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Design, development and performance prediction of solar heater for regeneration of adsorbent chamber

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Abstract. Adsorption cooling is the newest technology that can be used in the distribution of vaccines. The principle of adsorption cooling is applicable to make a new technology called portable vaccine cooler, using zeolite as the absorbent and heat energy to keep cold chain of vaccine which needs to be stored in temperature of 2°C to 8°C. There are many ways to heat the zeolite up. Instead of using fire that induces environmental pollution to heat the zeolite up, the authors choose to use solar energy as the source of the desorption process. The aim of this study is to support cooling module and get the best results of two types of solar heaters to be applied on cooling box. In this paper, performance prediction of two solar heater are simulated using ANSYS workbench, a platform which integrate simulation technologies and parametric CAD system. The result shows that the solar heater type 1 is better to use because it can heat the absorbent chamber up at the temperature of 109°C in an hour running, whereas the absorbent only needs the temperature around 70°C-80°C to make the process of desorption running perfectly.

1. Introduction

Vaccine has a huge effect to prevent some of the most horrible diseases in history (such as Hepatitis B, diphtheria, polio, etc.). Over the years, vaccines have put an end to myriad cases of diseases and saved millions of lives. With the large number of vaccines needed and they will increase linearly with total population, scientists spend a lot of time to developing the availability of vaccines, especially in Indonesia's rural areas. Indonesia is an archipelago state and this brings a challenge to distribute the vaccines from one place to another in Indonesia. WHO has published a bulletin which shows that freezing temperatures were recorded in 75% of baseline shipments in Indonesia. The highest rates of freezing occurred during transport from a province to a district, storage in district-level ice-lined refrigerators, and storage in refrigerators in health centers [1].

WHO states that vaccines need to be stored in temperature of 2°C to 8°C, this will enable flexible vaccine distribution strategies that could reduce vaccine freezing and costs, and increase capacity. There are various advanced technologies used to maintain the temperature of vaccines in the course of distribution process, such as implementation of thermoelectric, phase changing material, solar direct-drive refrigerators, and many others.

Adsorption cooling is the newest technology that can be used in the distribution of vaccine. The principle of this device is the refrigerant is adsorbed and desorbed during the process, analogues to the principle of absorption device. However, because the adsorbent is stationary (a solid), adsorption is built differently than desorption system. Usage of stationary adsorbents leads to intermittent operation of adsorption system. Continuous cooling requires two or more adsorbents, in which adsorption and desorption process occur alternately. [2]

The principle of adsorption cooling is applicable to make a new technology called portable vaccine cooler, using zeolite as the absorbent and heat energy to keep the chain cold. This technology is separated into 3 modules which are cooling module (contain zeolite and water), vaccine box, and heater. The cooling module uses adsorption as the cooling process using zeolite as the adsorbent to make a pressure drop and causes the decreasing temperature. There are many ways to heat the zeolite up. Instead of using fire that induces environmental pollution to heat the zeolite up, the authors choose to use solar energy as the source of desorption process using solar heater.

There is various type of solar heater that has been developed over the world. Generally, solar heater classified into three types; parabolic, box-type, and panel type solar heater. Two types of solar heater discuss in this paper have been developed with portable, simple and compact design as it needs to get the rural area to support cooling module in portable vaccine cooler.

The aim of this study is to support cooling module and get the best results of two types of solar heaters to be applied on vaccine cooler in Indonesia. In this paper, performance prediction of two solar heater are simulated using ANSYS workbench, a platform which integrate simulation technologies and parametric CAD system. As the results, one of those solar heaters uses the principle of greenhouse effect can work for an hour to reach the temperature of $109°C$ at the portable vaccine cooler adsorbent chamber. The other type of solar heater uses reflective material which is capable of focusing incident rays onto a focal area and it can work for an hour to reach the temperature of $45.7°C - 65.6°C$. Those solar heaters could be applied in Indonesia and offer the following novel and user-friendly features: (1) Heat the zeolite at any time convenient to the user (2) Fast Heating (3) Affordable cost (4) environmentally friendly.

2. Methodology and Materials

2.1. Solar Heater Type 1

This is a type of solar heater which uses a multi-faceted reflective panel using transparent medium cover to create greenhouse effect. The direct sunrays will be reflected into the solar heater and heat up the dark painted portable vaccine cooler. Panel cooker as a combination of box-type and parabolic cooker is however, not quite as robust as the box-type cooker, and it cannot heat as much load at once as the parabolic cooker.

