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Thermal performance of milk chilling units in remote villages working with the combination of biomass, biogas and solar energies

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ABSTRACT

The milk processing and preservation is a fast growing business in developing countries and it is facing problems due to high energy cost and environmental concerns in using conventional energy sources. The energy tapped from renewable energy sources through the technological innovations would be one of the best options to implement the milk preservation strategies at village level. In rural areas, bioenergy is one of the most versatile energy-generating options. Because of the diversity in feed stock and conversion technologies, suitable study is needed to implement renewable energy base technologies to provide a continuous flow of energy services. In this paper, the use of locally available renewable energy sources, in various combinations, to operate a milk chilling plant at village level has been analysed using the Matlab software. The effect of variations in the combination of renewable energy sources on the overall system COP has been studied. The study predicts that the best possible overall system COPs in hilly, rubber cultivation, paddy and seashore regions are 0.26, 0.25, 0.235 and 0.24 respectively. Moreover, suitable combinations identified in the aforementioned regions are Biomass/Gobar gas (0.7:0.3), Biomass/Biogas/Gobar gas (0.7:0.1:0.2), Biogas/Biomass/Gobar gas (0.6:0.15:0.25) and Biomass/Gobar gas/Biogas/Solar (0.5:0.25:0.125:0.125) respectively.

1. Introduction

India is the world's largest producer of milk and claims 20% of the world's total milk Production. According to milk production data by the National Dairy Development Board, milk production in India has increased by approximately 51% from 80.6 million tons to 121.8 million tons. Today, India's dairy industry is valued at INR 72,000 crore. Near 820 million people live and work in rural India, and almost 10% of rural families – 80 million – work in dairy production [1,2]. The Indian dairy market is currently growing at an annual growth rate of 7% at current prices [3]. Nowadays, it is important to consider the temperature of milk after milking process. If the milk is exposed to high temperature for several hours, it will have a bacteria reproduction. Milk should be stored at lower temperature to prevent bacteria reproduction and follow the permissible limit of bacteria content [4]. In the current scenario to understand the problems related to high energy consumption of the milk processing and to suggest methods for their active reduction with the help of different approaches needed proper management of the all processes used in the plant [5]. At present all most all dairy operations are performed using grid supply with diesel gen-set as backup. The village level co-operative societies for milk collections are provided by bulk milk coolers operating on conventional grid supply of electricity and in case of unavailability of electric supply diesel generator sets are provided for cooling the milk. To overcome the problem of continuous grid supply of electricity and diesel generator sets, renewable energy based refrigeration system for milk cooling at society level is quiet feasible [6]. 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 and solar energy resources, developing hybrid energy powered, thermally operated cold storage can help to meet the energy requirement in dairy process.

Many studies related to the renewable energy based cooling system have been reported in the literature. One strategy for small-scale farms to become competitive is to reduce their energy-related operational costs and greenhouse gas emissions. This can be achieved through taking energy efficiency steps, reducing overall energy consumption and generating energy through renewable

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Nomenclature

α	absorptivity of absorber surface
CV	calorific value, kJ kg^{-1}
η	efficiency
Q	heat transfer rate, kW
F_R	heat removal factor
m	mass flow rate, kg s^{-1}
C_1,C_2	solar constant
I	solar radiation, W m^{-2}
C	specific heat, kJ kg^{-1}
T	temperature, °C
τ	transmissivity of outer glass tube

Abbreviations

VARS	vapour absorption refrigeration system
VCRS	vapour compression refrigeration system
HR	hilly region
RR	rubber cultivation region
PR	paddy region
SR	sea shore region
GG	gobar gas source
BG	biogas source
BM	biomass source
SO	solar energy
ERBAMC	energy ratio for base and mixture component
CM	combination
COP	coefficient of performance
HES	hybrid energy system
TR	tonne of refrigeration
MSW	municipal solid waste

