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Improvement of Drag Reduction for Water Flow in Pipe Based Nanofluid

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Abstract— In the present work, the effect of Nano fluids as drag reducing agents for water flowing in pipelines was studied. Tap water was chosen to be the tested liquid and the Nano fluid was a dilute solution of water and titanium dioxide (TiO_2) Nano particles which was used at five different concentrations (50, 100, 150, 200, and 250) ppm. The test section of the experimental setup consisted of a stainless steel pipe of 29.6 mm I.D (DN25) and 1.2 m long. Water was pumped with eight different flow rates (1.0 - 8.0 m^3/hr) through the pipe at room temperature (35±1) ° C. The effect of the nano particle concentration and the flow rate (or Reynolds number) on percentage drag reduction (%Dr) and flow rate increases (%FI) was examined. Generally, a gradual increase of %Dr &%FI was observed with increasing the NP concentration and bulk velocity. The highest TiO_2 concentration of 250 ppm and Re.No. of 106230 offered the maximum drag reduction which was 29.7%. Friction factors were also calculated from experimental data. Their values for pure water transported lies near or at Blasuis asymptote. While by introducing the additives, their values were positioned below Blasuis asymptotes towards Virk maximum drag reduction asymptotes.

Keywords— Drag Reduction, Nanofluid, Energy Losses, Nano particles.

1. Introduction

Generally, it is needed to pump liquids over long distances in the processing industries, thus there will be a considerable drop in pressure in both the pipeline and in entity units. To recompense the frictional energy losses, more energy must be added. Therefore, reducing the friction loss leads to lower power consumption or a higher flow rate within the normal pumping conditions [3]. One of the methods that are used to increase the efficiency of piping systems is called "drag reduction technique". This phenomenon was first discovered by the British Chemist Toms in 1949, therefore it can be termed as "Tom's effect" [1].

Drag reduction may occur using different technologies with different type of materials. By adding small quantities of chemical additives (usually Polymers or Surfactants) to the turbulent liquid flow, noticeable reduction in pressure drop will be obtained. Another technique depends on adding small amount of solid particles (such as nano particles) to liquid flowing in turbulent mode during pipelines [12]. Modern experiments generally showed that these nanofluids can be used in petroleum transportation due to its advanced properties such as drag reduction, modification of wettability, binder for sand reinforcement and decreasing interfacial tension (Xiangling and Michael, 2010). Moreover, these fluids can be helpful in some other problems such as instability of well, lost circulation and pipe sticking troubles [12].

In the petroleum industry, the uses of NPs are in its early stages because of higher danger and elevated cost of adapting new technologies. According to the results in the laboratory tests and papers, large-scale recovery of oil and gas can be improved by nanotechnology and utilizing of nanotechnology is so expectable in the petroleum industry in the near next years [11].

The reason behind that various nanofluids have perfect lubricating properties is that these materials exhibit high friction reducing properties as the Nanoparticles in the fluid make a protecting layer with low hardness and elastic modulus on the surface.

Wasan and Nikolov in [4] utilized reflected light digital video microscopy to study the mechanism of spreading dynamics for liquids with nano polystyrene particles**.** They could show two dimensional crystal-like construction of the polystyrene spheres in water, this structure improves the dispersion properties for the micellar liquid in the three-phase area as shown in **Fig. 1** [4].

As meeting the oil drop, the polystyrene nanoparticles concentrate and reorganize near the drop making region like a wedge between the oil drop and the surface. The nanoparticles then distribute into the wedge film causing an increase in concentration and subsequently an increase in pressure around the film region. Owing to the increase in pressure, the oil-solution interface moves forward allowing the polystyrene nanoparticles to spread along the surface. This mechanism causes the oil drop to separate completely away of the surface. Additional work must be done to determine such behavior of nanofluids [4].

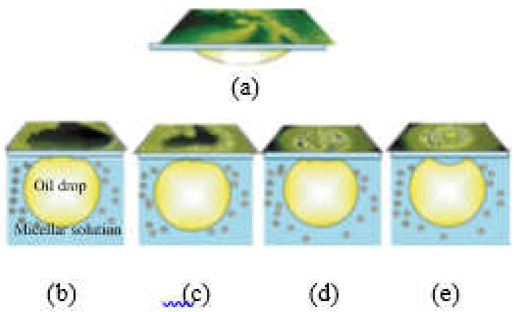

Figure 1: (a) Photomicrograph showing the oil drop placed on a glass surface and differential interference patterns formed at the three-phase contact region. (b)Photomicrographs taken after addition of the nanofluid at (b), 30 s; (c), 2 minutes; (d), 4 minutes; (e), 6 minutes region [4].

