Design, Fabrication and Monitoring of an Industrial-scale Solar Trough Collector at the Energy Park of Naresuan University, Thailand

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ABSTRACT

This paper presents the design, fabrication and monitoring system of a solar trough collector located in the Energy Park of the School of Renewable Energy Technology at Naresuan University. Standing at 6 m high, 50 m long and aperture area of 240 m^2, this solar trough is the largest and the first industrial-scale parabolic collector to be built and tested in Thailand under real solar conditions. This project represents the first high temperature study for a life-size trough collector that is carried out by a team which includes the public and private sectors. The solar trough was monitored for some periods and results have shown that its thermal performance during standard clear sky conditions was nearly comparable to the commercial LS-2 collector. This is significant as it means that it is possible to build large industrial-scale trough collectors in Thailand, using local materials and know-how. A semi-analytical mathematical model developed for the collector also showed that simulated data had related closely with measured ones.

Keywords: *Design, Industrial-scale, Solar trough collector.*

1. INTRODUCTION

The solar trough is the most important component in a parabolic trough solar thermal power plant. As such it is essential to study and research about solar trough collectors in order to better understands the characteristic performance of a concentrating solar thermal power system.

Worldwide, the best example of successful application of solar trough collector can be seen in the nine commercial Solar Electric Generating Systems (SEGS) located in the Mojave Desert of California, USA [1]. The collector system used in the SEGS plants consists of mainly LS-2 and LS-3 collectors from LUZ International, with each collector ranging between 47-99 m in length. These collectors operate with thermal oil as heat transfer fluid and can attain an overall solar-to-net electric efficiency of 9-14% [2]. Another notable example is the DISS (Direct Solar Steam) test-loop facility at the Plataforma Solar de Almeria (PSA) in Spain [3]. The DISS test-loop is consisted of nine 50-m and two 25-m LS-3 collectors connected in series, giving a total length of 550 m. The DISS collectors are capable of direct steam generation and can achieve an overall solar-to-net electric efficiency of up to 23% [4][5].

In contrast, the installation of solar trough collector in Thailand has always been limited to small prototypes, beginning with a modest 6 m^2 solar trough at the Asian Institute of Technology (AIT) in Bangkok about two decades ago. The last significant laboratory-scale trough collector was erected at the King Mongkut Institute of Technology Thonburi (KMITT) around the mid 1990s' with an aperture area of about 15 m^2. Since then, research interest in the subject had reduced due to the view that the high proportion of diffuse radiation was not conducive to the promotion of concentrating solar power technology in the country.

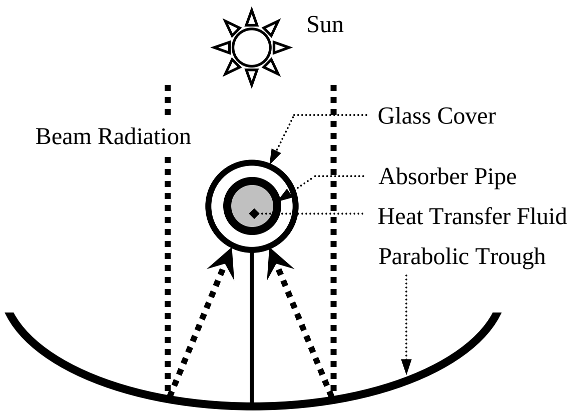
However in recent years, interest in the subject is rekindled because of the government's commitment to develop alternative and renewable energy sources to ensure the nation's long term energy security [6]. Other then solar energy, biomass is another renewable resource in Thailand that has a high exploitable potential. For example, a study by the Department of Energy Development and Promotion (DEDP) had found that the total amount of agricultural residues was about 61 million ton a year, of which 41 million ton or the equivalence to about 426 million MJ of energy was unused [7][8]. Thus, it is possible to operate biomass-hybrid solar trough power systems in appropriate sites, given the vast abundance of biomass resource in the country [9][10]. Furthermore, the expected uptrend of peak power demand from 17,000 MW in 2002 to a projected 30,000 MW by year 2011 also affirm the necessity to develop and implement more renewable-based technologies, including the solar trough [11].

