

Analysis of drag in pipes during a flow and its minimization by physical and chemical methods.

A study on drag reducing additives

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<p>Abstract: Transportation of fluids in pipes always creates a phenomenon called drag or friction which is opposing the flow of fluid. Considerable amount of energy loss is seen in pipes due to viscous and drag/frictional effects. This is considered as a pressing problem in material transportation due to the growing deficit of energy in present world. Through this thesis, the problem is intercepted by analysing the fluid flow behaviours in different flow regimes and by the use of drag reducing additives. These additives would decrease the energy loss by decreasing drag effects in a flow.</p> <p>The experiment was performed in Heat Transfer Laboratory/System of Arcada University of Applied Sciences where pipes of different lengths and diameters were investigated. The experiment was done by connecting the experimental pipes to the system and circulating fluid through them. The head loss and friction coefficients of fluid were analysed to understand their functioning under laminar and turbulent flow regimes. Flow improving additives were used on the system to study their effects on the friction and head loss. High molecular weight polymer, Polyethylene Oxide (PEO) and a surfactant, Sodium Salicylate (NaSal) were the two additives used in the fluid in the ratio of 500 ppm and 220 ppm respectively.</p> <p>Pressure drop was seen even in short length pipes of length 2.5 and 5 metres acknowledging the drag effects of pipes cannot be neglected. Friction and head loss are found to be influenced highly by Reynolds number depending on type of flow. Considerable amount of head loss reduction was achieved by introduction of the chemical additives. Maximum head loss reduction was observed in higher Reynolds number showing greater efficiency of the additives in turbulent flow.</p>	
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List of Symbols and abbreviations

μ	Viscosity of fluid
h_f	Frictional head loss
h	Head loss
ρ	Density
g	Acceleration due to gravity
Q	Volumetric flow rate
η	Efficiency
P	Power
\dot{m}	Mass flow rate
v	Velocity of fluid
A	Cross-sectional area of pipe.
D	Internal diameter of pipe
f	Frictional factor
Re	Reynolds number
e	Absolute wall roughness
e/d	Relative roughness
ppm	parts per million
NaSal	Sodium Salicylate
PEO	Polyethylene Oxide
PEX	Crossed – linked Polyethylene

1 Introduction

The transportation of materials through pipes is considered to be one of the oldest material transportation systems. Pipe transportation is also regarded as a system developed by humans after visualization of how nature works since basic transportation medium found in nature are pipes and conduits. There has been considerable technological development in the pipe transportation since its discovery around early centuries till now. The initial material used to make pipes were wood, clay and lead whereas, nowadays advanced materials like steel, plastic and composites are used. The present world demands a great extent of pipeline transportation in almost all the fields like irrigation, medicine, construction and hydropower to name few.

1.1 Background and Context

A very pressing matter in any engineering field in the 21st century is the energy consumption. As the amount of non-renewable sources like petroleum and coal are forecasted to gradually decrease in future, researchers have been highly engaged in developing energy-efficient systems. Energy efficiency denotes a system which works with least wasted effort (energy). It is the idea of doing the same work with less consumption of energy. An example can be fluorescent lamps which are more efficient than Tungsten lamps since they consume lesser electricity to give same amount of light.

While transporting liquid in pipes, energy loss due to friction between pipe wall and liquid molecules and also within liquid due to its viscous effects can be seen in considerable amount. Therefore researches are done to decrease the frictional force and ultimately decrease the energy loss.

Drag reducing additives, also known as DRA's are the chemicals which help to reduce the drag effect in pipes when fluid flows through it. Long polymer hydrocarbon chains and surfactant agents are mostly used additives for the drag reduction. The additives are mixed with fluids in a proportion of few parts per million to get better efficiency.

1.2 Scope and Objectives

The experiment deals with fluid drag effects and its optimization which is a key issue in different technical areas like irrigation systems, pipeline transportation of petroleum products, drilling applications, hydroelectric penstocks, fire fighting and jet cutting to name few.

In the case of fluid transportation in pipes, main factors affecting its efficiency are viscosity, friction, density etc. Through this experimental research, it is tried to focus on frictional effects within pipe and fluid. The main objectives of this thesis are:

- To analyse pressure drop on certain length of pipes due to frictional effects.
- Study the dependence of friction coefficient and head loss on Reynolds number, roughness and flow regimes.
- Experimental analysis of the effect of drag reducing additives on the flow.

2 Literature Review

A flow of fluid in a pipe can have different characteristics. Pipe flow is a type of flow where the flowing fluid has no free surface and pressure on the pipe is the pressure of the liquid. Liquid flows due to pressure difference between two ends of pipe. Example of this flow is drinking water pipes. In open channel flow, the liquid has free surface and pressure on pipe is atmospheric. Here, the movement of liquid is due to gravity. Example is drainage pipe.

Pipe flow has two different regions, namely- Entrance region and fully developed region/flow. When a fluid enters a pipe, flow is divided into boundary layer and inviscid core. The region where viscous effect of fluid is significant is called boundary layer and inviscid core is where it's insignificant. As fluid passed through the pipe, boundary layer grows and the velocity profile changes until a certain point where boundary layer fill the pipe. The region up to that point is called entrance region. The flow region where velocity profile is constant is called fully developed flow. [1] The velocity profile is parabolic in this region with maximum velocity at centre of pipe and minimum at the wall. (Figure 1)

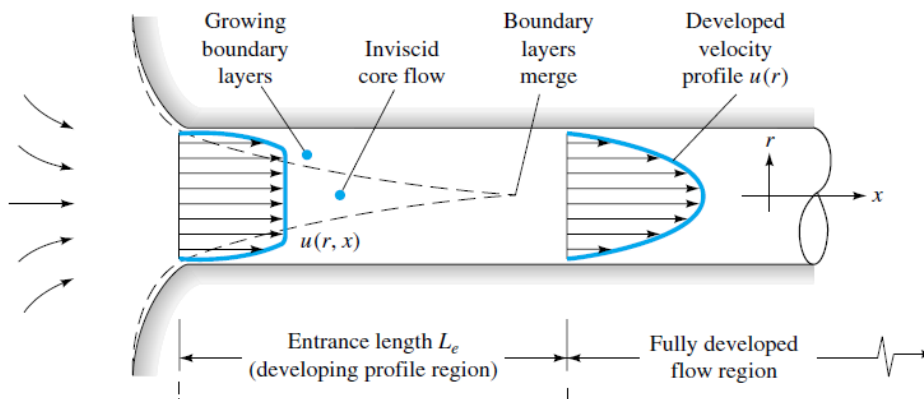


Figure 1. Flow regions [2]

Important terminologies governing fluid mechanics and this experiment are as follows:

2.1 Shear stress and Viscosity

Douglas et al [3] state that Shear stress is the ratio of Force (F) to area. i.e. $\tau = \frac{F}{A}$. In a closed boundary flow, the fluid will flow over the boundary in such a way that the fluid particles which are immediately in contact with the boundary have the same velocity as the boundary, while successive layers of fluid parallel to the boundary move with increasing velocities. It occurs due to the viscous effects of fluid. This is also supported by figure 1. Furthermore, they also state that for the fluids obeying Newton's law of viscosity, taking the direction of motion as the x-direction and v_x as the velocity of fluid in the x-direction at a distance y from the boundary, the shear stress in the x-direction is given by:

$$\tau_x = \mu \left(\frac{dv_x}{dy} \right) \quad \text{Equation 1.}$$

In the equation, viscosity is denoted by μ .

2.2 Extensive Bernoulli's equation

For any incompressible flow in a pipe, Bernoulli's principle is the governing equation. This equation is valid only for incompressible fluid which does not change its density or volume with the change in pressure.

It is as follows: [4]

$$\left[z_2 + \left(\frac{P_2}{\rho g} \right) + \left(\frac{v_2^2}{2g} \right) \right] = \left[z_1 + \left(\frac{P_1}{\rho g} \right) + \left(\frac{v_1^2}{2g} \right) \right] - h_f \quad \text{Equation 2.}$$

Where, z_2 = height at second point of pipe, P_2 = Pressure at second point, ρ = density of fluid, g = acceleration due to gravity, V_2 = velocity at second point, z_1 = height at initial point of pipe, P_1 = Pressure at initial position, V_1 = velocity at initial position, position and h_f = head loss due to friction (also known as major head loss expressed in metres).

The experiments are based on horizontal pipes i.e. $z_1 = z_2$. Since the flow is fully developed, velocity at two ends of pipe is same. i.e. $V_1 = V_2$. These conditions gives arise to a new

equation which makes the pressure loss a function of the head loss due to friction which is as follows:

$$h_f = \frac{\Delta P}{\rho g} \quad \text{Equation 3.}$$

2.3 Pump efficiency

Efficiency of a pressure pump (η) is a dimensionless quantity which is the ratio of the power developed by the flow (also known as water power in water pump) to the power required to drive the pump. [5]

$$\eta = \frac{Q\Delta P}{\text{Input power}} \quad \text{Equation 4.}$$

Where, Q = volumetric flow rate, ΔP = pressure head of pump.

The above equation is equivalent to the ratio of output power to input power.

2.4 Flow measurements

The different flow measurement terminologies used in the field of fluid mechanics are: [6]

2.4.1 Volumetric flow rate

It is the measure of volume of a substance through a given area over a given time. Its units are m^3/sec , ft^3/sec , etc. In formula,

$$\text{Volumetric flow rate (Q)} = \frac{\dot{m}}{\rho} \quad \text{Equation 5.}$$

Where, \dot{m} = mass flow rate.

2.4.2 Mass flow rate

It is the measure of mass of a substance passing through a given area of a surface at a given time. It is denoted by \dot{m} . Its unit is kg/s , g/m etc. It can be calculated from following equation:

$$\dot{m} = \rho \times v \times A \quad \text{Equation 6.}$$

Where, v = velocity of fluid, A = Cross-sectional area of pipe.

2.4.3 Velocity

It is the measure of how fast a fluid can cover a certain distance. Its unit are m/s, mph, fpm, etc. The velocity on a fluid is an average value of the velocity profile generated while flow.