Abdulbari et al. 2010 was reported that these materials are good drag reducers and their drag reduction ability increases with an increase in the particle concentration. In present work, TiO_2 nanoparticles which are confirmed to have good dispersivity, stability in organic solvents are used as drag reducing agents [5].

2. Experimental procedure

2.1 *Materials and preparation*

In this study, nanofluids with five different addition concentrations (50, 100, 150, 200, and 250) ppm were prepared by mixing tap water (base fluid) with the defined amounts of TiO_2 nanoparticles which were suspended in water. These concentrations were chosen based on the economical consideration to ensure inexpensive and effective drag reduction.

In this method, known as the two-step method the nano particles are purchased as dry powder and then dispersed in the liquid medium. The nano particle content is expressed in terms of ppm which represents the weight of solid in milligram respect to a liter of distilled water. The calculated amount of nanoparticle was added to a one liter of water under laboratory temperature and mixed using high speed mechanical mixer at 2000 rpm for at least 1 hour to ensure uniform distribution through the solution. This process was applied to break down the agglomeration between the particles, which leads to achieving a uniform dispersion and a stable suspention. The drag reduction performance of the solutions was then tested using the closed loop recirculation system. These nanoparticles were chosen because they are produced in large scale in industry and they are chemically more stable, easily available and not harmful for human being.

The characteristics of TiO_2 nanoparticles and water are presented in **Tables 1 and 2** respectively [10].

Table 1: Characteristics of TiO_2 nanoparticles

Characteristic	**Value**
Purity	99.9%
Color	White
Size Outer diameter	100 (nm)
Specific surface area	$85m^2/g$
Bulk Density	$0.65\ g/cm^3$
True Density	$3.9\ g/cm^3$

Table 2: Characteristics of water:

Characteristic	**Value**
Chemical formula	H_2O
Molar mass	18.02 (g/mol)
Density	989 (kg/m^3)
pH	7.5
Conductivity	356 (µs/cm)
T.D.S	174 (ppm)
Turbidity	0.26 NTU
Kinematic viscosity	$0.9*10^{\wedge-6}$ (m^2/s)

2.2. *Closed Loop Liquid Recirculation System*

A closed loop circulation system was designed to investigate the effectiveness of the TiO_2 Nano particles in tap water under turbulent pipe flow conditions. One test section of 1.2 m was used to investigate the performance of additives. (A photo of the final experimental set up is shown in **Fig. 2**.

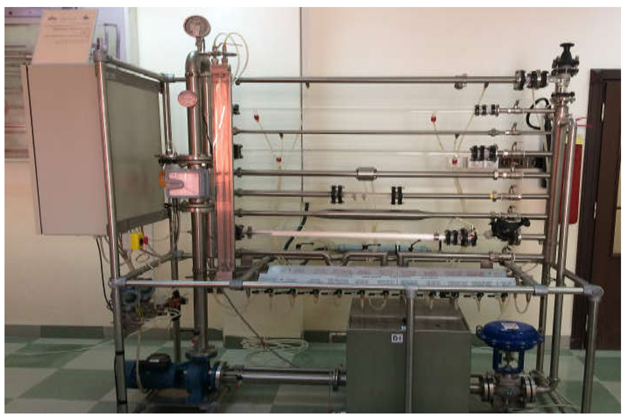

Figure 2: Photo of the final rig setup

Experiments of effectiveness of DRA were carried out in circulating manner during (10- 15) minutes. Prior to the test, the concentrated Nano fluid solution was mixed with tap water in the reservoir to get homogeneous fluid. Typically (15- 30) minutes mixing time was used depending on the Nano fluid concentrations (50-250) ppm.

Calibration of the test section for the pipe was performed with untreated water prior to testing the drag-reduction additives. A differential mercury manometer was used to calibrate the electronic differential pressure transmitters (PdI2). The tank was filled with tap water and operated at various flow rates then the readings of mercury manometer and of the differential pressure transmitter (PdI2) were recorded as shown in **Fig.3**.

