Thermal Performance Analysis of a Linear Fresnel Concentrating Solar Collector Absorber Tube

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 production etc. The thermal performance of a linear Fresnel solar collector absorber tube was 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 under steady-state conditions. The fluid flow was considered incompressible. This study is limited to a first order model approximation for thermal performance of a linear Fresnel solar collector absorber tube. The heat transfer fluid and absorber tube material properties were considered constant and independent of temperature. 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 with a great potential in abating overdependence of 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 have been developed over the years: (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 collector 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 their various applications are extensively discussed by Duffie and Beckman [4]. Fig. 1 shows a parabolic trough power plant set-up for electricity generation. 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.

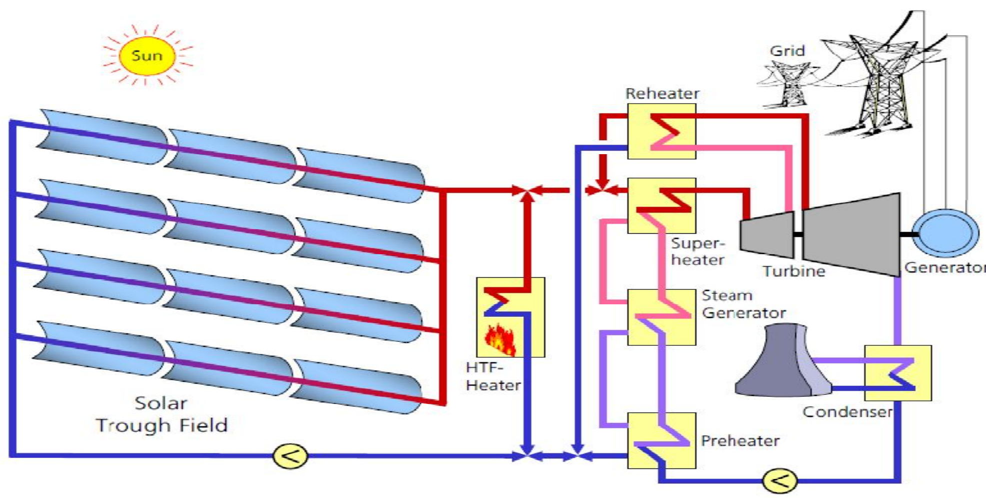


Fig. 1 Parabolic trough power plant set-up [5]

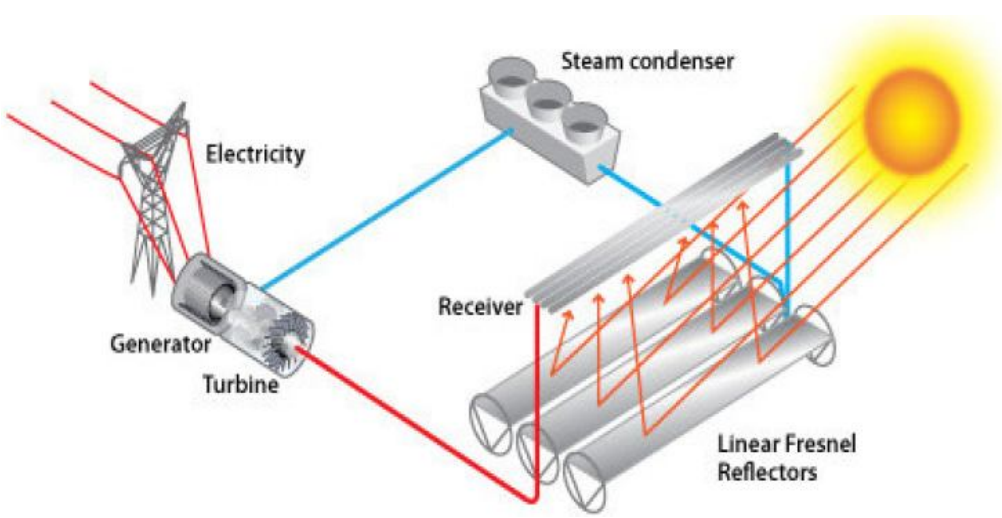


Fig. 2: Linear Fresnel power plant set-up [6]

2.0 MODELLING THE SOLAR COLLECTOR ABSORBER TUBE

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.