2.5 Reynolds number and flow categories in a pipe

Reynolds number is a numerical symbolic system developed by Osborne Reynolds in 1883. He performed experiment by injecting filament of dye in a tube containing flowing liquid. On low velocity of liquid, the dye remained intact and parallel. When velocity was increased, fluctuations were seen in dye without any particular pattern. The two completely different behaviour of dye proved that there were different types of flow. The formula to calculate Reynolds number for internal as well as external flow in pipes is given as follows: [7]

$$\text{Reynolds number (Re)} = \frac{\rho v l}{\mu} \quad \text{Equation 7.}$$

In internal flow like in pipes and conduits, v = average velocity of fluid and l = internal diameter of pipe (d)

In external flow like in airfoils and flat surfaces, ρ = density of fluid, v = velocity of fluid passing over the surface and l = characteristic length of the surface.

According to [4, pp.4-6], a flow in a pipe can be categorized into two types, called as Laminar and Turbulent flow. Laminar flow represents a steady flow of a fluid represented by Reynolds number lesser than 2300. In this type of flow, elements of the fluid flow in an orderly fashion without any macroscopic intermixing with neighbouring fluid. Velocity fluctuation is seen in very less amount. The velocity profile for this flow is parabolic.

Turbulent flow creates comparative unpredictability in the flow behaviour of a fluid. Reynolds number greater than 4300 indicates this type of flow. The velocity profile for this flow is rather flat. In turbulent flow, properties such as pressure and velocity fluctuate rapidly at each location. Turbulent flow has the advantage of promoting rapid mixing and enhances convective heat and mass transfer.

The type of flow with Reynolds number between laminar and turbulent flow is called as Transient flow. The properties are not well defined for this type of flow.

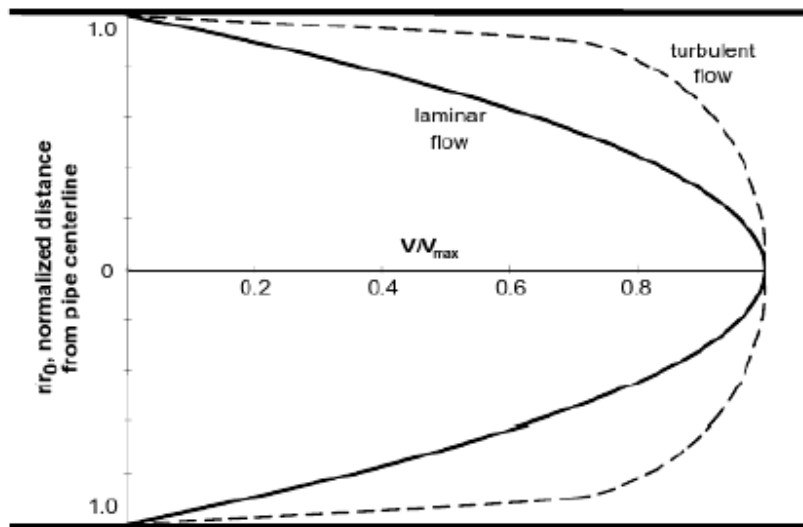


Figure 2. Velocity profile for different flows [8]

2.6 Head Loss

Head loss represents the loss of energy while a fluid flows through a certain length of pipe. It is normally expressed in Pressure/Pascal or length/metres. Depending on the flow, its value might depend on height, bends, friction, velocity and diameter of pipe. In a straight section of pipe, friction is the only cause of head loss.

2.6.1 Head loss in Laminar flow

Hagen-Poiseuille equation is used to calculate the head loss in laminar flow in conduits. [9]

$$\Delta P = \frac{128\mu l Q}{\pi d^4} \quad \text{Equation 8.}$$

In the equation, the head loss is denoted in the form of pressure difference (ΔP) across the sectional length of pipe, l = sectional length.

2.6.2 Head loss in Turbulent flow

White [2, pp.337-340] states Darcy-Weisbach equation is effectively used to measure head loss in turbulent regions of fluid flow. The equation was developed by a Henry Darcy, a French engineer in 1857. His equation consists of a new term called friction factor, also known as Darcy friction factor.

$$h_f = \frac{fv^2}{2dg} \quad \text{Equation 9.}$$

Where, h_f = head loss due to friction expressed in the form of length, f = friction factor, v = average velocity of fluid, g = acceleration due to gravity and d = inner diameter of pipe.

2.7 Friction factor

The friction while flow within pipes is a rather complicated terminology. The friction usually depends on various factors like viscosity, Reynolds number, roughness and type of flow. Since it acts against the fluid flow, it is the cause for the loss of energy in pipes. This can be elaborated by few equations relating to friction.

2.7.1 Friction in Laminar flow

Darcy equation and Hagen-Poiseuille equation can be solved to create a new equation for friction factor in laminar flow. The equation describes the friction as a function of Reynolds number only. [10]

$$f = \frac{64}{Re} \quad \text{Equation 10.}$$

Where, Re denotes Reynolds number.

2.7.2 Friction in Turbulent flow

Unpredictable behaviour of fluid particles in turbulent flow regime creates complications in calculating friction factor.

According to White [2, pp. 343-355], Coulomb discovered in 1800 that the friction in turbulent flow is affected by wall roughness of pipe. There are two widely accepted methods involving friction in turbulent flow:

2.7.2.1 Colebrook equation

Colebrook formulated an equation to calculate friction factor in turbulent flow in 1939. This equation is valid for both smooth and rough pipes.

$$\frac{1}{\sqrt{f}} = -2.0 \log \left[\frac{e}{3.7d} + \frac{2.51}{Re\sqrt{f}} \right] \quad \text{Equation 11.}$$

Where, e = absolute wall roughness, e/d = relative roughness

2.7.2.2 Moody Diagram

In 1944, Moody developed a graphical representation of Colebrook equation. His diagram is widely used in fluid mechanics applications. This diagram relates friction with Reynolds number and relative roughness. It can be used for both pipe flow and open-channel flows. Using this diagram, a third unknown term can be figured out from two known identities.

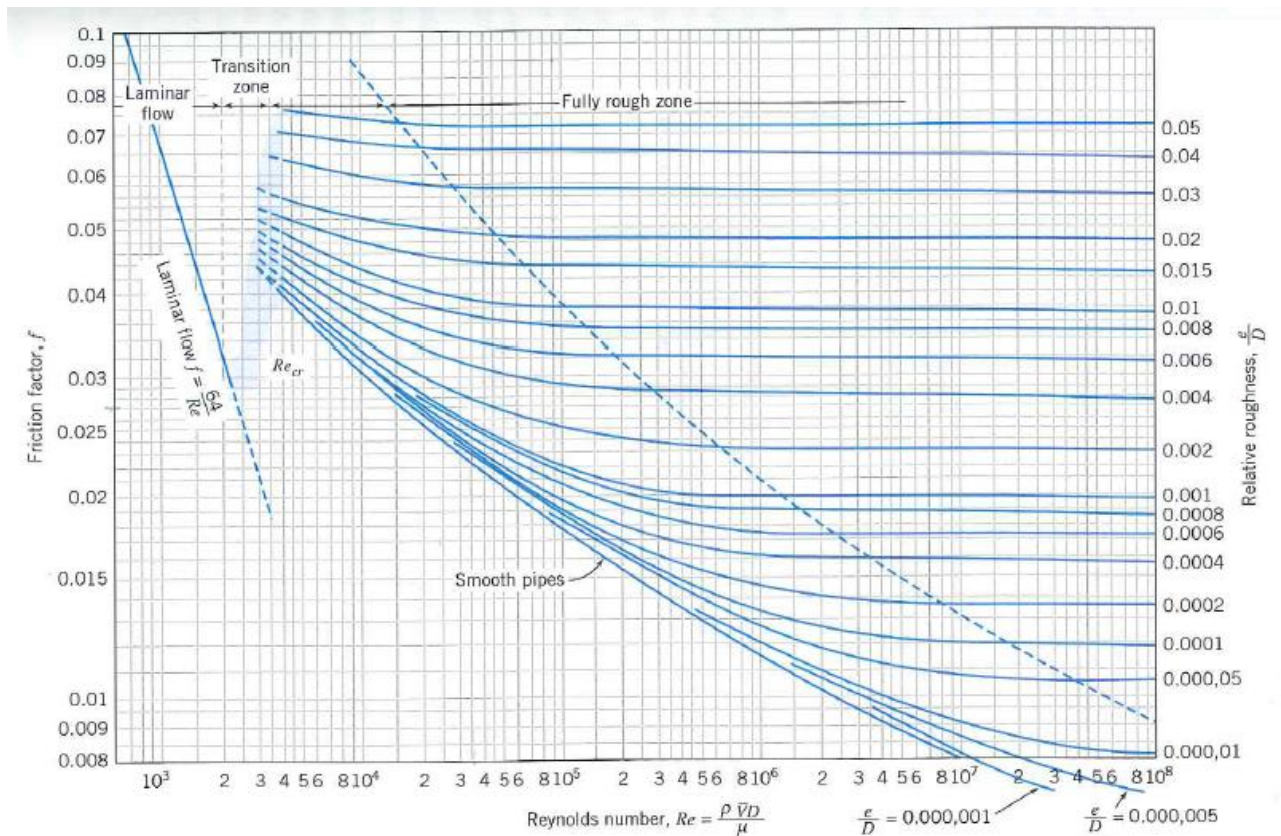


Figure 3. Moody Diagram [11]

2.8 Roughness

Roughness is simply a measurement of surface texture. It is the average height of the peaks and valleys formed from main surface. The topologies are impossible to be visible through naked eyes since the roughness is of few micrometres in length. The waviness consists of the more widely spread irregularities and is often produced by vibrations in machine. Relative roughness is the ratio of roughness to diameter of a pipe. [12]

Since roughness is a property of a material, its value unlike friction factor, is constant. Roughness is very effective in fully developed turbulent flow whereas its presence is negligible in smooth flow.

For plastic pipes like PEX and Polyester, absolute roughness value is within range of 1.5 to 7 micrometres. [13]

2.9 Boundary layer

Boundary layer concept was first introduced by Ludwig Prandtl in 1904. A boundary layer is the region near to a solid surface in which viscous stress and force are present. The stress and force are caused due to the shearing of a fluid at boundary layer. The viscous effects produce the velocity gradient. The viscous effect is maximum near the boundary surface where the velocity of fluid is lowest and the velocity gradually increases away from the surface.[14]

In figure 2, boundary layer thickness is the distance between solid boundary to the point where the velocity is maximum. It is quite clear that the boundary layer is higher in laminar than turbulent flow.

