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Flow Parameter (DG/ μ) and Pressure Drop Characteristics of Shell and Tube and Double Pipe Heat Exchangers

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ABSTRACT. Heat exchangers are essential equipment in various industrial processes, where hydrodynamic characteristics such as pressure drop play a role in determining performance and operational safety. This study aims to directly compare the pressure drop characteristics and the $(DG/\mu)_{av}$ parameter relationship between shell-and-tube and double-pipe heat exchangers at a laboratory scale. Experiments were conducted with varying fluid flow rates in the range of 0.8–1.2 GPM. Pressure drop values were measured using a U-tube manometer, while the $(DG/\mu)_{av}$ parameter was calculated based on the physical properties of the fluid at the average operating temperature. The experimental results indicate that increasing the flow rate causes an increase in pressure drop in both types of heat exchangers. However, a direct comparison at the same flow rate conditions shows clear differences in the hydrodynamic characteristics. The double-pipe heat exchanger exhibits a more consistent pressure drop relationship $(DG/\mu)_{av}$, while the shell-and-tube heat exchanger, especially on the shell side, exhibits more fluctuating pressure drop variations due to the complexity of the internal flow pattern. These findings indicate that the geometric configuration of the heat exchanger has a significant influence on the hydrodynamic response under laboratory-scale operating conditions.

1. Introduction

Thermal energy management, particularly in the development of the chemical, petrochemical, energy, food, and pharmaceutical industries, requires continuous improvement in process efficiency. Heat exchangers are key devices involved in energy optimization [1]. Heat exchangers transfer heat between two fluids without direct contact, allowing the thermal energy from one process to be reused in another [2]. Efficient use of heat exchangers can improve energy efficiency, reduce operational costs, and minimize environmental impacts resulting from inefficient energy use [3], [4].

In industrial environments, two types of heat exchangers are most commonly used: shell and tube and double pipe. The differences between these two types lie in their design and operational performance [1], [5]. Shell and tube heat exchangers are generally used for processes with large heat transfer capacities and high pressures, meeting the needs of large-scale industries [6]. Conversely, double-pipe heat exchangers have a simpler structure, are easier to maintain and clean, and are more commonly used in small to medium-sized systems [7].

Design variations between the two types directly impact heat transfer efficiency and the magnitude of pressure drop during fluid flow within the system [8]. The pressure drop parameter is a critical factor in heat exchanger design because it directly impacts pump energy consumption and overall efficiency. Too high a pressure increases energy costs, while too low a pressure can reduce heat transfer efficiency [9]. Heat exchanger efficiency is influenced by several key factors, such as fouling, which inhibits heat transfer [10], and pressure drop, which reduces the driving force of flow [9]. The Log Mean Temperature Difference (LMTD), which reflects the average temperature difference between two fluids, and the Reynolds number, which determines the stability and direction of fluid flow within the system [11]. Therefore, understanding pressure drop characteristics is crucial to ensure the safe and efficient operation of heat exchangers.

Although various studies have addressed pressure drop and flow characteristics in heat exchangers, most have focused on numerical simulations or heat transfer performance analysis. Experimental data directly comparing the relationship between the DG/μ parameter and pressure drop in shell-and-tube and double-pipe heat exchangers under identical operating conditions are still limited. Therefore, this study aims to provide simple experimental data that can serve as a baseline for evaluating pressure loss in both types of heat exchangers.

Therefore, this study aims to analyze the pressure drop characteristics in shell-and-tube and double-pipe heat exchangers at various flow rates, and to examine the relationship between the DG/μ parameter and pressure drop. The results of this experimental study are expected to provide a basic understanding of hydrodynamic aspects that can be used as a reference in evaluating pressure loss behavior in various heat exchanger configurations.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in this study were water as the hot and cold fluids. Water was chosen because of its stable thermophysical properties and its widespread use as a standard fluid in heat exchanger performance testing. Ice cubes were used to help maintain the temperature stability of the cold fluid throughout the experiment.

