Electrically tested nanofluids on printed mini channels

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ABSTRACT – The behavior of nanofluids bathed in constricted channels was observed by exciting these fluids with a low electrical potential. It was hypothesized that currents should flow through them because carbon is naturally a semiconductor. The results showed little currents were flowing in the circuit as the fluids recorded high resistances. However, the real nature of the fluids exposed to electrical potentials for a longer duration was still unknown.

1. INTRODUCTION

1.1 Experimental channel

Experimental channels (ECs) are canals that deliver chemical samples or analytes. The channels can be fabricated in polymers, silicon, glass, and metals. As such, the corresponding dimensions of the channel should be exceedingly small. There are various processes used to fabricate an EC that include surface micromachining, molding, bulk micromachining, embossing and micro cutting.

In general, there are two types of ECs. One is a channel for fluid control, and the other one is for heat transfer. The ECs have important applications in microdevices. It is due to their high surface-to-volume ratio and their small volumes [1]. The fluid flow and heat transfer in ECs have various applications in electronics, bioengineering, advanced fuel cells, and micro heat exchangers.

Channels are human-made systems. The transport processes occur across the channel walls. Meanwhile, the bulk flow takes place through the cross-sectional area of the channel. Thus, the channel cross-section acts as a duct to transport fluid to or away from the channel walls.

A channel aims to fulfill two objectives; First is to bring fluid into close contact with the channel walls and second is to bring fluid to the walls and remove fluid away from the walls as the transport process is achieved.

The rate of the transport process of the fluids depends on the surface area. For a circular tube, the surface area is varied with the diameter. Meanwhile, the flow rate depends on the cross-sectional area. Thus, this varies linearly with the square diameter, which means the tube surface area to volume ratio changes as the reciprocal of the diameter. When the diameter is decreased, surface area to volume ratio is increased. The diameter that affects the channel is called the hydraulic diameter [2].

The channel classification is based on the hydraulic diameter. A smaller channel size has different effects on different processes. Table 1 lists the classification with their respective hydraulic diameters range. Equation (1) defines the hydraulic diameter of a rectangular channel where B is the width and C is the depth of the channel.

$$\square_{\square} = \frac{2\square\square}{\square+\square} \quad (1)$$

Table 1 The channel classification scheme [2]

№	Channel type	Hydraulic diameter, $\square_{\square}$
1	Conventional	$\square_{\square} > 3\square\square$
2	Mini	$200\square\square < \square_{\square} \leq 3\square\square$
3	Micro-	$10\square\square < \square_{\square} \leq 200\square\square$
4	Transitional micro-	$1\square\square < \square_{\square} \leq 10\square\square$
5	Transitional nano-	$0.1\square\square \leq \square_{\square} \leq 1\square\square$
6	Nano-	$\square_{\square} \leq 0.1\square\square$

1.2 Nanoparticles

Among nanoparticles, carbon nanotubes (CNT) has the highest thermal conductivity. Macroscopic assemblies of CNTs seem to be advantageous as lightweight and highly conductive wires can be obtained. Nanofluids are considered as a passive technique, but also a promising way for advanced thermal fluid science. Any efforts to deploy them as heat transfer fluids by dispersing them into any kinds of base fluids called CNT nanofluids [3].

In preparing for the CNF-based nanofluid, the CNF powder was mixed with the base fluids containing ethylene glycol and deionized water to synthesize the CNF-based electrode. The reason for using ethylene glycol (EG) and deionized water (DW) as the base fluid was because they are the primary liquid base for convective heat transfer [4].

This work sought to observe how the nanofluids respond to electricity on constricted channels by exciting these fluids with a low electrical potential.

2. RESEARCH METHODOLOGY

2.1 Channel development

The channels were fabricated using the Vagler 3D printer. Before the channel was printed, their shape must be drawn. The outline of the channels is of an S-shape. SolidWorks was utilized to construct the channels in the 3D model. The model was later being sliced into a large number of horizontal layers. The file would be uploaded

to the 3D printer.

Table 2 lists the channels' dimensions. Channel-2 is much smaller than channel-1, regarding, the hydraulic diameter. Both of the channels are categorized as mini channels as their hydraulic diameter falls with the range shown in Table 1. Figure 1 shows the printed mini-channels.

Table 2 The channel's basic dimensions. Based on the values of the hydraulic diameter, we categorize our channels as mini channels, according to the listing of Table 1.