2.9.1 Turbulent flow zones

The boundary layer decreases as the turbulence increases. i.e. as the Reynolds number increases. In a turbulent flow, laminar sub-layer exists near the wall surface which represents the laminar flow of liquid because of its viscous effects. It is followed by a buffer layer where viscous effects are seen partially. This layer acts as a transition region. At certain Reynolds number, there will be no or negligible boundary layer. It is boundary layer which protects the flow from wall roughness and prevents drag effects due to roughness. Therefore Nikuradse differentiated turbulent pipe flow into three separate zones which are:[15]

2.9.1.1 Smooth turbulent zone

In this zone, the laminar sub-layer is thick enough to protect the flow from the roughness of wall. This is usually seen in extremely smooth pipes which have low roughness value. Examples are pipes with relative roughness around 0.0000001.

2.9.1.2 Transient turbulent zone

In this zone, the thickness of laminar sub-layer starts to decrease with increasing Reynolds number. As it starts to decrease lower than the average height of roughness, the effect of roughness on the flow can be seen i.e. the friction factor increases. (Figure 4)

2.9.1.3 Rough turbulent zone

This zone is also called as fully rough zone as in figure 3. In this zone, the laminar sub-layer is negligible. Due to this, the roughness effect remains constant with the increasing Reynolds number. Figure 3 and figure 4 show that the friction factor f remains constant when the flow is in fully rough zone. This occurs at high Reynolds numbers.

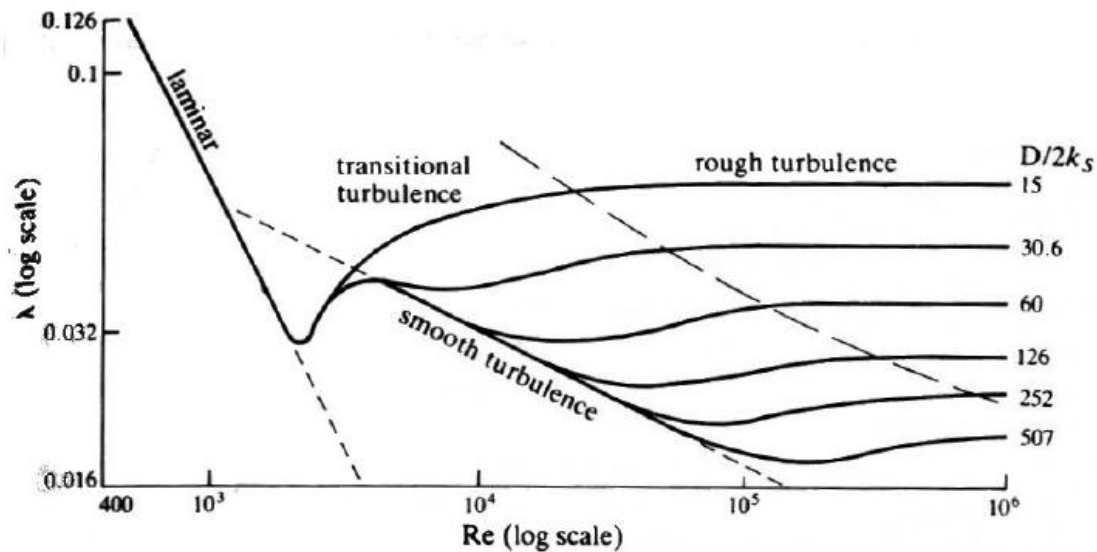


Figure 4. Turbulent flow zones (Friction factor Vs. Reynolds number) [15, pp.7]

2.10 Drag reducing additives

2.10.1 Polyethylene Oxide (PEO)

Polyethylene Oxide is a non-ionic, water soluble resin, with good lubricating, binding and forming properties. Found in powder crystalline form, it is white in colour and is a highly soluble hydrophilic polymer. It exhibits film forming and water retaining properties. It has very low toxicity which makes it suitable to use in liquids. Its molecular formula is $(-O-CH_2-CH_2-)_n OH$. Its molecular weight is 100,000 AMU (Atomic Mass Unit). [16]

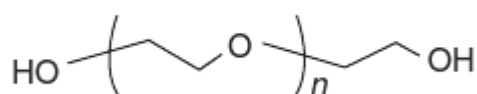


Figure 5. Structure of PEO [17]

During turbulent flow, high molecular weight polymers like PEO help to increase the viscosity of fluid in buffer layer. This leads to the increase in thickness of buffer layer and ultimately decreases the drag effects. [18]

2.10.2 Sodium Salicylate (Nasal)

Swarnlata [19] states Sodium Salicylate, which was discovered around 19th century is also known as 2-hydroxy benzoate, Glutosalyl etc. Its molecular formula is $C_7H_5NaO_3$ and molecular weight 160.10 AMU. It is freely soluble in water and found in crystals or powder in solid state.

When dissolved in water the negatively charged hydrocarbon group acts as surfactant by producing hydrophobic and hydrophilic parts.

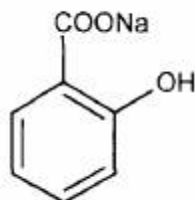


Figure 6. Structure of NaSal [19, pp.52]

3 Methodology

3.1 Equipment used

- Digital pressure gauges, 2 items.
- Pressure pump. Brand- Grundfos. Maximum power supplied-22 Watts.
- Measuring instruments- Vernier calipers, Measuring tape
- Plumbing equipment- bolts, nuts, O-rings, seal tape
- Analogue flow rate meter
- Stop watch

3.2 Materials and chemicals used

- Cross-linked Polyethylene (PEX) pipe with different lengths. Internal diameter of 8 mm and outer of 12 mm.
- Polyester pipe of length 5 metres. Internal diameter of 6 mm and outer of 12 mm.
- Water as the fluid
- Polyethylene oxide (PEO)
- Sodium Salicylate (NaSal)

3.3 Fluid flow environment

The experiment was done in the Energy/Heat Transfer lab at Arcada University of Applied sciences. The lab is a system which works by regulating a fluid through pipes with the help of pressure pump. As the fluid flows throughout the system, it is made to travel from a reservoir/boiler through different experimental equipment like radiators, heat exchanger and finally into reservoir again. The process is continuous. The system is used for different experiments relating fluid dynamics and heat transfer.

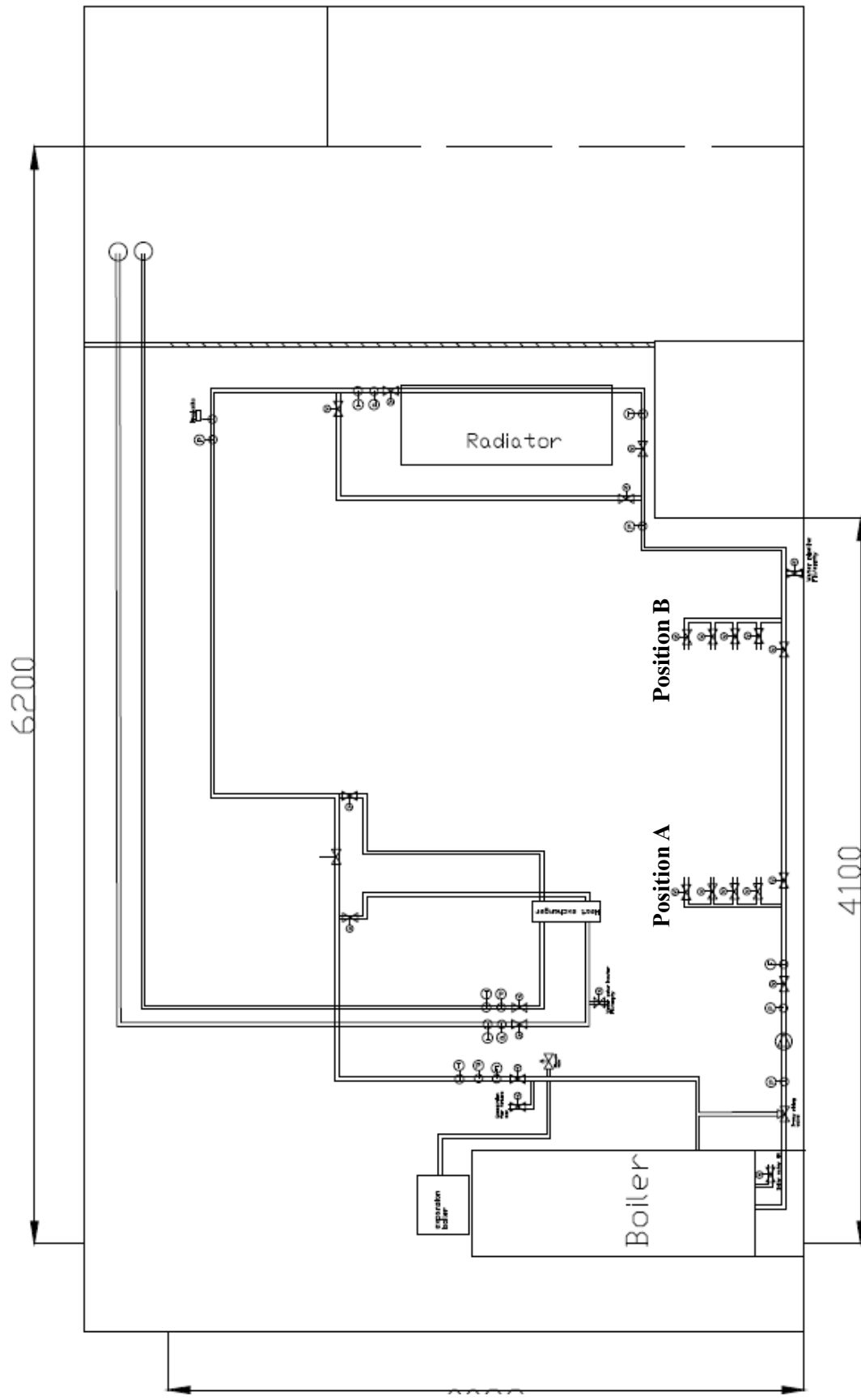


Figure 7. Drawing of heat transfer lab layout [20]

3.4 Experimental procedure

3.4.1 System set-up

A horizontal and straight section of PEX pipe was connected between position A and position B (figure 7, distances in mm.). Since the distance between A to B was only 1,4 metres, the pipe was set up in a different location and its two ends were connected to points A and B with some additional pipes. Two pressure gauges were connected to the two ends of the straight pipe. All the connections were made water-tight by O-rings and bolts. Since the experiment does not deal with radiators and heat exchangers, flow cut-off was done to these apparatus. Water inside the system was maintained at room-temperature.

