Supplementary Information

Experimental Testing of Hydrophobic Microchannels, with and without Nanofluids, for Solar PV/T Collectors

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The following supplementary information provides the background information on how the thermophysical properties of the nanofluids were calculated, how the pressure drop data was analysed, and how the uncertainty of the experiments was estimated for this present study.

1. Nanofluid Thermophysical Properties

Although many equations exist for calculating the effective properties of nanofluids, the present study elected to use simple relationships—relationships which have been found to provide good approximations at low volume fractions [34-36]. For the specific heat capacity, the nanofluid was calculated using the following simple linear mixing model, as was suggested in [34] using the following:

$$C_{P_{nf}} = \varphi C_{P_p} + (1-\varphi) C_{P_{bf}} \quad \textbf{(S-1)}$$

The subscripts nf, p, and bf refer to the nanofluid, particle, and the base fluid, respectively. φ is the volume fraction of the particle. The viscosity (μ) was estimated using the Einstein Model, as was suggested in [35], with the following equation:

$$\frac{\mu_{nf}}{\mu_{bf}} = (1 + 2.5\varphi) \quad \textbf{(S-2)}$$

And of the density (ϱ) of the nanofluid in this study was calculated with the following equation linear mixing model [36]:

$$\rho_{nf} = \varphi \rho_P + (1-\varphi)\rho_{bf} \quad \textbf{(S-3)}$$

In each of equations (1)-(3), the 'effective' nanoparticle properties were first calculated (using these same equations), based on the electron microscope measurements for the relative volumes of the core and shell. For equations 1-3, an average outer particle diameter of 100nm was used and a shell thickness (approximately 30nm) was assumed (e.g. see Figure 3c of the main manuscript and [29]), along with the properties of each bulk material (silver and silica).

The nanofluid volume % was found to be approximately 0.05%. Therefore, at the laboratory temperature ($\approx 20^oC$) the physical properties of water and the calculated nanofluid properties using equation S1-3 can be seen in Table S1.

Table S1. Comparison of the thermophysical properties of water and the nanofluid.

Water			Nanofluid		
$\rho\ (kg/m^3)$	$C_p (J/kg^oK)$	$\mu\ (Pa.s)$	$\rho\ (kg/m^3)$	$C_p (J/kg^oK)$	$\mu\ (Pa.s)$
998.19	4180	0.0010005	1000.305	4178.23	0.0010017

2. Pressure Drop Calculations

As mentioned in Section 3 of the main text, the results of the pressure drop experiments were presented as dimensionless numbers where possible. This was done by plugging the data into the following equations. This process starts by calculating the friction factor from the measured pressure drop data [43]:

$$f = \Delta P_L \frac{D_h}{L} \frac{2}{\rho U^2} \tag{S-4}$$

where ΔP_L, L, D_h, ρ, and U are the pressure drop along the microchannel, the length of the microchannel (30mm in this study), the hydraulic diameter, the fluid density, and the average fluid velocity, respectively. Hydraulic diameter, in turn, was calculated by the following:

$$D_h = \frac{4A_c}{p} = \frac{2WH}{(W+H)} \tag{S-5}$$

where A_c, p, W, and H are the area of cross section, the wetted perimeter of the channel, the channel width, and the channel height, respectively. The Reynolds number was calculated as follows:

$$Re = \frac{\rho U D_h}{\mu} \tag{S-6}$$

where μ is the dynamic viscosity of the fluid. Subsequently, the Poiseuille number was calculated using:

$$Po = fRe = \frac{2\Delta P_L {D_h}^2}{LU\mu} = \frac{8\Delta P_L}{L\dot{V}\mu} \frac{W^2H^2}{(W+H)^2} \tag{S-7}$$

where $\dot{V}$ is the volumetric flow rate.

3. Uncertainty Analysis

A detailed analysis of the experimental uncertainty is critical to the interpretation of the experimental results [44, 45]. Based on the test procedure and measuring instruments mentioned in the main text, the uncertainty in Poiseuille number here can be determined from the following terms:

$$\delta Po = \left[\left(\frac{\partial Po}{\partial \Delta P}\delta\Delta P\right)^2 + \left(\frac{\partial Po}{\partial W}\delta W\right)^2 + \left(\frac{\partial Po}{\partial H}\delta H\right)^2 + \left(\frac{\partial Po}{\partial \dot{V}}\delta\dot{V}\right)^2\right]^{\frac{1}{2}} \tag{S-8}$$

where $\dot{V}$ and U are the volumetric flow rate and the average flow velocity, respectively, and each term is as follows:

$$\frac{\partial Po}{\partial \Delta P} = \frac{8\, W^2H^2}{\mu LU(W+H)^2} \tag{S-9}$$

$$\frac{\partial Po}{\partial W} = \frac{16\, \Delta P\, WH^3}{\mu LU(W+H)^3} \tag{S-10}$$

$$\frac{\partial Po}{\partial H} = \frac{16\, \Delta P\, W^3H}{\mu LU(W+H)^3} \tag{S-11}$$

$$\frac{\partial Po}{\partial \dot{V}} = \frac{-8\Delta P\, W^2H^2}{\mu LU^2(W+H)^2} \tag{S-12}$$

