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Influence of Pipeline Flow Velocity on In-pipe Turbidity Detection

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Abstract: To explore the feasibility of the online turbidity meter installed in-line, we have to study the influence of flow velocity on in-pipe turbidity detection. In the laboratory self-designed water circulation system, the correlation between the in-pipe turbidity and flow velocity was studied by altering the water flow rate in the pipe. The results show that the in-pipe turbidity and flow velocity have a benign linear relationship for the slow flow; as the flow velocity increases, the in-pipe turbidity increases slightly but is limited. However, there is no significant correlation between the in-pipe turbidity and flow velocity for the fast flow.

Keywords: online turbidity meter; in-pipe turbidity; flow velocity; real-time data

1. Introduction

Turbidity is an essential indicator of water quality[1]. Turbidity detection is widely applied in various fields[2, 3], such as environmental, chemical, and pharmaceutical sciences[4], water treatment plants[5, 6], municipal water supply and drainage networks[7, 8], river and lake management[9, 10], beverage industries[11, 12], power plants[13], and so on. The online turbidity meter is widely used[3] and has different designs for various applications[9, 14, 15]. One representative design is adopting a stable tributary from the main pipeline to measure the real-time online turbidity.

This tributary approach has its pros and cons. The advantage is to provide a stable liquid flow with a constant flow rate for the online turbidity meter, which ensures the measurement environment for an accurate analysis of online turbidity. The disadvantage is listed below: a. The online turbidity meter employing this approach is usually expensive[16] because it contains more components (such as the tributary cell and transmitter) and is more complicated. b. After the water to be tested is drawn out, it may lead to contamination of the water sample. c. This method causes waste of water resources and economic loss. The extracted water is usually discharged into municipal sewage as wastewater to avoid polluting the main pipeline water, especially for the water supply system. Meanwhile, a sewage lift pump is probably required. Therefore, developing an online turbidity meter installed directly in the main pipeline is significant, especially for online monitoring of the water supply networks[16, 17]. When the online turbidity meter is directly installed in the main pipeline, the pipeline flow rate is the primary consideration for turbidity's accurate detection[18, 19].

Online turbidity meter suppliers usually provide the instrument's flow rate range. Different companies have similar requirements for pipeline flow rates, which are between 200 and 800 mL/min. However, verifying whether the online turbidity meter functions regularly outside this range is crucial.

This research explored the feasibility of installing the online turbidity meter directly in the pipeline without the tributary for low turbidity situations such as the water supply networks. The pipeline flow was divided into a slow and fast flow state with two different velocity ranges. A water circulation system was constructed to control the pipeline's water flow velocity. The relationship between in-pipe turbidity and flow velocity was investigated.

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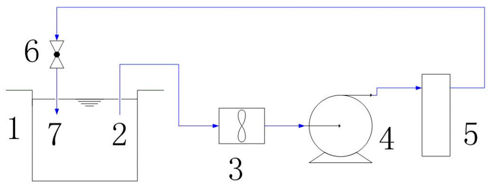
2. Materials and Methods

2.1 Experimental setup and operation mode

A water circulation system was built in the experiment, as shown in Figure 1. In the system, the water meter measured the water volume passed through. The variable frequency pump provided power for the entire system to ensure a stable water flow in the pipeline. The ball valve was installed at the outlet and downstream of the turbidity meter. We controlled the ball valve in an incompletely opened state because this arrangement provided the online turbidity meter with a certain pressure to inhibit the generation of air bubbles. The experimental water was municipal tap water.



1. Water tank； 2. Water inlet； 3. Water meter； 4. Variable frequency pump； 5. Chemitec online turbidity meter with a temperature sensor； 6. Ball valve； 7. Water outlet

Figure 1. Schematic diagram of the water circulation system

2.2 Turbidity detection

The online turbidity meter installed directly in the pipeline is the low-turbidity probe S461LT from the Italian manufacturer Chemitec. The optical source is 860 nm infrared light, and the measurement principle is 90° light scattering, with an accuracy of 1% in 0–10 NTU, a resolution of 0.001 NTU, a reproducibility of 2%, and an operating temperature of 0–50℃. Before starting the experiment, the turbidity meter was calibrated. In addition to turbidity measurements, the Chemitec online turbidity meter includes a temperature sensor that can record temperature data simultaneously. The probe can simultaneously detect turbidity and temperature data.

