International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 14 Issue 8 ǁ August 2026 ǁ PP. 26-33

Investigation of Differences of Water Reynolds Number to Methanol 25% In Heat Exchanger Double Pipe and Coil

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Abstract
The results of the investigation produced a learning medium for convection heat transfer using water and methanol. Experiments were conducted to determine the effect of Reynolds number on heat transfer rates by convection and measure the feasibility of instructional media and determine student responses to instructional media. The method used in development research with ADIE research design (Analysis, Development, Implementation, Evaluation). Development research material is a convection heat transfer learning media in the form of teaching aids. Props in the way of HE (Heat Exchanger). HE is a tool that is widely used in the processing industry and the power industry. One type of HE is an economizer; this tool serves to heat boiler feed water in a steam generator, while in the process industry, it is used to remove heat. HE will be combined with other components to form a prototype convection test equipment. The subject of the research was the manufacture of prototype convection test kits that support the heat transfer course. This investigation resulted in the highest Reynolds number occurring in 25% methanol fluid in HE types coil construction, which is 2649, and the smallest in water fluid in HE types DP construction is 1562.
Keywords: *ADIE, heat exchanger, methanol 25%, prototype convection test equipment, water.*

Date of Submission: 05-08-2026 Date of Acceptance: 17-08-2026

I. INTRODUCTION

Learning media are all things that can channel messages to stimulate students' attention, interests, thoughts, and feelings in learning activities to achieve learning goals. Several kinds of media are used in learning, for example, real objects or models (teaching aids/test equipment), printed text in the form of books, handouts, modules, and visuals. Use various types of learning media above include the senses of sight, hearing, touch, and feel involved in learning so that the learning process can be more meaningful and provide a learning experience. The potential of experiences to foster meaningfulness thus informs content selection, the design of learning experiences, and the articulation of learning outcomes. Students can readily accept the impact in the form of delivery. The development of instructional media should aim to improve the efficiency and effectiveness of teaching. Heat transfer is a branch of science that studies the heat exchange process that occurs between two fluids that have temperature differences. The heat exchange process that occurs is not visible in plain view. This condition makes it difficult to prove that there is a heat exchanger between two liquids. However, it can be felt through changes in the temperature of the liquid. Then the fluid flow and heat transfer occur due to the temperature difference between two vertical walls [1]. The impact of rising temperatures as a basis for the development of heat transfer learning media is the primary material about convection. So that it can prove the existence of the phenomenon of heat transfer that occurs in the form of the impact of rising temperatures. Convection heat transfer learning media can also be able to show the phenomenon of convection heat transfer directly that can give an impression so that it can provide a profound learning experience.

Heat Transfer is a subject that is considered problematic and requires a deep understanding. Understanding of Heat Transfer material is mainly convection using theories and calculations in its explanation. Where the Convection heat transfer mechanism is the most challenging mechanism for students to understand because of the complexity of the type of fluid that moves, the type of media, and the type of flow that occurs in the fluid so because of its complexity, there is no absolute equation to calculate it. To calculate heat transfer by convection, heat transfer experts use empirical equations. The selection of empirical equations uses Reynold numbers (for forced convection) or Grashoff numbers (for natural convection). Dimensional analysis of the problem of forced convective heat transfer shows that the Nusselt number (NNu) is dependent on the Reynolds number (NRe) and Prandtl number (NPr) [2]. The curvature-induced helical vortices (Dean Vortex) tend to suppress the onset of turbulence and delay transition. The Reynolds Number describes the transition from laminar to turbulent flow. After obtaining the value of a number to get the value of the heat transfer coefficient, then calculate the rate of heat transfer [3]. Multiplication of Grashoff number (NGr) with Prandtl numbers is Rayleigh number (NRa). Heat transfer in open cavities through natural convection has been investigated computationally as well as experimentally, and several studies have been carried out on the onset of Rayleigh–Benard convection, especially for infinite horizontal fluids layers [4].

