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INSOLUBLE NANO-POWDERS ADDITIVES ENHANCING THE FLOW OF LIQUID IN MICROCHANNEL: EFFECT OF PARTICLE SIZE

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ABSTRACT

Drag reduction is introduced by Toms, using polymers and surfactants as drag reducing agents. This technique is greatly applicable in industries and researches nowadays. Insoluble Nano-powder additives, in the present research, are introduced to enhance the flow of liquid in microchannel. Investigation on the effect of variable concentration (100 to 500 ppm) of three different sizes (7 nm, 200-300 nm and 500-700 nm) Fumed Silica (SiO_2) with 100 μm micro-channels by varying the flow rate, using syringe pump, on drag reduction is carried out. Higher concentration of Nano-powder solution has a positive effect on drag reduction, meanwhile, bigger particle size and addition of surfactant in Nano-powder solution has a negative effect on the performance of drag reduction. Maximum drag reduction up to 56% is achieved by using 500 ppm of 200-300 nm fumed silica. This breakthrough discovery may help to speed up the improvement in medical field.

Keywords: insoluble additives, nano-powder, micro-channels, drag reduction.

INTRODUCTION

Toms, pioneer in introducing drag reduction (DR) when he discovered unusual low friction factor after adding minute amount (part per millions) of high molecular weight polymers which later known as "Toms effect" (Truong, 2001). Since then, many researchers introduced and investigated both active (Abdulbari *et al.* Al-Sarkhi and Hanratty, 2001, Al-Sarkhi, 2010) and passive drag reduction techniques (Abdulbari *et al.* 2013, Kodama *et al.* 2000, Madavan *et al.* 1985).

Active drag reduction technique, by using different drag reducing agents (DRA) such as polymers (Abubakar *et al.* 2014, Al-Sarkhi, 2012, Benzi, 2010, Iaccarino *et al.* 2010, Resende *et al.* 2011) and surfactants (Drzazga *et al.* 2013, Li *et al.* 2008, Różański, 2011, Yu and Kawaguchi, 2006, Tuan and Mizunuma, 2013, Qi *et al.* 2011, Abdulbari *et al.* 2011b), were studied to compare in term of their performance. This is then greatly applicable in many fields such as pipelines, oil well operations, flood water disposal, firefighting, field irrigation, transport of suspensions and slurries, water heating and cooling systems, airplane tank filling, marine systems (Abdulbari *et al.* 2013), also drug discovery and delivery (Zhao, 2013, Weibel and Whitesides, 2006, Khan *et al.* 2013).

Surfactants play an important role for DR since the polymeric DRA has been found to be degraded with time and lost its effectiveness when exposed to high shear stress (Marhefka *et al.* 2008). Xia *et al.* (2008) reported that 30% of DR was achieved using non-ionic surfactant of Alkyl Polyglycoside (APG) comparing to 20% when using anionic Sodium Dodecyl Sulphate (SDS) surfactant in micro-channel. Same observations were also reported by Ushida *et al.* (2010, 2011) indicate that non-ionic surfactant has a greater potential in DR. However, due to the properties of non-ionic surfactant, which do not carry any charges, limits its performance in DR. Furthermore, it is proven that non-ionic surfactants only work well in limited range of concentration and temperature (Abdulbari *et al.* 2013).

In order to replace polymers and surfactants as DRA, many researchers have studied the feasibility of using insoluble additives to enhance the flow in pipes due to the non-degradable and non-reactive nature properties of insoluble additives (Abdulbari *et al.* 2011a, Akindoyo and Abdulbari, 2015). Therefore, in this study, insoluble additives, i.e., Nano-powders were introduced to enhance the flow of liquid. Microchannel was used in conducting this experiment to replace the conventional way as pipes can lead to several problems e.g., long preparation time and large amount of reagents used thus contribute to environmental problems (Philippe Nghea, 2010). Nano-powder solutions were injected through micro-channels and the percentage of drag reduction was calculated. Different parameters were investigated in this research including the effect of particles size and concentration of Fumed Silica. In addition, the effect of addition of surfactant into the Nano-powder solutions was also being investigated. The aim of this research is to study the feasibility of using insoluble Nano-powders as DRA. The results may contribute to medical field where insoluble additives can be used to enhance the flow of blood in semi-clogged blood stream. The microchannel was used to stimulate the semi-clogged real blood stream. Note that the investigated insoluble Nano-powders are not intended for use in human blood streams.

