Environmental Science and Pollution Research (2022) 29:16346–16370
https://doi.org/10.1007/s11356-021-16852-5

RESEARCH ARTICLE

A novel solar-powered milk cooling refrigeration unit with cold thermal energy storage for rural application

Shaji Sidney[1] · Rajendran Prabakaran[2,3] · Sung Chul Kim[2] · Mohan Lal Dhasan[4]

Received: 5 July 2021 / Accepted: 28 September 2021 / Published online: 14 October 2021

Abstract

This experimental study analyzed the use of solar photovoltaic energy for operating a novel twin-circuit DC milk chiller without batteries using water-based cold thermal energy storage for different seasons in Chennai, India. HFC-134a and HC-600a were used as refrigerants in the two individual circuits. For each season, the test was conducted continuously for 18 days to analyze the quantity of generated ice that could be utilized to chill 10 L of milk in the morning and in the evening. The average quantity of ice formed per day in the ice bank during monsoon, winter, and summer seasons was found to be 3.61, 19.75, and 27.97 kg, respectively. Thus, it is evident that the use of solar energy with thermal energy storage is effective for operating the milk chilling unit for two seasons, namely winter and summer. However, the system requires an additional power source for continuous operation during the monsoon season. It is noteworthy to mention that the use of a solar milk chiller instead of a conventional milk chiller resulted in 91.15% lesser CO_2 emission with 27.6% less LCC. In this study, solar photovoltaic power was observed to be a good choice for chilling milk in the context of global warming and energy consumption. The use of thermal energy storage also allows the initial cost to be reduced.

Keywords Solar energy · Milk chiller · DC compressor · HC-600a · HFC-134a · Total equivalent warming index

Nomenclature

$\dot{m}$	Mass flow rate (kg s^{-1})
AC	Alternating Current
CE	Cost of electricity
CO_2-eq	Carbon dioxide equivalent
COP	Coefficient of Performance
DC	Direct Current
E_{annual}	Annual electricity consumption (kWh)
EC	Penalty cost for releasing of CO_2
evap	Evaporator
GHGs	Green House Gases
h	Specific enthalpy (kJ Kg^{-1})
HC	Hydrocarbon
HFC	Hydrofluorocarbon
I	Current
IBT	Ice Bank Tank
IC	Investment Cost
OT_{year}	Operating hours per year
L_{annual}	Annual leakage rate of refrigerant (%)
LCC	Life Cycle Cost
n	System life time (years)
PCM	Phase Change Material
PUF	Polyurethane Form
PV	Photo Voltaic
Q	Heat Transfer (kW)
r	Refrigerant
R	Refrigerant charge (g)
rpm	Rotations per minute
RTD	Resistance Temperature Detector
TES	Thermal Energy Storage
TEWI	Total Equivalent Warming Impact

Responsible editor: Philippe Garrigues

Shaji Sidney, Rajendran Prabakaran, and Sung Chul Kim contributed equally to this work

✉ Mohan Lal Dhasan
dr.mohanlal29@gmail.com

[1] Research and Development, Tan90 Thermal Solution Private Limited, 600 097 Chennai, India

[2] School of Mechanical Engineering, Yeungnam University, 280 Daehak-Ro, Gyeongsan, Gyeongbuk 712749, Republic of Korea

[3] Department of Automobile Engineering, Kongu Engineering College, Tamil Nadu, Erode, India 638 060

[4] Refrigeration and Air Conditioning Division, Department of Mechanical Engineering, College of Engineering Guindy, Anna University, Chennai 600 025, India