Investigation of pressure loss in a circular pipe under ultrasonic waves released along main stream flow

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Abstract
Recently, ultrasound was discovered to have great potential in enhancing heat transfer from thermal systems. However, there is little information of the flow resistance, induced by its waves. Therefore, this research investigates the pressure loss of turbulent water flow in a circular pipe disturbed by 25 kHz ultrasound at the Reynolds number of 10,000, 12,500, 15,000, 17,500, 20,000, 22,500, and 25,000. The size of test section was modeled in accordance with the power plant’s condenser and the flow had been verified by the comparison of friction factor with theory. The maximum and minimum differences were 9.79 and 0.33%, respectively, confirming the reliability of the test setup. In this study, ultrasound was released along the mainstream flow from 3 and 15 transducers, installed upstream of the pipe. The results confirmed that the ultrasound was slightly affected on the friction loss of turbulent pipe flow. The average increase of pressure loss was 0.077% and 0.833% by the waves when they were emitted from 3 and 15 transducers, respectively. With very low inducement of flow resistance, ultrasound can be accounted as one of the most promising techniques for heat transfer enhancement, applicable to many thermal systems such as condensers, in the future.

Keywords: Condenser, Ultrasonic waves, Turbulent flow, Heat transfer enhancement, Pressure drop

1. Introduction
The heat transfer of a pipe flow is a basic phenomenon that is applicable to many heat exchangers. However, a heat transfer enhancement is needed for the reduction of operating cost. Following the advancement of numerical method and devices, this heat exchanger has been studied numerically and experimentally [1-6]. In an attempt to augment the heat exchanger’s performance, the heat transfer enhancement techniques such as the use of twisted tape [7], extended area [8], turbulent spot [9-12], porous media [13], water jet [14], etc. have been utilized. The use of ultrasound is one of those techniques, giving high performance to enhance the heat transfer [15-16]. When the ultrasonic waves are released into a liquid, 2 important phenomena occur and these typically use for heat transfer enhancement [17]. The first phenomenon is acoustic cavitation that appears during the compression and...
rarefaction by the variation of the local pressure [18]. When the local pressure is lower than the vapor pressure, gas bubbles are formed, oscillate, grow, and then collapse violently [19]. The bubble implosion around a solid-liquid interface disrupts thermal and velocity boundary layers and leads to the enhancement of heat transfer. Moreover, it was found that the process of acoustic cavitation reduced the turbulence intensity, leading to a reduction in wall friction loss [20]. Another phenomenon is acoustic streaming which arises from the dissipation of acoustic energy into the liquid [21]. When liquid streaming occurs due to the increase of momentum energy, the heat transfer rate around the surface can be enhanced. However, the information of not only heat transfer, but also the pressure loss of pipe flow under the ultrasound, emitted in the direction of the main flow is very little. Thus, this paper focuses on the measurement of pressure drop of water turbulent flow in a circular pipe, disturbed by the 28 kHz ultrasound. The obtained results in this research will clarify the pressure drop characteristics of a water pipe flow, under the interference of ultrasound.

2. Experimental methods

2.1 Experimental setup

The investigation was carried out in a closed-loop system, as shown in Figure 1. The apparatus consisted of a 1.65 kW centrifugal pump, supplying the water from a water tank to the ultrasound generating zone, installing fifteen 28kHz and 120 W ultrasonic transducers. Then, the water flowed through a copper tube that was the test section of this research and the tube had an outer diameter of 19.05 mm. The water was heated by heaters to maintain the constant temperature condition at 45˚C on the pipe surface. This condition was modelled from the operating condition of a condenser in the power plant. The heaters were controlled using proportional-integral-derivative (PID) controllers that received local input signals from eight stations of type-K thin leaf thermocouples which have an uncertainty of 0.75%. These thermocouples were installed between the surface of the copper tube and heaters. This setup was wrapped by a high thermal resistance insulator to prevent heat losses to the environment as shown in Figure 2. The temperature of the inlet water was controlled at 25˚C by water chiller. The water flow rate was measured and adjusted at the most downstream of the test section using an ultrasonic flow meter (TUF-2000H) and the gate valve, respectively. Finally, the water circulated back to the water tank and cooled down using a cooling coil.

![Figure 1. Schematic diagram of the experiment.](image-url)
In the test section, the pressure difference was measured using the differential pressure sensor (Siemens Sitrans P DS III) which has an uncertainty of 0.5% between the streamwise distances of 0.02m and 1.02m from the pipe entrance. This sensor received power from the power supply and sent the signal of the pressure difference to the transmitter. Then, the pressure difference data were achieved using the data logger (Graphtec midi LOCKER GL240), as shown in Figure 3. Before the tests, the differential pressure sensor would be calibrated for the accuracy of a measurement. After entering the steady-state condition, the data of pressure difference was recorded by the data logger for 10 minutes without the interference of ultrasound. After that, the system was disturbed by ultrasound and the data was grabbed for another 10 minutes. In order to provide reliable data, all experiments were repeated 3 times and the data was averaged to minimize the experimental error. In this research, the ultrasound would be released from 3 most top transducers and 15 transducers to see the effect of the waves, emitted from different number of transducers. Also, the measurement would be performed during the Reynolds number of 10,000 – 25,000 with an increment of 2,500.
2.2 Data analysis
The Reynolds number describes the relationship between density, velocity, diameter and viscosity. It can be calculated as follows:

\[ Re = \frac{\rho v D}{\mu} \]  

(1)

where \( \rho \) is fluid density \([\text{kg/m}^3]\) and \( \mu \) is dynamic viscosity of fluid \([\text{Pa} \cdot \text{s}]\).

