**SUPPLEMENTARY INFORMATION**

Thermal Performance and Physicochemical Stability of Silver Nanoprism-based Nanofluids for Direct Solar Absorption

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**No. of Figures:** 2

**No. of Tables:** 14



Figure S1 Schematic of experimental procedure

**Uncertainty of Measurements**

Table S1 Uncertainty of constant CwMw/IA for SSL tests. The half width between the upper and lower limits is denoted by a. The standard deviation is denoted by s and n is the number of measurements

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Source of uncertainty | Comment | Value / ±% | Probability distribution | Divisor | Standard uncertainty | Unit |
| Change in Cw with temperature | Cw changes from 4.182 to 4.190 KJKg-1K-1 over temperature range 20 - 70 °C | 0.19 | rectangular | a/√3 | 0.11 | % |
| Uncertainty in measuring Mw | 1000 µl Micropipette used to measure amount with accuracy of ± 0.3% | 0.3 | rectangular | a/√3 | 0.17 | % |
| Change in A with temperature | Due to thermal expansion of liquid | 4.0 | rectangular | a/√3 | 2.31 | % |
| Variation in I due to lamp output variation | Lamp output varies by ± 6% | 6.0 | rectangular | a/√3 | 3.46 | % |
| Combined standard uncertainty |  |  | Assumed normal |  | 4.17 | % |
| Expanded uncertainty |  |  | assumed normal (k = 2) |  | 8.34 | % |

Table S2 Uncertainty of the water measurements under SSL for the middle M position. Abbreviations as in Table S1.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Source of uncertainty | Comment | Value / ±% | Probability distribution | Divisor | Standard uncertainty | Unit |
| uncertainty of temperature measurement because of thermocouples | Assumed to be ± 0.5°C | 2.5 | rectangular | a/√3 | 1.44 | % |
| Combined standard uncertainty of constant | Calculated as 4.2 % (see Table S1) |  | rectangular | a/√3 | 4.17 | % |
| Result of 9 measurements of temperature | value obtained is 21.83°C ± 1.253°C | 5.74 | normal | s/√n | 1.91 | % |
| Combined standard uncertainty |  |  | Assumed normal |  | 4.81 | % |
| Expanded uncertainty |  |  | assumed normal (k = 2) |  | 9.62 | % |

Table S3 Uncertainty of the water measurements under SSL for the front F position. Abbreviations as in Table S1.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Source of uncertainty | Comment | Value / ±% | Probability distribution | Divisor | Standard uncertainty | Unit |
| uncertainty of temperature measurement because of thermocouples | Assumed to be ± 0.5°C | 2.5 | rectangular | a/√3 | 1.44 | % |
| Combined standard uncertainty of constant | Calculated as 4.2 % (see Table S1) |  | rectangular | a/√3 | 4.17 | % |
| Result of 9 measurements of temperature | value obtained is 18.68°C ± 0.952°C  | 5.10 | normal | s/√n | 1.70 | % |
| Combined standard uncertainty |  |  | Assumed normal |  | 4.73 | % |
| Expanded uncertainty |  |  | assumed normal (k = 2) |  | 9.45 | % |

Table S4 Uncertainty of the water measurements under SSL for the back B position. Abbreviations as in Table S1.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Source of uncertainty | Comment | Value / ±% | Probability distribution | Divisor | Standard uncertainty | Unit |
| uncertainty of temperature measurement because of thermocouples | Assumed to be ± 0.5°C | 2.5 | rectangular | a/√3 | 1.44 | % |
| Combined standard uncertainty of constant | Calculated as 4.2 % (see Table S1) |  | rectangular | a/√3 | 4.17 | % |
| Result of 9 measurements of temperature | value obtained is 18.75°C ± 1.063°C  | 5.67 | normal | s/√n | 1.89 | % |
| Combined standard uncertainty |  |  | Assumed normal |  | 4.80 | % |
| Expanded uncertainty |  |  | assumed normal (k = 2) |  | 9.60 | % |

Table S5 Uncertainty in WP for the UV-vis spectroscopy data presented in Figure 3a (P-A). Abbreviations as in Table S1.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Source of uncertainty | Comment | Value / ±% | Probability distribution | Divisor | Standard uncertainty | Unit |
| Resolution of wavelength | Step-rate 1 nm. Max uncertainty is at 200 nm | 0.5 | rectangular | a/√3 | 0.29 | % |
| For Figure 3a P-A uncertainty in WP | value of 851 ± 13.6 nm for 3 samples | 1.60 | normal | s/√n | 0.92 | % |
| Combined standard uncertainty |  |  | Assumed normal |  | 0.97 | % |
| Expanded uncertainty |  |  | assumed normal (k = 2) |  | 1.93 | % |

