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INVESTIGATION OF COLD FILLING RECEIVER PANELS AND PIPING IN MOLTEN-NITRATE-SALT CENTRAL-RECEIVER SOLAR POWER PLANTS

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ABSTRACT

Cold filling refers to flowing a fluid through piping or tubes that are at temperatures below the fluid's freezing point. Since the piping and areas of the receiver in a molten-nitrate salt central-receiver solar power plant must be electrically heated to maintain their temperatures above the nitrate salt freezing point (430°F, 221°C), considerable energy could be used to maintain such temperatures during nightly shut down and bad weather. Experiments and analyses have been conducted to investigate cold filling receiver panels and piping as a way of reducing parasitic electrical power consumption and increasing the availability of the plant. The two major concerns with cold filling are: 1) how far can the molten salt penetrate cold piping before freezing closed and 2) what thermal stresses develop during the associated thermal shock.

Cold fill experiments were conducted by flowing molten salt at 550°F (288°C) through cold panels, manifolds, and piping to determine the feasibility of cold filling the receiver and piping. The transient thermal responses were measured and heat transfer coefficients were calculated from the data. Nondimensional analysis is presented which quantifies the thermal stresses in a pipe or tube undergoing thermal shock. In addition, penetration distances were calculated to determine the distance salt could flow in cold pipes prior to freezing closed.

NOMENCLATURE

Bi = Biot number
Cp_s = specific heat of solid
Cp_m = specific heat of liquid
D = diameter of pipe
E = modulus of elasticity
Fo = Fourier number
h = heat transfer coefficient
h_f = heat of fusion
k = thermal conductivity of pipe (Eq. 5)
L = wall thickness
Nu = Nusselt number
Pr = Prandtl number
r = radial coordinate of pipe
r_i = inner radius of pipe
r_o = outer radius of pipe
r^* = nondimensional pipe radius
R = radial coordinate of inner radius of pipe
R_o = radial coordinate of frozen layer
Re = Reynolds number
T = temperature
T_f = freezing point
T_i = initial wall temperature
T_o = inlet liquid temperature
T_w = wall temperature
T_∞ = fluid temperature
x^* = nondimensional distance from insulated surface
z = distance to freeze closed
α = thermal diffusivity (Eq. 3) or coefficient of thermal expansion (Eq. 9)
α_m = thermal diffusivity of liquid
α_s = thermal diffusivity of solid
$\delta = 1 - r_i^*$ = nondimensional wall thickness
λ_n = characteristic values of transient conduction equation
γ = parameter measuring the relative importance of sensible to latent heat, assumed to be 0.7 (water)
θ^* = nondimensional temperature
θ_o^* = nondimensional temperature at the insulated surface
σ_θ = circumferential stress
σ_r = radial stress
σ_z = axial stress
σ^* = nondimensional thermal stress
ν = Poisson's ratio

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