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View Factor of Solar Chimneys by Monte Carlo Method

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Abstract

A typical solar chimney power plant (SCPP) system mainly contains three components, namely, solar collector, tower and turbine. The collector heats up ambient air entering to the system by buoyancy force. Updraft airflow is then generated in the chimney and drives the pressure-staged turbine in the chimney base to generate electricity or ventilation of buildings. A part of the solar radiation is absorbed by solar collector directly, which is greater than which reflected by collector to the tower. But this amount of reflection can enhance the efficiency of the system. Determining more precise view factor between collector and the tower is essential for solving heat transfer equation. In this study, results obtained by Monte Carlo method are compared with analytical method which is available in literature for calculating the view factor. With increasing the ratio of the length to the radius of the tower, configuration factor increases slightly. Also, at higher radius of the collector, supposing length and outer radius of the chimney are unchanged, the view factor decreases. This behaviour can also be seen by analytical solution, but the result of analytical solution is much lower than that one obtained by Monte Carlo solution. It is suggested to designers and researchers to use the results obtained by Monte Carlo method, which seems to be more accurate.

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Keywords: Radiation; View factor; Monte Carlo method; Analytical solution; Solar chimney, Heat transfer.

1. Introduction

One of the important ways to energy transfers at high temperatures is heat radiation. Radiation heat transfer depends on the orientation of the surface relative to each other. To account the effects of orientation on radiation heat transfer between two surfaces, one parameter is defined that called view factor, which is a purely geometric quantity and is independent of surface properties and temperature.

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For complex geometries and when the arrangement of surfaces and shapes is arbitrary, it is unavoidable to compute the configuration factors for the particular geometry and arrangement of surfaces at hand. For such cases, approximate techniques using numerical algorithms and computers must be used [1]. One of the most efficient commonly used numerical solutions is Monte Carlo method. The use of Monte Carlo method in radiation heat transfer goes back as far as the paper by Howell and Perlmutter [2]. Monte Carlo method is a class of numerical techniques based on the statistical characteristics of physical processes, or analogous models that imitate physical processes. The analysis of previous works shows that Monte Carlo offers a beneficial method for finding the values of configuration factors as it is able to incorporate all important effects in a radiative heat transfer simulation without approximation [3]. Monte Carlo method has some drawbacks, such as the immense requirement for computer time and the statistical fluctuation of the results [4]. Maltby and Burns [5] investigated performance, accuracy and convergence in a three-dimensional Monte Carlo radiative heat transfer simulation with a code including capabilities mixing specular and diffuse reflection models, banded spectral material properties, transmission through external surfaces, and simulation of beam radiation. Also, Miyahara and Kobayashi have developed new numerical method for calculating the configuration factors for an axially symmetrical geometry [6]. It was compared with the area integration and Monte Carlo methods for concentric coaxial cylinders, and was seen to be 19 times and 3 times faster than them, respectively. A two dimensional Monte Carlo method by Qualey et al. [7] was applied to a classic radiant energy exchange problem that models the interior of an industrial furnace. The configuration involved a source as an infinite radiating plane and the heat sink as parallel rows of infinitely long tubes. With developing this method and after two years, Hong and Welty used Monte Carlo simulation of radiation heat transfer in a three dimensional enclosure containing a horizontal circular cylinder [8]. A fast Monte Carlo scheme was presented in the research by Mazumder and Kresch [9]. The basic algorithm was the classical surface to surface ray-tracing algorithm. In addition, a modified form of the binary spatial partitioning (BSP) algorithm was implemented to speed up ray tracing by at least a factor of 3. The results demonstrated a high level of accuracy with fairly low computational cost. Chai et al. [10] applied finite volume method to calculate configuration factors between surfaces of control volumes. In a study by Xia et al. [11] through discretizing the medium into many sub layers and employing a linear refractive index approximation for each sub layer, a curve Monte Carlo method was developed to solve the radiative heat transfer in an absorbing and scattering gradient-index medium. In some researches, Monte Carlo was implemented for combined radiative and conductive heat transfer. For instance, Schweiger et al. [12] applied this method for combined conduction and radiation heat transfer in honeycomb type transparent insulation materials. In their work a good agreement between numerical and experimental results was shown. Mirhosseini and Saboonchi [13] applied Monte Carlo method to determine configuration factor for the plate including strip elements to circular cylinder. The analysis displayed the differences between the numerical results obtained and analytical solutions for the 20, 30, and 45 element discretized figures and for (30^4), (50^4) and (70^4) rays per element. Also, Mirhosseini and Saboonchi [14] determined configuration factor for the plate including strip elements to two parallel circular cylinders as a case in industrial heating and cooling processes. Details can be observed in these two researches completely. Hajji et al. [15] used three methods for calculating view factor of a strip to in-plane parallel semi-cylinder. They reported high difference between results obtained by Monte Carlo method and the analytical solution.

In our investigation, determining more precise view factor between collector (base plate) and the tower of solar chimney is considered because of its importance for solving heat transfer equation. In this study, Monte Carlo method is implemented by a code plus analytical method which is available in the literature.

2. Solution methods

In fact, view factors represent the fraction of radiant energy leaving any given surface that is incident upon a reference surface and dependent upon problem geometry via the solid angle subtended by one surface upon the