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The Experimental Model of a Solar Simulator Using the Metal-Halide Lamp

Ashraf Hussien Mislem[1], Ehab Mouris Mina[2], Gamal Mosaad Hennes[3], ElDessouky Eid[4]
[1,2,3]Ain Shams University Mechanical Power Department
[1]Higher Technological Institute of "10th of Ramadan"
[3]Suez University
([1]a_hussien88@hotmail.com, [2]ehab_mina@eng.asu.edu.eg)

***Abstract*-**Solar simulator produces irradiance similar to that coming from the sun. It is used to run experiments under constant heat flux conditions without the need for natural solar radiation. This work describes in detail the construction of a solar simulator. The simulator is used to produce irradiance as input to solar air heater. The distribution of the flux is measured and reported in the results.

Keywords- *Solar Heater, Sun Simulator, Parabolic Trough, Pyranometer, Metal Halide*

I. INTRODUCTION

Solar air heaters are widely used for low and moderate temperature applications including space heating, crop drying, timber seasoning and other industrial applications[1][2]. In order to increase the efficiency of the solar air heater it is important to study several configurations under the same input conditions[3]. Given the fact that solar irradiance varies in magnitude and direction during the day[4], and the total irradiation varies from day to day, solar simulator comes as a solution to run experiments indoor under controllable conditions[5]–[8].

Metal-halide lamp is used to give irradiance in the same spectrum as the sun[9]., A number of researchers have investigated the use of xenon lamp and metal-halide lamp to create same solar intensity[3], [10] Metal halide lamps are reported to be far cheaper than xenon arc lamps [11], [12] and consequently are used to test in this study.

This study documents the construction and procedure to design and test a solar simulator for the use of solar air/water heater tests. The solar simulator consists of parabolic trough with mirror slices attached to its surface. Two 400-W metal halide lamps are placed in the focal line of the reflective surface. The irradiance on the targeted surface, the upper glass cover of a solar air heater in our case, is a combination of rays coming directly from the lamps and rays reflected from the parabolic-shaped mirror. A sketch visualizing this idea is shown in figure 1. The adjustable height of the simulator, the lamps together with the mirror, helps in obtaining different irradiance distribution. This study relates the simulator height above the glass to the average irradiance. The uniformity of solar irradiance is reported for each height level.

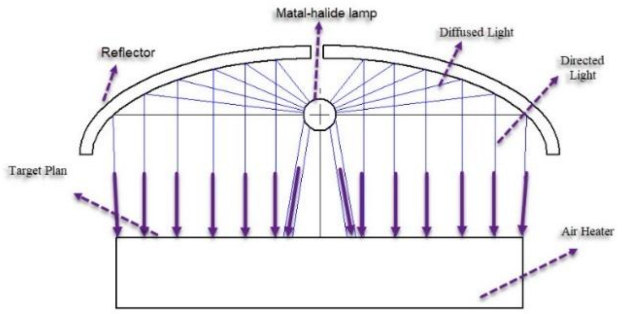
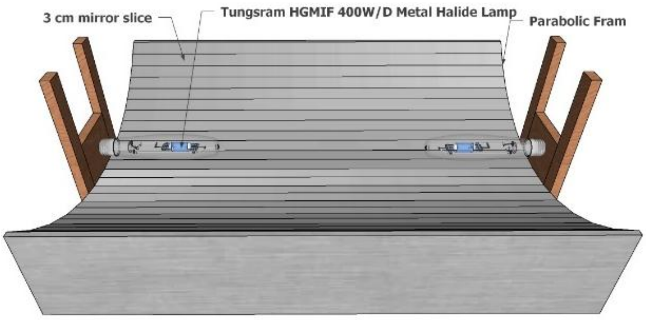


Figure 1. Diagram showing the basic form of a solar simulator

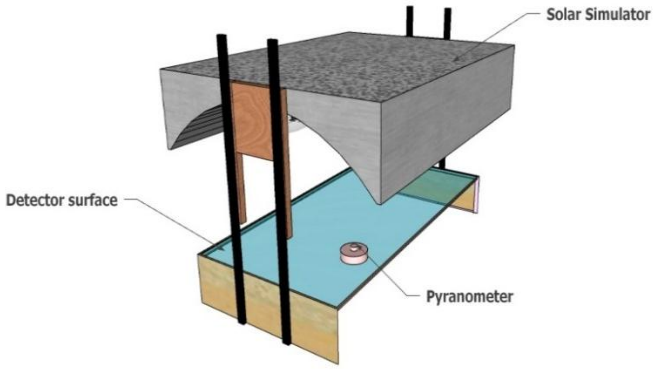
II. EXPERIMINTAL WORK

This section is divided into three parts the first part describes the setting of the experimental work in detail. The second part lists the setting to model the setup on a ray tracing software, and present the results obtained at three different distances below the focus of the optical system. Finally, experiment to obtain the desired irradiance is performed and consequently conveys the message of this paper.

