

Understanding the effects of end-loss on linear Fresnel collectors

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Abstract. In this paper, the end loss effect of linear Fresnel collector was analyzed. The aim of this work was to investigate the seasonal effects of end losses on the linear Fresnel collectors deployed, and analyze the change of the month average for end loss at different locations. Furthermore, a end loss compensated approach is proposed, and the increased instantaneous thermal efficiency of the experimental system is measured. A two-meter long linear Fresnel collector experimental system with horizontal north-south axis is performed, The result that compensation of the end loss of the linear Fresnel reflector system stands a good improvement for thermal performance. Meanwhile, in comparison with the reflector field prior to the change, an instantaneous thermal efficiency has increased by approximately 50%, and it increased by almost 20% at the afternoon time. All this work can offer some valuable references to the further study on high-efficiency linear Fresnel concentrating system.

1. Introduction

Concentrating solar power techniques used some reflector-mirrors to focus sun-light on receivers with relatively small apertures[1]. As a commercial type of concentrating solar power(CSP) technology, linear Fresnel reflector (LFR) concentrator has been widely utilized, has been widely used in solar collecting heat and concentrated photovoltaic system[1][3]. The majority of the application need medium temperature levels(100-300°C) and linear Fresnel collector(LFC) is the most appropriate solar collector, as it has been stated from many researchers[4][5]. LFC as the most appropriate technology for industrial heat production and a promising technology for CSP domain because of its simplicity in structural design and the relative low construction cost[4]. Lancereau et.al(2015) also added the low land utilization and the low material utilization as extra advantages of this technology[5]. Extra advantages of LFC are the elimination of thermal dilation and moving junction problems which are usually in parabolic trough collector(PTC)[6]. However, the thermal efficiency of the LFC is lower than the efficiency in PTC, due to higher optical losses(shading and blocking losses)[7]. In the LFR system, the receiver is often equipped with wider apertures as well as higher receivers in contrast to parabolic trough receivers in order to get higher concentration. These render it very important to reflect the sunlight loss at the receiver end, particularly, in small linear Fresnel receivers. The losses or terminal effects, need to be resolved for two reasons. At the same location, terminal loss of the mirror geometry of the receiver is more serious at the same time within the smaller system[5]. Two elements stunts the LFR concentrator ground application ratio as well as optical efficiency. Therefore, it is necessary to minimize the difference between neighboring mirrors and reduce the end loss. Zhu and Huang(2014) suggested using a semi parabolic LFR concentrator to mitigate the effects of covering



and occlusion, while having a lower manufacture cost and higher ground usage[9]. However, the losses are not taken into account at the same time.

In a compact solar energy utilization in view of LFR, the end loss as well as its impact on solar energy thermal performance is the key topics. Three ways are provided to decrease the end loss, making the mirror field longer[5], setting a flat mirror at final receiver[10][11], and tracing the sun through double shafts[12]. The first two approaches could help to reduce end losses through merely adding reflector-mirrors at the scene as well as the collector end respectively. Final reflector-method changes mechanical structure to biaxial tracking and allows the light to be exposed to the mirror field at normal incidence. Besides, the moving reflector-mirror field is put forward, and this was also an efficient way to decrease end losses.

Aimed at the end loss effect of LFR system at different regions, a new method that can effectively compensate its end loss effect is shown in this paper. Mainly analyzed the end loss of the LFR system caused by the latitude, calculation of the end loss is made together with the proposition of the compensation method of the receiver end loss. Meanwhile, using an infrared thermal imager is shot the receiver end loss at different times before and after the compensation, and combining with the LFR system of instantaneous thermal efficiency changes.

2. Experimental methodology

2.1. Designing the primary reflector-mirror field of LFR system

The linear Fresnel experimental system researched in this document was shown in Figure 1, sun tracking system, pipeline system and measurement system. Subsequent to the reflection of the light from the plane mirror, part of the light is directly absorbed by the vacuum tube, and in the other part of the compound parabolic collector (CPC) subsequent to the secondary reflection by the vacuum collector tube absorption. Some parameters of the linear Fresnel collecting system are given in Table 1.

