Applied Energy 165 (2016) 308–317

Contents lists available at ScienceDirect

Applied Energy

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

Solar thermal–photovoltaic powered potato cold storage – Conceptual design and performance analyses

Dipankar N. Basu [a], A. Ganguly [b,*]

[a] Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati 781039, India
[b] Department of Mechanical Engineering, Indian Institute of Engineering Science and Technology, Shibpur, Howrah 711103, India

HIGHLIGHTS

- Loss of food crop is a huge problem in India due to the shortage of cold storage.
- Conceptual design of a power system using solar energy for a potato cold storage.
- Integration of flat plate collector and SPV module with suitable operating strategy.
- System provides a net energy surplus of about 36 MW h over a calendar year.
- Rudimentary economic analysis found payback period of less than four years.

ARTICLE INFO

Article history:
Received 26 August 2015
Received in revised form 13 November 2015
Accepted 17 December 2015
Available online 4 January 2016

Keywords:
Cold storage
Absorption system
Solar photovoltaics
Flat plate collector

ABSTRACT

Wastage of food crops due to the dearth of proper cold storage facilities is a huge problem in underdeveloped and developing countries of the world. Conceptual design of a potato cold storage is presented here, along with performance appraisal over a calendar year. The microclimate inside the cold storage is regulated using a water–lithium bromide absorption system. Proposed system utilizes both solar thermal and photovoltaic generated electrical energy for its operation. A suitable operation strategy is devised and the performance of the integrated system is analyzed from energy and exergy point of view to identify the required numbers of thermal collectors and photovoltaic modules. The proposed system is found to provide a net surplus of about 36 MW h energy over a calendar year, after meeting the in-house requirements. A rudimentary economic analysis is also performed to check the financial viability of the proposed system. Both the thermal and photovoltaic components are found to have payback periods less than four years.

1. Introduction

The issue of food losses is of paramount importance in pursuit to combat hunger and improve the food security, especially in the poor and developing nations. Such losses not only deprive the under-privileged societies, but also epitomises substantial waste of resources employed during its production. The exact reasons and extent of such losses vary round the globe and are heavily dependent on the specific conditions, as well as indigenous factors prevailing in a specific country. However, the concern is universal, as roughly one-third of the edible parts of worldwide food production gets lost or wasted, which amounts to about 1.3 billion tons annually [1]. The post-harvest deterioration contributes towards a significant fraction of the total loss in food grains, especially in the developing countries of the world, owing to poor storage facilities and lack of infrastructure. The hot and humid climate prevailing in the tropical and subtropical countries is also seriously responsible for such enormous decay. Thus, establishment of cold storages is the need of the hour, to reduce the wastage of perishable commodities, as well as, for the economic benefit of both the growers and consumers.

One major hindrance towards such initiative is the considerable energy required by a cold storage for its powering and operation. This is a serious concern in the underdeveloped and developing countries, where a substantial fraction of the rural population does not have access to the grid electricity. In a developing country like India, there are about 94,000 un-electrified villages and 25,000 of them are so remotely located that the extension of power grid there is not economically viable [2]. Operation of cold storage powered through alternative energy can be a perfect solution in this

* Corresponding author. Tel.: +91 33 26684561; fax: +91 33 26682916.
E-mail address: aritra78@gmail.com (A. Ganguly).

http://dx.doi.org/10.1016/j.apenergy.2015.12.070

Nomenclature

A_C	collector area (m^2)
$\dot{E}$	electrical power (W)
G	incident solar flux (W/m^2)
H_{resp}	heat of respiration (J/kg)
J	electrical energy (A h)
M	storage mass (kg)
$\dot{Q}$	rate of heat transfer (W)
S	useful solar flux (W/m^2)
U_L	overall loss coefficient (W/m^2 K)
V	system voltage (V)
C_p	specific heat (J/kg K)
F_R	heat removal factor
h	enthalpy (J/kg)
I	current (A)
$\dot{m}$	mass flow rate (kg/s)
p	pressure (N/m^2)
R	thermal resistance (K/W)
T	temperature (K)
v	specific volume (m^3/kg)
$\dot{W}$	rate of work transfer (W)