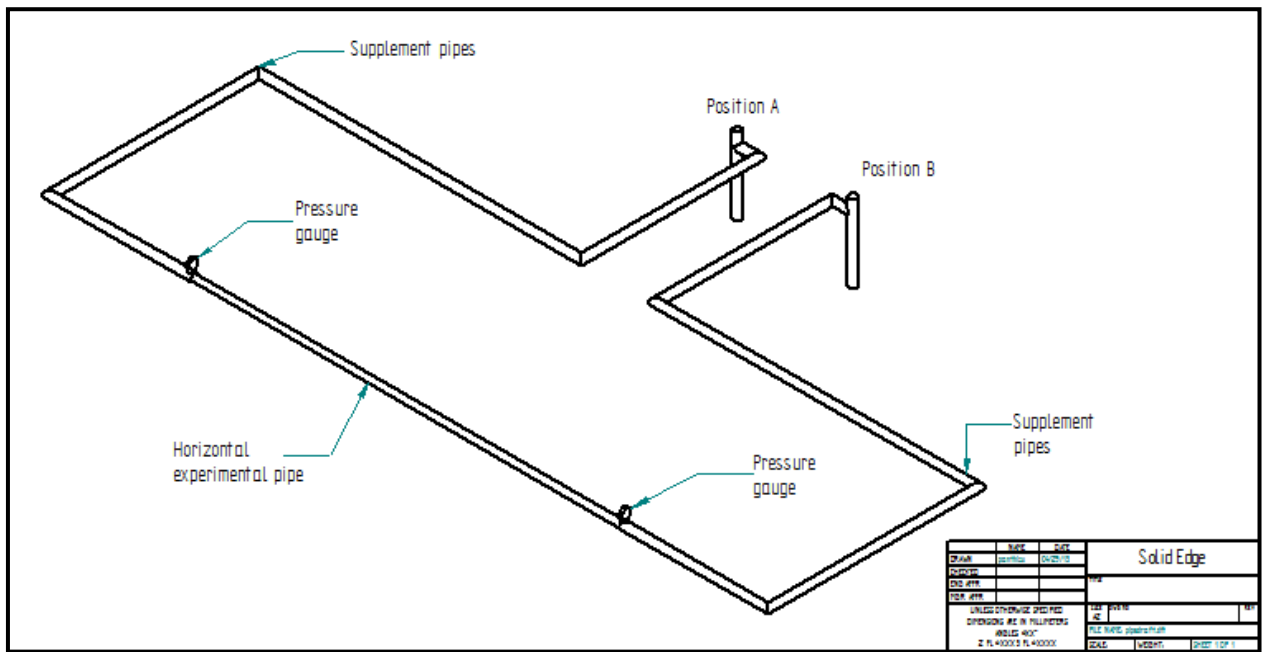


Figure 8. Detailed pipe layout sketch

3.4.2 Experiment

The liquid was made to flow in the system after connecting the pump to power source. When the flow was steady, different measurements were taken which were as follows:

3.4.2.1 Internal diameter of pipe

The internal diameter of pipe was measured by electronic Vernier calipers.

3.4.2.2 Pressure before and after pump

Two fixed pressure gauges of the system were used to measure pressures before and after the pump. The pressure measurement was taken in Bars.

3.4.2.3 Electric power and efficiency

Reading of electric power with which pump was operating was done through the information displayed on the pump. Its efficiency was calculated from Equation 4.

3.4.2.4 Volumetric flow rate

The volumetric flow rate of the liquid was measured by flow rate meter. As the flow rate meter was an analogue machine, the value was obtained by recording revolutions at certain time. Time was recorded with stop watch.

$$1 \text{ revolution} = 0.001 \text{ m}^3$$

$$\text{Flow rate (Q)} = \frac{N \times 0,001 \text{ m}^3}{T} \quad \text{Equation 12.}$$

Where, N = number of revolutions, T= time taken (seconds)



Figure 9. Flow rate meter

3.4.2.5 Initial and final pressure on experimental pipe

Pressure readings were recorded from two pressure gauges located at two ends of the pipe as shown in figure 3. The initial pressure was at the point where fluid flows into the experimental pipe and final pressure was at the point where it left.



Figure 10. Digital pressure gauge

After knowing values of the terminologies above, further calculations were done to obtain Reynolds number, friction factor and relative roughness. (Equation 7, 10 and 11)

The Reynolds number was varied for the experiment starting from maximum value the pump can generate to the lowest. By doing this, the flow was made to be on the different phases- Turbulent, Transient and Laminar flow. In this way, the flow characteristics of different flow phases were observed. The Transient flow was not taken into observation since this flow represents irregularities in the behaviours and a certain result on this phase might conflict with itself.

The System set-up and experiment was repeated four times for different lengths of PEX pipes. The lengths were 15, 10, 5, and 2,5 metres. Then, it was done once more with Polyester pipe of length 5 metres. Results were recorded in tabular form.



Figure 11. PEX pipes



Figure 12. Polyester pipes

3.5 Introduction of additives

Two additives with different chemical, structural and molecular properties are chosen for the experiment. First additive was PEO which is a high molecular weight polymer and the other was NaSal which is of less molecular weight.

At first, PEO was added to the system. For this, at first the water of the system was removed and the reservoir was made empty. The amount of PEO to be added was 500 ppm. The total amount of fluid needed in the system was 100 litres. Therefore, 50 grams of PEO was used for the experiment. 50 grams of PEO, after measuring in weighting machine, was mixed in a beaker of water and stirred until it partially dissolved in water. Then, the mixture was transferred to the system and more water was added until it reached 100 litres.

3.5.1 Experiment with additive

Measurements were taken for the water with additive as in step 3.4.2 Experiment. The experiment was performed only for 5 metres length PEX pipe. Polyester pipe was not included for the experiment with additives.

After this, the fluid in the system was again withdrawn and the system was cleaned. Introduction of NaSal followed after PEO. 220 ppm of NaSal was selected for the experiment.

Therefore, 22 grams of NaSal was used for 100 litres of water. This was also dissolved in water in a beaker and then transferred to the system. Extra water was supplied until it reached 100 litres. Step 3.5.1 Experiment with additive was repeated with NaSal as an additive.



Figure 13. PEO additive

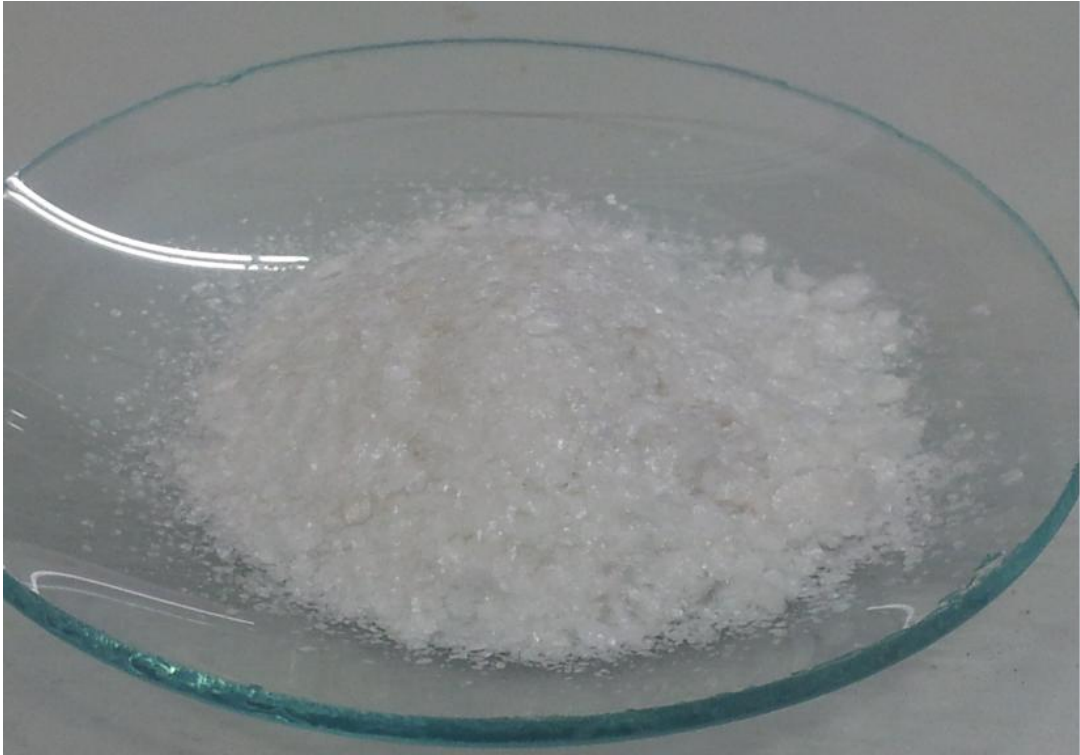


Figure 14. NaSal additive

4 Results

The results for measurements taken for the experiment in step 3.4.2 *Experiment* are listed in tabular form. The different tables are as follows:

1. 15 metres PEX pipe with water as fluid
2. 10 metres PEX pipe with water as fluid
3. 5 metres PEX pipe with water as fluid
4. 5 metres Polyester pipe with water as fluid
5. 2,5 metres PEX pipe with water as fluid
6. 5 metres PEX pipe with water and PEO as fluid
7. 5 metres PEX pipe with water and NaSal as fluid
8. 5 metres PEX pipe 2nd experiment with water as fluid

The units for different terminologies used for the following tables are as follows:

- Length – metres
- Diameter – millimetres
- Pressure – bars
- Power – Watts
- Efficiency - %
- Flow rate – m^3/s
- Head loss – metres
- Velocity – m/s

Table 1. 15 metres pipe experimental datasheet.

