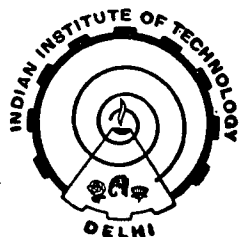


# **ANALYSIS AND PERFORMANCE EVALUATION OF LINEAR COMPOSITE SOLAR CONCENTRATORS**

by  
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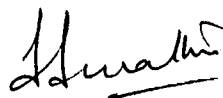
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C E R T I F I C A T E

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'Analysis And Performance Evaluation Of Linear Composite  
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## S U M M A R Y

The present thesis deals with the geometrical-optical design and performance evaluation of linear composite concentrating systems. A brief review of the research and development work done on composite solar concentrators has been presented. A somewhat new design of a linear Fresnel reflector system is proposed. The proposed design avoids blocking of radiation and gives rise to somewhat more uniform illumination over the focal plane as compared to conventional Fresnel reflector system.

A detailed study of the concentration characteristics of a composite parabolic trough has been made using a ray-trace model. It is found that concentration characteristics of such concentrators are more sensitive to the absorber defocussing as compared to the tilt of the absorber. The effect of insulating the unirradiated portion has also been investigated.

Some approximate formulae has been derived which may be used to calculate the geometrical concentration ratio over a flat/tubular absorber, the contribution of individual mirror element etc. with reasonable accuracies

for the two linear composite concentrators discussed above. Some of the results are generalized in nature and could be used for any concentrator-receiver combination of the above kind.

Results of detailed optical and thermal performance tests conducted on one prototype of each of these systems have been presented. Such studies may provide an idea of the practical feasibility of such systems.

Finally, results of some preliminary studies in nomographic form have been presented. The nomographs may be used for practical installation purposes for selecting the site, concentration type, and other specifications of the concentrator-receiver system for a particular application.

## P R E F A C E

Present trends of converting solar radiation to thermal energy are being directed toward designing collectors capable of delivering energy at higher temperature with minimum losses. Solar concentrators employing single or multiple reflective (mirror like) or refractive (lens) elements are of special interest in this context. The thermal efficiency of such collectors can be improved significantly since heat loss area is small as compared to a flat plate solar collector. Recent investigations in this direction have resulted in the development of several solar concentrator designs suitable for specific purposes [1-5].

A solar concentrator is characterized by several design and performance parameters which define its optical and thermal performance characteristics [6]. Geometrical and local concentration ratios, receiver intercept factor and the optical efficiency are some of the parameters which define the optical performance of a concentrator whereas the thermal performance can be specified in terms of stagnation temperature, heat

loss coefficient, time-constant and the overall thermal efficiency.

Solar concentrators can be classified as point focussing and line focussing [7]. Point focus system possess circular symmetry and provide high concentrations whereas line focus systems are cylindrically symmetrical systems and are used when intermediate concentration is sufficient to meet the requirements. A paraboloid of revolution, central tower receiver system and a circular Fresnel lens come in the category of point focussing systems while line focus systems can be exemplified as a cylindrical parabola, Fresnel lens/reflector, Russel's fixed mirror solar concentrator and a compound parabolic concentrator. Applications of solar concentrators include production of process hot water and steam, space heating, single and two stage absorption cooling and refrigeration, drying operations and power generation.

Linear solar concentrators providing intermediate temperatures ( $100^{\circ}$ - $300^{\circ}$ C) can be used to supplement industrial energy needs which consume a significant portion of the national gross energy input. Such

concentrators require single-axis tracking which may be easier and less expensive than that required by point focussing systems. Linear solar concentrator systems may also be suitable for purposes like irrigation pumping and power generation.

The fabrication of single piece linear solar concentrators of large dimensions is a technically difficult and expensive task. However, it is possible to synthesize the concentrator surface from smaller flat or curved components [52,69]. These approximate components can be more easily produced than the true surfaces so that their manufacture can represent a saving in cost and time. In cylindrical (linear) geometry a possible approximation is a composite parabolic trough concentrator made up of smaller flat mirror elements [13]. A linear Fresnel reflector concentrator is another alternative to a cylindrical parabolic concentrator. One advantage of such a design is that the various mirror elements lie essentially in a plane which offers a simpler and hence less expensive structure.

Geometrical-optical performance studies are required to have a proper understanding about local

concentration ratio distribution over the absorber surface, relationship between size of the absorber and the amount of energy intercepted and effects of tracking and absorber misalignment errors on the performance of a solar concentrator. The surfaces of composite concentrators are often described by discontinuous functions, therefore, an analytical treatment of composite solar concentrators may not provide complete information in some cases as found from earlier studies [13-14,17]. Ray trace techniques may give much more realistic information about geometrical-optical behaviour of such systems. Although some studies have been made to explore the geometrical-optical performance characteristics of a perfect parabolic trough using ray trace techniques, but such studies have not been made for a composite parabolic trough and a linear Fresnel reflector system, which may be more useful designs for practical applications. In the proposed thesis the geometrical-optical performance of a composite parabolic trough and a Fresnel reflector system has been studied in detail using ray trace techniques.

A cylindrical absorber is generally used with line focussing concentrators. A certain portion of such

an absorber always remains un-irradiated which may be insulated in order to reduce heat losses. An analysis of distribution of local concentration ratio over such an absorber and effects of insulating the absorber on concentration characteristics may be helpful from practical application point of view. Such a study for composite parabolic trough and a Fresnel reflector system has been presented in the proposed thesis.

