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Enhanced heat transfer performances of molten salt receiver with spirally grooved pipe

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HIGHLIGHTS

- Spirally grooved tube is a very effective way for solar receiver enhancement.
- Heat absorption model of receiver is proposed with general heat transfer correlation.
- Spirally groove tube increases absorption efficiency and reduces wall temperature.
- Operating temperature of molten salt remarkably increases with groove height.
- Heat absorption performance is promoted for first and second thermodynamics laws.

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ABSTRACT

The enhanced heat transfer performances of solar receiver with spirally grooved pipe were theoretically investigated. The physical model of heat absorption process was proposed using the general heat transfer correlation of molten salt in smooth and spirally grooved pipe. According to the calculation results, the convective heat transfer inside the receiver can remarkably enhance the heat absorption process, and the absorption efficiency increased with the flow velocity and groove height, while the wall temperature dropped. As the groove height increased, the heat losses of convection and radiation dropped with the decrease of wall temperature, and the average absorption efficiency of the heat receiver can be increased. Compared with the heat receiver with smooth pipe, the heat absorption efficiency of heat receiver with spirally grooved pipe $e/d = 0.0475$ can rise for 0.7%, and the maximum bulk fluid temperature can be increased for 31.1 °C. As a conclusion, spirally grooved pipe can be a very effective way for heat absorption enhancement of solar receiver, and it can also increase the operating temperature of molten salt.

1. Introduction

Solar thermal power [1] is a very promising and challenging technology for clean and renewable energy. In solar thermal power system, the heat receiver [2] absorbs concentrated solar radiation to increase the temperature of the working fluid, and it will directly affect the operating temperature and thermodynamic efficiency of the whole system. Since the heat receiver is the critical equipment for photo-thermal transformation, its heat transfer performance and enhancement technology are important problems for solar thermal system.

The thermal performances of heat receiver have been widely investigated in available literature, and it is mainly affected by the convection and radiation. Clausing [3] analyzed the convective heat loss from cavity solar central receiver. Fujiwara et al. [4] conducted thermal analyses and fundamental tests on the heat pipe receiver. Dehghan and Behnia [5] investigated combined natural convection conduction and radiation heat transfer in a discretely heated open cavity. Reddy and Kumar [6] researched the surface radiation and natural convective heat transfer in a modified cavity receiver of solar parabolic dish. Muftuoglu and Bilgen [7] numerically investigated the heat transfer in inclined rectangular receivers under concentrated solar radiation condition. Prakash et al. [8] found that the natural convection and radiation played the premier role in the heat loss of solar receiver. The solar selective coatings are also used to increase the absorption efficiency of heat receiver, and Cindrella [9] described the real utility ranges of the solar selective coating.

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Nomenclature

c_p	thermal capacity (J kg^{-1} K^{-1})
D	outer pipe diameter (m)
d	inner pipe diameter (m)
e	groove height (m)
F_r	view factor (−)
H	receiver height (m)
h	heat transfer coefficient (W m^{-2} K^{-1})
I	energy flux (W m^{-2})
L	pipe length (m)
q	heat flux (W m^{-2})
T	temperature (°C)
u	velocity (m/s)

Greek symbols

ρ	density (kg m^{-3}), reflectivity (−)
ε	emissivity (−)
λ	thermal conductivity (W m^{-1} K^{-1})
μ	viscosity (kg m^{-1} s^{-1})
η	efficiency (−)
κ	reflectivity (−)
σ	Stefen Boltzmann constant (W m^{-2} K^{-4})

Subscripts

0	inlet
a	air
av	average
c	cavity
f	flow
fc	forced convection
ins	insulation
nc	natural convection
s	surrounding condition
p	pipe
w	receiver wall

Available research mainly investigated the heat transfer outside the receiver surface, while the convective heat transfer performance of molten salt inside the receiver pipe was only investigated in very few literature. Hoffman and Cohen [10] measured the heat transfer characteristics of mixed molten salts NaF–KF–LiF. To increase the heat transfer of molten salt in the receiver pipe, enhanced pipes like spirally grooved pipe are effective ways [11]. Barba et al. [12] numerically analyzed the flow in a spirally fluted tube. Rabas et al. [13] investigated heat transfer correlation for spirally grooved tubes in surface condensers and multistage flash evaporators. Akgun and Parlar [14] studied the flat-plate solar collector with spiral tubing. Lu et al. [15] experimentally investigated the transition and turbulent convective heat transfer of molten salt in spirally grooved tube. However, the heat absorption enhancement of solar receiver with enhanced pipes need to be further analyzed.