S.N	1	2	3	4	5	6	7
Pipe length (l)	15	15	15	15	15	15	15
Diameter (D)	8	8	8	8	8	8	8
Pressure before pump (P3)	0,837	0,837	0,837	0,837	0,837	0,837	0,837
Pressure after pump (P4)	1,197	1,068	1,197	1,126	1,027	1,197	1,197
Electric Power (P)	22	12	22	16	10	22	22
Water power(P_w)	7,99E-01	3,47E-01	4,50E-01	2,89E-01	1,58E-01	2,09E-01	7,81E-02
Efficiency (E)	3,63	2,89	2,05	1,81	1,58	0,95	0,36
Volumetric flow rate (Q)	2,22E-05	1,50E-05	1,25E-05	1,00E-05	8,30E-06	5,80E-06	2,17E-06
Velocity (v)	0,44	0,30	0,25	0,20	0,17	0,12	0,04
Reynolds number (Re)	3533,24	2387,32	1989,44	1591,55	1320,99	923,10	345,37
Type of flow	Transient	Laminar	Laminar	Laminar	Laminar	Laminar	Laminar
Initial pressure (P1)	1,168	1,051	1	0,994	1,012	0,95	0,916
Final pressure (P2)	1,048	0,978	0,948	0,94	0,96	0,918	0,895
Pressure difference (ΔP)	0,12	0,073	0,052	0,054	0,052	0,032	0,021
head loss (h)	1,22	0,74	0,53	0,55	0,53	0,33	0,21
Friction factor (f)	0,07	0,03	0,03	0,04	0,05	0,07	0,19

Table 2. 10 metres pipe experimental datasheet.

S.N	1	2	3	4	5
Pipe length (l)	10	10	10	10	10
Diameter (D)	8	8	8	8	8
Pressure before pump (P3)	1,19	1,19	1,19	1,19	1,19
Pressure after pump (P4)	1,55	1,47	1,545	1,47	1,47
Electric Power (P)	22	16	22	16	16
Water power (P_w)	6,01E-01	2,47E-01	4,72E-01	1,22E-01	6,57E-03
Efficiency (E)	2,732727	1,5435	2,146136364	0,760725	0,0410725
Volumetric flow rate (Q)	1,67E-05	8,82E-06	1,33E-05	4,35E-06	2,35E-07
Velocity (v)	0,332236	0,175468	0,264595093	0,086480817	0,00466921
Reynolds number (Re)	2657,89	1403,75	2116,76	691,85	37,35
Type of flow	Transient	Laminar	Laminar	Laminar	Laminar
Initial pressure (P1)	1,355	1,32	1,385	1,315	1,34
Final pressure (P2)	1,275	1,255	1,31	1,265	1,29
Pressure difference (ΔP)	0,08	0,065	0,075	0,05	0,05
Head loss (h)	0,82	0,66	0,77	0,51	0,51
Friction factor (f)	0,02	0,05	0,03	0,09	1,71

Table 3. 5 metres PEX pipe experimental datasheet.

S.N	1	2	3	4	5	6	7	8
Pipe length (l)	5	5	5	5	5	5	5	5
Diameter (D)	8	8	8	8	8	8	8	8
Pressure before pump (P3)	2,45	2,45	2,45	2,45	2,45	2,45	2,45	2,45
Pressure after pump (P4)	2,805	2,805	2,8	2,8	2,81	2,81	2,81	2,81
Electric Power (P)	22	22	22	22	22	22	22	22
Water power(P _w)	1,29	1,20	1,04	0,93	0,52	0,38	0,32	0,08
Efficiency (E)	5,84	5,45	4,75	4,25	2,37	1,75	1,44	0,36
Volumetric flow rate (Q)	3,57E-05	3,33E-05	2,94E-05	2,63E-05	1,43E-05	1,05E-05	8,70E-06	2,17E-06
Velocity (v)	0,71	0,66	0,59	0,52	0,28	0,21	0,17	0,04
Reynolds number (Re)	5681,83	5305,11	4681,02	4187,37	2272,73	1675,26	1383,85	345,99
Type of flow	Turb.	Turb.	Turb.	Turb.	Lam.	Lam.	Lam.	Lam.
Initial pressure (P1)	2,749	2,712	2,702	2,683	2,597	2,582	2,577	2,565
Final pressure (P2)	2,668	2,641	2,644	2,63	2,559	2,55	2,547	2,541
Pressure difference (ΔP)	0,081	0,071	0,058	0,053	0,038	0,032	0,03	0,024
head loss (h)	0,83	0,72	0,59	0,54	0,39	0,33	0,31	0,24
Friction factor (f)	0,051	0,0516	0,0542	0,06190	0,0281	0,03820	0,046247	0,1849780
roughness value	0,015	0,0156	0,0178	0,02731	-	-	-	-

Table 4. 5 metres Polyester pipe experimental datasheet

S.N	2	1	3	6	4	5
Length of pipe (l)	5	5	5	5	5	5
Diameter (D)	6	6	6	6	6	6
Pressure before pump (P3)	0,725	0,725	0,725	0,725	0,725	0,725
Pressure after pump (P4)	1,045	0,96	1,045	1,065	1,065	1,085
Electric Power (P)	22	20	22	22	22	22
Water power(P _w)	6,08E-01	3,17E-01	3,55E-01	2,58E-01	2,34E-01	4,07E-02
Efficiency (E)	2,763636	1,58625	1,614545455	1,174545455	1,06481818	0,184909091
Volumetric flow rate (Q)	1,90E-05	1,35E-05	1,11E-05	7,60E-06	6,89E-06	1,13E-06
Velocity (v)	0,671988	0,477465	0,392582193	0,268795015	0,2436839	0,039965575
Reynolds number (Re)	4031,925	2864,789	2355,493158	1612,77009	1462,10341	239,7934476
Type of flow	Transient	Laminar	Laminar	Laminar	Laminar	Laminar

Initial pressure (P1)	1,023	0,988	0,926	0,892	0,872	0,852
Final pressure (P2)	0,931	0,928	0,876	0,866	0,856	0,842
Pressure difference (ΔP)	0,092	0,06	0,05	0,026	0,016	0,01
head loss (h)	0,938776	0,612245	0,510204082	0,265306122	0,16326531	0,102040816
Friction factor (f)	0,065195	0,084221	0,103814685	0,115154498	0,08622164	2,003446989

Table 5. 2,5 metres PEX pipe experimental datasheet

S.N	1	2	3	4	5	6
Pipe length (l)	2,5	2,5	2,5	2,5	2,5	2,5
Diameter (D)	8	8	8	8	8	8
Pressure before pump (P3)	0,75	0,75	0,75	0,75	0,75	0,75
Pressure after pump (P4)	1,137	1,062	1,055	1,062	1,17	1,17
Electric Power (P)	22	22	16	22	22	22
Water power (P_w)	1,55E+00	1,04E+00	8,45E-01	4,43E-01	2,80E-01	5,25E-02
Efficiency (E)	7,04	4,72	5,28	2,01	1,27	0,24
Volumetric flow rate (Q)	4,00E-05	3,33E-05	2,77E-05	1,42E-05	6,66E-06	1,25E-06
Velocity (v)	0,795774	0,6624	0,55107	0,282500	0,1324	0,02486
Reynolds number (Re)	6366,197724	5299,8596	4408,59192	2260,000192	1059,9719	198,943679
Type of flow	Turbulent	Turbulent	Turbulent	Laminar	Laminar	Laminar
Initial pressure (P1)	1,07	1,02	0,964	0,924	0,939	0,929
Final pressure (P2)	1,038	1	0,947	0,915	0,935	0,927
Pressure difference (ΔP)	0,032	0,02	0,017	0,009	0,004	0,002
head loss (h)	0,33	0,20	0,17	0,09	0,04	0,02
Friction factor (f)	0,03234072	0,02916495	0,03582689	0,028318582	0,060379	0,32169909
roughness value	0,00	-0,01	0,00	-	-	-

Table 6. 5 metres PEX pipe experimental datasheet (additive – PEO)

S.N	1	2	3	4	5	6	7	8	9
Pipe length (l)	5	5	5	5	5	5	5	5	5
Diameter (D)	8	8	8	8	8	8	8	8	8
Pressure before pump (P3)	2,16	2,16	2,16	2,16	2,16	2,16	2,16	2,16	2,16
Pressure after pump (P4)	2,52	2,508	2,508	2,508	2,444	2,39	2,52	2,52	2,52

Electric Power (P)	22	22	22	22	16	12	22	22	22
Water power (P_w)	1,27E+00	1,15E+00	1,08E+00	1,01E+00	8,03E-01	2,88E-01	3,00E-01	2,55E-01	1,55E-01
Efficiency (E)	5,79	5,22	4,90	4,61	5,02	0,00	0,00	0,00	0,00
Volumetric flow rate (Q)	3,57E-05	3,33E-05	3,13E-05	2,94E-05	2,86E-05	1,25E-05	8,33E-06	7,14E-06	4,35E-06
Velocity (v)	0,71	0,66	0,62	0,59	0,57	0,25	0,17	0,14	0,09
Reynolds number (Re)	5681,83	5299,86	4973,59	4682,34	4547,06	1989,44	1325,76	1136,37	691,85
Type of flow	Turb.	Turb.	Turb.	Turb.	Turb.	Lam.	Lam.	Lam.	Lam.
Initial pressure (P1)	2,455	2,452	2,44	2,405	2,398	2,291	2,276	2,272	2,27
Final pressure (P2)	2,391	2,399	2,389	2,355	2,351	2,258	2,244	2,241	2,24
Pressure difference (ΔP)	0,064	0,053	0,051	0,05	0,047	0,033	0,032	0,031	0,03
head loss (h)	0,65	0,54	0,52	0,51	0,48	0,34	0,33	0,32	0,31
Friction factor (f)	0,040600	0,03864	0,04222	0,04670	0,04655	0,032169	0,048274	0,0563	0,092506
roughness value	0,004131	0,00170	0,00459	0,00883	0,00839	-	-	-	-