The mechanism of convection for fluid flow to move through a solid medium has often been used for heat transfer since a few decades ago. The motivation behind this work is rich and varied in theoretical and experimental literature heat transfer is available, starting from the last six decades. Research on the effect of fin spacing on turbulent heat transfer in a channel with a cascade rectangular-triangular fin [5]. Waisted use triangular baffles to increase heat transfer at a constant temperature on rectangular ducts [6]. Analysis of natural convection mechanisms, the media used for the cooling process is equipped with cross fins [7]. To understand the combined buoyancy effects of thermal and mass diffusion on the turbulent mixed convection flows inside a tube [8]. A numerical study of mixed convection heat and mass transfer along a vertical channel with a curved wall is performed [9]. An Experimental study of heat and mass transfer for liquid evaporation along with a vertical plate covered with a porous layer [10]. Stability analysis without convection in a flat plane bounded by a two-dimensional rectangle [11].

The existence of teaching aids such as convection heat transfer props will significantly help to understand the material. This teaching aid application gives a deep impression and a good learning experience. The form of information and presentation presented by the author in visual aids is an increase in temperature between two fluids as evidence of convection heat transfer. One fluid is a coolant, and another fluid as a heat receiver. As supporting material and guidelines for the use of heat transfer props, students use modules so that they can learn independently and directly. The existence of the module can also provide training to students to examine the temperature rise that occurs in visual aids with fluid variations and calculate the rate of convection heat transfer at each fluid. The results will show different heat transfer rates due to the other characteristics of various liquids. Making HE uses glass material so that you can see the shape of the flow.

II. RESEARCH METHOD

The research design applied in this study is the ADIE model. The ADIE model has stepped in eveloping analysis, design, development, implementation, and evaluation. The stages of ADIE development are as follows:

2.1. ANALYSIS

Analyze the data by applying it to the forced convection equation. And in this experiment, observing the Double Pipe (DP) and Coil type heat exchangers. Double Pipe type heat exchanger is a device for heat transfer between hot fluid through the inner pipe and water through the annulus, while for Coil type, the hot liquid passes through the coil, and water passes through the tube. The results of the data in the form of temperature and flow rate, from temperature to look for thermodynamic properties which can finally calculate the value of heat transfer rate (q). The equation for calculating the rate of heat transfer in the condenser [12] is:

$$q = U \times A \times (\Delta t)_m \tag{1}$$

Where U_i is the overall heat transfer coefficient, W/ (m^2 ^{o} C); Ai is heat of transfer area, m^2; Δt LMTD is a logarithmic mean temperature difference, ^{o} C; Ft is a correction factor. With the equation for calculating the logarithmic mean temperature difference is as follows:

$$\Delta t_m = \frac{(\Delta T)_{01}) - (\Delta T)_{02})}{\ln\left[\frac{\Delta T_{01}}{T_{02}}\right]} \tag{2}$$

2.2. OVERALL HEAT TRANSFER COEFFICIENT (U)

Calculate the overall heat transfer coefficient using the following equation [13]:

$$\frac{1}{U} = \frac{1}{h_i} + \frac{A_i ln\frac{r_o}{r_i}}{2\pi k_f L} + \frac{1}{h_o} \tag{3}$$

Where Ai is the heat transfer area of the pipe, m_2; A_o is pipe heat transfer area, m^2; L is pipe length, m; r_i is the radius of the inner tube, m; and r_o is the radius of the outer pipe, m. h_i is the coefficient of displacement heat through the inner tube, W / (m^2 ^{o}C), and ho is heat of transfer coefficient through the outer tube (annulus), W/ (m^2 ^{o} C).

The heat transfer that takes place in HE follows a forced convection mechanism since it involves a circulatory system controlled by a pump. The heat transferred in the convection event is considered a sensible heat; the heat is associated with an increase or decrease in temperature without a phase change. The heat transfer coefficient in a HE is calculated according to equations 4, 5 [14], and six [15] below:

$$N_{St} = 0.023\, N_{Re}{}^{-0.2} N_{Pr}{}^{-2/3} \quad \text{(for turbulent flow)} \quad (4)$$

$$\mathrm{N_{Nu}} = 0.036\, \mathrm{N_{Re}}^{0.8} \mathrm{N_{Pr}}^{\frac{1}{3}} (\frac{\mathrm{d}}{\mathrm{L}})^{0.055} \quad \text{(for transition flow)} \quad (5)$$

or

$$\left[\frac{h_m}{C_p G}\right]\left[\frac{C_p \mu}{k_f}\right]^{2/3} = 1.85\, (\frac{d}{L})^{1/3} (\frac{\mu}{\mu_w})^{0.14} \left[\frac{d \times G}{\mu}\right]^{-2/3} \quad \text{(for laminar flow)} \quad (6)$$

