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TEMPERATURE DECREMENT RATE OF BATH TUB WATER FOR ICE BATH THERAPY

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ABSTRACT
The objectives of this study are to evaluate the decrement rate in the ice bath water temperature in different environment conditions and study the decrement rate in the ice bath water temperature using a different pump capability. First, in the study of different environment conditions, the decrement rates of water temperature were tested with and without top cover. In addition, both conditions were tested with their environments i-exposed directly to sunlight, ii-exposed indirectly to sunlight and iii-tested in the air-conditioned rooms. The study was done experimentally using a chiller provided by Institut Jantung Negara (ISN). Second, in the study of the decrement rate in the ice bath water temperature, two pumps with Hilea chiller are considered. Two pumps with different flow rate were used using Hailea chiller model HS-90A where 1400 litre per hour and 4000 litre per hour of pump were tested. All temperature data for each experiment were taken and plotted in the graph using linear equation y = mx + c for each experiment. Using the equation, the duration of time required for the ice bath water temperature reaches 12°C can be evaluated. Therefore, the best experimental conditions can be determined through the shortest period of time. Where the test done in air-conditioned rooms and bath tub with top cover were the best conditions for ice bath cooling process. Whereas, for the test with different pump flow rate, pump A with 1400 litre per hour has a better rate of temperature decrease compared to pumps B with 4000 litres per hour.

Keywords: temperature decrement, ice bath therapy.

INTRODUCTION
Ice bath treatment has become a popular treatment to overcome the "Delayed Onset Muscle Soreness" (DOMS). DOMS is pain that occurs in muscles usually caused by strenuous exercise (Armstrong, 1990). Usually, this treatment is performed by immersing the athlete in a container filled with water and ice. Water and ice cubes will be entered into the containers provided. When the temperature reached about 12°to 15°C, then an athlete will be entered into the container filled with water and ice. Immersion usually done for 10 to 15 minutes sometimes can reach up to 20 minutes (Fatima, 2010). In addition, the treatment of alternating cold and warm has also performed as an alternative treatment for this therapy (Bleakly, 2012). Figure-1 shows ice immersion therapy with and without the use of ice cubes.

At National Sports Institute, ice bath therapy and also known as ice cool bath requires approximately two hours to two hours and 30 minutes of duration for cooling process of ice bath therapy to the desired temperature. However, according to National Sports Institute, the duration is still too long for the cooling process. Therefore, a study of place and environment that most suitable for cooling process of ice bath therapy were done. Where, the environment is one of the important factors that affect the rate of cooling of ice bath therapy. This is because the condition and ambient temperature of surrounding have a major impact on the cooing process of ice bath therapy. A study was done to study the rate of decrease in the ice bath water temperature in different environmental conditions and using different chiller pump capability.

Figure-1. Cooling bath therapy with and without ice cubes.

Several studies on ice bath therapy especially in cooling process without the use of ice cubes have been drawn many researchers interest.

Lei Zhao *et al.* (2013) explained basic cycle cooling process gas compression that similar used in water cooling machine. Ice water immersion cooling device using gas compression refrigeration system has four basic components in the gas compression refrigeration system. This component is the compressor, condenser, expansion valve and evaporator.

Other than cooling process gas compression technique, there are many alternatives cooling technologies being developed and has potential to replace gas compression technology (Fischer, *et al.*, 1994). Alternatives cooling technologies include trans-critical CO_2 refrigeration system (Brown, *et al.*, 2014), solar absorption cooling system (Wang, *et al.*, 2009) and thermo-acoustic refrigeration (Garrett, 2004). Trans-critical CO_2 refrigeration and solar absorption cooling system has similar features to gas compression cooling. Except for the coolant used is CO_2 (R-744) and the heat released into force on the critical temperature of the coolant of 31 °C compared to the commonly used refrigerant which is 101.1 °C for R-134a. Meanwhile in solar absorption cooling system, thermal energy will be replaced with mechanical energy from the solar collector to drive condenser and compressor. In third technologies of thermo-acoustic refrigeration, acoustic energy is converted into heat energy. In which the acoustic wave will react in expansion of then coolant and thus reduces the pressure and temperature of the coolant. The differences in pressure will affected the process of cooling and heating.

Shahril (2015) studied differences in the time taken to cool the water to the desired level when the inlet and outlet pipes location were changed. It was found that pipe arrangement plays an important role in the process of cooling the ice water immersion. The results showed that the position of the pipe placed at two opposite ends provide fastest decreases in the water temperature compared to other positions. The wider the distance between the ends of pipes and pipe products enter the shorter the time to lower the water temperature.

