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Study on the allowable flux density for a solar central dual-receiver

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Abstract

Direct steam generating solar power towers begin to develop dual-receiver concept that enables dynamic and accurate solar flux control on boiling and superheating section. The allowable flux density on each receiver is an important parameter to ensure allowable strains of tube material are not exceeded. A physical model is verified and applied to analyse the change of allowable flux density with tube inner diameter, main steam pressure, saturated steam velocity. For both boiling and superheating section, reducing tube inner diameter or increasing saturated steam velocity will enhance allowable flux density. Decreasing main steam pressure of boiling section also makes allowable flux density higher. For superheating section, when pressure less than 10 MPa, increasing allowable flux density with increasing pressure, but result is the opposite when pressure greater than 10 MPa. Last a sensitivity analysis is used to compare the influence of above factors on allowable flux density.

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Keywords: Direct steam generating solar tower; Boiling section; Superheating section; Allowable flux density

1. Introduction

Of all CSP technologies available the central receiver system (CRS) is moving to the fore front. CRS can achieve higher temperatures (up to 1000 ^{0}C) and thus higher efficiency than parabolic trough and linear Fresnel systems [1].

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Nomenclature

d_i	tube inner diameter, m
d_i*	ratio of current and reference tube inner diameter
d_o	tube outer diameter, m
h	heat transfer fluid coefficient, W/m^2 K
P	main steam pressure, Pa
P*	ratio of current and reference main steam pressure
t	tube wall thickness, m
r	ratio of outer and inner tube diameter
q_o	incident allowable flux density, W/m^2
q_{omax}	incident maximum allowable flux density, W/m^2
q_{omax}*	ratio of current and reference maximum allowable flux density
k_m	thermal conductivity of tube wall, W/m K
S	maximu allowable stress of tube material, Pa
R_{cond}	conductive thermal resistance, K/W
R_{conv}	convective thermal resistance, K/W
T_w	average tube wall temperature, ^{0}C
T_f	heat transfer fluid temperature, ^{0}C
v_s	saturated steam velocity, m/s
v_s*	ratio of current and reference saturated steam velocity
x	steam quality
ε	strain
ε_{as}	allowable strain

Using water/steam instead of molten salt or sodium as heat transfer fluid makes possible to feed directly the turbine with steam produced in the solar receiver reducing the number of heat exchangers and cost [2].

Solar one, CESA-Ⅰ, EURELIOS, Beijing Badaling are direct steam generation solar towers that apply only one receiver to heat water to superheating steam [1]. One main operational difficulty was found: A lack of controllability of the system, especially during transient conditions, mainly caused by the strong differences in thermal properties during phase change from water to steam [3]. Since 2009, Abengoa Solar, BrightSource, and eSolar companies are operating their own experimental plants based on dual-receiver concepts [3]. Dual-receiver concept is characterized by physical separation of two receivers, one of them for boiling and another for superheating, both using external cylinder or cavity structure receiver. Then the allowable flux density [4] in each receiver is an important design parameter to ensure not exceeding the allowable stress of tube material.

Although previous studies give information about allowable flux density for dual-receiver [5,6], they do not analysis the influence of some factors on allowable flux density. Therefore, in this paper, allowable heat flux density varies with tube inner diameter, main steam pressure, saturated steam velocity respectively for boiling and superheating section are discussed.

2. Physical modeling

Gregory J. Kolb [7], Zhirong Liao [8] proposed physical model for calculating the allowable heat flux density of solar power central receiver using molten salt as heat transfer fluid. And direct steam generating solar central receiver can apply similar physical model.

It is assumed that heat flux conducts one-dimensionally through a thin tube wall into the heat transfer fluid. Because of tube curvature, heat flux normal to the tube surface has a cosine distribution.

One key problem is to determine the forced convection heat transfer coefficient inside tube. For one-phase as water only or vapor only flowing in the tube, it can be obtained by [9],