Drag reduction of nata de coco suspensions in circular pipe flow

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Abstract. Reducing pipe friction by adding a drag-reducing agent has attracted interest as a means to reduce energy consumption. In addition to reducing drag, these agents are required to have a low environmental load and conserve natural resources. However, no drag-reducing agent currently satisfies both these conditions. We focused on nata de coco and found that the nata de coco fiber reduced drag by up to 25%. With respect to the mechanism of drag reduction by nata de coco fiber, the relationship between drag-reduction phenomena and the fiber form of nata de coco was investigated by visualization. We also found that the drag-reduction effect appeared to be due to the formation of networks of tangled fibers of nata de coco. However, drag reduction did not occur in the case in which fibers of nata de coco did not form networks.

Key Words: Pressure loss, Visualization, Drag reduction, Nata de coco suspension

1. Introduction

There has been growing interest in the research on energy consumption [1] with the aim of resolving environmental issues. For instance, one study investigated the effect of friction drag reduction by injecting drag-reducing agents into a pipe flow in a heat transport system. The reduction of pressure loss in a pipeline was found to significantly reduce energy consumption because it reduces the cost of operating pumps in the air conditioning and other systems. Drag-reduction techniques also have the potential to enable smaller and more efficient fluid flow devices. Many techniques can be used to reduce flow resistance. In particular, the addition of a drag-reducing agent (typically a polymer [2]) to the fluid base has been shown to achieve the highest reduction in flow resistance. Drag reduction by adding surfactants [3–5] has been applied to regional heating systems and air-conditioning systems in buildings. However, these techniques require careful disposal to prevent the drained solutions from contaminating rivers and soil because these additives are made of synthetic chemicals. Therefore, these additives are applied to only closed-loop pipelines. In contrast, naturally occurring biopolymer additives have recently been receiving much attention because they are considered to have a low environmental load. For this reason, we focused on nata de coco, which is considered to have a low environmental load, and investigated its drag-reduction effect [6]. Furthermore, the nata de coco has shown drag-reduction behavior similar to that of biopolymers. However, the mechanism of the drag reduction using a nata de coco has not been revealed. The purpose of this study is to investigate the use of nata de coco as a drag-reducing agent in a pipeline-flow loop.
2. Experimental setup and procedure

2.1. Nata de coco suspensions

The tested nata de coco suspensions were made from commercial sources. Nata de coco contains over 99% water and less than 1% cellulose. Therefore, we had to remove fluid from the nata de coco and dry it. First, the nata de coco was washed with tap water and then immersed in tap water for 24 hours to remove sugar. Second, the nata de coco was pressed at 10 tons/m² and then dried in a refrigerator. Fig. 1 shows the dried nata de coco. Finally, nata de coco suspensions were prepared by mixing the dried nata de coco with tap water in a blender. The mixing time of the blender, $T_{\text{blender}}$, was 1–10 min. The suspension concentration, $C_w$, was determined based on the mass ratio of dried fiber to tap water, which is defined by

$$C_w [\text{ppm}] = \frac{M_n}{M_n + M_w} \times 10^6,$$

where $M_n$ and $M_w$ denote the masses of fiber and tap water, respectively.

2.2. Experimental apparatus

Fig. 2 shows a schematic of the experimental apparatus used in this study. The experimental apparatus consists of a tank, pump, injection device, pressure transducer, and flow meter. The suspensions were circulated by a pump (25SCD 5.25: Ebara Technologies, Inc.), which was controlled by an inverter (Sysdrive 3G3MV: Omron Electronics, Inc.). The pressure transducer data was recorded by a data logger (NR-1000: Keyence Japan). The pressure drop was determined by averaging 50 data points measured at intervals of 100 ms. The flow rate was measured by an electromagnetic flow meter (COPA-XE: Nippon Flow Cell Co., Ltd). The total length of the pipeline, which was made of stainless steel, was 5100 mm, and the inner diameter of the test section was 15 mm. The volume of water was 4 L. The temperature of the suspension was maintained within ±0.5 °C of the target temperature (20 °C) using a constant-temperature reservoir (LTB-125: As One Corporation). The length of the test section with the pressure drop was 300 mm. Since the entrance length was 1020 mm, the flow was fully developed. The pressure drop was measured by injecting additives into the circulating tap water. Fig. 3 shows the detail of the pipe from the injection port to the measurement part for the pressure drop (test section). Nata de coco suspensions were injected through an injection port (inner diameter $\varphi = 3$ mm). The flow velocity of injection was 0.7 mm/s, which was about 0.05–0.09% of the flow velocity in the pipe.

