Applied Energy 228 (2018) 351–389

Contents lists available at ScienceDirect

Applied Energy

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

Global advancement on experimental and thermal analysis of evacuated tube collector with and without heat pipe systems and possible applications

K. Chopra[a,b], V.V. Tyagi[a,*], A.K. Pandey[c], Ahmet Sari[d,e]

[a] School of Energy Management, Shri Mata Vaishno Devi University, Katra 182320, Jammu & Kashmir, India
[b] School of Mechanical Engineering, Shri Mata Vaishno Devi University, Katra 182320, Jammu & Kashmir, India
[c] Research Centre for Nano-Materials and Energy Technology (RCNMET), School of Science and Technology, Sunway University, No. 5, Jalan Universiti, Bandar Sunway, Petaling Jaya, 47500 Selangor Darul Ehsan, Malaysia
[d] Department of Metallurgical and Material Engineering, Karadeniz Technical University, 61080 Trabzon, Turkey
[e] Center of Research Excellence in Renewable Energy (CORERE), Research Institute, King Fahd University of Petroleum & Minerals (KFUPM), 31261, Saudi Arabia

HIGHLIGHTS

- ETC and ETC-HP system is discussed with possible applications.
- Performance of heat pipe ETC is higher compared to direct flow ETC.
- PCMs application in ETC system proves it more efficient as compared to without PCM.
- Heat Pipe ETC found more suitable for industrial/domestic applications.
- Thermal Analysis of ETC-HP and direct flow ETC is discussed.

ARTICLE INFO

Keywords:
Solar energy
Solar collectors
Evacuated tube collector
Heat pipe
Thermal analysis
Water heating system
Air heating
Thermal energy storage
PV/thermal collector

ABSTRACT

Sun is the prime source of energy. There are two types of technologies available for the harnessing of solar energy i.e. Solar Thermal and Solar photovoltaic. Solar thermal energy having a potential to provide the domestic and industrial energy demand for hot water, air heating, solar cooling, solar drying etc. Among multiple applications of solar energy, water heating, space heating, and cooling are consuming more energy. The energy consumption in production of hot water represents a large contribution of total building energy consumption. The Collector is the important aspect for efficient energy needs for these applications. Among all thermal collectors specifically for low/medium temperature applications, evacuated tube collector is found to have the best efficiency. This paper addresses the advancement, different types of evacuated tube collectors and its low/medium temperature applications. The use of heat pipe in evacuated tube has been studied by many researchers around the globe to overcome the lower performance issue in direct flow evacuated tube collector. This turns out to be one of the most important advancement in this area. Another, important advancements in this research have been found to be integration of phase change materials with evacuated tube collector which has the great impact on its performance. This makes the evacuated tube technology more efficient, reliable and user-friendly. This review covers the recent research areas of the direct flow and heat pipe evacuated tube collector with different applications and comprehensive knowledge of the theoretical analysis. This paper also provides financial advantages, classification with and without thermal energy storage, advantages and drawbacks of evacuated technology and future recommendation for future improvement and recent research trend have also incorporated in this manuscript for researchers and practice engineers.

1. Introduction

The demand of energy is increasing with the expansion of industrialization while, fossil fuels sources are declining with time due to limited reserve. Moreover, global warming and pollution due to the extensive use of fossil fuels are becoming the major problem for society. However, renewable energy sources especially, solar energy is having the potential to meet global energy demand without compromising the environmental pollution [1]. Solar energy is freely available, safe, clean and available in abundance. Solar energy reaching on the earth can be

* Corresponding author.
E-mail address: vtyagi16@gmail.com (V.V. Tyagi).

https://doi.org/10.1016/j.apenergy.2018.06.067
Received 21 March 2018; Received in revised form 31 May 2018; Accepted 12 June 2018

Nomenclature

A	area, m^2
C	specific heat, J/kg·K
D	diameter, m
F	efficiency factor
F_R	heat removal factor
h	convective heat transfer coefficient, $W/m^2 K$
h_{fg}	latent heat of fusion, J/kg
I	solar isolation, W/m^2
k	thermal conductivity, W/m·K
l	length, m
$\dot{m}$	mass flow rate, kg/s
N	number
NTU	number of transfer unit
P	perimeter, m
$\dot{Q}$	rate of heat transfer, W
U	overall heat transfer coefficient, W/m^2·K
R	thermal resistance, K/W
SF	shape factor
T	temperature, K
t	thickness, m
V	velocity, m/s