Subscripts

m	milk
e	evaporator
i	inlet
o	outlet
ch	chiller
c	conversion
co	collector
t	total
g	generator
os	overall system

energy resources and technologies [7]. Biogas based absorption cooling system which is generated from the waste water treatment plant from a dairy industry has minimized the exergetic manufacturing costs, which is normally very high for conventional cooling systems [8]. The absorption cooling is a viable option for increasing the energy utilization factor for biomass boilers, besides, biomass can be used as a top up for solar cooling, when there is a lack of solar energy. The potential of combined solar and biomass combustion as a heat source for absorption cooling/heating in climates with low solar radiation can be coupled with biomass waste [9]. A vapour absorption cooling system, powered by down-draft woody biomass gasifier which is used to store fruits and vegetables. The study shows that the COP of the system can be maintained between 0.2 and 0.35, and the operating cost is 25–30% less than that of conventional cooling systems [10].

A number of research tasks had been done in dealing with the design and optimal allocation of hybrid renewable energy based power systems. Hybrid energy systems becoming popular in remote area power generation applications due to advancements in renewable energy technologies and substantial rise in prices of petroleum products. This is to improving the system efficiency and reduces the energy storage requirements for stand-alone applications [11]. Hybrid system is becoming cost competitive with the biomass-only system, and it will tackle the biomass supply chain issues easily [12] besides, it can tackle the electricity supply issues in isolated and rural areas [13]. Unit cost to be very low for the selected hybrid energy system, besides providing 100% renewable energy contribution eliminating the need for conventional diesel generator [14]. A Cogeneration plant based on the biogas can be hybridized with auxiliary solar energy source, besides having the advantage of financial incentives [15,16]. The hybridization of other energy sources with solar energy was studied, and it was found that the cost of generation could be reduced. They also suggested the combination of solar, biogas and biomass system in order to improve the environment and socio-economic conditions in remote places. The cost of energy from biogas, biomass and solar are reported as INR 6.39, 5.04 and 17.60/kWh respectively. Two of these resources are even cheaper than the conventional diesel generation system. Among them solar system alone is costlier. Through the integration of such renewable energy systems, the cost of energy is reduced to INR 10.92/kWh, which is cheaper than the existing conventional diesel generation system [17]. A hybrid air conditioning system was developed based on solar-biomass energy sources, and an average overall system COP of about 0.11 has been reported. It is also reported that the auxiliary energy source can be used to improve the overall system performance [18,19]. Solar energy system is selected to compensate the energy deficiency, when the limited biomass and biogas resources. The proposed hybrid energy model is chosen to fully utilize all biomass resources. The MILP (mixed integer linear programming) model is used to design the cost effective integrated biomass-solar energy system [20]. Moreover, the hybrid renewable energy system would be more economical if the price of diesel is increased significantly [21]. Due to high efficiency at high temperature, evacuated tube solar collectors have been chosen to supply heat to the generator of a vapour absorption cooling system [22]. Integrated renewable energy system is used to reduce the energy shortages and environmental impacts of fossil fuel used in remote areas. Lindo and Homer software tools are used for the optimal allocation of renewable energy sources based on availability [23]. The renewable hybrid energy based Polygeneration system is competitive for replacing conventional energy sources in remote communities [24].

The mixed integer linear mathematical programming model (time series), and the combined dispatch strategy based control algorithm were used to determine the optimal operating cost of a hybrid energy generation system consisting of a photovoltaic array, biomass (fuel wood), biogas, hydro, a battery bank and a fossil fuel generator [25–27]. The OREM (optimal renewable energy model) was used to optimize the contribution of various renewable energy sources to satisfy the energy demand for the end users [28]. Multi-objective optimization with a MCDM (multi-criterion decision making) technique to support decision makers in the process of designing HESs. A decision support tool based on Fuzzy TOPSIS and level diagrams is proposed to analyse the Pareto front and support the subsequent decision-making activity [29]. PSO (particle swarm optimization) is used to improve the performance of stand-alone