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Experimental Investigation on Phase Change Materials as Heating Element for Non-Electric Neonatal Incubator

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Abstract. High number of preterm births is one of the issues in improving health standard. The effort to help premature babies is hampered by high cost of NICU care in hospital. In addition, uneven distribution of electricity to remote area made it hard to operate the incubator. Utilization of phase change material beeswax to non-electricity incubator as heating element becomes alternative option to save premature babies. The objective of this experiment is to investigate the most efficient mass of beeswax according to Indonesian National Standard to earn over time and ideal temperature of incubator. Experiment was performed using prototype incubator, which utilizes natural convection phenomenon in the heating process of incubator. Utilization of fin is to accelerate heat distribution in the incubator. Result of experiment showed that the most efficient mass of PCM is 3 kg, which has 2.45 hours of running time for maintaining temperature of incubator in range of 32-36 °C.

Keywords: Non-electric Neonatal Incubator; Phase Change Material; Beeswax

INTRODUCTION

Indonesia occupied the 5th position in the number of preterm births and the 9th position on the rate of preterm birth per 100 births worldwide. Premature is defined as babies whom are born before 37 weeks of the pregnancy. There are three sub-categories of premature births, which are extremely preterm (<28 weeks), very preterm (28 to <32 week) and moderate to late preterm (32 to <37 week) [1]. Treatment of premature infants is complicated because of the risks that could lead to baby death. Therefore, it is required to have a high experience, skill, knowledge and patience to treat the premature babies. In the other hand, medical instrument like incubator is necessary to guarantee the survival of them.

The main function of incubator is to keep the premature babies's body temperature stable due to the ineffectiveness of their temperature regulation. It is caused due to lack of the subcutaneous fat tissue in the baby's immature thermoregulatory system. The problem could be solved by nursing action which is maintaining the temperature at 36.5-37.2 °C by checking the temperature every 1-4 hours, maintaining the temperature of neutral environment, maintaining the temperature of the baby in an incubator and sustaining oxygen requirement by assessing the respiratory status [2]. This temperature is maintained primarily to prevent the occurrence of either hypothermia or hyperthermia in premature infants [3]. In developing countries, there are many problems to be faced in the utilization of incubators such as economy issue, lack of skilled manpower, maintenance cost and the other problems [4].

Phase Change Material (PCM) is a substance, which has a high heat of fusion, can melt and solidify at constant temperature. PCM can store and release large amounts of energy. Heat can be absorbed or released when the material changes phase from solid to liquid and vice versa, thus, classified as latent heat storage (LTS) unit. Different organic PCMs such as paraffins, fatty acids, fatty alcohols, PEGs, and their eutectic mixtures have been

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generally preferred for LTS for heating and cooling applications because of some advantageous properties: high latent heat capacity, appropriate phase change temperature, non-corrosivity, non-toxicity, good thermal/chemically stability, low vapor pressure and little super cooling. [5-8]. In other hand, container of material should be considered for application as thermal storage due to its effect to melting time of phase change material. In order to ensure its reliability, the size and shape of container must comply with properties of phase change material. PCM is generally placed in a container in the form of long thin pipes, container cylindrical or rectangular container.

Beeswax is honeycomb compounds composed of fatty acid esters and various long chain alcohol compounds. The empirical formula of beeswax is $C_{15}H_{31}COOC_{30}H_{61}$. Beeswax has a low melting point, between 62-64 °C. If it is heated above 85 °C, a color change occurs. Beeswax starts to burn at temperatures 204.4 °C. The density of beeswax at a temperature of 15 °C is 958 to 970 kg/m³ [9].

Infant incubator innovations in power efficient with a more affordable cost have been developed for remote area application. According to World Bank data, among the ASEAN countries, electricity consumption per capita of Indonesia in 2011 remained low at 680 kWh / capita. As a solution to the limitation of electricity energy, Sekar et al have developed non-electricity incubator based on Phase Change Material (PCM) as a heating element [9]. However, temperature must be controlled to prevent overheat in incubator. High temperature will cause symptoms in infants that their skin becomes red due to blister and pale because of fluid loss. As a result, the baby will suffer a shock and her blood pressure dropped dramatically [5].

