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Experimental study of exfoliated graphite solar thermal coating on a receiver with a Scheffler dish and latent heat storage for desalination

Chandrashekara M. *, Avadhesh Yadav

Department of Mechanical Engineering, National Institute of Technology, Kurukshetra, India

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A B S T R A C T

In this paper, a low-cost and efficient method based on Scheffler reflector, exfoliated graphite (EG) coating and paraffin wax are developed for desalination system. The solar coating plays a key role in increasing the absorptivity of concentrated solar energy to raise the temperature of the receiver. So, A new type of coating such as exfoliated graphite is adopted on the receiver for desalination. In this work, the coating is experimentally investigated for thermal stability and performance with a Scheffler dish. The brief fabrication procedure with Jigs has been discussed for easy fabrication of unskilled labour to promote entrepreneurship. Extensive tests have been carried out under the sun to find out the effect of exfoliated graphite coating on the absorber assisted with latent heat energy storage unit. It has been observed that the Scheffler reflector with EG coating on absorber plate gives the enhanced thermal performance up to 42% and thermal stability even up to 420 °C with absorptivity more than 97% of the solar incident.

1. Introduction

The lack of drinking water is always affecting life sustainability. The solar still productivity is directly influenced by solar intensity which causes the rise in temperature of water (Effect of climatic, 2003). Hawking said that the air pollution and overcrowding of the population are the major threat to humanity. The air pollution has been increased over the past five years and more than 80% of inhabitants are in urban areas are exposed to unsafe levels of air pollution. It is estimated that the population will increase to 11 billion by 2100. The energy requirement is also increasing with the population, so it is the necessity to utilise solar energy to meet energy needs of low and medium temperature and betterment of humanity.

Many remote and coastal areas do not have resources of electric power for producing potable water by using conventional desalination techniques such as multi-stage flash, reverse osmosis and vapour compression (Kalogirou, 2005; Eltawil et al., 2009; Bhardwaj et al., 2015). Soteris Kalogirou (2004) reviewed different types of solar collector used to harnessing the full potential of solar thermal energy, their applications, performance and thermal analysis. It was also included full technical details of a wide range of collectors for the different application of solar energy like desalination, space heating, water heating, cooling, thermal, solar chemistry etc.

Morad et al. (2017) showed the vacuum pump integrated with evaporator enhances water yield by reducing the boiling point of water. Maximum yield of 10.94 and 7.27 L/d were observed at different flow rate of 0.8 and 0.40 L/h with least cost of 0.031 and 0.030 US $/L respectively. The model setup was developed with a low cost of 290 and 185 US $ for developed and ordinary desalination setup. Liu et al. (2013) carried out desalination experiment using ETC observed that increasing temperature of water increases yield and reduces evaporator area and fresh water cost. The number of effects increases fresh water production, but the volume of evaporator increases slightly.

Munir et al. (2010) developed the design principle and construction details of 8 sq.m surface area of Scheffler concentrator. In this, it has been carried out mathematical calculations to design the reflector parabola curve and elliptical frame with respect to the equinox. In this paper shape, angles, slopes, profiles, daily tracking mechanism, seasonal tracking mechanism, flexible crossbars, frame and installation procedure are reported. Kumar et al. (2008) prepared the construction manual of 2.7 sq. m Scheffler reflector with materials requirement and fabrication procedure. Daniel Philippen reported the construction manual of 2 sq. m Scheffler reflector with PV tracking.

Munir and Hensel (2010), Munir et al. (2014) experimentally investigated a solar distillery for the oil extraction with a Scheffler reflector. They reported that the productivity of 33.21%, focus

* Corresponding author.
E-mail addresses: chandru3@nitkkr.ac.in (M. Chandrashekara), avadheshyadava@nitkkr.ac.in (A. Yadav).

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Nomenclature

EG	exfoliated graphite	C_{sp}	average specific heat between T_i and T_m (J/kg K)
LHS	latent heat storage	C_{lp}	average specific heat between T_m and T_f (J/kg K)
TES	thermal energy storage	Q	quantity of heat stored (J)
NREL	National Renewable Energy Laboratory	T	temperature °C
DLS	double layer structure	T_i	initial temperature °C
T_a	temperature of ambient air °C	T_m	melting temperature °C
T_v	temperature of water vapour °C	T_f	final temperature °C
T_w	temperature of water °C	λ	latent heat of fusion (J/kg)
δ	declination angle (°)	ρ	density (kg/m^3)
C_p	specific heat (J/kg K)	ρ_k	density of phase k in PCM (kg/m^3)
T_s	receiver surface temperature		

temperature 300–400 °C under solar beam radiation of 700–800 W/m^2. The optimisation of solar distillation system has been reported. The major application of Scheffler reflector is used for a low-pressure steam generation with low investment and higher payback as shown in Table 1. Munir et al. (2010) fabricated and tested the Scheffler parabolic solar cooker with heat storage elements of sensible heat with solid aluminium and tin. The thermal storage reduces the fluctuations of energy input to the system even with the variation of solar energy. The latent heat storage system will be more efficient up to 72% with PCM and 58% for the sensible heat storage. The using of low-cost phase change materials is more advantages to increase efficiency. Ruelas et al. (2013) integrated Scheffler reflector with 3 kWe Stirling engine to generate direct electricity. The mathematical model has been done to improve the performance of Scheffler type solar concentrator (STSC).