In this paper, the heat absorption performances of heat receiver with spirally grooved pipe were investigated. The basic physical model of heat absorption process was proposed using the general heat transfer correlation of molten salt in spirally grooved pipe. The heat transfer performances of heat receiver were further investigated by considering the incident solar flux, inlet temperature, flow velocity, and groove height. In addition, the absorption efficiency of the receiver and maximum operating temperature of molten salt flow were reported.

2. Physical model of heat absorption process

2.1. The heat absorption model of heat receiver

Our previous article [16] investigated the heat transfer performances of the receiver with smooth pipe, and the results showed that the average wall temperature and absorption efficiency of the receiver pipe circumference under unilateral solar radiation were almost equal to those calculated from the uniform model with average concentrated energy flux. As a result, the receiver can be investigated under uniform solar radiation in present article, and the effects of pipe structure and operating conditions will be considered. According to the energy conservation law, the incident solar energy flux on the receiver surface is equal to the energy loss outside the receiver and the inner energy increment of working fluid inside the receiver.

For external receiver as Fig. 1a, the heat absorption process on the receiver pipe surface can be described as [16]:

$$I = \rho I + h_{\mathrm{nc}}\left(T_w - T_s\right) + h_{\mathrm{fc}}\left(T_w - T_s\right) + \varepsilon\sigma\left(T_w^4 - T_s^4\right) + q_f \quad (1)$$

where I means average incident solar flux on the receiver pipe surface, T_w means the outer wall temperature of the receiver, T_s is surrounding temperature, ρ is the reflectivity of the receiver, ε is the emissivity of the receiver, σ is Stefen Boltzmann constant, and q_f is the average absorbed energy flux on the pipe surface. In Eq.

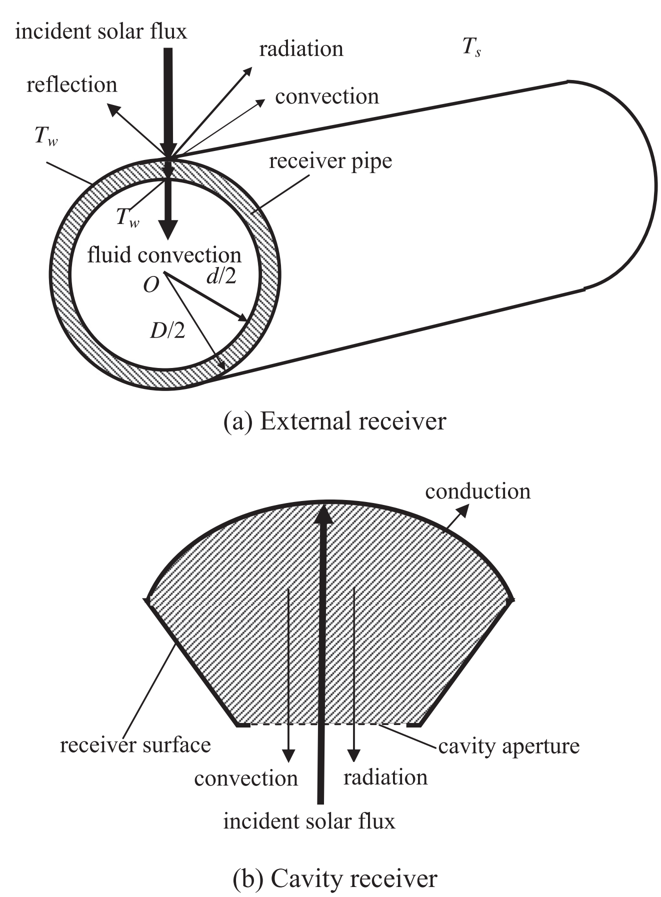

Fig. 1. Basic heat absorption model of solar receiver.