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To cite this article: M. A. Asidin *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **606** 012008

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Observation on the drag reducing effect of low concentration chitosan solution in turbulent pipe flow

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Abstract. Polymer-based drag reducing agent (DRA) is used widely in various industries due to its ability to enhance fluid flow as well as economically beneficial to various sectors. This study is conducted to observe the drag reducing effect of chitosan as DRA and observed its effect on the turbulent flow inside the pipe. The experiment is conducted in a closed loop circulation system where water is the transport medium. The pipe system consist of acrylic pipes with 0.013 m, 0.025 m and 0.038 m diameter. The chitosan was extracted from shrimp shells and five different concentration of chitosan were tested. The degree of deacetylation of the chitosan shows 97% which indicates its solubility in water. It was found that the highest drag reduction percentage were obtained from 0.038 m pipe of 33 ppm concentration which is 28%. The flow pattern inside the pipe is also analysed and discussed in this study

1. Introduction

Turbulence inside a pipeline caused fluid particles to move randomly which eventually lead to friction. Drag is defined as the frictional force that acts against the motion of an object through a fluid [1]. Pressure head losses happened due to drag inside the pipeline and cause the flow rate of the fluid to decrease. Thus, more energy is needed to uphold the desired flow rate [2] which result in installing more pumping station. Therefore, many methods have been researched to tackle this problem throughout the years and known as drag reduction. Abdulbari et al. [3] defined drag reduction as the science of improving fluid flow by reducing the pressure drop across a channel. The most well-known method to reduce drag is by using additives. These additives are known as Drag Reducing Agent (DRA) and consist of three types: polymer, surfactant, and solid suspensions. DRAs are very viscoelastic and mostly hydrocarbon which does not affect the physical properties of the transported fluid. The mixture between DRA and solvent will produce a solution that is shear-degradable, viscoelastic, time-independent and non-Newtonian fluids [4]. Polymeric DRA is considered as the most effective and economically beneficial due to its rheological properties and its resistance to shear force [3]. Polymeric DRAs are the long-chain polymer with high molecular weight. The polymer used commercially nowadays have a fast dissolution rate and slow degradation rate [5]. When injected into a pipeline, the polymer DRA will interact with the fluid flow and dampened the outbreak of turbulence namely at the buffer region of the flow. Lumley [6] proposed that the stretching of a coiled polymer will increase the extensional viscosity and dampened the small eddies in the buffer layer resulting in a more effective drag reduction. Polymer DRA is widely applied in various sectors such as firefighting [7], district cooling and heating system [8,9], sewage system [10] and also medical field [11,12]. In spite of the benefit of polymer in drag reduction, there are a few major issues regarding the use of artificial polymers. The effectiveness of polymers will reduce in time due to mechanical degradation. Early experiments on mechanical degradation stated that the degradation mostly occurs due to its dependence to molecular weight [13] and the chain scission that occurs around the midpoint of the polymer chain suggesting that the polymer is highly extended when it breaks [14]. These theories are further supported by Shanshool et al. [15] which stated that high molecular weight polymers prone to shear-induced degradation, and polymers with linear -chain structure are more vulnerable than branched polymers. In recent years, there are some concerns about the toxicity and environmental impact of conventional polymer additives [3]. Despite the proven excellence in drag reduction properties, these synthetic polymers will affect the environment



due to the chemical contents build up in the ground and become pollutants [16]. Therefore, researchers have begun to switch to new natural and organic additives as alternatives to conventional DRA. This research was conducted to study the potential of an environmentally friendly DRA extracted from biopolymers and observe its ability to reduce drag at low concentration and its effect to different pipe diameter. The flow pattern inside the pipeline is observed and discussed. The DRA for this research is chitosan which is extracted from shrimp shell. These shrimp shells consist of 20-30% of chitin, 30-40% of protein, and 30-50% of calcium [17]. Chitosan can be used as DRA due to its abundance in nature and its non-toxicity, biocompatibility, biodegradability, and adsorption.[18].