![Figure 1. Micrograph of dried nata de coco (35×).](image1)

![Figure 2. Experimental apparatus.](image2)
3. Results and discussion

Fig. 4 shows the effect of the injected nata de coco on drag reduction, DR. To quantitatively estimate the amount of drag reduction, the experimental results are expressed in terms of the drag-reduction coefficient $DR$:

$$DR[\%] = \frac{\lambda - \lambda_s}{\lambda_s} \times 100,$$

(2)

where $\lambda$ and $\lambda_s$ denote the friction coefficient for tap water and nata de coco suspensions, respectively. The horizontal axis is the injection volume, $V$, and the vertical axis is the drag reduction. It shows that DR was ~0% when the tap water was injected into the pipe. However, DR increased with increase in the injection volume and concentration of nata de coco suspensions. The concentrations of suspensions in the pipe after injection were 12.5, 25, and 50 ppm. Fig. 5 shows the experimental results for the friction coefficient. The dashed line in the figure was obtained by the Blasius equation for turbulent flow, which is given by

$$\lambda = 0.3164 Re^{-0.25}.$$

(3)

The measured friction coefficient of tap water was within 2% of that calculated using the Blasius equation. The nata de coco suspensions had lower friction coefficients than tap water for each concentration (~200 ppm). DR increased with the increasing concentration of the suspensions and the slope of this increase was parallel to the line of Blasius equation. Fig. 6 shows the effect of concentration on DR at 0–200 ppm. It shows that DR increased with the increasing concentration and reached up to 25% more than its original value when the concentration was increased to 50 ppm. At a concentration more than 50 ppm, drag reduction was nearly constant.

We researched the relation between the scattering time in the blender and DR because DR was greatly affected by the scattering time during the experiment. Fig. 7 shows the effect of scattering time in the blender, $T_{blender}$, on DR. $T_{blender}$ on the horizontal axis is the mean of the scattering time in the
blender when the nata de coco suspensions were prepared. DR was observed for scattering times of ~1–3 min, although a change in DR was not observed in the case of long scattering times (more than 5 min). This shows that DR is greatly affected by scattering time in the blender. In the case where the scattering time was less than 1 min, experiments could not be conducted due to the nata de coco fibers not being sufficiently dispersed.

We observed fiber formation in the case of 1.5 and 10 min of scattering time through the investigation into the mechanisms of DR. Fig. 8 shows a micrograph of nata de coco fibers (a) before and (b) after experiments in the case of 0% DR at 10 min of $T_{\text{blender}}$. Significant differences were not observed between (a) before and (b) after the experiments. Fig. 9 shows a micrograph of nata de coco fibers (a) before and (b) after experiments in the case of 20% DR at 1.5 min of $T_{\text{blender}}$. The fibers were tangled, and a large network of fibers was formed. This shows that a large network of fibers had formed when drag reduction occurred.
4. Conclusions
In the present work, we investigated the use of nata de coco as a drag-reducing agent in a pipeline flow loop:

(1) Drag reduction increased with increasing concentration and reached up to 25% when the concentration was increased to 50 ppm.
(2) Drag reduction was observed when scattering times were ~1–3 min and a network of fibers was formed.
(3) In the case of scattering times of more than 5 min, drag reduction was not observed and a network of fibers was not formed.
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