2.2 Heat Exchanger Equipment and Specifications

This research used two types of heat exchangers: a shell and tube heat exchanger and a double-pipe heat exchanger, found in the Chemical Engineering Operations lab unit.

The shell and tube heat exchanger has the following main specifications: a shell inner diameter of 3.882 inches, a shell outer diameter of 4 inches, a shell length of 15 cm, 11 tubes, a tube length of 90 cm, a tube inner diameter of 0.296 inches, a tube outer diameter of 0.375 inches, and a tube pitch of 0.33 inches.

The double-pipe heat exchanger consists of an inner tube with an inner diameter of 0.296 inches and a length of 60 cm per pass. The annular flow cross-sectional area is 2.79 ft^2, and the inner pipe flow cross-sectional area is 0.07 ft^2.

Supporting equipment includes a constant-head tank, circulation pump, heater thermostat, rotameter for flow rate regulation, temperature indicators at the fluid inlet and outlet, and a U-tube manometer for measuring pressure drop. A systematic series of tools in Figure 2.1

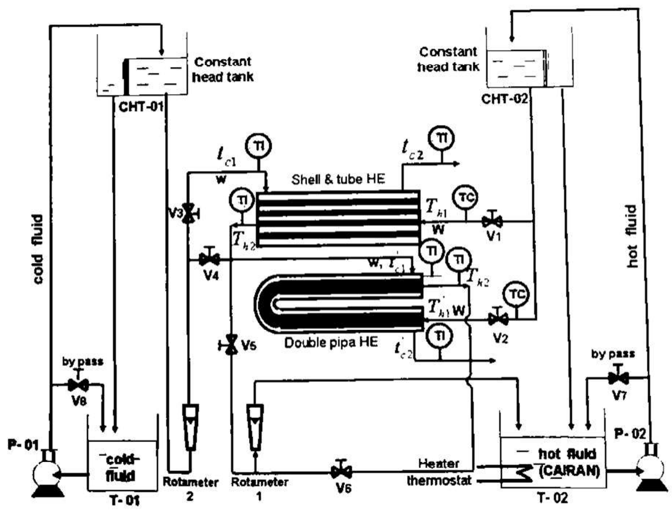

Figure 2.1. Heat Exchanger Equipment Chart [12]

2.3 Experimental Procedure

The hot fluid was heated to the desired operating temperature, while the cold fluid was continuously circulated. The flow rates of the hot and cold fluids were varied by 0.8, 1.0, and 1.2 GPM. After the system reached steady state, the inlet and outlet temperatures of each fluid, the flow rates, and the difference in mercury column heights in the U-tube manometer were recorded. In a shell-and-tube heat exchanger, the hot fluid flows through the shell side, while the cooling water flows through the tube side. In a double-pipe heat exchanger, the hot fluid flows through the inner tube, while the cooling water flows through the annulus. All experiments were conducted in a counter-current flow configuration. Data collection is conducted after the system reaches a steady state, characterized by stable inlet and outlet temperatures of the hot and cold fluids (changes $\leqslant \pm 1$ °C) for at least 5 minutes, and a fluid flow rate that is maintained at the specified operating condition

2.4 Data Analysis Method

Pressure drop was calculated based on the difference in mercury column heights in the U-tube manometer and converted to pressure units. Mass flow rate was calculated from the volumetric discharge and cross-sectional area of the flow. Fluid viscosity was determined based on the average fluid temperature using Kern (1983).

The DG/μ parameter was used as an indicator of flow characteristics, and its relationship to pressure drop in both types of heat exchangers was analyzed.

Definition of DG/μ

The DG/μ parameter is another form of the Reynolds number (Re), which expresses the ratio of inertial forces to viscous forces in a fluid flow and is formulated as:

$$Re = \frac{DG}{\mu} \tag{1}$$

The D value is the characteristic diameter of the flow, namely the inner diameter of the tube for the tube side, the hydraulic diameter for the shell side, and the hydraulic diameter of the annulus in the double pipe heat exchanger.