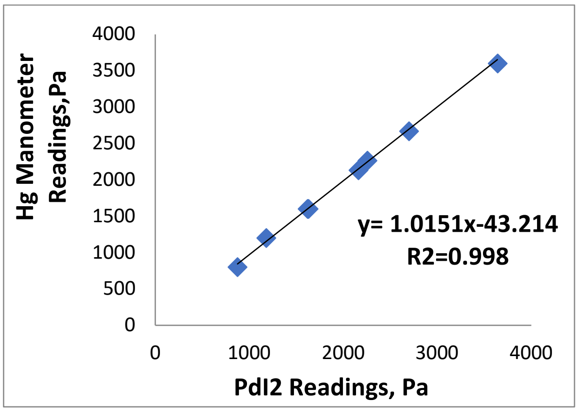

Figure3: Test loop calibration data for tap water in st.st pipe of DN25.

The effectiveness of a drag reducer is expressed in terms of percent drag reduction. At a given flow rate, the percent drag-reduction is calculated from the following equation:-

$$\%DR = \frac{(\Delta p)_{untreated} - (\Delta p)_{treated}}{(\Delta p)_{untreated}} \times 100 \qquad (1)$$

$(\Delta p)_{untreated}$= pressure drop in the pipe without a DRA.

$(\Delta p)_{treated}$= pressure drop in the pipe when the DRA

is added.

The increase in the throughput, %FI which is more practical term than drag reduction percentage for a given pipeline, can be estimated using the following equation:-

$$\% FI = \left\{ \frac{1}{\left(1 - \frac{\% DR}{100}\right)^{0.55}} - 1 \right\} \times 100 \qquad (2)$$

Eq. (2) assumes that the pressure drop for both treated and untreated fluids is proportional to flow rate rise.

3. Results and discussion:

3.1 *Effects of Different Parameters on Drag Reduction:*

3.1.1 Effect of Concentration

Drag reduction efficiency of TiO_2 Nano particles had been studied in turbulent flow of tap water as a function of concentration. This concentration ranged from 50 up to 250 ppm.

Figure 4 shows that percentage drag-reduction increases gradually as TiO_2 concentrations increase. Such results are expected since any increase in the additives concentration means increasing the number of additives molecules involved in the drag reduction process and that will cover wider range of the turbulent eddies in the turbulence suppression process.

The maximum percentage drag-reduction about 29.6 % for Nano titanium oxide at 250 ppm and Reynolds number equal to 106230 as illustrated in **Fig.4**.

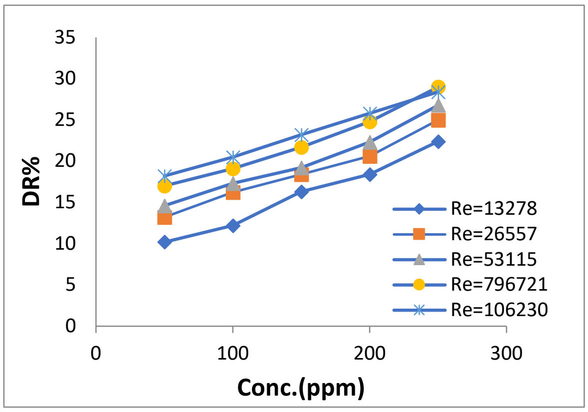

Figure 4: Effect of concentration on percent drag reduction for TiO_2 through st.st pipe of DN25.

In addition, the effect of nanofluid concentration on percentage flow increase FI% for TiO_2 at different Reynolds number was also calculated as in **Fig.5**. A noticeable increase in the pump ability of water was achieved. DRA concentration effect is essential for increasing flow rate capacity. FI% values were about 15% as the minimum and 20.4% as the maximum when the added concentrations of TiO_2 were 50 and 250 ppm respectively at the maximum Reynolds number.

