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By I Nyoman Suamir

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Thermal Performance of Bio-Nano-PCM based Passive Cooling for Vaccine Carriers I Nyoman Suamir a, I Wayan Adi Subagia b, Luh Putu Ike Midiani c, I Dewa Gede Agus Tri Putra d and I Made Rasta e Mechanical Engineering Department, Politeknik Negeri Bali, Campus Street, Kuta Selatan, Badung, Bali 80364, Indonesia Keywords: Temperature Performance, Bio-Nano-PCM, Passive Cooling, Vaccine Carrier. Abstract: Vaccine storage requires special attention because vaccines are biological supplies that are susceptible to changes in environmental temperature. Vaccines are also biological products that are easily damaged so they must be stored at temperature of 2 to 8 ºC. The vaccine can be damaged if exposed to direct sunlight. The vaccine distribution box (vaccine carrier) presented in this paper was developed with considerations the box is easy to carry, have aesthetics, light weight, practical use and save energy while still having good cooling capabilities of 2-8 ºC. The vaccine box incorporates 3.2 kg Bio-Nano PCM as cold thermal storage material. The box has a capacity of 2.8 liters or capable of loading 20 bottles of vaccine. Total weight of vaccine carrier is approximately 7 kg. Test results

showed that Bio-Nano PCM technology integrated in the vaccine carrier box could cool and kept the vaccine at temperature range of 2-8 ºC for more than 24 hours. 1 INTRODUCTION In the current situation of the Covid-19 pandemic, the distribution of vaccines is very important and vital for the people of Indonesia. The Indonesian government is currently preparing various types of vaccines for all Indonesian people. Considering that Indonesia is an archipelagic country consisting of 34 provinces, the distribution of vaccines is very important for the community so that when the vaccine arrives it is still in good and safe conditions. In general, vaccine distribution boxes (vaccine carriers) are indeed needed in the national vaccine program for eradicating infectious diseases and infections. More specifically, the national Covid-19 vaccination program is urgently needed to protect and prevent the spread of the Covid-19 pandemic in Indonesia (World Health Organization, 2020). Vaccination or immunization is very important for both children and adults. Therefore, immunization can prevent the transmission of various diseases and infections by increasing the body's immunity. The
a https://orcid.org/0000-0003-0594-7511 b https://orcid.org/0000-0001-9261-3549 c https://orcid.org/0000-0002-2256-6035 d https://orcid.org/0000-0002-9422-7876 e https://orcid.org/0000-0002-9610-3738
obstacle encountered in immunization activities in Indonesia is maintaining the cold chain from the vaccine manufacturer until the immunization activity is carried out. Cold chain is a procedure and devices used in the delivery or storage of vaccines starting from the manufacturer until the vaccines are given to the community. Vaccine storage requires special attention because vaccines are biological supplies that are susceptible to change in environmental temperature. According to the Minister of Health Regulation number 12 (2017) concerning the implementation of immunization, it is stated that vaccines are biological products that are easily damaged so they must be stored at a certain temperature, namely at a temperature of 2 to 8ºC for freeze sensitive vaccines (not frozen), and at a temperature of -15 to -25ºC. for heat sensitive vaccines. Currently, only polio vaccine still requires storage at temperatures below 0 °C. A number of vaccines can potentially be damaged if they exposed to freezing temperatures. Meanwhile, other vaccines can potentially be damaged if they exposed to hot
Suamir, I., Subagia, I., Midiani, L., Putra, I. and Rasta, I. Thermal Performance of Bio-Nano-PCM based Passive Cooling for Vaccine Carriers. DOI: 10.5220/0010944900003260 In Proceedings of the 4th International Conference on Applied Science and Technology on Engineering Science (iCAST-ES 2021), pages 329-334 ISBN: 978-989-758-615-6; ISSN: 2975-8246

