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Design charts for Scheffler reflector

Desireddy Shashidhar Reddy, Mohd. Kaleem Khan*, Md. Zeeshan Alam, Haroon Rashid

Department of Mechanical Engineering, Indian Institute of Technology Patna, Patna 801106, India

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ABSTRACT

This paper presents parametric design charts for the Scheffler reflector, which has distinctive advantages such as flexible surface curvature, fixed focal area and shadow less concentration over other solar concentrators. Manufacturers would require design charts for quick estimation of various design parameters like section plane angle, concentration ratio and dimensions of crossbars for the Scheffler reflectors. The input parameters required for the development of design charts are aperture area and focal length, which are dependent on customers' need. The governing equations of the Scheffler reflector have been solved iteratively to obtain the design parameters, which are then used to develop various design charts. Due to design constraints of the Scheffler reflector, inclination angle could not be varied beyond the range of 42° to 44.9°. Error due to circular approximation of crossbars is quantified and is found to be insignificant. A general equation for seasonal change in parabolic profile of the Scheffler reflector has been proposed. Further, a simplified equation for concentration ratio has also been developed to ease the design process.

1. Introduction

Since the man first invented fire for cooking and for protection from weather, the search for fuels began. The main purpose of this fossil fuel is to produce heat through their combustion. Due to the deteriorating impact of conventional fossil fuel, the quest for a reliable energy source that doesn't harm the environment has intensified. Solar energy is one such alternative; wherein on an average earth receives 1000 W/m^2 of energy on its surface from the sun by radiation. However, utilizing solar energy is challenging due to its low energy density. Concentrating the solar energy is a viable option to increase the energy density (Suman et al., 2015; Naik et al., 2017; Hafez et al., 2017). There is a variety of solar concentrators available in the market. One such concentrator is the Scheffler reflector generated by an inclined plane intercepting a paraboloid, as shown in Fig. 1. This revolutionary concentrator was originally designed by a German engineer WolfGang Scheffler. Scheffler reflector has speciality that it has flexible surface curvature, a non-moving focal area and its absorber does not cast a shadow on the reflector (Oelher and Scheffler, 1994; Scheffler et al., 2006a). These peculiar features of Scheffler reflectors have made them unique.

Like any other concentrating collector, a Scheffler reflector can also be employed for a wide range of applications such as baking ovens, cooking food, sterilizing, distillation, processing of plants for oil, cremation of dead people etc. Scheffler et al. (2006b) built a reflector of 50 m^2 area (A) for cremation of dead people. Chandrashekara and Yadav (2017a, 2017b) used a 2.7 m^2 Scheffler reflector for latent and sensible heat storage for desalination of brackish water. Tyroller et al. (2006) developed a 10 m^2 Scheffler reflector to run a 76 L standard autoclave in a hospital. Munir and Hensel (2010) used an 8 m^2 Scheffler concentrator to run a solar distillation system to process medicinal and aromatic plants. Agrisani et al. (2013) developed a novel concept of solar biomass cogeneration system using Scheffler reflector. Hafez et al. (2016) simulated solar parabolic dish Stirling engine and performed thermal analysis. The estimated output power was 9.707 kW at 990 W/m^2 solar intensity. Afzal et al. (2017) used a hybrid solar system comprising of 10 m^2 Scheffler reflector and photovoltaic solar panel to extract essential oils from medicinal plants and herbs.

A survey of literature has also revealed that a few studies pertaining to fixed focus solar concentrators (FFSCs), in which focus remains fixed during tracking (Ruelas et al., 2013, 2015, 2017). FFSCs have low concentration compared to parabolic dish concentrators of same aperture area. Ruelas et al. (2017) classified FFSCs into three categories viz. high temperature concentrator (HTC), Scheffler concentrator and Scheffler-type solar concentrator (STSC). With moderate concentration ratio, moderate thermal efficiency and high cost, HTCs were generally not preferred. Although STSCs were reported to have high thermal efficiency, they posed difficulty in operation and maintenance due to elevated receivers. Though Scheffler concentrators gave lowest thermal efficiency among others, still they found more acceptability worldwide due to superior design features and low maintenance cost.

Keeping in view of the several advantages and owing to unique features of Scheffler reflector over other parabolic concentrators, its

* Corresponding author.
E-mail address: mkkhan@iitp.ac.in (M.K. Khan).

