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Supplementary Information

Synthesis of Polyethylene Glycol-Functionalized Multi-Walled Carbon Nanotubes with Microwave-Assisted Approach for Improved Heat Dissipation

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Dispersion

Unsurprisingly, the dispersibility of TFPEG -treated MWCNT (PMWCNT) has been appreciably increased in aqueous media. It can be seen that the image of TFPEG-treated MWCNT illustrates only a negligible deposition after 168 h, despite the fact that the pristine sample has deposited immediately as the sonication performed (Figure S_1). The easily-miscible TFPEG functionalities in water can elucidate the excellent dispersion of the TFPEG-treated MWCNT.

Figure S_1. Photographs of TFPEG-treated MWCNT and pristine after (a) 12 h (b) 48 h (c) and 168 h

Raman spectroscopy

Raman spectroscopy was employed to provide basic information for studying the covalent functionalization of MWCNT. Raman characterization was determined by an eminent sensitivity to the disordered band on the structure depending upon the optical skin depth [1, 2]. The Raman spectra of the pristine MWCNT and PMWCNT are shown in Figure S_2. It can be seen that the Raman spectra of the pristine sample and PMWCNT are shown the D and G bands at 1343 and 1573 cm^{-1}, respectively. The Raman-D mode at 1343 cm^{-1} is attributed to the amorphous carbon, which is caused by the disordered structure from the substrate doping. In contrast, the tangential G mode of the MWCNT at 1573 cm^{-1} is connected to the motion in the opposite direction of two adjacent carbon atoms in a graphitic framework[1-3]. Here, the G band corresponds to the existence of crystalline graphitic carbon in the MWCNT. Overall, the Raman spectra are utilized to identify the amount of disordered carbon relative to the graphitic carbon using the ratio of I_D/I_G. Thus, the higher value of I_D/I_G means the higher degree of covalent functionalization, which is obvious in PMWCNT. As can be seen that the intensity ratios (I_D/I_G) of PMWCNT is higher than that of the pristine MWCNT, which confirms functionalization of MWCNT with TFPEG and/or inducing defects in CNT by sonication[4, 5].

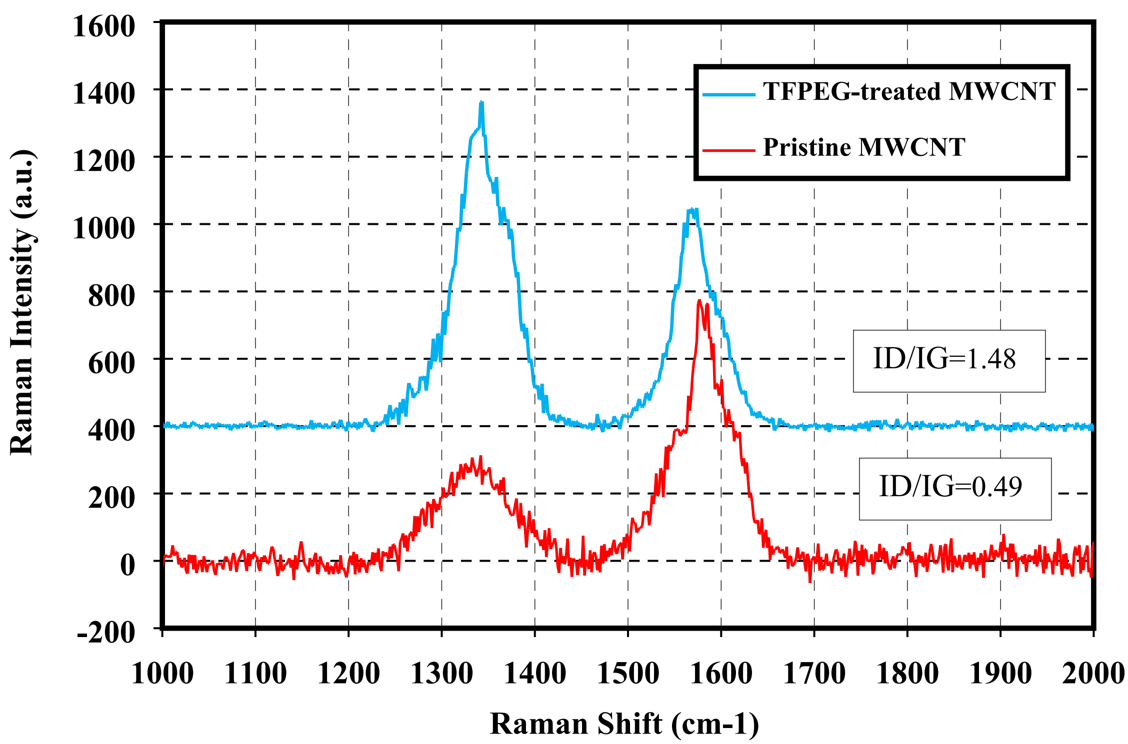

Figure S_2. Raman spectra of the pristine and TFPEG-treated MWCNT.