Hence, it is with the above rationale that the School of Renewable Energy Technology (SERT) has installed a parabolic trough collector in its Energy Park, within the Naresuan University (NU) campus, for research purposes. With a length of 50 m, aperture area of 240 m^2 and standing at 6 m high, it is the largest and the first industrial-scale trough collector ever to be built and studied in Thailand under real solar conditions. Data collection is carried out using a computerised data monitoring and acquisition system which is integrated with the collector. This solar trough is important because it is the first high temperature study for a life-size trough collector in Thailand that is jointly undertaken by a diverse team that includes SERT, NU, the Ministry of Education and the private sector. This project also constitutes part of a wider study under the Commission on Higher Education to assess the possibility of using solar trough technology for power generation in Thailand. The purpose of this paper is to present a summary of the design, fabrication and monitoring system of the solar trough collector at the Energy Park.

2. DESIGN AND FABRICATION OF THE SOLAR TROUGH

The parabolic trough collector (or concentrator) at the Energy Park (referred to as "EPC") is the main part of the solar trough test facility in SERT which includes a feedwater loop and a data acquisition system to monitor the thermal performance of the collector (Fig.1a).

a



b

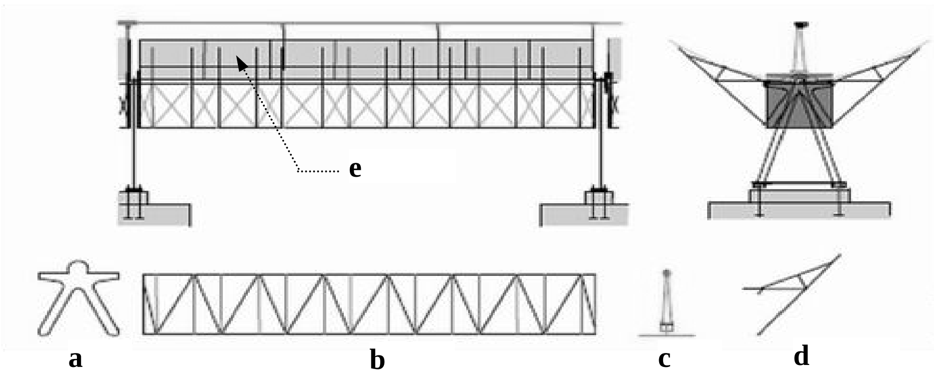
Fig. 1 Shows (a) the complete EPC at the Energy Park and (b) section of a parabolic trough concentrator.

In general, a parabolic trough concentrator works by focusing direct sunbeam onto a linear receiver (Fig.1b). A heat transfer fluid (HTF), usually thermal oil, gets heated up as it flows through the receiver. The hot HTF then leaves the collector and is used to produce steam in a boiler. The resulting steam can be used as process steam or in a generator to produce electricity.

Table 1 Main physical parameters of two commercial parabolic trough collectors & the EPC.

Collector type	LS-2	LS-3	EPC
Aperture length (m)	47.1	95.2	48.0
Aperture width (m)	5.00	5.76	5.00
Aperture area (m^2)	235.5	548.3	240.0
Concentration ratio (geometric)	22.7	26.1	22.7
Focal distance (m)	1.49	1.71	1.71
Rim angle (degree)	79.9	80.2	72.3
Absorber diameter (m)	0.07	0.07	0.07

The first step in the design of the solar trough EPC begins with a study of the physical characteristics of the LS-2 and LS-3 (LUZ system) collectors used in the commercial SEGS plants. Whenever suitable, some aspects of these characteristics have been incorporated in the final design of the EPC. Table 1 highlights some similarities between the LS-2, LS-3 and EPC.



a **b** **c** **d**

Fig.2 Each EPC collector module is consists of (a) endplates; (b) torque-box central frame; (c) receiver supports; (d) cantilever arms and (e) trough-base.

a **b** **c**

Fig.3 Shows (a) torque-box framework; (b) setting the parabolic curve and (c) cantilever arm.

The solar trough EPC is designed to consist of eight elements or modules connected in series to form a complete solar collector assembly. Each module is comprised of the following: 2 end-plates, 6 pairs of cantilever arm, 1 torque-box central frame, 10 pieces of trough-base and 3 receiver supports (Fig.2). Each linear receiver is consisted of a cylindrical absorber pipe and a glass cover.

Table 2 List of material for main components of EPC module.

Component	Material
Absorber pipe	Carbon steel pipe
Glass cover	Borosilicate glass pipe
Receiver support	Anodized aluminum
Reflective surface	Outdoor grade, 0.5 mm thick anodized aluminum, reflectivity = 93%
Cantilever arm	3 mm thick, 38 mm square tubular mild steel
Torque-box central frame	3 mm thick, 38 mm square tubular mild steel
Trough-base	3 mm thick aluminum sheet

The reflective surface of the trough is composed of 80 highly polished anodized aluminum facets mounted on the trough-base. The design of the central frame is based on the “torque-box” model of the advance European-design “EuroTrough” which have shown to provide better structural rigidity compared to the LS-2 and LS-3 collectors [12][13] (Fig.3a).