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Nomenclature

f	focal length of paraboloid, m
A	aperture area, m^2
A_i	area of solar image, m^2
B_1	major axis of elliptical rim, m
B_2	minor axis of elliptical rim, m
CR	concentration ratio
d	depth of crossbar, m
D	distance from bottom end of elliptical rim, m
l	length of crossbar, m
L	distance between focal point and top end of elliptical rim, m
n	day of the year
R	radius of crossbar, m
W	width of crossbar, m
x_i	x-intercept of section plane

Greek symbols

α	section plane angle, deg
δ	solar declination angle, deg
ϕ	angle between axis of paraboloid and FE1, deg

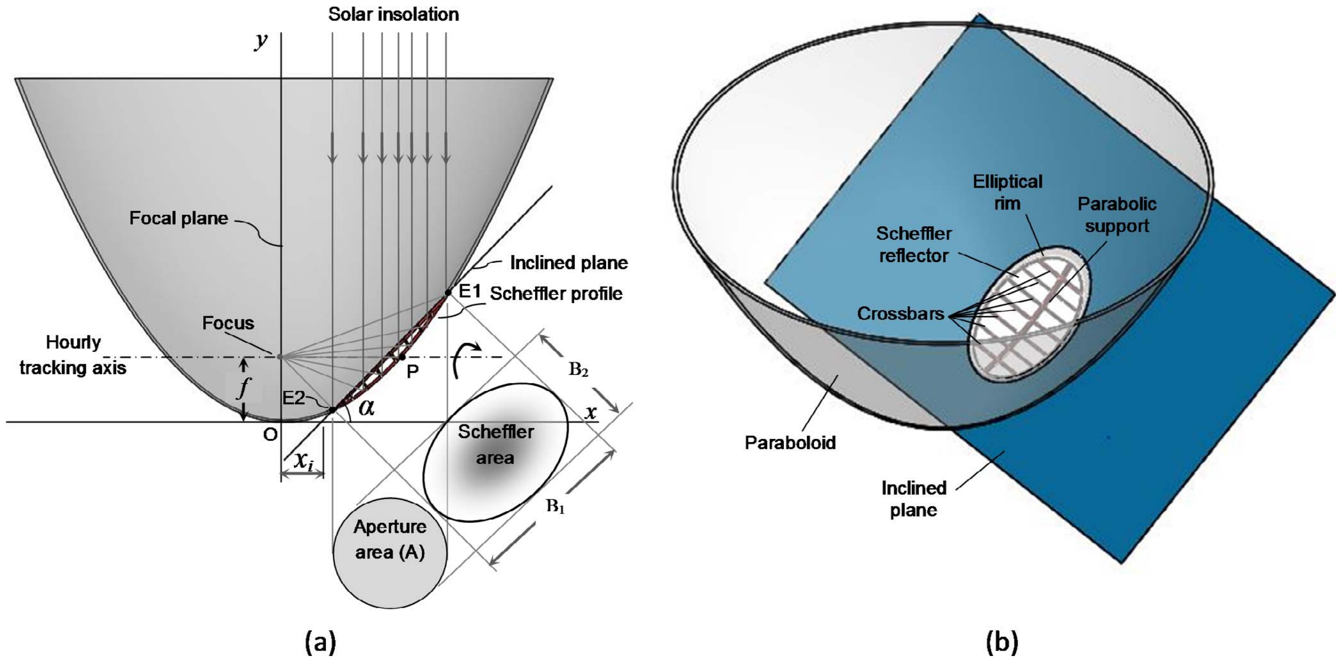

Fig. 1. Details of Scheffler reflector (a) schematic (b) solid model.

potential to employ for numerous applications and the difficulties associated in its design and fabrication, it is resolved to simplify the design methodology and to provide design charts for the ease in manufacturing of Scheffler reflector and its supporting frame. Till date, only Munir et al. (2010) presented the design principle and calculations for an 8 m^2 Scheffler concentrator. A comprehensive design methodology is, in fact, required for manufacturing the Scheffler reflectors at large-scale. The present work is an effort in that direction. This paper presents a simple, systematic and well-defined design methodology for Scheffler reflector. The purpose of this paper is to provide design charts and to eliminate the need for complex calculations for the construction of Scheffler reflector of any desired size.

2. Design methodology

This section presents the design methodology for Scheffler reflector's elliptical rim and the crossbars with respect to the equinox (solar declination angle $\delta = 0°$), i.e. when duration of day and night is same. The elliptical rim and crossbars of Scheffler reflector are shown in the solid model in Fig. 1(b). The two parameters that are required to begin the construction of a Scheffler reflector using the design charts are (a) The aperture area and (b) The focal length of the parabola. Aperture area A is the projected area of Scheffler concentrator and focal length f is the distance of focus of paraboloid from vertex as shown in Fig. 1(a).

2.1. Design of elliptical rim of Scheffler reflector

The parabola, shown in Fig. 1(a), is the mid-section plane of the paraboloid from which the Scheffler reflector is to be constructed. The equation of parabola having focal length f and its vertex at origin is given by

$$x^2 = 4fy \tag{1}$$

The equation of the section line (inclined plane) with slope α and x-intercept x_i can be taken as

$$y = \tan\alpha\,(x - x_i) \tag{2}$$

If E1 (x_1, y_1) and E2 (x_2, y_2) are the points of intersection of section line (inclined plane) and parabola, the major and minor axes of the elliptical rim of Scheffler reflector are respectively given by

$$B_1 = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{3}$$

$$B_2 = 2\sqrt{\frac{A}{\pi}} \tag{4}$$

where B_2 is also the diameter of the aperture circle.

Also, from the geometry shown in Fig. 1(a)

$$B_1 = \frac{B_2}{\cos\alpha} \tag{5}$$

Using Eqs. (1)–(5), following relations can be derived