In order to verify the reliability of the in-pipe turbidity, we took the outlet water samples to test the offline turbidity. The Hach 2100Q turbidity meter was selected for the offline test, and its measurement method was also based on the principle of 90° scattered light.

2.3 Flow velocity calculation and classification

Volumetric flow rate is the volume of fluid flowing past a point through an area per unit of time. The fluid volume was measured by the water meter, and the time by the timer on a cellphone. Firstly, we powered on the variable frequency pump, allowing the water circulation system to stabilize for a few minutes. Next, read the data V0 of the water meter, and start timing. Afterward, at the following time points t1 (5 minutes), t2 (30 minutes) and t3 (60 minutes), read the water meter readings V1, V2, and V3. Finally, the volumetric flow rate qvi can be calculated by the following formula (1).

$$q_{vi} = \frac{V_i - V_{i-1}}{t_i - t_{i-1}},\ i=1,2,3 \qquad (1)$$

For each test, we repeated a minimum of three times in order to reduce the random error. The test would be redone if the maximum error between each flow rate was more significant than 2%. The final selected qv is the average value of each volumetric flow rate under the same operating condition:

$$q_v = \frac{1}{3}\sum_{i=1}^{3} q_{vi} \qquad (2)$$

The pipe flow was categorized into two groups: one is slow flow and the other fast flow. The slow flow refers to the flow whose volumetric flow rate is within 2 L/min, covering the flow range (0.2 ~ 0.8 L/min) that the online turbidity meter work typically according to instrument suppliers.

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The following data points were selected for the slow flow experiments: 0.2, 0.5, 0.8, 1.1, 1.4 and 1.7 L/min.

Fast flow has a volumetric flow above 2 L/min (including 2 L/min). The following data points were selected for the fast flow experiments: 2, 5, 8, and 11 L/min.

Although the volumetric flow rate is widely applied in engineering and scientific research, the flow velocity is the parameter that probably affects the in-pipe turbidity. Therefore, the volumetric flow rate should be converted to flow velocity. Flow velocity is defined as the volumetric flow rate per unit cross-sectional area and can be calculated based on the volumetric flow rate and inner pipe diameter. The inner diameter of our pipeline is 8 mm. After calculation, the flow velocity of our experiments from small to large is 0.07, 0.17, 0.27, 0.36, 0.46, 0.56 m/s for slow flow and 0.66, 1.66, 2.65, 3.65 m/s for fast flow.

3. Results and Discussion

3.1 Relationship between in-pipe turbidity and flow velocity for slow flow

The in-pipe turbidity was measured by the online turbidity meter installed inline directly. Under various working conditions, the in-pipe turbidity kept relatively stable for slow flow, as shown in Figure 2.

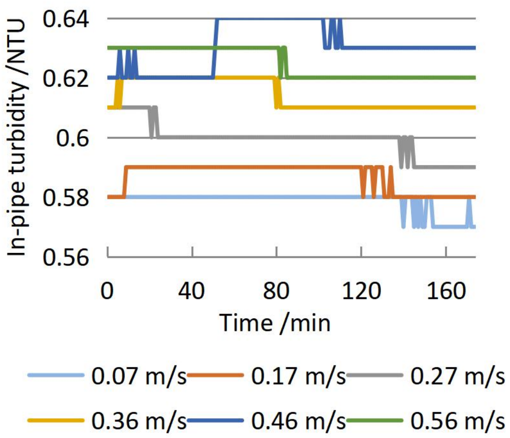

Figure 2. Real-time in-pipe turbidity for slow flow

Figure 3 recorded the real-time water temperature measured simultaneously with the in-pipe turbidity. Because the running pump generated heat and transferred the heat to the water going through, the water temperature increased. However, the water temperature went up slowly and tended to be stable. All temperatures were well maintained between 23℃ and 29℃ during the tests. In addition, the water temperature change trend is different from the in-pipe turbidity change, indicating that the water temperature variations in the tests were insufficient to cause the regular change of in-pipe turbidity. Moreover, in-pipe turbidity and water temperature distribution under different working conditions were also inconsistent. Therefore, this experiment could not verify the issue of whether the in-pipe turbidity is affected by the water temperature.