The experimental apparatus is sketched using an engineering design program. The design is portrayed in Figure 2. The reflector surface made out of strips of 3 cm-wide mirrors is shown in figure 2A. The figure also shows the wooden frame carrying the mirror and the metal halide lamps. The simulator is shown connected to a solar air heater in Figure 2B, also a representation of the pyrometer used to validate the simulation is shown. It could be noticed that the whole body of the simulator, shown in fig. 2B, can slide as one body on metal bars attached to the sides of the air heater, figure 2B, and hence the height could be adjusted with respect collector surface. Fig. 3 shows three different levels of the simulator with respect to the collector. The simulator dimensions are of 60cm×100cm, while the collector absorber surface is 50cm×100cm.



(a)



(b)

Figure 2. Solar Simulator Design.

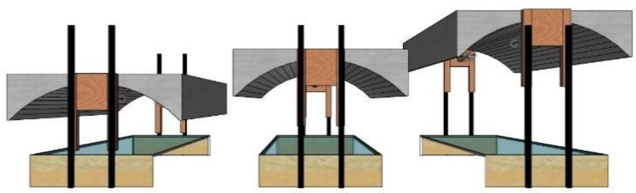


Figure 3. Various Elevation for the Simulator

The setup was sketched on a ray tracing software (Zemax trial version). The output rays of the lamps were traced as they reflect from the inverted parabolic-shaped mirror and reach the measurement surface. The sketch used is shown in figure 4A. Rays used to obtain the irradiance are also shown as they reach the measurement surface directly or after reflection from the mirror in figure 4B.

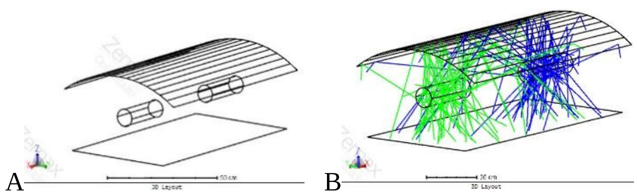


Figure 4. Sketch of the Simulator on Zemax A) without the rays B) with the 100 rays originated from each tube sketched

The settings used in the software are mentioned in table 1. Dimensions are set to centimeters power is Watts, and the analysis unit is W/m^2. The values refer to the elevation of the toroidal surface and the lamps will be changes in range of (45, 50, 55) and (25, 30, 35) respectively. Also, any other values not mentioned in the table will be also set to zero.

Many configurations were modeled on the ray tracing software. Each configuration has a different distance between the focus of the parabola (the centerline of the light tubes) and the absorber surface. Three of these results are displayed in detail in the next section. In order to obtain comparable results to the experimental measurements, the resolution of the detector view is restricted to a resolution of 35X35 pixels.

The Final part of the investigation is experimental verification of the solar simulator analyzed. The experimental setup is photographed in figure 5. A calibrated Pyranometer is used to obtain the distribution on the surface of the solar heater.

TABLE I. SETTING USED IN ZEMAX SOFTWARE

	Detector rectangle	Source tube	Source tube	Toroidal surface
X position	0	20	-45	0
Z position	12	25,30,35	25,30,35	45,50,55
Tilt about X	0	0	0	180
Tilt about Y	0	90	90	0
Material	Absorb			Mirror
X half width	50			50
Y half width	25			30
Layout rays		100	100	
Analysis rays		10000	10000	
Power		400	400	
Radius		4	4	50
Length		25	25	

Figure 5. The constructed Simulator to be used in indoor tests of solar heaters

III. ANALYSIS AND RESULTS

A. *Numerical results*

This section analyses the results obtained from ray tracing. A figure similar to 4B is produced from each experiment. Figure 6 shows a 2-D view of such figure where the rays that will miss the detector surface are not extended. A detector view is obtained for each run. Figure 7 displays the detector view obtained for 25, 30, and 35 cm from the below the focal line of the optical system.

The distribution obtained on the detector is presented in contour plot, figure 8. The maximum, minimum and average are obtained for each configuration, table 2. A representation of the glass surface of the collector (74cm X 49 cm) is marked with a dotted red line. These results show that the average irradiance is inversely proportional to the distance from the source. It is also concluded that the deviation around the mean is severe when the source comes closer than 30 cm. On the other side, at 35 cm elevation more of radiation will be dissipate due to high height and ray cannot reach the surface.

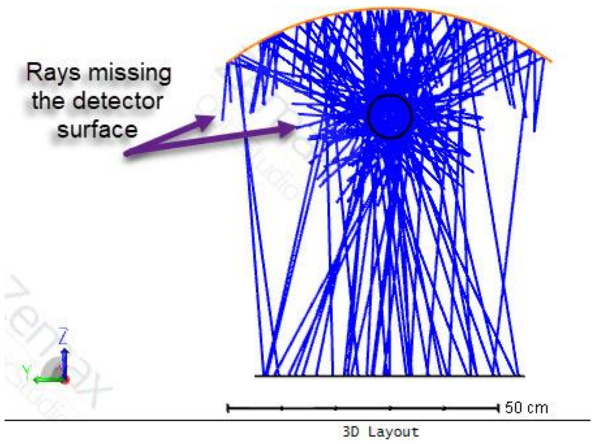


Figure 6. Rays from tube to the detector surface shown on 2-D view of the setup, rays missing the surface are not extended in this view