Where N_{Nu} = (h ×d)/k; N_{Pr} is Prandtl number = (Cp× $\boldsymbol{\mu}$)/k_f, dimensionless; N_{Red} is Reynolds number = (ρ × d × v)/$\boldsymbol{\mu}$; N_{St} is Stanton number = h/ (ρ× v ×Cp)]; dimensionless; k_f is thermal conductivity, W/ (m ºC); Cp is heat of capacity, J/ (kg ºC); ρ is density, kg/m^3; d is the diameter of the pipe, m; L is the length of the tube, m; and μw is the viscosity at temperature wall, kg/ (m.s).

2.3 DEVELOPMENT

At the development stage, the prototype of heat transfer props by forced convection and module testing until the data is appropriate. Besides, testing of heat transfer props to see the ability to measure the rate of heat transfer with various moving fluids. After validation, it produces a product that can be used for application as a learning medium for heat transfer.

2.4 IMPLEMENTATION

The application phase is the use of teaching aids used as a medium of heat transfer learning. This test is conducted for the rate of heat transfer by forced convection with moving fluid variations. The results of this application phase are in the form of data, which is then analyzed and drawn a conclusion.

2.5. EVALUATION

Evaluation is an improvement stage of the continued use of the heat transfer by forced convection. The form of evaluation activities in this research is a revision at the end of each test, which then becomes a product.

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III. RESEARCH METHODOLOGY

3.1. CONVECTION TEST SYSTEM CREATION

The first forced convection testing system (Figure 1.) is a mechanism of convection heat transfer with a circulatory system, which is a pump (forced convection). The test equipment consists of a modified fluid bottle for hot fluid and cold fluid. Hot fluid flows in the inner pipe to the HE using a pump, and water flows through the annulus, resulting in heat transfer between the hot liquid and water. HE is equipped with thermocouples to measure the in and out temperatures for both hot and cold fluids. Besides being provided with a thermocouple, it is also equipped with a flowmeter to measure hot fluid flow rates and cold fluid flow rates.

(a) **(b)**

Figure 1. System for forced convection testing: a. System for forced convection testing; b. HE types coil.

In the same way, replace the hot water liquid with 25% methanol. The making of the other test system is HE type cartridge and coil using the same test as the first test system, namely hot fluid passing through the coil and cold fluid passing through the cartridge.

The testing procedure is as follows:

• Adjust the valve opening and valve cover so that the fluid flow is unidirectional. When both liquids flow, heat transfer begins. Retrieval of data in the form of temperature read on the sensor (thermocouple).

• Take the rate of flow of cold and hot fluids when the temperature changes in cold liquids and hot liquids that

come out are constant.
• The purpose of taking data after the constant temperature is to get more accurate data.
• The initial temperature of the first fluid is constant because there is no heat.
• The first liquid that flows in the heat exchanger is water so that the absorption of heat that occurs from the hot fluid can be optimum. This treatment is because heat tends to cause lower temperatures so that the regulation of hot liquid does not go directly to the pipe wall because, in addition to damaging the pipe wall, it will also increase the use of hot liquid.
• When a new hot liquid passes through the HE pipes (before meeting with water), the tube feels hot. This condition is due to the process of heat transfer from the hot liquid to the water.

IV. RESULTS AND DISCUSSION

4.1 TEST RESULTS

The results of the experiment are the temperature of the hot and cold fluids in and out, the wall temperature, the volume flow rate of hot and cold liquids. Inlet temperature data (Tf). Tf is to look for chemical and physical properties (ρ, $\boldsymbol{\mu}$, cp, k, and NPr). These properties are to calculate NRe, then the values of the properties are tabulated as Table 1 and Table 2.

