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Comparison in net solar efficiency between the use of concentrating and non-concentrating solar collectors in solar aided power generation systems

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HIGHLIGHTS

- Non-concentration collector integrated into solar aided power generation (SAPG) is proposed.
- SAPG with concentration and non-concentration collectors are studied and compared.
- SAPG with non-concentration collector shows higher net solar efficiencies.
- Using non-concentration collectors is a more cost-effective way for SAPG.

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ABSTRACT

Solar Aided Power Generation (SAPG) technology offers the promise of a higher energy efficacy and lower carbon emissions. In virtually all pilot-scale SAPG projects, concentrating solar collectors (e.g. parabolic trough collectors) are used to produce solar heat with a temperature ranging from 300 °C to 350 °C, to replace the feed water pre-heating in high pressure feed-heaters (HPH) in regenerative Rankine steam cycles. Although concentrating solar collectors offer a higher solar thermal efficiency, whether the use of this type of solar collector in a SAPG system can still offer both higher net solar thermal and net solar to power efficiencies remains unknown. This paper investigates the performance of an SAPG with either concentrating collectors or non-collectors (evacuated tube collectors). It was found that non-concentrating collectors are able to generate more power through the SAPG mechanism and exhibit higher net solar efficiencies than concentrating collectors on the per unit land area basis. This outcome suggests that the use of non-concentrating collectors in SAPG systems is more efficient than the use of concentrating collectors.

1. Introduction

Solar energy as a clean energy source has drawn more attention than ever before. Although stand-alone solar thermal power plants offer the advantage of low greenhouse gas emissions, the efficiency and costs of these power plants are unattractive. However, integrating solar energy into existing coal-fired Rankine cycle power plants is a cost-effective way to use low to medium temperature solar resources for power generation purposes. It has been proven that integrating solar energy into existing regenerative Rankine cycle power plants, through the so-called Solar Aided Power Generation (SAPG) technique, has much higher solar to power efficiency than that of stand-alone solar thermal power plants [1]. Kolb [2] pointed out that integrating solar energy into existing Rankine cycle power plants also has economic advantages in terms of lower infrastructure costs over solar stand-alone power plants.

The benefits of using solar energy for power generation are well known, but the costs of building and operating a solar thermal power system offset part of these benefits. Therefore efficiency and economy are key factors influencing the further development of solar thermal power plants. According to engineering thermodynamics, in any thermal energy system, the greater the heat source temperature, the greater the theoretical efficiency of the system will be. In other words, the efficiency of a solar thermal (alone) power generation system is limited by the maximum temperature of the solar collector output, which is generally lower than that of a conventional fuel fired power plant. That is the reason why in

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contemporary design, all solar thermal plants built and/or planned to be built, the concentration type of collector is the only choice to be used. However, in a SAPG plant, the solar heat is used to replace the extraction steam to preheat feedwater in a regenerative Rankine power plant (over 90% of power plants in the world are of this type). The maximum temperature of the SAPG plant is no longer the output temperature of the solar collectors, but the combustion temperature. Thus solar (thermal) to power efficiency in a SAPG system is no longer limited by the solar collector output temperature. Therefore, SAPG is a system that could potentially utilize low to medium temperature (solar or other) heat to generate power efficiently. However, in all known SAPG projects and previous studies [3–12], only concentration collectors were considered to supply solar heat, due to the lack of knowledge of integrating non-concentration collectors into SAPG systems. The technical performance of SAPG in terms of power plant thermal efficiency has been analysed by previous studies, but that of SAPG from a net solar efficiency point of view, with different solar collectors, has rarely been studied.

Non-concentration collectors have been overlooked in SAPG applications. It is true that, without consideration of cost, the same amount of higher temperature solar input by the concentrators would deliver more power than that which medium to low temperature solar heat could deliver. However, the non-concentration collectors can collect total solar radiation, i.e. both direct and diffuse radiations, while concentrators can only collect direct radiation. Generally speaking, depending on the location, direct radiation accounts for approximately 70% in the total solar irritation. The remaining 30% of the solar energy potentially collected by non-concentrating collectors may well compensate for their temperature “weakness” in terms of annual performance, especially in locations where solar resources are not ideal. In addition, when compared with non-concentration solar collectors (e.g. evacuated tube collectors), concentration types of solar collector are more costly in terms of initial capital and maintenance costs and utilize greater land area. This paper presents the results of a study looking into the total solar thermal energy that could be collected by concentration and non-concentration collectors on the same piece of land, and the electrical power that could be produced if it were to be used in a SAPG power plant. The results show that the non-concentration collectors are technically and economically superior to concentration collectors in this application.

