Case Studies in Thermal Engineering 7 (2016) 36–46

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

journal homepage: www.elsevier.com/locate/csite

Experimental study on solar-powered adsorption refrigeration cycle with activated alumina and activated carbon as adsorbent

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ARTICLE INFO

Article history:
Received 14 November 2015
Received in revised form
19 January 2016
Accepted 25 January 2016
Available online 26 January 2016

Keywords:
Solar energy
Adsorption cycle
Activated alumina
Activated carbon

ABSTRACT

Typical adsorbent applied in solar-powered adsorption refrigeration cycle is activated carbon. It is known that activated alumina shows a higher adsorption capacity when it is tested in the laboratory using a constant radiation heat flux. In this study, solar-powered adsorption refrigeration cycle with generator filled by different adsorbents has been tested by exposing to solar radiation in Medan city of Indonesia. The generator is heated using a flat-plate type solar collector with a dimension of 0.5 m × 0.5 m. Four cases experiments of solar-powered adsorption cycle were carried out, they are with generator filled by 100% activated alumina (named as 100AA), by a mixed of 75% activated alumina and 25% activated carbon (75AA), by a mixed of 25% activated alumina and 75% activated carbon (25AA), and filled by 100% activated carbon. Each case was tested for three days. The temperature and pressure history and the performance have been presented and analyzed. The results show that the average COP of 100AA, 75AA, 25AA, and 100AC is 0.054, 0.056, 0.06, and 0.074, respectively. The main conclusion can be drawn is that for Indonesian condition and flat-plate type solar collector the pair of activated carbon and methanol is the better than activated alumina.

1. Introduction

In some remote areas of Indonesia, there are many villages where electricity is presently unavailable or far from sufficient. Such areas need refrigeration machine in order to preserve foods and vaccines. Most of the refrigeration machines currently in service based on vapor compression cycle which is powered by electricity. On the other hand, Indonesian archipelagos are located around equator. Such areas receive solar radiation constantly for entirely year and long sunshine hours. According to measurements and predictions, for clear sky radiation total solar energy in Indonesian archipelagos can vary from 16 to 18 MJ/m^2 per day [1,2]. Therefore, the solar-powered refrigeration machine for harvesting the abundant solar thermal energy in order to preserve foods and vaccines is a promising application for those areas. Thus, solar-powered refrigeration machine is an interesting topic to be studied and very applicable for Indonesian remote areas.

Many researchers have been reported their works that dealt with producing cooling based on adsorption cycle powered by solar radiation. Pons and Guillminot [3] pioneered the research of solar-powered adsorption cycle to produce cooling. They designed and tested a solar-powered ice maker based on adsorption cycle. The solar collector is a flat plate type with

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http://dx.doi.org/10.1016/j.csite.2016.01.006
2214-157X/

Nomenclature

A	altitude, km
AA	activated alumina
AC	activated carbon
a_0	a constant for atmospheric transmittance
a_1	a constant for atmospheric transmittance
B	a parameter for solar time
COP	coefficient of performance
c_p	specific heat, kJ/kg K
E	the equation of time, minute
G	solar radiation, W/m^2
H	heat of desorption, kJ/kg
I	total solar intensity, W/m^2
k	a constant for atmospheric transmittance
L	latent heat, kJ/kg
L_{st}	standard meridian for the local time zone, for Medan city 105°
L_{loc}	longitude of the experiment location, 98°
m	mass, kg
P	pressure, mbar
ST	solar time
STD	standard time
Q	energy, kJ
T	temperature, °C or K
t	time, sec
tss	time at sunset, sec
tsr	time at sunrise, sec
x	concentration of adsorbed methanol, kg/kg

Greek symbol

α	absorbance
δ	declination angle, °
ε	emissivity
τ_g	glass transmittance
τ	atmospheric transmittance, –
θ_z	azimut angle, °
φ	latitude angle, °
ω	hour angle, °

Subscripts

1, 2, 3,4	points on Clapeyron diagram
ad	adsorbent
amb	ambient
b	beam radiation
con	condenser
eva	evaporator
gen	generator
m	methanol
on	extraterrestrial
sur	surrounding
tot	total

collector area of 6 m^2. It is loaded with 130 kg activated carbon and 18 kg of methanol as refrigerant. The machine was tested by exposing to solar radiation in Orsay, France with latitude 48 °N. The solar radiation varied from 19–22 MJ/m^2/day. It was reported that their refrigeration machine can produce 30–35 kg of ice per day. Li et al. [4] carried out analysis and performance testing of a solar-powered refrigeration machine. The solar collector consists of two flat-plates with area of 1.5 m^2. The generator is loaded with activated carbon and evaporator is filled with methanol as refrigerant. Performance testing was carried out in laboratory by exposing the collector to quartz lamps as a solar simulator. By using radiation of 28–30 MJ, the refrigeration machine can produce ice of 7–10 kg ice.

Khattab [5] studied a small scale of solar-powered adsorption cycle. A prototype is designed, fabricated and tested in Cairo (30 °N). The local produced activated carbon and methanol were used. In order to enhance the heat transfer rate in the activated carbon grains are mixed with small pieces of blackened steel. Test results showed that the generator bed temperature is above 100 °C was found to be 5 h with a maximum temperature of 120 °C in winter. In summer, the corresponding values 6 h and 133 °C. The daily ice production was claimed to be 6.9 and 9.4 kg/m^2 and COP is 0.13 and 0.159 for winter and summer climate, respectively. Li et al. [6] developed a solar-powered ice maker with no valve. The used collector is flat plate type with area of 1 m^2 and it contains 19 kg activated carbon produced in China. The machine was tested by exposing directly into solar radiation of 18–22 MJ/m^2/day. The results showed that it can produce ice about 5 kg.

Literature review shows that there are several drawbacks in the solar-powered adsorption refrigeration cycle [7] and those are mainly in generator. Among the problems are: adsorption and desorption process is yet unknown perfectly, low heat transfer rate from the absorber plate into adsorbent layer, and low adsorption capacity of the adsorbent. Typical adsorbents in an adsorption refrigeration cycle can be divided into physical adsorbents and chemical adsorbents. Physical adsorbents such as activated carbon, zeolite, and silica gel. Chemical adsorbents are metal chlorides, salt and metal hydrates, and metal oxides. In order to enhance the heat transfer coefficient and adsorbent capacity, some researchers [8,9] made compound adsorbents, such as a combination of activated carbon and metal chlorides or combination silica gel and chemical adsorbent. To the present, activated carbon is the most used adsorbent for solar-powered adsorption refrigeration cycle. However, its performance is yet not satisfied and it needs improvements.

Adsorption capacity of the working pairs is one of the key on development high performance solar-powered adsorption refrigeration cycle. Shmroukh et al. [10] reported a literature review on adsorption working pair for adsorption cooling chiller. Their review based on adsorption capacity and environmental impact of both classical and modern adsorption refrigerant pairs. The results showed that maximum adsorption capacity for classical working parking pairs was 0.259 kg/kg for activated carbon methanol pair. It was suggested that further investigations are still needed to improve the performance