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Performance prediction of vaccine carrier using adsorption process and 13x/$c_a cl_2$ composite zeolite as adsorbent

Nasruddin[1,a], Q H Alius[1], Djubaedah[1,2], A Taufan[3], R G Gurky[1], and A P Arsyad[1]

[1]Departement of Mechanical Engineeering, Universitas Indonesia, Depok – Indonesia
[2]Agency for the Assessment and Application of Technology (BPPT), Serpong, Indonesia.
[3]Development Center for Appropriate Technology, Indonesian Institute of Sciences, Subang -Indonesia

[a]E-mail: nasruddin@eng.ui.ac.id

Abstract. Vaccine is one of the biggest problem that happen in Indonesia. Almost 75% vaccine is frozen on shipment process from Province to healthcare in district. Vaccine usually is transferred using a vaccine box whose the temperature has to be maintained at 2-8°C. The newest technology of vaccine box uses adsorption cooling and solar energy to keep the cold chain. This technology is separated into 3 modules which are cooling module (contain zeolite and water), vaccine box, and solar heater. The cooling module using adsorption as the cooling process, where the adsorption makes a pressure drop and causes the decrease of the temperature. The decrease temperature will be used as source of the cooling in the vaccine box. After the zeolite in cooling module reach the saturation because of adsorption process, it has to be heated up using solar cooker as the media. The solar cooker collects the energy from the sun using the principle of greenhouse effect. This study aimed to analyze if the design of vaccine box using adsorption cooling system and 13x/$c_a cl_2$ composite zeolite as the adsorbent is suitable or not for holding the optimum temperature for vaccines. From simulation using MATLAB, an integrated technical computing including computation, visualization, and programming, the vaccine box could reach temperature 5°C and can be maintained for 12 hours with COP is 0.146. For the desorption process, it needs heat 150 KW and 23 minutes to complete the process.

1. Introduction

Vaccine, as described on The Basic Concept of Vaccination by Pharmaceutical Research and Manufacturers of America (PhRMA), is a biological preparation that enhance immunity against a disease by stimulating the production of antibodies [1]. Vaccines are administered in liquid form, either by injection, by oral, or by intranasal routes. This method which also known as immunization is proven to be the most cost-effective public health intervention diseases such as polio, measles, hepatitis B, tetanus, pertussis, diphtheria, and childhood tuberculosis. WHO guidelines and vaccine labels state that the use of hepatitis B, diphtheria– tetanus–pertussis, diphtheria–tetanus, and tetanus toxoid vaccines must be stored at temperatures of 2°C–8 °C to ensure the quality of vaccine. It must not be frozen because it can lead a loss of potency and compromised protective immunogenicity in recipients.

Unfortunately, there still some obstacles faced by health worker in Indonesia to distribute vaccine to reach rural area due the lack of transportation access and source of electricity. A study that monitored Hepatitis B vaccine in Indonesia state that 75% of vaccine shipments were being frozen, mostly during the transport from provincial to district warehouse.

The laboratory research that the newest technology of vaccine cold box using cool water packs [3] to prevent freezing during transportation and the result is with the extreme ambient temperature (43°C) with the temperature inside cool box around 20°C. In while there are technology that use a thermoelectric [2] as cooling system and the temperature could reach -10°C and range of the temperature is 2°C-8°C. However from all the technology need electricity to used and not suitable for remoted area.

Adsorption cooling system in vaccine cooling module believed can give a better performance since this technology has simple control system, low maintenance, and also this technology doesn't need electricity at all. Using zeolite as the adsorbent also give an advantages since the adsorbent can be heated using solar energy so it can applied in rural area. This study aimed to analyze if the design of vaccine box using adsorption cooling system and 13x/c_acl_2 composite zeolite as the adsorbent is suitable or not for holding the optimum temperature for vaccines.

2. Methodology and Concept Design

2.1. Adsorption and Desorption Process

On thermocycle of adsorption process cooling consist of two process which is adsorption and desorption process. The working principle of the adsorption cooling can be described by using clayperon diagram as shown in figure 1.

