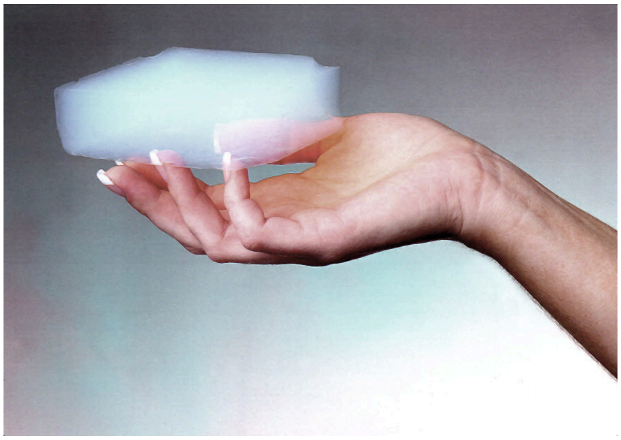
Effectiveness and Assessment of Aerogel Use and Light Variability on Thermal Collection

Eric Kim
S-EGSD-001

Introduction



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In recent years, there has been a growing demand for intermediate temperature thermal energy in the United States, with more than 627 TWh of energy consumed annually (Kurup, P., & Turchi, C., 2015). This energy is used for a variety of applications such as providing hot water, heating homes and businesses, and generating steam for power plants. However, the traditional methods of generating thermal energy using fossil fuels have been associated with significant environmental impacts (Intergovernmental Panel on Climate Change, 2014). To address this issue, there has been a growing interest in exploring alternative methods for generating thermal energy that are more environmentally friendly. One such method is the use of solar thermal systems, which can harness the power of the sun to generate thermal energy. However, the efficiency and potential of solar thermal systems have been limited by factors such as cost, complexity, and the availability of suitable materials. In this context, the development of new materials such as aerogel has opened up new possibilities for boosting the efficiency and potential of solar thermal systems. Aerogel is the world's lightest material that consists of up to 99.98% air and is capable of withstanding high temperatures without losing its structural integrity (Stardust | JPL | NASA, 2002). Moreover, aerogel is highly transparent, which makes it an ideal candidate for use as an artificial greenhouse medium in solar thermal systems (Weinstein et al., 2015). Analogous to the greenhouse effect, the aerogel transmits light but confines heat by blocking thermal emission. Findings from my investigation have important implications for the development of more efficient and sustainable methods for generating thermal energy.

Aim of Research

Based on a known solar flux, I will test the effectiveness of aerogel application in thermal energy collection by measuring the temperature of a black plate absorber with aerogel and/or glass covers. This method may support an efficient and novel method of converting the sun's energy straight into heat, rather than using electricity.

