A Simulation of Solar Ice-maker in Indonesia -1 (Design and Tests)

Sonki Prasetya[1], C. Faber[2], Nasruddin[1]
[1)]Refrigeration and Air-Conditioning Laboratory, Mechanical Eng.Dept. University of Indonesia
[2)]FH Aachen-Solar Campus, Juelich Germany

ABSTRACT

Sunshine in a tropical country such Indonesia is easily to find almost everyday. The solar energy utilization is the answer especially for daily needs for this land which has thousands small islands. A refrigeration without using electricity for remote areas are preferred to be the solution to preserve medicine particularly vaccines by means of an alternative/renewable energy. An adsorption refrigeration method with the solar heating is chosen for this study due to the simplicity and the cost to construct this system. Diagrams generated from Matlab simulink software as the base of the simulation are presented as the result of solar irradiation data input as a consideration to support the system.

1. INTRODUCTION

1.1. *Indonesia and Its barrier*

1.1.1. Geographical Fact

Indonesia is a tropical country and consists of thousands of islands. The territory of this country stretches from 6°08' north latitude to 11°15' south latitude and from 94°45' to 141°05' east longitude [1]. It is surrounded by two oceans (Pacific and Indian) and bordered by two nations (Malaysia and Papua New Guinea). Natural resources spread along islands. Not all islands have the same resources compared with others. One similarity of those islands is the season. Because Indonesia lies in the equator area, it has only two seasons which are dry seasons and wet/rainy seasons. The sun radiates in an almost exact period every day (six o'clock in the morning to six o'clock in the evening).

1.1.2. Electricity

One of the problems that come along for being an archipelago country is the difficulty in electricity distribution. The state owned Electricity Company (PLN-Perusahaan Listrik Negara) has the responsibility to supply and cover all electricity demand in Indonesia [2]. The fact is that not all areas in Indonesia can enjoy this facility. Only 54% of the total area is supplied by PLN. From 100% electric capacity generated by PLN, 83% is generated by oil, gas and coal, 14% by hydropower and the rest by renewable energies [3]. From those statistics, it can be concluded that conventional technologies using fossil fuels are heavily used and renewable energies have not been considered as a potential alternative for fossil fuels in practice. To improve the usage of renewable resources, the government has introduced policies to support the application of renewable energy [4].

1.1.3. Health System

Health is the important problem in this country. To cover this problem, government and several foundations that care about health especially for poor people erected a small health centre called Puskesmas in several areas. According to data of the Health Department in 1999 about 36.000 small health centres have been recorded [5]. Usually a small health centre covers health problems of citizens in one sub district. But sometimes there are not enough, government also makes a lot of effort to supply health care through villages and for some unreachable villages. The government has set up a program of mobile health centres using cars or even boats.

Government and foundations (national and international) provide several medicines because poor people cannot pay for their health. A program such as immunization for children is one of some examples [6].

1.2. *Proposed Solution*

In rural areas where electricity does not exist, an alternative solution should be created. The cooling technology to preserve food (such as fish), vaccines (drugs or medicine equipment) for rural health centres (Puskesmas-Pusat Kesehatan Masyarakat), and agricultural products, using renewable energy such as solar energy should be considered.

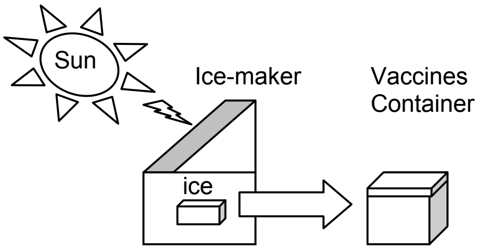

Figure 1.1. Proposed System

The preservation container (such vaccines) should be a box that provides very low temperatures that isolate the object to be conserved from ambient (see figure 1.1). It has to be an easy-to-build system and economically feasible. A compact and easy assembled solar icemaker/ refrigerator can also be a solution for disaster or catastrophic problems (recently such as a tsunami/ an earthquake) that provides cheap and potential food storage for refugees where there is no power supply electricity available due to the disaster.

