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A theoretical study on the performance of a solar collector using CeO_2 and Al_2O_3 water based nanofluids with inclined plate: Atangana–Baleanu fractional model

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A R T I C L E I N F O

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A B S T R A C T

Nanofluids are developing fluids with improved thermal properties than the traditional fluids. The use of nanofluids achieves the maximum possible thermal performance with the smallest possible concentration by uniform dispersion and constant suspension of the nanoparticles in the base fluid. Nanofluid plays a decisive role in different thermal applications, such as the automotive industry, heat exchangers and solar power generation. The purpose of this article is to provide the mathematical formulation for the nanofluid and to simulate the use of nanoparticles to increase the heat transfer rate of solar equipment by obtaining the exact solutions for the problem under consideration. Furthermore, the fluid is considered to pass through a rigid inclined plane. The classical model of nanofluid is transformed into a fractional model using the newly developed Atangana–Baleanu time fractional derivative. The Laplace transform method is used to represent the flow profile and the heat transfer profile. Variations in the Nusselt number have been observed for different nanoparticles and their volume fractions. In addition, the influence of the volume fraction of nanoparticles on the fluid velocity has been studied in the illustrations. The obtained solutions are reduced to the corresponding solutions for the classical model of the nanofluid.

1. Introduction

Energy conversion systems are facing the problem of having low thermal performance. The low thermal conductivities of the working fluids. The way to overcome this problem is to suspend the nanosized solid particles in a base fluid to increase its thermal conductivity. Nanofluids are a novel class of nanotechnology-centered heat transfer fluids engineered by dispersing and stably suspending nanoparticles with distinctive size of 1–50 nm in customary heat transfer fluids. Choi [1] in 1995 was the first to use the term "nanofluid", with improved thermal properties, high rheological properties, and high thermal conductivity compared to the suspensions having the nanofluidic millimeter or micron-sized particles.

Nanoparticles are widely used in industrial and biomedical applications. The use of nanoparticles in the energy field causes great interest. Nanoparticles can play an important and intellectual role in different fields of energy such as energy conversion (fuel cells, solar cells, and thermoelectric devices), energy storage (rechargeable batteries and capacitors), energy saving (insulating materials such as aerogels, glazes, powerful lightning such as light emitting diodes and organic light emitting diodes). Nanofluids have demonstrated the potential for increasing the rate of heat transfer in many areas, such as nuclear reactors, refrigeration, industrial transport, micro-electromechanical systems (MEMS), nano-electromechanical systems (NEMS), electronics and instruments for measurement and biomedical applications [2,3]. Increasing thermal conductivity may affect performance and reduce operating costs [4], other related studies can be found in [5–9]. The impact of various frameworks on natural and forced convection of nanofluids flows are evaluated by different specialists [10–13]. Nanofluids can improve the thermal performance, which is of great importance in industries, especially heating or cooling of solar thermal systems. Because of its superior wettability and dispersion properties, nanofluidics can also be used to manufacture important nanostructured materials and clean surfaces in complex fluid engineering [14]. Another use of nanofluids is the administration of nanomedicine e.g. [15]. The high thermal conductivity of

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Nomenclature

u	fluid velocity in x-direction
F	dimensionless velocity
τ	dimensionless time parameter
T_∞	ambient temperature
g	acceleration due to gravity
k_{nf}	thermal conductivity of nanofluids
ρ_f	fluid density
ρ_s	density of the solid particle
c_p	specific heat
φ	nanoparticles volume fraction
$\wp_t^\alpha(.)$	Atangana–Baleanu time fractional operator
$\delta(.)$	Derac delta function
$I_1(.)$	Bessel function of the first kind
k_1	mean absorption coefficient
T	temperature
Θ	dimensionless temperature
T_w	wall temperature
u_0	characteristic velocity
p	the Laplace transform parameter
$(\rho c_p)_{nf}$	specific heat capacity of nanofluids
$M = \frac{\nu_f{}^2\sigma_f B_0^2}{\mu_f u_0{}^2}$	magnetic parameter
$Gr = \frac{\nu_f g\beta_f}{u_0{}^3}(T_w - T_\infty)$	thermal Grashof number
$Nr = \frac{16\sigma_0 T_\infty{}^3}{3k_f k_1}$	radiation Parameterjlv
$Pr = \frac{\nu_f(\rho c_p)_f}{k_f} \in$	Prandtl number
α	fractional order
σ_0	Stefan–Boltzmann
q_r	constant heat flux
$\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}}$	$(\rho\beta_T)_{nf} = (1-\varphi)(\rho\beta_T)_f + \varphi(\rho\beta_T)_s$
$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s$	$(\rho c_p)_{nf} = (1-\varphi)(\rho c_p)_f + \varphi(\rho c_p)_s$
$\sigma_{nf} = \sigma_f\left(1 + \frac{3(\sigma-1)\varphi}{(\sigma+2)-(\sigma-1)\varphi}\right)$	$\frac{k_{nf}}{k_f} = \frac{(k_s+2k_f)-2\varphi(k_f-k_s)}{(k_s+2k_f)+\varphi(k_f-k_s)}$
$\sigma = \frac{\sigma_f}{\sigma_s}$	