Figure 1 shows the baby incubator that was used for this study. This incubator has larger holes to increase the natural convection heat transfer rate. Thus, it will reach the desired temperature faster than conventional incubator. The heat source of this incubator is from the lamp beneath of the baby tray. When this incubator is turned on, the air around the lamp will be heated and it will go up into the baby tray due to the natural convection heat transfer. Uniform laminar flow occurred due to the holes on the plate which allowed hot air to circulate naturally. Upper part of the incubator was made of acrylic with thickness of 5 mm. Fig 1 shows the incubator prototype, which was used in this research.

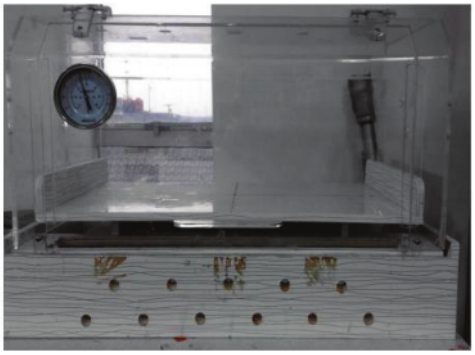


FIGURE. 1 Baby Incubator

One of the disadvantages from the incubator is electricity dependence. Thus, non-electronic incubator is developed. Utilization of phase change material with appropriate mass has a goal to reach the suitable temperature for the infant survival. However, phase change material should be changed to provide the heat from the bottom of the incubator. Therefore a phase change material backup must be provided before the temperature drop drastically. The objective of further experiment is to obtain the appropriate incubator temperature range and most effective time range with a mass reduction of PCM. PCM storage container was designed into cylinder pipe with fin to enlarge its heat transfer area.

METHODS

Fig. 2 shows the experimental setup of utilization of beeswax as heat energy storage on infant incubator. The baby incubator was made from acrylic with dimensions of 615 mm on length, 310 mm on height, 420 mm on wide. Physical properties of beeswax have been measured using differential scanning calorimeter (DSC) [9]. PCM

cylinder container is charged with beeswax varying from 2 kg, 3 kg, to 4 kg and placed at bottom of incubator. PCM cylinder containers were made of copper pipe and some fins are welded at the outer cylinder. Design of fin considers the distance between fin, load of fin to the mass of incubator, and heat transfer rate in the incubator. Distance between fins on the tube container of PCM is 2.5 cm. The goal of fin application is to reduce the time for reaching desired temperature in incubator. Fig 3 (a) shows the application of fin into the tube of PCM and Fig 3(b) displays the placement of cylinder container inside the incubator. Total of six PCM tube containers is put on the bottom of incubator as alternative heat source. The bottom of incubator should be coated with aluminum foil to prevent heat loss and keep it clean if there is leakage from PCM container. Thermocouple type K with 0.2 mm diameter is used for temperature measurement. There are five points of thermocouple placement in the incubator as shown in Fig 4. The position of thermocouple is 10 cm above the baby tray. Experiment data is collected using NI Data Acquisition, which is connected to PC.

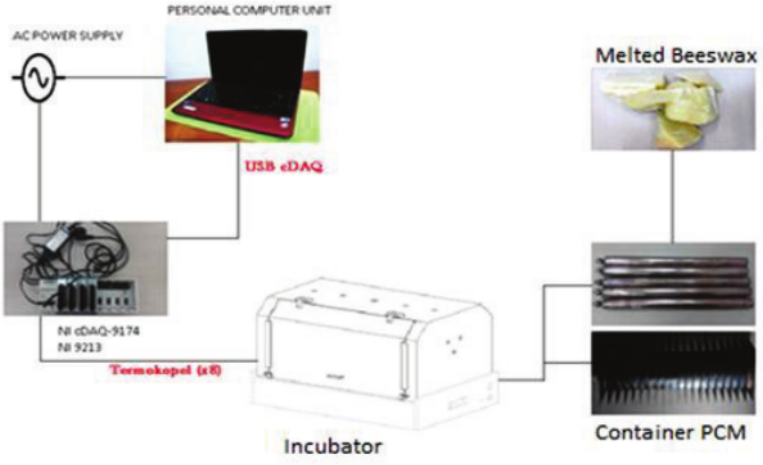
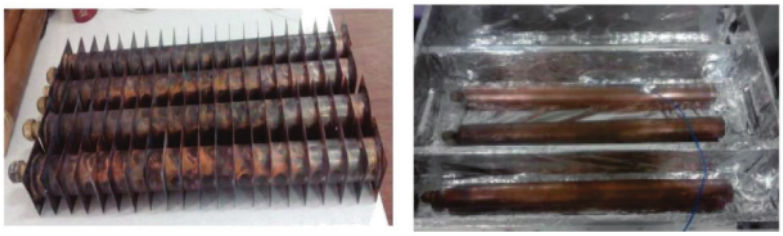