1.3. *Technology*

A solar technology would be appropriate for this country because of the abundant source of the sun in almost every area of Indonesia. This country has 12 hours diurnal sunshine for nearly a year (especially during dry season). With the solar irradiation more than 1000 W/m² (maximum) and ambient temperature of around 27°C (According to Meteorological data Serpong), a solar thermal application can be used for refrigeration.

To make a simple design, especially to reduce electricity, regarding the price of the equipment and also the environmental effect, adsorption techniques can be used for this application. Using physical and chemistry principles, a refrigeration system can be achieved. An issue of endangering people can be ignored because of the usage of the harmless material for the environment. In other word, this is environmentally friendly.

Actually researchers that are involved with solar thermal technologies have done experiments about this. And some of their modules have been tested during a whole year such as in China [7]. Although the performance is lower compared to electrical power refrigerator, this technology would be a big favour for rural or remote areas that does not have electrical supply at all.

Compared to other solar technologies, this Solar Thermal technology is chosen because it is customized for some applications that we need. Since this technology is easier to build especially in contrast with photovoltaic systems that are comprised of highly sophisticated methods, the result would be an economical value for manufacturing. Incorporated with local available materials (materials that are easy to find in this country), difficulties to assemble this system will be reduced.

2. CHOSEN DESIGN

2.1. Chosen Refrigerant Pairs

Activated carbon is considered as adsorbent and methanol as the adsorbate. This unique couple has the following advantages. Methanol is defined as the refrigerant because it is a unique liquid with a good performance fluid due to [8]:

- It will evaporate at a temperature largely below 0°C (melting point 179K).
- The enthalpy of vaporization is relatively high (L≈ 1200 kJ/kg at –5°C).

- The size of molecules is rather small (around 4 $\overset{\circ}{A}$), thus it can easily be adsorbed in micropores with diameters smaller than 20 $\overset{\circ}{A}$.
- Its normal boiling point is around 65°C at standard atmosphere and is much higher than room temperature.
- Working pressure of this liquid is always lower than atmospheric pressure. This is a safety factor because any abnormal behaviour of the system can be detected before methanol leaks from the system.

On the other hand activated carbon has also advantages that:
- It has a significant volume of micropores of convenient size for adsorption.
- It has good performance adsorbing methanol

2.2. Ice-maker System

This system is a simple applicable solar ice-maker machine that does not need electricity to generate the ice. Using natural flow as a base of the cycle, this machine will be suitable for such an application in area or countries that have enough solar radiation to be utilized. It has been tested by several researchers using a simple technology, that ice can be generated by employing solar irradiation.

This system's arrangement consists of [9]:

Table 2.1. Parts of the system.

	Parts
1	Collector plate
2	Adsorbent bed
3	insulation
4	condenser
5	evaporator
6	water tank
7	cold box
8	glazing

The arrangement of the system can be described on the picture below (figure 2.1).

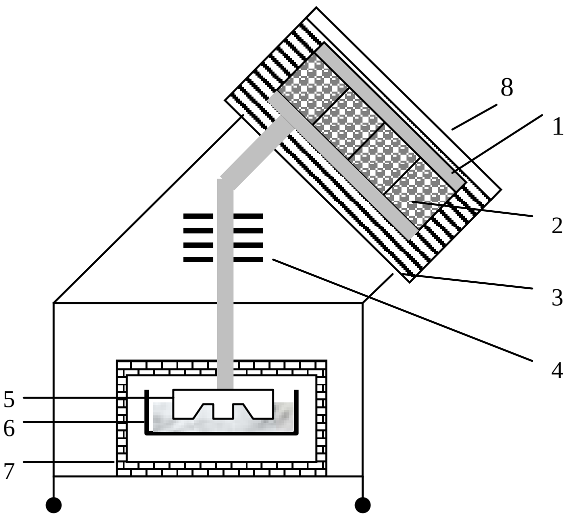

Figure 2.1. Solar ice-maker in a scheme [10,11]