Methods and Materials

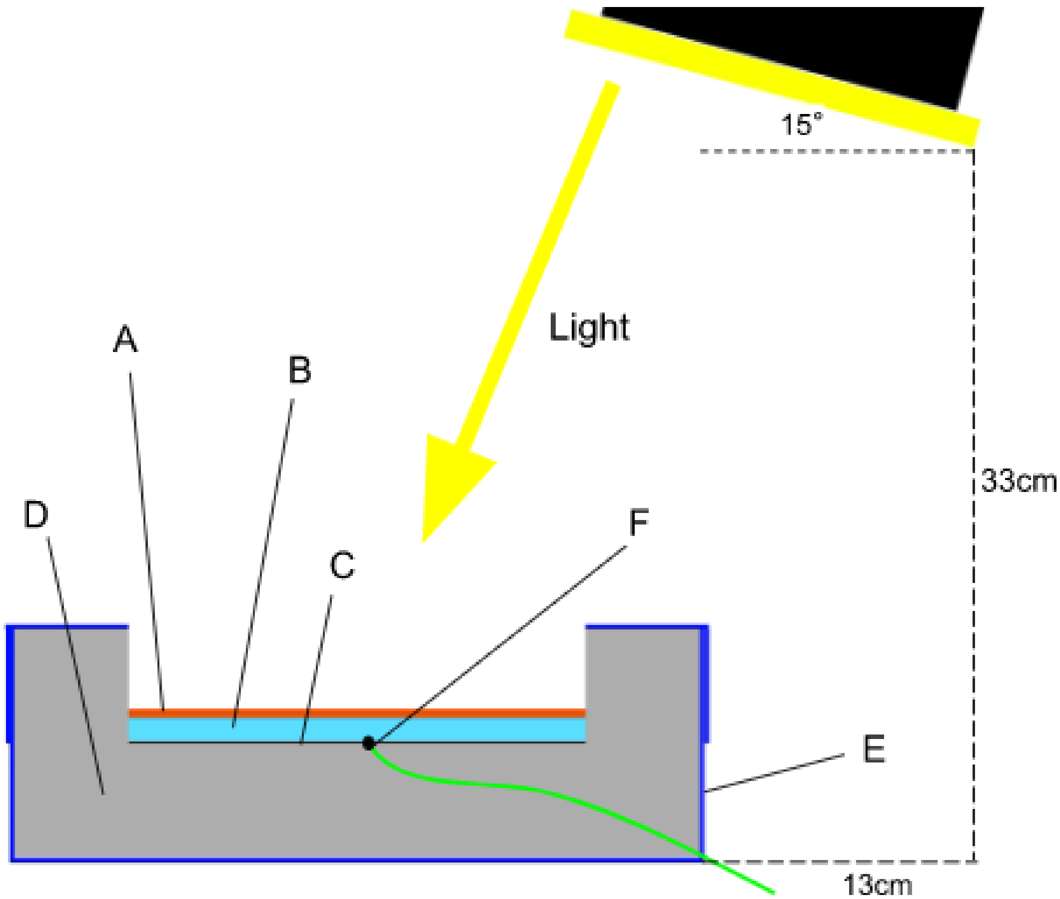

Figure 1 (side view of the Aero-Plexi collector; not drawn to scale)

To investigate the extent to which the application of Aerogel and/or Plexiglas as covers using the greenhouse effect leads to a greater solar collection of thermal energy, the following experimental setup was utilized.

The following materials were used for the solar collectors(Figure 1):

A. 2mm Plexiglas
B. 5mm Monolithic silica aerogel with ~95% transparency from the Union Aerogel Laboratory
C. A black 0.45mm Copper sheet was used as the absorber plate
D. Cyrogel insulation to prevent heat loss through the back of the absorber and the side of the aerogel
E. 5mm Aluminum sheet to hold in the collectors
F. Thermocouple to measure temperature of copper sheet

The height of the collector was 5cm, and the blackbody absorber was 2.5cm from the bottom. The lamp was 15 degrees from horizontal, and the collector was 13cm from the far side of the lamp. The lamp was 33cm above the ground.(Figure 1) The blackbody absorber was 10cm by 10cm, with a 2.5cm border of insulation around the perimeter.(Figure 2). Aerogel and glass covers are letting light energy hit the blackbody absorber and helping it stay.(Figure 1)

Solar collectors were exposed to a controlled amount of light to compare temperatures and effectiveness. The experimental design consisted of four positions and treatments. Positions 1 and 2 were paired with one lamp, and Positions 3 and 4 were paired with a second lamp.(Figure 3) The four treatments were as follows:

