AN EXPERIMENTAL INVESTIGATION FOR WATER FLOW ENHANCEMENT IN HORIZONTAL PIPES BY USING NANOPARTICLES

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Abstract
This work has been devoted to investigate experimentally, the increase in range of horizontal discharge distance and velocity of water flow for pipes of fire-hoses and water jet propulsion systems in small ships. The enhancement method of water flow depends on increase the drag reduction and best uniform flow. One of the important practice techniques is adding a small amount of some materials, cheap and locally available added into water flow in a horizontal pipe. A simple experimental system is designed and constructed to investigate the increase in drag reduction. Nanoparticles (aluminum oxide – 30 nm diameters) and polyacrylamide (PAM) have been added alone and gain time together. Experimental calculations of average flow velocity, Reynolds number, and friction factor and percentage drag reduction are experimentally calculated under water heads of 75,100, 125,150,175 and 200 cm. The effects of concentration ratios of nanofluid (AL_2O_3) on friction factor and drag reduction are studied and calculated. The present results showed that addition of AL_2O_3 and PAM are caused reducing in friction factor, increase in range of horizontal discharge distance and the velocity of water flow. Also the results indicated that, drag reduction was 2٦% increased at addition of AL_2O_3 and 3٩% at PAM while at mixing them together was 52 % as average for six heads were chosen. The results are represented graphically to explain the degrees of enhancement of increasing in drag reduction, flow velocity and the range of discharge distance for water in horizontal pipes. The originality of this work was addition materials of nanopartcles with polyacrylamide together.

Keywords: Fluid dynamics; Turbulent& laminar flow; Drag reduction; Nanofluids; Friction factor.

تحقق عملي لتحسين جريان الماء في الانابيب الافقية باستخدام دقائق نانوية

الخلاصة
اختص هذا العمل على التحقق العملي من امكانية زيادة مدى التدفق الافقي للماء وسرعة جريانه في الانابيب الافقية المستخدمة لخراطيم اطفاء الحرائق ومنظومات الدفع النفاث للمياه في السفن الصغيرة. تركز طريقة التحسن المقترحة على تنظيم افضل للجريان و تحقيق زيادة في تقليل الاحتكاك . واحدة من اهم التقنيات العملية هي اضافة دقائق متناهية الصغر من بعض المواد الرخيصة والمتوفرة محليا الى جريان الماء في الانابيب الافقية . تم تصميم وبناء منظومة مبسطة للتحقق العملي من استخدام تلك الدقائق النانوية وتم اختيار دقائق اوكسيد الالمنيوم بقطر ٣٠ نانوميتر ودقائق من مادة بوليميرية تسمى (PAM) اضيفت كل مادة لوحدها مرة و مرة اخرى اضيفتا معا. عمليا تم حساب معدل سرعة الجريان ونسبة الزيادة في التدفق الافقي وعدد

رينولد ومعامل الاحتكاك والنسب المئوية لتقليل الاحتكاك تحت ارتفاعات 75 ,125,100 ,175,150و ٢٠٠ سم . تم حساب تاثيرات النسب الوزنية للدقائق النانوية لثنائي اوكسيد الالمنيوم على تقليل الاحتكاك وبقية المتغيرات الاخرى . نتائج العمل الحالي اثبتت عمليا تحقيق زيادة في مدى تدفق الماء افقيا وفي سرعة الجريان نتيجة لتقليل الاحتكاك وتنظيمه بصورة افضل باضافة الدقائق النانوية والبوليمرية الى الماء. كذلك بينت النتائج ان نسب الزيادة في تقليل معامل الاحتكاك كانت ٢٦% عند اضافة دقائق ثنائي اوكسيد اللامنيوم و ٣٩% عند اضافة المادة البولميرية و ٥٢% عند اضافة المادتين معا . تم تمثيل النتائج بيانيا لتوضيح نسب الزيادة في تقليل الاحتكاك وسرعة الجريان ومدى التدفق الافقي للماء في الانابيب الافقية . الاصالة في هذا العمل هو اضافة المواد النانوية والبولميرية معا.

1. Introduction and literature survey

In an engineering practice the most flows are turbulent liquid flow, therefore, it is important needing to explain how turbulence in liquids flow effects on the rate of wall shear stress. Turbulent liquids flow is a very complex mechanism devoted by disturbances, the theoretical researches in turbulent liquid flow remains not enough to understanding these fluctuations. Turbulent liquid flow is described by random motion of liquid particles in directions transverse to the direction of the main liquid flow so that the liquid flow is unstable **[1]**.Turbulent liquid flow is described by a rapid disturbance of swirling areas of liquid, named eddies, during the water flow. These disturbances provide an additional mechanism for momentum and energy transfer. For laminar liquid flow, the particles of liquid flow in an orderly manner along path lines, and energy and momentum are transferred across streamlines by molecular diffusion while for turbulent liquid flow, the swirling eddy transport mass, energy, momentum, to other areas of flow more rapidly than molecular diffusion, greatly improving mass, momentum, and heat transfer, therefore, turbulent liquid flow is mainly devoted on the values of friction factors **[2]**.The turbulent liquid flow characteristic is strongly changed so that the study of nanofluids and polymeric drag reducing could help in gaining more knowledge about the turbulence itself.The application of addition of some nanofluids in water pipes that will minimize energy required for pumping and improve thermal properties of working fluid would allow one to save electrical energy needed to work of installations and reduce their operational costs **[3]**. One of the effective a possible improvement methods is the application of nanofluids and polymer materials with drag reducing. Because of the polymer materials are not expensive; the drag reduction has many practice applications, such as reduction of pumping energy requirements of oil pumping stations, increasing the speed and decreasing the fuel consumption of ships, extending the discharge distance of water from fire hoses. **[4]**. Turbulent eddies of liquid flow are generated at the pipe wall and move in to the center of the pipe. More energy is required to transport liquid at a given average flow velocity in turbulent liquid flow because not all of the energy goes toward overcoming viscous resistance to motion down the pipe. The velocity distribution can be considered independent of the axis - direction of water flow, and the water flow is called to be fully developed, **[5]**.An application in reduction of energy losses in water pipelines has active intense research into reducing drag over big and small ships and has recently gained attention for enhancing efficiency in all heating and cooling systems, which heated water is generated at the area in a city center and pumped to the houses in the surrounding location. Addition of materials as nanofluid or polymer will causes a change in physical properties of liquid. Addition of small amount of these materials to a liquid flow leads to decrease the pressure drop. All types of additives, such as nanoparticles, solid spheres, fibers, bubbles, lead to drag reducing in the turbulent liquid flow. Because of the turbulent flow disturbances, changes in rate of shear stress can lead to profound alterations in the macroscopic characteristics of the flow (e.g., transition to turbulence, skin friction drag, turbulence energetic, and heat transfer). These flow changes consider mainly difference between non-Newtonian turbulence and Newtonian. An example of these differences is explained by the reducing in skin-friction drag (up to 80%) showed in turbulent liquid flows of polymers materials **[2, 6]**.