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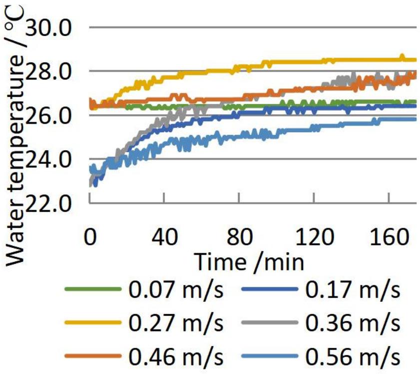

Figure 3. Real-time temperature in slow flow

Figures 2 and 3 recorded real-time in-pipe turbidities and water temperatures, respectively, describing how they changed over time. In order to compare the situation under various flow conditions, the arithmetic means of the in-pipe turbidity and water temperature at each flow velocity were calculated, respectively. All calculation results were plotted simultaneously in the double vertical axis coordinate system, as shown in Figure 4. It can be seen that the in-pipe turbidity and the flow velocity have a benign positive linear relationship for the slow flow. The in-pipe turbidity slightly increases for slow flow when the flow velocity rises. The relational expression of the fitted straight line is as follows:

$$\Delta y = 0.0966 \cdot \Delta x \qquad (3)$$

In the formula, y is the in-pipe turbidity; Δy is the change of the in-pipe turbidity; x is the flow velocity; Δx is the flow velocity change.

The maximum flow velocity difference in the slow flow state is 0.66 m/s, so when the water quality and other environmental factors maintain constant, and the flow velocity is the only varying parameter, the in-pipe turbidity's maximum volatility is 0.0628 NTU. Therefore, in the slow flow state, the increase of the in-pipe turbidity caused by the flow velocity rise is insignificant. The slight increase of the in-pipe turbidity is probably the change in the measurement result caused by a small number of micro-bubbles introduced by the flow velocity increase[20]. The turbidity meter mistakes bubbles for suspended particles. Hence, the slight turbidity change here does not verify the change in the characteristics of the pipeline water.

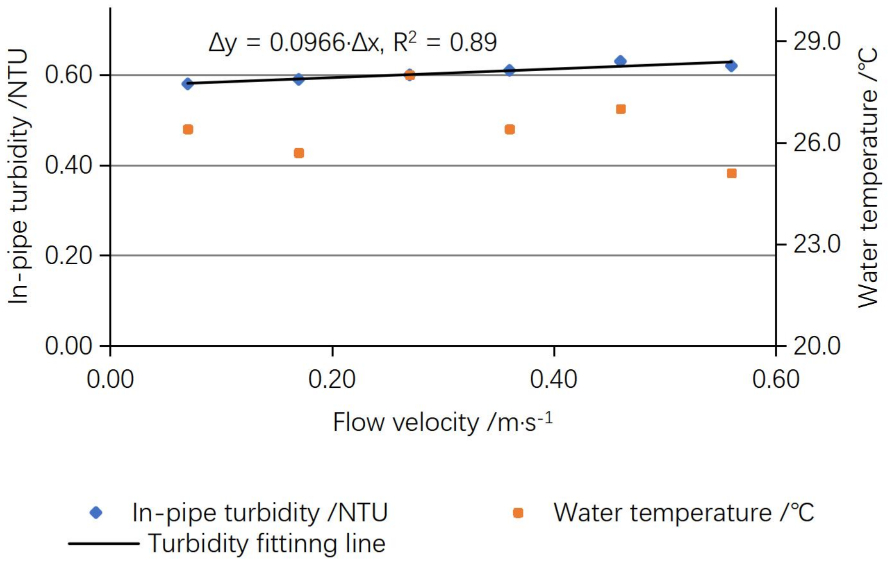

Figure 4. Relationship between in-pipe turbidity and flow velocity for slow flow

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3.2 Relationship between in-pipe turbidity and flow velocity for fast flow

