Supplementary Information for the paper: Nanofluids for Solar Thermal Collection and Energy Conversion
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This document contains additional information that we used in conducting the simulation and experiments.

Table 1 - Commonly used nanoparticles (left) and base fluids (right) used to synthesize nanofluids [4]

| Nanoparticle Materials          | Base Fluids       |
|--------------------------------|-------------------|
| Aluminium Oxide - Al₂O₃        | Ethylene Glycol   |
| Copper Oxide - CuO             | Ethylene Oxide    |
| Iron(III) Oxide - Fe₂O₃        | Ethanol           |
| Magnesium Oxide - MgO          | Glycerol          |
| Silicon dioxide - SiO₂         | Kerosene          |
| Titanium dioxide - TiO₂        | Toluene           |
| Zinc oxide - ZnO               | Water             |
| Silver - Ag                    |                   |
| Aluminium - Al                 |                   |
| Gold - Au                      |                   |
| Copper - Cu                    |                   |
| Iron - Fe                      |                   |
| MWCNTs                         |                   |

Table 2 - Specific heat capacity models

| Model                        | Expression                                      | Remarks           | φ (%) | dₚ (nm) | T (ºC) |
|------------------------------|-------------------------------------------------|-------------------|-------|--------|--------|
| Pak and Cho (1)              | \( c_{p,nf} = c_{p,f}(1 - \phi) + c_{p,p}\phi \) | Theoretical Equation | -     | -      | -      |
| Xuan and Roetzzel (2)        | \( c_{p,nf} = \frac{\rho_f c_{p,f}(1 - \phi) + \rho_p c_{p,p}\phi}{\rho_{nf}} \) | Theoretical Equation | -     | -      | -      |
| Sekhar and Sharma (3)        | \( c_{p,nf} = c_{p,f} 0.8429 \Big(1 + \frac{T_{nf}}{50}\Big)^{-0.3037} \Big(1 + \frac{d_p}{50}\Big)^{0.4167} (1 + \phi)^{2.272} \) | Empirical Equation | 0-4   | 15-50  | 20-50  |
| Model                  | Expression                                                                 | Remarks                                                                 | φ (%) | d_p (nm) | T (°C) |
|------------------------|----------------------------------------------------------------------------|-------------------------------------------------------------------------|-------|----------|--------|
| Pak and Cho (1)        | $k_{nf} = k_f (1 + 7.74 \varphi)$                                         | Empirical Equation                                                      | -     | 13       | 25     |
| Bruggeman (4)          | $k_{nf} = 0.25 k_f \left( (3\varphi - 1) \frac{k_p}{k_f} + [3(1 - \varphi) - 1] + \sqrt{\Delta_B} \right)$ | Theoretical Equation Valid for high-volume concentrations, spherical particles and random distributions. No limitation on the concentration For low concentrations, the Bruggeman model shows almost the same result as the Maxwell–Garnett’s model. | -     | -        | -      |
| Mintsa et al. (5)      | $k_{nf} = k_f (1 + 1.72\varphi)$                                         | Empirical Equation                                                      | 0-18  | 36, 46   | 20-50  |
| Hamilton–Crosser (6)   | $k_{nf} = k_f \frac{k_p + (n-1)k_f + (n-1)\varphi(k_f - k_i)}{k_p + (n-1)k_f + \varphi(k_f - k_p)}$ | Theoretical Equation Valid for spherical and non-spherical particles For spherical nanoparticles, $n = 3$ (also called Wasp or Maxwell Model) For cylindrical nanoparticles, $n = 6$. | 0-4   | -        | -      |
| Lu and Lin (7)         | $k_{nf} = k_f (1 + 2.25\varphi + 2.27\varphi^2)$                           | Theoretical Equation Valid for spherical nanoparticles                   | -     | -        | -      |
| Yu and Choi (8)        | $k_{nf} = k_f \frac{k_p + 2k_f + 2\varphi(k_f - k_i)(1+\beta)^3}{k_p + 2k_f + \varphi(k_f - k_p)(1+\beta)^3}$ | Theoretical Equation Modified Maxwell Model that considers nanolayer effect. Valid for spherical nanoparticles. Suggests the new approach that adding smaller (<10-nm diameter) particles could be potentially better than adding more particles | < 20  | -        | -      |
| Chon et al. (9)        | $k_{nf} = k_f \left( 1 + 64.7 \varphi^{0.746} \left( \frac{d_f}{d_p} \right)^{0.369} \left( \frac{k_p}{k_f} \right)^{0.746} \right)$ | Empirical Equation Considers effect of Brownian motion of the nanoparticles in the nanofluid | 1     | 11-150   | 20-70  |

Table 3 - Thermal conductivity models
## Table 4 - Viscosity models

| Model                  | Expression                                      | Remarks                        | \(\phi\) (\%) | \(d_p\) (nm) | \(T\) (°C) |
|------------------------|-------------------------------------------------|--------------------------------|----------------|---------------|-------------|
| Einstein (10)          | \(\mu_{nf} = (2.5\phi + 1)\mu_f\)             | Theoretical Equation           | \(\leq 2\)     | -             | -           |
| Ho et al. (11)         | \(\mu_{nf} = \mu_f (1 + 2.93\phi + 222.4\phi^2)\) | Empirical Equation            | 0–4            | 33            | 15–40       |
| Maiga et al. (12)      | \(\mu_{nf} = \mu_f (1 + 7.3\phi + 123\phi^2)\) | Empirical Equation            | 0.5            | 13, 28        | 25          |
| Batchelor (13)         | \(\mu_{nf} = \mu_f (1 + 2.5\phi + 6.2\phi^2)\) | Theoretical Equation          | -              | -             | -           |
| Nguyen et al. (14)     | \(\mu_{nf} = \mu_f (1 + 0.025\phi + 0.015\phi^2)\) | Empirical Equation            | 1–9.4          | 36, 29        | 20–75       |
| Brinkman (15)          | \(\mu_{nf} = \mu_f (1 - \phi)^{-2.5}\)       | Theoretical Equation          | \(< 5\)         | -             | -           |
| Masoumi et al. (16)    | \(\mu_{nf} = \mu_f + \frac{\rho_p V_B d_p^2}{72 C_\delta} + \frac{V_B}{d_p^3} \left(\frac{18 k_B T}{\pi \rho_p d_p}\right)\) | Empirical Equation            | 0–5            | 28, 36        | 22–65       |

\(k_B = 1.38 \times 10^{-23} \text{ m}^2 \text{ kg s}^{-2} \text{K}^{-1}\)

\(C = \mu_f^{-1}[(C_1 d_p + C_2)\phi + (C_3 d_p + C_4)]\)

- \(C_1 = -1.133 \times 10^{-6}\)
- \(C_2 = -2.771 \times 10^{-6}\)
- \(C_3 = 9 \times 10^{-8}\)
- \(C_4 = -3.93 \times 10^{-7}\)

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