Table 7. 5 metres PEX pipe experimental datasheet (additive – NaSal)

S.N	1	2	3	4	5	6	7	8	9
Pipe length (l)	5	5	5	5	5	5	5	5	5
Diameter (D)	8	8	8	8	8	8	8	8	8
Pressure before pump (P3)	2,52	2,52	2,52	2,52	2,52	2,52	2,52	2,52	2,52
Pressure after pump (P4)	2,867	2,86	2,86	2,867	2,785	2,86	2,86	2,86	2,86
Electric Power (P)	22	22	22	22	16	22	22	22	22
Water power (P_w)	1,26E+00	1,15E+00	1,05E+00	1,04E+00	7,50E-01	4,93E-01	3,62E-01	2,46E-01	1,73E-01
Efficiency (E)	5,71	5,23	4,75	4,71	4,69	0,00	0,00	0,00	0,00
Volumetric flow rate (Q)	3,57E-05	3,33E-05	3,03E-05	2,94E-05	2,78E-05	1,43E-05	1,05E-05	7,14E-06	5,00E-06
Velocity (v)	0,71	0,66	0,60	0,59	0,55	0,28	0,21	0,14	0,10
Reynolds number (Re)	5681,83	5305,16	4822,39	4680,75	4420,37	2272,73	1671,13	1136,81	795,77
Type of flow	Turb.	Turb.	Turb.	Trub.	Turb.	Lam.	Lam.	Lam.	Lam.
Initial pressure (P1)	2,809	2,777	2,755	2,757	2,72	2,632	2,616	2,615	2,615

Final pressure (P2)	2,732	2,715	2,699	2,699	2,667	2,598	2,589	2,592	2,591
Pressure difference (ΔP)	0,077	0,062	0,056	0,058	0,053	0,034	0,027	0,023	0,024
head loss (h)	0,79	0,63	0,57	0,59	0,54	0,35	0,28	0,23	0,24
Friction factor (f)	0,048847	0,04511	0,049316	0,05421	0,05555	0,02815	0,03829	0,0562	0,080424
roughness value	0,012860	0,00816	0,012097	0,01786	0,01909	-	-	-	-

Table 8. 5 metres PEX pipe 2nd experiment with less pressure

S.N	1	2	3	4	5	6	7	8	9	10
Pipe length (l)	5	5	5	5	5	5	5	5	5	5
Diameter (D)	8	8	8	8	8	8	8	8	8	8
Pressure before pump (P3)	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88
Pressure after pump (P4)	1,24	1,24	1,24	1,24	1,24	1,24	1,073	0,982	0,982	1,115
Electric Power (P)	22	22	16	22	22	22	10	5	5	16
Water power (P_w)	1,38E+00	1,35E+00	1,22E+00	1,20E+00	1,03E+00	9,97E-01	5,02E-01	1,54E-01	1,19E-01	1,18E-01
Efficiency (E)	6,28	6,14	7,65	5,45	4,68	4,53	5,02	3,08	2,39	0,73
Volumetric flow rate (Q)	3,84E-05	3,75E-05	3,40E-05	3,33E-05	2,86E-05	2,77E-05	2,60E-05	1,51E-05	1,17E-05	5,00E-06
Velocity (v)	0,76	0,75	0,68	0,66	0,57	0,55	0,52	0,30	0,23	0,10
Reynolds number (Re)	6111	5968	5411	5299	4547	4408	4138	2403,24	1862,11	795,77
Type of flow	Trub.	Turb.	Turb.	Turb.	Turb.	Turb.	Turb.	Lam.	Lam.	Lam.
Initial pressure (P1)	1,16	1,15	1,1	1,18	1,05	1,106	1,029	0,957	0,941	0,929
Final pressure (P2)	1,08	1,08	1,04	1,124	0,998	1,055	0,98	0,937	0,923	0,917
Pressure difference (ΔP)	0,08	0,07	0,06	0,056	0,052	0,051	0,049	0,02	0,018	0,012
head loss (h)	0,82	0,71	0,61	0,57	0,53	0,52	0,50	0,20	0,18	0,12
Friction factor (f)	0,0438	0,0402	0,0419	0,0408	0,0515	0,0537	0,0586	0,0709	0,1063	0,3880
roughness value	0,0079	0,0041	0,00506	0,00377	0,01421	0,01673	0,02259	-	-	-

From the tables above, different characteristics of fluids can be seen. For simplicity, some graphs are produced based on the tables above.

4.1 Result before using additives

Below, some graphs represent the results. The graphs show inter-relationship between friction factor, relative roughness, pressure loss, head loss and Reynolds number when water is used as the fluid.