Overall thermal efficiency of the Solar Heater was calculated by following equation [3]:

$$\eta_u = \frac{M_f C_f \Delta T_f}{I_{av} A_C \Delta t} \quad (1)$$

where η_u is overall thermal efficiency (%), M_f is mass of cooking fluid (kg), C_f is specific heat of cooking fluid (j/kg.K), ΔT_f is difference between the maximum and ambient air temperature, I_{av} is average solar intensity (W / m^2), A_C is the aperture area (m^2) of the cooker, and Δt is time required to achieve the maximum temperature of the cooking fluids (s).

The Cooking Power of the solar heater was calculated by the following equation [4]:

$$P = \frac{T_{w_2} - T_{w_1}}{t} m_w C_{pw} \quad (2)$$

where P is heating power (W), T_{w_2} is final water temperature (°C), T_{w_1} is initial water temperature (°C), t is time (s), m_w is mass of water (kg), C_{pw} is water heat capacity (4.168 kJ/kg.K).

2.1.1 Design of Solar Heater Type 1

Figure 1 shows the parts of the solar heater type 1. This solar heater uses PYD aluminum foil to reflecting the sunrays and plastic as the lid to make the sunrays trapped inside. The lid can be opened and closed using a zipper. The hole located on the base of the solar heater type 1 is an adsorbent chamber mounting hole.

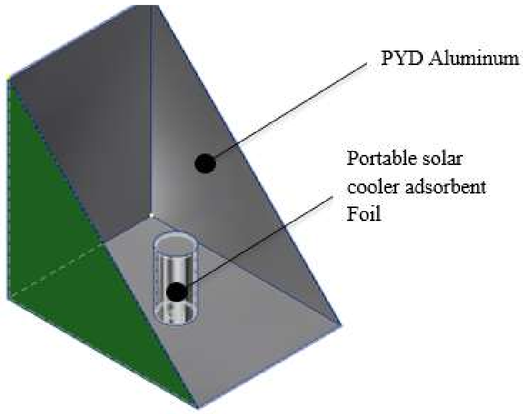

Figure 1.Parts of solar heater type 1

Table 1. Specifications of solar heater type 1

The height of the solar heater type 1	490 mm
The width of the solar heater type 1	370 mm
The length of the solar heater type 1	490 mm
Adsorbent chamber mounting hole diameter	76.2 mm
Solar heater type 1 internal material	PYD Aluminum Foil
Portable vaccine cooler adsorbent	Zeolite
Solar heater type 1 lid material	Plastic

2.2. Solar Heater Type 2

This type of solar heater is made by reflective material made from solar zenith with conical frustum shape. This system is a conical lens capable of focusing incident rays onto a focal area. When this solar heater is directed to sunlight, incident rays on the reflective internal surface are reflected towards the focal area at the base. Design of solar heater type 2 is shown by figure 2 as below:

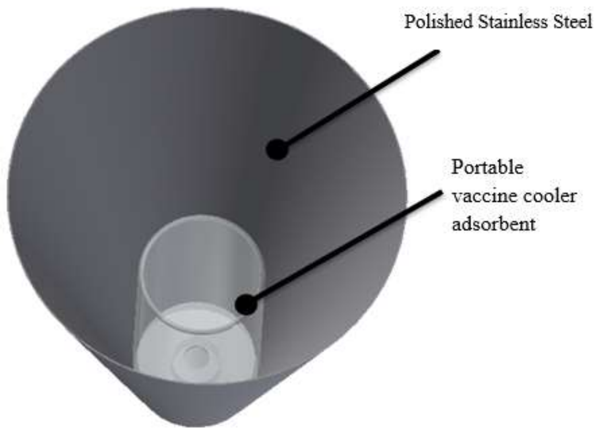

Figure 2. Parts of solar heater type 2

The formula derivation of geometric concentration of this type is expressed below [5]:

$$C = \frac{A}{a} = \frac{\pi R_1^2}{\pi R_2^2} = \frac{R_1^2}{R_2^2} \quad (3)$$

Where *A*=area of the large end; *a*=area of the small end; R_1=radius of opening; R_2=radius of the focus and $\Delta C'CB'$, where $C'B'C = \theta$, where θ is the apex angle of cone:

$$R_1 = R_2(2\cos\theta + 1) \tag{4}$$

From equation (3) and (4) we can obtain:

$$\text{Then } C = (2\cos\theta + 1)^2 \tag{5}$$

Equation (3) represents the average concentration at CC' in (figure 1)

Concentration systems are approximately classified into: low concentration range (C<10), medium concentration range (10<C<100), and high concentration range (C>100) [3].