The PHD syringe pump accuracy was 1% of the experimented flow rate. The Keyence laser scanning microscope (VK-X210) has a display resolution of 0.012 μm and repeatability of 0.012 μm in height measurement, whereas the Zeiss microscope used for the width measurements has a resolution of 19.55 μm/px. The uncertainties of both height and width measurements can be determined by the following equations:

$$\delta H_{\mathrm{sys}} = \left[(\delta H_{\mathrm{resolution}})^2 + (\delta H_{\mathrm{repeatability}})^2\right]^{\frac{1}{2}} \tag{S-13}$$

$$\delta H = \left[(\delta H_{\text{sys}})^2 + (t_{95,v}\frac{S}{\sqrt{n}})^2\right]^{\frac{1}{2}} \quad \textbf{(S-14)}$$

$$\delta W = \left[(\delta W_{\text{sys}})^2 + (t_{95,v}\frac{S}{\sqrt{n}})^2\right]^{\frac{1}{2}} \quad \textbf{(S-15)}$$

"Sys" subscript stands for the systematic error. The second term of δH and δW is the researcher's t-statistic with a 95% confidence level (remember: H and W were measured 10 times each).

The differential pressure transducer used in the experiments has an accuracy of 0.08% (linearity, hysteresis, and repeatability combined). With a pressure range of 7000 Pa, the systematic error in the pressure drop measurement can be calculated as follows:

$$\delta \Delta P_{L,sys} = 7000 \times 0.08\% = \pm 5.6\ Pa \quad \textbf{(S-16)}$$

Then, the uncertainty in the pressure drop measurements can be determined by combining the instrument error and the random error of the pressure drop measurement over the time interval.

$$\delta \Delta P_L = \left[(\delta \Delta P_{L,sys})^2 + (t_{95,v}\frac{S}{\sqrt{n}})^2\right]^{\frac{1}{2}} \quad \textbf{(S-17)}$$

Regarding the temperature measurement, T_m calculated using the following (e.g. for calibrated, T-type thermocouples):

$$T_m = \frac{1}{2}(T_i + T_o) \quad \textbf{(S-18)}$$

where i and o subscripts are inlet and outlet. For T_i and T_o also we have:

$$\delta T_i = \left[(\delta T_{i,sys})^2 + (t_{95,v}\frac{S}{\sqrt{n}})^2\right]^{\frac{1}{2}} \quad \textbf{(S-19)}$$

$$\delta T_o = \left[(\delta T_{o,sys})^2 + (t_{95,v}\frac{S}{\sqrt{n}})^2\right]^{\frac{1}{2}} \quad \textbf{(S-20)}$$

So, for T_m we can write:

$$\delta T_m = \left[(\frac{1}{2}\delta T_i)^2 + (\frac{1}{2}\delta T_o)^2\right]^{\frac{1}{2}} \quad \textbf{(S-21)}$$

As for efficiency, the uncertainty can be expressed using the following equation:

$$\delta \eta = \left[\left(\frac{\partial \eta}{\partial G}\delta G\right)^2 + \left(\frac{\partial \eta}{\partial T_i}\delta T_i\right)^2 + \left(\frac{\partial \eta}{\partial T_o}\delta T_o\right)^2 + \left(\frac{\partial \eta}{\partial \dot{m}}\delta \dot{m}\right)^2\right]^{\frac{1}{2}} \quad \textbf{(S-22)}$$

where:

$$\frac{\partial \eta}{\partial G} = \left(\frac{\dot{m} C_P \Delta T}{A}\right).\left(\frac{-1}{G^2}\right) \quad \textbf{(S-23)}$$

$$\frac{\partial \eta}{\partial \dot{m}} = \frac{\partial \eta}{\partial (\rho \dot{V})} = \left(\frac{\rho C_P \Delta T}{AG}\right) \quad \textbf{(S-24)}$$

$$\frac{\partial \eta}{\partial T_i} = -\left(\frac{\dot{m} C_P}{AG}\right) \quad \textbf{(S-25)}$$

$$\frac{\partial \eta}{\partial T_o} = \left(\frac{\dot{m} C_P}{AG}\right) \quad \textbf{(S-26)}$$

For the X-axis the following can be used:

$$\frac{\partial (\frac{T_m - T_a}{G})}{\partial T_O} = \frac{\partial (\frac{(((T_o + T_i)/2) - T_a)}{G})}{\partial T_o} = \frac{\dot{m} C_p}{2AG} \quad \textbf{(S-27)}$$

$$\frac{\partial\left(\frac{T_m - T_a}{G}\right)}{\partial T_i} = \frac{\partial\left(\frac{(((T_o + T_i)/2) - T_a)}{G}\right)}{\partial T_i} = \frac{-\dot{m}C_p}{2AG} \tag{S-28}$$

$$\frac{\partial(\frac{T_m - T_a}{G})}{\partial G} = \frac{-(T_m - T_a)}{G^2} \tag{S-29}$$

The light power meter had an accuracy of 1mW. The main contributors to the uncertainties of the pressure drop measurements and the efficiency are W, T_i and T_o, respectively.