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Thermo-economic assessment of hybrid renewable energy based cooling system for food preservation in hilly terrain

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A B S T R A C T

In the commercial food sector, preservation and transportation is responsible to avoid the 22% spoilage of the total food production in developing countries like India. To reduce the spoilage, preservation of such produce including milk is needed in remote places. Due to the increased fossil fuel costs, issues in grid extension and environmental concerns, there has been a renewed interest in hybrid renewable energy systems for cooling applications in remote/rural areas. In this paper, the overall thermal performance and economic aspects of a hybrid energy based milk cooling system for hilly terrain have been analysed using the MATLAB software and the appropriate hybrid energy systems has been predicted. The results indicate that the biomass and gobar gas combination can show the overall thermal performance as 0.17–0.23 with lowest Payback period and life cycle cost of 4.5 years and INR 2.8 × 10^7 respectively. The sensitivity analysis shows that the maximum influence of uncertainty in input parameters on the overall COP, capital cost, running cost and payback period are 6.8, 5.1, 5.3 and 6.1 percentages respectively.

1. Introduction

Milk and agro processing has a potentially important role in the economic development of developing countries. In the Indian context, milk has a special role to play for its many nutritional advantages besides providing supplementary income to 70 million farmers in remote villages [1]. However, 20–25% of the total milk production is spoiled due to improper preservation [2]. This may be a great loss to the farmers and the country. The spoilage can be reduced by implementing suitable preservation strategies in the places where it is produced [3,4].

The major approved methods of milk preservation are refrigeration and/or heat treatment, although both methods have limitations with respect to processing [5]. Fresh milk, after milking, normally has a temperature of 33 °C. Proper milk cooling is essential to ensure good quality, because bacteria multiply rapidly when milk is cooled too slowly or if it is stored at temperatures above 4 °C. Cooling and storage is very important, especially if there is a long delay (more than 2 h) between milking and delivery at the collection center. In such cases, ideal storage temperature is 1–2 °C. Cooling should be done in two stages. First, fresh milk is pre-cooled to 15–20 °C or lower. Then, it is cooled to storage temperature. For any subsequent milk (arriving in batches) the mixed or blended temperature should not go above 10 °C [6]. The vapor compression refrigeration system working with conventional energy has been used for most of the cooling applications. In recent years, the focus of the nations is shifted to renewable energy technologies because of the issues associated with conventional sources of energy. If the cooling facility is located near the raw materials, the post-harvest losses can be minimized.

In remote places, farmers use salting and drying for food preservation, and due to the unhygienic methods used, the spoilage is very high [7]. Some places the preservation of fruits and vegetables is done by mixing chemical preservatives and antioxidants [8]. Non-availability of cooling or chilling system and high ambient temperature are the main constrains in milk collection and distribution. These conditions decrease or shorten the shelf life of raw milk [9]. The problems related to milk marketing include lack of quality control, lack of cooling and storage facilities, poor quality of milk supplied from rural areas, sale of raw milk, inappropriate handling and storage vessels, gap in the cold chain and transport facilities, and spoilage due to lack of preservation and processing facilities [10,11].

The studies conducted on a biomass-based sorption cold storage

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Nomenclature

m	mass flow rate, kg s^{-1}
T	temperature, °C
CV	calorific value, kJ kg^{-1}
Q	heat transfer rate, kW
η	efficiency
d	annual interest rate

Abbreviations

COP	coefficient of performance
HR	hilly region
GG	gobar gas source
BG	biogas source
BM	biomass source
VARS	vapour absorption refrigeration system
VCRS	vapour compression refrigeration system
TR	tonne of refrigeration
CC	capital cost (INR)
RC	running cost (INR)
PBP	payback period (years)
NPV	net present value (INR)
LCC	life cycle cost (INR)
PWC	present worth cost (INR)
RE	replacement cost (INR)
SV	salvage value
HES	hybrid energy system
INR	Indian rupee (1 USD = INR 62.5)

Subscripts

m	milk
e	evaporator
i	inlet
o	outlet
ch	chiller
c	conversion
os	overall system
g	generator
t	total
n	life time (years)

system of capacity 15 MT [12] show that the operating cost is 25–30% lower than that of the conventional cooling system for the same capacity. The research conducted on solar powered cooling system for food preservation in rural areas also shows that the COP can be maintained between 0.45 and 0.65 with the payback period of 4.5–6 years [13–16]. Biogas based cooling system minimizes the exergetic manufacturing cost, which is normally very high for conventional energy based cooling system [17].