EXPERIMENTAL PROCEDURE MATERIAL AND SOLUTION PREPARATION

In this work, Fumed silica (SiO2) also known as pyrogenic silica provided by Sigma-Aldrich and distilled water were used to make Nano-powder solution. As quantified by the vendor, the particle sizes are 7 nm, 200-300 nm and 500-700 nm. The specious physical properties of the nominated powder are shown in Table-1.

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Table-1. Fumed Silica physical properties.

Assay	99.99% Purity
Shape	Spherical
Surface area	180-600 m^2/g
Bulk density	2.4 g/cm^3

From Table-1, it is shown that the density of the insoluble additives is double of density of water. The movement of the insoluble additives was by the force of flowing water where the energy of the flowing water would carry the particle and hence would not be affected by gravitational force. In this work, Nano-powder with different sizes was dissolved in distilled water by magnetic stirrer to produce Nano-powder solution with five different concentrations ranging from 100 ppm to 500 ppm. In order to gain optimum dispersion, the fluids were homogenized for at least 4 hours with magnetic stirrer and before each experiment start, the solution need to be stirred again for 2 hours in order to avoid agglomeration.

In additional, surfactant was used in order to produce stable Nano-powder solution. By adding surfactant in insoluble additives solution, the "micelles" formed by surfactant would wrap the insoluble additives thus ensuring the uniformity distribution of insoluble additives in the transported liquid. For this purpose, Glycolic Acid Ethoxylate Lauryl Ether as the surfactant agent was dissolved and mixed to Nano-powder solution.

EXPERIMENTAL SET-UP

An experimental apparatus was erected as shown in Figure-1 for obtaining drag reduction data at wide range of Nano-powder concentrations.