Once the design of the EPC has been determined, the next step is to consider the choice of material for the components of the collector assembly. Here again, reference is made to the successful experience of the commercial LS-2 and LS-3 collectors. However, the final decision is usually based on a compromise between cost, availability and acceptable quality. Table 2 shows the list of material that was used to fabricate the main components of the EPC module.

Fabrication of the EPC can begin once the selection of material has been finalized. A simple jig is fabricated based on the standard equation of the parabola. Once the aperture width and the focal distance of the parabolic trough are determined, the shape of the parabolic curve can be formed (Fig.3b). Next, the cantilever arms supporting the trough and the torque-box framework are constructed and assembled (Fig.3c & 4a). This is followed by the placement of the trough-base and reflective surface, and the partially-completed module is now ready for receiver alignment testing (Fig.4b). If the receiver is well-aligned, an intense glow of light can be seen on the underside of the receiver (Fig.4c). On a sunny day, it is possible for the temperature at the receiver to reach up to 175 ^{o}C or higher (Fig.4d).

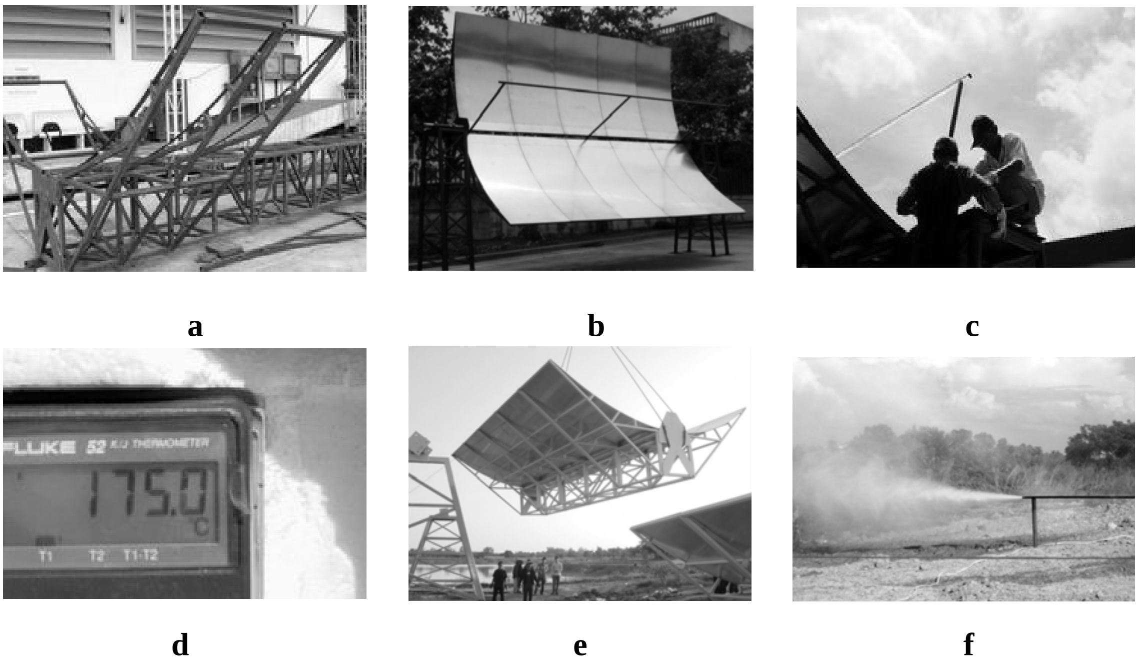


Fig.4 Shows (a) construction of framework; (b) partially-finished module; (c) receiver alignment test; (d) temperature at receiver; (e) on-site installation and (f) steam at collector exit.

When all the individual modules are ready, they are transported to the Energy Park at SERT and installed on site (Fig.4e). The fully-assembled solar trough is oriented to operate on a horizontal north-south axis and tracks the sun by a mechanical drive, from east to west, at an angular velocity of 15 degrees per hour. Water is used as the thermal and working fluid, and direct solar steam can be available at the exit of the collector (Fig.4f).