Table 1. Chemical and physical properties of water

$T_{f\,hot}$ (°C)	ρ kg/m³	μ kg/m s	Cp kJ/kgK	k W/mK	NPr
55.2	985.12	0.000502	4.1830	0.6492	3.2369
54.6	985.43	0.000507	4.1828	0.6486	3.274
53.5	986.07	0.000519	4.1824	0.6475	3.34
52.9	986.41	0.000522	4.1821	0.6469	3.376
51.6	987.17	0.000529	4.1816	0.6456	3.4268
50.5	987.81	0.000537	4.1812	0.6445	3.484
49.7	988.22	0.000549	4.1809	0.6435	3.532
48.6	988.66	0.000561	4.1807	0.6420	3.466
47.3	989.18	0.000573	4.1804	0.6402	3.388
46.5	989.5	0.000581	4.1803	0.6391	3.345

Table 2. Chemical and physical properties of methanol 25%

$T_{f\,hot}$ (°C)	ρ kg/m³	μ kg/m s	Cp kJ/kg K	k W/m K	N_{Pr}
55.5	927.4	0.00047	3.829	0.536	3.724
54.6	928.3	0.00047	3.823	0.535	3.784
53.3	929.1	0.00048	3.82	0.534	3.846
52.9	929.5	0.00049	3.818	0.534	3.883
51.5	930.4	0.00051	3.817	0.533	3.961
50.8	930.6	0.00051	3.817	0.532	3.983
49.5	931.2	0.00051	3.816	0.532	4.049
48.9	931.7	0.00051	3.817	0.531	4.102
47.6	932.3	0.00053	3.816	0.529	4.187
47.1	932.7	0.00054	3.815	0.528	4.206

4.2. DISCUSSION

The chemical and physical properties of Table 1 and Table 2 for calculating Reynolds number, heat transfer coefficients, and heat transfer rates in the HE system of Double Pipe (DP) type and coil type. The calculation results are made in the form of a graph of the relationship between the Reynolds number of cold water fluid to the coefficient of heat transfer (ho) of cold water through the annulus for DP (Fig. 2), while for the coil

(Fig. 3); graph of the relationship between the Reynolds number to the heat transfer coefficient (hi) of hot water or 25% methanol through the inner pipe for DP (Fig. 4), while for the coil (Fig. 5) and the graph of the relationship between the overall heat transfer coefficient (U) to the heat transfer rate (q) for the DP (Fig. 6) and the graph of the relationship between the overall heat transfer coefficient (U) and the heat transfer rate (q) for the coil (Fig. 7).

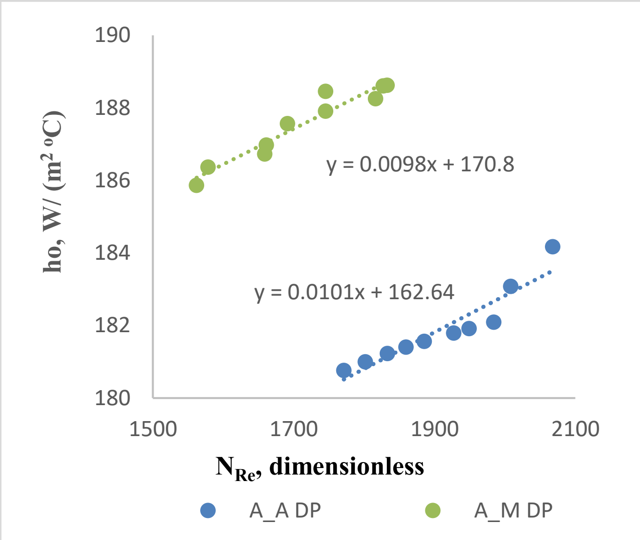

Figure 2. N_{Re} vs. h_o on HE DP

Fig. 2 shows that the ammonia heat transfer coefficient is 25% higher than liquid water. This condition indicates that ammonia transfers heat faster than water because of the characteristic of ammonia, which is its high heat capacity. One that affects the value of the heat transfer coefficient is the Prandtl Number, where this number is directly proportional to the heat capacity. The flow that occurs in methanol shows a Reynolds number above two thousand or transition flow [16].