3. RESULTS AND DISCUSSION

3.1. Evaluation of the Work Results of the Shell and Tube Heat Exchanger

Table 3.1. Shell and Tube Experimental Data

Run.	W (GPM)	t_{c1}	t_{c2}	Th_1	Th_2	G (lb/jam.ft^2)	$(DG/\mu)_{av}$	ΔP_{av} (psi)
1	0.8	50˚C	51˚C	60˚C	40˚C	1.756	3.126	0.0062
2	1.0	55˚C	59˚C	59˚C	42˚C	2.195	3.895	0.0073
3	1.2	56˚C	59˚C	59˚C	54˚C	2.634	5.445	0.0102

Table 3.1. The table shows the results of experimental data carried out with three variations of experimental data on shell and tube.

Table 3.2. Pressure Drop shell and tube

Pressure Drop (ΔP)		
Calculation Data		
Flow Rate	Shell (psi)	Tube (psi)
0.8 GPM	0.004	0.008
1.0 GPM	0.002	0.011
1.2 GPM	0.002	0.017
Maximum value (ΔP) according to Kern (1983)		
10 psi		

Based on Table 3.2. The pressure drop (ΔP) values in the shell and tube heat exchanger exhibit different behavior between the shell and tube sides. At a flow rate of 0.8 GPM, the pressure drop was recorded at 0.004 psi on the shell side and 0.008 psi on the tube side. As the flow rate increased to 1.0 GPM and 1.2 GPM, the pressure drop on the tube side increased 0.0011 psi and 0.017 psi, respectively, which is in line with fluid mechanics theory that increasing flow velocity increases the frictional force of the fluid against the flow wall [13], [14]. In contrast, the ΔP values on the shell side showed relatively small variations and did not exhibit a monotonic trend with increasing flow rate. The decrease in ΔP measured on the shell side is suspected to be influenced by the limited resolution of the U-tube manometer, non-uniform flow distribution, and the possibility of bypass flow on the shell side. Therefore, the shell side pressure drop data in this study are treated as experimental indications with limited accuracy, and are not used as the main basis for theory verification.

