| TM 71-1.0-6.0 | 3.8 | 5.8 | 20.0 | 22.04 |
Table 3. Values of Heat Load Absorbed by Peltier Plate using Power Bank

| Part Number   | I (A) | V (V)  | Q̇c (W) | P_in (W) |
|---------------|-------|--------|--------|-----------|
| TM 127-1.0-3.0| 2.1   | 12.0   | 21.0   | 25.20     |
| TM 71-1.0-4.0 | 2.1   | 5.0    | 9.0    | 10.50     |
| TM 71-1.0-6.0 | 2.1   | 3.1    | 12.0   | 6.51      |

The design of the heat exchanger will be proposed to improve the performance. The proposal of the heat exchanger will include the selection of the material of heat exchanger, tube and fluid as well as the selection of the device such as Peltier plate, battery, DC cooler fan and pump. This proposal is proposed in the mechanical definition. Table 4 shows the proposal made based on the results.

Table 4. The selection for the design of heat exchanger with description.

| Design Criteria            | Selection Proposed  | Description                                  |
|----------------------------|---------------------|----------------------------------------------|
| Material of heat exchanger | Copper              | Higher heat transfer rate                     |
| Material of tube           | Silicone Rubber     | Higher percentage of elongation, soft material|
| Fluid                      | Alumina nanofluid   | Higher heat transfer rate                     |
| Types of Peltier plate     | TM 127-1.0-3.0      | Able to absorb 20 W of heat load with low power input |
| Battery                    | LiPo battery pack   | Able to provide higher current and voltage   |
| Fan                        | DC cooler fan       | Able to provide the air flow rate of 0.1302 m³/min |
| Pump                       | DC micro pump       | Able to provide the water flow rate of 0.0249 x 10⁻³ m³/min |

4. Conclusion and Recommendation

In a nutshell, the human body behaviour on heat is studied and the analysis of the head surface heat load is done. The thermal behaviour of the heat exchanger cooling system is investigated by using ANSYS Fluent. The effect of changing the materials in the heat exchanger cooling system is analysed as well. Last but not least, the design of heat exchanger cooling system that having the best cooling performance is proposed. By summing up all the results, the conclusions are:

- The human body behaviour on heat is done by metabolic heat production, heat conduction, heat convection, heat radiation and evaporation. The range of the thermal comfort for human is from 20 °C to 25 °C.
- The analysis of the heat load on the human head surface shows there is a different heat load between genders. A range from 10.56 W to 16.39 W of the heat load is analysed from them.
- Based on the temperature contours, alumina nanofluid and copper heat exchanger have a higher heat transfer rate, whereas there is no effect on changing the tube materials.
- A combination of copper heat exchanger, silicone rubber tube, nanofluid, Peltier plate model TM 127-1.0-3.0, LiPo battery pack, DC cooler fan and DC micro pump is proposed for the design to boost the performance of cooling system.

In this research, the heat exchanger cooling system is analysed by changing the fluid as well as the materials for heat exchanger and tube. There is a significant effect on heat transfer by changing of fluid. However, a different dimension of the heat exchanger may affect the performance and the
heat transfer rate. Hence, it is recommended to research and study on the effect of changing the dimension of the heat exchanger.

In addition, this research is studied and a best performance of the design for heat exchanger is proposed in the mechanical definition only. Therefore, this research of design best performance of the heat exchanger in term of mechatronic field or electrical field is suggested to study in the future. For example, the design of microcontroller to control the current passing through the Peltier plate, DC cooler fan and DC pump. A changing of the current in power source may affect the performance of the Peltier plate, DC cooler fan and DC pump. At the same time, this may affect the heat transfer rate in the heat exchanger as well which it is recommended to study the design of the heat exchanger in term of mechatronic field or electrical field.

Acknowledgments
The author would like to acknowledge the support from the Malaysian Institute of Road Safety Research (MIROS), Ministry of Transport Malaysia for their research grant scheme under Universiti Malaysia Perlis (UniMAP) project code number of 9002-00072.

References
[1] Baldry M, Timchenko V and Menictas C 2018 Thermal modelling of controlled scalp hypothermia using a thermoelectric cooling cap J. Therm. Biol. 76 8–20.
[2] Uhlik M and Sladecek V 2018 Cooling Device with Peltier Element for Medical Applications IFAC-PapersOnLine 51 (6) 54–59.
[3] Ho C J, Liao J -C, Li C -H, Yan W -M and Amani M 2019 Experimental study of cooling performance of water-based alumina nanofluid in a minichannel heat sink with MEPCM layer embedded in its ceiling Int. Commun. Heat Mass Transf. 103 1–6.
[4] Afifah A N, Syahrullail S and Nor Azwadi C S 2015 Natural convection of aluminium oxide-water nanofluid J. Teknol. 75 (11).
[5] Lechner N 2015 Heating, cooling, lighting : sustainable design methods for architects.