1. Plexiglas
2. Plexiglas on top of Aerogel
3. Aerogel
4. No cover

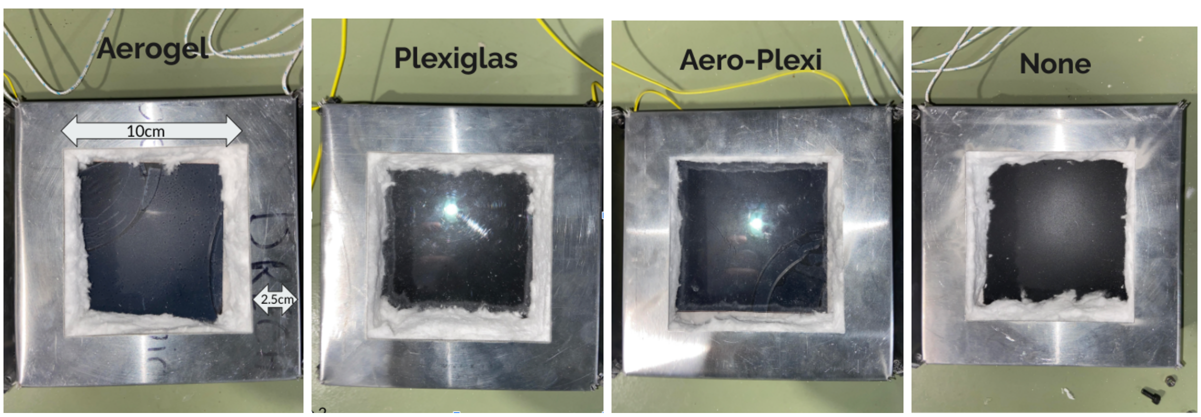

Figure 2 (top view of collectors)

Two Exposure 500 watt Halogen Light lamps were used to simulate solar flux, which is a measurement of solar radiation in a given area. The lamps acted as the sun, and the setup was designed to achieve a simulated solar flux of ~1000W/m^2. (Figure 3)

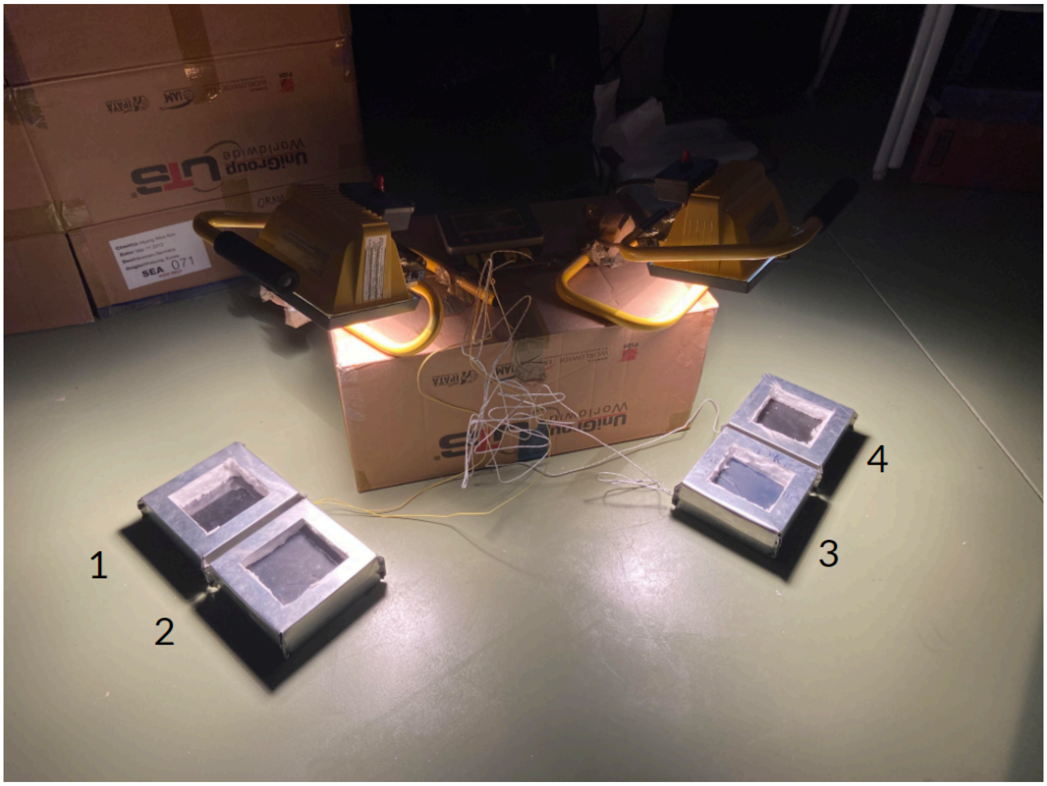

Figure 3 (positions 1, 2, 3, 4 are labeled)

The peak sun hours for a flat solar panel facing directly towards the sun's rays are typically around 1000W/m^2 (National Renewable Energy Laboratory [NREL], 2021).