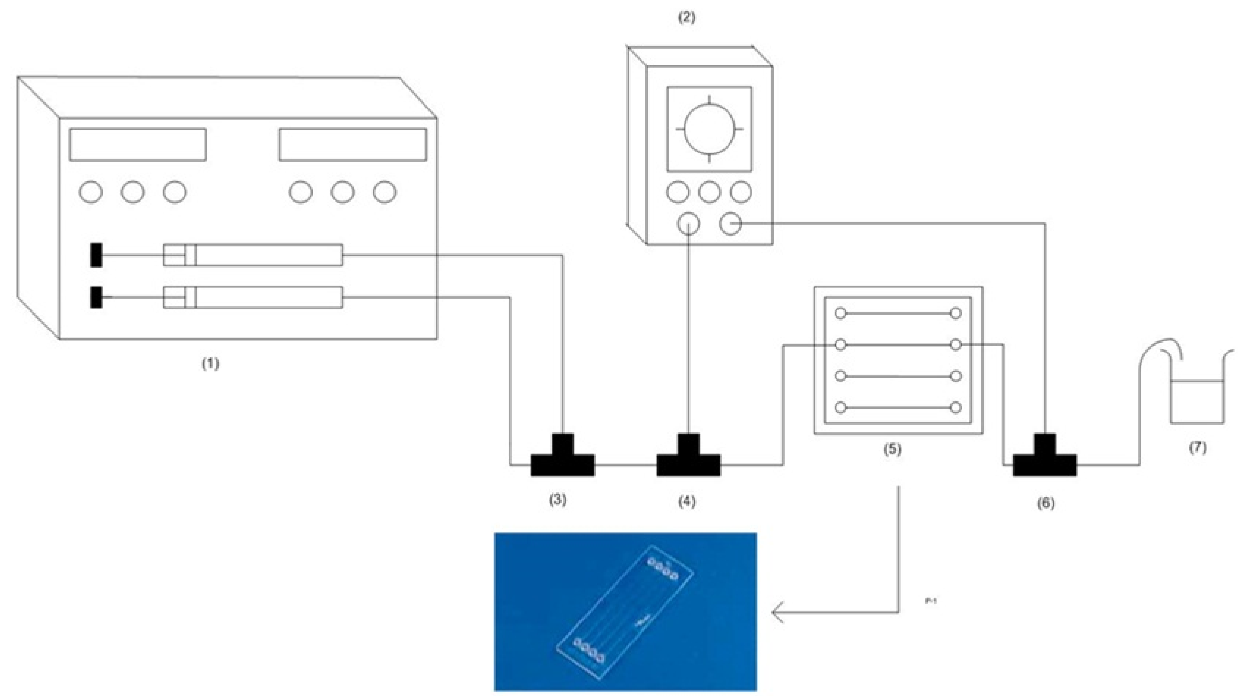

Figure-1. Schematic Diagram of experimental set-up. (1) Syringe pump, differential pressure transmitter, (3, 4 and (6) T-junction, (5) Microfluidics Chip and (6) collection beaker.

The experimental setup comprised of syringe pump (model: SN-50F6), costume-made thermoplastic polymer (Topas) straight micro-channel (size: 100 μm) provided by Chip-shop in Germany, a differential pressure transmitter (model: STK336) with 0.001 mbar precision, tube connection and a beaker as storage tank. The structure started with the connection of a syringe pump with two syringes to the first T-junction connected by tube. The inlet of the pressure transmitter was connected to the second T-junction while the outlet was connected to the third T-junction where through the micro-channel was in between in order to measure the pressure gradients. Finally, the remaining Nano-powder solution coming out from the third T-junction was collected in the beaker.

EXPERIMENTAL PROCEDURE

All the experiments were controlled in an assembled liquid circulation system, experimenting different variables:

i. Nano-powder size (7, 200-300 and 500-700 nm)
ii. Suspended solid concentration (100, 200, 300, 400 and 500 ppm)
iii. Solution flow rates (1000, 1100, 1200, 1300, 1400 and 1500 ml/h)

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The procedure began by testing every different size and concentration of the drag reduction agent, the operation started when the syringe pump delivered the solution across the tube length. Required flow rate was manipulated by using syringe pump. By varying the solution flow rate, pressure drop readings measured to the flow rate were recorded. This method was repeated for each Nano-powder solution concentrations to check its effect on the DR operation.

From the flow rate capture, the velocity of flow (V) is calculated depending on area of micro-channel. Then, the Reynolds Number is found out by the formulae as follows:

$$N_{Re} = \frac{\rho V D}{\mu} \qquad (1)$$

where

ρ = density of water (kg/m^3)
V = velocity (m/s)
D = diameter of micro-channel (m)
μ = viscosity of water ($Pa.s$)

Pressure drop readings before and after the addition of DRA were needed in order to find the percentage of drag reduction (%DR) based on the formulae below:

$$\%DR = \frac{\Delta P_b - \Delta P_a}{\Delta P_b} \times 100 \qquad (2)$$

Where
ΔP_b = pressure drop before the addition of DRA
ΔP_a = pressure drop after the addition of DRA.

