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A new zero energy cool chamber with a solar-driven adsorption refrigerator

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ABSTRACT

A new zero energy cool chamber (ZECC) consisting of two cooling systems, a solar-driven adsorption refrigerator and an evaporative cooling system, was developed and then evaluated as low-cost and eco-friendly cooling storage for storing fruit with moderate respiration rates. The solar-driven adsorption refrigerator, consisting of a solar collector containing activated carbon as an adsorbent, a condenser and an evaporator, cools water based by evaporating methanol and adsorbing it on activated carbon, and then makes ice. The methanol adsorbed on the activated carbon is desorbed by applying solar heat. The ice is then used to cool the storage space, which can be done for a long time without the need for electricity. The evaporative cooling system also cools the storage space by evaporating water from the wet walls containing wet filler. The combined use of two cooling systems reduced the average inside temperature of the new ZECC to 12.07 °C compared with an average outside temperature of 31.5 °C and extended the shelf life of tomatoes from 7 to 23 days. These results suggest that the new ZECC proposed here is low-cost and energy-saving and is useful for storing fruit and vegetables in areas where electricity is unavailable.

1. Introduction

Cooling is required to maintain the freshness of fruit and vegetables during storage. Conventional vapor compression cooling systems that use chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) contribute to ozone depletion and global warming. The International Institute of Refrigeration in Paris (IIF/IIR) has estimated that approximately 15% of all the electricity produced in the world is employed for refrigeration and air-conditioning processes of various kinds, and the energy consumption for air-conditioning systems has recently been estimated at 45% for all households and commercial buildings [1]. Therefore, an eco-friendly refrigerant with a newer refrigeration system is required to reduce the emissions of harmful gases.

In recent years, adsorption refrigerators driven by solar energy have been receiving much attention as a replacement for conventional vapor compression refrigeration cycles driven by electricity. In the adsorption system we are proposing, methanol is used as a refrigerant instead of harmful CFCs, HCFCs or HFCs, and solar energy is used to drive the refrigerant (methanol) without electricity. Adsorbent (activated carbon) is used to adsorb the methanol and promote its evaporation. The storage space is cooled using ice made by the adsorption refrigerator. Solar energy is safe, environmentally friendly and abundant. Therefore, a solar-driven adsorption refrigerator is lowcost, eco-friendly, energy-saving and simple in structure. Several noiseless and non-corrosive solar refrigeration systems such as liquid/vapor, solid/vapor absorption, adsorption, vapor compression and photovoltaic-vapor/compression systems have been developed [2–11]. However, the most promising method of producing ice by using solar energy is with an activated carbon (adsorbent)-methanol (adsorbate) pair, which could be driven by relatively low heat temperatures and is less expensive [2,12]. The cooling load of such a system is generally high when solar radiation is high.

In developing countries, most agricultural areas do not have a grid electricity supply. As a result, large quantities of fruit decay due to the unavailability of electric-powered vapor compression refrigeration systems. This lack of refrigeration also causes sharp differences in food supplies between the harvest and off harvest periods. Using an evaporative cooling technique is effective in overcoming this problem. We have developed a zero energy cooling chamber (ZECC) using an evaporative cooling technique [13]. We

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Nomenclature

ZECC	zero energy cool chamber
P	pressure (Pa)
T	temperature (°C, K)
V	control valve
COPS	solar coefficient of performance
Q	thermal energy (kJ)
M	mass (kg)
Cpw	specific heat capacity of water (kJ kg^{-1} K^{-1})
L	latent heat of ice fusion (KJ Kg^{-1})
I	total amount of heat input absorbed by the solar collector during one day of operation (MJ)
$X1$	initial weight (g)
X	final weight (g)

Greek symbols

Δ	variance

Subscripts

w	liquid water
amb	ambient
gen	generation
con	condensation
ev	evaporation
ads	adsorption
fus	fusion
max	maximum
ref	refrigerant
co	cooling effect

also applied an intelligent optimization technique to minimize the inside temperature of the ZECC by controlling the watering [14]. The ZECC is low-cost, eco-friendly and energy-saving and is useful for increasing the shelf life of stored fruit [15–17]. The evaporative cooling process in the field is quite complex and is affected by many factors such as solar radiation, ambient temperature, relative humidity, the watering condition for evaporative cooling, and the loading condition of stored fruit [12].