Unfortunately, any single renewable energy source could not provide a continuous power supply due to variations in weather and climate conditions. So the combination of two or more energy sources can improve the power supply reliability by using the complementary characteristics of other energy sources [18]. During low solar radiation, other renewable energy is integrated with solar energy, which gives better COP [19]. Effective and optimum use of the energy sources in stand-alone systems can help in meeting the energy demands of remote, inaccessible areas and make them self sufficient [20].

The hybrid renewable energy based systems are mainly used in the power generation sector because it has an excellent solution for electrification of remote areas [21] where the grid extension is non-economical. The photovoltaic/diesel hybrid energy system with battery backup is a good alternative energy source for diesel-powered generator, and it has high energy potential and low carbon emission at affordable cost of electricity [22–24]. The hydro-wind hybrid energy system can be used in remote areas with the nominal unit cost of electricity [25]. Hybrid system will become an increasingly attractive option as the cost of solar thermal falls, and the prices of feedstock, fossil fuel and land continue to rise [26]. Hybrid energy systems with suitable combination of renewable energy sources can possess the advantages of both systems. Thus reduction in implementation and maintenance cost, improvement in reliability, techno-economic viability and environmental friendliness etc., could be achieved [27–29]. A Cogeneration plant based on the biogas can be hybridized with auxiliary solar energy source, having the advantage of financial incentives [30]. Biomass-solar hybrid energy based absorption cooling system could extend the evaporator's operation time [31]. Wind-biomass and Biomass-solar- Hydel based hybrid energy systems are very good alternatives for the wind-diesel system, because of their attractive energy price [32]. Solar-wind hybrid energy system has the lowest value of levelised cost, operating cost, net present cost, life cycle cost and emission [33]. The overall efficiency of the system is increased with the payback period of 8 years when the biomass and fuel cell energies are combined [34]. The life cycle cost, life cycle unit cost and the present worth cost of waste heat operated cooling system is lower than that of presently operated conventional cooling systems [35].

From the review of the literature, it is seen that most of the investigations on the hybrid renewable energy systems focuses on the production of electrical energy. However limited studies are reported on the feasibility of hybrid energy operated cooling systems in remote areas. The studies conducted by the authors' [36,37] on rubber, paddy and sea shore regions to apply hybrid energy based cooling system for food preservation shows that the conventional energy based cooling system can be retrofitted with hybrid renewable energy. To further extend the study for the implementation of hybrid energy based cooling systems in remote hilly regions, additional survey was conducted.

The data on the availability of biomass, biogas and gobar gas energy sources have been studied. The possibility of combining these energy sources to meet the total cooling requirement for the preservation of milk, which is produced in the hilly region, has been studied and the various thermo-economic parameters are analysed and presented in this paper.

2. Selection of hybrid energy system for hilly region (HR)

To utilize the available energy sources efficiently in remote places, a study has been conducted in few remote hilly villages situated in the southern part of India. The photographical view taken from the study area of hilly regions are shown in Fig. 1. Data pertaining to the available energy resources, energy consumption pattern and current usage of renewable energy sources in the study area are collected with appropriate questionnaires. The important observations from the survey are given in Table 1. The major biomass energy sources identified are, tapioca stem, coconut shell, wood chips, wood pellets etc. Similarly the biogas and gobar gas sources are calculated from the quantity of municipal solid wastes, population of cows, cattle, buffalos and goats. Milk, fruits, agro produce and bio-waste obtained from livestock are calculated from the survey.