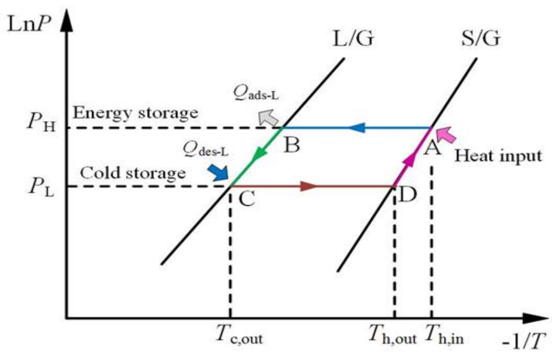

Figure 1. Clayperon schematic diagram [11]

The process of cooling happened at line C – D. These cooling process actives when the pressure below one atmospheric and the valve between two chambers is opened. Unsaturated adsorbent will adsorb the refrigerant on the other side. The result is the chamber 2 will decrease the temperature swiftly because the decreasing of pressure (Pressure drop). The temperature on chamber 2 depends many variable such as mass of adsorbent, mass of water, isotherm of adsorbent and etc. At line A-D is the process when adsorbent reach saturated condition and the cooling process not run effectively anymore. Therefore the line C-D-A is what called as adsorption process, while at line A-B-C is the process of desorption. Line A-B is when the heat from the heat source input into saturated adsorbent. The heat input continuously until the water inside of the adsorbent transform into vapor. Because of the difference the pressure and temperature between the chamber 1 and 2 the vapor will move into chamber where the temperature and pressure are low. At B-C line is process when the vapor became water because of condensation.

2.2. System Description

The vaccine box separated into 3 module which are cooling module, cool box, and solar cooker. Each module have difference function. The cooling module consist of two chambers and manual valve as shown by Figure 2. These two chambers contains zeolite and water for adsorption cooling. These two chambers made of stainless steel 304 to prevent from deformation. The water will adsorp by zeolite through pipe that connected to valve. Cooling box has a function to hold the temperature between 2-8°C while shipment.

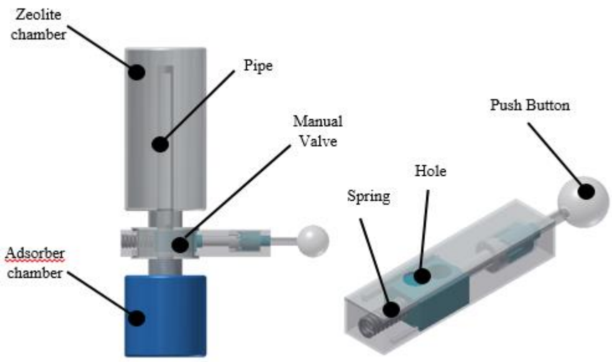

Figure 2. Parts of cooling module and valve

Cooling module will put in the vaccine storage. The cool box specification is on the table 1.

Table 1. Specification of cooling box

Vaccine Storage Capacity	1.6 liter
Approximation External Dimension	400 mm X 400 mm X 300 mm
Vaccine Storage Dimension	10 mm X 10 mm X 10 mm
Insulation Thickness	30 mm
Insulation Material	Polyurethane Foam
Vaccine Storage Material	High Impact Polystyrene (HIPS)
External Surface Material	High Density Polyethylene (HDPE)

2.3. Analyze Performance of Cooling Module

This Analyze the performance of this cooling box is using MATHLAB as the software for simulation. There are several assumptions that used in this simulation

1. Pressure and temperature are homogenous in adsorbed
2. The process of adsorption and desorption are fully isobaric
3. The refrigerant is adsorbed homogenously
4. There are no differences of pressure between two chambers.

There are several variable that used in simulation. The variable is shown in table 2.

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Table 2. Variable and value used in simulation

C_a J/KgK	C_{st} J/KgK	$C_{w,v}$ J/KgK	C_{air} J/KgK	C_w J/KgK	$U_{e/c}$ W/K	U_b W/K	ΔH J/Kg	M_w Kg	M_{air} Kg	M_a Kg	$M_{e/c}$ Kg	E_a J/mol	R_p m	L J/Kg	D_{so} m²/s	R J/molK
836	520	1850	1005	4721.8	0.08	0.38	3800000		0.2	2.3	0.606	28035	0.0001	2500000	3.92×10^{-6}	8.314