In Practical applications, to understand the system in a given period of time without shadow operation under the premise, the distance between the mirror and the centre of the mirror ought to be as small as possible so as to increase ground coverage of the LFR system, and reduce the height of the receiver. This is beneficial in making the mirror layout more compact. Thereby reducing LFR system costs and improving land use. Meanwhile, the following simplified assumptions have been made in the paper: Only considering the reflection on the centre of the mirror fields; The mirrors are ideally reflecting, not any errors; Direct solar rays is understood as parallel; The absorber and the mirror fields have same length.

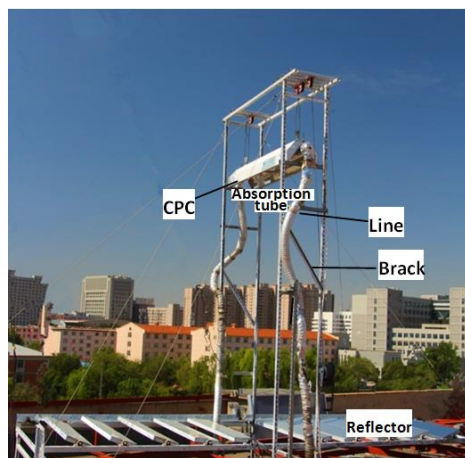


Figure 1. The schematic diagram of experimental set-up

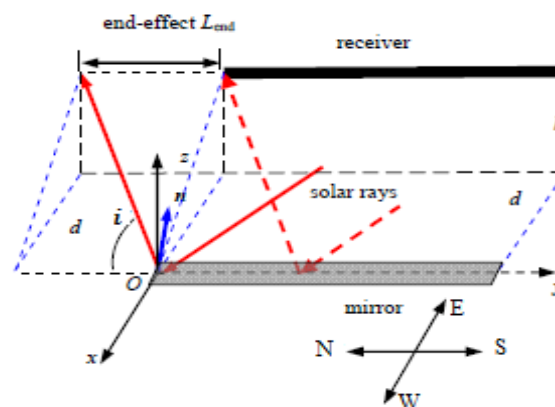


Figure 2. Schematic representation the end-effect of a linear Fresnel concentrator.

Table1. Geometric and optical parameters.

| Project | Value | Project | Value |
|--------------------------------|-------|--|-------|
| Mirror number n | 10 | Mirror reflectivity ρ_1 | 0.91 |
| Mirrorwidth W/mm | 300 | Width of CPC /mm | 400 |
| Mirror length L/mm | 1820 | Reflectivity of CPC ρ_2 | 0.91 |
| Mirror wheelbase S_n /mm | 490 | Absorptivity of absorber tube α_1 | 0.92 |
| Height of absorption tube H/mm | 3000 | Outer tube radius r_2 /mm | 50 |
| Inner tube radius r_1 /mm | 20 | | |

2.2. End loss effect of the receiver for the LFC field

As evident from the expression of the size of the end loss depends on the angle of incidence (i), the length of the mirror field L and the receiver height H . Moreover, the small linear Fresnel collector system possesses a shorter field. In addition, the end loss mandatorily required to be considered in the optical loss of the system. Meanwhile, the size of the end loss and tracking methods and seasonal changes shares a specific connection.