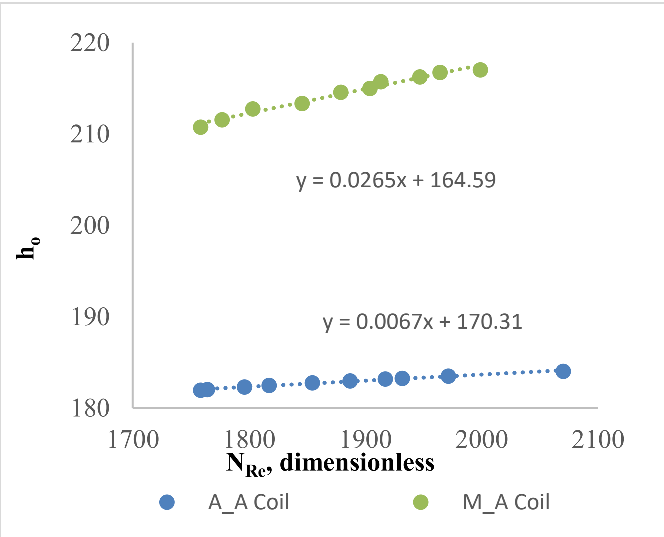

Figure 3. N_{Re} vs. h_o on HE Coil

Figure 3 shows that the ammonia coefficient of heat transfer is 25% higher than that of water fluid, as in Figure 2. Still, both Figure 2 and Figure 3, the Reynolds number is more significant than water, because the water characteristic, that is the density of water is more significant than 25% methanol. The thickness is directly proportional to the value of the Reynolds number [17].

The high heat transfer coefficient of 25% ammonia, which through the coil type HE, also shows the characteristics of ammonia with chemical properties, i.e., low viscosity and through the coil shows that the coil type increases turbulence. Synchronize the viscosity properties with the coil type device, which makes the coefficient of heat transfer by the coil higher than liquid water through DP type HE. In other words, the value of viscosity is low; consequently, the value of the Reynolds number is inadequate because it is inversely proportional between Reynolds number and viscosity. Pipes with the straight flow do not have a turbulence effect, which is the value of turbulence is closely related to the amount of Reynolds number.

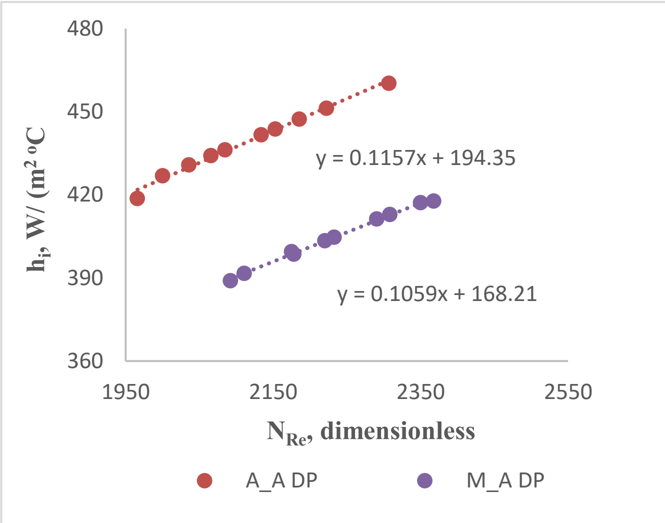

Figure 4. N_{Re} vs. h_i on HE DP

Fig. 4 shows that the value of the water heat transfer coefficient is higher than 25% of ammonia because ammonia releases heat more rapidly than water fluid so that the amount of heat capacity decreases, while water has a higher density. One that affects the value of the heat transfer coefficient is the Prandtl Number, where this number is directly proportional to the heat capacity. The highest heat transfer coefficient is 470 W / (m $^{2\,o}$C) for water, while for the most increased ammonia it is 418 W / (m $^{2\,o}$ C).