FIGURE 2. Experimental Setup [9]

Beeswax was melted at 65 °C before put into cylinder container. Injection process of beeswax should be done carefully to prevent agglomeration at inlet tube. Valve was used to seal the tube container to avoid leakage of beeswax PCM. PCM could be heat recharged by using boiling water. The cylinder container was heated for 25 minutes with lid open to avoid overpressure in the tube.

Heat was released from the cartridge wall and warmed up inside of infant incubator. 6 channels of K-type thermocouples measured released heat. 5 thermocouples were placed inside infant incubator, and 1 thermocouple was outside infant incubator to measure ambient temperature. PCM beeswax in incubator is tested at different time with different ambient temperature to know the performance of infant incubator. For the daytime measurement it began at 07:00 A.M to 06:00 P.M., while in the nighttime measurement started at 07:00 P.M to 06:00 A.M.



(a) (b)

FIGURE 3. (a) Cylinder Tube with Fin (b) The Placement of Phase Change Material Cylinder Container inside the Incubator

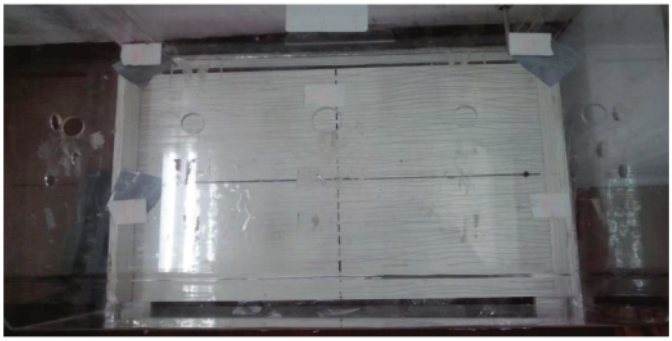
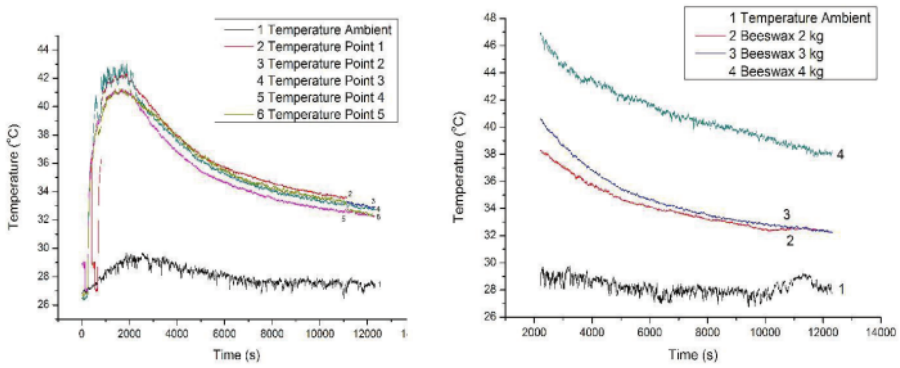


FIGURE 4. Thermocouples placement on the Incubator

RESULT AND DISCUSSION

Non-Electric Incubator Performance at Noon

The results from experiment at noon are presented in Fig 5(a). In this case, cylinder container PCM has no fin. At the initial stage, temperature in the incubator increased until maximum temperature 42 °C then decrease to be the required temperature (32-36 °C). From the figure it can be seen that distribution temperature for all thermocouples in the incubator are almost same. This result indicated that thermal system with PCM as heat source in the incubator could comply with standard for infant incubator. The required temperature range for infant in the incubator is around 32 °C until 36 °C based on Indonesia National Standard (SNI). The utilization of PCM in this study is successful to keep the temperature around the required temperature.