2. Materials and methods

2.1. Preparation of chitosan

The raw material of fresh shrimp shells was dried up to produce crispy shells. The shells were grounded to form a powder. The powder was demineralized using 5% HCl for 24 hours at room temperature. The ratio of the weight of shells and volume of HCl (w/v) is 1:5 [19]. After that, it is rinsed with water to neutralize the pH value. It was then treated with 10% HCl to ensure complete demineralization of the shell which showed no bubble formation. Then, the powder was deproteinized using 5% NaOH and dried up to produce chitin. Finally, the chitin was deacetylated by treating it into 60% of NaOH solution. The solution is heated then rinsed with distilled water and dried up to produce chitosan. The chitosan powder produced was mixed with distilled water and stirred constantly until the solution fully mixed and become homogenous. During the mixing process, heat is constantly supplied to prevent clumping. This solution must be continuously stirred because the polymer is insoluble in water. Then, the solution is cooled down at ambient temperature before the addition of 100% glacial solutions of acetic acids. Different concentrations of chitosan solution which are 7 ppm, 13 ppm, 20 ppm, 27 ppm, and 33 ppm were prepared based on the amounts of acetic acid solution added. The solution needs to be mixed with water before injecting into the pipe systems a night before to ensure its solubility in water.

2.2. Experimental rig

The rig is a closed loop circulatory system with water as the transporting medium. The design of the experimental rig is shown in figure 1. The system consists of reservoir tanks, pipes, valves, and pumps. The main reservoir tank is joined by two pipes which connect the centrifugal pump with the piping system. The centrifugal pump will deliver water across the system. This pipe design consists of three transparent polyvinyl chloride (PVC) pipe that has different size of inside diameter (0.013 m, 0.025 m, and 0.038 m). These pipes have testing sections where all the readings will be taken during the experiment. The main purpose of the rig is to study the drag reducing effect of chitosan with low concentrations in different pipe diameters and flowrates.

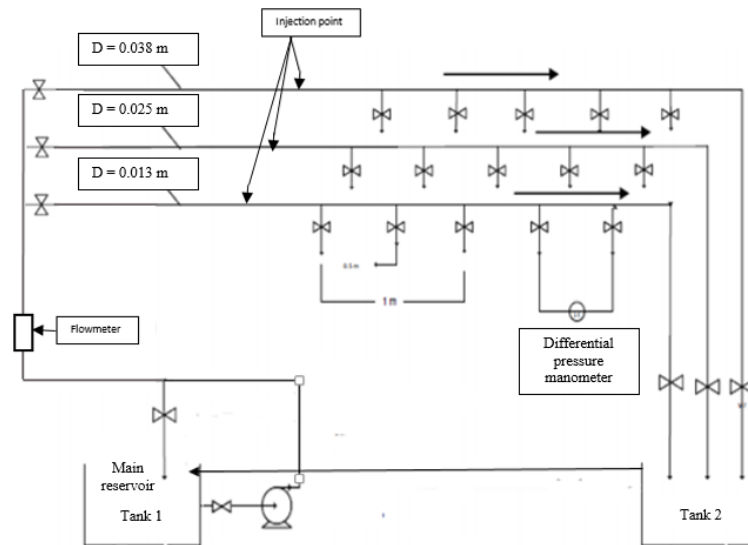


Figure 1: Schematic diagram of the experimental rig.