Channel №	Length (□□)	Width (□□)	Depth (□□)	Hydraulic diameter (□□)
1	284	2	5	2.86
2	284	1	5	1.67

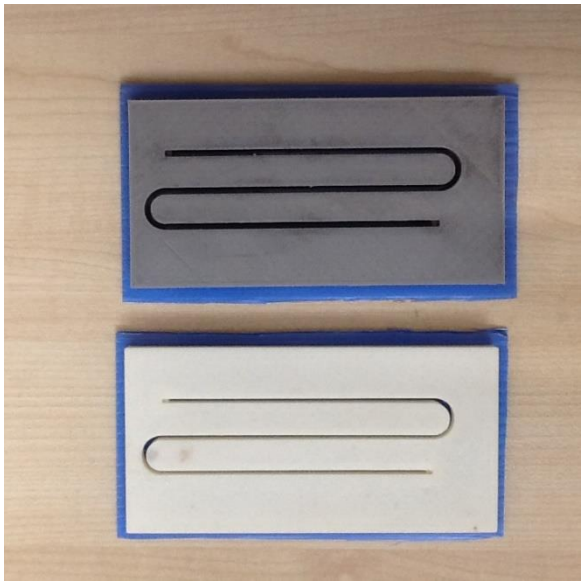

Figure 1 The mini-channels that were produced by 3D-printing using ABS filament. Channel-1 (above, gray) hydraulic diameter is 2.86 mm while channel-2 (below, white) hydraulic diameter is 1.67 mm.

2.2 Nanoparticle preparation

Figure 2 shows nanofluid samples with respective percent weight used in this work. There are three CNT-based and another three CNF-based liquids. The bottles labeled with green stickers that mark the respective liquids according to the percent weight. The samples have different values of concentration. From left the concentration in %wt for each sample fluid are: CNF\0.3, CNF\0.6, CNF\0.9, CNT\0.3, CNT\0.6, CNT\0.7.

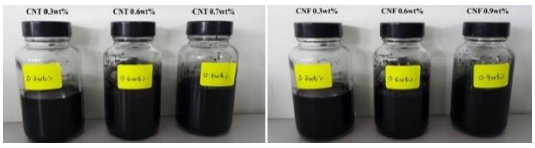

Figure 2 The samples of CNT and CNF used in the experiment.

2.3 Experimental setups

A direct current power supply of low voltage was used to provide the potential across the circuit depicted in Figure 4. The schematic is showing the power supply, the standard resistor (R1), the channel that holds the fluid resistant (R2), and how the electrical behavior would be evaluated. The supply voltage was a fixed 5V.

The equipment used in assessing the samples electrical response was the Digilent Analog Discovery (DAD), the AMPROBE PM51A multimeter, a generic digital multimeter, and general model analog and digital multimeters. The DAD provides a USB Oscilloscope and power supplies. So, the power supply came from the DAD while the measurement from the DAD and also the multimeter. The generic multimeter was used to check for circuit continuity.

A low voltage supply would induce stress to the bathed channel (R2) so that how the fluid would respond to the electrical potential across it may be observed. There is a standard resistor (R1) connected in series with the channel. It works as a transducer that would confirm the existence of current flow in the circuit by measuring the voltage across it.

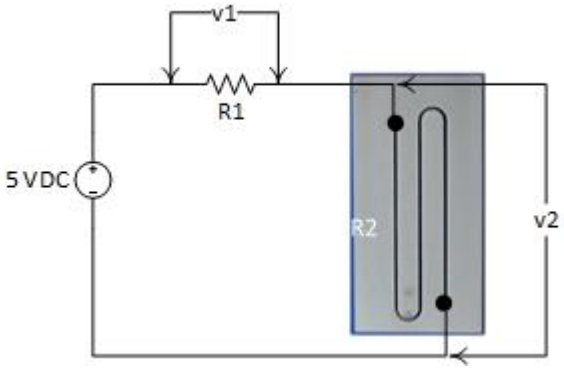

Figure 3 The schematic used to run the tests.

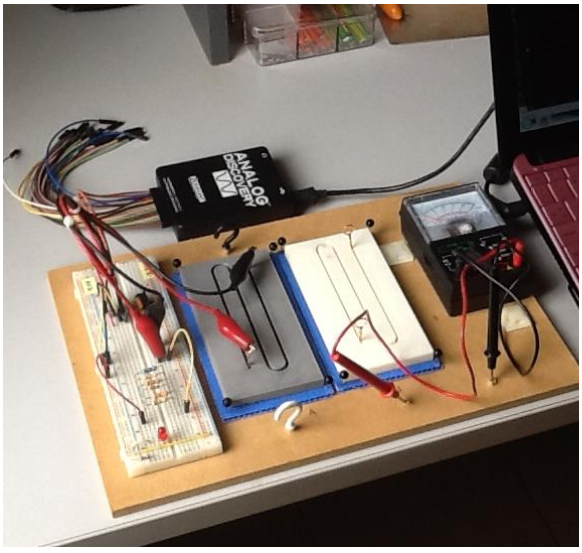

Figure 4 The resistances obtained by direct measurement on the channels bathed with the samples.

3. RESULTS AND DISCUSSION

Table 3 lists the results for CNT of 0.3%wt. Since the sample has high resistance, the voltage drop across it was high enough comparable to the supply voltage. The only observable potential was found across R1 because of very small resistance relative to R2. The results showed that as the resistance of R1 increased the voltage drop across it also showed the same symptom. At the same time, the potential across R2 slowly decreased. The current, however, did not exhibit drastic change. Throughout all the tests, the current was reaching saturation.