Greek symbols

ϵ	effectiveness
Δh	enthalpy difference (J/kg)
η	efficiency
ΔT	temperature difference (K)
ρ	density (kg/m^3)

Subscripts

air	ambient air
b	beam
C	condenser
en	energy
E	evaporator
F	cooling fan
i	inlet
p	potato
PV	solar photovoltaic
ss	strong solution
ws	weak solution
A	absorber
c	collector plate
d	diffused
ex	exergy
f	cooling fluid
G	generator
o	outlet
P	pump
r	refrigerant
U	useful gain

Abbreviations

COP	coefficient of performance
FPC	flat plate collector
SPV	solar photovoltaic
VARS	vapor absorption refrigeration system

perspective, as that offers the dual advantage of primary energy savings and reduced environmental menace.

However, studies related to cold storage powered through renewable energy are quite scarce in open literature. As an initial effort, Sethu et al. [3] presented a comprehensive design of a 10 TR solar-powered potato cold storage based on aqua-ammonia vapor absorption refrigeration system (VARS). The cold storage used 152 selectively-coated flat plate collectors (FPCs) to supply hot water at a temperature of 95 °C. Devres and Bishop [4] developed a computer model to calculate the energy consumption and moisture loss in a potato cold storage, using the data from an actual unit at Cambridge. The model predicted numbers were very close to the actual values. Perier-Muzet et al. [5] studied the dynamic behavior of a cold storage combined with a solar-powered thermoacoustic refrigerator. Development of various alternate designs of solar-powered VARS for the climatic conditions of Saudi Arabia was reviewed by Said et al. [6]. Continuously-operating aqua-ammonia system with refrigerant storage was found to be the most suitable design for uninterrupted cooling. Adoption of refrigerant storage was also suggested by Al-Ugla et al. [7], as they analyzed three alternative storage designs for a solar-powered H_2O–LiBr absorption system for 24 h operation. Yuan et al. [8] proposed an OTEC-based solar-assisted combined cycle for simultaneous electricity generation and powering a fishery cold storage, considering ammonia/water as working pair and the warm/cold sea water as the heating/cooling source. A response strategy for active and passive cold storages was presented by Cui et al. [9], to reduce the immediate and stepped power demand through chillers shutdown. Bao et al. [10] designed a resorption system for application in cold storage and for long distance refrigeration. Manganese chloride and ammonium chloride were used as high temperature and low temperature salts respectively. A fluidized bed based CO_2 hydrate cold storage was modeled by Zhou et al. [11], whereas Xie et al. [12] experimented with a novel small-scale gas hydrate cold storage apparatus with inner heat exchanger and outer crystallization pump. Shi and Zang [13] made a comparative study of different methods for generation of tetra-n-butyl-ammonium bromide clathrate hydrate slurry in a cold storage air-conditioning system. In recent years, use of phase change materials (PCMs) for cold storage application has been explored quite a bit [14–16] and a comprehensive review on relevant applications of solid–liquid PCMs is available in [17]. However, despite the promise of low running cost, PCMs can be twice as expensive compared to conventional coolers [18], and hence solar-based systems seem to be a better option.

Comparative review of Kim and Ferreira [19] identified single-effect H_2O–LiBr system as the most feasible one among several options of solar-electric and solar–thermal cooling systems. Pongtormkulpanicha et al. [20] developed an absorption chiller of 10 TR capacity coupled with evacuated tube solar collector. About 19% of total thermal energy requirement was met through LPG-fired backup heating unit, which highlights the prime concern for solar thermal-based coolers. Appropriate energy storage option must be provided to sustain operation beyond daytime, which is not economical at present. Said et al. [6] suggested the inclusion of liquid ammonia storage of 1845 kg capacity and 55 m^2 of collector area for a cooling load of just 5 kW. Such huge space requirement often necessitates the use of auxiliary heaters during the period of insufficient solar radiation. The escalating growth in solar photovoltaic (SPV) technology offers an option in this context, which, if used alone, can be expensive. Experimental study of Chien et al. [21] required 1.78 m^2 area of solar cell for a paltry cooling load of