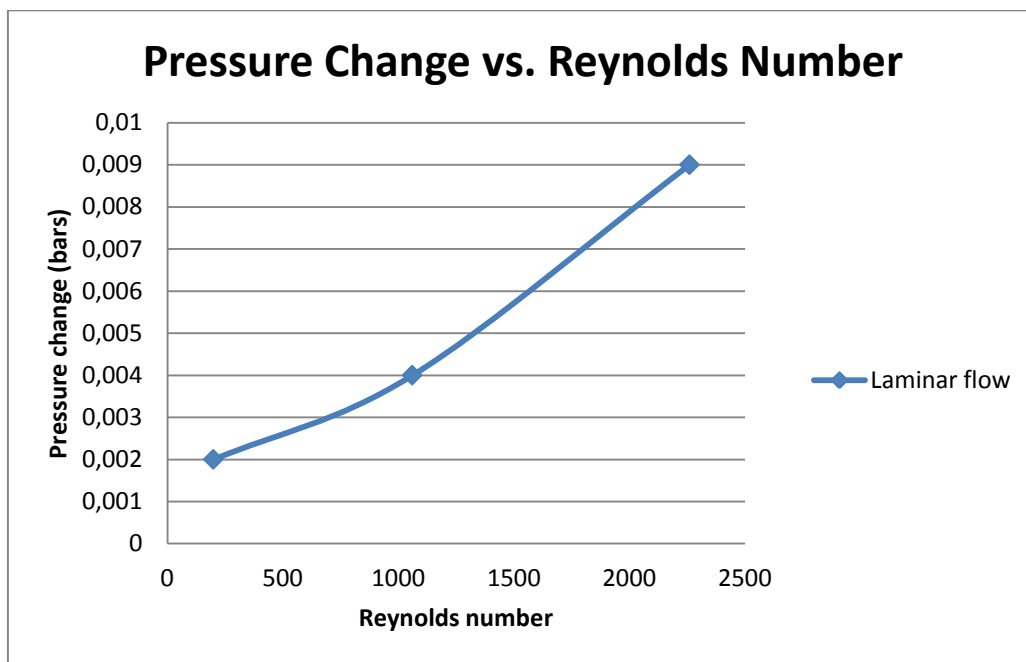


Figure 15. Pressure difference vs. Reynolds number

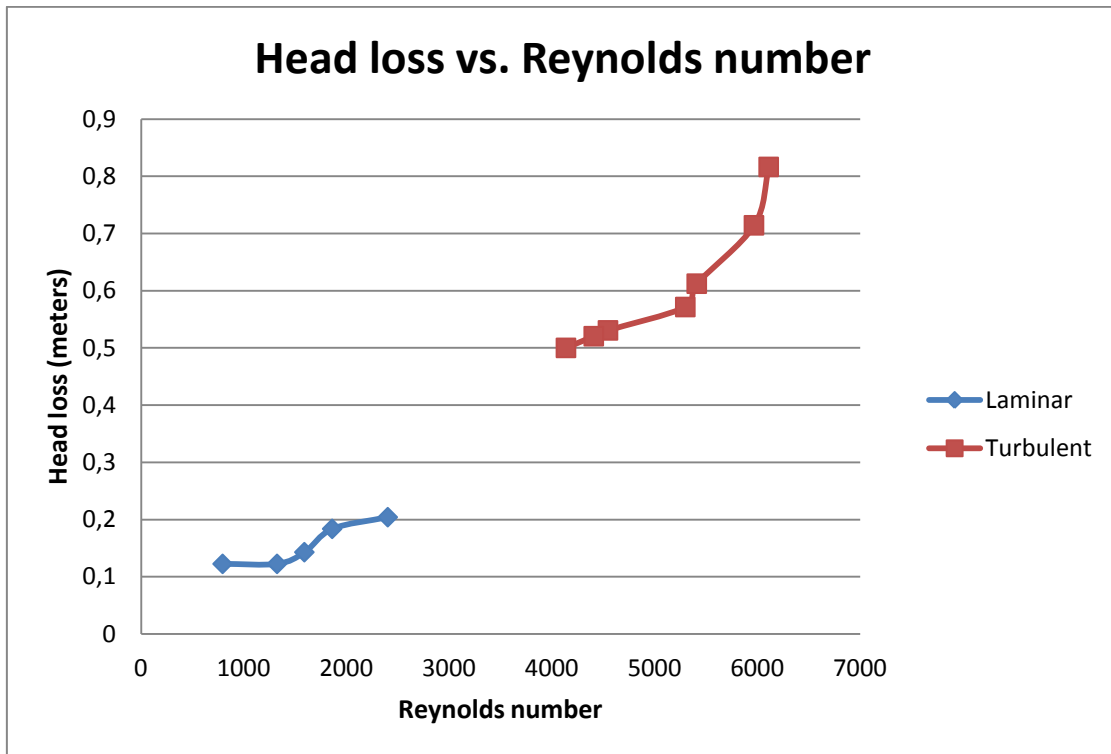


Figure 16. Head loss vs. Reynolds number

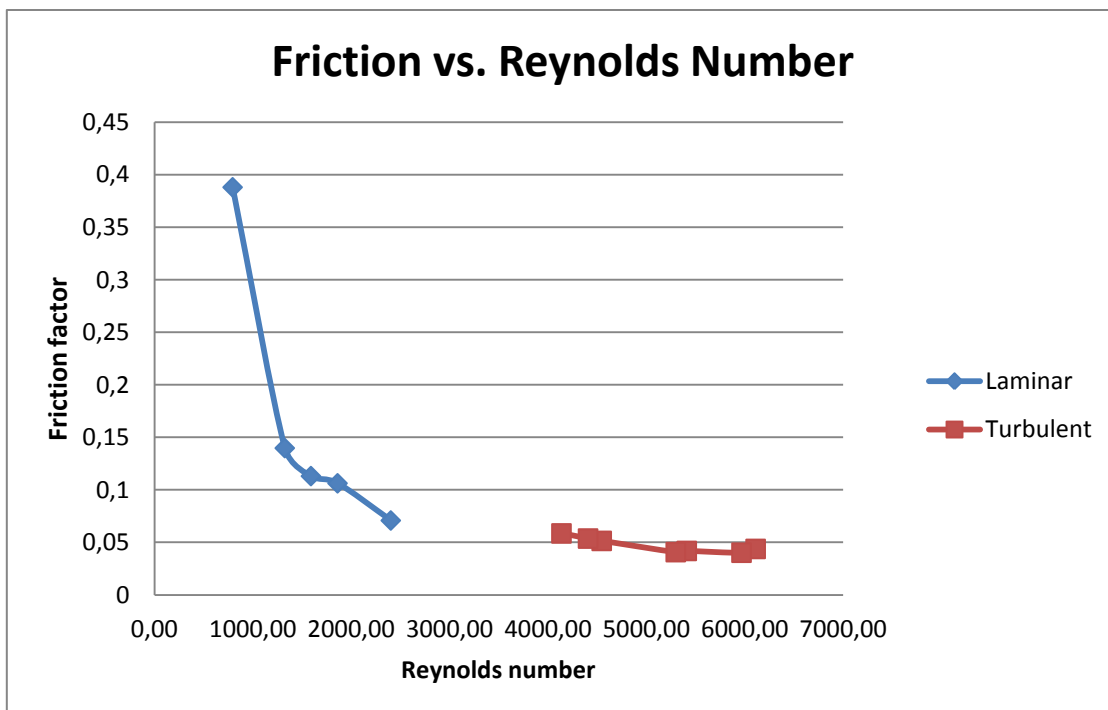


Figure 17. Friction factor vs. Reynolds number

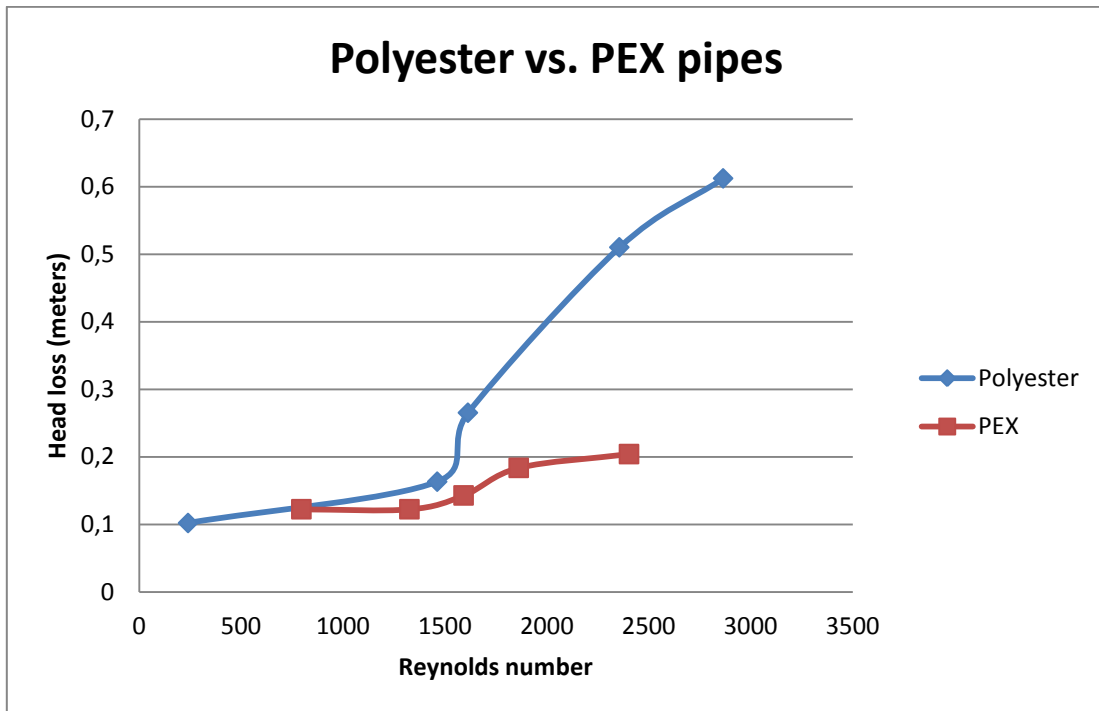


Figure 18. Head loss in two different pipes

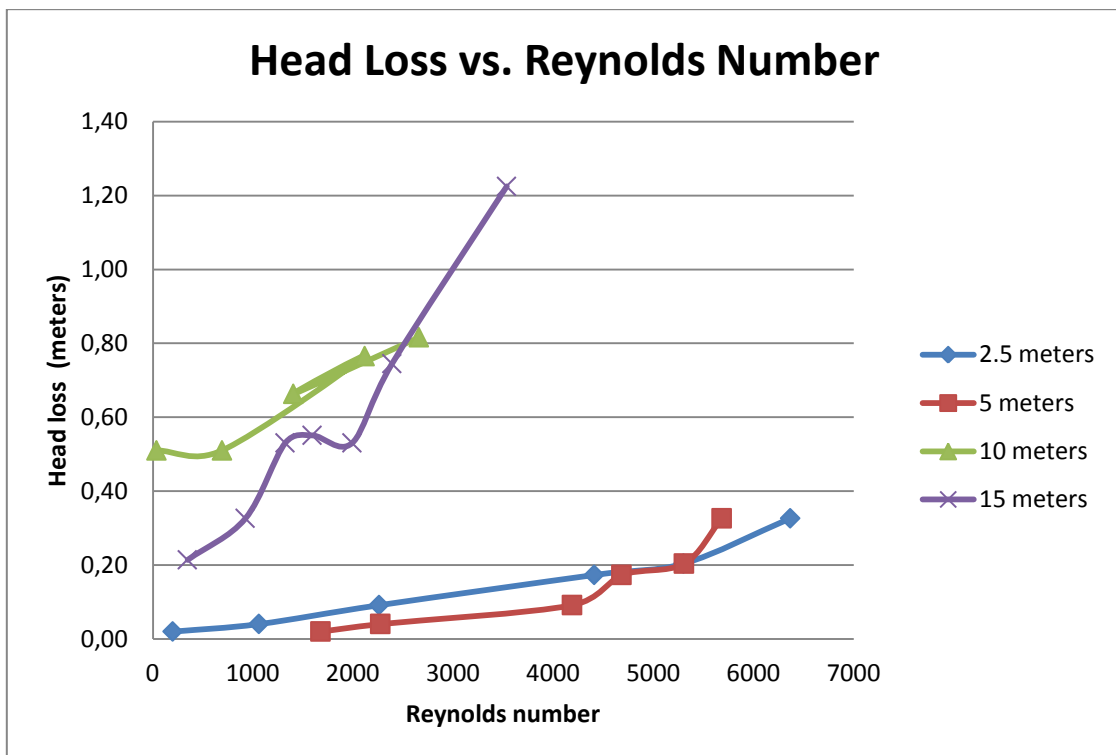


Figure 19. Head loss in different pipe lengths

4.2 Results after using additives

The cost price of additives was as follows: PEO cost price was € 480/kg and NaSal cost price was €130/kg. The cost price of PEO and NaSal used for the experiment was €24 and €2,86 respectively.

The effect of two additives PEO and NaSal and their difference in fluid's characteristics are presented in graphical way.