When the flow velocity deviates from the flow rate range specified in the operating regulations provided by suppliers, that is, under the fast flow state mentioned in this paper, the overall fluctuation of the in-pipe turbidity is not significant, as shown in Figure 5. The most extensive fluctuation range is when the flow velocity is 3.65 m/s; however, the total fluctuation turbidity is maintained within 0.04 NTU. For other flow velocities conditions, such as 0.66 m/s, 1.66 m/s, and 2.65 m/s, fluctuation ranges of the turbidity are all within 0.03 NTU. Therefore, the in-pipe turbidity measurement disturbance with a significant flow rate may increase. Nonetheless, the in-pipe turbidity keeps stable and reliable unless an abnormal situation is encountered.

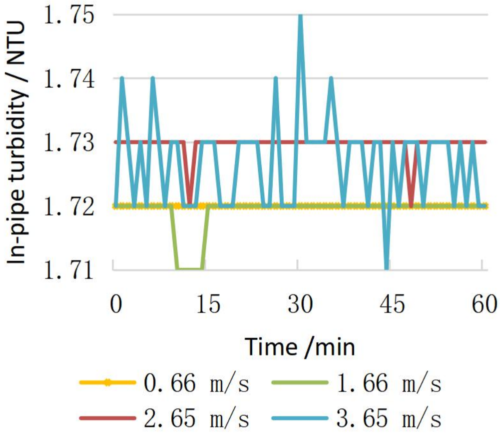

Figure 5. Real-time in-pipe turbidity for fast flow

The real-time water temperature in the fast flow state was similar to that in slow flow. The water temperature would rise due to the heat generated by the pump operation. In the fast flow state, the pump provided more power for the pipeline water having a more significant flow velocity, resulting in a rapid temperature rise. In order to prevent the pump from being damaged by excessive temperature, we have cooled the water in the tank. We put a clean ice pack in the tank. The real-time pipeline water temperature is shown in Figure 6. The water temperature changing trend is inconsistent with the in-pipe turbidity changing trend. This inconsistency shows that the water temperature change in the experiment is insufficient to cause the regular turbidity change, which is similar to that in the slow flow state. Furthermore, the in-pipe turbidity distributions among various flow conditions are inconsistent, the same for the water temperature distributions. Therefore, the experiment for fast flow still cannot verify the problem of whether the in-pipe turbidity is affected by the water temperature.

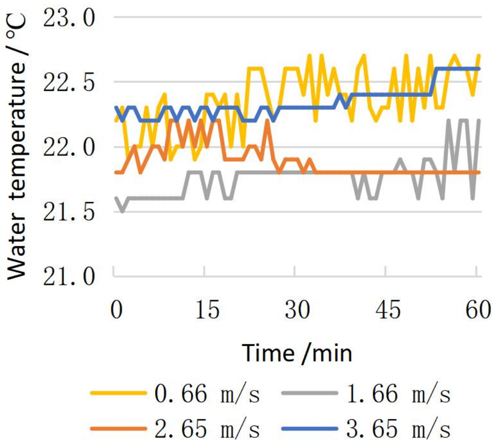

Figure 6. Real-time temperature for fast flow

Figures 5 and 6 recorded real-time in-pipe turbidities and water temperatures, respectively, describing how they changed over time for fast flow. In order to compare the situation under various flow conditions, the arithmetic means of the in-pipe turbidity and water temperature at each

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flow velocity were calculated, respectively, the same as for the slow flow. The results are shown in Figure 7. Although there is a favorable positive linear relationship between in-pipe turbidity and flow velocity in the slow flow state, this relationship cannot be found for fast flow. In the fast flow state, there is no apparent linear relationship between the in-pipe turbidity and the flow velocity. Under normal circumstances, the flow velocity does not affect the in-pipe turbidity. However, the abnormally significant bubble interference factor cannot be ruled out because the turbidity meter mistakes bubbles for suspended solids.