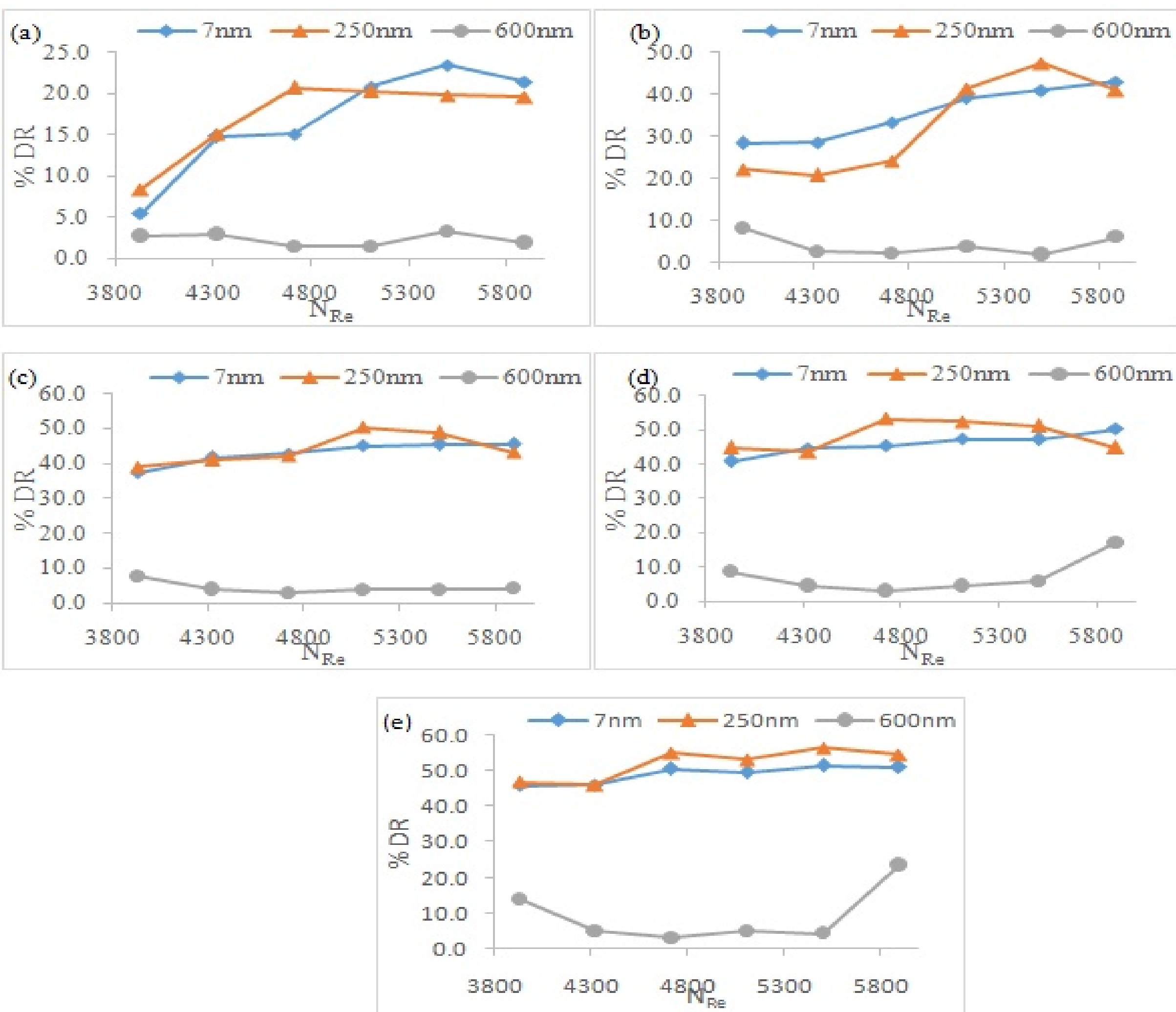

Figure-2. Variation of %DR with different particle size of Fumed Silica with concentration of (a) 100ppm (b) 200ppm (c) 300ppm (d) 400ppm (e) 500ppm in 100µm micro-channel size.

RESULTS AND DISCUSSIONS

A series of experiments were performed to study the effects of particle size and Nano-powder solutions concentration in drag reduction. In addition, the effect of addition of surfactant in Nano-powder solution was also investigated.