Convective heat transfer coefficient

Figure S_3 illustrates the enhancement of the convective heat transfer coefficient as a function of axial distance at different TFPEG-treated MWCNT concentrations. Obviously, PMWCNT- based water nanofluids at different concentrations show the significant enhancements as compared with pure water, which confirm that adding PMWCNT with insignificant weight concentration can also play a vital role in enhancing the convective heat transfer coefficient as compared with the pure water. The following observations may be attained from the Figure 8:

- The presence of TFPEG-treated MWCNT gives a good enhancement on the heat transfer performance at all of the x/D.
- The enhancement of convective heat transfer coefficient decreases with x/D initially, reaches a minimum at the x/D of 35.714, and then increases with a further growth in x/D.
- Consist with our results, the maximum amount of convective heat transfer coefficient enhancement for PMWCNT-based water nanofluids is 221% for a weight concentration of 0.2%. This phenomenon is attributed to the non-homogeneous agitation at the entrance of tube. During hydrodynamic entry length, there is an agitation, which decrease the temperature difference between wall and bulk, which may intensify in the presence of PMWCNT with increasing thermal conductivity and decreasing thermal boundary layer thickness[6, 7], and resulted in lower temperature difference between wall and bulk fluid at the entrance. At x/D higher than 30, the deviations of convective heat transfer coefficient for PMWCNT-based water nanofluid and water are similar, which are obvious in Figure 8.