The solar flux was measured using a DBTU1300 Solar Power Meter. (Figure 4) The measurement of flux was not directly at the collector, but at a fixed distance from the collector.

Three experiments were performed to gather data on the concrete floor of my basement (Figure 3) in Latham, NY from 11 P.M. to 1 A.M. All windows and lights were covered and turned off. The ambient temperature was measured in the second and third experiments to account for any abnormalities. (Figure 7)


Figure 4

In the second experiment, the positions of each treatment were switched to determine if the position made a difference.(Figure 5) Other variables such as distances and the angle of the lamp were kept the same.

To capture the data, a 4 Channel K Thermocouple SD Card Logger was used. The data from the three experiments were then averaged and plotted. The bold color lines in the later graph represent the average of the three experiments. (Figure 7)

Position	Measured Flux (W/m^2) (% deviation from average of 4 fluxes)	Cover
1	1053(+0.19%)	Plexiglas
2	1035(-1.5%)	Aerogel-Plexi
3	1049(-0.19%)	Aerogel
4	1065(+1.3%)	No Cover

Position	Measured Flux (W/m^2) (% deviation from average of 4 fluxes)	Cover
1	1023(+0.49%)	No Cover
2	1006(-1.2%)	Plexi
3	1021(+0.29%)	Aerogel-Plexi
4	1023(+0.49%)	Aerogel

Position	Measured Flux (W/m^2) (% deviation from average of 4 fluxes)	Cover
1	1020(+0.20%)	Plexiglas
2	1015(-0.29%)	Aerogel-Plexi
3	1012(-0.59%)	Aerogel
4	1025(+0.69%)	No Cover

Figure 5

Fluctuations in ambient temperature or positions of each treatment did not significantly affect results (scatter in flux and temperatures were minimal), suggesting that experiments were repeatable (Figure 5,7). Additional experiments were performed using 2mm silica glass(typical home window glass) rather than Plexiglas with altering flux(Figure 6)

Position	avgFlux(W/m^2) (+% from average)	Cover
1	1064(-0.68%)	Glass
2	1073(+0.16%)	Aerogel-Glass
3	1077(+0.54%)	Aerogel
4	1071(-0.02%)	None

Position	avgFlux(W/m^2) (+% from average)	Cover
1	2047	Glass
2	2074	Aerogel-Glass
3	2028	Aerogel
4	2072	None

Figure 6

Flux was doubled in order to evaluate effectiveness under solar concentration systems, where flux can be much higher than the typical 1000W/m^2 (Figure 6,9). 2 aerogels were stacked on top of each other, increasing thickness of aerogel in order to evaluate effectiveness of greater aerogel thickness (Figure 10,11)