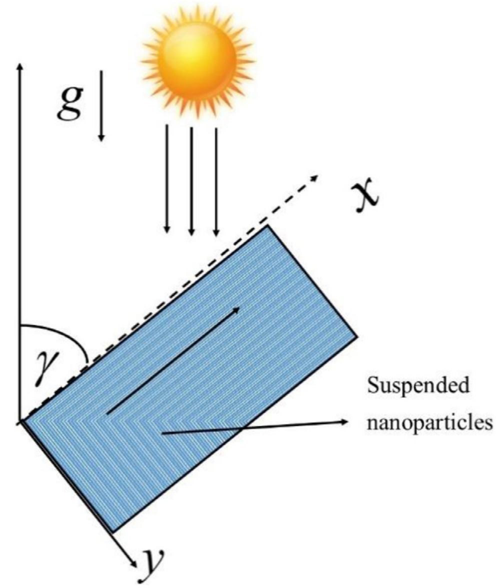

Fig. 1. Direct absorption solar collector.

nanofluids is vital to diminish clogging in the walls of transporting medium, high energy productivity, better execution, and lower cost [16]. Hussanan et al. [17] examined the microrotation and microinertia consequences for the stream of nanoparticles for energy upgrade in water, kerosene oil, and motor oil. In this article they have used the micropolar fluid model. Tesfai et al. [18] experimentally studied the thermal management of graphene and graphene oxide suspension. They have investigated the rheological characteristics and intrinsic viscosity of grapheme suspension. Ali et al. [19] obtained the exact solutions for the flow of Brinkman type fluid with different nano particles. They have obtained the exact solutions by using the Laplace transform technique. Wu and Zahao [20], presented a review article on the engineering applications of nanofluids. In this article they have discussed the heat transfer and critical heat flux enhancement. Khan [21], discussed the influence of different shaped nanoparticles in the base fluid on the enhancement of heat transfer rate. Sheikholislami and Bhatti [22] used the finite difference method to calculate the numerical solutions for the nanofluid flow. In this article they have briefly discussed the enhancement in heat transfer due to nanoparticles. Rashidi et al. [23] discussed the effects of magnetic field on the flow of generalized Burgers' nanofluid over an inclined wall. The performance of solar stills, using the nanofluid is discussed by Mahian et al. [24]. In this article they have presented the experimental and theoretical results. Kasaeian et al. [25], presented a brief review article on the applications of nanofluid.

A solar collector is a special type of heat exchanger that converts solar energy into internal energy of a transportation media. These devices absorb entering solar radiation, transform it to heat, and transfer heat to the fluid flowing to the collector (usually air, water or oil). The stored energy can be directly delivered from the working fluid to water or air conditioning equipment or thermal storage reservoirs that can be used at night or in cloudy weather [26]. One of the most important equipment in the field of solar energy is solar collector. Mahian et al. [27], discussed the applications of nanofluids in the enhancement of the efficiency of the solar collectors or solar water heaters in the review article. Also, the viewpoint is presented on the economic and environmental aspects in this article. Sheikh et al. [28], obtained the exact solution for the generalized fluid flow by using the Laplace transform technique. They have observed from the theoretical study that the performance of solar collector can be enhanced by adding nanoparticles to the base fluid. In addition, natural convection of the roof or solar collector is important for the control of heat transfer by inclined or corrugated walls. However, with these complex geometries (Fig. 1), the flow field and the temperature field are very complex [29].

Fan et al. [30] studied the heat transfer and flow distribution in a solar collector with an absorber consisting of inclined strips.They have analyzed the performance of solar collector, theoretically and experimentally. Hatami et al. [31] considered the solar collector with inclined plate and obtained the numerical solutions by finite difference method. They have reported that the possible maximum values of volume fraction of nanoparticles can enhance the efficiency of solar collector.

The concept of fractional differentiation and integration is one of the most commonly used concepts in applied mathematics and mathematics. This is because memory effects and filtering effects can be incorporated into partial differential equations or ordinary differential equations describing real world problems [32–36]. Recently, Atangana and Baleanu [37] presented new definition of frac-