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Techno-economic studies on hybrid energy based cooling system for milk preservation in isolated regions

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ABSTRACT

In developing countries like India, about 70% of the population is engaged in the production of milk, fruits and vegetables. Due to the lack of proper storage and transit facilities, the agricultural produce, in remote areas loses its value. This spoilage could be prevented at the local village level, by providing cooling units for short term preservation. In this paper, the possibility of a hybrid energy based thermally operated cold storage has been considered to meet the cooling needs of the villages in the southern parts of India, where biomass, biogas and gobar gas are available in abundance. A milk cooling system that uses various combinations of locally available renewable energy sources to operate an aqua ammonia vapour absorption cooling system has been analysed using the Matlab software. The impact of various combinations of renewable energy sources on the Coefficient of Performance (COP), Net Present Value (NPV) and payback period of the total cooling system has been studied. The analysis shows that the COP and payback period of the proposed hybrid renewable energy based milk cooling system are 0.16–0.23 and 4–6 years respectively.

1. Introduction

In rural areas, more than 22% of the milk, fruits and vegetables produced are spoiled due to lack of storage and transportation facilities. To avoid this spoilage, cooling units for short term preservation are needed. Most of the cooling units need electrical power, which is not freely available in remote areas. Moreover, the cooling facility has to be located near the source of the raw materials, because it would help in reducing post-harvest losses and wastes. Since India has enormous bio energy resources, developing hybrid energy powered, thermally operated cold storage can help to meet this shortage.

Many studies related to the generation of power from hybrid renewable energy sources have been reported in the literature. Instead of stand-alone systems, the hybridisation of other energy sources with solar energy has shown a reduction in the power generation cost [1], moreover it can improve the quality of life in remote areas of developing countries [2]. Diesel consumption and environmental pollution are also reduced, if the wind energy system is combined with the existing power system [3]. Compared to the stand-alone systems, the hybrid system is cost competitive, and will effectively tackle the issues related to the supply chain, energy security, land required for farming, operating cost, and pollutant emissions [4,5]. The hybrid system is economically feasible compared with the stand-alone systems. However, the payback period of the hybrid system is slightly higher than that of the stand-alone systems, but it has a considerable positive environmental impact [6]. It is also reported that the life cycle cost, life-cycle unit cost and capital cost of solar-biomass; wind-biomass and PV-wind-biomass hybrid systems are always less than that of the stand-alone solar power systems [7,8]. When hybrid systems are used for cogeneration, the solar and biogas based systems have the advantage of financial incentives [9]. The study conducted on a 3TR capacity biomass based aqua ammonia absorption system shows that the operating cost is 30% less than that of the conventional vapour compression cooling system of the same capacity [10].

Mathematical models have been developed to predict the performance of hybrid systems. The Optimal Renewable Energy Model (OREM) has been used to optimize the contribution of various renewable energy sources to satisfy the energy demand of the end users [11–13]. The hybrid energy system designed in HOMER shows that the wind-biomass and biomass-solar-hydel systems are very good alternatives for the wind-diesel system, because of their attractive energy price [14,15]. The Linear programing model, Mixed Integer Linear mathematical programming model and the combined dispatch strategy based control algorithm have been

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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
RR	Rubber Cultivated Region
PR	Paddy 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
PBP	payback period (years)
NPV	Net Present Value (INR)
MC	maintenance cost (INR)
CC	capital cost (INR)
RC	running cost (INR)
OC	operating cost (INR)
CRF	capital recovery factor
CM	combination
TAC	Total Annual Cost (INR)
ACC	Annualised Capital Cost (INR)
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
BG	biogas source
BM	biomass source
g	generator
t	total
n	life time (years)

used to determine the optimal operating cost of a hybrid energy generation system [16–18].