EFFECT OF PARTICLE SIZE

Figure-2 shows the percentage of drag reduction versus Reynolds Number for different particle size of Fumed Silica. It was obvious that the 600 nm Fumed Silica had the lowest drag reduction performance where the %DR did not exceed 20% for all concentration. In contrast, smaller particle size of Fumed Silica gave higher %DR where both 7 and 250 nm Fumed Silica achieved around 50% and 60%, respectively, when the concentration was 500 ppm. It is believed that, reducing the particles size will increase the number of particles interacting with the turbulence structures (at the same concentration used for larger particle size) and that will enhance the drag reduction performance. Within the same flow conditions (turbulence intensities), larger particles will interact in a different manner when compared to the smaller ones. The amount of momentum consumed or needed to maintain the suspension condition of the larger particles is higher and that will lead to the breakup the balance monitored with the smaller ones. It is believed that, for higher degree or turbulence, higher NRe, the drag reduction effectiveness of the large particles will be higher due to the balance between the turbulence and the particles size, shape, density and concentration. Such very high degree of turbulence is not achievable in the present work due to the channel size limitations that allows certain NRe range. (Abdulbari *et al*. June 2010).

From Figure-2 (e), there was a sharp increase of %DR for higher degree of turbulence, NRe=5800. This is due to the setup point that determines the optimum flow and drag reduction conditions i.e, at 500 ppm, the optimum degree of turbulence needed to keep the 600 nm particles interactive with the flow media was at NRe = 5800. It is expected that, if further increase in the value of NRe, the %DR will continue to increase until it reach its maximum value at optimum NRe.