temperatures. In general, the vaccines, however, can be damaged if they exposed to direct sunlight (Primadi, 2017). The toughest obstacle arises when it comes to bringing vaccines to remote areas that do not yet have major infrastructure such as motorized driveways and electricity networks to run refrigerators. The tools commonly used in the distribution of vaccines for long distances are cold boxes that use icepacks as a cooling medium. The tools have disadvantage of not being able to maintain the temperature of the vaccine in the proper range from 2-8 °C, as well as they have a limited cooling time. Efforts have been made to help overcome this problem, prototype vaccine carriers have been developed using a Peltier element (Putra et al., 2005; Putra et al., 2006; Putra, 2006). The vaccine boxes developed with Peltier elements is able to maintain the vaccine temperature from 2-8 °C, but they still have disadvantages in terms of prototypes compactness and they also still require other supporting equipment which makes the products are less practical. The concepts of the vaccine carrier have also been developed in Indonesia. The concepts are based on thermo-electric refrigeration and are also combined with ice-packs. The first concept was developed at the University of Indonesia. This vaccine carrier looks less practical when carried by health workers as a carrier. The second concept was developed by ITS Surabaya. This vaccine carrier concept uses thermoelectric refrigeration with power supply from solar panels and is combined with ice-pack or blue- ice. The technology concept applied to the vaccine carrier developed in this study is the concept of passive cooling (passive refrigeration) using a cold storage material based on natural materials, namely Bio-Nano PCM with a phase change temperature in the range of 0 °C as an application. sustainable technology. The Bio-Nano PCM is housed in an encapsulation and integrated with a specially designed heat transfer wall so that it is able to maintain the vaccine chamber temperature in the range of 2-8 °C. The volume of Bio-Nano-PCM was designed so that the vaccine carrier is able to maintain a minimum time storage for 24 hours. For comparison purposes, the paper also presents the most famous PCM that is water because it has good thermal properties, but has the disadvantage of high super-cooling when applied as thermal storage at below 0 °C. Bio-PCM using ester oil in water mixture is also presented as an alternative use of the bio-thermal energy storage. The Bio-PCM has a good advantage with lower super cooling than pure water but it can maintain the advantage of high phase change enthalpy of the water as reported in Rasta and Suamir (2018), Rasta and Suamir (2019), and Suamir et al. (2019). The bio-Nano PCM vaccine carrier developed in this study was also designed through a concept of applying appropriate technology which was made to meet the right needs according to its use. The use of technology is in accordance with local natural, social, economic and cultural conditions and can help improve the economic standard and quality of life of the community. Therefore, the technology has to have technical characteristics, such as easy to manufacture, safe to use, economically inexpensive, low impact to the environment and energy efficient (Putra et al., 2006; ITSmis, 2020; Pearce et al., 2014; Zelenika and Pearce, 2011). The technology is also projected to be applicable, comfortable, healthful, practical and efficient (Zelenika and Pearce, 2012; Pearce, 2012; Shin et al., 2019; Patnaik and Bhowmick, 2019, Boakye-Ansah, 2020). 2 MATERIALS AND METHODS 2.1 Vaccine Carrier Box The development of the vaccine carrier with Bio- Nano PCM involved several stages such as design, assembly, installation of instrumentation and performance testing. For the carrier box material, a cool box that is already on the market is used with an outer size of 32 cm x 22 cm x 25 cm as shown in Figure 1. Figure 1: The cool box used as the base container of the vaccine carrier. The Bio-Nano PCM used in this carrier is liquid at room temperature. Therefore, in its integration into the vaccine carrier, the Bio-Nano PCM has to be Thermal Performance of Bio-Nano-PCM based Passive Cooling for Vaccine Carriers contained in an enclosure. In this study acrylic enclosure are applied. There are two types of containers used which include: ice-pack boxes (available in the market) and acrylic enclosures (designed and made specifically to fit in the box and the vaccine