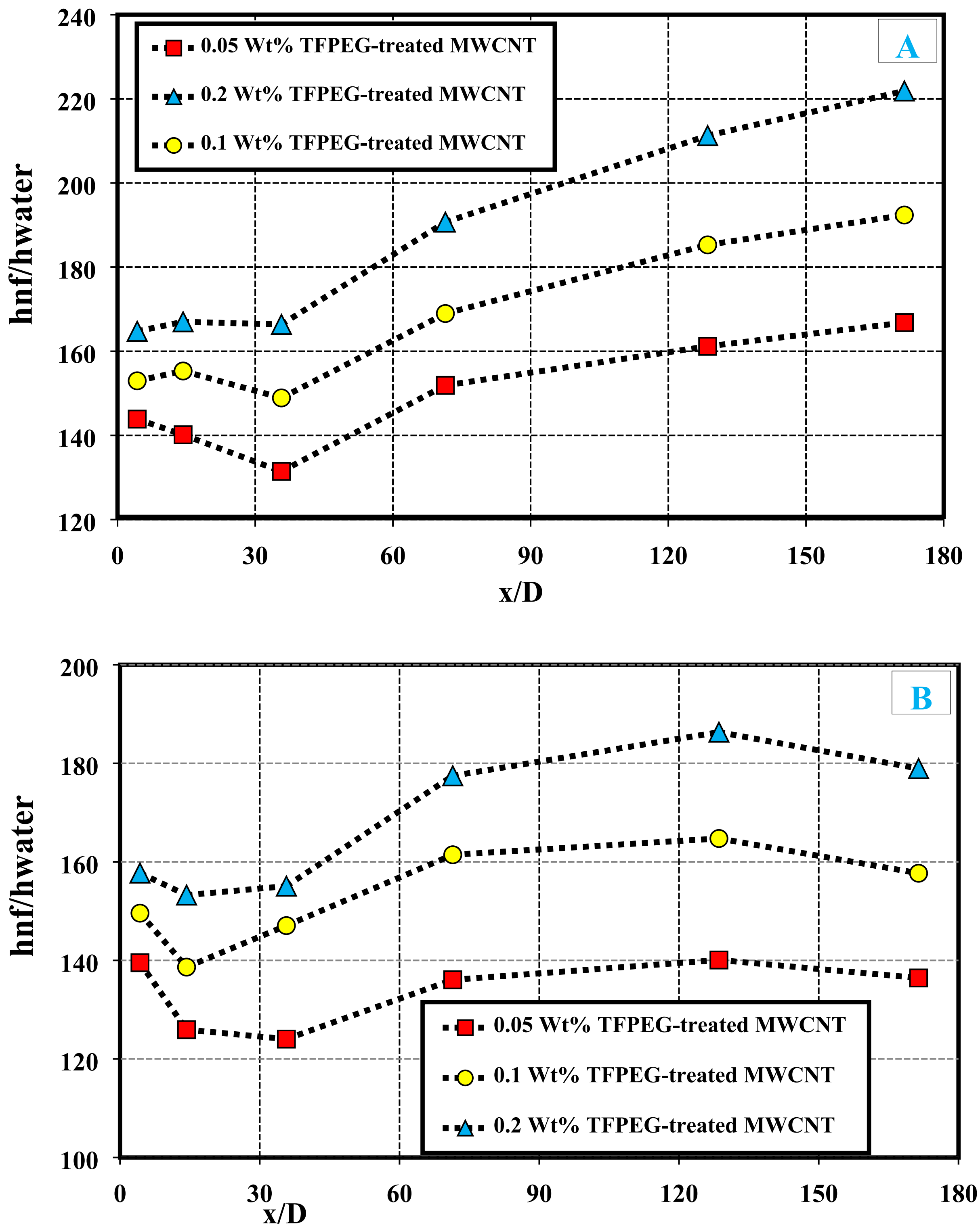

Figure S_3. Measured convective heat transfer coefficient of PMWCNT-based water nanofluids at different weight concentration with respect to water.

Nusselt Number

Figure S_4 illustrates the measured Nusselt number of PMWCNT-based water nanofluid at weight concentration of 0.1% for different Reynolds numbers. It is observed that the Nusselt number decreases quickly with the increase in x/D. Also, as the Reynolds number increases, the Nusselt number increases.

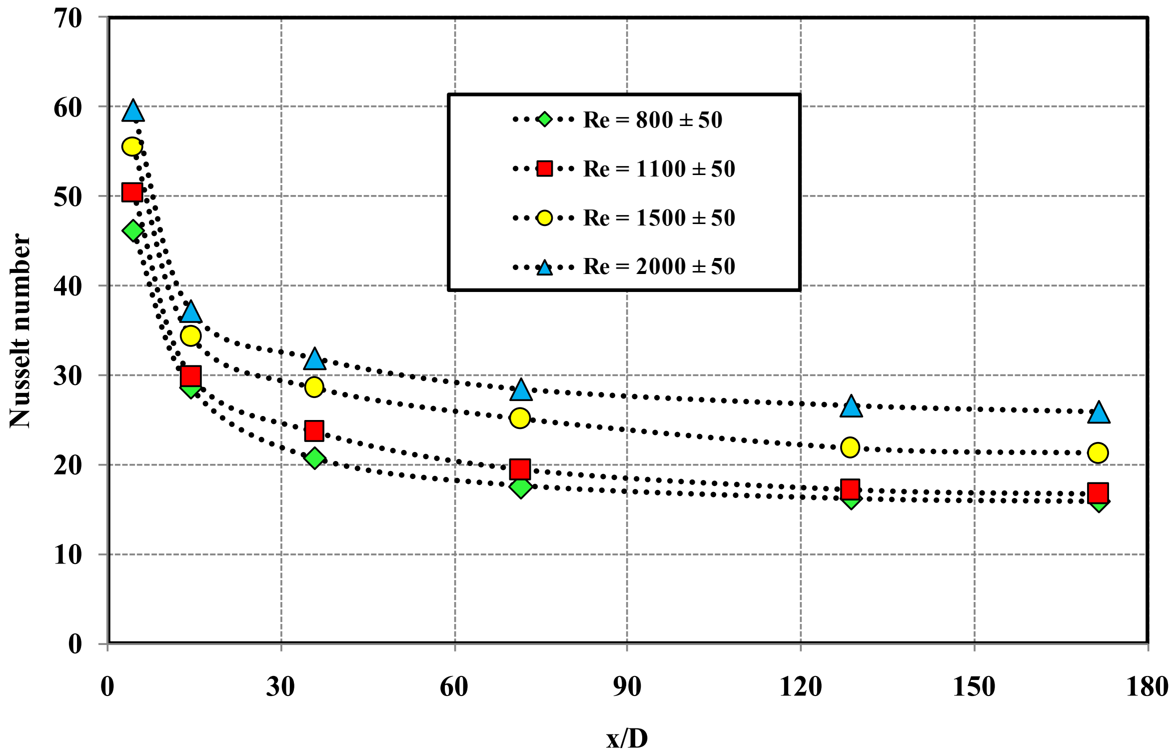

Figure S_4. The measured Nusselt number of PMWCNT-based water nanofluid at weight concentration of 0.1% at different axial distances.

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