

# Thermal Performance Analysis of a Linear Fresnel Concentrating Solar Collector

## ABSTRACT

Linear Fresnel solar collectors are suitable for a wide range of applications, which include steam generation for power generation, industrial process heat, solar cooling, institutional and domestic hot water system etc. The thermal performance of a linear Fresnel solar collector system is investigated in this study for different fluid mass flow rates, heat flux intensities, heat transfer fluid inlet temperatures, ambient air temperatures and external loss heat transfer rate. Turbulent flow liquid water heat transfer fluid and uniform circumferential heat flux distribution boundary were considered. The results indicated that the absorber tube outlet heat transfer fluid temperature decreased with an increase in the Reynolds number and increased with the heat flux intensities. Thermal efficiency increased with an increase in the heat transfer fluid mass flow rate and however, decreased with increase in pressure drop and the consequent pumping power requirement. It was also found that the thermal efficiency of the collector decreased with an increase in the fluid bulk inlet temperature and decreased with an increase in the external loss heat transfer rate.

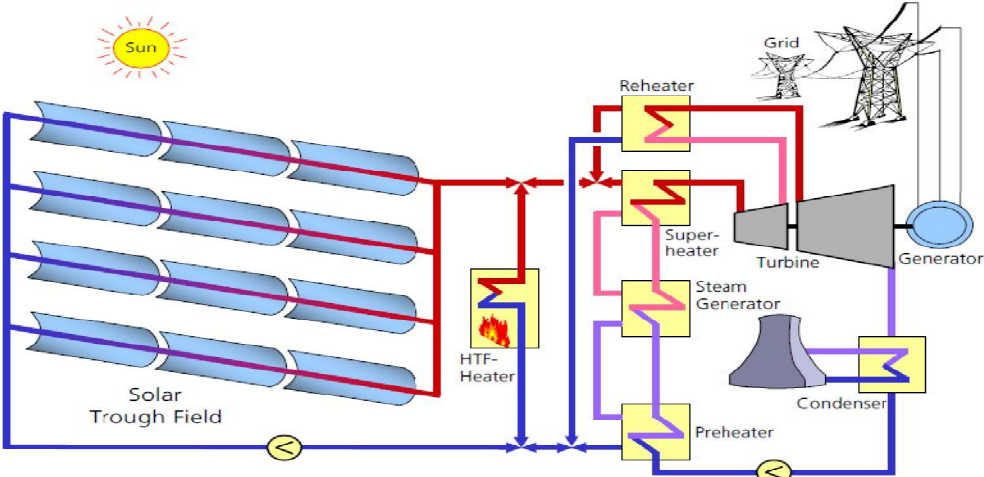
**Keywords:** linear Fresnel solar collector, thermal efficiency, heat flux intensity, heat transfer fluid temperatures.

## 1.0 INTRODUCTION

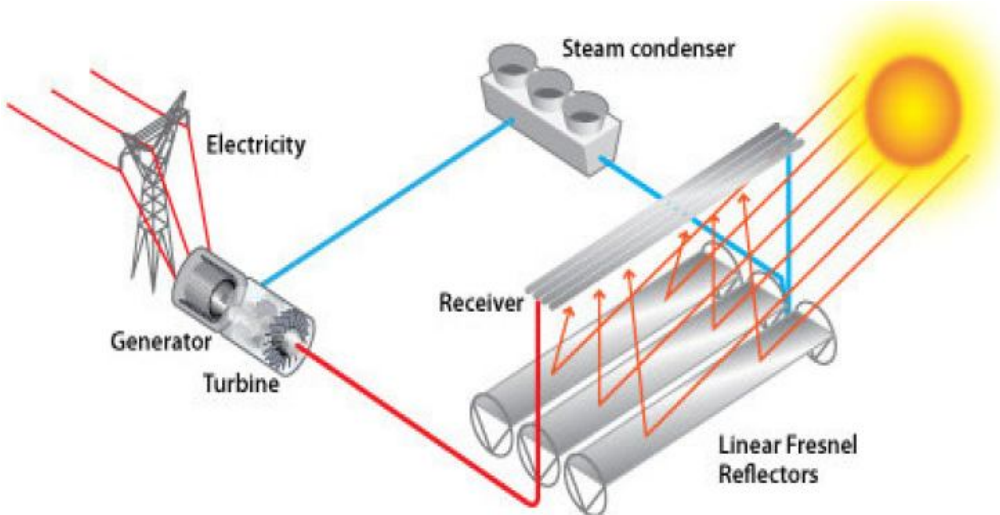
Solar thermal energy is one of the most important sources of clean and renewable energy has great potentials in abating overdependence of the global economy on fossil fuels and in mitigating greenhouse gas emissions [1]. The design and development of solar thermal systems that efficiently capture and convert solar energy into usable thermal energy, with minimum optical and thermal losses have continued to pose enormous challenges to thermal engineers. Two basic types of solar thermal collectors: (i) Non-concentrating collectors, e.g. Flat-plate and evacuated tube collectors, suitable for low to medium temperature applications. (ii) Concentrating collectors e.g. cylindrical, linear Fresnel, parabolic and dish trough type collectors, suitable for medium to high temperature applications [2]. Parabolic trough solar collectors is the most popular concentrator among other solar concentrating collectors due to the success of the solar power generating plants in the Mojave Desert of Southern California in late 1980s [3]. Different solar thermal systems and various applications are extensively discussed by Duffie and Beckman [4]. Fig. 1 shows a parabolic trough power plant set-up. Another important linear concentrator which has, in recent time, received a considerable attention is the linear Fresnel solar concentrator due to its simplicity. Fig. 2 shows a linear Fresnel power plant