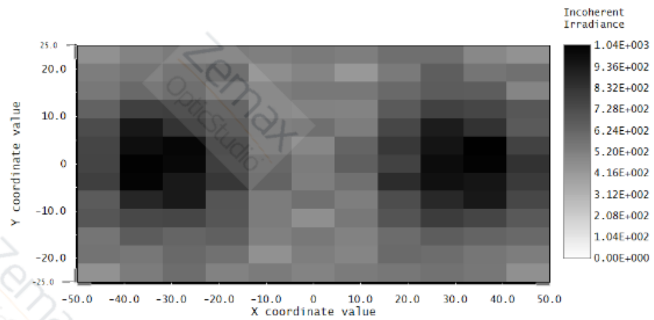


Figure 7. The detector view obtained from ray tracing with spacing 30 cm between the tube and the detector with the detector resolution 11X13 pixels

B. *Experimental results*

The setup, shown in figure 5 is operated with spacing 30 cm to validate the results. A calibrated pyranometer is used to obtain the distribution on the detector surface. The distribution was very similar to that obtained theoretically using ray tracing. A plot showing the comparison of the measured and numerical results is shown in figure 9. The red circles represent the simulation, while the black diamonds represent the measurements.

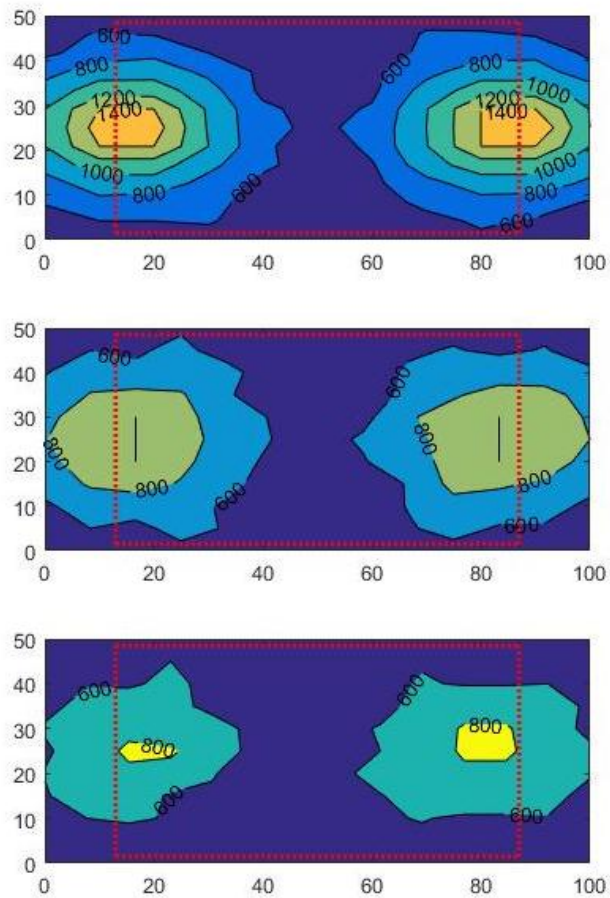


Figure 8. Radiation distibustion on Detector surface for source above the detector by 25cm (up) – 30cm (middle) - 35 cm (lower)

TABLE II. TABLE 1 RESULTS OF IRRADIANCE AGAINST ELEVATION

	Min. (w/m^2)	Average (w/m^2)	Max. (w/m^2)
25 cm	413	745	1605
30 cm	480	656	1013
35 cm	448	590	837

IV. CONCLUSION

This research presents a theoretical and experimental analysis of the use of metal halide lamps fitted in a parabolic tough shape acts as a solar simulator. The construction of the simulator is described in detail, the performance is simulated to decide a suitable elevation above the device. Finally, the proposed setup was built and simulation was validated at a height with suitable uniformity in the irradiance distribution. The conclusion of the paper is the use of such device if the irradiance distribution reported is suitable. If a more uniform distribution is sought, the procedure described above could be followed to obtain the desired setup.

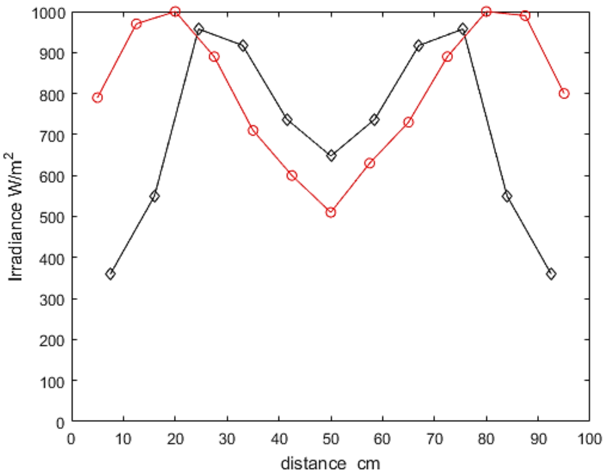


Figure 9. Comparison between the irradiance results obtained on the centerline of the solar heater (red circles) numerical, (black diamonds) measurements

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