3. TEST-LOOP AND MONITORING SYSTEM

The solar trough test facility is consisted of a closed-loop collector system where the outlet end of the EPC is connected to its inlet end in a continuous circulating flow manner. The steam or water-steam mixture that emerges from the collector is piped to two storage tanks of capacity 10 m^3 each before it is pumped back into the collector again. A computerised data monitoring and acquisition system supplied and installed by Yokogawa Electric Corporation makes up the rest of the solar trough test-loop as shown in Fig.5. Table 3 shows a list of instruments of the monitoring system and the parameters they measured. The location and installation of the pyrheliometer, flowmeter, temperature and pressure transmitters are illustrated by Fig.6a-f.

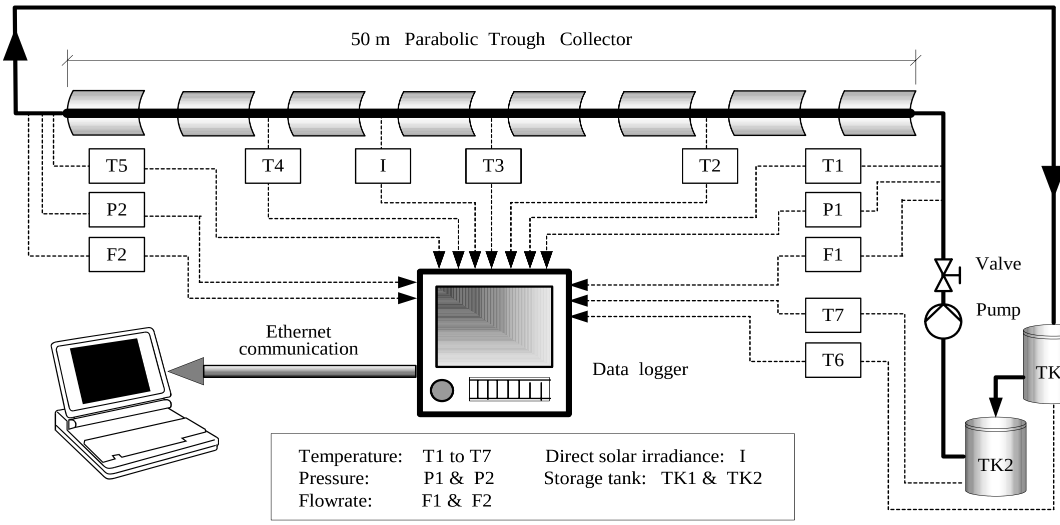
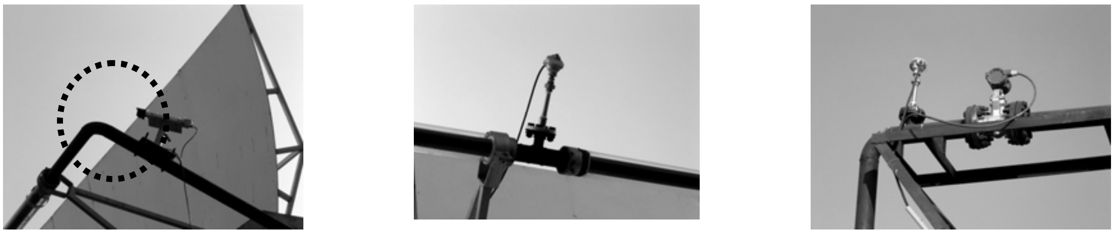


Fig.5 Solar trough test-loop with computerised data monitoring and acquisition system.

Table 3 Instruments of the monitoring system and parameter measured.

Instrument	Manufacturer	Model	Set	Parameter measured
Pyrheliometer	Kipp & Zonen	CH1	1	Direct solar irradiance
Magnetic flowmeter	Yokogawa	AXFA14G	1	Inlet flow rate
Vortex flowmeter	Yokogawa	DY	1	Outlet flow rate
Temperature transmitter	Yokogawa	YTA	7	Temperature
Pressure transmitter	Yokogawa	EJA510A	2	Pressure
Data recorder	Yokogawa	DX200	1	Data logging

a b c



d **e** **f**

Fig.6 Shows (a) magnetic flowmeter, F1; (b) temperature sensor, T1; (c) pressure sensor, P1; (d) Pyrheliometer; (e) temperature sensor, T2 and (f) vortex flowmeter, F2.