Sundar, et. al. (2010) **[7],** calculated experimentally, the friction factor at different concentrations ratios for water flow in a tube. The physical properties such as the viscosity of nanofluid are calculated by many experiments at different concentrations ratios.**Kumar, et. al. (2012) [8],** performed a computational fluid dynamic experimental investigation of turbulent flow of heat transfer enhancement of a pipe. Mixing of very small sized nano particles to the liquid is one of the many important methods used for enhancing rate of heat convection in water flow in pipes. The practical problems such as high pressure loss, erosion of the material can be solving by addition small particles, which is a dispersion of nanosized particles in a base liquid.**Ali Mohammud, (2009)**, **[9]**, studied that the additions of many polymer materials to water flow. He was proved that the polymer materials of (PAM, PEO, CMC1 and CMC2) are more suitable to be used for improving the discharge distance of water flow. He achieved an increasing in extending of distance of water up to 30 % with them. Some polymer materials used for reducing the drag friction such as, PAM > PEO > CMC1 > CMC2. **Naik, et. al. (2013)**, **[10]** studied the turbulent water flow with addition of copper oxide nanofluids with propylene glycol-water by volume ratio of (30:70). They provided to be the behavior of heat at the wall pipe uniform .Nanofluids concentrations ratios and the main parameters are investigated on the liquid flow in a circular pipe.

The present work aims to increase the range of horizontal discharge distance and velocity of water flow in pipes by using nanofluids (AL_2O_3) and polymer material (PAM) together and study the effects of concentration ratio of nanofluid (0.1, 0.2, 0.3, 0.4 and 0.5 %) on the enhancement of percentage of drag reduction DR% and decreasing in the friction factor.

2. Theoretical part

The horizontal and vertical distances that are traveled by the jet during time (t) and velocity (u) as the following of set equations be the average velocity of the jet, then **[11];**

$$x_i = u_i \times t \quad (1)$$

$$y = \frac{1}{2} g t^2 \quad (2)$$

$$t = \sqrt{\frac{2y}{g}} \quad (3)$$

$$u_i = x_i \sqrt{\frac{g}{2y}} \quad (4)$$

To calculate the friction factor according to the Fanning equation, water flowing at a velocity (u) through a diameter of pipe (D) and length of pipe (L), f can be calculated from the following equations of friction factor **[12]** :-

$$f = \left(\frac{g\,h}{2\,u^2} - 0.375\right)\left(\frac{D}{L}\right) \quad (5)$$

$$f = \left(\frac{g\,h}{50\,x^2} - 0.375\right)\left(\frac{D}{L}\right) \quad (6)$$

$$f = 0.06447\,\frac{h}{u^2} - 0.00123 \quad (7)$$

There is a relationship between friction factor and Remolds number (Re) for smooth pipes .The fiction factor can be achieved with turbulent water flow of Newtonian fluids in smooth cylindrical pipes related to Reynolds number (Re) a according to Blasius equation **[13]**.

$$f = 0.0791\ Re^{-0.25} \quad (8)$$

While the equation that describes the relationship between (f) and (Re) at the maximum drag reduction in turbulent liquid flow in pipes according to the following equation **[14]**:

$$f = 0.59\ Re^{-0.58} \quad (9)$$

After the values of average velocities are measured, Reynolds number (Re) can be calculated from the following Eq. **[15]:-**

$$Re = \frac{\rho\,u\,D}{\mu} = \frac{u\,D}{\upsilon} \quad (10)$$

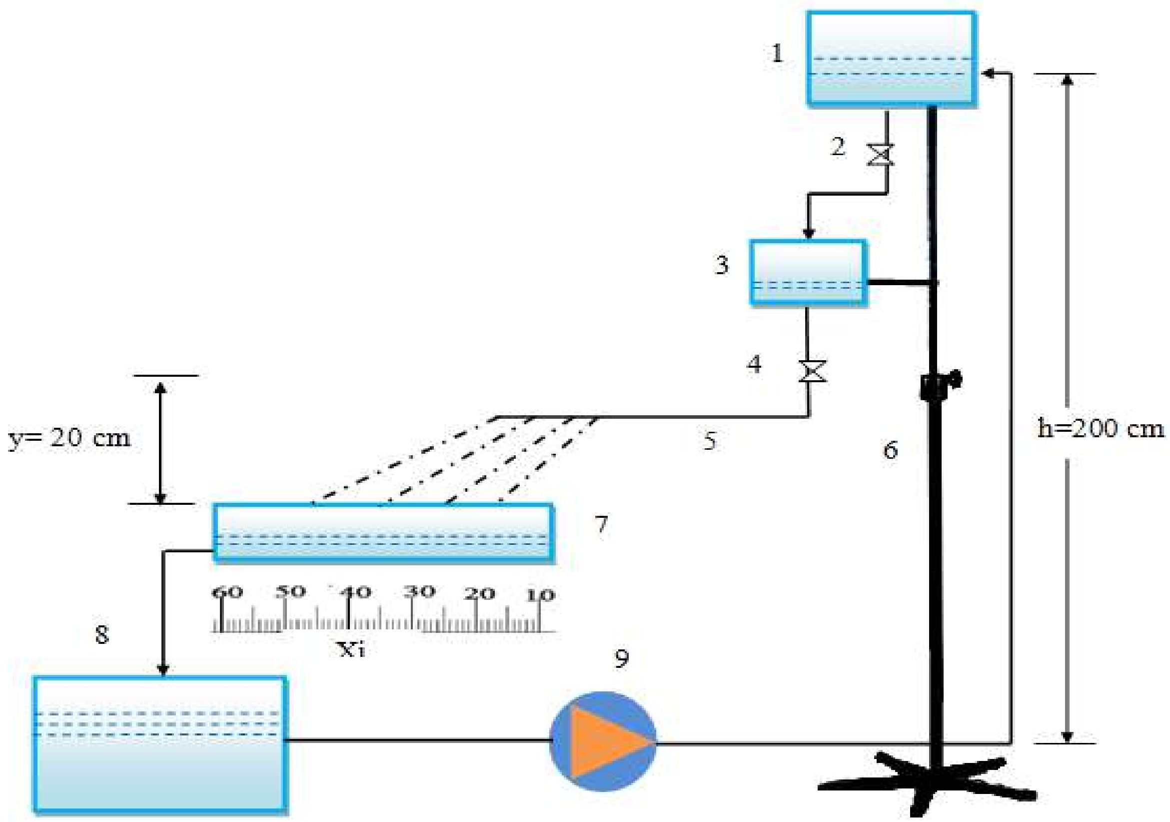
The percentage of drag reduction (%DR) can be calculated from the following Eq. **[16]**: -