This study evaluates the decrement rate of temperature in ice bath tub specifically for ice bath therapy. The experiments had been conducted in two conditions comprises different environmental temperature and using coolant pump with different flow rate capability. The next part will discuss on experimental set up and testing procedures. The results then will be analysed and discussed corresponds to the data acquired. Finally, the conclusion will be made correspond to the aims of this study.

EXPERIMENTAL SET UP AND TESTING

Some experiments set-up have been made to obtain the decrement rate of bath tub temperature. For the study in different environment conditions, the decrement rates of water temperature were tested with and without top cover. In addition, both conditions were tested within different environments i-exposed directly to sunlight, ii-exposed indirectly to sunlight and iii-tested in the air-conditioned rooms. The study was done experimentally using a chiller provided by Institut Jantung Negara (ISN). A chiller consists of basic components such as a motor, compressor, condenser, evaporator and the valve. Meanwhile for the study of the decrement rate in the ice bath water temperature, two pumps with Hilea chiller with different flow rate capability of 1400 and 4000 litre per hour were considered.

The testing will be conducted with following different set up:

i. ISN Chiller + Bath Tub without Top Cover + Without Direct Sunlight.
ii. ISN Chiller + Bath Tub without Top Cover + With Direct Sunlight.
iii. ISN Chiller + Bath Tub without Top Cover + Air-Conditioned Room.
iv. ISN Chiller + Bath Tub with Top Cover + Without Direct Sunlight.
v. ISN Chiller + Bath Tub with Top Cover + With Direct Sunlight.
vi. ISN Chiller + Bath Tub without Top Cover + Air-Conditioned Room.
vii. Hailea Chiller + Bath Tub with Top Cover + Air-Conditioned Room + 1400 litre per hour Pump.
viii. Hailea Chiller + Bath Tub with Top Cover + Air-Conditioned Room + 4000 litre per hour Pump.

Set up for vii and viii are conditions for second testing. Figure-2 and 3 show different chiller of ISN and Hilea respectively.

Figure-2. ISN chiller.

Figure-3. Hailea chiller.

Measurements were made using thermocouple where it can detect temperature changes of input and output pipeline system. The sensor is then connected to the TC-08 Thermocouple Data Logger that stores temperature data during the experiment. Figure-4 shows bath tube that had been tested with top covered. Positions of thermocouple was located between inlet and outlet pipe as shown in schematic diagram of Figure-5.

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Figure-4. Bath tube.

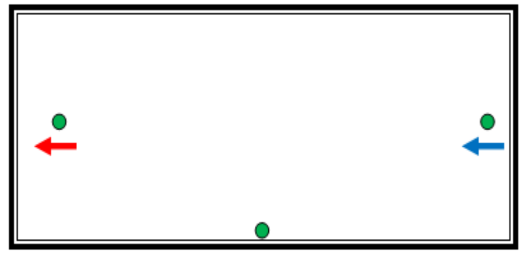

Figure-5. Position of thermocouple, inlet and outlet pipe.

Table-1. Result of time and rate of temperature decreases for ISN chiller.

Test condition		Rate of temperature decrease		Conclusion
		Rate of decrease, *m*	**Time to reach 12 °C (minute)**	
ISN Chiller + Bath Tub Without Top Cover	1) Without Direct Sunlight	0.0796	150.04	Test was done in Air - Cond Room is the best.
	2) Direct Sunlight	0.0412	167.38	
	3) Air - Conditioned Room	0.1341	84.29	
ISN Chiller + Bath Tub With Top Cover	4) Without Direct Sunlight	0.106	126.75	Test was done in Air – Conditioned Room is the best
	5) Direct Sunlight	0.0587	136.41	
	6) Air - Conditioned Room	0.1343	76.99	

Table-2. Result of time and rate of temperature decreases for Hailea chiller.

Test condition		Rate of temperature decrease		Conclusion
		Rate of decrease, *m*	**Time to reach 12 °C (minute)**	
Hailea Chiller + Bath Tub with Top Cover + Air - Conditioned Room	7) Pump A - 1400 litre per hour	0.0346	126.75	Test was done using pump A with 1400 litre per hour is the best
	8) Pump B - 4000 litre per hour	0.0305	136.41	

RESULT AND DISCUSSIONS

Based on the data that been plotted in the graph, the linear equation was derived for each test condition. Then, the rate of decrease from the value of m from equation $y = mx + c$. After that, time taken for the temperature to reach 12°C was calculated to see which condition has the shortest time needed to reach 12°C.