With an apex angle of 30°, the average geometric concentration calculated by equation 5 is 7.46. The concentrated sunrays at the focal area used to heat the zeolite up to keep the cold chain.

Details of calculated solar heater type 2 dimensions are stated in table 2.

Table 2. Details of calculated solar heater type 2

No	Dimension	Value	Unit
1	R_1	11.98	cm
2	R_2	3.81	cm
3	L	46.28	cm
4	l	31.56	cm
5	H	44.7	cm
6	h	30.48	cm
7	A	450.65	cm
8	a	45.58	cm
9	C	7.46	-
10	E	300	watt
11	θ	30°	Degree
12	Φ	93.17°	Degree

The appropriate dimension for the conical frustum solar heater can be calculated as below [5]:
The length of cone side L is represented by An from $\Delta Ann'$

$$L = \frac{R_1}{\sin\frac{\theta}{2}} \tag{6}$$

Where $\left(\cos\theta = 1 - 2sin^2\frac{\theta}{2}; R1 = 11.98;\ \theta = 30°\right)$

$$L = R_1\left[\frac{2}{(1-\cos\theta)}\right]^{0.5}$$

The length of the reflecting part l is represented by AC in ΔABC where (R_2=3.81)

$$l = (R_1 - R_2)\left[\frac{2}{(1-\cos\theta)}\right]^{0.5} \tag{7}$$

The height of the reflective part h is represented by nn' by $\Delta Ann'$

$$\frac{R_1}{H} = \tan\frac{\theta}{2}, where \left(\tan\frac{\theta}{2} = \sqrt{\frac{1-\cos\theta}{1+\cos\theta}}\right) \tag{8}$$

$$\therefore H = (R_1)\left[\frac{1+\cos\theta}{1-\cos\theta}\right]^{0.5}$$

The height of the reflective part h is represented by BC. In ΔABC we can obtain

$$\frac{BA}{BC} = \frac{R_1 - R_2}{h} = \tan\frac{\theta}{2} \tag{9}$$

$$\therefore h = (R_1 - R_2)\left[\frac{1+\cos\theta}{1-\cos\theta}\right]^{0.5}$$

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The expanded angle Φ of the complete cone is the angle at the apex when the frustum is undone From (equation (6)) in (Equation (10)):

$$\Phi = \frac{2\pi R_1}{L} \tag{10}$$

$$\Phi = 180[2(1-\cos\theta)]^{0.5} = 180[2(1-\cos 30°)]^{0.5} = 93.17°$$

3. Results and Discussion

The simulation is assumed running for an hour in Indonesia condition, at Depok coordinate, 6.4025° S, 106.7942° E. The simulation is running with assumption of the time is 12:00 pm, the weather is sunny, hot, and not windy with irradiation constant of $700 watt/m^2$ (Department of Mechanical Engineering Universitas Indonesia, 2015). The solar thermal will affect the adsorbent chamber through the solar heaters with each of its ways. The first solar heater type 1 will make the solar thermal trapped inside and use the solar thermal as the source to heat the adsorbent chamber. Meanwhile, the solar heater type 2 reflects sun rays onto a focal area and uses the solar thermal as the source to heat the adsorbent chamber. With the low concentration range of the solar heater type 2, the authors predict that the solar heater type 2 will not be able to heat the adsorbent chamber up in an hour in the temperature up to100℃.

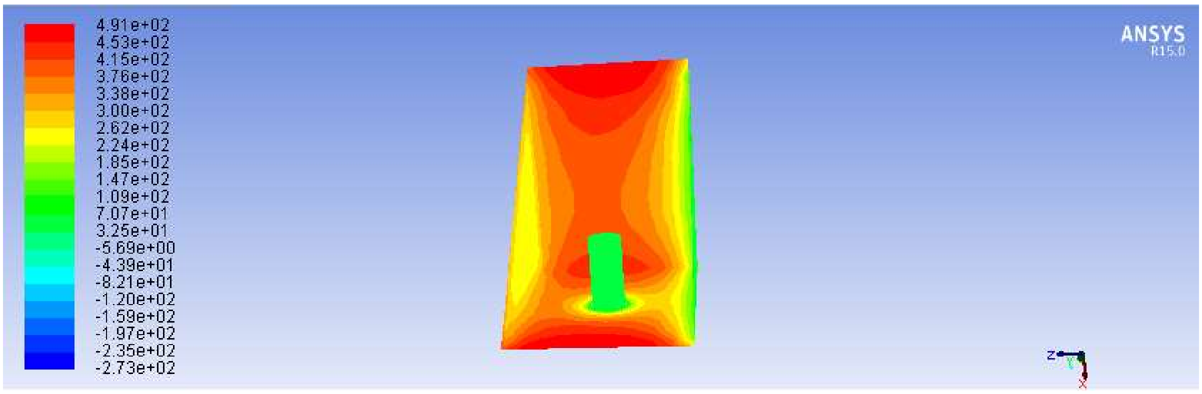

Figure 3 . The simulation result of solar heater type 1 (running for an hour)