$$\%DR = \frac{f_w - f_{np.}}{f_w} \times 100 \quad (11)$$

3. vjxjExperimental part

3.1 Experimental system description

The experimental system of this work which designed and constructed in Electromechanical-Eng. Dep.-University of Technology-Baghdad-Iraq for measurement of the discharge distance of water flow from the horizontal pipe. It consists of three reservoirs which are small containers that were used to supply water in order to maintain constant head throughout the experiment. The reservoir is connected to a pipe (16) cm with diameter of (1.2) cm which is connected to a valve and a slide conduit of (180) cm and with diameter of (1) cm. This, in turn, is connected by flexible pipe to a horizontal pipe (٩٠) cm with diameter of (0.3) cm. The efflux from the horizontal pipe is allowed to fall freely a distance of (20) cm (y) into a trough, in such a way that the distance traveled horizontally, (x) is clearly measured.



[1-supplying container, 2-valve, 3 mixing container, 4- valve,5- rubber tube ,6- variable stand (head 75-200cm) ,7- trough (x measured),8- reservoir container, 9- pump,]

Figure (1): Schematic diagram of design and construction of the system

3 .2- Materials and methods

A- Nanofluid (AL_2O_3)

In the present work nanopowder of aluminum oxide-30 nm diameter, there are two step procedures for nanofluid preparation. Step one, is putting a small amount of nanopowder was weighted and suspended in reverse osmosis water. Step two, the mixture was continuously circulated through the ultrasonic device. Nanofluid has been prepared in the Laboratory of

Corrosion of the Materials Engineering - University of Technology. The summary steps of nanofluid preparation are shown in figure (2). The concentration ratios of five samples (0.1, 0.2, 0.3, 0.4 and 0.5) % were prepared.

B- Polyacrylamide (PAM)

In this present work, polyacryamide (PAM) have molecular weight (4 x 10^6 g/mol.), and concentration ratio (0.1% with 99% water), was selected according to their drag reducing properties as recorded by many researches. The homogenous solution preparation of PAM needs to 5 hr. with 75 rpm by Mechanical stirrer device (it start at 35 rpm and increased by 10 rpm for each two hours, then, the preparation of homogenous solution of PAM became ready to use . The reason for choosing PAM due to a very cheap and it uses in many applications such as fire- fighting water.

2.3-Measurment devices

Three devices are used in this work. First of these devices is to measure nanoparticles weights. The different weights of nanoparticle (0.1, 0.2, 0.3, 0.4, and 0.5) % have been measured using a sensitive balance named (Digital balance) Laboratory type, model number KD-TN, Power supply AC/DC, rated load (100 g) and accuracy is 0.0001g.Second device is Magnetic mixer which confuses the fluid (water + nanoparticles of Al_2O_3 was added) .Magnetic mixer is laboratory device that uses magnetic field to mixing the fluids. The mixing time of water and Al_2O_3 was 3 hrs. Third device is Ultrasonic homogenizer model type JY92-IIN has frequency (20-25 KHz), power 650w, mainframe weight (14kg) and packing size (534x295x435mm). The working time was 20 minute to disperse the particles in the water so that they become equally distributed.

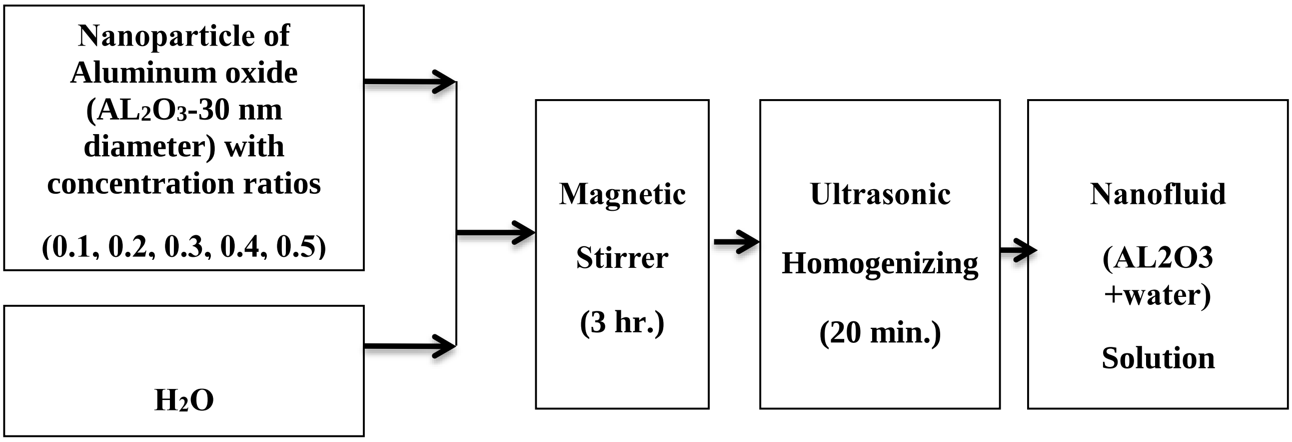


Figure (2): Summary of steps of preparation process of Nanofluid

4. EXPERIMENTAL MEASURMENTS

As shown in figure (1), the distance (x) is measured for pure water flow and with additions of naonoparticle (AL_2O_3) and PAM for different concentrations of AL_2O_3 (0.1, 0.2, 0.3, 0.4 and 0.5) % and under different heads (75, 100, 125, 150, 175 and 200 cm) by many experimental tests. Then, the values of discharge distances (x) are used to calculate the average velocities (u) according to the fundamental of fluid mechanics for free discharging of liquids through orifices and mouthpieces **[11].**