From Figure 2, the perspective between incident sunlight(i) as well as the roll between the axis of rotation of the mirror or the solar unit vector and the axis X can be represented as[7]:

$$\tan i = \frac{\sqrt{\cos^2 \alpha \sin^2 \gamma + \sin^2 \alpha}}{\cos \alpha \cos \gamma} \quad (1)$$

The angle i is also the same as the angle of the rotation axis of the reflected solar unit vector and the mirror element[5]. The angle i is a distance between the mirror and the receiver in the mirror field, and the position of the solar ray arriving at the receiver varies with the altitude angle and the azimuth angle. Using L_{end} to indicate the end loss length, and the length of the end loss of the LFR system for east-west tracking is[7]:

$$L_{end} = \frac{\sqrt{d^2 + H^2}}{\tan i} = \frac{\sqrt{d^2 + H^2} \cdot \cos \alpha \cos \gamma}{\sqrt{\cos^2 \alpha \sin^2 \gamma + \sin^2 \alpha}} \quad (2)$$

For the above equations, the angles α and γ are the solar altitude angle and solar azimuth angle respectively, corresponding to position, date and time. From the equation(2), it can be seen that unless α or γ is 90° , the end loss always exists. In addition, it is obvious that the end loss is not only related to the focal length of the reflector-mirror element also position, date, as well as time, etc. In terms of the North-South mirror mirrors, there is a greater distinction in the end loss in distinct seasons. For the solar noon, having γ is equivalent to zero. This is illustrated in equation (3):

$$L_{end} = \sqrt{d^2 + H^2} \cot \alpha \cos \gamma \quad (3)$$

3. Theoretical analysis and calculation of end loss

3.1. End loss calculation

Calculated from the equation(3) apparent where the same reflector mirrors field geometry, and end loss variation with solar altitude angle and solar azimuth angle changes. However, the solar altitude angle and azimuth angle are linked to the geographic locations(latitude and longitudes). In order to analyze these changes for different geographic locations, calculated a monthly end loss at different latitude and longitudes in Chinese 7 cities. Where the geographic locations of these 7 Chinese cities are shown in Table 2.

Table 2.Latitudes and longitudes of 7 Chinese cities.

| City name | North latitude(°) | East longitude(°) |
|-------------|-------------------|-------------------|
| Dunhuang | 40.08 | 94.41 |
| Haicheng | 40.51 | 122.43 |
| Laohekou | 23.23 | 111.40 |
| Erlianhaote | 43.38 | 111.58 |
| Heihe | 50.14 | 127.29 |
| Hetian | 37.09 | 79.55 |
| Hohhot | 40.87 | 111.65 |

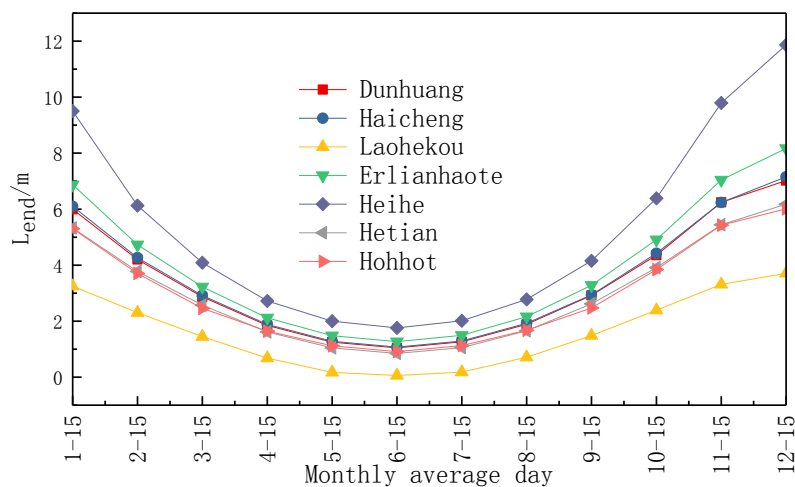
**Figure 3.**Variation of end losses in different locations.

Figure 3 shows that the variation of optical end loss at different locations from the day of a monthly, which indicates that the change of end loss have a same variation trend for almost same latitudes and larger difference longitudes. However, there is a different trend for almost same longitudes and larger difference latitudes, such as Laohekou and Erlianhaote regions.