(a) (b)

FIGURE 5. (a) Temperature Distrbution in incubator for noon experiment (b) Temperature in incubator with variation of mass of beeswax

Figure 5b showed average temperature in incubator with variation of weight of beeswax. As for 2 kg mass of beeswax, the required temperature can be kept for around 86 minutes without any electrical heater resource. On the other side, 3 kg mass of beeswax shows the better result in the period of time, which is 147 minutes with the same temperature range and for 4 kg mass of beeswax, the period of time is around 181 minutes. However, it has a longer waiting time for incubator temperature to drop to the maximum allowable temperature at 36 °C.

When beeswax PCM is used as heat source for incubator and is placed into the bottom of incubator, the temperature will rise to the maximum temperature, then it drops to the required temperature for infant. Period from the maximum to the required temperature is called waiting time in this study. The waiting time for 2 kg, 3 kg, and 4 kg of Beeswax PCM is 2, 2.45, and 3.01 hours respectively.

Non-Electric Incubator Performance at Night

In order to confirm the 3 kg mass of beeswax as the most efficient for application in the incubator, experiment at night with beeswax PCM was conducted. Fig 6 shows the results for night experiment. The results showed that the 2 kg, 3 kg, and 4 kg have 1.43, 2.45, and 2.79 hours to keep the temperature around 32-36 °C. However, the maximum temperature of 2 kg mass is not appropriate for the incubator application and the 4 kg mass has a longer waiting time that will cause inconvenience for the user of this incubator.

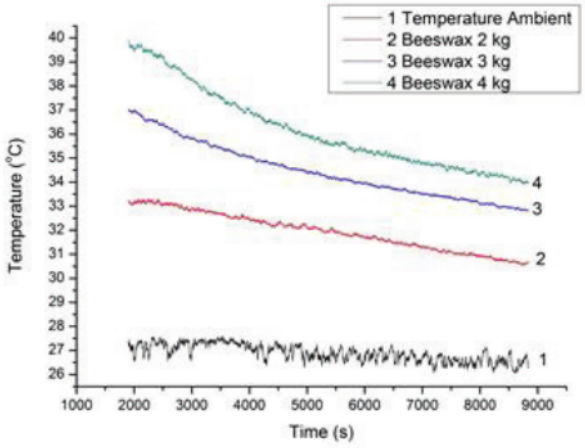


FIGURE 6. Average Temperature in Incubator at Night

TABLE 1. Data of Experiment

Characteristic	Without Fin						With Fin	
	Noon			Night			Noon	Night
	2 kg	3 kg	4 kg	2 kg	3 kg	4 kg	3 kg	3 kg
Ambient Temperature (°C)	28.13	27.84	28.08	26.87	27.54	27.09	27.87	26.86
Period of Time (hours)	2	2.45	3.01	1.43	2.45	2.79	2.2	2
Max. Temperature (°C)	39.72	43.05	43.35	34.17	38.13	40.95	36.10	35.10
Waiting Time (minutes)	59.64	84	90.84	10.44	51.24	79.92	5.1	10.93

Effect of Fin to the Incubator Performance

Though, the waiting time is still too long for the incubator application. To overcome this drawback, the application of fin is assembled. The purpose of fin is to increase the heat transfer rate which then will reduce the waiting time for incubator application.

Table 1 shows the summary and the comparison of cylinder container with and without fin. It is established that cylinder container with fin can make waiting time shorter which is just 5.1 and 10.93 minutes at the noon and the night respectively.

CONCLUSION

Result of experiment showed that the most efficient mass of PCM is 3 kgs, which can maintain the required temperature in incubator at 32-36 °C for 2.45 hours. The used of fin on PCM cylinder container can make waiting time shorter. The overall tests confirmed that beeswax as local PCM material is able to store and extricate heat energy as the substitution heater on infant incubator and it has good ability to store heat energy at the temperature above 32 °C in infant incubator.

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