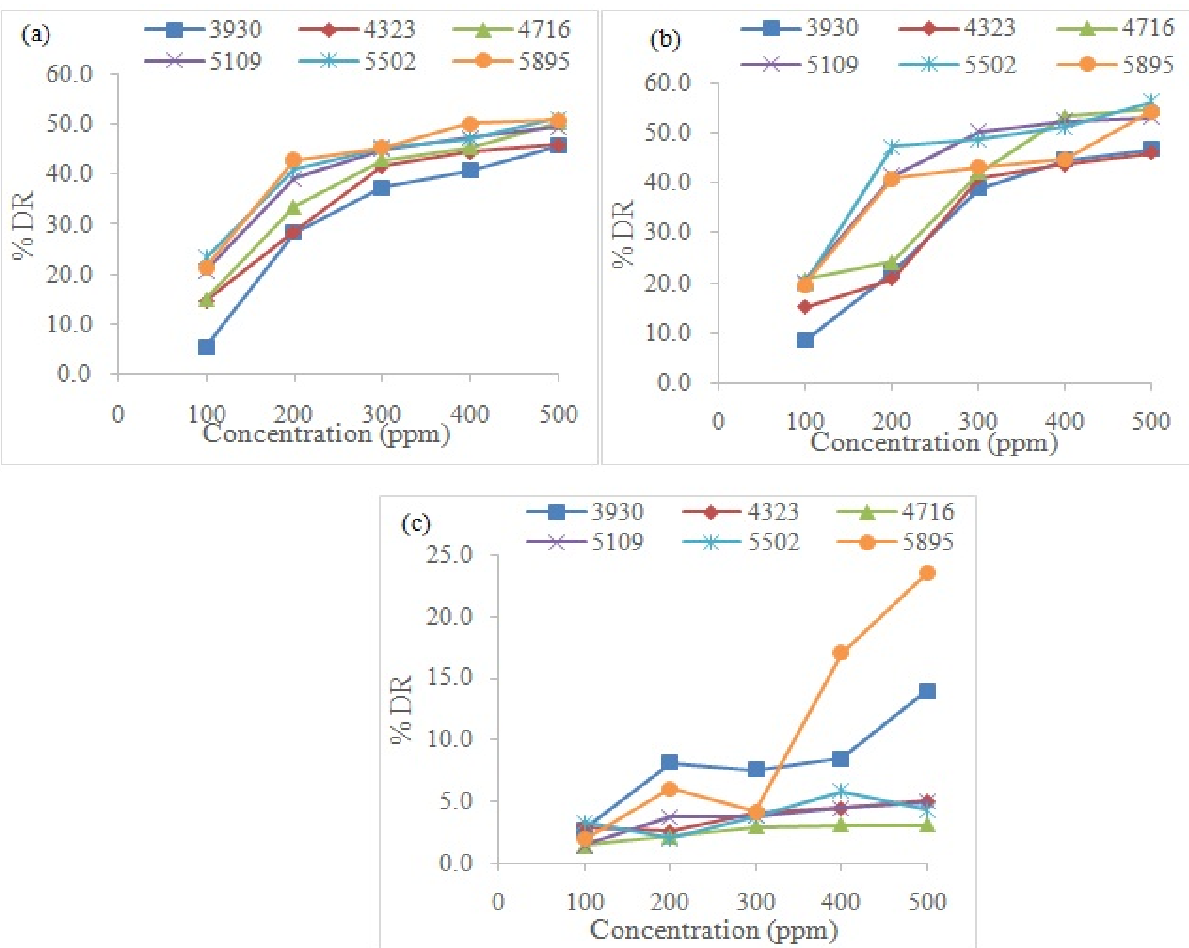

Figure-3. Variation of %DR with different Nano-powder solution concentration with particle size of (a) 7nm (b) 250nm (c) 600nm in 100µm micro-channel size.

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EFFECT OF NANO-POWDER SOLUTION CONCENTRATION

Figure-3 depicts the percentage of drag reduction versus concentration for different Reynolds number. From the results obtained, it shows that by increasing the concentration of the Nano-powder solution, the %DR has increased. Higher concentration of Nano-powder solution provides bigger platform for the Nano-powder to perform as drag reduction additives in micro-channel (Sun *et al.* 2014). Increasing the Nano-powder concentration means increasing the numbers of particles involved in the drag reduction operation. This also means that the turbulence spectrum covered by the insoluble additives will be higher and more turbulence will be suppressed.

EFFECT OF ADDITION OF SURFACTANT

In this study surfactant (Glycolic acid Ethoxylate lauryl ether) is added to the Nano-particle solution in order to ensure uniform distribution in the transported liquid. The surfactants themselves are considered as drag reducing agents and their effectiveness was recognized and reported in many literatures. In the present work, the purpose of using the surfactants was to ensure the best possible particles distributions. The surfactant drag reduction performance was tested. The test was conducted at different concentrations (200 to 800 ppm) and with different NRe. The results did show that a maximum %Dr of 26% is achievable at 800 ppm and within the operation conditions. The 800 ppm is the minimum concentration needed to create an optimum particles distribution. Figure-4 shows that, in all cases, the %DR achieved by the Nano-powders solutions was the highest followed by surfactants solutions alone. It is also obvious that the performance of Nano-powder solutions mixed with surfactant was the lowest where negative %DR was observed too.

Figure-4 (a) shows the effect of surfactant concentration on the drag reduction performance of 7 nm fumed silica. This figure compares the drag reduction before and after the addition of surfactant with two different concentrations (200 and 800 ppm). It is very interesting to see that, the surfactants used (Glycolic Acid Ethoxylate Lauryl Ether) had negative effect on the drag reduction performance of the 7nm powder where the maximum %DR was reduced from almost 50% to 10% when adding 200 ppm of the surfactant and reduced further to -10% when increasing the surfactant concentration to 800 ppm. Such surprising behavior might be due to the very complex relation between soluble and insoluble additives when forming complexes. Knowing that the surfactant have an excellent drag reduction performance published earlier by Hayder et.al (Abdulbari and Hawege, 2015, Abdulbari and Yunus, 2009), its performance with Nano-powders was completely different (altering). The same behavior was observed with larger fumed silica particles sizes (Figure-4 (b)). Increasing the particles size to 600 nm eliminated the surfactant effect in most of the experimental points with slight enhancement in the drag reduction performance (Figure-4 (c)). It is believed that the surfactant aggregates "micelles" will be formed in the solution and these aggregates will attract Nano-particles to agglomerate and form bigger masses in the main flow and that will reduce the Nano-particles distribution in the solution which will lead to the reduction in turbulence suppression effect.