Results and Discussion

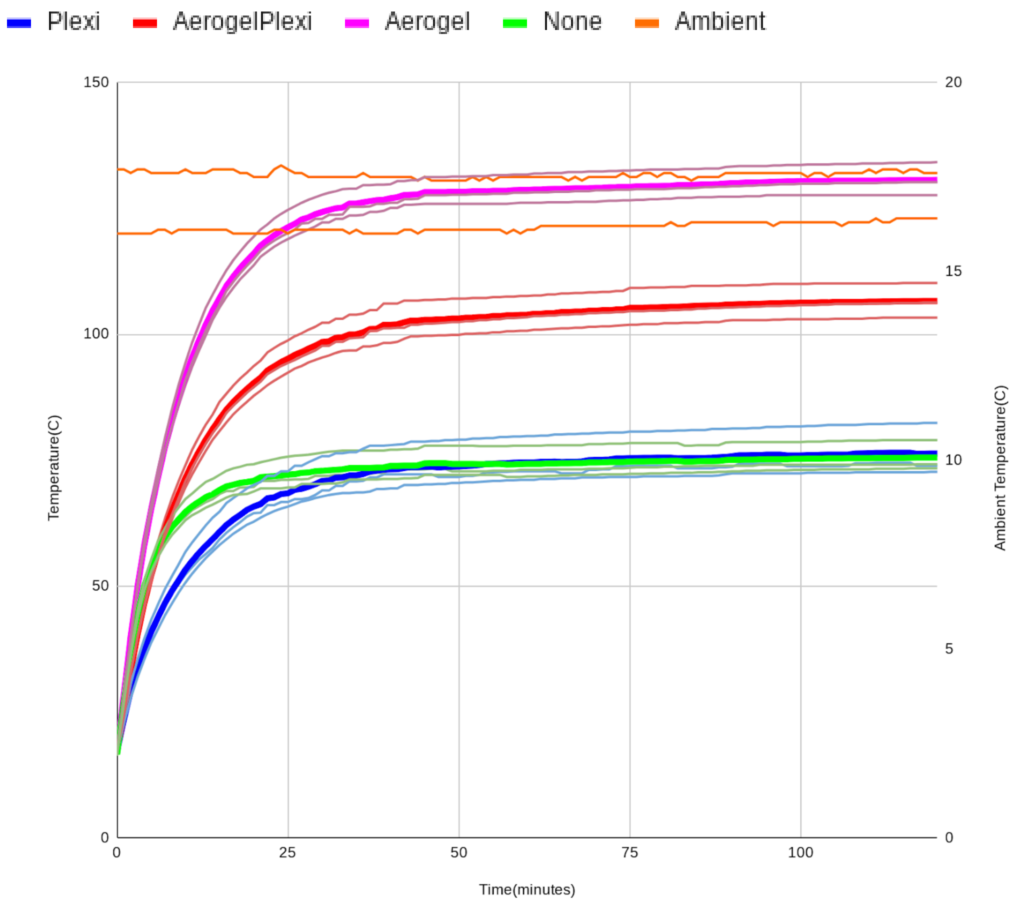

Figure 7

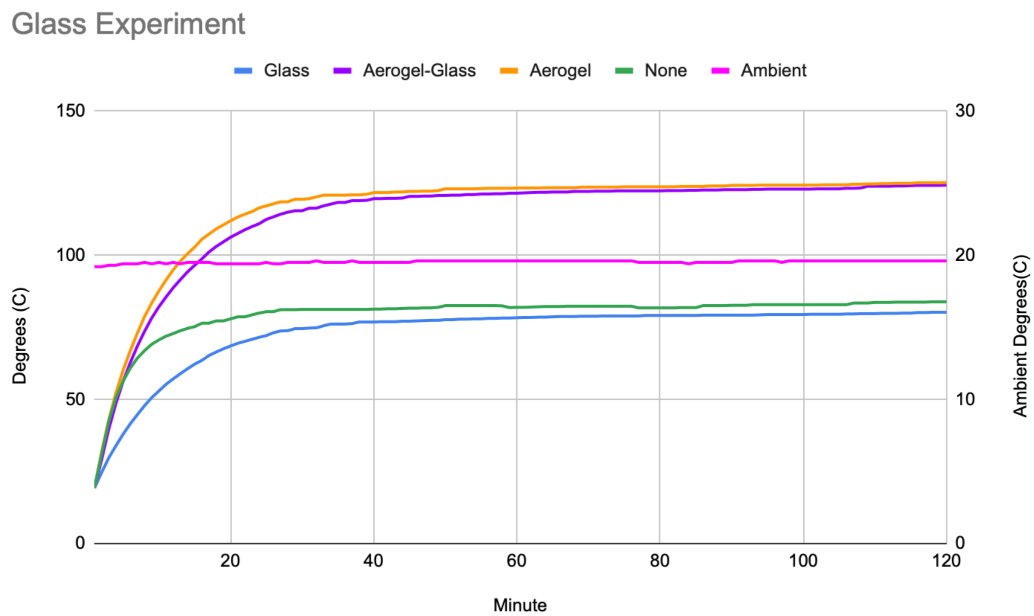

Figure 8

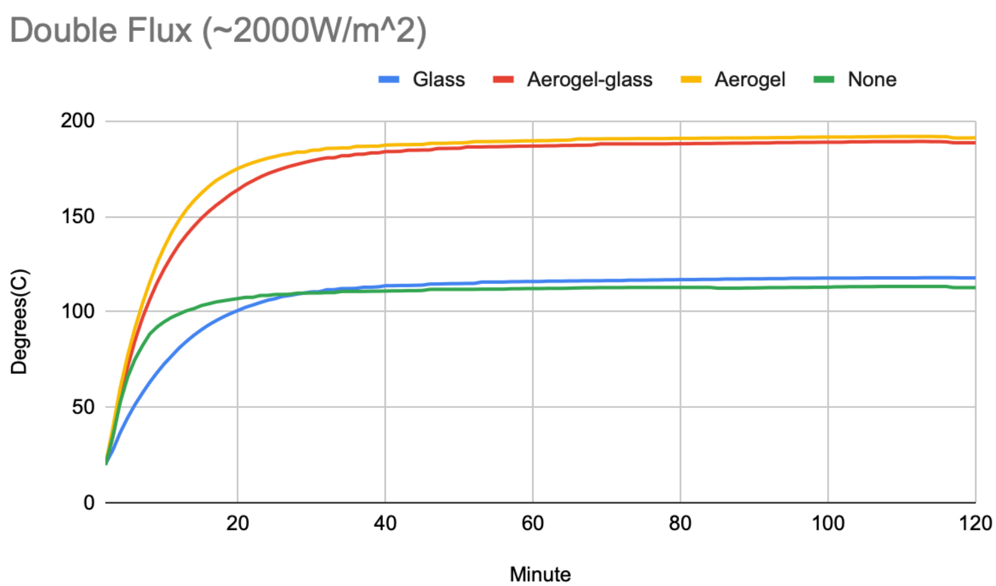

Figure 9

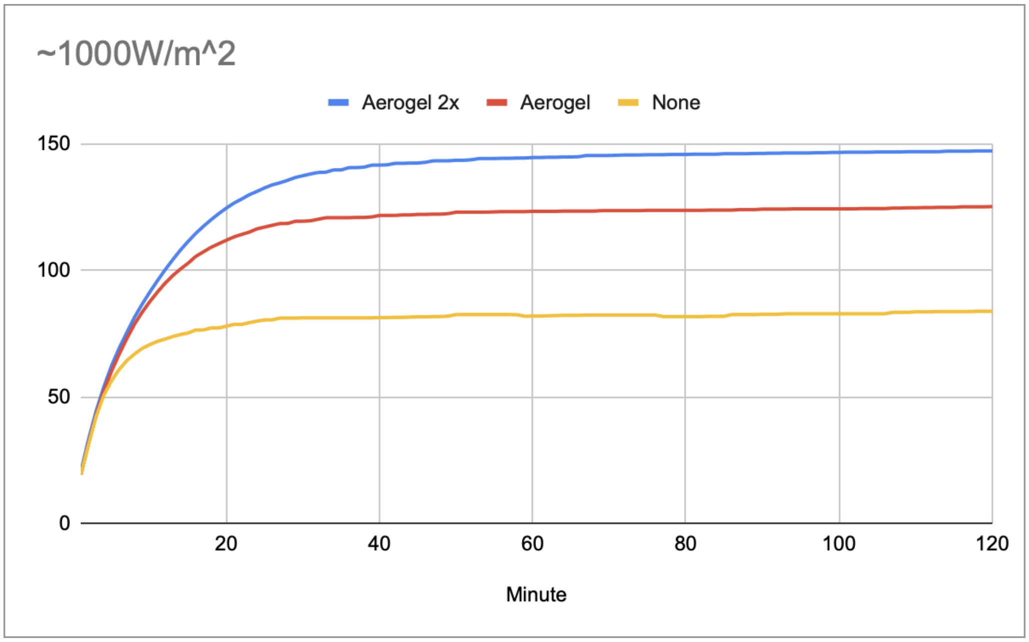

Figure 10

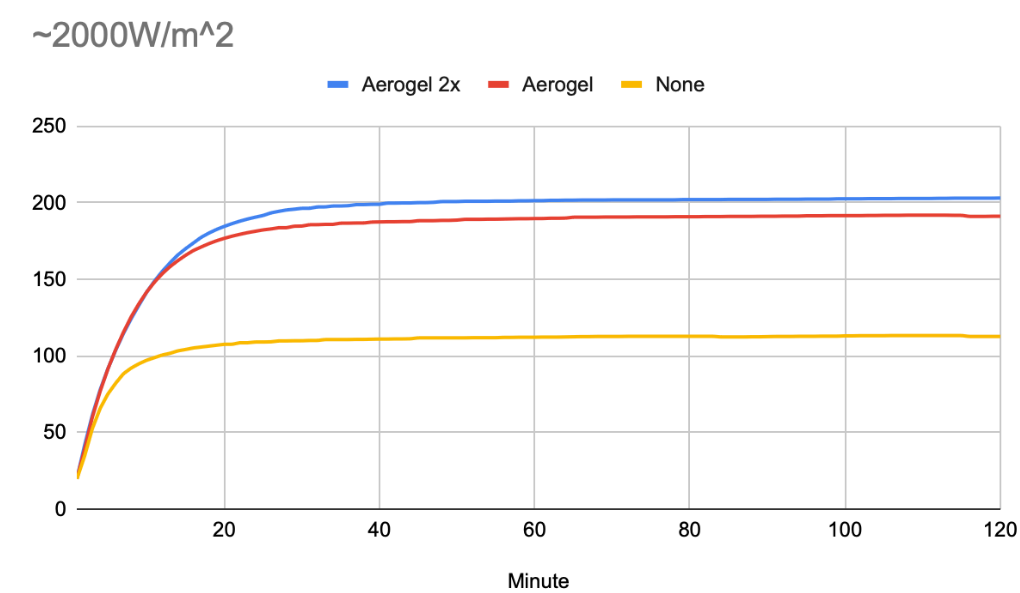

Figure 11

The use of aerogel clearly demonstrates a greater solar thermal efficiency and capacity. Under 1000W/m^2 and with an aerogel height of only 5mm, Plexi-Aerogel and Aerogel got above 100C in less than an hour, which is enough to boil water (Figure 7)

Surprisingly, Plexi-Aerogel performed much worse than Aerogel despite having two covers compared to only one (Figure 7). This might be because Plexiglas reflected/absorbed light(as seen in Figure 2) Subsequent experiments also showed that Plexiglas prevented 26.9% of light from hitting the absorber.

