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Flow of a nanofluid in the microspacing within co-rotating discs of a Tesla turbine

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ABSTRACT

This article presents, for the first time, the fluid dynamics of the rotating flow of a nanofluid through the narrow spacings within co-rotating discs of a Tesla turbine. The inter-disc-spacing of multiple concentric discs of a Tesla disc turbine is usually of the order of 100 µm. The study is conducted with the help of both mathematical analysis and computational fluid dynamic simulations. Numerical values are reported for a specific nanofluid which is a dilute solution of ferro-particles in water (maximum volume fraction considered is 0.05). The velocity field, pressure field and fluid pathlines are calculated in the three-dimensional, axi-symmetric flow domain for prescribed boundary values for the velocity components at inlet. Detailed comparisons between the analytical and computational solutions are provided. It is explained how the fluid dynamics of rotating flow within a Tesla disc turbine is influenced by the change in volume fraction of nanoparticles. The present study reveals that, with an increase in the volume fraction of nanoparticles, the pressure-drop in the radial direction increases; the tangential velocity at any point inside the computational domain tends to increase (even though its boundary value at inlet is kept fixed for each set of computation); however, the radial velocity field remains almost invariant. The present analysis shows that, with a suitable selection of the combination of geometric and flow parameters, the use of nanofluid leads to a significant improvement in the power output (the magnitude of increase would depend on the choice of nanofluid; the sample calculations show more than 30% increase in power output when the volume fraction of nanoparticles increases from 0 to 0.05). Moreover, the gain in power output is achieved without appreciably affecting the efficiency of the turbine. Indeed the present study shows that it is possible to achieve a high efficiency (a figure of 56% is included in the paper as a sample case), revealing the potential of the Tesla disc turbine to emerge as an attractive engineering product in the field of micro-turbines.

1. Introduction

A Nanofluid is a dilute suspension of nano-sized particles (1–100 nm) in a base fluid [1]. Nanofluids have been primarily studied for their improved thermal characteristics (such as, enhanced thermal conductivity etc.) as compared to the conventional coolants [2,3]. This has opened up their applications in a variety of fields such as, cooling of electronic components [4],

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Nomenclature

b	gap between the two discs
d_s	diameter of the particle
p	pressure
Q	volume flow rate
R	non-dimensional radius, $R \equiv r/r_i$
r	radial direction in cylindrical co-ordinate system
U	velocity of fluid in the absolute frame of reference
V	velocity of fluid in the relative frame of reference
$\dot{W}$	power output
z	z-direction in cylindrical co-ordinate system
Γ_{shear}	torque produced by one side of a single disc
Δp_{io}	pressure drop between inlet and outlet
ϕ	volume fraction of nanoparticle
γ	tangential speed ratio at inlet, $\gamma \equiv \overline{U}_{\theta,i}/(\Omega r_i)$
η	efficiency
μ	dynamic viscosity of working fluid
ν	kinematic viscosity of working fluid
θ	azimuthal direction in cylindrical co-ordinate system
ρ	density of working fluid
Ω	rotational speed of disc

Subscripts

bf	properties of base fluid
eff	effective properties of nanofluid
i	at rotor inlet
o	at rotor outlet
r	component along the r direction
s	properties of solid particle
z	component along the z direction
θ	component along the θ direction

Superscripts

$\overline{()}$	sectional-averaged flow variables, $\overline{X}(r) \equiv (1/b)\int_0^b X(r)dz$

transformer cooling [5], nuclear systems cooling [6] and many more. The density of a nanofluid increases with particle loading. Both experimental investigations [7] and theoretical studies [8,9, etc.] show that the viscosity of a nanofluid depends on the volume fraction of the suspended nanoparticles and the viscosity of the base fluid. Generally, the viscosity of a nanofluid is greater than the viscosity of its base fluid [7]. Consequently, frictional resistance and pressure drop for the flow of a nanofluid are greater than those for the flow of a pure fluid. New investigations on the frictional and thermal characteristics of nanofluids [10–13] are still being reported. The consequence of using nanofluids in devices and situations, where results for traditional fluids are known, has become an important and widespread topic of current research in many areas of fluid mechanics. In this article, we have presented a new application of nanofluids, and have investigated the effects of using nanofluids on the fluid dynamics of flow through co-rotating discs and on the performance of a Tesla disc turbine. The two facts that the presence of nanoparticles increases both viscosity and density of a nanofluid, and, that the work transfer in a Tesla disc turbine depends on the viscous shear force on the disc surfaces [14], together gave rise to the germination of a central idea of the present study that the use of nanofluids might improve the performance of a Tesla disc turbine.

The Tesla disc turbine was invented by the famous scientist Nikola Tesla in 1913 [15]. Unlike a conventional bladed turbine, the rotor of a disc turbine is formed by a series of flat, parallel, co-rotating discs which are closely-spaced and attached to a central shaft. The working fluid is injected nearly tangentially to the rotor by means of one or more inlet nozzles. The injected fluid, which passes through the narrow gaps between the discs, approaches spirally towards the exhaust port located at the centre of each disc. The viscous drag force causes the rotor of the disc turbine to rotate. There is a housing surrounding the rotor, with a small radial and axial clearance.

Rice [16] described the advances up to 1991 in the study of Tesla disc turbines. Recently, Lemma et al. [17], Hoya and Guha [18] and Guha and Smiley [19] have performed detailed experiments with Tesla disc turbines. A simple but very effective technique for measuring the net power output and overall loss called the angular acceleration method is developed by Hoya and Guha [18], which is particularly useful when the angular speed is high and torque is low. Theoretical advances in Tesla disc turbines (for single-phase flow) can be found in references [14,20–22]. A systematic dimensional analysis