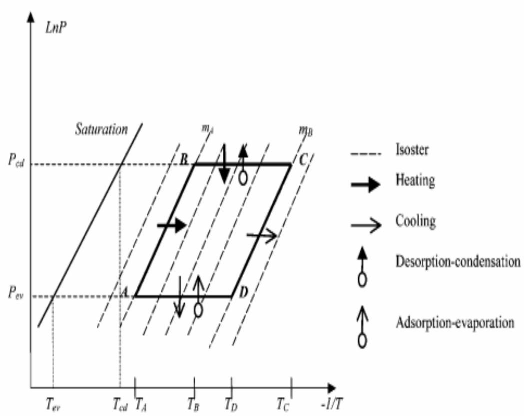

Figure 2.2. Clapeyron Diagram

There are four basic phase principles (figure 2.2) that happen in this system [9, 12, 13, 14], and they are:

1. Isosteric heating (point A-B)
2. Isobaric desorption (point B-C)
3. Isosteric cooling (point C-D)
4. Isobaric adsorption (point D-A)

This simulation process is only the event that happens in the 2nd stage of the Clapeyron diagram when the desorption starts (point B-C). By using the incident in this stage, it is sufficient for us to find out the important indicators of this system. With a model of flat plate collector, heat transfers can be represented into these formulas:

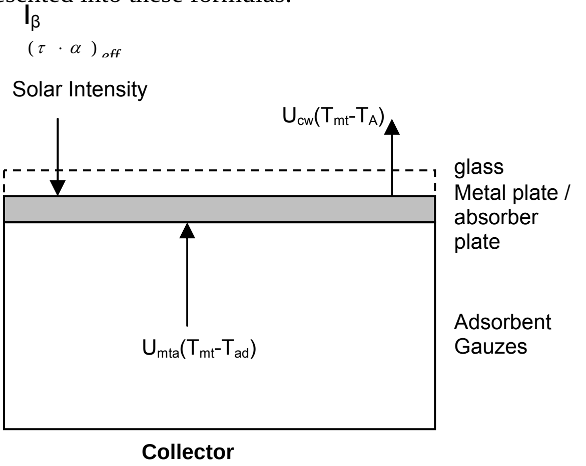

Figure 3.14. Solar Collector Discretization and Heat Flows in the System

Where:

U_{cw} = Global heat transfer coefficient of metal to ambient [W/m²K]
U_{mta} = Global heat transfer coefficient of adsorbent to metal [W/m²K]
T_{mt} = Metal temperature (K)
T_{ad} = Adsorbent temperature (K)
T_A = Ambient temperature (K)

using a general formula:

$$mc\frac{dT}{dt} = \sum \dot{E}$$

$$mc\frac{dT}{dt} = \sum \dot{E}_{in} - \sum \dot{E}_{out}$$

where:

m = Mass of the matter (kg)
c = Specific heat of the matter (J/kgK)
T = Temperature of the matter (K)
$\dot{E}$ = Energy persecond [input/output] (J/s)

with Solar intensity as an input, another formula is developed:

$$\sum \dot{E}_{in} = A_0 (\tau \cdot \alpha)_{eff} I_\beta$$

where:

A_0 = Solar collector area (m²)

$(\tau \cdot \alpha)_{eff}$ = Transmissivity/absorption coefficient

I_β = Incident solar energy per unit time (W/m²)

Losses energy from adsorbent to metal and from metal to ambient influence can be summarized into these formulas:

1. $A_0(\alpha)_{eff} I_\beta = m_{mt} c_{mt} \frac{dT_{mt}}{dt} + U_{mta} A_{mta} (T_{mt} - T_{ad}) + U_{cw} A_{mte} (T_{mt} - T_A)$
2. $A_0(\tau \cdot \alpha)_{eff}\, I_\beta = \pm \Delta H_{ad}\, m_{ad} (\frac{dw}{dt}) U_{mta} A_{mta} (T_{mt} - T_{ad}) +$
   $(m_{ad} c_{ad} + w m_{ad} c_{mnl} + m_p c_{pp}) \frac{dT_{ad}}{dt}$
3. $\frac{dw}{dt} = k \frac{dT_{ad}}{dt}$