set-up. Linear Fresnel solar collectors are suitable for a wide range of applications such as steam generation, industrial process heat, solar cooling, and hot water system for institutional and domestic uses. Unlike parabolic solar collectors, it does not require rotating joints and metal-glass welding at the ends of each receiver tube. It has relatively low construction, maintenance and operating costs. It also has low wind loads and higher land use efficiency, which makes it suitable for installation where space is restricted. The present study analytically investigates the influence of fluid inlet temperature, mass flow rate and heat flux intensities on the thermal performance of an absorber tube for a linear Fresnel solar collector type absorber tubes with different inner diameters.

**Materials and method**



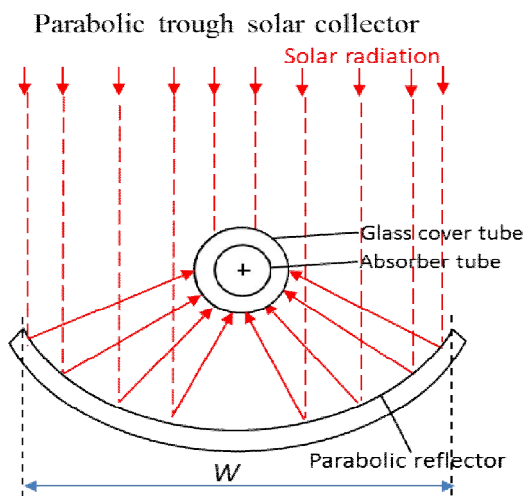
**Fig. 1** Parabolic trough power plant set-up [5]



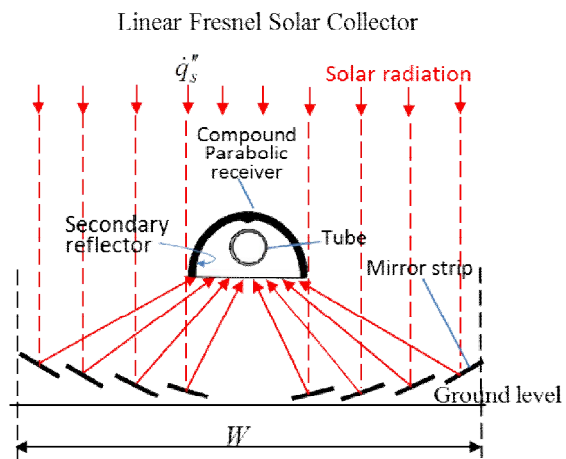
**Fig. 2:** Linear Fresnel power plant set-up [6]

## LINEARLY FOCUSING SOLAR THERMAL COLLECTOR

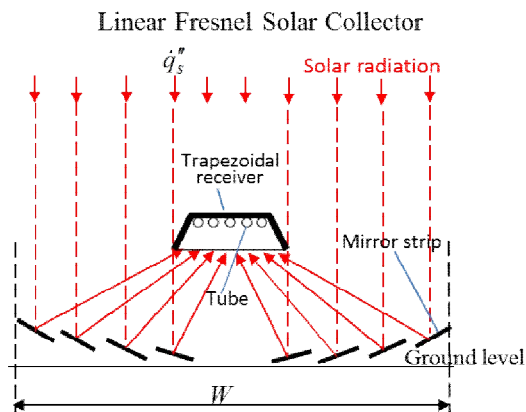
Fig. 3 represents a parabolic trough solar collector with an absorber tube mounted inside a glass cover tube to reduce heat loss by convection, while the parabolic reflector concentrates the solar heat flux on the absorber tube. Fig. 4 represents a linear Fresnel solar thermal collector with a compound parabolic receiver with a single absorber tube of higher diameter and secondary reflector to increase thermal performance of the collector. Fig. 5 is another linear Fresnel solar thermal collector with a trapezoidal receiver cavity with multiple absorber tube of smaller diameter. The linear Fresnel solar collectors consists of slightly curved reflecting mirror strips, which are less expensive compared to parabolic trough solar collector. Fig. 6 shows the heat losses from the trapezoidal receiver cavity of a linear Fresnel solar thermal collector. The heat losses from the cavity are dominated by radiation heat loss followed convective heat loss.