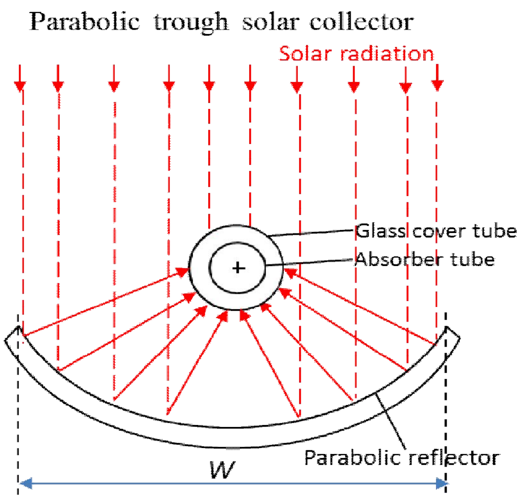


Fig. 3: Parabolic trough collector

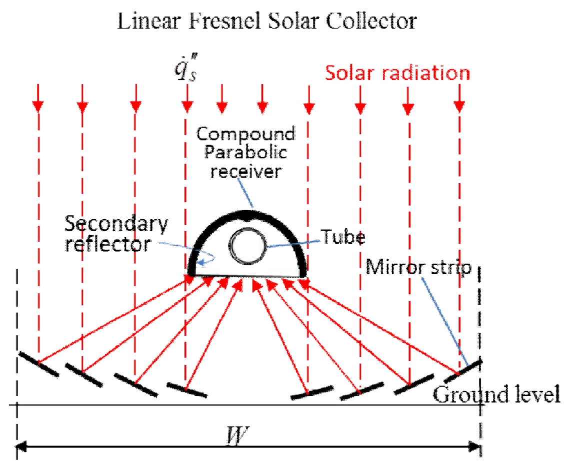


Fig. 4: Linear Fresnel collector

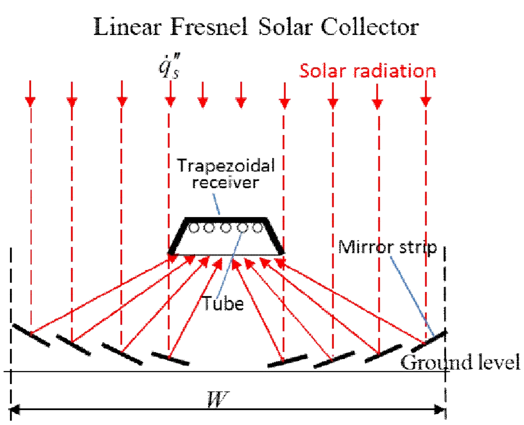


Fig. 5: Linear Fresnel collector
With a compound parabolic receiver

Fig. 6: Heat Losses from the trapezoidal receiver cavity

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

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

Where $q_{o,}$ is the heat transfer rate on the outer wall surface, m is the mass flow rate, c_p is the specific heat capacity of the heat transfer fluid at constant pressure, $T_{b,L}$ is the bulk (averaged) outlet fluid temperature at position $x = L$, and $T_{b,0}$ is the bulk inlet fluid temperature at $x = 0$. A linear Fresnel solar collector consists of a single or multiple absorber tubes of identical geometry and thermal performance characteristics and thus a single absorber tube is considered here, which represents an absorber tube length for a linear Fresnel solar collector. The outlet temperature considered here depends on solar heat flux incident on the absorber tube, the tube diameter and wall thickness, tube material properties, and outer and inner wall surfaces conditions of the tube, which all influence the internal heat transfer coefficient of the absorber tube collector. In the overall design of a linear Fresnel power plant, the inlet fluid temperature depends on the outlet temperature of the turbine. Also, design of a power plant turbine demands a particular temperature. However, this study investigated the influence of different fluid inlet temperature of an absorber tube on the internal heat transfer coefficient of a solar collector tube. Eq. 1 gives a first order model approximation for thermal performance of a linear Fresnel solar collector absorber tube, which is very essential prior to detailed modelling of the collector absorber tube considering the complex differential equations in numerical modelling. The absorber tube material properties were assumed constant and independent of temperature.

The fluid flow through the collector absorber tube encounters pressure drop due to friction loss at the internal wall boundary of the tube. Thus, the pressure drop (Δp) along the tube length (L) due to friction loss at the inner wall boundary can be expressed [2] as:

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

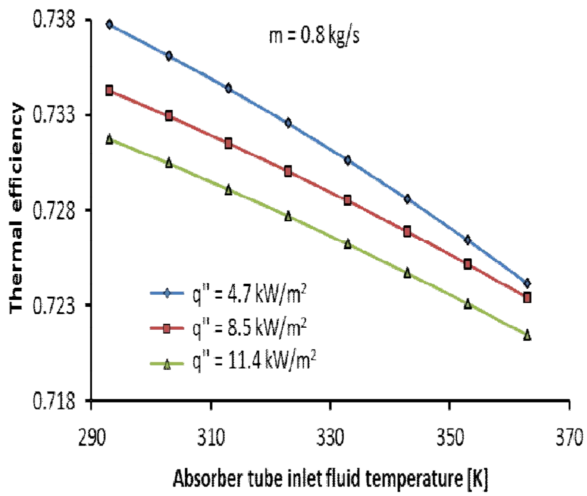
Where R_i is the internal diameter of the absorber tube, v is the average fluid flow velocity, ρ is the fluid density and f is the friction factor. The heat transfer fluid thermal properties considered here are independent of temperature. The fluid flow through absorber tube was considered incompressible.