5. Results and discussion

5.1 Effect of additions of nanoparticles on the velocity of water.

It is generally believed that the discharge distance (x) of the efflux falling freely from the horizontal tube is directly related to the liquid head above the discharge point (h). Turbulence flow causes changes of momentum from core of pipe to liquid near to the pipe wall. Figures (3, 4 and 5) explain such variations with Al_2O_3 and PAM. The values of increasing in these figures proved that the effect of small particles addition on extending the discharge distance (x) and the velocity of water flow (u) in horizontal pipe under heads of (75, 100, 125, 150, 175 and 200 cm) are very effective .The best increasing achieved in discharge distance and velocity of water flow at mixing Al_2O_3 and PAM together. The result of the present work seems to be in good agreement with those observed by previous researchers. The different distances can achieve with a hose water jet for pure water (short jet distance) and for an addition of nanoparticles and polymers materials (long jet distance).

5.2 Effect of concentration ratios of nanofluid on the horizontal discharge distance

The variations of the discharge distance with nanofluid concentration under different liquid heads are shown in Figures (6 and 7) for Al_2O_3,the results indicate that %DR is considerably increased with increasing of nanofluid concentration so that %DR with Al_2O_3 is considerably increased with increasing the concentration from (0.1 – 0.5) % under a liquid heads. The results explained that PAM is more efficient additive for drag reduction than nanofluid (Al_2O_3). Al_2O_3 interactions are considerably increased with increasing of its concentration and degree of turbulence which is directly related to the liquid head in the present work. Reduces the possibilities of shear degradation since the water was free falling by gravity without any applied force of pumping or rotating the water as in classical flow systems commonly used in such investigations.

5. 3 Effect of concentration ratios of nanofluid on friction factor

Figures (8, 9, 10, 11 and 12) explain that the water flow entirely obey to Blasius equation. It is important to note that the behavior of the experimental data points of Nanofluid (Al_2O_3) with concentration ratios of (0.1, 0.2, 0.3, 0.4, and 0.5) % is due to the higher %DR observed with Al_2O_3 at these concentrations with different of water heads (75, 100, 125, 150, 175 and 200 cm). The behavior of these figures explains that, friction factor was decreased due to the increasing of concentration ratio of nanofluid and increasing of heads. Best increasing of DR% was at 0.3% concentration ratio.

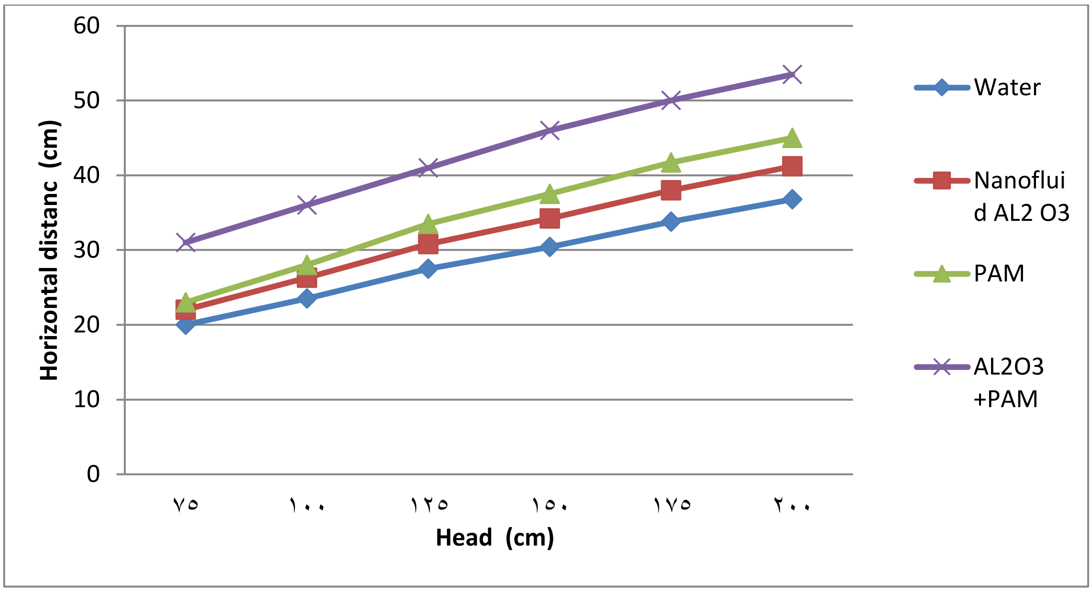


Figure (3): Variation of discharge horizontal distance of water flow with nanofluid and PAM .