4. TESTING AND RESULTS

The thermal output of a parabolic trough collector depends on the absorbed solar radiation incident on the collector reduced by the heat losses of the collector. A semi-analytical mathematical model for the solar trough EPC has been developed from the three standard basic energy balance relationships outlined in references [14][15][16],

$$Q_u = Q_{abs} - Q_{loss} \quad (1)$$

$$Q_{abs} = A_a \cdot F_R \cdot S \quad (2)$$

$$Q_{loss} = \frac{A_a F_R U_L}{C_g}\left(T_{fi} - T_a\right) \quad (3)$$

where A_a is the aperture area, S is the absorbed irradiation per unit aperture area, F_R is the collector heat removal factor, U_L is the collector heat loss coefficient, C_g is the geometric concentration ratio, T_{fi} is the fluid inlet temperature and T_a is the ambient temperature.

4.1. Validation of collector's thermal analysis model

On a normal test day, the EPC trough collector operated from 08:00 am to 16:00 pm and the required data were collected at an interval of every 4 minutes.

In order to validate the accuracy of the mathematical model of the EPC, the fluid exit temperatures measured for a typical sunny day and a typical partly cloudy day were compared to the simulated results generated by the mathematical model. On both test days, the fluid mass flux was set at 0.15 kg/s and the average wind speed was about 3 m/s. The average direct normal irradiance during the time of testing for the sunny day and partly cloudy day was about 750 W/m^2 and 460 W/m^2 respectively.

In both cases, it was observed that the simulated results related closely with the measured data where the % average deviation between simulated exit temperatures and actual exit temperatures was less than 6%. This difference can be attributed partly to the collector's conduction heat losses and partly to the effects of solar transient. A summary of the average fluid inlet temperature T_{fi} and exit temperature T_{fo} for both sunny and partly cloudy weather conditions is given in Table 4.

4.2. Comparison of performance: EPC versus LS-2 collector

In order to give an indication as to how well the EPC has been constructed, it is useful to compare its performance with that of a commercial collector like the LS-2. The thermal output of the LS-2 was calculated using the LS-2 thermal analysis model described in reference [17].

Table 4 Summary of average fluid temperatures: sunny vs. partly cloudy weather conditions.

Average wind speed: 3 m/s	Weather Condition			
Fluid mass flux: 0.15 kg/s	Sunny		Partly Cloudy	
Average direct irradiance (W/m^2)	750		460	
	T_{fi}	T_{fo}	T_{fi}	T_{fo}
Simulated ave. temperature (deg. C)	70	198	61	141
Actual ave. temperature (deg. C)	68	188	60	133

Fig.7 shows the monthly useful energy gain of the EPC and LS-2 evaluated based on the standard clear sky condition of Phitsanulok province. From the analysis, it was found that the annual thermal output of the EPC was 103,947 MJ (or about 88.5%) compared to 117,515 MJ from the LS-2 collector. This difference can be explained by the fact that the EPC operates with a non-evacuated receiver annulus which hence result in a lower thermal performance due to the higher convective heat losses from the receiver.

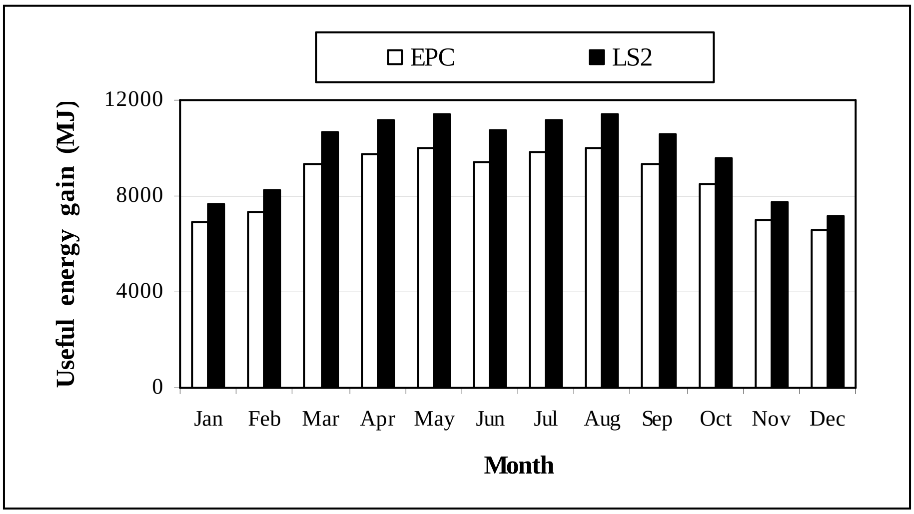


Fig.7 Useful energy gain: EPC versus LS2 collector.

