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A mathematical model for determining the optimal reflector position of a double exposure flat-plate solar collector

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ABSTRACT

A double exposure, flat-plate solar collector (DEFPC) can absorb solar irradiation from both its upper and lower absorber surfaces (LAS). Absorption from the LAS is accomplished using a flat-plate reflector placed below and parallel to the collector. This paper presents a mathematical model for determining the optimum reflector position of the DEFPC in the condition where the LAS is fully irradiated. Compared to other models, this model enables the calculation of the instantaneously irradiated area of the LAS for arbitrary finite dimensions of the reflector and the collector, their arbitrary mutual positions and at any position of the sun in the sky. The optimum reflector positions were obtained by simulating the model in FORTRAN for the spring (autumn) equinox and the winter and summer solstices. The simulations were performed for the optimal yearly position of the collector at 44° N Latitude (Kragujevac, Serbia) and for equal dimensions of the collector and the reflector whose minimum dimensions allow the full irradiation of the LAS. The model was experimentally verified, and the range of the reflector movement during a single year, as well as the optimal reflector dimensions for minimum movement, was determined.

1. Introduction

The increasing need for renewable energy sources, specifically solar energy, requires that research be conducted to improve the efficiency of solar systems. The most common systems used for absorbing solar energy are flat-plate (water) solar collectors (FPCs), which receive solar irradiation through the upper absorber surface. The greatest limitations to increasing the use of conventional collectors are their relatively low average efficiency and high investment cost. For this reason, significant research on improving the efficiency of FPCs has been carried out. Results from peer-reviewed studies indicate that the greatest theoretical improvements to the collector efficiency can be achieved by utilising internal fins in the collector pipes and using concentrating or reflective surfaces (reflectors) [1]. Many studies have been performed to investigate the effect of using a reflector on the FPC [2–8]. McDaniels et al. [2], Larson [3] and Tanaka [4] studied the effect of a top reflector on the solar collector and determined the optimal tilts of the reflector and collector. Ekechukwu and Ugwuoke [5] designed and tested a solar cooker augmented with a top plane reflector. Grassie and Sheridan [6] investigated various reflector–collector configurations with the reflector placed either in front of or on top of the collector at variable collector tilts. Kostic et al. [7] analysed a solar collector with top and bottom reflectors and calculated the optimum yearly tilt angle of both of the reflectors for a fixed collector tilt angle of 45° (43° N Latitude). Hellstrom et al. [8] studied the effect of placing a plane reflector between two collector rows and reported that the reflector increased the expected annual output from 19.9% to 29.4%, depending on the reflector material. In all of these studies, the collector–reflector system (CRS) included a flat-plate reflector, which is connected to the collector.

In this paper, a modified CRS, called a double exposure flat-plate solar collector (DEFPC), is analysed. The term DEFPC is related to the solar collector, which has the ability to receive and absorb solar irradiation from the upper and lower surfaces of the absorber. Absorption of solar irradiation from the lower absorber surface (LAS) is accomplished using a flat-plate reflector placed in parallel below the collector. In contrast to conventional FPCs, the collector analysed here has no insulation mounted in the lower part of the collector box, and the lower box surface is replaced by a glass cover.

There are several studies [9–12] that are exclusively related to this type of CRS. This concept was first proposed by Souka [9] and Souka and Safwat [10,11]. These papers studied the optimum orientations for reflectors placed behind and separately from the collector for particular sun positions and the thermal performance

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