where:

m_{mt} = Mass of the metal (kg)
c_{mt} = Specific heat of the metal (J/kgK)
A_{mta} = Heat transfer surface metal/ adsorbent (m²)
A_{mte} = Heat transfer surface metal/ environment (m²)
m_{ad} = Mass of the adsorbent (kg)
c_{ad} = Specific heat of the adsorbent (J/kgK)
c_{mnl} = Specific heat of the methanol (J/kgK)
m_p = Mass of the plate (kg)
c_{pp} = Specific heat of the plate (J/kgK)
w = ratio of methanol contained in adsorbent
k = constant

3. RESULTS

In this simulation, it is necessary to determine several values such as:

- Temperature of condenser (T_c)
- Temperature of evaporator (T_e)
- Temperature of ambient (T_A)
- Initial concentration of methanol in the adsorbent (conc) and
- Solar irradiation intensity

For this experiment, we define values of:
T_c = 293K,
T_e = 273K,
T_A = 300K,
conc = 0.27,
and the solar radiation data of February 15th, April 15th, June 15th, August 15th, October 15th and December 15th are chosen as input data.
The results (three diagrams) can be seen on these pictures below.
These pictures depict values of solar irradiation intensity in a day from 11 o'clock until 18 o'clock (assumed desorption time).

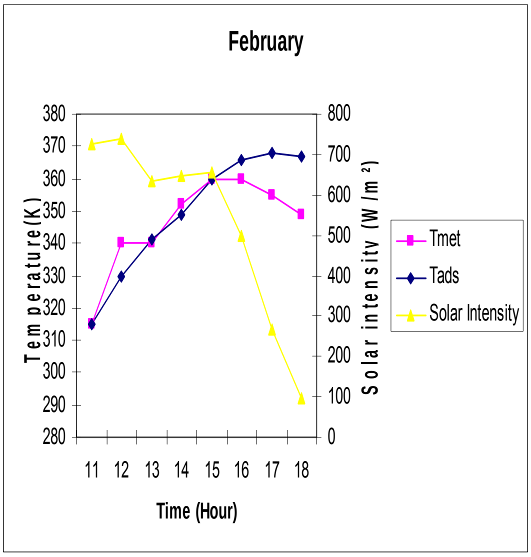

Figure 3.2. Solar irradiation, metal temperature, adsorbent temperature in February

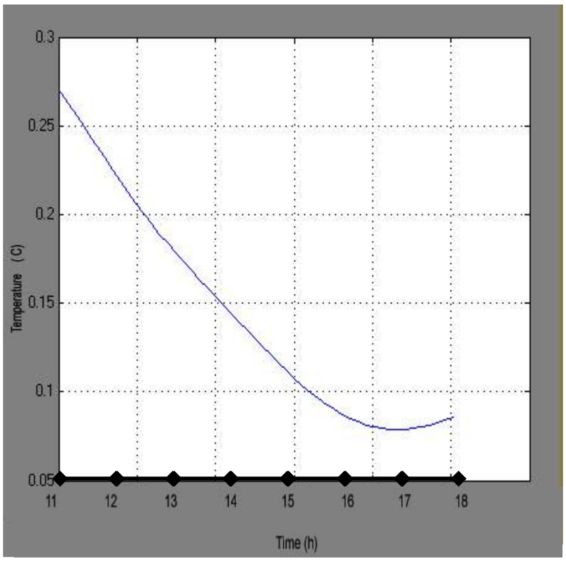

Figure 3.3. Concentration of methanol in February

The solar radiation varies from around 100 W/m² to 750 W/m². At the beginning of the simulation (at 11 o'clock), the solar intensity shows 700 W/m². Around 12 o'clock it reaches 740 W/m², hence that is the peak of solar radiation of that day. After then, it starts to decrease until 100 W/m² at 17 o'clock and then no emission of solar as a result of night hours.
The red curve describes the temperature of metal that has been hit by the sun. It shows an increasing trend from 320 K up to 360 K.
The blue one symbolizes the temperature of adsorbent (activated carbon). This line increased from 315 K up to 368 K.