bottle holder. The ice- pack bio-Nano PCM enclosures used are 14 with similar size 11 cm x 9 cm x 3 cm and each enclosure can contains 195 g of Bio-Nano PCM. So the total weight of bio-Nano PCM reaches 2.7 kg. Figure 2: The bio-Nano PCM containers and vaccine bottle holder. The acrylic PCM box is made of 5 boxes. With 3 boxes of size 250 mm x 160 mm x 30 mm. Each acrylic box can contain 0.865 kg. Two other smaller boxes size 90 mm x 160 mm x 30 mm which can contain 0.3 kg bio-Nano PCM each. Therefore, total mass of bio-Nano PCM for acrylic boxes is 3.2 kg. The acrylic box construction and the vaccine bottles holder are presented in Figure 2. Figure 3: The cooler box completed with bio-Nano PCM containers and vaccine bottle holder. The bio-Nano PCM vaccine carrier used in this study can be detailed: (i) Vaccine carrier with ice- pack PCM enclosure; (ii) Vaccine carrier with acrylic PCM enclosure. Furthermore, to place the vaccine safely in the carrier, both carriers are equipped with vaccine holders as shown in Figure 2 and Figure 3. Each vaccine carrier can accommodate 2 vaccine holders arranged in two layers: top and bottom. Each holder can accommodate 10 bottles of vaccine, so that each vaccine carrier can accommodate 20 vaccine bottles. Between the vaccine holders and the PCM enclosures, an acrylic wall partition is installed to avoid direct contact between the vaccine holder and the PCM enclosure. The complete assembly of the bio-Nano PCM vaccine carrier is shown in Figure 3. 2.2 Methods The type of research is an experimental study. This research was initiated by conducting surveys and literature studies to obtain secondary data about vaccines and vaccine carriers including storage conditions. A survey was also conducted to obtain the characteristics of the Bio-Nano PCM that can be used so that it is able to maintain the temperature of the vaccine storage room. Simulation methods with inventor and EES (engineering equation solver) were also applied to simulate the design of the Bio-Nano PCM vaccine carrier and components as well as simulation of vaccine room temperature based on secondary data. Furthermore, the simulation was developed using the primary data from the test results. The prototype of the Bio-Nano PCM vaccine carrier was made and function tests were carried out as well as testing the characteristics of the vaccine room conditioning process with various conditions of control variables. Testing is carried out at the laboratory level. Primary data from the test is recorded and processed to obtain a consistent conditioning process and in accordance with the target temperature in the range of 2-8 °C. 3 RESULTS AND DISCUSSION 3.1 Bio-Nano PCM Cooling and Heating Characterization An effective alternative PCM material can be used as a passive cooling material. A vaccine carrier has been tested for the characteristics of charging or cooling and discharging or heating. The test results for tap water, bio-Nano PCM and bio-PCM are presented in Figure 4. From Figure 4, it can be seen that the 10% bio- PCM has a phase change temperature, especially during discharging, which is relatively less stable than the other two materials, namely tap water and bio-Nano PCM. In addition, the phase change time is very short, although the temperature change rate is relatively slow and the phase change temperature (PCT) of -5 °C is quite far from the vaccine temperature requirement between 0 °C and 10 °C precisely in the range from 2 °C up to 8 °C. The 10% bio-PCM is a PCM made from the mixture of 10% of corn oil ester and 90% tap water by volume as reported in Rasta and Suamir (2018). This result shows that if the Bio-PCM 10% is used, the vaccine holder and the Bio-PCM must be equipped with a thermal wall capable of maintaining the temperature difference in such a way that the temperature of the vaccine is in the storage range. Otherwise, the temperature of the vaccine can be drop down below 0 °C then increase sharply to follow the discharging (heating) characteristic as shown in Figure 4. This can also make the vaccine temperature exceed 8 °C in far less than 24 hours. The temperature performance tests were carried out in two stages: (i) the first test was vaccine carrier utilizing acrylic enclosure bio-Nano PCM with total mass of 3.2 kg and the test results are shown in Figure 5; (ii) the second test was vaccine carrier utilizing ice- pack enclosure bio-Nano PCM with total mass of 2.7 kg and the test results are presented in Figure 6. 