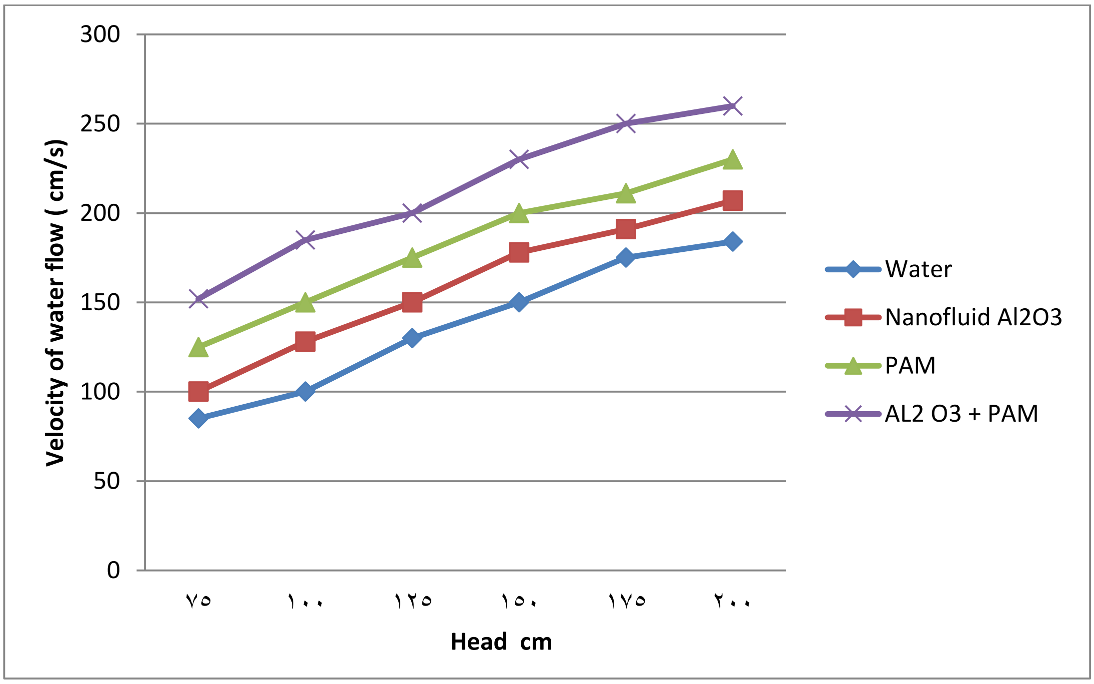


Figure (4): Variation of velocity water flow with nanofluid and PAM and with mixing together.

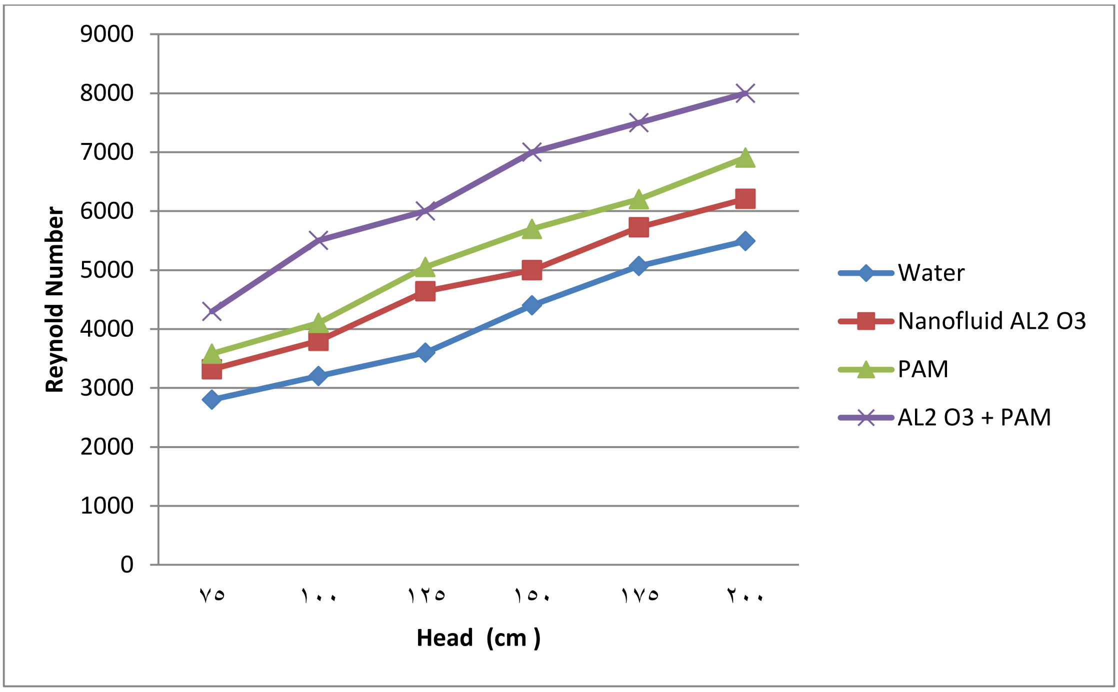


Figure (5): Variation of Reynolds number of water flow with nanofluid and PAM and with them.