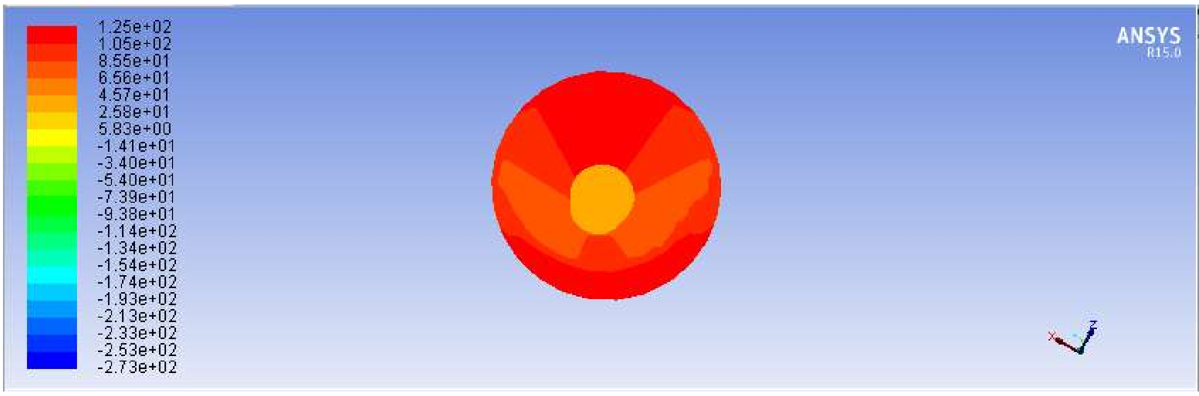

Figure 4. The simulation result of solar heater type 2

In figure 3, the solar heater type 1 wall temperature is heated up to the temperature of 262℃ − 491℃. The wall succeeds to reflect the sun rays and make it trapped inside, so the adsorbent chamber can be heated up to temperature of 109℃ in an hour of running simulation. In figure 2, the solar heater type 2 reflective material is heated up to the temperature of 85.5℃ − 125℃, but the reflective material cannot make the adsorbent chamber be heated up like the solar heater type 1 does. The solar heater type 2 can only make the adsorbent chamber be heated up to temperature of 45.7℃ − 65.6℃ in an hour of running simulation. Just as the authors' prediction before the simulation is started, the solar heater type 2 is not able to heat the adsorbent chamber up in the temperature up too 100°C because of the low concentration range of the solar heater to focusing the sun rays onto its focal area.

As a reference, in another research by N. L. Panwar [6] found that maximum temperature of water was 94.85°C, whereas its exergy output was in the range, 7.37-46.46 W. This experiment analyzed a domestic size parabolic solar cooker in actual use which is running from 10:00 to 13:30 solar time. Compare to this experiment, solar heater type 1 has the closest result than the solar heater type 2 [6].

Table 3. Details of comparison between solar heater type 1, type 2, and reference

	Type 1	Type 2	Reference
Maximum wall temperature (°C)	491	125	-
Maximum adsorbent temperature (°C)	109	65.6	94.85

4. Conclusion

The solar heaters are made in order that they can be taken to rural areas with the portable vaccine cooling easily. The design of the solar heaters are very mobile because they can be folded and be carried easily with compact design, standard dimension. The solar heater type 1 simulation result shows that the solar heater type 1 can heat the adsorbent chamber up at the temperature of 109°C in an hour running; now in fact we only need the temperature around 70^0-80^0 C to make the process of desorption running perfectly. This means that the solar heater type one can be used to keep the cold chain. This simulation result is different from the solar heater type 2 simulation result where the solar heater type 2 can only heat the adsorbent chamber up at the temperature of 45.7°C − 65.6°C in an hour running. This means it needs more time to heat the adsorbent chamber up at the temperature of 70-80°C. So, it can be concluded that it is better to use solar heater type 1 because it can heat the adsorbent chamber up faster than the solar heater type 2.

5. Acknowledgment

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