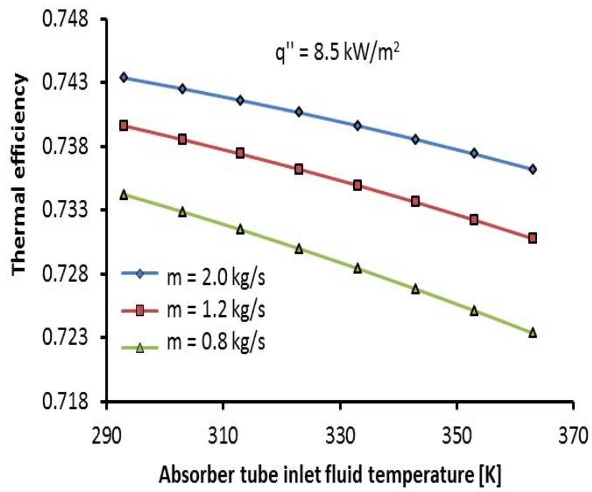
3.0 RESULTS AND DISCUSSION

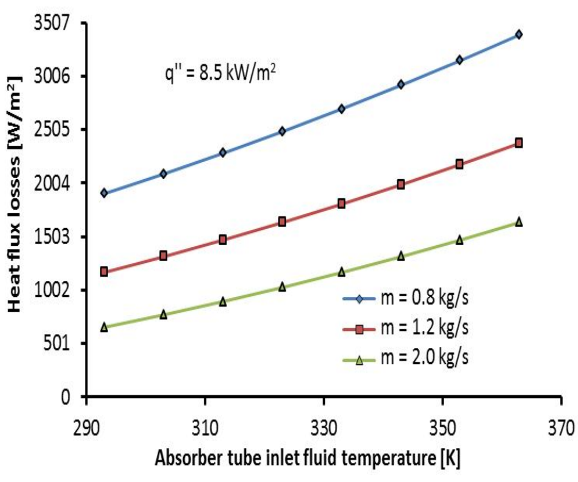
1-D steady state turbulent flow of liquid water was considered for uniform solar heat flux intensity on the absorber tube for quick capturing of the thermal performance. The fluid mass flow rate in the range of 0.5 kg/s to 10 kg/s, two absorber tubes with diameters of 0.052 m and 0.032 m of same thickness,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

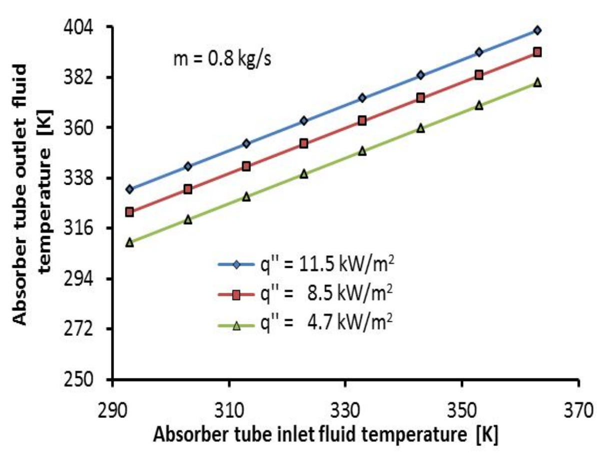
3.1 Thermal Performance Analysis

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.









