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Heat transfer enhancement of a molten salt parabolic trough solar receiver with concentric and eccentric pipe inserts

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Abstract

In this work, numerical investigations have been performed on the enhanced flow and heat transfer in a parabolic trough receiver (PTR) with molten salt as heat transfer fluid(HTF). A three-dimensional simulation model is established, and the non-uniform heat flux and detailed temperature distribution of a PTR is successfully simulated by combining a MCRT code and FLUENT software. Concentric and eccentric pipe inserts were used to enhance heat transfer potential in the absorber tube of PTR, and the effects of key parameters of the inserts were investigated by comparison. The thermo-hydraulic performance has been evaluated. The results show that the inserts can significantly improve the comprehensive heat transfer performance of more than 1.64 times than a PTR without inserts when the PTR is inserted by A3. And the eccentric pipe inserts of B3 performs significantly better than the concentric tube inserts for its excellent performance in decreasing the maximum temperature of absorber tube and molten salt. The results of this study are helpful in the optimization design of a PTR with molten salt HTF technology.

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Keywords: Heat transfer enhancement; parabolic trough collector; Absorber tube; Concentric pipe; Eccentric pipe; Molten salt

1. Introduction

Owing to the advantages such as clean, sustainability and inexhaustibility, solar energy is considered as a promising renewable energy. Among the solar power technologies, the parabolic trough solar technology is one of the most mature and cost-effective power technologies presently [1]. Using molten salt as the heat transfer fluid (HTF) is promising in the parabolic trough solar power plants owing to the distinct advantages such as high thermal capacity and low cost. The receiver tube plays a crucial role in the parabolic trough collector (PTC) system, which has been

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Nomenclature			
c_p	specific heat, $Jkg^{-1}K^{-1}$	δ	thickness, m
D	hydraulic diameter, m	v	kinematic viscosity, m^2s^{-1}
h	convective heat transfer coefficient, $Wm^{-2}K^{-1}$	*Subscripts*	
k	heat conductivity, $Wm^{-1}K^{-1}$	a	ambient or environment
L	length, m	ave	average
Nu	Nusselt number	f	fluid
q	heat flux, Wm^{-2}	i	inner
T	temperature, K	o	outer
Greek symbols		ref	reference
α	thermal diffusivity of the fluid, m^2s^{-1}	exp	experimental
μ	dynamic viscosity of the fluid, $kgm^{-1}s^{-1}$	sim	simulation
ρ	density, kgm^{-3}	ss	stainless steel
		w	wall

studied intensively. The early investigations on the heat transfer models of PTC receivers often assume the uniform temperature distribution around the receiver's circumference and neglect the influences of the non-uniform distribution of concentrated solar flux on the receiver [2-7]. Recently, the authors in Ref. [8] reported three-dimensional numerical simulation results of the receiver when the non-uniform distributions of solar energy flux are considered.

Cheng ZD et al [9,10] developed a new modeling method and unified code with Monte Carlo Ray-Trace (MCRT) for PTC heat flux simulation and numerically studied the heat transfer enhancement in a PTR with unilateral milt-longitudinal vortex generators. The Nusselt number and the friction factor increase with the increase of each geometric parameter, while the average wall temperature and the heat loss decrease with the increase of each geometric parameter. Wang P et al[11] numerically studied the effect of inserting metal foams in PTR on heat transfer. The result shows that for constant layout and porosity, the geometrical parameter effects on the thermal performance greatly. While for constant layout and geometrical parameter, the porosity effects on the thermal performance slightly. Wang FQ et al [12,13]numerically investigated heat transfer enhancement of PTR with a symmetric outward corrugated tube. The effective heat transfer coefficient can be enhanced up to 8.4% and maximum thermal strain can be decreased up to 13.1%. Ghadirijafarbeigloo et al[14] presented the numerical studied of heat transfer and flow in PTR with louvered twisted tape inserts. The Nusselt number and friction factor increase of 1.5 times and 2.1 times over plain tube. Chang C et al[15] numerically investigated the heat transfer under non-uniform heat flux and the heat transfer enhancement in a molten salt solar receiver tube with twisted tapes inserts. The heat transfer increase with the clearance and twist ratios of twisted tape decrease. Lu JF et al[16,17] experimentally investigated the convective heat transfer of ternary nitrate salt in the transversely grooved tube and spirally grooved tube with uniform heat flux. Results show that Nusselt number of transversely grooved and spirally grooved tube is remarkably higher than that of the plain tube, and molten salt should avoid worsening phenomena for high-temperature difference and low heat transfer coefficient.

Although the enhanced heat transfer methods such as metal foam and the porous disc can achieve higher heat transfer effect, they all cannot meet the operation of molten salt draining when molten salt is used as HTF. Moreover, due to the limitation of industrial processing and manufacturing costs, the structure of PTR should not be changed greatly. Therefore, there is little possibility that the enhanced heat transfer methods such as a corrugated tube, spiral tubes, and internally finned tubes can be adopted in PTR. To make matters worse, corrugated tube, spiral tubes will aggravate the thermal bending deformation damage of the PTR. The concentric rod and eccentric rod inserts are simple and feasible choices for heat transfer enhancement in this situation [18–22]. While molten salt with variable thermophysical properties as HTF and the highly non-uniform heat flux make the enhanced heat transfer in PTR becomes more different. Since there is no article focus on this condition, so in the present paper, three-dimensional numerical investigation on the PTR by inserting a concentric rod and a eccentric rod is performed. Realistic non-uniform heat flux thermal boundary condition and experimentally verified thermophysical properties of molten salt are employed to accurately describe the heat transfer enhancement. The effect of heat flux, diameter ration and eccentricity ratio on heat transfer and fluid flow are analyzed. A comparative analysis of comprehensive heat transfer enhancement is also carried out. The results of this study are helpful in the optimization of PTR with molten salt HTF technology.