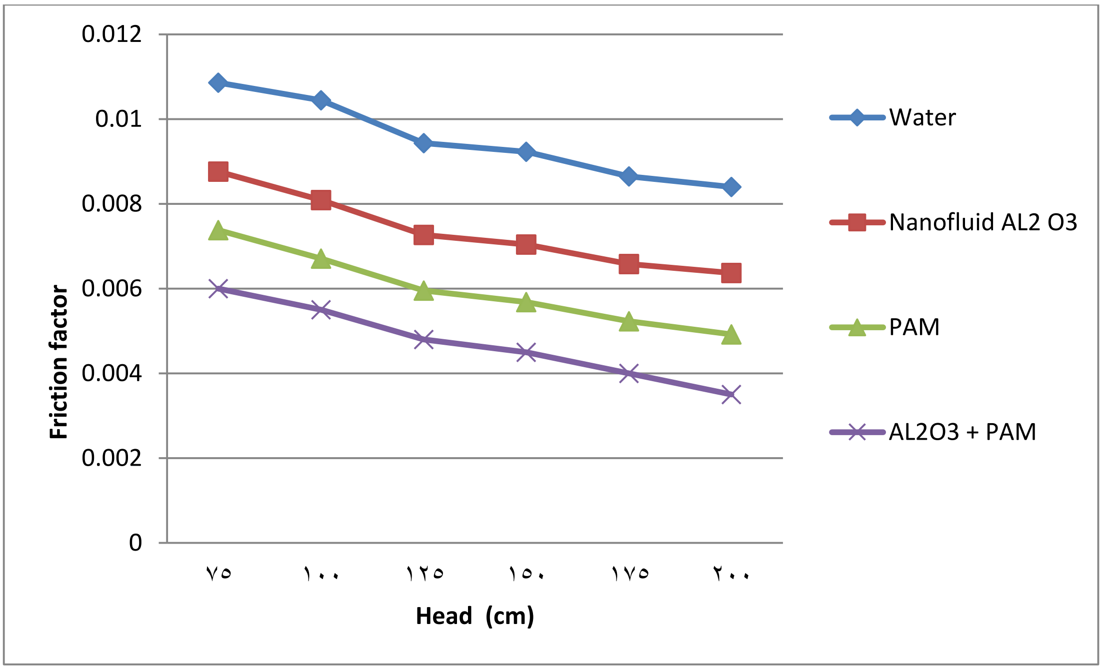


Figure (6): Variation of friction factor of water flow with nanofluid and PAM

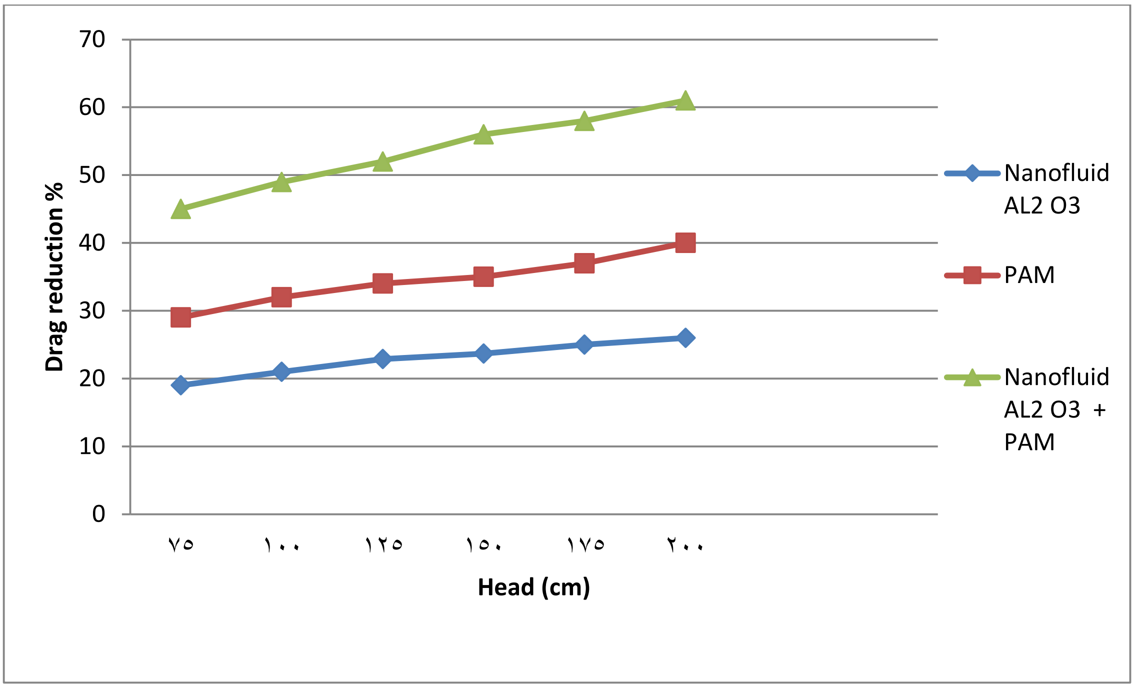


Figure (7): Variation of drag reduction of water flow in pipes with nanofluid and PAM.

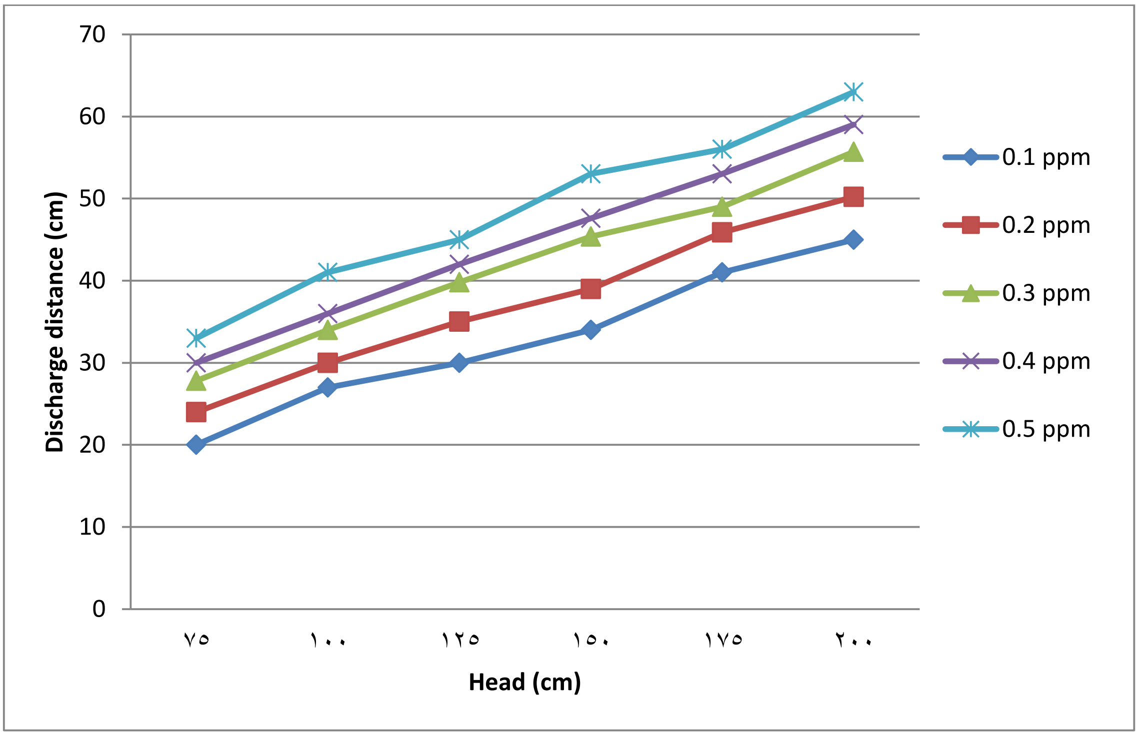


Figure (8): Effect of concentration ratio of nanofluid (Al_2O_3) on the discharge horizontal distance of water flow in pipes