Our aerogels are extremely brittle and hydrophilic, so there must be a cover to protect the aerogel's fragility, but Plexiglas is clearly not the best option. Although silica glass is more expensive than Plexiglas, silica glass prevented only 13.5% of light passing through, resulting in a lower temperature difference between glass treatments and non-glass treatments (Figure 8,9) However, Aerogel-Glass still did not exceed Aerogel as expected–this might be because glass has a higher thermal inertia than aerogel.

Under 2000W/m^2, every treatment reached above boiling temperature, with Aerogel and Aerogel-Glass reaching near 200C in less than half an hour (Figure 9) When aerogel thickness was doubled under 1000W/m^2, the difference between 1xAerogel and 2xAerogel was 21.3C at the hour mark, compared to 11.7C under 2000W/m^2 (Figure 10,11). This suggests that as flux increases, the effectiveness per aerogel decreases. Future research could locate the optimal thickness of aerogel and point of diminishing returns, which will be important to designers of solar collectors.

This novel system suggests a viable sustainable alternative to existing costly and environmentally harmful methods of thermal energy collection, and suggests that the application of aerogel as an artificial greenhouse medium using the greenhouse effect can lead to a greater solar collection of thermal energy. Given that thermal energy at intermediate temperature is in high demand in the US (Kurup, P., & Turchi, C., 2015), our findings could contribute to developing more environmentally-friendly thermal energy systems for countless uses such as providing hot water, heating for homes/businesses, and steam for power plants.

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