4. Reflector field adjustment for end loss compensation

4.1. Reflector field adjustment

The purpose of this experiment is to verify the feasibility of this compensation method. To reduce the end loss at noon, the present experiment proposed a method of compensation for the end of the loss, in which the mirror field is fitted as per the different seasons. That is, the North end of the mirror field is raised, while the angle between the reflector field and the North direction is maintained θ (see Figure 4). After the system is placed in the default adjustment region ($N-\theta$) latitudes, the solar elevation angle and the azimuth angle change accordingly. For the Hohhot area for instance, when $\theta = 20^\circ$, the default mirror field region is at latitude 20.87° .

Taking the different seasons of Hohhot as an example, when θ is changed at noon, the end loss changes as showed in Figure 5. End losses for the vernal equinox and autumn are the same size and changes trend. When $\theta = 0^\circ$, the end loss of is almost 3% of the receiver, with the increase in the length loss of θ . Consequently, when $\theta = 30^\circ$, the end loss accounts for 0.14%. During summer solstice, when θ at 15° - 20° end loss of the length of the change is not large, but rather adjusts the angle in the interval and continues to increase the θ . The end loss occurs in the direction of change, so that the focal spot area is decreased. Meanwhile, the winter solstice end loss change tendency is evident.

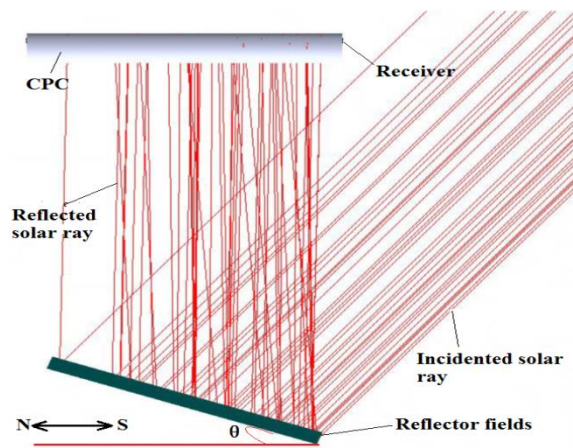


Figure 4. The inclining LFR system.

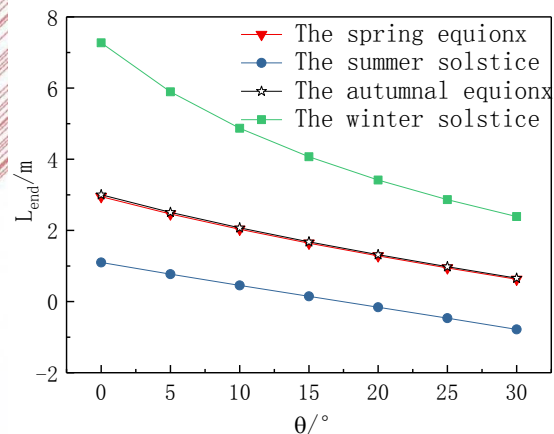


Figure 5. The end effect loss changed in different θ .

4.2. End loss after adjustment compensation

In order to analyze the changing regular pattern of the focal spot of the receiver, Fluke Ti55FT infrared imager is used to capture the focal spot change of the receiver from 10:30 am to 15:30 pm before and after the adjustment of the reflector. The infrared imager can visually analyze the distribution of the focal spot of the collector and show the temperature of the absorber tube.

Figure 6 gives the variation of the focal area of a receiver before a reflector-mirror field is adjusted. At the beginning of the test, the end of the loss occurred in the working side of the export side, and at 10:30 am receiver end loss is approximately one-fifth of the length of the receiver length. With the change of solar altitude angle and azimuth angle, the loss at the end of the line reaches one-half at 12:30 noon, and the loss is right on the exit of the working medium. Figure 7 shows the variation of the end loss of the receiver after the adjustment of the mirror field. The end loss is presented at the opposite side of the inlet end of the working fluid which is contrary to the change of the end loss of the receiver before a reflector-mirror field adjustment. After the compensation of the east-west tracking LFR system receiver in the morning and evening end losses is respectively the largest and the smallest at noon.