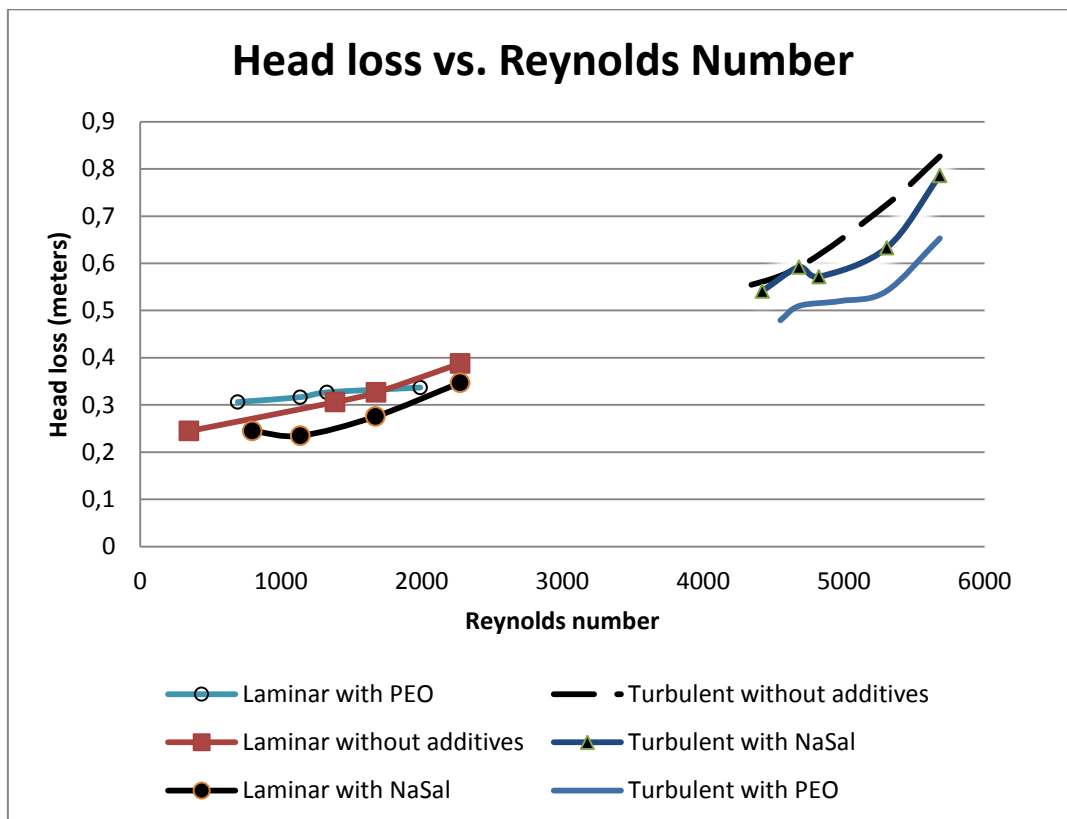


Figure 20. Head loss after additives

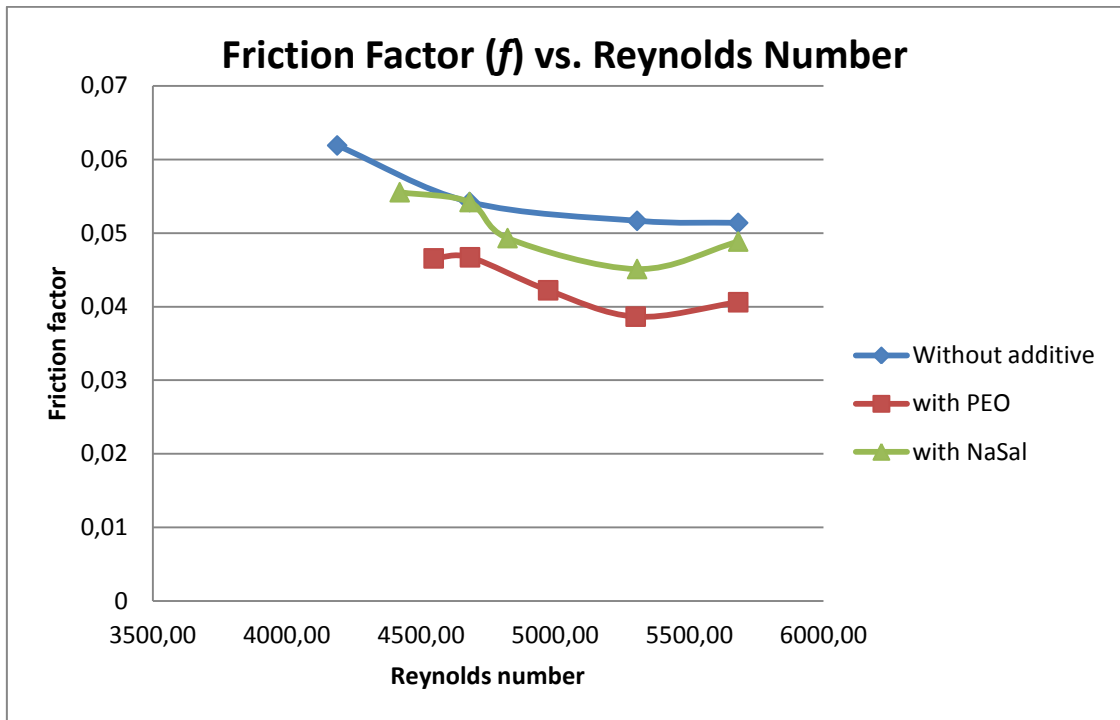


Figure 21. Friction factor after additives in Turbulent regime

4.2.1 Calculation of drag reduction

Percentage drag reduction for 5 metres PEX pipe after introduction of additives is shown in table 9.

Table 9. Percentage drag reduction

Common Reynolds number	Head loss without additives	Head loss with PEO (bars)	Head loss with Na-Sal (bars)	Drag reduction % with PEO	Drag reduction % with Nasal
5681,83	0,83	0,65	0,79	21,68674699	6,153846154
5305,16	0,72	0,54	0,63	25	16,66666667
4680,75	0,59	0,51	0,59	13,55932203	0

Table 10. Drag effect as percentage decrease of initial pressure

	Reynolds Number	Head loss (bars)	Initial pressure (bars)	% decrease
15 m pipe	3533,24	0,12	1,168	10,2739726
10 m pipe	2657,8	0,08	1,355	5,904059041
5 m pipe	5681,83	0,081	2,749	2,946526009
5 m pipe with PEO	5681	0,064	2,455	2,606924644
5 m pipe with PEO	5300	0,053	2,452	2,161500816

5 Discussion

The results reflect that head loss increases with the increase in Reynolds number. However, the pattern of increase is different according to the types of flow. In laminar flow, head loss changes linearly. Whereas, there is exponential increase of head loss in turbulent flow. Friction decreases linearly with the increase in Reynolds number in laminar flow. Friction in turbulent flow is with less fluctuation. Figure 18 shows that the drag effect of pipe depends on the characteristic length of the pipe. Higher head loss is seen in pipe with smaller diameter (Polyester pipe-diameter 6mm) than of bigger diameter (PEX pipe – diameter 8mm). With 2 mm bigger diameter pipe, the maximum head loss reduction on a laminar zone was 60.7% for the same sectional length of pipe. Analysis from figure 16 shows that the head loss when a fluid flows through is less when the fluid is flowing in laminar flow than in turbulent. The maximum of 0,2 metres head loss seen in laminar flow is seen to increase up to 0,8 metres in turbulent flow for 5 metres length experimental pipe.

Drag effects have found to be decreased after the use of the chemical additives on the experiment. Polyethylene Oxide (PEO) which is a high molecular weight polymer showed the greater drag reducing effect than Sodium Salicylate(NaSal). PEO helped to reduce the head loss by 25% at turbulent flow with Reynolds number 5300. At the same flow rate, head loss reduction of 16.6% was obtained with NaSal. A significant drag reduction was not seen in laminar flow from PEO. But, NaSal decreased the head loss by 12%. From *table 10*, it can be seen that the head loss can be decreased to the value of 2% of initial energy supplied by pump with the use of PEO form 3% seen in fluid without additives. When considering cost price of the additives, 25% of drag reduction was obtained from PEO with the cost of €24. Whereas, 16% of drag reduction was seen from NaSal with the cost of €2,86.

The drag effect is believed to be caused by friction which also decreased after the introduction of drag reducing additives. In turbulent regime, friction factor, f of the fluid which was of value around 0.52, decreased to 0.4 by the use of PEO. NaSal depressed the friction factor to 0.45 (figure 21). The reduction of head loss after the use of drag reducing additives shows that the additives are useful to save energy during the pipeline transportation. The concentration of the additives that are needed in a fluid is very less which is in the unit of

milligrams per litre. Therefore, use of additives would not be too much expensive taking into account the amount of energy it saves.

The different pipe lengths like 5, 10, 15 and 2.5 metres showed diverse head loss patterns. The head loss caused by friction was of maximum value of about 0.12 bars in 15 metres pipe with fluid flowing in Reynolds number 3533. Head loss is certainly not a quantity to neglect in straight pipes since the head loss actually grows with the increase in Reynolds number. *Table 10* shows that the head loss in 15 metres pipe can be 10% of the initial energy applied by the pump which is extremely high. The head loss in small length pipes like 5 and 2.5 metres was smaller compared to longer pipes like 10 and 15 metres. (Figure 19)

The head loss comparison is done on the same Reynolds number because flows in a pipe with same Reynolds number indicate identical flow. All the head losses taken for the study are from experiments and not from theoretical formula. Therefore, head loss actually is the length representation of pressure difference across experimental pipe.

Digital pressure gauge used for experiments displayed a rather wide range of data. Therefore an average of lowest and highest limits for a reading was taken for the value of pressure. Some values while on observation were recorded to be completely out of a pattern, therefore they were omitted. The pressure pump used was of a small capacity. The maximum power supplied was only 22 Watts. This limited the flow rate for the pipes. The maximum Reynolds number supplied by the pump was 6400. Therefore, higher turbulent flows could not be experimented. The flow of turbulent regime was limited to only transient zone. Fully rough zone was not achieved.

During the experiment, few things should be taken into consideration to make sure the tests run smoothly with minimum error. Fully developed flow is needed to perform experiments. Therefore, the diameter of pipes should not be altered. Great attention should be given to measure the digital reading of pressure gauge which shows large fluctuations.

6 Conclusion

6.1 Summary

The study has shown that the characteristics of head loss and friction changes with change in type of flow. Linear and simple behaviour of laminar flow like head loss and friction is changed when it enters turbulent flow where characteristics are rather chaotic and unpredictable. Also it was found that the total head loss for a flow of certain volume is lesser when the fluid is flowing in laminar flow than turbulent.

The research on drag reduction showed that the additives decreased a significant amount of head loss. PEO was more efficient in decreasing the drag effects of a fluid than NaSal in turbulent regime. However, NaSal decreased the head loss effectively in laminar flow where PEO was unable to perform. Even though there is still no clear-cut concept on functioning of additives, the lack of performance of PEO in laminar flow can be correlated to its absence of buffer layer where the polymer works. The performance of additives seemed to increase with the increase in Reynolds number. Therefore, it can be predicted that a great amount of head loss reduction by the additives can be seen in high Reynolds number. The experiment with lower turbulent flow suggests that NaSal is more cost effective solution for drag reduction than PEO due to very high price of PEO. However, the cost-effectiveness still remains to be seen in high turbulent flows.

The research successfully achieved its aims in analysing the friction within pipe flow and relating head loss to the Reynolds number and type of flow. The main achievement was to attain reduction of head loss by the use of drag reducing additives.

6.2 Implication

In the present context where every system is engineered to be energy efficient, the energy wastage in fluid transportation caused by head loss due to drag effects need to be addressed. The results of this study indicate that the drag reducing additives could be an affordable and practical solution to the problem of energy waste during pipeline transportation in industries. For example, the use of these additives in hydropower penstocks would increase hydropower capacity. Energy loss in irrigation of water could be diminished.

6.3 Future Work

This experiment has raised many queries which should be further investigated. Also it should be taken into consideration that the flows of very high Reynolds number might show different values of head loss and friction. Therefore, research should be conducted in rough turbulent zones where roughness plays big role. Higher turbulent flow is required to understand the additives effect in higher flow rates. It can be increased by getting a high power pump or increasing pipe diameter.

Drag reducing additives might not be the only solution for head loss reduction. Therefore, its alternatives should also be investigated. Further research can be done to develop more effective additives.

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