The desorption process of 27% of the methanol contained in the adsorbent will result in decreasing concentration down to 7% left of the methanol contained in adsorbent (or 74% has been desorbed). The temperature will increase from 318 K (at the beginning of the desorption) up to 368K at the end of the desorption.

This figure 3.4 shows that the solar intensity in this month is the highest among other samples. It reaches 1000 W/m² at noon (middle of the day). In the beginning of desorption, it shows an increase but not radically. After it has reached the temperature peak in the middle of the day, it severely falls down to 100 W/m² in only about four hours. The higher solar irradiation intensity will lead to the rapid drop after it reaches the peak.

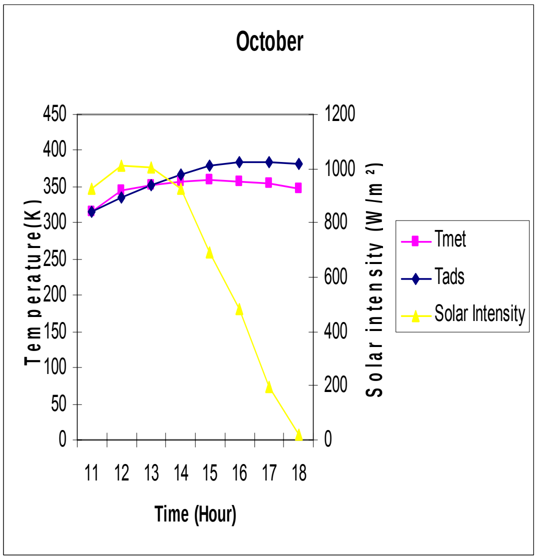

Figure 3.4. Solar irradiation, metal temperature, adsorbent temperature in October

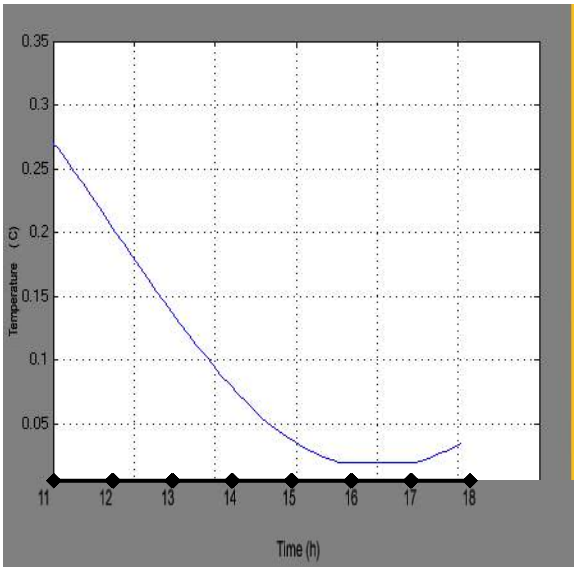

Figure 3.5. Methanol concentration in October

Figure 3.5 describes a decline concentration curve of the methanol desorption.

Here, the concentration experiences the lowest and minimum value. Around 90% of methanol contained in the adsorbent is released during the desorption. And this value can not be higher than that since the adsorbent has a characteristic of minimum desorption value in combination with the methanol as refrigerant. Thus around 2% of methanol is still trapped in the activated carbon.

Figure 3.6 illustrates the solar irradiation data for input data simulation.