A hybrid air conditioning system developed based on solar and biomass has shown that the auxiliary energy source can be used to improve the overall system performance [19]. It is reported that the fruits, vegetables and fish in remote areas could be maintained below 5 °C, using biomass and the solar operated hybrid aqua ammonia absorption refrigeration system [20]. The biogas based ammonia-water absorption refrigeration system gives the best performance, when the generator temperature is kept at a low value for any fixed evaporator pressure [21]. Thermoeconomic concept can be applied for the optimisation of LiBr–water or aqua ammonia vapour absorption refrigeration system to minimize the overall product cost [22,23]. The energy cost of the LiBr–H_2O system is less than that of the H_2O–NH_3 system, but the crystallisation problem is eliminated in the ammonia water absorption system [24].

In isolated areas, biomass, biogas and gobar gas energy sources are available in abundance, and if they are suitably integrated to operate a heat driven cooling system, the energy requirement for food preservation could be solved. From the previous studies, related to this area, it is observed that there is a need for research to check the feasibility of this approach. In this work, the overall system was modelled in the software Matlab, and a techno-economic study has been carried out to check the possibility of using the locally available renewable energy sources, to meet the energy need for milk cooling.

2. Modelling and simulation

The data pertaining to the bio-sources, livestock population and cooling requirement were collected from the local Gram Panchayats, Govt. and non-Govt. agencies, etc., and their reliability was confirmed from the local people. Based on the nature of activities undertaken, the villages are grouped as Rubber Cultivated Region (RR) and Paddy Region (PR), and the quantities of energy available and required are given in Table 1. The maximum cooling need is found in the paddy region, because of the high cattle population.

Since a single or a combination of any two energy sources cannot meet the cooling requirement of a region, all the energy sources have to be used in suitable combinations.

The various stages of the simulation are depicted in Fig. 1. In the biomass gasifier, wood chips, tapioca stem, coconut stem, coir pith, paddy hay, rice husk, coconut shell, etc., are used as energy crops. In the biogas plant, municipal solid waste and food waste from houses are the sources of energy. In the gobar gas plant, cow dung is used as an energy crop. The vapour absorption system with either LiBr–water or water–NH_3 refrigerant-absorbent pair can be used for the cooling purpose. However aqua ammonia VARS is preferred because LiBr–water VARS cannot be operated below 5 °C cooling temperature [25,26]. The COP of VARS has been taken as 0.6, 4–10 °C evaporator temperature and 120–150 °C generator temperature [27,28]. The COP of the VARS assumed is used to calculate the generator heat requirement and based on that the required combinations of energy sources from the availability of biomass, biogas and gobar gas, are selected, and further used in the analysis to find the performance and economic parameters. To reduce the complexities of the study, few assumptions, like constant calorific values for energy sources, constant conversion efficiency for a particular energy source, continuous operation of the chilling plant, stable COP for the vapour absorption system, stable cooling requirement throughout the year, negligible variation in labour cost, properties of milk is constant, additional expense for diesel due to flexibility in fuel prices is negligible, are made.

The energy conversion has been calculated, based on the conversion efficiencies of biomass ($\eta_{c,BM}$), biogas ($\eta_{c,BG}$) and gobar gas ($\eta_{c,GG}$), and their values are taken as 0.46, 0.25 and 0.36 respectively [29–33]. The heat produced from the biomass energy source (Q_{BM}) is determined from

$$Q_{BM} = m_{BM} \times CV_{BM} \times \eta_{c,BM} \quad (1)$$

The quantity of bio-waste required to produce 1 m^3 biogas is assumed as 23 kg [34], and the heat produced from the biogas energy source (Q_{BG}) is determined from

$$Q_{BG} = m_{BG} \times CV_{BG} \times \eta_{c,BG} \quad (2)$$

The gobar gas production from cow dung has been worked out, based on the assumption that 4–7 kg dung per cow per day is available, and the quantity of cow dung required to produce 1 m^3 gas is 12 kg [1]. The heat produced from the gobar gas energy source (Q_{GG}) is determined from