Greek letters

γ	transmittance
β	absorptivity
ε	emissivity
ρ	density, kg/m^3
η_{fin}	fin efficiency
μ	dynamic viscosity, $N·s/m^2$

Subscript & superscript

a	ambient
ab	absorber/absorb
air	air between absorber tube and heat pipe
cr	collector
con	condenser
cond	conductive
conv	convective
en	solar radiations entering through glazing cover
evap	evaporator
f	fluid
fi	fluid inlet
fo	fluid outlet
gi	inner glass
go	outer glass
hd	hydraulic
hp	heat pipe
i	inside
l	liquid
loss	heat loss to ambient
o	outlet
rad	radiative
s	solid
sat	saturated
sf	surface
v	vapour
w	wick

Abbreviation

ETC	evacuated tube collector
THES	thermal energy storage
FPC	flat plate collector

utilized in two different ways viz. directly (using Photovoltaic panels) and indirectly (using solar thermal collectors). One of the prominent options for harvesting the solar energy is through solar thermal collectors to meet growing energy demands and to minimize the emission of greenhouse gases. Solar collectors are used to collect solar energy by different methods of collection. Solar collectors can be categorized into three groups: Flat plate collectors (FPC), Evacuated tube collector (ETC) and concentrating collector. Over the past few years, owing to cheap and simple design, FPC dominated the market at a temperature range of 30–80 °C applications. On the other hand, concentrating collectors are being used to produce heat above 300 °C to generate electricity. Despite the large number of applications (solar cooling, water/air heating, desalination, food processing and electricity generation), concentrated solar collectors have limited use due to its high cost compared to conventional energy sources and Photovoltaic modules [2]. Although, the ETCs are capable to produce heat above 100 °C at relatively low cost [3]. According to recent market scenario, 77.8% of newly installed solar collectors are ETC due to its cheap cost and high efficiency. IEA (International Energy Agency report) reported that in 2010 more than 50% of total solar collectors installed word widely were ETC [4]. In last 20 years, ETCs overtook the market of flat plate collectors due to the growth of inexpensive sputtering technology for producing twin glass evacuated tubes. The characteristics such as higher performance, easy installation at low cost enabled evacuated tube collectors to be used widely for various applications. In ETC, convective and radiative losses are very minimal. Higher energy and exergy efficiencies are two most crucial design factors for twin glass evacuated tubes [5,6].

Over the recent years, in ETC technology, mainly two developments have occurred which has increased the performance in a profound manner. One is heat pipe based ETC and other is a phase change materials (PCMs) based ETCs for different potential real life applications. Jafarkazemi and Abdi [7] investigated a heat pipe ETC, experimentally and theoretically. The theoretical results such as collector efficiency, mass flow rate of working fluid, collector area and heat gain were compared with results obtained from experiment. The results of the theoretical model showed good agreement with experimental results. Kumar et al. [8] reported that heat pipe collector performance is highly sensitive to outside conditions such as ambient temperature and solar radiation. The evaporator length is a crucial design parameter for heat pipe design. The effect of number of heat pipes on the performance of solar collector was studied by Azad [9]. He concluded that efficiency of heat pipe solar collector can be enhanced firstly by increasing number of heat pipes and secondly by an effective & proper design of condenser. Abokersh et al. [10] compared the forced circulation finned and unfinned U-pipe ETC with phase change material under same external conditions. The system was investigated simultaneously under real water consumption profile as well as on-demand operation. The improvement in heat transfer characteristics and system stability was observed in developed finned system.

Owing to crucial properties of heat pipe such as high performance, anti-freezing property, constant temperature level and heat flow transmitter (from evaporator to condenser) enabled heat pipe ETCs to grab mammoth interest for industrial and household applications [11,12]. Ismail and Abogderah [13] compared performance analysis