From Figure-6 to 8, temperature readings was taken within 277 minutes in different day. The highest temperature decreases at 0.134 for ISN Chiller and bath tub without top cover were observed in air conditioning room. Without exposed to direct sunlight the temperature decrement 0.076 is higher if compared with exposed to direct sunlight i.e. 0.0412. Unsteady temperature under direct sunlight do not facilitate the process of cooling. Testing within lab environment aircond was observed that time to reach 12 ^{0}C in 84.295s is the shortest.

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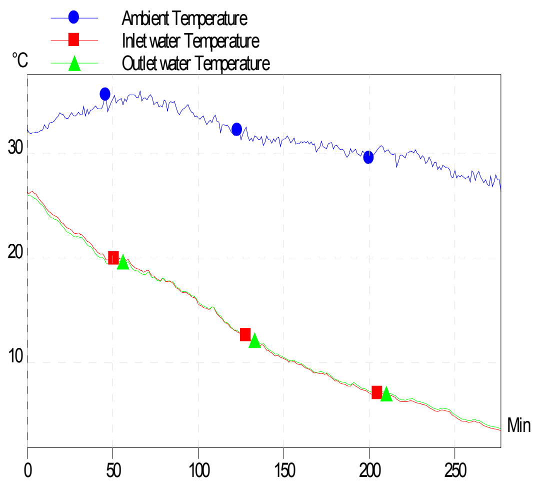

Figure-6. Graph for testcondition i.

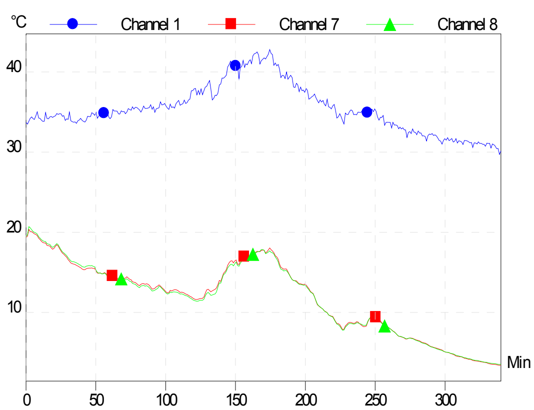

Figure-7. Graph for testcondition ii.

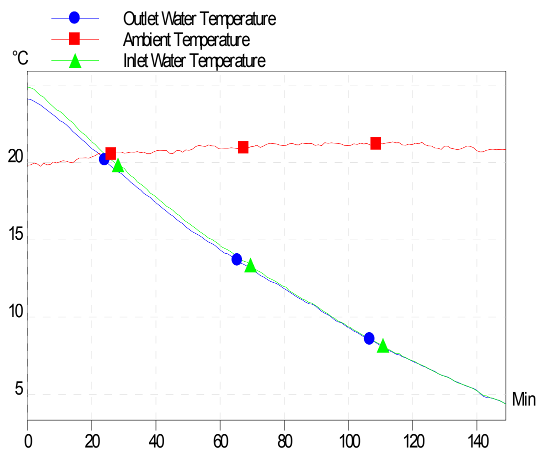

Figure-8. Graph for testcondition iii.

From Figure-9 to 11, temperature readings were recorded for bath tub with top cover with similar duration in different day. Without exposed to direct sunlight the temperature decrement 0.1343 is higher if compared with exposed to direct sunlight i.e. 0.0587. However steady temperature under direct sunlight also do not facilitate the process of cooling. Testing within lab environment aircond was observed that time to reach 12°C in 84.295s is the shortest.Comparing both data, it shows that bath tube with top cover and air condition room arrangement, still has a room of improvement.

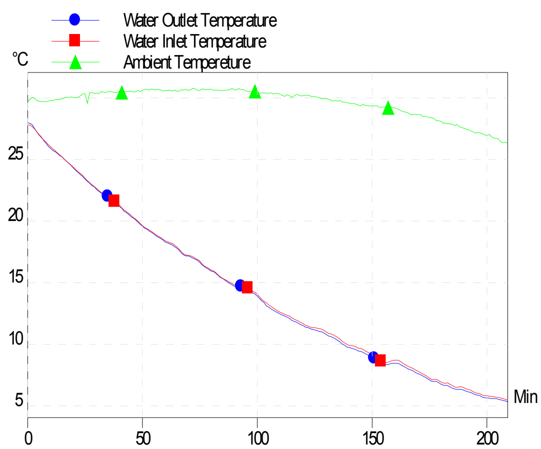

Figure-9. Graph for testcondition iv.

