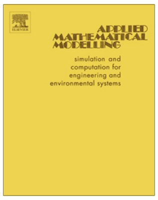
Applied Mathematical Modelling 38 (2014) 5126–5148

Contents lists available at ScienceDirect

Applied Mathematical Modelling

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



Inverse modeling of a solar collector involving Fourier and non-Fourier heat conduction

Arka Bhowmik [a], Rohit K. Singla [a], Ranjan Das [a,*], A. Mallick [b,c], R. Repaka [a]

[a] School of Mechanical, Materials and Energy Engineering, Indian Institute of Technology Ropar, Punjab 140 001, India
[b] Department of Mechanical Engineering, Tezpur University, Napaam 784 028, India
[c] Department of Mechanical Engineering, Indian School of Mines, Dhanbad 826 004, India

ARTICLE INFO

Article history:
Received 12 December 2012
Received in revised form 1 March 2014
Accepted 1 April 2014
Available online 13 April 2014

Keywords:
Fourier
Non-Fourier
Direct and evolutionary search
Fourier number
Solar collector

ABSTRACT

This article applies the golden section search method (GSSM), simplex search method (SSM) and differential evolution (DE) for predicting the unknown Fourier number (*Fo*), Vernotte number (*Ve*) and non-dimensional solar heat flux (S^*) in a flat-plate solar collector when subjected to a given temperature requirement. The required temperature field is calculated using an analytical forward method by considering Fourier and non-Fourier heat conduction, and using this, the inverse problem is solved to predict the *Fo*, *Ve* and S^* which are assumed to be the unknown parameters. The study reveals that the temperature field is highly sensitive to the *Fo*, thus even a small error in the temperature measurement can result in an unrealistic estimation of heating time of the collector. The present study is proposed to be useful in determining the time, the time lag and solar heat flux for controlled heating of an absorber plate within a stipulated time, which will be required to attain a prescribed/desired temperature distribution. Additionally, the study also shows that subjected to different time levels, the same temperature distribution is possible through different absorber plate materials. It has been observed from the present study that apart from SSM and DE, GSSM fails to estimate the unknown parameters at large value of *Ve* and small value of *Fo*, due to the associated fluctuation in the measured temperature field. The present study further discusses the computational performance of direct search method (e.g. GSSM and SSM) with that of the evolutionary method (DE) in terms of the maximum number of iteration and CPU time required to achieve the desired objective.

1. Introduction

The growing environmental concern, the increasing energy demand and the depleting fuel reservoir have made the solar energy one of the important renewable resources. This is mainly due to the fact that solar energy is abundant and clean [1]. As a result, in recent time, the interest has been devoted to utilize the solar thermal energy efficiently for various domestic and industrial purposes. The use of solar energy for various thermal applications primarily relies on two important solar harnessing systems, viz., solar collectors and thermal energy storage component (e.g. PV cell for recharging batteries, phase change materials, etc.). The solar collector is a special form of heat exchanger that receives the radiant energy and transforms

---

* Corresponding author. Address: School of Mechanical, Materials and Energy Engineering, Indian Institute of Technology Ropar, Nangal Road, Rupnagar, Punjab 140 001, India. Tel.: +91 1881 242245; fax: +91 1881 223395.

E-mail addresses: ranjandas81@gmail.com, ranjandas@iitrpr.ac.in (R. Das).

http://dx.doi.org/10.1016/j.apm.2014.04.001
0307-904X/

Nomenclature

a	lower limit of the unknown variable within the search range
b	upper limit of the unknown variable within the search range
B_v	best vertex of simplex
C	thermal propagation speed = $\sqrt{\frac{\alpha}{\tau}}$, (ms^{-1})
C_v	contraction point of simplex
CR	crossover probability
e	measurement error
E_v	expansion point of simplex
Fo	Fourier number (dimensionless time) = $\frac{\alpha t}{L_1^2}$
G_v	good vertex of simplex
J	objective function
k	thermal conductivity of the material, Wm^{-1}K^{-1}
L_1	length of the absorber plate, m
M_p	mid-point
p	first intermediate point within the search range
P	population in differential evolution
q	second intermediate point within the search range
$rand$	random number
R	reduction ratio
R_v	reflection point of simplex
r	golden ratio
S	solar heat flux incident on the absorber plate, Wm^{-2}
S^*	non-dimensional solar heat flux incident on the absorber plate
S_v	shrinkage point of simplex
T	local plate temperature, °C
T_a	ambient temperature, °C
T_t	isothermal temperature at the boundary from which water receives the heat, °C
t	time, s
t_p	thickness of the absorber plate, m
U_l	overall heat loss coefficient, W m^{-2} K^{-1}
Ve	Vernotte number, $\frac{\tau C}{L_1}$
W_v	worst vertex of simplex
x	any location along the length of the absorber plate, m
x^*	non-dimensional distance = x/L_1
z_k	child vector in differential evolution
Z_0	thermo-geometric parameter of absorber plate
Z_k	parent vector in differential evolution

Greek symbols

α	thermal diffusivity, m^2 s^{-1}
λ	Eigen constant
θ	non-dimensional temperature = $\frac{T-T_a}{T_t-T_a}$
ϑ	variable
τ	thermal relaxation time, s
ς_k, ψ_k, χ_k	vectors in differential evolution
Ω	scaling factor

it to heat energy. The study of solar collectors is one of the interesting subjects in the field of renewable energy due to its applications in numerous places such as in domestic water and space heating, industrial processing, cooling applications using vapor absorption systems, material processing using solar furnaces, phase change processes, etc. [1,2]. In general, there are three major types of solar collectors, viz., flat plate collectors, concentrating/focusing type collectors and passive collectors. Among all available types, the flat plate collectors are commonly used for low and medium heating demands. Due to its simplicity and ease of manufacturing, it is a common choice for low and medium heating applications.

In a flat plate collector, the solar energy throughout the day passes through the transparent glass cover and impinges on a flat conductive absorber plate (black surface) having high absorptivity. The amount of heat generated due to solar radiation is transferred from the absorber plate to a working fluid. The hot fluid flowing through the tubes are then used for various heating demands [3,4]. The thermal performance of a typical flat plate collector is a function of the nature of transparent covers used, the absorption and thermal properties of the absorber plate, the wavelength of the absorbed solar radiation, size