This paper proposes a new ZECC with two cooling systems, a solar-driven adsorption refrigerator and an evaporative cooling system, aimed at developing a low-cost, eco-friendly and energy-saving fruit-storage system which would be useful in developing countries. The cooling performance and the shelf life of fruit and vegetables in the new ZECC were mainly investigated during the hot and dry seasons of the year.

2. Materials and methods

2.1. Structure of the new ZECC

A new zero energy fruit-storage chamber with two eco-friendly cooling systems, a solar-driven adsorption refrigerator and an evaporative cooling system, was set up at the Faculty of Agriculture, Ehime University, as shown in Fig. 1. The chamber consists of a double wall (inner and outer walls), a filler (evaporating medium) inside the double wall, a storage space for fruit and vegetables, two cooling systems, and a shading curtain. The outer and inner walls of the zero energy storage chamber were made of porous lava stones and solid clay bricks, respectively. The storage space was 1100 mm long × 900 mm wide × 600 mm high. The evaporating medium between the walls consisted of two layers: sand-zeolite and gravel stone. The gap between the outside and inside wall was 65 mm, 55 mm of which was packed with filler consisting of a mixture of sand (80%) and natural zeolite EOLITE No. 1 (ITT, Japan) (20%), and the remaining 10 mm was packed with filler consisting of gravel stone (2 mm). The natural zeolite was added to the sand to increase the water retention capacity and gravel stone was used to enhance the evapotranspiration rate. Tap water from an overhead water tank (97 mm wide × 25 mm deep; at a height of 150 mm) was supplied to the filler material through a G240 low pressure micro sprinkler (Takagi, Japan) with 0–10 GPH and 360-degree gentle stream pattern. The amount of watering was set to 0.40 ml s^{-1}. A two-port pilot kick type PKA valve (CKD Corporation, Japan) controlled by a programmable timer supplied water to the water pipe. The inside wall and bottom of the storage area was covered with 5 mm thick polystyrene (expanded type) heat insulation

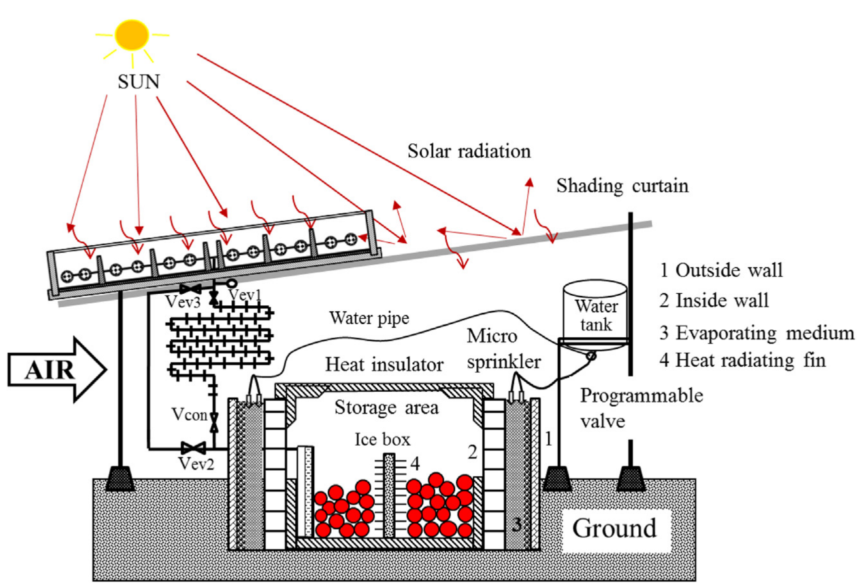

Fig. 1. A new zero energy cool chamber (ZECC) with two cooling systems, a solar-driven adsorption refrigerator and an evaporative cooling system.