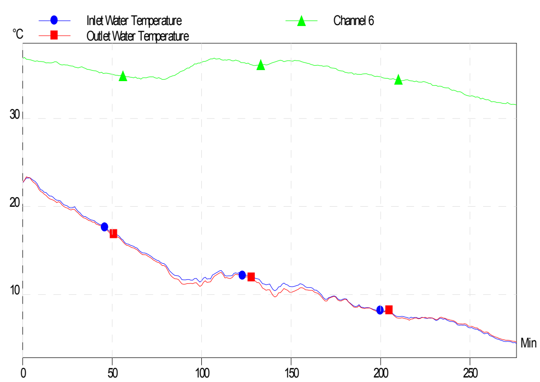

Figure-10. Graph for testcondition v.

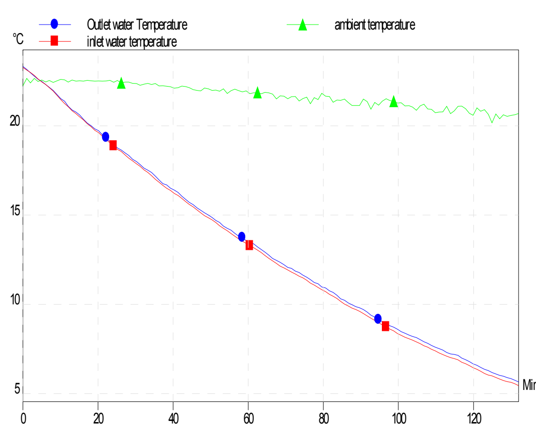

Figure-11. Graph for testcondition vi.

Using Hailea Chiller with environment of bath tub and top cover and under air conditioning room, Figure-12 and 13 shows linear correlation between 1400 l/hour and 4000 l/hour pumps.It also seen that overuse of 4000l/hour as its performance. This means that high flow rate pump does not necessarily give a higher temperature decrease rate.

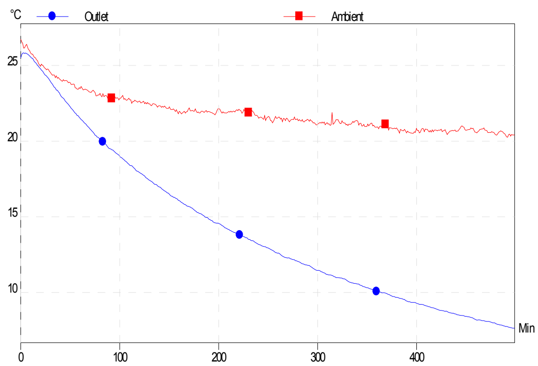

Figure-12. Graph for testconditio n vii.

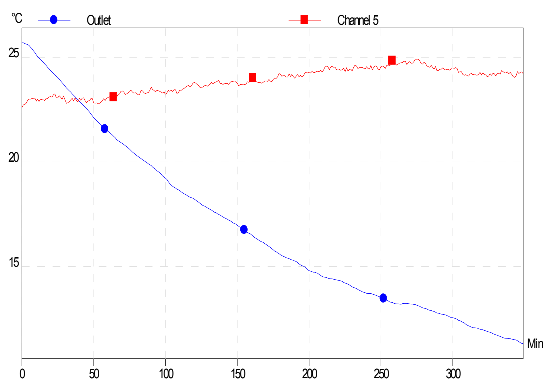

Figure-13. Graph for testcondition viii.

CONCLUSIONS

Experimental conditions in air-conditioned rooms have the highest drop in temperature compared to other conditions. Meanwhile, the condition of the experiment that without direct sunlight is the second highest in both experiments. Direct sunlight experimental condition has the lowest value compared to others. For the experimental conditions using pumps, pump A with flow rate 1400 litres per hour had the highest decrease of temperatures below 10 °C compare to pump B that has 4000 litre per hour flow rate. This shows that the pump with higher flow rate does not necessarily give higher rate of temperature decrease especially in ice water immersion.

Overall, the state and the best place to carry ice water immersion chilling process are in the air-conditioned rooms and bath tub with top cover. In addition, using a pump capable of much higher flow rates do not necessarily mean that the increase in the rate of decrease in temperature. Therefore, a suitable pump should be used to get the best rate of temperature decrease.

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