Table S6 Uncertainty in absorption maxima for the UV-vis spectroscopy data presented in Figure 3a (P-A). Abbreviations as in Table S1.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Source of uncertainty | Comment | Value / ±% | Probability distribution | Divisor | Standard uncertainty | Unit |
| Uncertainty in value due to spectroscope resolution | Assumed to be same % uncertainty as wavelength | 0.5 | rectangular | a/√3 | 0.29 | % |
| For Figure 3a P-A uncertainty in WP | value of 1.6 ± 0.08 au for 3 samples | 5.00 | normal | s/√n | 2.89 | % |
| Combined standard uncertainty |  |  | Assumed normal |  | 2.90 | % |
| Expanded uncertainty |  |  | assumed normal (k = 2) |  | 5.80 | % |

Table S7 Uncertainty of TEM measurements for the triangular P-B1 nanoparticle measurements depicted in Table S11. Abbreviations as in Table S1.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Source of uncertainty | Comment | Value / ±% | Probability distribution | Divisor | Standard uncertainty | Unit |
| Calibration of line length | Assumed to be ± 1 nm on a line length of 100 nm | 1.0 | rectangular | a/√3 | 0.58 | % |
| Resolution of TEM | Assumed to be ± 1 nm - for a particle of 50 nm | 2.0 | rectangular | a/√3 | 1.15 |  |
| For Table S11 P-B1 before solar testing - Triangles | Mean = 43.7 ± 11.25 where n = 208 | 25.74 | normal | s/√n | 1.79 | % |
| Combined standard uncertainty |  |  | Assumed normal |  | 2.20 | % |
| Expanded uncertainty |  |  | assumed normal (k = 2) |  | 4.41 | % |

Table S8 Absorption maxima and ODmax before solar testing

|  |  |  |  |
| --- | --- | --- | --- |
| Sample ID | Cuvette employed | Max absorption (between 400 – 900 nm) / au | ODmax / au |
| P-A1 | 10 mm quartz | 1.65 | 1 |
| P-A2 | 1.58 | 1 |
| P-A3 | 1.48 | 1 |
| P-B1 | 4 mm ZEN0040 | 1.98 | 3.01 |
| P-B2 | 1.69 | 2.67 |
| P-B3 | 1.74 | 2.94 |
| P-C1 | 1.79 | 2.72 |
| P-C2 | 1.77 | 2.79 |
| P-C3 | 1.90 | 3.20 |
| P-D1 | 0.94 | 1.43 |
| P-D2 | 1.06 | 1.67 |
| P-D3 | 0.96 | 1.62 |

Table S9 Absorption maxima and ODmax before and after NSL testing

|  |  |  |  |
| --- | --- | --- | --- |
| Sample ID | Cuvette employed | Max absorption (between 400 – 900 nm) / au | ODmax / au |
| P-Amean | 10 mm quartz | 1.56 | 1 |
| P-Bmean before NSL | 4 mm ZEN0040 | 1.66 | 2.66 |
| P-Bmean after NSL | 0.42 | 0.67 |
| P-Cmean before NSL | 1.36 | 2.17 |
| P-Cmean after NSL | 1.19 | 1.91 |

Table S10 Absorption maxima and ODmax before and after SSL testing, and after being stored in the dark for 3 weeks

|  |  |  |  |
| --- | --- | --- | --- |
| Sample ID | Cuvette employed | Max absorption (between 400 – 900 nm) / au | ODmax / au |
| P-Bmean before SSL | 4 mm ZEN0040 | 1.80 | 2.89 |
| P-Bmean after 12 hours SSL | 1.63 | 2.62 |
| P-Cmean before SSL | 1.82 | 2.91 |
| P-Cmean after 6 hours SSL | 1.65 | 2.65 |
| P-C1 dark | 1.71 | 2.60 |
| P-C2 dark | 1.01 | 1.60 |
| P-C3 dark | 1.58 | 2.66 |

**Size analysis of nanoparticles**

Table S11 Size analysis for AgNPr before solar testing

|  |
| --- |
| P-B1 before solar testing |
|  | Triangles | Other |
| Mean / nm | 43.7 | 29.2 |
| SD / nm | 11.25 | 11.41 |
| N | 208 | 145 |
| P-B2 before solar testing |
|  | Triangles | Other |
| Mean / nm | 38.2 | 27.8 |
| SD / nm | 11.31 | 15.12 |
| N | 414 | 121 |
| P-B3 before solar testing |
|  | Triangles | Other |
| Mean / nm | 38.5 | 27.5 |
| SD / nm | 10.84 | 13.85 |
| N | 773 | 421 |

Table S12 Size analysis for SiO2@AgNPr before solar testing

|  |
| --- |
| P-C1 before solar testing |
|  | Silver cored | Silica only | Silver Multi-cored |
| Mean / nm | 143.0 | 86.8 | 152.4 |
| SD / nm | 13.29 | 13.79 | 17.25 |
| N | 185 | 465 | 7 |
| P-C2 before solar testing |
|  | Silver cored | Silica only | Silver Multi-cored |
| Mean / nm | 142.7 | 91.0 | 138.2 |
| SD / nm | 11.95 | 12.43 | 6.68 |
| N | 234 | 274 | 10 |
| P-C3 before solar testing |
|  | Silver cored | Silica only | Silver Multi-cored |
| Mean / nm | 138.6 | 88.9 | 138.2 |
| SD / nm | 12.5 | 12.53 | 11.72 |
| N | 183 | 208 | 19 |