The equation based on energy balance in every part in cooling module and cool box. There are equations on the adsorbed chamber, chamber 2, and the cool box. The chamber 2 can be used as evaporator while adsorption process and can be used as condenser in desorption process. The non-equilibrium adsorption of zeolite water kinetics [1] is defined by formula [1]:

$$\frac{dX}{dt} = \frac{15}{R_p^2} D_{s0}\, exp\left(-\frac{E_a}{RT_b}\right)(X_{eq} - X) \tag{1}$$

Where X_{eq} is the equilibrium capacity of the adsorber and can be defined by formula [2]

$$X_{eq} = {}^{1}\!/_{(C_0 + C_1 T_b + C_2 T_b^2 + C_3 T_3^3)} \tag{2}$$

Where $C_{i=0-3}$ is the numerical constant for composite zeolite. Where C_1, C_2, C_3 for absorption is 381.4, -3.463, 0.01008, and -9.153 x 10^{-6} while for desorption 400.8, -3.532, 0.01002, and -8.908 x 10^{-6}. θ is the flag refers to process absorption and desorption.

If the θ have valued 1 then simulation at adsorption phase, while if θ is 0 then simulation at desorption phase. θ is the flag refers to process adosrption and desorption. If the θ have valued 1 then simulation at adsorption phase, while if θ is 0 then simulation at desorption phase.

2.3.1 Energy Balance at Adsorber Chamber

$$\frac{d\,T_b}{d\tau}\left[M_a\left(C_a + C_{p,w}X\right)\right] = M_a\, \Delta H\, \frac{dw}{d\tau} - (1-\delta)U_b A_b\left(T_b - T_{amb}\right) - \theta\, M_a C_{w,v}\left(T_b - T_e\right)\frac{dw}{d\tau} + Q_h \tag{3}$$

Q_h is heat that input to adsorber chamber for desorption process while ΔH is the isotheric adsortion at adsorption process. On the left part of the equation is heat transfer inside the adsorber and case of the chamber while and the other side is the heat transfer between adsorber chamber to environment, adosorber chamber to evaporator, adsorption heat and heat source.

2.3.2 Energy Balance at Adsorber Chamber as Evaporator

$$\frac{d\,T_e}{d\tau}\left[M_{e,w}\, C_{p,w} + C_{ss}\, M_e\right] = \delta\left[-L\, M_a\, \frac{dX}{d\tau} - U_e A_e\left(T_e - T_{room}\right)\right] \tag{4}$$

Where L is evaporation latent heat of transfer. The equation on left part represents the heat transfer inside the evaporator included the refrigerant and the Chamber. The right side represent the heat transfer between evaporator latent heat to adsorbed and evaporator to environment.

2.3.3 Energy Balance at Adsorbed Chamber as Condenser

$$\left[M_{e,w}\, C_{p,w} + C_{ss}\, M_c\right]\frac{dT_c}{d\tau} = (1-\delta)\left[-L\, M_a\, \frac{dX}{d\tau} - C_{wv}\, M_a\, \frac{dX}{d\tau}\left(T_c - T_b\right) - UA\left(T_c - T_{amb}\right)\right] \tag{5}$$

The left side of the formula is the heat transfer inside the chamber. The other side contains 3 terms of heat transfer. There are heat transfers between condensers with latent heat of water's condensation, condenser to environment, and condenser to bed.

2.3.4 Energy Balance at Cooling Box

$$C_{air}\, M_{air}\, \frac{dT_r}{d\tau} = Q_l + U_{cb}A_{cb}\, \left(T_{amb} - T_r\right) + \; U_e A_e \left(T_e - T_r\right) \tag{6}$$

Where Q_l is the internal heat loads that are comes from the vaccine itself. Right side of the equation represents of heat transfer between the evaporator to cool box and also cool box to environment.