Concentration solar collectors (e.g. Parabolic trough (PT) collectors) in practice can output solar heat at a relatively high temperature (300 °C–350 °C) while non-concentration collectors (e.g. Evacuated tube (ET) collectors) normally output solar heat at a low to medium temperature (100 °C–200 °C). In a SAPG plant, solar thermal energy with a relatively high temperature (300 °C–350 °C) could be used to replace extraction steam in high pressure (HP) feedwater heaters (FWH) while low to medium temperature (100 °C–200 °C) solar heat could be used to replace the extraction steam in intermediate pressure (IP) or low pressure (LP) FWHs.

Fig. 1 shows a schematic diagram of a SAPG system with parabolic trough (PT) collectors and evacuated tube (ET) collectors. As shown in Fig. 1, PT collectors could be used to substitute or replace extraction steam for the HP FWH1 at point A and ET collectors could be used to replace extraction steam for the IP FWH (FWH4) at point E. Although the ET collectors output solar heat at lower temperature levels, more collectors could be installed on a given piece of land when compared with parabolic troughs. Therefore, more solar energy could be collected and more power could be generated by ET array than that by PT array.

2. Outputs from solar fields

2.1. Solar radiation falling on land

The instantaneous total solar radiation falling on the land of a solar field can be calculated as follows:

$$Q_{\text{Total,land}} = I_{g,n} A_{\text{Land}} \tag{1}$$

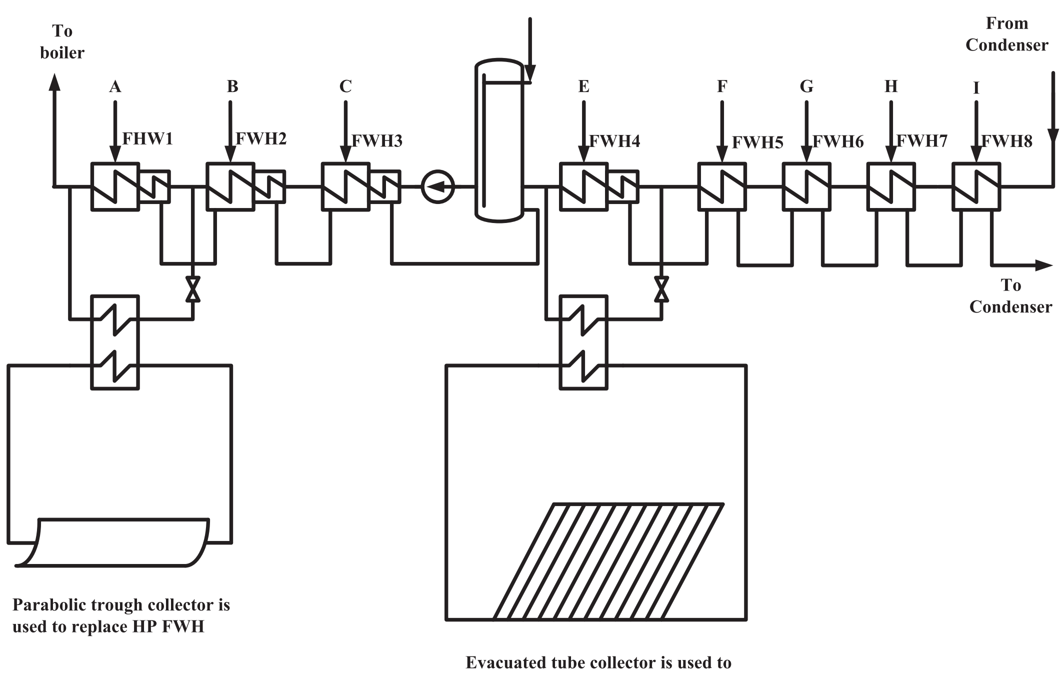

Fig. 1. Schematic diagram of SAPG system with parabolic trough collectors and evacuated tube collectors.