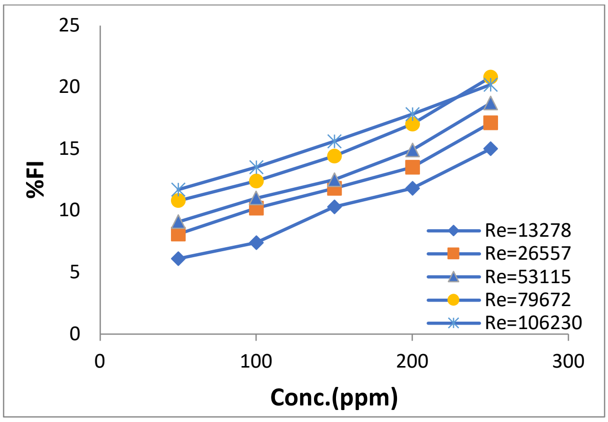

Figure5: (%FI) as a function of Reynolds number for TiO_2 through st.st pipe

3.1.2 Effect of Reynolds number

It is well known that the drag reduction phenomenon as it is recognized, works in turbulent flow [2, 6]. Therefore, the degree of turbulence has a predominant effect on its effectiveness, as shown in **Fig. 6**. **Figure 6** shows the variation of drag reduction with Reynolds number for water flowing in a pipe at different nano concentrations. It is shown that the percentage drag reduction increases as the Reynolds number increase (flow rate increase). Such behavior agrees with Berman and his workers [7, 8] who reported that the degree of turbulence is highly controlled by the liquid flow rates, especially in turbulent flow where the turbulence structures are formed (eddies). This will lead to control the additive contact interaction with turbulent structures formed inside the pipe and this will enable more Nano molecules to interfere within the turbulent median and suppress the eddies formed inside the pipe and thereby the flow is improved

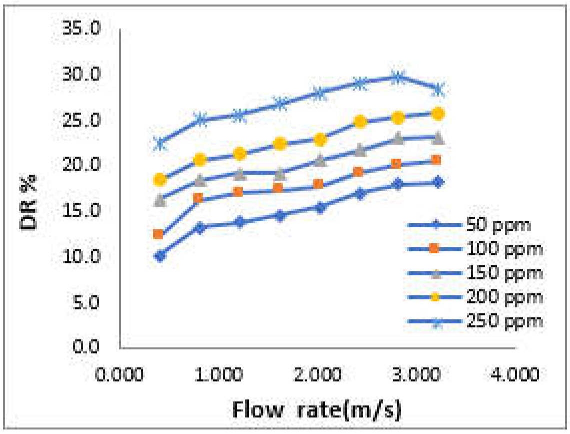

Figure 6: Effect of flow rate on percentage drag reduction for Nano TiO_2

The combined effect of concentration and Reynolds number on percent drag reduction have been illustrated in three dimension plots. For more elaboration, Fig.7 is plotted for this purpose, which represent the extension of overlapping the two effects on percent drag reduction.

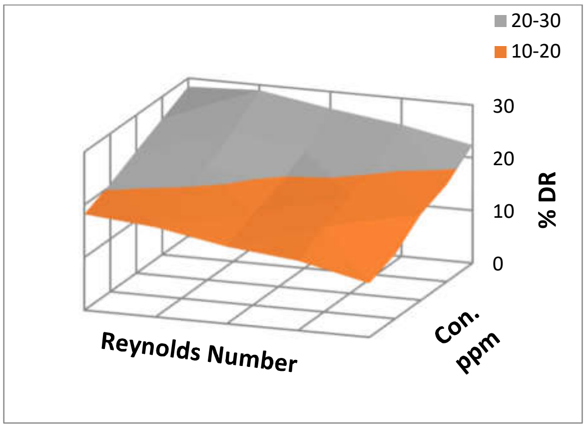

Figure7: Effect of concentration and Reynolds number on percent drag reduction for Nano TiO_2

3.2 *Effects of Friction Factor as function of Reynolds Number*

The drag-reduction properties of solutions could be explained as the fanning friction factor versus solvent Reynolds number. The use of Reynolds number based on the solvent viscosity and pipe diameter provides a direct indication of the degree of drag reduction. The Friction factor was calculated from the experimental data based on pressure drop measurements, as in equation 3.

$$f = \frac{\Delta hg}{2} \frac{1}{u^2} \frac{D}{L} \quad (3)$$

The effect of Nano additives at various concentrations on friction factor values as function of Reynolds number are plotted in **Figs. 8 & 9.** It is shown that for untreated solvent friction factor values lies near Blasius asymptote **(Fig.8),** while by adding minute amounts of Nano particles into the flow, the friction factor values were positioned below Blasius asymptote towards the maximum drag reduction region which is represented by "Virk asymptote"[9] as in **Fig.9**.

