Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 105 (2014) 455–467

SOLAR ENERGY

www.elsevier.com/locate/solener

Semi-empirical relation for forced convective analysis through a solar collector

Rehena Nasrin *, M.A. Alim

Department of Mathematics, Bangladesh University of Engineering & Technology, Dhaka 1000, Bangladesh

Received 25 July 2013; received in revised form 17 September 2013; accepted 27 March 2014
Available online 6 May 2014

Communicated by: Associate Editor Brian Norton

Abstract

A numerical study has been conducted to investigate the forced convection through a flat plate solar collector. The water alumina nanofluid is used as the working fluid inside the riser pipe of the solar collector. The governing differential equations with boundary conditions are solved by finite element method using Galerkin's weighted residual scheme. The effects of major system parameters on the forced convection heat transfer are simulated. These parameters include the the Reynolds number (*Re*) and Prandtl number (*Pr*). Comprehensive average Nusselt number, average temperature, mean velocity, percentage of collector efficiency, mid-height temperature for both nanofluid and base fluid through the collector pipe are presented as functions of the governing parameters mentioned above. The numerical results show that the highest heat loss rate is observed for both the largest *Re* and *Pr*. Percentage of collector efficiency enhances for growing *Re* and falling *Pr*. A correlation is developed among average Nusselt number, Reynolds number and Prandtl number. Then a semi-empirical relation is established from this correlation with experimental data found in the literature.

Keywords: Forced convection; Flat plate solar collector; Finite element method; Water-Al_2O_3 nanofluid; Semi-empirical relation

1. Introduction

The flat-plate solar collector is commonly used today for the collection of low temperature solar thermal energy. It is used for solar water-heating systems in homes and solar space heating. Because of the desirable environmental and safety aspects it is widely believed that solar energy should be utilized instead of other alternative energy forms, even when the costs involved are slightly higher. Solar collectors are key elements in many applications, such as building heating systems, solar drying devices, etc. Solar energy has the greatest potential of all the sources of renewable energy especially when other sources in the country have depleted. The fluids with solid-sized nanoparticles suspended in them are called "nanofluids." Applications of nanoparticles in thermal field are to enhance heat transfer from solar collectors to storage tanks, to improve efficiency of coolants in transformers. The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9 m. The solar energy strikes our planet a mere 8 min and 20 s after leaving the giant furnace. The sun has an effective blackbody temperature of 5762 K.

Sandhu (2013) experimentally studied temperature field in flat-plate collector and heat transfer enhancement with the use of insert devices. Various new configurations of the conventional insert devices were tested over a wide range of Reynolds number (200–8000). Comparison of these devices showed that in laminar flow regime, wire mesh proved to be an effective insert device and enhanced

* Corresponding author. Tel.: +880 01913583407.
E-mail address: rehena@math.buet.ac.bd (R. Nasrin).

http://dx.doi.org/10.1016/j.solener.2014.03.035
0038-092X/

Nomenclature

A	surface area of the collector (m^2)
C_p	specific heat at constant pressure ($J\ kg^{-1}\ K^{-1}$)
h	local heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
I	intensity of solar radiation ($W\ m^{-2}$)
k	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
L	length of the riser pipe (m)
m	mass flow rate ($Kg\ s^{-1}$)
Nu	Nusselt number, $Nu = hL/k_f$
Pr	Prandtl number, $Pr = \nu_f/\alpha_f$
Re	Reynolds number, $Re = \frac{U_{in}L}{\nu_f}$
T	dimensional temperature (K)
T_{in}	input temperature of fluid (K)
T_{out}	output temperature of fluid (K)
u, v	dimensional x and y components of velocity ($m\ s^{-1}$)
U, V	dimensionless velocities, $U = \frac{u}{U_{in}}$, $V = \frac{v}{U_{in}}$
U_i	input velocity of fluid ($m\ s^{-1}$)
X, Y	dimensionless coordinates, $X = x/L$, $Y = y/L$
x, y	dimensional coordinates (m)

Greek symbols

α	fluid thermal diffusivity ($m^2\ s^{-1}$)
β	thermal expansion coefficient (K^{-1})
ϕ	nanoparticles volume fraction
ν	kinematic viscosity ($m^2\ s^{-1}$)
η	collector efficiency, $\eta = \frac{mC_p(T_{out}-T_{in})}{AI}$
θ	dimensionless temperature, $\theta = (T - T_{in})/(T_{col} - T_{in})$
ρ	density ($kg\ m^{-3}$)
μ	dynamic viscosity ($N\ s\ m^{-2}$)
V	dimensionless velocity field

Subscripts

av	average
c	collector
f	fluid
nf	nanofluid
s	solid particle

Nusselt number by 270% while in turbulent flow regime. While in Reynolds number range 2700–8000, concentric coil insert significantly increased the heat transfer and an increase of 460% in Nusselt number was witnessed. Martín et al. (2011) also analyzed experimental heat transfer research in enhanced flat-plate solar collectors. To test the enhanced solar collector and compare with a standard one, an experimental side-by-side solar collector test bed was designed and constructed. Modeling of flat-plate solar collector operation in transient states was conducted by Saleh (2012). This study presents a one-dimensional mathematical model for simulating the transient processes which occur in liquid flat-plate solar collectors. The proposed model simulated the complete solar collector system including the flat-plate and the storage tank.

Azad (2009) investigated interconnected heat pipe solar collector. Performance of a prototype of the heat pipe solar collector was experimentally examined and the results were compared with those obtained through theoretical analysis. Zambolin (xxxx) theoretically and experimentally performed solar thermal collector systems and components. Testing of thermal efficiency and optimization of these solar thermal collectors were addressed and discussed in this work. Piao (1994) studied forced convective heat transfer in cross-corrugated solar air heaters. Kolb (1999) experimentally studied solar air collector with metal matrix absorber. Nag et al. (1989) analyzed parametric study of parallel flow flat plate solar collector using finite element method. Lund (1986) analyzed general thermal behavior of parallel-flow flat-plate solar collector absorbers. Tripanagnostopoulos et al. (2000) investigated solar collectors with colored absorbers.

Mahian et al. (2013) performed a review of the applications of nanofluids in solar energy. The effects of nanofluids on the performance of solar collectors and solar water heaters from the efficiency, economic and environmental considerations viewpoints and the challenges of using nanofluids in solar energy devices were discussed. Enhancement of flat-plate solar collector thermal performance with silver nano-fluid was conducted by Polvongsri and Kiatsiriroat (2011). With higher thermal conductivity of the working fluid the solar collector performance could be enhanced compared with that of water. The solar collector efficiency with the nano-fluid was still high even the inlet temperature of the working fluid was increased. Natarajan and Sathish (2009) studied role of nanofluids in solar water heater. Heat transfer enhancement in solar devices is one of the key issues of energy saving and compact designs. The aim of this paper was to analyze and compare the heat transfer properties of the nanofluids with the conventional fluids. Struckmann et al. (2008) analyzed flat-plate solar collector where efforts had been made to combine a number of the most important factors into a single equation and thus formulate a mathematical model which would describe the thermal performance of the collector in a computationally efficient manner.

Generally a direct absorption solar collector (DAC) using nanofluids as the working fluid performs better than a flat-plate collector. Much better designed flat-plate collectors might be able to match a nanofluid based DAC under certain conditions. Tyagi et al. (2009) investigated Predicted efficiency of a low-temperature nanofluid-based direct absorption solar collector. It was observed that the presence of nanoparticles increased the absorption of