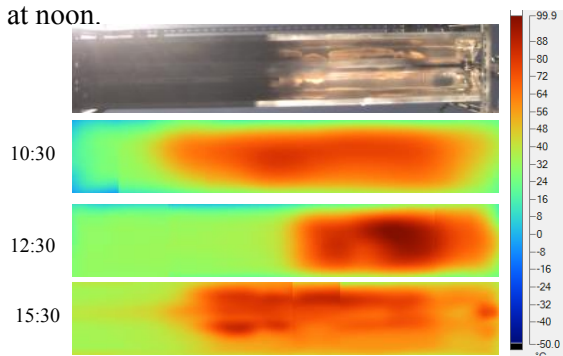


Figure 6. The end loss before reflector field adjusted.

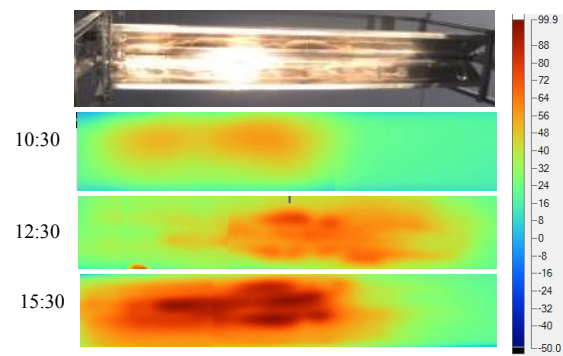


Figure 7. The end loss after reflector field adjusted.

4.3. Results analysis and discussion

To analyze the effect of the end loss before and after the receiver compensation on the instantaneous thermal efficiency of the LFR system. It would be three times of comparison results (increased the inlet and outlet temperature and increased thermal efficiencies) would also be made, which indicates that these data have the same tendency. Therefore, selecting a set of experimental data analyzes the thermal performance influence of the system for compensation effect.

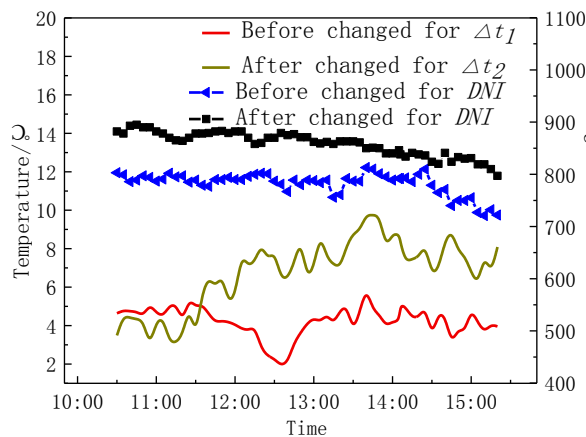


Figure 8. Variation of fluid inlet and outlet temperature.

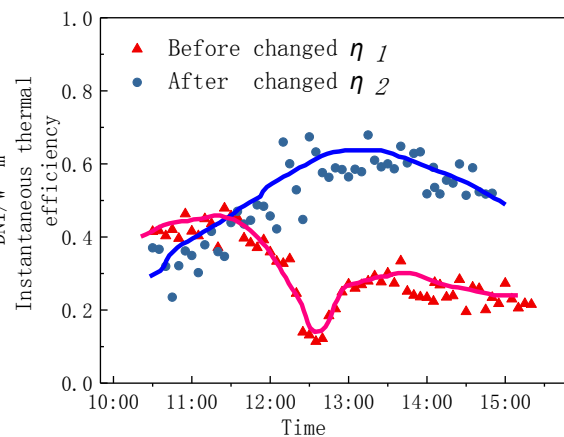


Figure 9. Comparison for instantaneous thermalefficiency.