5. CONCLUSION

Parabolic trough solar thermal power plants are a proven technology to provide reliable electricity to meet demand. It is therefore necessary to study about the parabolic trough collector as it is the most critical and important component in the system. For the first time, an industrial-scale solar trough was installed at the Energy Park of SERT to provide for more research into high temperature solar thermal technology, thus paving the way for the possible commercial application of concentrating solar power in the country one day.

In this paper, a summary was presented on the design, fabrication and monitoring of the solar trough at the Energy Park. Data collected under real solar conditions were analysed and a semi-analytical model for the collector was developed. The simulated results generated by the model were found to relate closely with the measured data. It was also observed that the locally fabricated EPC collector was able to perform up to nearly 90% of the capability of the commercial LS-2. This was achieved despite the fact that the EPC was operating with a non-evacuated receiver annulus that resulted in higher convective heat loss. Future improvement to reduce thermal losses should make the performance of the EPC comparable to the LS-2 collector.

Acknowledgements

The authors are grateful for the financial support from the Commission on Higher Education of the Education Ministry and the National Research Council of Thailand to carry out this study. They are also thankful for the technical assistance provided by the staff of the School of Renewable Energy Technology, Naresuan University, Sunluck Solarpower Company and Yokogawa Electric Corporation.

References

[1] Geyer M, Quaschning V (2000). Solar thermal power – The seamless solar link to the conventional power world. Renewable Energy World 2000;3(4):184-91.
[2] Escalante PB (1998). Operation of parabolic trough solar collectors. In: solar thermal electricity generation course, CIEMAT – Plataforma Solar de Almeria, 13-17 July, Spain, p.423-49.
[3] PSA (2003). Plataforma Solar de Almeria annual technical report 2003. Available online at website, http://www.psa.es.
[4] Zarza E, Eck M, Weyers HD, Hennecke K (2001). The DISS project: Direct steam generation in parabolic troughs operation and maintenance experience update on project status, Proceedings of Solar Forum 2001: Solar Energy - The power to choose, 21-25 April, Washington DC, p.71-8.
[5] Eck M, Zarza E, Eickhoff M, Rheinlander J (2003). Applied research concerning the direct steam generation in parabolic troughs. Solar Energy 2003;74(1):341-51.
[6] EPPO (2003). Energy strategy: Energy for Thailand's competitiveness, Ministerial workshop on strategic energy in Thailand, 28 August, Energy Policy and Planning Office, Thailand.
[7] Prasertsan S, Sajjakulnukit B (2006). Biomass and biogas energy in Thailand: Potential, opportunity and barriers. Renewable Energy 2006;31(5):599-610.
[8] Sajjakulnukit B, Yingyuad R, Maneekhao V, Pongnarintasut V (2001). Assessment of sustainable national biomass resource potential for Thailand. Department of Energy Development and Promotion (DEDP), Bangkok.
[9] EC-ASEAN Cogen Program (1998). Evaluation of conditions for electricity production based on biomass, Bangkok.
[10] Loh HC, Rakwichian W (2002). Design for optimization of a solar thermal power plant, In: Proceedings of the International Conference on Village Power from Renewable Energy in Asia, 11-14 November, Phitsanulok, Thailand, p. 122-7.
[11] DEDE (2002). Power Development Plan (99-01 revised), Department of Alternative Energy and Efficiency, Ministry of Energy, Thailand.
[12] Geyer M, Lupfert E, Schiel W, Zara E, Gonzalez-Aguilar RO, Nava P (2000). EuroTrough – A new parabolic trough collector with advanced light weight structure, Solar Thermal 2000 International Conference, 8-10 March, Sydney, Australia.
[13] Lupfert E, Geyer M, Osuna R, Esteban A, Schiel W, Schweitzer A et al. (2002). EuroTrough – Parabolic trough collector developed for cost efficient solar power generation, Symposium on Concentrating Solar Power and Chemical Energy Technologies, 4-6 September, Zurich, Switzerland.
[14] Duffie JA, Beckman WA (1991). Solar engineering of thermal processes. 2^{nd} ed. New York: John Wiley & Sons.
[15] Tiwari GN, Suneja S (1997). Solar thermal engineering systems. New Delhi: Narosa Publishing House.
[16] Stine WB, Harrigan RW (1985). Solar energy fundamentals and design (with computer applications). New York: John Wiley & Sons.
[17] Quaschning V, Kistner R, Ortmanns W (2001). Simulation of parabolic trough power plants, Fifth Cologne Solar Symposium, 21 June, Cologne, p. 46-50.