Flow piping system started from the main reservoir tank. The water is pumped until it reaches the connection that split the pipe into three sections with different pipe diameter and testing section. The flowrate is controlled and determined using the flowmeter connected to the main pipe. The experiment is conducted at two different flowrate which are 0.5 m³/h and 1 m³/h. The pressure drop data before the addition of additives which is the pressure drop reading of raw water flow will be recorded first before the DRA is added. The DRA is added into the system from the injection point by using a peristaltic pump. There are five variables of chitosan concentration varied from 7 ppm to 33 ppm. The pressure drop value can be read at the moment the DRA solution has begun to flows across the test section. The pressure drop reading is obtained by using the differential pressure manometer. Since the pipes at the testing sections are transparent, the flow pattern of the solution can be observed by looking at the visible pipe wall. The observation of the flow pattern is important to analyze the interaction between the water medium and the DRA. It will be conducted by using a high definition camera. The solutions that have flown across the pipeline will then reach the reservoir tank 2 and will flow back into the main reservoir tank and this process is continuous.

3. Results and discussion

The performance of chitosan as DRA is determined by the drag reduction percentage. The drag reduction percentage of pipe flow is obtained based on pressure drop or head loss before and after the addition of DRA into the water circulation system as expressed by the following equation:

$$\%DR = \frac{\Delta P - \Delta P_{dra}}{\Delta P} \times 100 \quad (1)$$

Where ΔP is the value of the head loss of tap water before the addition of chemical additive and ΔP_{DRA} is the value of pressure drop after addition of DRA into the system.

3.1. Effect of different DRA concentration

The percentage of drag reduction against chitosan concentration for flowrate $1 \text{ m}^3/\text{h}$ is shown in Figures 2. Generally, the graph shows an increasing trend in drag reduction. The graph also shows that the percentage of drag reduction increase as the concentration of chitosan increase for each pipe size. For all pipe size, the highest drag reduction percentage obtained is 28% for 0.038 m, 29% for 0.025 m and 6% for 0.013 m. The %DR increase notably in 0.025 m pipe with the concentration of 21 ppm to 33 ppm. This result agrees with the early observation made by Tom in 1948 which stated that only a small amount of additives needed to reduce drag significantly. In Figure 3, there is a slight fluctuation of drag reduction percentage for pipe diameter 0.025 m and 0.013 m. The %DR decrease at 21 ppm concentration and increase at 27 ppm and 33 ppm. From the graphs, we can propose that a bigger diameter pipe will produce higher drag reduction compared to a pipe with smaller diameter. Several researchers have investigated the effects of internal diameter to drag reduction performance and found that the %DR increase as the diameter increase [20,21]. Karami and Mowla [22] investigating the %DR of three different solutions in two different pipe diameters and observed that DR decreases as the pipe diameter increase which is contradicting with the result of this research. Theoretically, this phenomena is related to the eddied formation inside the turbulent flow and the capabilities of the DRA to suppress that formation. At larger pipe diameter, the magnitude of eddies is smaller but in a larger size. Thus, they can be broken and suppress easily by the DRA. Compared to smaller pipe diameter, even though these eddies formed are small, they are higher in number. The interaction between the DRA and the fluid takes more time to break up most of the eddied before the energy is lost [23].

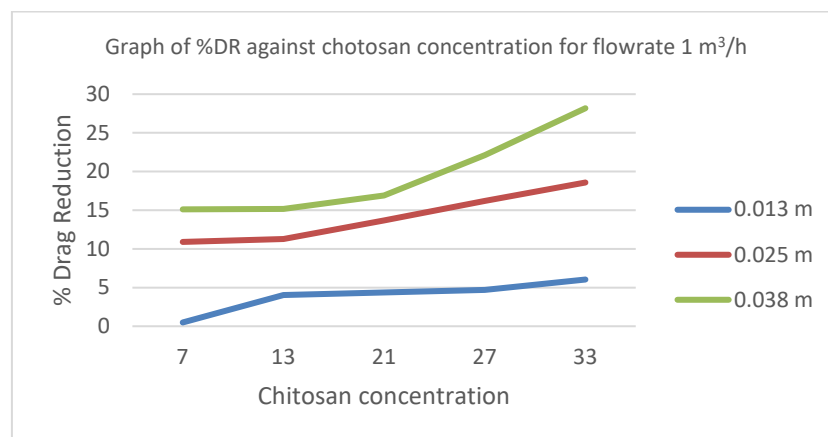


Figure 2: Graph of %DR against chitosan concentration for flowrate $1 \text{ m}^3/\text{h}$