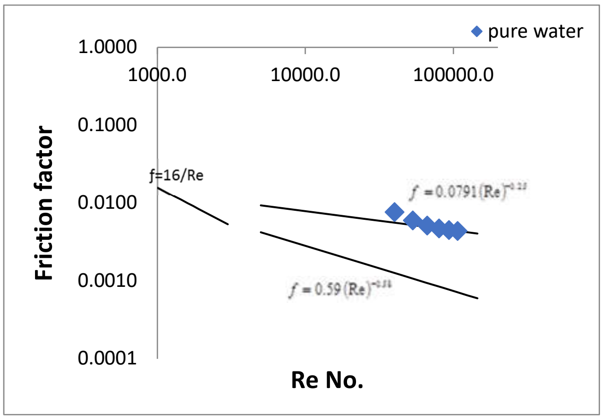

Figure 8: Effect of f as function of Re No. for pure water

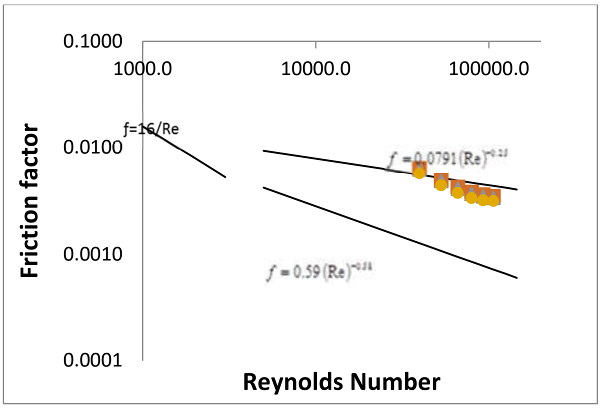

Figure 9: Effect of TiO_2 additives with different concentration on friction factor as function of Re

An attempt was made to correlate the fanning friction factor values as a function of Reynolds number, for the considered Nano concentrations.

The friction factor is usually correlated as a function of Reynolds number as shown in the following formula

$$f = a\left(\mathrm{Re}\right)^{b} \tag{4}$$

According to the above formula and by using appropriate software program, the constants a, b had been found. Therefore, the correlation results for friction factor calculation by **Eq. (4)** are illustrated in **Table 3** for different concentrations of TiO2.

Table 3: Values of a & b of correlation equations for friction factor as result of Reynolds number in st.st pipe of DN25

Material	Conc. ppm	a	b	Correlation eq.
Pure water	0	3.231	-0.575	f=3.231Re$^{\wedge-0.575}$
TiO_2	50	4.452	-0.622	f=4.452Re$^{\wedge-622}$
TiO_2	150	4.938	-0.634	f=4.938Re$^{\wedge-0.634}$
TiO_2	250	4.151	-0.627	f=4.151Re$^{\wedge-0.627}$

The calculated results give a good agreement with the friction factor obtained experimentally and calculated by **Eq. (4).**

4. Conclusions:

The drag reduction efficiency of titanium dioxide (TiO_2) Nano particles was examined in tap water flow loop. The results show that the considered nanoparticle solutions are effective in turbulent drag reduction and that their efficiencies increase as their concentrations and flow velocities increase. Lower friction factors were obtained for high additive concentrations and high Reynolds number.