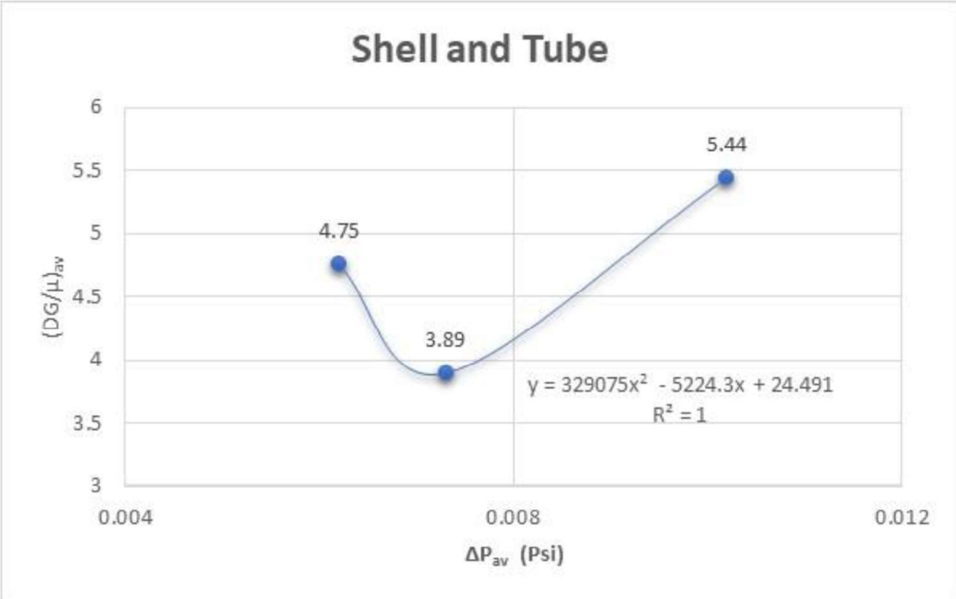

Figure 3.1. Relationship Graph of $(DG/\mu)_{av}$ vs. ΔP_{av} in Shell and Tube

Figure 3.1 shows the relationship between the average pressure drop (ΔP_{av}) and the average $(DG/\mu)_{av}$ value in a shell-and-tube heat exchanger. A second-order polynomial regression curve is shown to visually demonstrate the data trend and was not used as a mathematical model due to the limited number of experimental data points, namely, three data points. Based on the graph, the maximum (DG/μ) average value of 5.44 was obtained at a ΔP of 0.0073 psi, while the minimum value of 3.89 also occurred at a ΔP of 0.0073 psi. The graph shows that the (DG/μ) average value fluctuates. This is influenced by temperature changes during the experimental process, which cause changes in fluid viscosity [15]. Because viscosity is in the denominator of the DG/μ equation, relatively small temperature changes can result in variations in the $(DG/\mu)_{av}$ value even if the flow rate is kept relatively constant. Furthermore, fluid flow on the tube side tends to reach turbulent conditions more quickly, while bypass flow can occur on the shell side, resulting in non-uniform flow distribution [16]. This condition causes local flow velocity fluctuations and contributes to variations in $(DG/\mu)_{av}$ values [17]. Pressure drop variations are also influenced by the limitations of reading the difference in mercury column height on the U-tube manometer. These variations reflect the limitations of laboratory-scale experiments and are not interpreted as new physical phenomena.

3.2 Evaluation of the Work Results of the Double Pipe Heat Exchanger

Table 3.3 Double Pipe Experimental Data

Run.	W (GPM)	t_{c1}	t_{c2}	Th_1	Th_2	G (lb/jam.ft^2)	$(DG/\mu)_{av}$	ΔP_{av} (psi)
1	0.8	38˚C	40˚C	56˚C	53˚C	2930.63	59.40	0.0078
2	1.0	46˚C	48˚C	57˚C	55˚C	3663.29	77.39	0.0093
3	1.2	49˚C	52˚C	58˚C	55˚C	4395.90	97.04	0.0101

Table 3.3. The table shows the results of experimental data carried out with three variations of experimental data on double pipe.

Table 3.4. Pressure Drop Double Pipe

Pressure Drop (ΔP)	
Calculation Data	
Flow Rate	ΔP_{av}
0.8 GPM	0.0078 psi
1.0 GPM	0.0093 psi
1.2 GPM	0.0101 psi
Maximum value (ΔP) according to Kern (1983)	
10 psi	

Table 3.4 shows that the pressure drop value at a flow rate of 0.8 GPM is 0.0078 psi, and when the flow rate increases to 1.0 GPM, the ΔP is 0.0093 psi. At a flow rate of 1.2 GPM, the pressure drop shows the highest value, namely 0.0101 GPM. The pressure drop value shows an increase because the greater the fluid flow rate (Stewart, 2016), the fluid friction against the wall also increases [18]. Pressure drop is directly proportional to the square of the fluid flow velocity [19]. The double-pipe heat transfer system works safely and efficiently, without the risk of pressure loss, even though the actual pressure drop value is still below the maximum limit of 10 psi.