**Fig. 3:** Parabolic trough collector



**Fig. 4:** Linear Fresnel collector



**Fig. 5:** Linear Fresnel collector  
With a compound parabolic receiver

**Fig. 6:** Heat Losses from the trapezoidal receiver  
cavity

The thermal efficiency ( $\eta_{th}$ ) for a single absorber tube model in the receiver cavity can be expressed as follows:

$$\eta_{th} = \frac{mc_p(T_{b,M} - T_{b,0})}{q_o} \quad (1)$$

Where  $q_o$  is the heat transfer rate on the outer wall surface,  $T_{b,M}$  is the bulk (averaged) outlet fluid temperature at position  $m = M$ , and  $T_{b,0}$  is the bulk inlet fluid temperature at  $x = 0$ . Pressure drop ( $\Delta p$ ) along the tube length ( $L$ ) due to friction loss at the inner wall boundary can be expressed [7] as:

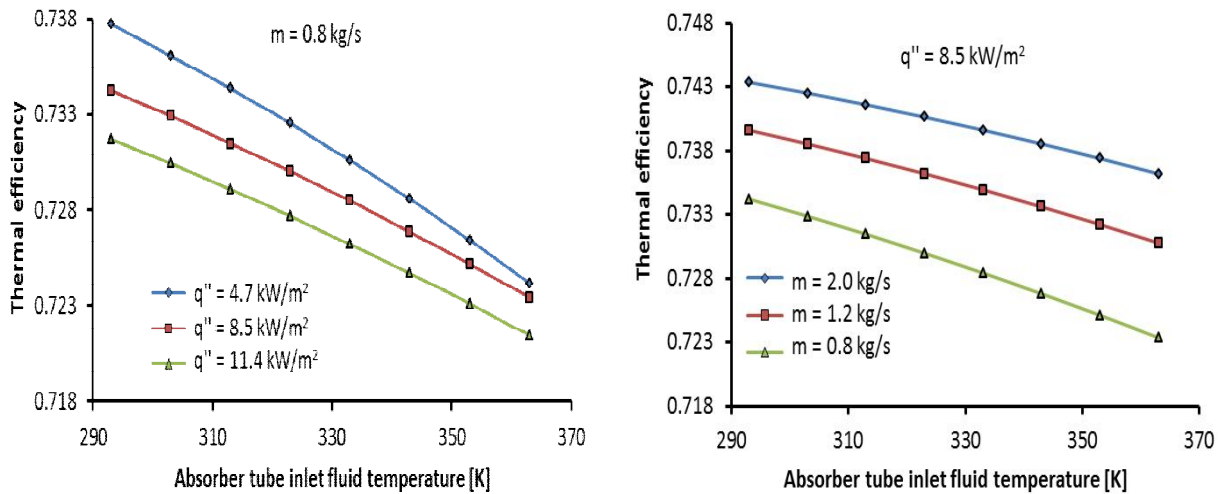
$$\Delta P = f \frac{L}{2R_i} \frac{\rho \bar{v}^2}{2} \quad (2)$$