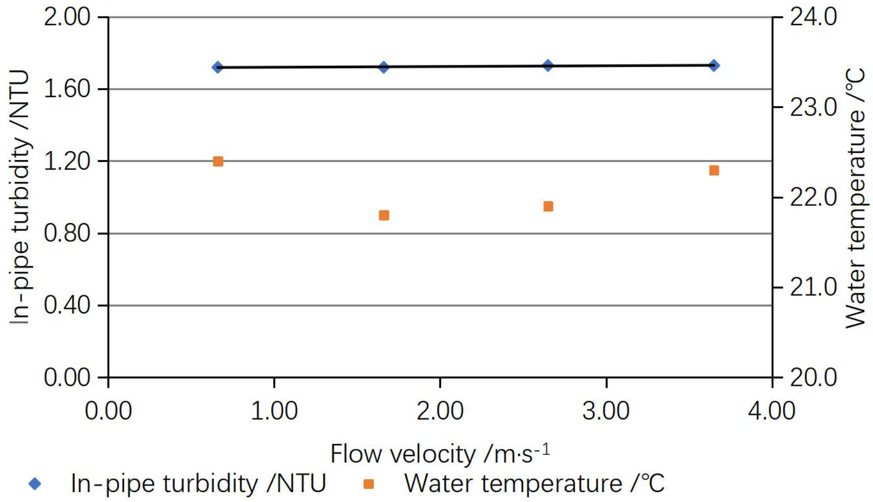
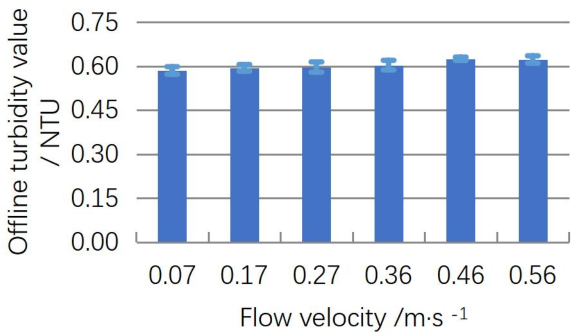


Figure 7. Relationship between in-pipe turbidity and flow velocity for fast flow

3.3 Offline turbidity detection

Besides the in-pipe turbidity measurements, water samples were taken from the outlet for offline turbidity detection. The offline results are shown in Figure 8. In order to keep the same water quality in the experiment, we took a large amount of water for circulation, around 40 L each time, trying to eliminate the influence of the inner wall attachments along the pipeline and instruments. We kept the same water for the same group test and changed water for another group. That is to say that the test water quality in the slow and fast flow states is different, so we plotted two sub-figures to describe these two flow states. Under the same group of the flow state, the test conditions are relatively consistent except for the flow velocity, and the offline turbidity is close to the corresponding in-pipe turbidity, which verifies that the in-pipe turbidity measurement is reasonable and the online turbidity meter could be installed directly inline.



(a) Slow flow condition

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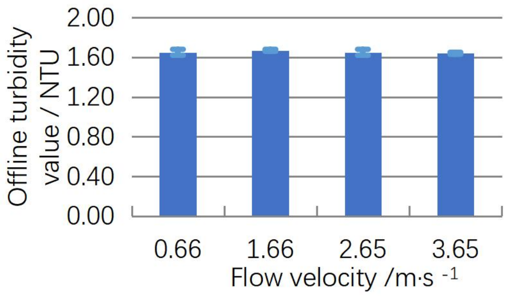

(b) Fast flow condition

Figure 8. Offline turbidity for slow and fast flow states

4. Conclusion

We explored the feasibility of the online turbidity meter installed in-line. Whether the flow velocity would affect the in-pipe turbidity is the primary consideration. The relationship between the in-pipe turbidity and flow velocity can be grouped into two situations: slow flow and fast flow state. There is a benign positive linear relationship between in-pipe turbidity and flow velocity for slow flow, and the increments are small. There is no apparent correlation between the in-pipe turbidity and flow velocity for the fast flow.

To sum up, the online turbidity meter can be installed directly in pipelines. In practical applications, there might be a risk that large air bubbles will be generated and attached to the instrument's lens, especially for the large flow velocity. Further studies are still needed to analyze the causes of bubbles and formulate defoaming strategies to utilize the online turbidity installed directly in-pipe.

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