**Definition of T-test**

A T-test is a hypothesis test that allows you to compare means. A two-sample T-test allows the comparison between two means from two different sets of samples. The null hypothesis is that the two means are the same. The formula is:

$$t= \frac{\overbar{X}\_{2}-\overbar{X}\_{1}}{\sqrt{s^{2}\left(\frac{1}{n\_{1}}\right.}+\left.\frac{1}{n\_{2}}\right)}$$

Equation S1

Where *t* = T value (which can be looked up in standard T-tables or using a statistical software package to determine significance). $\overbar{X}\_{1}$ = Mean of sample 1 and $\overbar{X}\_{2}$ = Mean of sample 2, *n1* and *n2* are the number of results in each sample set and *s2* is the pooled sample variance given by the equation:

$$s^{2}= \frac{\sum\_{i=1}^{n\_{1}}\left(X\_{i}-\overbar{X}\_{1}\right)^{2}+\sum\_{j=1}^{n\_{2}}\left(X\_{j}-\overbar{X}\_{2}\right)^{2}}{n\_{1}+n\_{2}-2}$$

Equation S2

**Solar Simulator results**



Figure S2 Spectra obtained from the solar simulator lamp and from sunlight

The wavelengths and absorption of the lamp is close to that of sunlight over the range measured. However, there are some large peaks in the lamps output especially the one at 825 nm. Other researchers have used similar lamps with large peaks in their output to test nanofluids ([Gorji and Ranjbar, 2016](#_ENREF_1)).

Table S13 Solar simulator results for repeat measurements on the base-fluid water. The confidence interval (CI) shows the range of possible values for the mean

|  |  |  |  |
| --- | --- | --- | --- |
| Position | B | F | M |
| N | 9 | 9 | 9 |
| Grouping (different letters = significantly different) | B | B | A |
| ∆T after 3600 s |
| Mean / oC | 18.75 | 18.68 | 21.83 |
| SD / oC | 1.063 | 0.952 | 1.253 |
| 95% CI of mean / oC | 18.00-19.50 | 17.92-19.43 | 21.08-22.59 |
| Slope (∆T/∆t) / oCs-1 |
| Mean / oCs-1 | 0.017 | 0.016 | 0.020 |
| SD / oCs-1 | 0.0016 | 0.0012 | 0.0017 |
| 95% CI of mean / oCs-1 | 0.016-0.018 | 0.015-0.018 | 0.019-0.021 |

**Size analysis after simulated sunlight exposure**

Table S14 Size analysis from the TEM photographs after exposure for 12 hours (P-B1, B2 and B3) and 6 hours (P-C1, C2 and C3). Note that the number of silver only particles is greater than the total of multi-cored and silver coated with SiO2 particles as the multi-cored particles contain more than one silver

|  |  |  |  |
| --- | --- | --- | --- |
|  | P-C1 | P-C2 | P-C3 |
| Silver coated with SiO2 |
| Mean / nm | 137.8 | 133.6 | 134.7 |
| SD / nm | 16.45 | 12.45 | 12.36 |
| N | 65 | 46 | 96 |
| Silica only |
| Mean / nm | 98.3 | 92.8 | 96.9 |
| SD / nm | 13.99 | 12.42 | 12.30 |
| N | 110 | 59 | 111 |
| Multi-cored |
| Mean / nm | 124.9 | 139.1 | 138.1 |
| SD / nm | 22.23 | 11.53 | 16.64 |
| N | 18 | 20 | 24 |
| Silver only |
| Mean / nm | 26.4 | 21.1 | 27.0 |
| SD / nm | 12.07 | 9.03 | 9.28 |
| N | 102 | 97 | 153 |
| Free silver particles |
| Mean / nm | 50.6 | 33.4 | 29.9 |
| SD / nm | 5.46 | 24.23 | 8.08 |
| N | 3 | 6 | 3 |
|  | **P-B1** | **P-B2** | **P-B3** |
| Triangles |
| Mean / nm | 45.5 | 42.2 | 37.8 |
| SD / nm | 10.93 | 11.34 | 10.64 |
| N | 234 | 218 | 40 |
| Other |
| Mean / nm | 33.5 | 33.3 | 28.5 |
| SD / nm | 11.19 | 12.04 | 10.98 |
| N | 770 | 256 | 329 |

**References**

Gorji, T.B., Ranjbar, A.A., 2016. A numerical and experimental investigation on the performance of a low-flux direct absorption solar collector (DASC) using graphite, magnetite and silver nanofluids. Solar Energy, 135, 493-505, <https://doi.org/10.1016/j.solener.2016.06.023>.