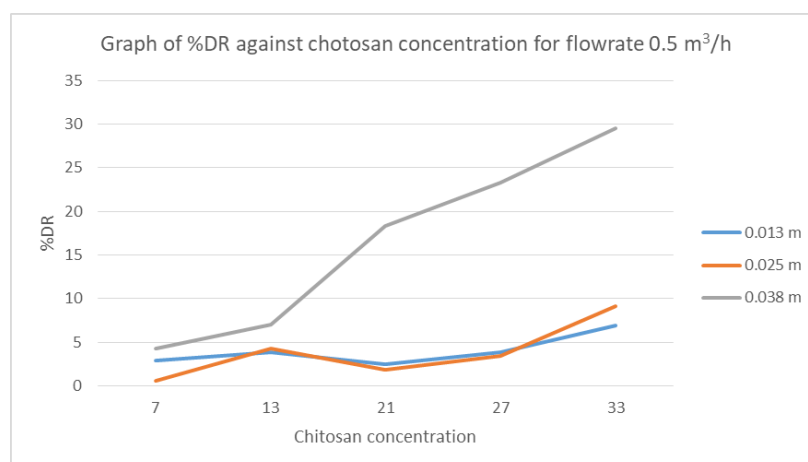


Figure 3: Graph of %DR against chitosan concentration for flowrate $0.5 \text{ m}^3/\text{h}$

3.2. Observation of flow pattern inside the pipe

The observation of flow pattern inside the pipe is made using a high definition camera. The visualization is made on the 0.038 m diameter pipe because there are no visible differences obtained from the pipes with 0.013 m and 0.025 m diameter. The parameters for this observation are kept constant which is 1 m³/h flowrate and 33 ppm chitosan concentration. The parameters are constant to compare the flow pattern of the fluid with and without additives. Figure 4 shows the visualization of the flow inside the pipe that shows the difference between pipe flow without and with the addition of DRA. There are some fluctuation near the pipe wall in Figure 4(a) indicating that there are some eddies forming. These eddies are caused by the chaotic movement of the fluid particle inside the pipe. Eddies formed are randomly distributed alongside the pipe wall. The flow in Figure 4(b) shows more stream-wise fluctuations near the pipe wall. The flow after the addition of DRA is more streamline and define compared to the flow without DRA. The difference that can be seen between these two types of flow is that the flow with DRA appears to be as horizontal stripes [24].



Figure 4(a): The flow inside the pipe without DRA.



Figure 4(b): The flow inside the pipe with DRA.

Figure 4: The visualization of the flow inside the pipe that shows the difference between pipe flow without and with the addition of DRA.

4. Conclusion

Chitosan is a biopolymer with polysaccharides properties such as non-toxicity and biodegradability. The process involves in the extraction of chitosan from shrimp shell is demineralization, deproteinization, deacetylation, and dilution. Chitosan shows good drag reduction ability with the highest %DR is 28% for 33 ppm chitosan concentration in 0.038 m pipe diameter and 1 m³/h flowrate. The drag reduction percentage increase as the chitosan concentration increase. The diameter of the pipe will affect the drag reduction performance. Bigger pipe diameter produces a smaller amount of eddies compared to smaller pipe diameter but bigger in size. This will give the chitosan enough time to interact and suppress eddies formation. This interaction makes the flow inside the pipe more streamline and lower the pressure drop.

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Acknowledgments

This work was supported by the grant FRG0416-TK-1/2015 from the Ministry of Higher Education Malaysia and grant GUG0052-TK-2/2016 from UMSgreat. Sincere gratitude to fellow corresponding authors for guidance and persistent support.