References

[1] B. A. Toms, "Detection of a Wall Effect in Laminar Flow of Solutions of Linear Polymer." Journal of Colloid Science, 4, pp. 511-521, 1949.
[2] C. Elata, J. Leher, and A. Kahanovitz, “Turbulent Shear Flow of Polymer Solution,” *Israel J. Technol.*, 4, pp. 87, 1966.
[3] D. H. Marlin, and J. Chatterji, “Study of Oil Soluble Polymers as Drag Reducers,” *Polym. Eng. Sci.*, 20, pp 473-477, 1980.
[4] D. T. Wasan, and A. D. Nikolov, “Spreading of nanofluids on solids,” Nature, vol. 423, no. 6936, pp. 156–159, 200
[5] H. A. Abdulbari, M. Y. Rosli and Arun Gupta” Introducing slag powder as drag reduction agent in pipeline: An experimental approach”, Faculty of Chemical and Natural Resources Engineering, University Malaysia Pahang, 2010.
[6] H. C. Hershey, and J. L., Zakin, “Existence of Two Types of Drag Reduction in Pipe Flow of Dilute Polymer Solutions”, *Chem. Eng. Sci.*, 6, pp. 381, 1967.
[7] M. T. Landahl, and F. Bark, “Application of a Two-Scale Boundary Layer Turbulence Model to Drag Reduction,” *Inter. Polym. Lubrification*, Brest, 1974.
[8] N. S. Berman, “Drag Reduction of the Highest Molecular Weight Fractions of Polyethylene Oxide,” *Phys. Fluids*, 20, pp. 715, 1965.
[9] P. S. Virk, E. W. Merrill, H. S. Mickely, K. A. Smith, and E. L. Mollo-Christensen, “The Toms Phenomenon-Turbulent Pipe Flow of Dilute Polymer Solutions,” J. Fluid Mech., 30, pp. 305, 1967.
[10] US Research Nanomaterials, The advanced nanomaterial provider.
[11] X. Kong and M. Ohadi, “applications of Micro and Nano Technologies in the Oil and Gas Industry,” Abu Dhabi International Petroleum Exhibition and Conference, 2010.
[12] Zainab. Y. SH., “Enhancing the Flow of Multiphase System in Pipeline,” Ph. D. Thesis, University of Malysia, Pahang, 2015.

Nomenclature

f	Fanning friction factor
D	Diameter (m)
L	Length (m)
h	Hight (m)
g	Acceleration of gravity(m/s^2)
u	Flow velocity(m/s)
a,b	Constants in correlation equation of friction factor as a function of Reynolds number

Abbreviations

TiO_2	Titanium dioxide
DN25	Stainless steel pipe of 29.6mm I.D
%Dr	Percentage drag reduction
%FI	Percentage flow increase
Re	Reynolds number
ppm	Parts per million
rpm	Revolution per minute
DRA	Drag reducing agents
TDS	Total dissolved solids
ΔP	Pressure drop
PdI2	Differential pressure indicator

تحسين تقليل الاعاقة لجريان المياه في الانابيب باضافة المواد النانوية

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الخلاصة – تم في هذا البحث دراسة تأثير الموائع النانوية كعوامل مقللة لخسائر الطاقة الناتجة اثناء نقل المياه في خطوط الانابيب. حيث تم اختيار مياه الحنفية ليكون السائل الذي يجري اختباره والمائع النانوي المستخدم عبارة عن محلول مخفف من جزيئات نانو ثاني أوكسيد التيتانيوم (TiO_2) والماء والذي استخدم بخمسة تراكيز مختلفة (50 ,100, 150, 200 و250) جزء في المليون. يتكون جزء الاختبار من المنظومة الرئيسية من انبوب فولاذي المقاوم للصدأ بقطر 29.6 ملم (DN25) والذي تم ضخ المياه خلاله بثمان معدلات جريان مختلفة (من 1.0 الى 8.0) م^3/ساعة وبدرجة حرارة الغرفة (35±1) ^{0}م. تمت دراسة تأثير (تركيز الإضافة، ومعدل الجريان) على نسبة التقليل من الاعاقة (%DR) ونسبة الزيادة في التدفق (%FI) كنسب مئوية ، كما تم حساب افضل الظروف التشغيلية اللازمة لتقليل الاعاقة في الانبوب ، حيث لوحظ زيادة تدريجية في نسبة تقليل الاعاقة (%DR) ونسبة التدفق(%FI) مع زيادة تركيز المادة النانوية وعند استخدام السرع العالية، كما اظهر المائع النانوي ذو تركيز 250 جزء في المليون عند اعلى رقم رينولدي والذي يساوي 106230 اعلى حد (او تقليل) من الاعاقة في الأنبوب (%DR) بمقدار29.7%. كما تم حساب قيم عوامل الاحتكاك للانبوب باستخدام المادة النانوية حيث لوحظ وجود انخفاض في قيم عوامل الاحتكاك وذلك بسبب التقليل في خسائر الاحتكاك مع الجدار الداخلي للانبوب.

الكلمات الرئيسية – تقليل الاعاقة، الموائع النانوية، خسائر الطاقة، جزيئات ثاني اوكسيد التيتانيوم النانوية.