The results in Table 3 to Table 8 summarize the behavior of the nanofluids of different concentration when excited by a low voltage power source. Tiny currents were recorded flowing in the circuit. The phenomenon was apparently due to a low potential and a very high overall circuit resistance.

The voltage drops were obtained by direct measurement using a multimeter on the simple network that consists of a power supply and an assortment of resistors in series with the bathed mini-channels. The channels act as a resistor module, R2. When tested on channel-1, the sample of CNTs exhibit increased in the current flow as the liquid concentration decreased. Also, CNFs exhibit increased in the current flow as the liquid concentration decreased.

Table 3 CNT of 0.3% wt.

Actual Resistance □1 (Ω)	In series with Channel 1			In series with Channel 2		
	□1 (□□)	□2 (□)	□ (□□)	□1 (□□)	□2 (□)	□ (□□)
40.90	0.30	5.00	7.33	0.10	5.00	2.44
56.50	0.40	5.00	7.08	0.20	5.00	3.54
217.20	2.40	4.99	11.05	1.40	4.99	6.45
466.00	5.60	4.99	12.02	3.20	4.99	6.87
994.00	12.30	4.98	12.37	10.60	4.98	10.66

Table 4 CNT of 0.6%wt.

Actual Resistance □1(Ω)	In series with Channel 1			In series with Channel 2		
	□1 (□□)	□2 (□)	□ (□□)	□1 (□□)	□2 (□)	□ (□□)
40.90	0.1	5.00	2.44	0	5.00	0.00
56.50	0.4	5.00	7.08	0.3	5.00	5.31
217.20	2.1	5.00	9.67	1.4	5.00	6.45
466.00	4.9	4.99	10.52	3.3	4.99	7.08
994.00	10.6	4.98	10.66	7.4	4.99	7.44

Table 5 CNT of 0.7%wt

Actual Resistance □1 (Ω)	In series with Channel 1			In series with Channel 2		
	□1 (□□)	□2 (□)	□ (□□)	□1 (□□)	□2 (□)	□ (□□)
40.90	0.2	5.00	4.89	0.1	5.00	2.44
56.50	0.3	5.00	5.31	0.3	5.00	5.31
217.20	1.7	4.99	7.83	1.5	4.99	6.91
466.00	3.9	4.99	8.37	3.3	4.99	7.08
994.00	8.9	4.99	8.95	7.4	4.99	7.44

Similarly, when tested on channel-2, the sample of all CNTs and CNFs allowed some current to flow in the circuit, except CNT of 0.3%wt allowed the largest current. It was evident that minute current was flowing in the circuit proving that the nanofluids were naturally electrolytic of high resistant.

Table 6 CNF of 0.3%wt

Actual Resistance □1 (Ω)	In series with Channel 1			In series with Channel 2		
	□1 (□□)	□2 (□)	□ (□□)	□1 (□□)	□2 (□)	□ (□□)
40.90	0.1	5.00	2.44	0.3	5.00	7.33
56.50	0.3	5.00	5.31	0.2	5.00	3.54
217.20	1.8	4.99	8.29	1.5	4.99	6.91
466.00	4.1	4.99	8.80	3.5	4.99	7.51
994.00	9.0	4.98	9.05	7.8	4.98	7.85

Table 7 CNF of 0.6%wt

Actual Resistance □1(Ω)	In series with Channel 1			In series with Channel 2		
	□1 (□□)	□2 (□)	□ (□□)	□1 (□□)	□2 (□)	□ (□□)
40.90	0.2	5.00	4.89	0.1	5.00	2.44
56.50	0.3	5.00	5.31	0.2	5.00	3.54
217.20	1.9	4.99	8.75	1.3	4.99	5.99
466.00	4.3	4.99	9.23	3.0	4.99	6.44
994.00	9.4	4.98	9.46	6.7	4.99	6.74

Table 8 CNF of 0.9%wt

Actual Resistance □1 (Ω)	In series with Channel 1			In series with Channel 2		
	□1 (□□)	□2 (□)	□ (□□)	□1 (□□)	□2 (□)	□ (□□)
40.90	0.1	5.00	2.44	0.1	5.00	2.44
56.50	0.3	5.00	5.31	0.2	5.00	3.54
217.20	2.1	4.99	9.67	1.5	4.99	6.91
466.00	4.8	4.99	10.30	3.4	4.99	7.30
994.00	10.4	4.98	10.46	7.5	4.98	7.55

4. SUMMARY

Two mini channels were constructed using additive manufacturing approach. The nanofluids filled up the channels where they were subjected to electricity to see their response to a small voltage. Minute currents were recorded flowing through the fluids for a short period. The fluids themselves were found to have high resistances. However, the real nature of the fluids exposed to electrical potentials for a longer duration is

unknown.

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