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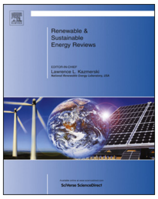

Review of heat transfer fluids in tube-receivers used in concentrating solar thermal systems: Properties and heat transfer coefficients

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ABSTRACT

The Heat transfer fluid (HTF) is a key component of solar thermal power plant because it significantly impacts the receiver efficiency, determines the type of thermodynamic cycle and the performance it can achieve, and determines the thermal energy storage technology that must be used. This paper reviews current and future liquid, gas, supercritical, two-phase and particulate HTFs. Thermophysical properties are presented as well as correlations to determine the receiver tube-HTF heat transfer coefficients. Variations of convective heat transfer coefficients as a function of temperature are illustrated for all selected HTFs in their stable operation temperature ranges. Finally, recent developments on new HTFs working at 700 °C and beyond are discussed.

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1. Introduction

1.1. Concentrating solar technologies

With the increasing interest in sustainable power production and the need to reduce CO_2 emissions, renewable energy sources are becoming an important element in the world energy balance. Among them are the Concentrated Solar Power (CSP) technologies (parabolic trough, linear Fresnel reflector, parabolic dish and central tower) are gaining importance [1–8]. They work by transforming solar radiation into heat used to trigger chemical reactions or produce electricity. A solar thermal electricity power plant consists of four major components: the solar concentrating system, the receiver, the thermal energy storage and the thermodynamic cycle coupled with the electric generator. Each CST has its own reflector configuration to concentrate the sunrays onto a line or a central point, where the receiver is located. The receivers can be different in shape, size or composition, but their common purpose is to absorb the concentrated solar radiation and transmit it to a heat transfer fluid (HTF). The heat is finally transmitted to the working fluid of the thermal block that converts the heat into mechanical energy. Again, various thermodynamic cycles are available, each with its own range of working temperature. They are mainly Rankine cycles [9] (with saturated or super-heated steam) for large power plants, Brayton [10] and Stirling [11] cycles for medium and small-scale facilities. The type of thermodynamic cycle puts a constraint on the type of HTF to use. At the same time, the HTF's working conditions limits result in constraints on the solar receiver.

The overall thermal efficiency of a solar thermal power plant highly depends on the concentrating system and on the receiver. The solar concentrating systems can be divided in two main categories: linear and point focusing. There exist two types of concentrators for linear systems: the parabolic trough [12–15] and the linear Fresnel [15,16]. The receiver is an evacuated tube for the first and a tube bundle for the second. Linear concentrators are characterized by low average concentration ratios, from 30 to 100. High concentration ratios, from 300 to 1500 and more, are achieved by point focusing concentrators. Point focusing systems concentrate all the sun's rays onto a central spot located at the focal point of the parabola, for parabolic dish systems, and at the top of the tower for central tower systems. The technology options for receivers adapted to point focusing concentrating systems are wider than for linear ones. Various types of central solar receivers exist and have been assessed [1,17]. Volumetric receivers [18] are conceived to let the concentrated solar radiation enter the absorber, which in this case is a porous media made of metallic wires or ceramic foam. In this way, the whole solid volume gets heated up and the external temperature is lower than it is for surface absorbers, which reduces the infrared radiation heat losses. The porous structure acts as a convective heat exchanger where the heat transfer fluid, mainly air, receives heat from the solid absorber. The big challenges of this kind of receiver are unstable flow and heterogeneous heating caused by changes of the temperature-dependent working fluid properties, in particular viscosity and density, which may lead to overheating and local failures in the receiver material. Tubular receivers were designed for either gas or fluid HTFs. For the first option, the main challenge is to overcome the limited convection heat transfer between the tube wall and the gas. Various prototypes have been developed in the past forty years, an example of which is presented in [19]. Presently, the possibility of using high efficiency supercritical CO_2 (sCO_2) Brayton cycles with CSP leads to a particular interest in receivers using sCO_2 as HTF [20]. Tubular liquid receivers [21,22] generally consist in an array of thin-walled tubes that are arranged to shuttle the working fluid in multiple passes through incident concentrated sunlight. The tube size and wall thickness are selected to maximize heat transfer while minimizing pumping losses, thus resulting in an optimum diameter. Lastly, particle suspension receivers, which are especially applied to central tower systems, work following various concepts. A recent work [23] reminds all the studies done since the 1980s, including the recent dense particle suspension receiver [24,25]. In the latter, the fluidized particles, in a state of dense suspension with about 30% particle volume fraction, circulate inside a vertical tube just like a liquid HTF. This brief overview of the receiver designs shows that among the variety of geometries, the tube