Also, the friction factor is defined as:

\[ f = \frac{2L \Delta P}{\rho L v^2} \]

(2)

where \( L \) is the characteristic length \([\text{m}]\), \( \Delta P \) is the pressure difference \([\text{Pa}]\), and \( L \) is the distance to measure differential pressure \([\text{m}]\).

2.3 The verification of friction factor
In this research, the friction factor under the condition without ultrasound was verified with the friction factor of turbulent flow in a smooth tube following Petukhov [22]. It could be calculated as follows:

\[ f = (0.79 \ln(Re) - 1.642)^2 \text{ for } 3000 < Re < 5 \times 10^6 \]  

(3)

The percentage error of the comparison between the results from the experiment and Petukhov’s correlation was defined as follows:

\[ \%Error = \left( \frac{f_{\text{exp}} - f_{\text{eqn}}}{f_{\text{eqn}}} \right) \times 100 \]

(4)

where \( f_{\text{exp}} \) is the experimental friction factor [-], and \( f_{\text{eqn}} \) is the friction factor from [22] [-].

Table 1 shows the percentage errors of the comparison between the friction factor from the experiment and Petukhov’s correlation during the \( Re \) of 10,000 – 25,000. It is found that they are in the same tendency that the friction factor is decreasing with the increase in the \( Re \) as depicted in Figure 4. The maximum and minimum percentage errors are 9.79% and 0.33% at the \( Re \) of 25,000 and 17,500, respectively. These results shown that this experimental setup is reliable and able to conduct an experiment of ultrasound.

**Table 1.** Friction factor averaged from experiment and calculated from Petukhov’s correlation.

| \( Re \) | \( f_{\text{eqn}} \) | \( f_{\text{exp}} \) | \%Error |
|---|---|---|---|
| 10,000 | 0.0315 | 0.0304 | -3.47 |
| 12,500 | 0.0296 | 0.0307 | 3.64 |
| 15,000 | 0.0282 | 0.0273 | -3.24 |
| 17,500 | 0.0271 | 0.0272 | 0.33 |
| 20,000 | 0.0262 | 0.0259 | -0.99 |
| 22,500 | 0.0254 | 0.0246 | -3.27 |
| 25,000 | 0.0247 | 0.0271 | 9.79 |
3. Results and discussion

Figure 5 shows an example of pressure difference signals, recorded during the experiment by a data logger. The signals were obtained when the experiment was conducted under the conditions without and with ultrasound from 3 ultrasonic transducers (3 UTs) and 15 ultrasonic transducers (15 UTs). The data show that the magnitudes of pressure difference fluctuate because of the turbulent flow, and the magnitude of pressure drop can be decreased, due to the effects of ultrasound. Therefore, these data were averaged and used in the evaluation of pressure difference and friction factor.

Figure 6 shows the pressure difference ratio and the friction factor ratio under the condition with and without the disturbance of 28 kHz ultrasound versus the Reynolds number during 10,000 – 25,000. In this figure, the subscript w and nw represent the condition with and without interference of ultrasound, respectively. From Figure 6a, it is found that the pressure difference changed by ultrasound and the ratio
was in the range between 0.9805 - 1.0188 and 0.9883 - 1.0378 when the system was induced by 3 and 15 transducers, respectively. The maximum pressure difference ratio under the effect of 3 transducers is 1.0188 at the $Re$ of 20,000 while the case of 15 transducers shows the ratio of 1.0387 at the $Re$ of 17,500. Furthermore, the average ratio of pressure difference increased about 0.077% and 0.833% under the waves from 3 and 15 transducers, respectively. The value of friction ratio was similar to the pressure difference as depicted in Figure 6b. Finally, the results showed that the range of Reynolds number that mostly affected the pressure difference or friction factor was during 15,000 – 20,000 for the case of 15 UTs. Meanwhile, the pressure difference and friction factor under the case of 3 UTs did not show a significant change by the waves.

![Figure 6](image)

**Figure 6.** (a) pressure difference and (b) friction factor ratios under ultrasound, released from 3 and 15 transducers.

### 4. Conclusion

This research investigated the pressure difference and friction factor of turbulent water flow, in a circular pipe under the 28kHz ultrasound released along the mainstream flow, at the Reynolds numbers of 10,000, 12,500, 15,000, 17,500, 20,000, 22,500, and 25,000. The water flow in the pipe was heated to maintain the constant surface temperature of 45˚C. The reliability of experimental setup was verified by comparing friction factor with those calculated from theory. The maximum and minimum percentage errors were 9.79% and 0.33% at the $Re$ of 25,000 and 17,500, respectively. The results were presented as the ratio of pressure difference and the friction factor under the condition with and without the interference of 28 kHz ultrasound. The maximum ratios are 1.019 and 1.038 under the ultrasonic waves from 3 and 15 transducers, respectively. Meanwhile, the ratios increased averagely about 0.077% and 0.833% when the system was induced by waves from 3 and 15 transducers, respectively. Thus, these results show that the ultrasound slightly affects the pressure drop and friction factor of the flow system. It can be accounted as one of the promising techniques for heat transfer enhancement, applicable to many thermal systems, such as condensers in the future.

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