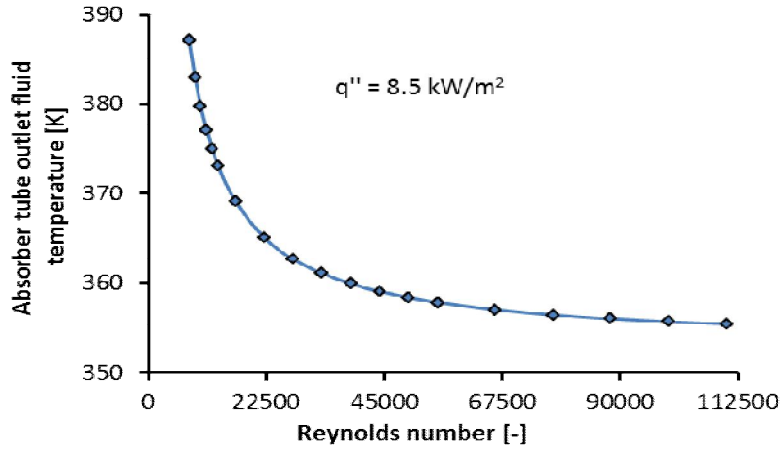
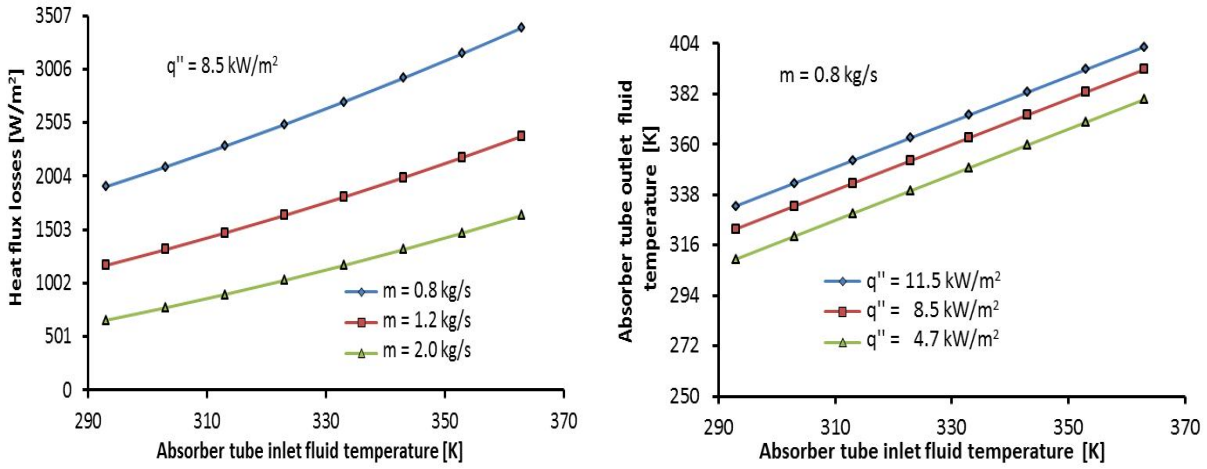
### 3.0 RESULTS AND DISCUSSION

1-D steady state turbulent flow of liquid water was considered for uniform solar heat flux intensity on the absorber tube for quick capturing of the thermal performance. The fluid mass flow rate in the range of 0.5 kg/s to 10 kg/s, two absorber tubes with diameters of 0.052 m and 0.032 m of same thickness, solar heat flux intensities of 4.7 kW/m<sup>2</sup>, 8.5 kW/m<sup>2</sup> and 11.4 kW/m<sup>2</sup>, tube inlet fluid temperature range of 300 K to 370 K were considered in this study.

#### 3.1 Thermal Performance Analysis

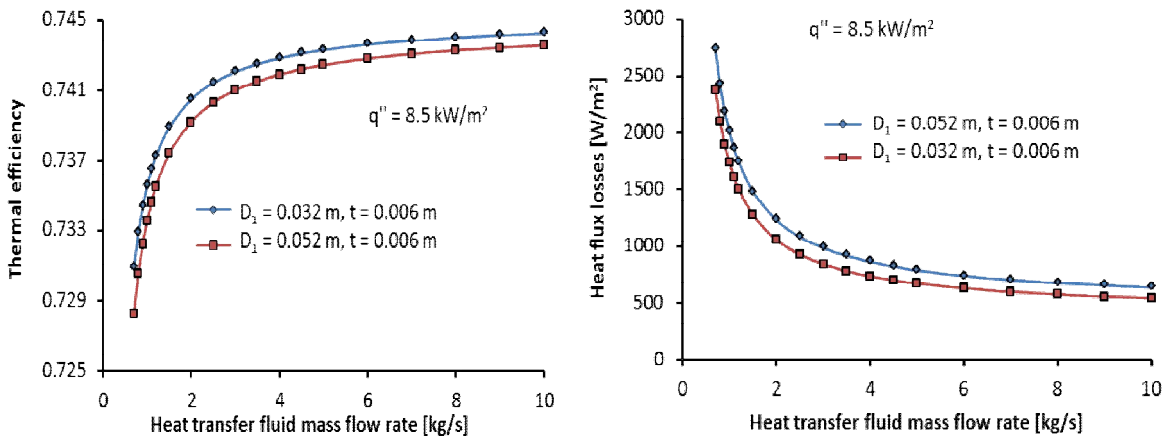
Fig. 7 shows the thermal efficiency of an absorber tube at different inlet fluid temperature at mass flow rate of 0.8kg/s. It can be observed that the thermal efficiency decreases with an increase in heat flux intensity and the increase in fluid inlet temperature and this could be due to increase heat loss resulting from the increase in the absorber tube wall temperature. In Fig. 8, it can be seen that at a given heat flux intensity, the thermal efficiency of the absorber tube increased with an increase in mass flow rate of the heat transfer fluid due to decrease in heat losses as show in Fig. 9.