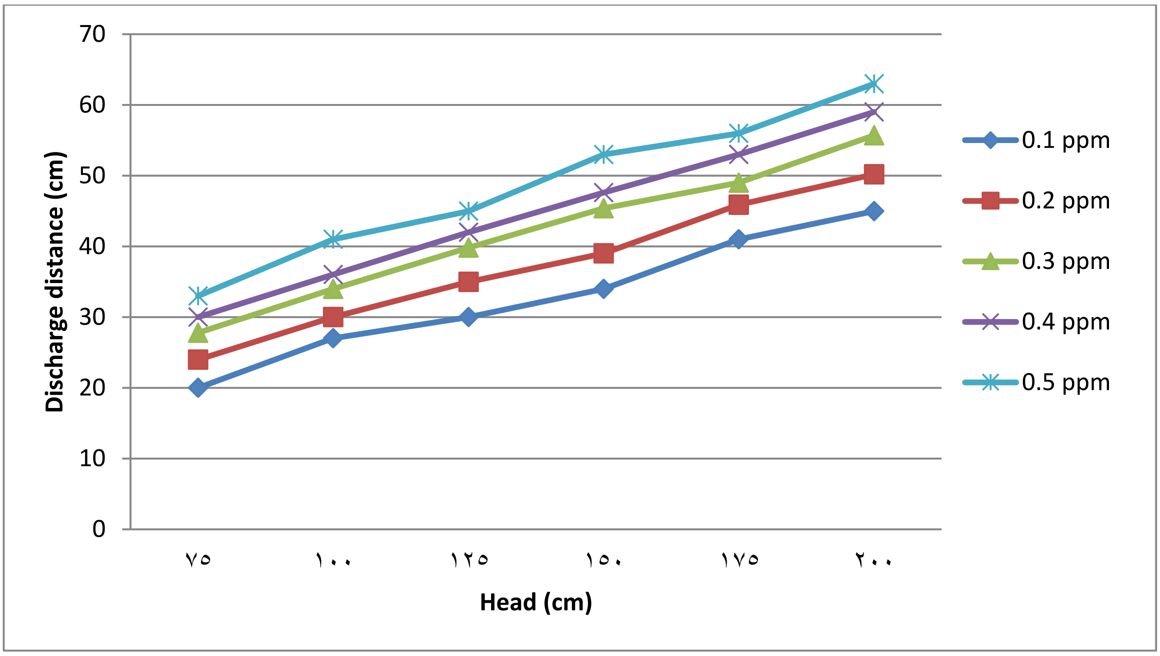


Figure (9): Effect of concentration ratio of nanofluid (Al_2O_3) on the discharge horizontal distance of water flow in pipes

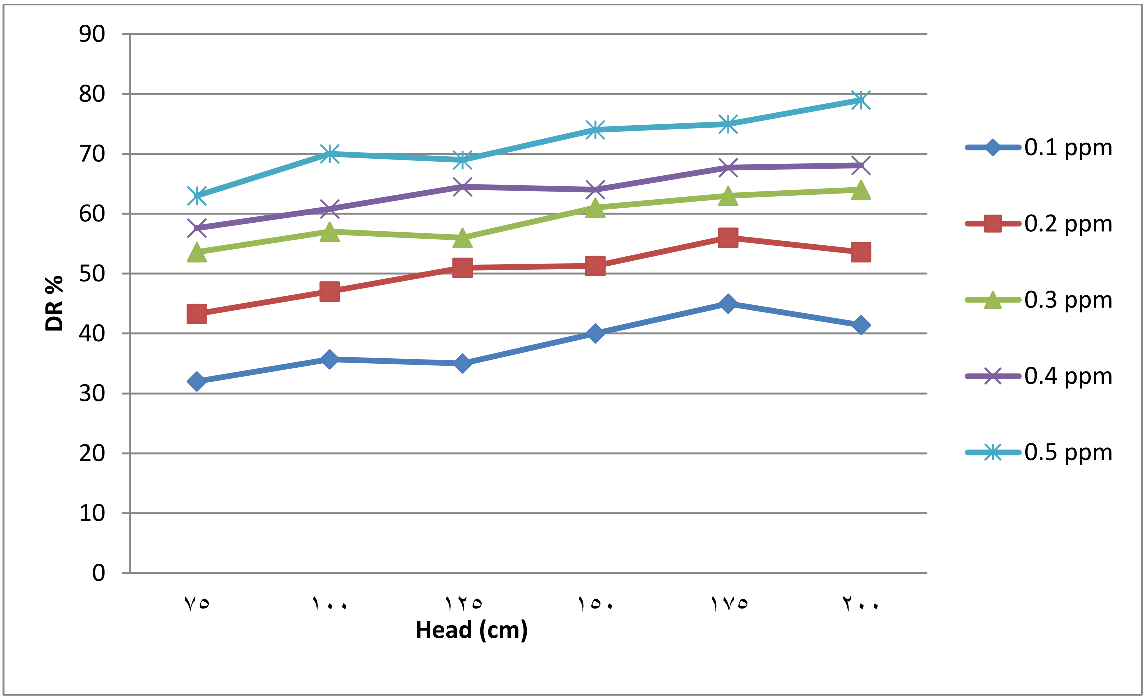


Figure (10): Effect of concentration ratio of nanofluid (Al_2O_3) on the drug reduction DR% of water flow in pipes