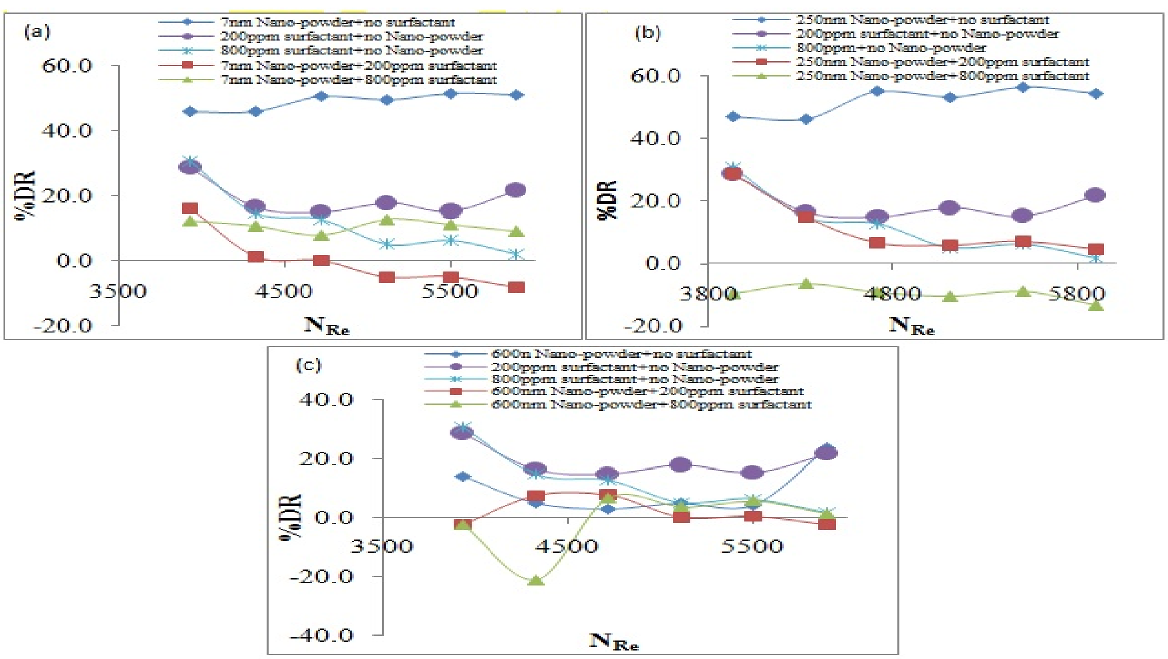

Figure-4. Variation of %DR with different Glycolic Acid Ethoxylate Lauryl Ether concentration with particle size of (a) 7nm (b) 250nm (c) 600nm in 100µm micro-channel size.

CONCLUSIONS

It is observed that the performance of DR increases with the increasing of concentration of Nano-powder solution. Bigger size of Nano-powder does not have positive effect on DR. The maximum DR is achieved by 200-300 nm particles size Fumed Silica at 500 ppm whereas 600 nm Fumed Silica only achieved %DR less than 20%. Moreover, the addition of surfactant in Nano-powder solution decreases the performance of DR. It is believed that the phenomenon is due to the "micelles" formed from surfactant aggregates which will attract Nano-particle to agglomerate and thus reduce the distribution in the solution.

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