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Insoluble additives for enhancing a blood-like liquid flow in micro-channels*

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Abstract: This study introduces an approach for flow enhancement in the bloodstream using insoluble additives as non-degradable drag reducing agents that can replace the polymeric soluble additives. An open micro-channel liquid flow system with three different channel sizes was assembled and used to test the drag reduction performances of the solutions investigated. Three different nano-powders (with five different addition concentrations) were investigated and used to form solutions of artificial blood with blood-like rheological properties. The experimental results showed that the optimum drag reduction performance was achieved using bismuth III oxides (65%) for a 200 ppm concentration solution flowing through a 100 μm channel, while titanium IV oxides and fumed silica achieved 57 and 55% drag reduction for a 200 ppm concentration solution flowing in a 50 μm channel, respectively.

Key words: Microchannels, pressure drop, drag reduction, nano-powder additives

Introduction

Flow enhancement in pipes and conduits using minute quantities of viscoelastic polymeric additives was first introduced by Toms in the early 1940s. Since then passive[1-4] and active[5-8] drag reduction techniques were introduced and tested by many researchers. Active drag reduction techniques inspired many researchers to introduce different drag reducing agents (DRAs) that can enhance the liquid flow in pipes up to 80% by addition of only a few parts per million of additives. This phenomenon was easily incorporated into many industrial applications, such as pipeline transportation, firefighting, drag reduction in marine vessels, slurry transportation, and heat transfer, among many others.

One of the important medical applications for the drag reduction phenomenon is the enhancement of blood flow in blood streams using long chain polymeric additives[9-11]. Several authors reported a substantial reduction in blood pressure and degree of turbulence by injecting low concentrations of polyethylene oxide (PEO)[12-15]. This polymeric additive was highly capable of laminarizing the turbulent blood flow structures (eddies) and reducing the pressure fluctuation along the blood stream. It was also found that the addition of a long chain polymeric DRA to RBC-phosphate-buffered saline could reduce the thickness of the plasma layer in an artificial macrovesicle system. One of the conditions for any additive to distinguish itself as a drag reducing agent is its solubility in the flow media, a criterion that reduced the availability of economically feasible additives that can be safely used to improve flow in blood streams[16]. Although the tested soluble additives showed excellent drag reduction performance in blood streams, their health effects are not yet completely known due to the artificial nature of these additives and the potential risk of degradation due to the possibilities of reactions with other components of the blood.

The flow of liquids in microchannel was utilized to simulate the flow behavior in real blood streams. It is known that most of the blood flow in the human normal blood vessels is laminar, but turbulent flow will occur when clogged blood vessels are investigated[16]. Superhydrophobic surfaces are considered the

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Table 1 Bismuth (III) oxide powder physical properties

Assay	Shape	Particle size	Surface area	Bulk density
99.8% trace metal basis	Spherical	55 nm-80 nm	BET surf. area 3.2 m^2/g-3.5 m^2/g	8.9×10^{-6} gm/m^3

Table 2 Titanium (IV) oxide powder physical properties

Assay	Shape	Particle size	Surface area	Bulk density
99.99% trace metal basis	Spherical	40 nm-60 nm	BET surf. area 50 m^2/g (±18)	4.3×10^{-6} gm/m^3

Table 3 Fumed silica powder physical properties

Assay	Shape	Particle size	Surface area	Bulk density
99.99% Purity	Spherical	80 nm	255 m^2/gm	0.07×10^{-6} gm/m^3

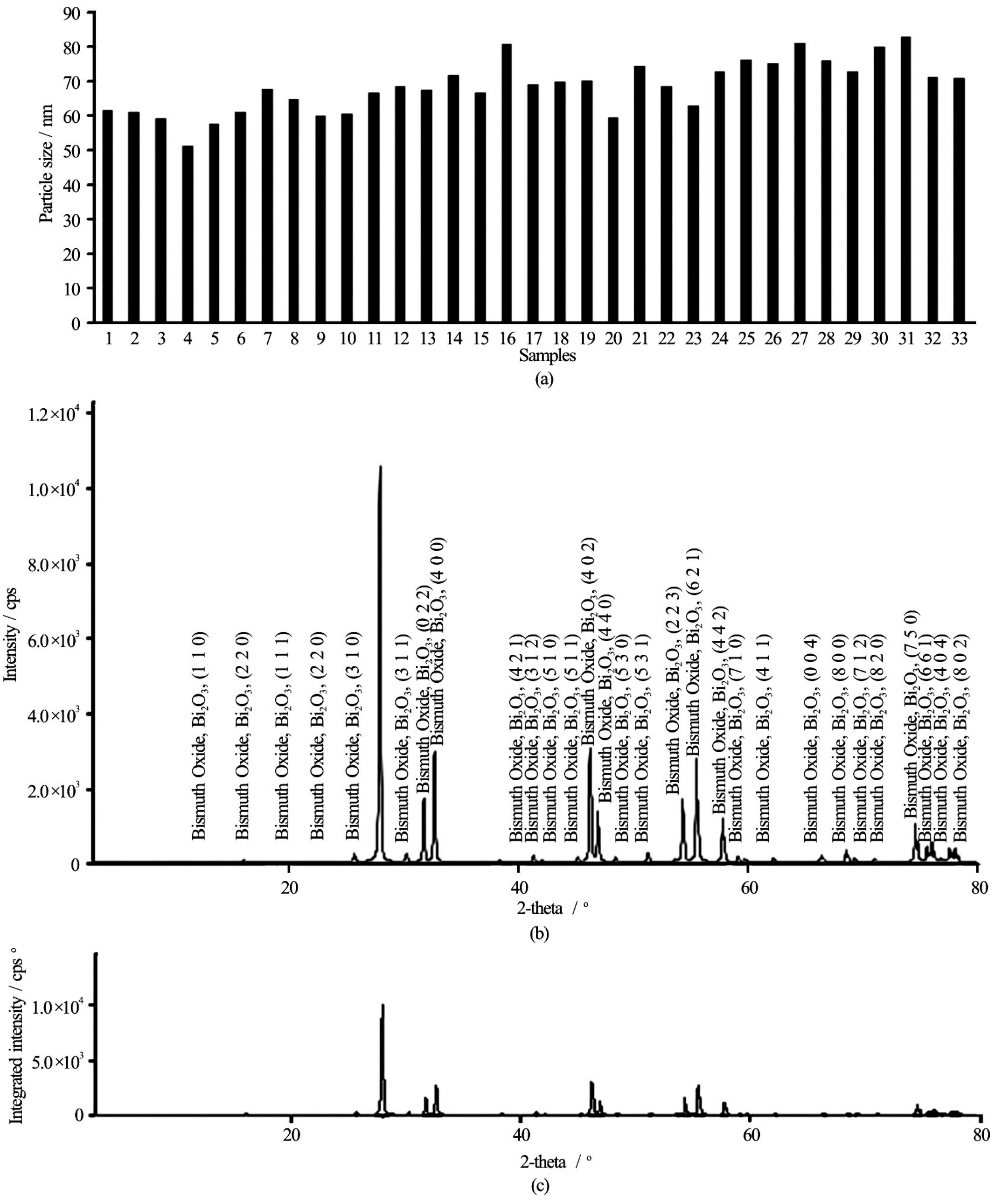

Fig.1 Particles size distributions of the Bismuth (III) oxide powder using XRD