The excellent thermal stability up to 450 °C, excellent adhesion to the aluminium substrate and very high absorptance 97.5 is achieved by applying a layer of Boehmite (AlOOH) on top of the carbon nanotube (CNT) film by solution-processed spray deposition (Bera et al., 2016).

long Meng et al. (2016) designed and analysed volumetric solar receiver experimentally as well as theoretically by using a cup-shaped Al_2O_3 porous absorber. Analysis revealed that porosity increases surface temperature and radiation loss is reduced by the higher flow rate of the fluid, thus improves efficiency. The expanded graphite/RT44HC as composite materials increases thermal conductivity by 20–60 times, thus heat transfer rate increases proportionally with thermal conductivity and increases with packing density (Ling et al., 2015). The EG with the combination of hydrated salts further coated with paraffin increases thermal conductivity. The EG/hydrated salts with paraffin coated composite have high latent heat storage, high thermal conductivity, thermal reliability. The composite has the thermal conductivity as high as 3.643 W/m K (Wu and Wang, 2015).

Esposito et al. (2016) optimisation technique of cermet based solar coatings has been designed to increase the performance. Six diverse sunlight based coatings with Ag as back reflector have been optically designed by semi-exact methodology where a layer on layer ellipsometric characterization was used. Also reported highest sunlight thermal conversion efficiency with cermet based solar coatings having absorptive more than 92% at 400 °C and more than 85% at 550 °C further increased by annealing cycles at 580 °C under vacuum for the total duration of 85 days.

The M-AIN cermet coatings have the absorptivity of 0.92–0.96 of the solar incident and normal emittance of 0.03–0.05 at ambient temperature (Zhang, 1998). The AlMoN(H)/ AlMoN(L) solar coating has absorptance of 0.93 and normal emittance of 0.13. The selective coating was thermally stable up to 600 °C for 435 h in the vacuum as well as tandem absorber was thermally stable up to 450 °C for 2 h in air (Selvakumar et al., 2015). Wu et al. (2016) reported high-temperature coatings for concentrating solar power. In this, a simple and low-cost process for depositing the high-temperature solar absorber is tested. The Fe_2O_3 layer has high solar absorptivity (0.909–0.922) and their emittance value (0.18–0.38) and thermally stable up to 900–1000 °C.

The double layer structure (DLS) generates solar steam with high efficiently up to 85% by localising of solar heat. The flexible networked structure generates high pressure with temperature of the steam in the range of 100–525 kPa and 100–156 °C (Seyed Mohammad Sajadi et al., 2016). The thermal efficiency of the DLS is high i.e. 85% even at a low solar intensity of 10 kW/m^2 compare to other methods and further can be increased by increasing concentration ratio of the system. The exfoliated graphite layer has absorptivity more than 97% of the irradiated solar power of minimum thickness of 5 mm (Hadi et al., 2014; Seyed Mohammad Sajadi et al., 2016).

The electrical energy consumption is very high for heating application like hot air generation for space heating, air conditioning systems, ventilation in buildings (Navarro et al., 2016). The thermal energy storage coupled with solar thermal technologies for a centralised system in buildings greatly enhances the energy efficiency of the systems and reduces the electrical energy demand as well as the cost of consumption. Fig. 2 shows that energy stored per unit volume with different types of materials. The thermochemical heat storage system stores the high amount of heat energy per unit volume, but the cost of chemicals is too expensive. The latent heat storage system uses phase change materials to store heat energy. This system is widely used in the various solar power plant to reduce uncertainty due to weather disruption. The sensible heat storage system uses solid elements which charge and discharges thermal energy without a change in phase.

Fig. 1 shows power generation through renewable energy by 2022 in India. The major share is from solar energy for generation of electricity. The sun elemental gives us life and energy, today in our quest for new, clean renewable sources of energy. India is blessed with plenty of sun; it receives solar radiation for at least

Table 1
Application of Scheffler reflector.

Location	Potential
Mount Abu in Rajashtan	Power generation 1 MW, cogeneration for power and cooking, hot water for Pilgrimage
Shirdi	Community cooking
Tirupati	Community cooking
NISE, Delhi	Research and development
Kirlosker Copeland Ltd., India	Steam for washing compressor components
Ahmadnagar	Steam for evaporation of water from milk for preparing sweets.