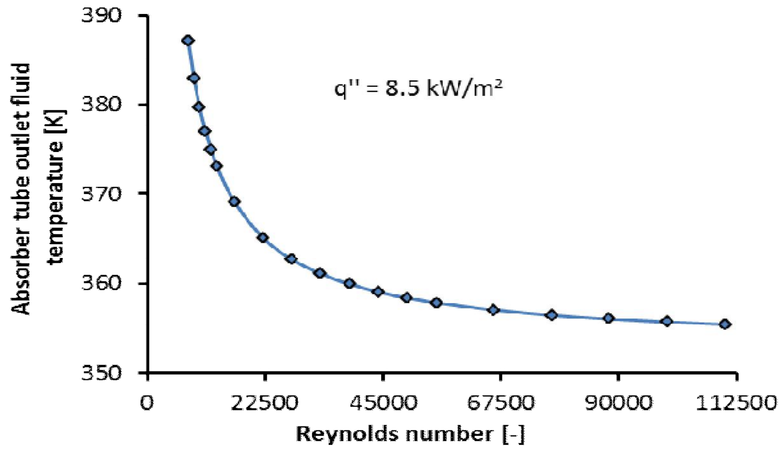
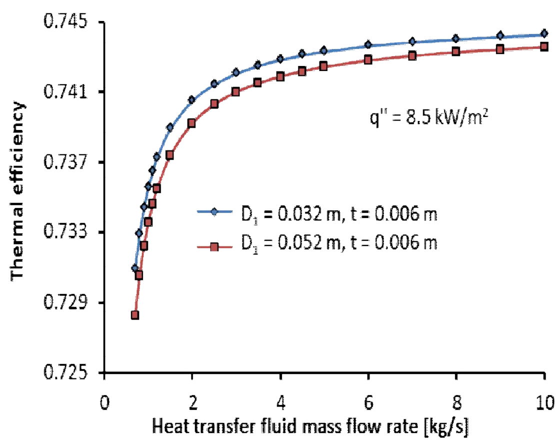


Fig. 11: Absorber tube Outlet temperature at different Reynolds number

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



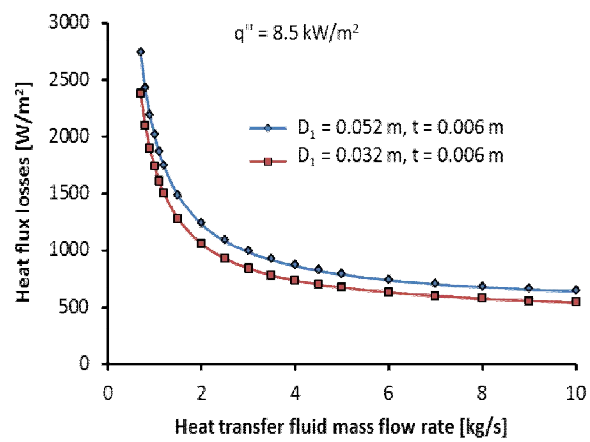
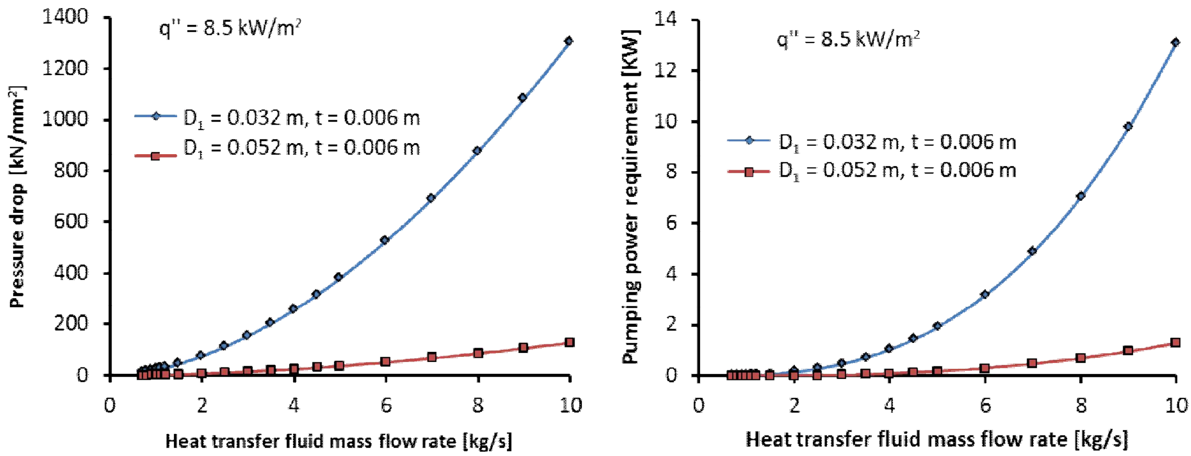


Fig. 12 shows that at a given heat flux intensity, the thermal efficiency increased with a decrease in the absorber tube diameter at different fluid mass flow rate. It can be observed in Fig. 12 that the increase in thermal efficiency with the mass flow rate consists of two portions. In the first part, 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.

3.2 Pressure Drop and Pumping Power Requirement over the Tube Length



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. 14 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. 15, 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 analytically 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. Turbulent flow heat transfer fluid and uniform heat flux distribution boundaries were considered under steady-state conditions. This study is limited to a first order model thermal performance of a linear Fresnel solar collector absorber tube. The heat transfer fluid and absorber tube material properties were considered constant and independent of temperature. 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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