Concentrating optics in solar concentrators

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Abstract

Concentrators can be classified the reflectors or refractors, cylindrical or surfaces of revolution, and continuous or segmented. Receivers can be convex, flat, or concave and can be covered or uncovered. Many modes of tracking are possible. Concentration ratio (the ratio of the collector aperture area of absorber area, which is approximately the factors by which radiation flux on the energy-absorbing surface is increased) can vary over several orders of magnitude. In this paper basics of optics are presented

Abstract: Solar energy, concentrators, solar optics

1. Introduction to Geometrical Optics

Geometrical optics is a class of optics obtained from Maxwell's equations in which the spatial variations of the electromagnetic field are much bigger than the wavelength. At this small-wavelength limit the ray can be defined as a normal to any surface of constant phase of light waves (in terms of the wave theory of light). This surface is called geometrical wavefront, or simply a wave front, as long as its scale is a large number of wavelengths. Then a ray trajectory is a characteristic curve of this field of normals, i.e. tangent to the field at all its points, which coincides with the trajectory of the photons from the quantum perspective.

2. Solar radiation

Sun (5760 K surface temperature) can be assumed as a black body radiation source because of selective absorption of wavelength in atmosphere [1].

This radiation is of two types:

- ❖ Direct Normal Irradiance (DNI)
- ❖ Diffuse or Scattered radiation

CSP systems use DNI component of solar radiation. Direct normal irradiance (DNI) is defined as the flux density (Insolation/radiant flux/irradiance) of un-scattered sunlight. This is measured on a flat plane perpendicular to the solar radiation. The value 2011 1367 W/m^2 is solar constant [2].

This is defined as intensity of solar radiation on plane in outer atmosphere of earth. Another parameter is concentration ratio which is heart of CSP as it amplifies radiation to higher intensity [3].

3. Concentration Ratio

The light concentration process is typically characterized by the concentration ratio (C). By physical meaning, the concentration ratio is the factor by which the incident energy flux (I_o) is optically enhanced on the receiving surface (I_r) - see Figure 1. So, confining the available energy coming through a chosen aperture to a smaller area on the receiver, we should be able to increase the flux.

$$C_{geo} = \frac{\text{area of the aperture}}{\text{area of the receiver}} = \frac{A_a}{A_r}$$

In the above equation, C_{geo} is called the geometric concentration ratio. It is easy to use, as the areas of the devices are known, although it is adequate only when the radiation flux is uniform over the aperture and over the receiver. Also, please note that for some imaging concentrators, the area of the available receiver surface can be different from the area of the image produced by the concentrator on the receiver. So, if the image does not cover the entire surface of the receiver, we need to use the image area to estimate the concentration ratio.

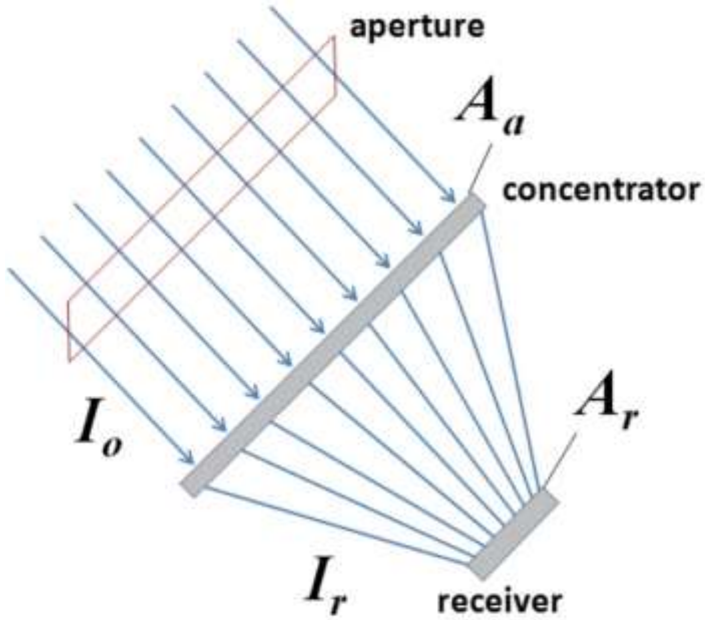

Figure 1 Schematic representation of light concentration process.

- The optical concentration ratio, C_o
- The geometric concentration ratio, C_g

C_o is the fraction of receiver surface irradiance (G_r) to the incident solar irradiance (G):

$$C_o = \frac{G_r}{G}$$

It may be defined at any position of an output flux distribution. However, special reference is given to the point of highest light intensity and peak concentration ratio of a flux distribution.

Cg is expressed as the ratio of aperture area of collector (Ac) to area of the receiver (Ar):

$$C_g = \frac{A_c}{A_r}$$

“Number of suns” is also referred to define concentration ratio. For example, a geometric

concentration ratio of 1,300 would be called as ‘1,300 suns’. Hence, it would result to 1.3 MW/m^2 for an assumed solar flux of 1,000 W/m^2 at the surface of the receiver. Moreover, the sun positioncan be precisely tracked with equations developed already for both linear as well as point focus systems.

4. Secondary optics

Degree of concentration up to 80-90% of thermodynamic limit in case of configurations Figure 2 like Trombe-Meinel cusp, Compound Parabolic Concentrator (CPC) , Mouchot conical mirror etc [4].

Figure 2. A secondary Trombe-Meinel cusp concentrator [4].

Conclusion

Solar concentrators are classified by their optical characteristics such as the concentration factor, distribution of illumination, focal shape, and optical standard. Concentration factor . Concentration ratio (the ratio of the collector aperture area of absorber area, which is approximately the factors by which radiation flux on the energy-absorbing surface is increased) can vary over several orders of magnitude.

References

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