**Fig. 11:** Absorber tube Outlet temperature at different Reynolds number

Fig. 9 indicates that heat flux losses increases with a decrease in mass flow rate of the heat transfer fluid and that heat flux losses increases with an increase in the fluid inlet temperature of the absorber tube. It can be seen in Fig. 10 that at a given mass flow, the absorber tube outlet fluid temperature increased with an increase in the heat flux intensity due to increase in heat transfer rate to the fluid, while in Fig.11 the absorber tube outlet fluid temperature decreased with an increase in Reynolds number



### 3.2 Pressure Drop and Pumping Power Requirement over the Tube Length

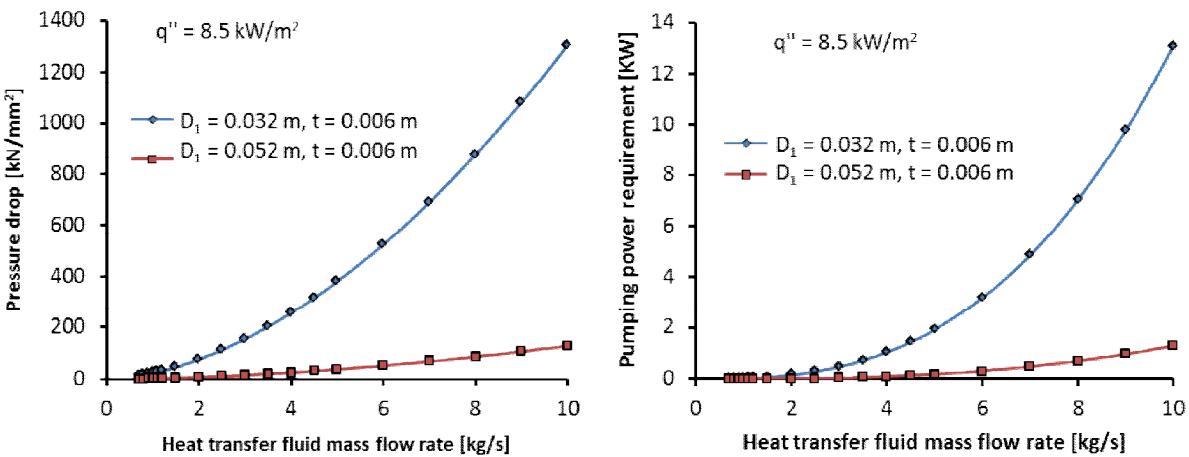


Fig. 12 shows that at a given heat flux intensity, the thermal efficiency increased with a decrease in the absorber tube diameter at different fluid mass flow rate. It can be observed in Fig. 12 that the increase in thermal efficiency with the mass flow rate consists of two portions. In the first part, the thermal efficiency increased rapidly, while in the second part it becomes slowly at high mass flow rate. This indicates lower heat transfer rate to the fluid at high mass flow rate. In Fig. 13, the heat flux losses decreases with an increase mass flow rate of heat transfer fluid and that the heat flux losses increases with an increase in the absorber tube diameter due to its higher surface area. Fig. 13

shows that at a given heat flux intensity, the pressure drop over the absorber tube length increases with the fluid mass flow rate and decreases with an increase in the absorber tube diameter. While in Fig. 14, the pumping power required to overcome the pressure drop increased with the fluid mass flow rate and decreases with an increase in the absorber tube diameter.

#### **4.0 CONCLUSION**

This study has numerically investigated the thermal performance of a linear Fresnel concentrating solar collector type absorber tube at different mass flow rate, tube diameter and wall thickness and heat flux intensity. It was found that the absorber tube outlet fluid temperature decreased with an increase in the Reynolds number increased with the heat flux intensities and increased with the fluid inlet temperature. Thermal efficiency increased with an increase in the heat transfer fluid mass flow rate and decreased with an increase in the fluid inlet temperature. It decreased with an increase in the external heat flux losses decreased with an increase in the absorber tube diameter. It was also found that decreasing the absorber tube diameter to increase thermal efficiency results in an increase in pressure drop and the consequent increase in pumping power requirement.

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