2.3.5 Performance

The performance of Vaccine box can be determined by cooling capacity of the adsorbent. Cooling capacity shows the difference temperature between starting point of adsorption process and end point when the adsorbent on saturated condition. To determine the performance can use equation

$$Q_r = \int_0^{\tau} (C_{air}\, M_{air}) * \left(T_{r,end} - T_{r,start}\right) d\tau \tag{7}$$

$$COP = {}^{Q_r}/_{Q_h} \tag{8}$$

3. Result and Discussion

From the model of cold box and cooling module that have designed, the performance could be obtained by the Simulation of MATHLAB. The simulation begin with assumption of the internal heat load of vaccine is 20.16 Watt based on capacity of vaccine storage. The internal heat load will affect temperature of vaccine storage room. Adsorbent begin adsorption with capacity 0.08 kgw/kgad where the maximum capacity for adsorption is 0.8 kgw/kgad. For desorption phase, author makes assumption that the solar collector will gain 150 watt constantly from solar sun. From figure 5, the temperature suddenly decrease when the adsorption process begin and vaccine storage room temperature reach 6°C - 5°C in 2 minutes while the temperature of evaporator reach 3°C. After that temperature tend to decrease because of adsorption still running. The temperature of vaccine storage will constantly below 5°C as long for 12 hours but for adsorption process it only takes 2 minutes and after that the zeolite will completely saturated. The adsorption process still continuous as long the zeolite isn't heated up. However, adsorbent still adsorb but definitely doesn't affect significantly to cooling capacity. The temperature of adsorbent increase because of isotheric heat comes from adsorption process. In figure 5, the capacities of adsorbent reach the maximum capacity in 2 minutes. Range of time adsorption process is short because of the mass of adsorbent is 2.3 kg and while the mass of refrigerant is only 1 kg. The simulation result of cooling capacity that can occur when adsorption process is 1043.7 kJ.

For desorption process the solar irradiation is based on the location of depok which is 106.818610 longitude and -6.4 longitudinal with assumption constantly at 150 Watt. Based on the power that given on solar collector. From figure 7 and 6 the desorption process occurs for 23 minutes until all the water changed phase into vapor. The beginning capacity of adsorbent is 0.7 kg/kg and reaches 0.045 kg/kg. From figure 9, the graphic tend to decrease linearly between time and fraction of adsorbent.

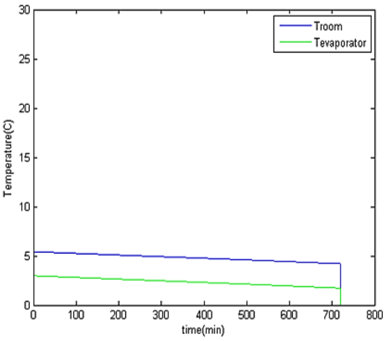

Figure 3. Temperatur of vaccine storage (adsorption)

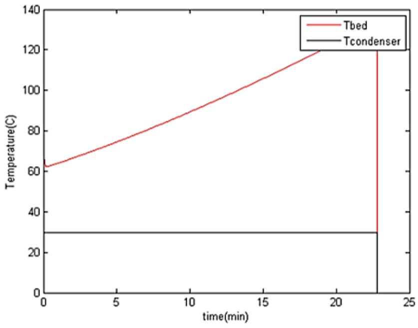

Figure 4. Temperatur of vaccine storage (desorption phase)

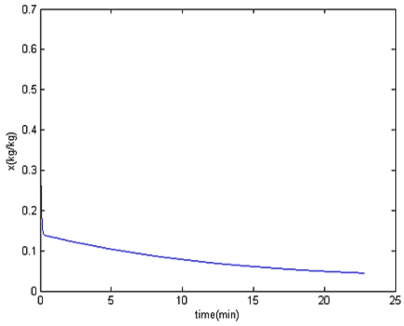

Figure 5. Capacity Vs Time at Desorption Phase

4. Conclusion

The simulation of these vaccine box is designed for shipment of vaccine from province to healt center in each district of remoted area in Indonesia. The aim of this study is to get an information the design is suitable or not for holding the optimum temperature for vaccines. The design of these vaccine box is very mobile with mass 15 Kg included the cooling module and cool box. From the simulation the cooling capacity that produced by cooling module is 1043.7 Kj or 24 Watt with the internal load of vaccine is 20.16 watt. As the result the temperature of vaccine storage is below than 5°C with evaporator temperature is 3°C. Adsorption process takes 6 second to decrease the temperature from ambient temperature to 5°C. However, vaccine box can hold the temperature for 24 hours without any removal the vaccine in vaccine storage. After the vaccine is stored to healt centre in district, it can be used again by heating up the adsorbent chamber. The adsorbent chamber is heated up for 24 minutes until the fraction of the chamber is decrease from 0.7Kg/Kg to 0.045 Kg/Kg. As the result COP of this design is 0.146.

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