8°C 2°C PCT-1 (0°C) PCT-2 (-5°C) Figure 4: Charging and discharging test results of PCM alternatives. From the figure, it can also be seen that tap water and bio-Nano PCM are two materials that are very suitable to be used for vaccine carrier applications. These two PCM materials have a PCT at 0 °C. However, the bio-Nano PCM can provide better higher enthalpy difference of phase change. Therefore, the vaccine carrier utilizing Bio-Nano PCM as the passive cooling materials is chosen and discussed in this paper. 3.2 Temperature Performance of the Bio-Nano PCM Vaccine Carrier The test results on the temperature performance of the Bio-Nano PCM vaccine carrier with different PCM enclosure or different PCM mass are presented in Figures 5 and 6. Where T8 is the ambient temperature, T1-3 is the vaccine temperatures and T5-7 is the bio-Nano PCM temperatures. In these tests, water is used to represent the vaccines which are placed in the vaccine bottles. Figure 5: Vaccine carrier test results utilizing bio-Nano PCM with total mass of 3.2 kg. Figure 5 shows the discharging test results of the vaccine carrier utilizing acrylic enclosure bio-Nano PCM with total mass of 3.2 kg. From the graph, it can be clearly seen that the vaccine temperature can be maintained within a safe range between 2 °C and 8 °C for more than 24 hours. At the beginning of the test shows that the vaccines have been store at correct temperature range and then their temperature decrease gradually for about two hours until about 2° C when the bio-Nano PCM temperature is still below its phase change temperature (PCT) of 0°C. Then, the vaccine temperatures very slowly increase for more than 24 hours but still far below 8 °C when bio-Nano PCM temperature reaching its PCT. These show that vaccine carrier with 3.2 kg bio-Nano PCM can keep the vaccines safely for more than 24 hours, precisely 28 hours in total. While Figure 6 shows the test results of the vaccine carrier utilizing ice-pack enclosure bio-Nano PCM with total mass of 2.7 kg. It can be seen that the vaccine temperatures can be maintained within a safe range for only 22 hours. It also shows at the beginning of the test that the vaccines have been store at correct temperature range and then their temperature decrease gradually for about two hours until about 2 °C when the bio-Nano PCM temperature is still below its phase change temperature (PCT) of 0°C. Then, the vaccine temperatures steadily increase for more than 18 hours

but still below 8 °C when bio-Nano PCM Thermal Performance of Bio-Nano-PCM based Passive Cooling for Vaccine Carriers temperature at its PCT. The vaccine temperatures then gradually increase after the bio-Nano PCM temperatures leaving its PCT and the vaccine temperatures exceeding 8 °C after 22 hours. Results presented in Figures 5 and 6 have shown that the time difference of safely maintaining temperature of the vaccines is mainly caused by the different amounts of bio-Nano PCM mass. For the Bio-Nano PCM ice-pack vaccine carrier, PCM mass is 2.7 kg which is much lighter than the acrylic Bio-Nano PCM vaccine carrier with 3.2 kg PCM mass. 8°C 2°C Figure 6: Vaccine box test results using bio-Nano PCM with total mass of 2.7 kg. 4 CONCLUSIONS The vaccine carrier with novel bio-Nano PCM passive cooling has been developed and tested. It is found that vaccine carrier utilized with 3.2 kg bio- Nano PCM can safely maintain the vaccine for more than 24 hours. The vaccine carrier is easy to carry, have aesthetics, light weight, practical use and energy efficient while still having good cooling capabilities of 2-8 ºC. The vaccine carrier has a capacity of 2.8 litres and it is capable of loading 20 bottles of vaccine with total weight of approximately 7 kg.
ACKNOWLEDGEMENTS Authors appreciatively acknowledge the financial support from the Politeknik Negeri Bali through institutional research with funding scheme: DIPA Politeknik Negeri Bali number: SP. DIPA-023.18.2. 677608/2021, dated 23 November 2020. The authors also gratefully thank Centre of Research and Community Services (P3M) Politeknik Negeri Bali for the technical and administrative assistances.
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