Recently, considerable interest is being shown in the development of linear composite solar concentrating systems using smaller flat mirror elements. This is due to the availability of small sized mirror elements everywhere including most of the energy-conscious developing countries. However, the theoretical studies in connection with their concentration characteristics available so far are mostly based upon cumbersome numerical techniques. It would be of great help if some easier procedures could be developed which could predict the concentration characteristics of such systems with reasonable accuracy. In the present work such procedure is presented for the case of two linear composite concentrators under considerations, namely, the composite parabolic trough and a linear Fresnel reflector. The

methods presented give the geometrical concentration ratio, the contribution of individual mirror elements and other important parameter of such systems without using numerical techniques.

Prototypes of a composite parabolic trough and a linear Fresnel reflector have been fabricated using locally available materials. Results of the tests made to study the optical and thermal performance of both of these systems are presented in the proposed thesis.

Most of the tracking type solar concentrators do not collect a significant portion of the diffuse radiation, and, therefore, at locations with large amounts of diffuse radiation, high concentration devices will collect a small fraction of total incident solar radiation. A prior knowledge of the dependence of amount of energy collected on the local insolation characteristics will be of considerable help while planning to install a solar concentrating system to meet specific requirements. Generalized curves providing the desired information have been presented in the proposed thesis. These curves will be of practical importance while selecting proper sites for installing solar concentrating systems.

A chapter-wise summary of the proposed thesis is given below:

#### CHAPTER I

This chapter presents a review of the research and development work done in the field of composite solar concentrating systems. Efforts have been made to include all the recent literature to make it upto date. Several aspects such as design, fabrication, concentration characteristics, thermal performance etc. are taken into account in preparing the review.

#### CHAPTER II

The design and concentration characteristics of a linear Fresnel reflector concentrator has been evaluated in this chapter. In the present study the position, shift and tilt parameters associated with the constituent mirror elements are calculated in such a manner so as to avoid blocking of the radiation and obtain more uniform distribution than that obtained in a conventional linear Fresnel reflector systems. The effects of various design parameters such as focal length concentrator aperture and mirror element size on geometrical concentration characteristics have been investi-

gated. The results lead to a geometrical optimization of the design parameters. The local concentration ratio distribution over a flat absorber has been obtained. A ray-trace model has been developed in order to study the ray distribution over flat and cylindrical absorbers. The effect of insulating the un-irradiated portion on the geometrical concentration characteristics has also been investigated for flat and cylindrical absorbers. The results are plotted graphically and discussed.

### CHAPTER III

In the present chapter, a ray-trace model has been developed to study the concentration characteristics of a composite parabolic trough. The ray distribution over flat and cylindrical absorber surfaces have been obtained and intercept factor has been calculated for a typical composite parabolic trough. The effects of absorber misalignments on the concentration characteristics of the composite parabolic trough concentrator is also presented in this chapter. Preliminary results of an analysis taking into account the effect of insulating the un-irradiated portion of absorber have been reported for both flat and cylindrical absorbers.

#### CHAPTER IV

Some important features of a composite parabolic trough and a linear Fresnel reflector system are presented in this chapter in somewhat generalized form. The results show good resemblance to those obtained from iterative techniques used earlier and may be useful in selecting proper values of concentrator design parameters. Efforts will be made to present an analytical basis to show the uniformity of illumination over the focal plane and also the comparatively higher tolerances of such systems to mirror placement and trough pointing errors.

#### CHAPTER V

This chapter presents the results of detailed optical and thermal performance tests conducted on prototype composite parabolic trough and linear Fresnel reflector systems. The optical flux mapping experiments using a calibrated solar cell have been performed for both the concentrators. Measurements have been made to study distribution of local concentration ratio, variation of concentration along the focal line and to investigate effects of tracking and defocussing errors on

their concentration characteristics. Thermal performance tests were also conducted to find stagnation temperature, optical efficiency, heat loss coefficient, time constant and the thermal efficiency for such concentrators.

#### CHAPTER VI

The variation of the fraction of total energy collected by a typical concentrator-receiver system as a function of the amount of diffuse radiation has been studied and results are plotted graphically. Generalized curves in the form of nomographs which can provide useful informations such as ground area required for certain power requirement, the threshold radiation for desired operating temperature, concentration ratio required for a certain operating temperature and cost per unit of power produced are also presented in this chapter.

The above mentioned work has partially appeared in the following publications.

1. Performance analysis of a linear solar concentrator under different flow regimes; Applied Energy, 13(1), 77(1983).

2. Geometrical-optical performance studies of a linear Fresnel reflector; (Communicated)
3. Geometrical-optical performance characteristics of linear composite concentrating systems; (communicated).
4. Experimental evaluation of a composite parabolic trough (communicated).
5. Performance testing of a linear Fresnel reflector concentrator (Communicated).
6. Ray-optical evaluation of a composite parabolic trough; 9th IASTED International Conference, San Francisco, U.S.A. (1984).
7. Studies on installing solar concentrating systems; 9th IASTED International Conference, San Francisco U.S.A. (1984).
8. Thermal performance analysis of a focussing parabolic trough as an air heater; IASTED International Conference, Nice, FRANCE (1984).
9. Mathematical modelling of a solar concentrator using sinusoidal input; 8th IASTED International Symposium, Florida, U.S.A. (1983).

10. Mirror losses in solar energy concentrators, 8th IASTED International Symposium, Florida, U.S.A. (1983).
11. Geometrical-optical design and performance studies of a linear Fresnel reflector; Proc. of National Solar Energy Convention, New Delhi, India (1982).
12. Generalized optical performance characteristics of a parabolic trough using a fin receiver; Proc. of National Solar Energy Convention, Bangalore, India (1981).
13. Optical performance characteristics of a cylindrical parabolic concentrator using a fin receiver; 9th All-India Symposium on Optics, Madurai, India (1980).

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