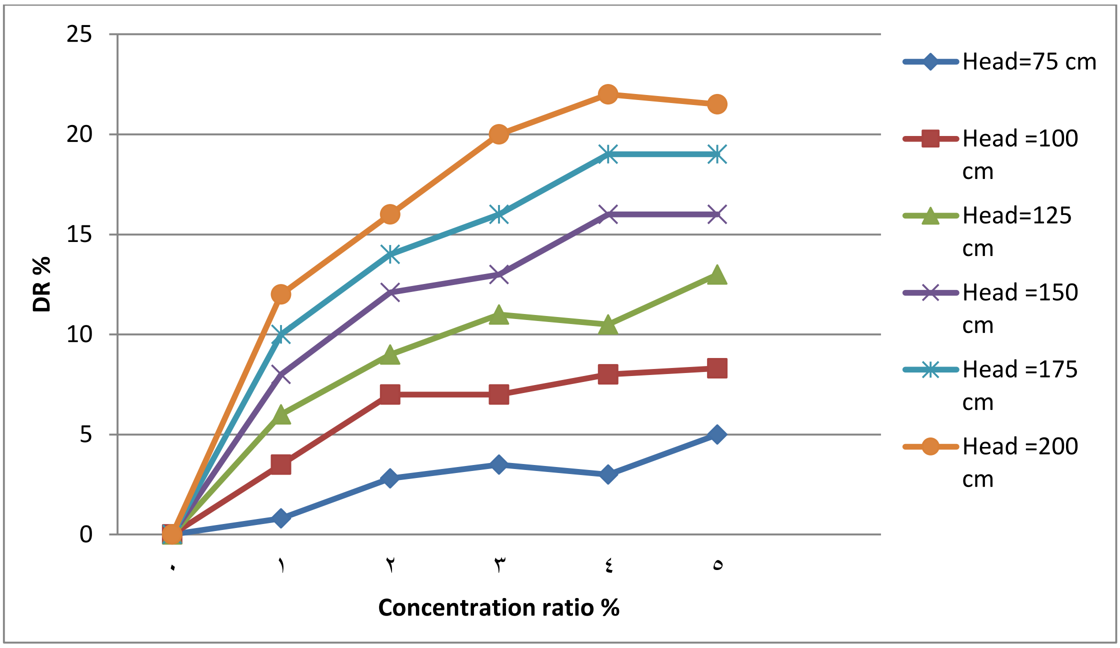


Figure (11): Effect of concentration ratio of nanofluid (Al_2O_3) on the drug reduction DR% at different water heads

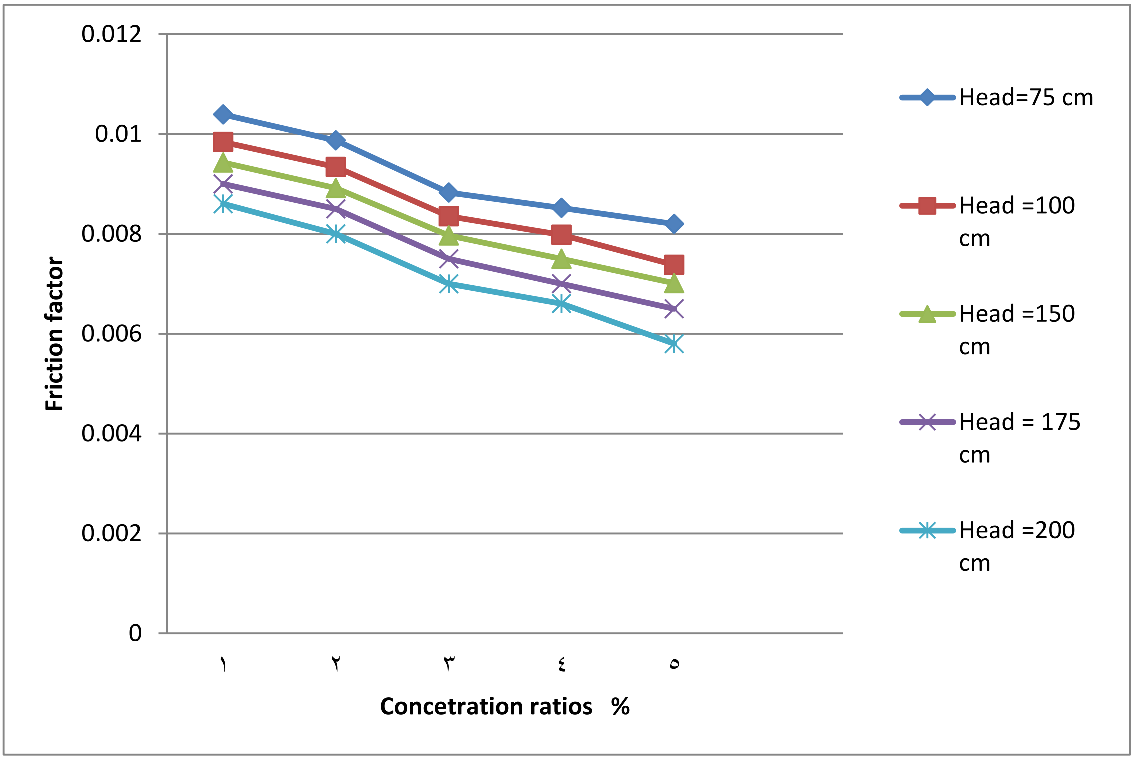


Figure (12): Effect of concentration ratio of nanofluid (Al_2O_3) on the friction factor at different water heads

6. CONCLUSIONS

This work concluded the following conclusions:-

1- Aluminum oxide AL_2O_3 and Polyacrylamide PAM are efficient materials to use for increasing the velocity of water flow in long horizontal pipelines and horizontal distance (x) of water because % DR is increased.

2- PAM is more efficient than AL_2O_3. The percentage of DR noticed with PAM is higher than Aluminum oxide; this is due to the higher molecular weight of PAM compared to AL_2O_3.

3- The differences in % DR observed with AL_2O_3 solutions are considerably increased with increasing concentration ratio which it is significantly decreased and slightly influenced by the liquid head.

4- The %DR is considerably increased with increasing of AL_2O_3 concentration and liquid head for all tested additives. The friction factors measured with water entirely obey to Blasius equation.

5- Addition of aluminum oxide AL_2O_3 and polyacrylamide PAM caused direct effect on the center line of velocity profile of water flow while it decreases the velocity profile near the wall pipe.

6- The value of eddy viscosity decreased when added aluminum oxide AL_2O_3 and Polyacrylamide PAM together. The minimum value will be at the touching area of the pipe wall. Therefore, disturbance of the water flow in this region will be very small value when mixing them together and this give advantage of decreasing in the disturbance of water flow in this region.

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NOMENCLATURE

D: Pipe diameter [cm]

g: Acceleration due to the gravity 981 [cm /s^2].

h: Head [cm]

Re: Reynolds number [-]

u: Fluid velocity [cm /s]

x: Horizontal discharge distance [cm]

y: Vertical distance [cm]

%DR: Percentage drag reduction

DR: Drag reduction

PAM: Polyacrylamide

ρ : Fluid density [g/cm^3]

μ : Dynamic viscosity [g/cm.s]

υ : Kinemetic viscosity [cm^2 /s]

f : Fanning friction factor [-]

f_w : Friction factor for water [-]

$f_{n.p.}$: Friction factor for nanoparticle[-]

PAM: Polyacrylamide

PEO: Polyethylene oxide

CMC: Sodium carboxymethyl cellulose

CMC1: CMC with MW of4 x 10^5

CMC2: CMC with MW of 1 x 10^5