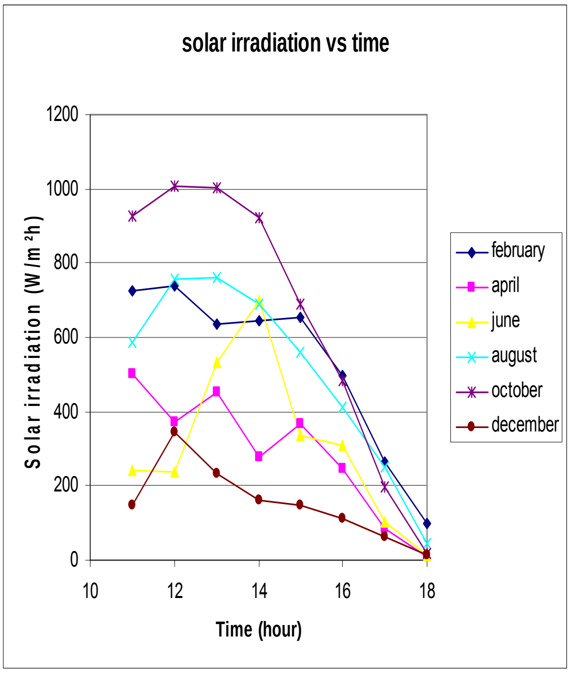

Figure 3.6. Solar irradiation during desorption process

From the picture above, it is seen that the value of the solar radiation in October will be the highest and the solar radiation in December will be the lowest value. Those data will result in the value of the concentration of the methanol contained in the activated carbon. The higher solar irradiation data, the concentration value of the methanol contained in the activated carbon will be lower.

4. SUMMARY

From the observations and simulations as it was described, it can be concluded that:

- This solar ice maker simulator is built with several boundaries. An ideal cycle of adsorption refrigeration is used as an orientation of the system.
- The solar irradiation intensity in Indonesia fluctuates every month with increasing trend in the middle of the year and it will decrease in the end of the year.
- In February 15th with a peak solar intensity of 700 W/m^2, it produces a temperature of 368K for the adsorbent temperature and thus results in the methanol contained in the adsorbent that has been desorbed 74% from its initial concentration.
- The October 15th simulation reaches the highest values for the desorption process. Around 90% of methanol contained in the adsorbent is released with the peak adsorbent temperature of 383 K and the peak solar intensity of 1000 W/m^2.
- In December simulation, the maximum intensity of the solar radiation can reach only 340 W/m^2. This affects the concentration of the methanol in the adsorbent to decrease about 14% from its initial value with the peak adsorbent temperature of 327 K.

REFFERENCES

[1] http://www.suedostasien.unibonn.de/suedostasien/download/working_19.doc
[2] http://www.aseanenergy.org/energy_sector/electricity/indonesia

[3] http://www.britain-in-indonesia.or.id/commer10.htm

[4] Indarti, Economic and social commission for Asia and the Pacific Regional seminar Guangzhou China, June 2001.

[5] Kathrin Mende and Debora Tydecs, Basisgesundheitsversorgung in Indonesien: Die Bedeutung der PUSKESMAS für die nationale Gesundheitsversorgung, Southeast Asian Studies paper 19, Bonn Germany 2003.
[6] http://www.auick.org/index.html
[7] H.L Luo, Y.J Dai, R.Z. Wang, Tang Runsheng, M. Li, Year round test of a solar adsorption ice maker in Kunming China, Energy Conversion and Management, June 2004.
[8] Antonio Pralon Ferreira Leite, Michel Daguenet, Performance of a new solid adsorption ice maker with solar energy regeneration, Energy Conversion & Management, November 1999.
[9] Boubakri A, A new conception of and adsorptive solar-powered ice maker, Renewable Energy; June 2001.
[10] R.Z Wang, R.G Oliviera, Adsorption refrigeration – an efficient way to make good use of waste heat and solar energy, International Sorption Heat Pump Conference, June 2005.
[11] R.Z Wang, M. Li , A study of the effects of collector and environment parameters on the performance of a solar powered solid adsorption refrigerator, Renewable Energy 2002.

[12] A.O Dieng, R.Z. Wang, Literature review on solar adsorption technologies for ice-making and air-conditioning purposes and recent developments in solar technology, Renewable and Sustainable Energy Reviews. January 2001.
[13] A Boubakri, J.J. Guilleminot , F Meunier, Adsorptive solar powered ice maker: experiments and model, Solar Energy vol 69, January 2000.
[14] Catherine Hildbrand, Philippe Dind, Michel Pons, Florian Buchter, A new solar powered adsorption refrigerator with high performance, Solar Energy, October 2002.