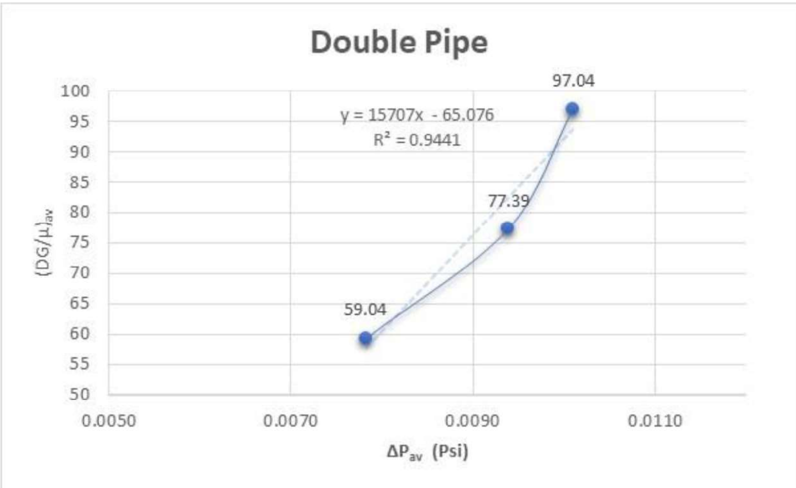

Figure 3.2. Relationship Graph $(DG/\mu)_{av}$ vs ΔP_{av} in Double Pipe

Figure 3.2. Shows the relationship between $(DG/\mu)_{av}$ and ΔP_{av} in a double-pipe heat exchanger, with a linear increase. The highest $(DG/\mu)_{av}$ value of 97.04 was obtained at a flow rate of 1.2 GPM with a pressure drop of 0.0101 psi, while the lowest value of 59.04 occurred at a flow rate of 0.8 GPM with a pressure drop of 0.0079 psi. This increase in $(DG/\mu)_{av}$ and ΔP_{av} indicates that increasing fluid flow rate causes an increase in the Reynolds number, which in turn increases the frictional force between the fluid and the pipe wall. This increased frictional force results in a greater pressure drop in the double-pipe system [20]. Under these conditions, fluid flow tends to move toward a more turbulent regime, thereby increasing flow resistance. More turbulent flow conditions also have the potential to increase the heat transfer rate due to intensified fluid mixing and increased convective heat transfer coefficients [21].

3.3 Comparison of Pressure Drop Characteristics between Shell-and-Tube and Double-Pipe Heat Exchangers

In the flow rate range of 0.8–1.2 GPM, both heat exchangers exhibit an increase in pressure drop with increasing fluid flow rate. However, the pressure drop increase characteristics, and their relationship to the parameter $(DG/\mu)_{av}$ show clear differences between the shell-and-tube and double-pipe heat exchangers. In the shell-and-tube heat exchanger, the pressure drop on the tube side increases from approximately 0.008 psi to 0.017 psi, while on the shell side, the pressure drop variation is within a narrower range (0.002–0.004 psi) and does not always show a monotonic trend. This variation indicates the influence of flow complexity on the shell side, such as non-uniform flow distribution and the possibility of bypass flow [22]. In contrast, the double-pipe heat exchanger exhibits a more consistent pressure drop $(DG/\mu)_{av}$ relationship, with the pressure drop increasing from approximately 0.0078 psi to 0.0101 psi over the same flow rate range. This pattern reflects a simpler flow configuration and a more defined flow path. When directly compared, the double-pipe heat exchanger exhibits a more stable hydrodynamic response to flow rate changes than the shell-and-tube heat exchanger, while the shell-and-tube heat exchanger exhibits a higher maximum pressure drop on the tube side. This difference confirms that the hydrodynamic characteristics of both heat exchangers are significantly influenced by their geometric configuration [23], which is an important aspect in laboratory-scale performance evaluation.

Conclusion

Based on the experimental results and analysis, it can be concluded that increasing fluid flow rate causes an increase in pressure drop in both shell-and-tube and double-pipe heat exchangers. In the double-pipe heat exchanger, the relationship between the (DG/µ)av parameter and pressure drop shows a relatively consistent trend with increasing flow rate, reflecting the simpler flow configuration and more uniform flow distribution. Conversely, in the shell-and-tube heat exchanger, the pressure drop on the tube side reaches a higher value than in the double-pipe type, while the pressure drop variation on the shell side tends to be smaller and does not always show a monotonic trend. This behavior is attributed to the complexity of the internal geometry, non-uniform flow distribution, and the possibility of bypass flow on the shell side. A direct comparison between the two heat exchanger types shows that the double-pipe type has a more stable hydrodynamic response to changes in flow rate, while the shell-and-tube type exhibits greater sensitivity to internal flow characteristics. This study has limitations, including the limited number of experimental data points, the use of pressure drop measuring instruments with modest resolution, and the laboratory scale of the equipment. Therefore, further research is recommended using a wider flow rate range, higher-accuracy measuring instruments, and more detailed separate analyses of the shell and tube sides. Larger-scale testing is also needed to obtain results more representative of industrial operating conditions.

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