There is only one LFR system, and to realize the experimental purpose, the change of weather conditions. The two-day test conditions compare with the instantaneous thermal efficiency of the LFR system before and after the adjustment of the mirror field. The test time is between 10:30 am and 15:30 pm, without continuous wind direction, working fluid flow of 0.18 m/s, heat transfer density of 868 kg/m³ (20°C) of the heat transfer oil, the pipeline cycle. The temperature difference Δt_1 , Δt_2 and the Direct Normal solar Irradiance (DNI W/m²) of the working fluid before and after the adjustment of the mirror as it is illustrated in Figure 8. Figure 9 shows the instantaneous thermal efficiency η_1 and η_2 of the system before and after the adjustment of the mirror field. Comparison with Figure 8 and Figure 9, we can see that η_1 decreases first and then increases and the maximum value is 45%. η_1 minimum value is achieved at noon, with the end of the length of the receiver length of about one-half, instantaneous thermal efficiency of 10%. After 13:00 the end loss decreases, and the system instantaneous thermal efficiency is stable at about 30%. The above analysis illustrates that the LFR system after the compensation of end loss can effectively use the solar radiation energy at noon.

5. Conclusions

For the paper, the end loss of the system is analyzed theoretically, the size of the end loss mainly depends on the length of the mirror, the height of a receiver, the height of the sun as well as the azimuth angle, which must reduce the end loss by reducing the height of the receiver while avoiding the inter-mirror block and shadow loss. The process can be modified according to seasonal changes in the mirror field and the north direction of the angle θ to reduce the end loss. The change trend of the end loss of the LFR system after the mirror field is changed, and the instantaneous thermal efficiency is 65% at noon. The thermal efficiency was increased by 50%, and it can effectively obtain the solar radiation energy at noon and validate the end loss of the receiver at the receiver of the LFR system.

References

- [1] Abu-Hamdeh N H, Alnefaie K A 2016 Design considerations and construction of an experimental prototype of concentrating solar power tower system in Saudi Arabia[J] *Energy Conversion & Management* **117** 63-73
- [2] Abbas R, Muñoz-Antón J, Valdés M, et al. 2013 High concentration linear Fresnel reflectors[J] *Energy Conversion & Management* **72**(4) 60-68
- [3] Zhu G, Wendelin T, Wagner M J, et al. 2014 History, current state, and future of linear Fresnel concentrating solar collectors[J] *Solar Energy* **103**(May 2014) 639-652
- [4] Lin M, Sumathy K, Dai Y J, et al. 2013 Experimental and theoretical analysis on a linear Fresnel reflector solar collector prototype with V-shaped cavity receiver[J] *Applied Thermal Engineering* **51**(1-2) 963-972
- [5] Lancereau Q, Rabut Q, Itskhokine D, et al. 2015 Wind Loads on Linear Fresnel Reflectors'

- Technology: A Numerical Study[J]*Energy Procedia***69**116-125
- [6] Balaji S, Reddy K S, Sundararajan T2016 Optical modelling and performance analysis of a solar LFR receiver system with parabolic and involute secondary reflectors[J]*Applied Energy***179**1138-1151
- [7] Rungasamy A E, Craig K J, Meyer J P2015 3-D CFD Modeling of a Slanted Receiver in a Compact Linear Fresnel Plant with Etendue-Matched Mirror Field [J]*Energy Procedia***69**188-197
- [8] Pu S, Xia C2011 End-Effect of Linear Fresnel Collectors[C]*Asia-Pacific Power and Energy Engineering Conference*IEEE Computer Society1-4
- [9] Zhu J, Huang H2014Design and thermal performances of Semi-Parabolic Linear Fresnel Reflector solar concentration collector[J]*Energy Conversion & Management***77**(1)733-737
- [10] Xu C, Chen Z, Li M, et al2014Research on the compensation of the end loss effect for parabolic trough solar collectors[J]*Applied Energy***115**(4)128-139
- [11] Li M, Xu C, Ji X, et al.2015 A new study on the end loss effect for parabolic trough solar collectors[J]*Energy***82**382-394
- [12] Zhu Y Q, Yu-Jian L I, Wang L L, et al2014 Design and Experimental Study on Linear Fresnel Reflector Solar Collector System[J]*Advances in New & Renewable Energy*