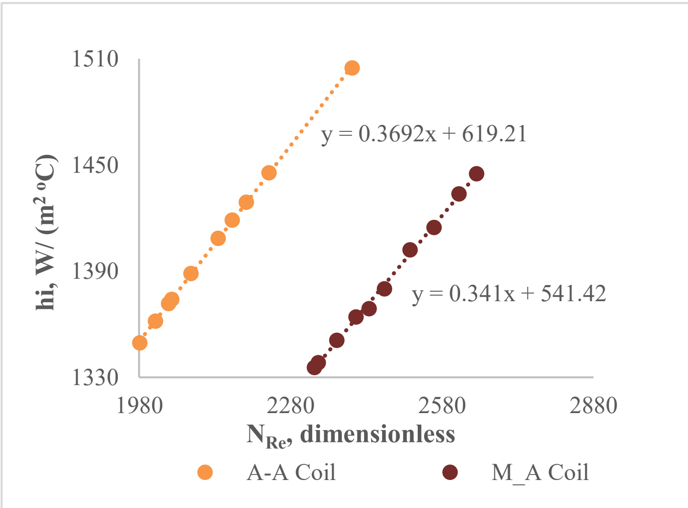

Figure 5. N_{Re} vs. h_i on HE Coil

Fig. 5 shows that the heat transfer coefficient value is higher than 25% ammonia, which is the same as HE DP, but the highest value reaches 1505 W/ (m $^{2\,o}$ C), and for ammonia, it reaches 1445 W /m^2 [18]. The amount of the heat transfer coefficient on the coil is higher than the HE DP shows that the coil increases turbulence, where this turbulence is directly proportional to the heat transfer coefficient.

Methanol 25% with the highest Reynolds number is 2649, and the lowest is 2327, while the highest water is 2402, and the lowest is 1980. The greater the Reynolds number does not always result in a high heat transfer coefficient. However, the measurement results show the heat transfer coefficient of ammonia is 25% lower than that of water, but Reynold's number of ammonia is 25% higher than that of ai. This proves that the heat transfer coefficient depends not only on the Reynolds number but also on the Prandtl number. The value of heat capacity influences the Prandtl number; in this case, the amount of heat capacity of ammonia drops rapidly.

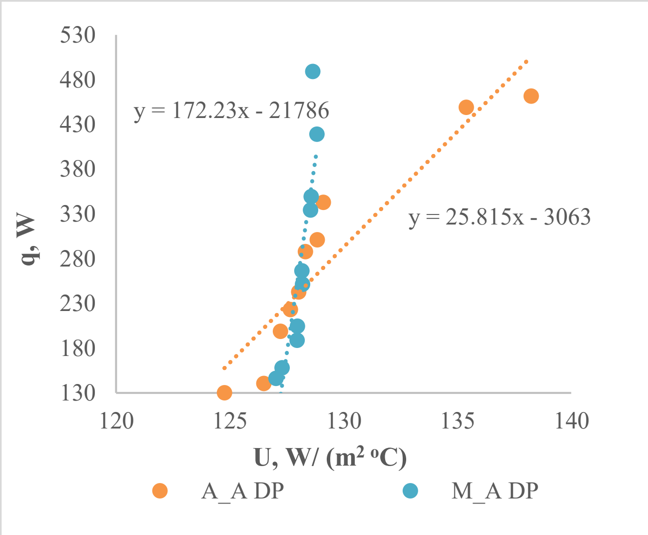

Figure 6. U vs. q on HE DP

Figure 6 shows that the highest heat transfer rate in HE DP for water fluid is 461 W and 479 W for 25% methanol fluid. Figure 7 indicates that the HE Coil heat transfer rate is highest for 25% ammonia 514 W and water 489.7 W.

Compared to HE DP, the value of heat transfer rate on the HE coils type is higher, indicating that turbulence for coil construction is very influential in increasing the heat transfer rate [19]. The highest value of the overall heat transfer coefficient is 25% Methanol fluid through HE coils type, and this is because the individual heat transfer coefficient value that occurs in ammonia is also the highest.

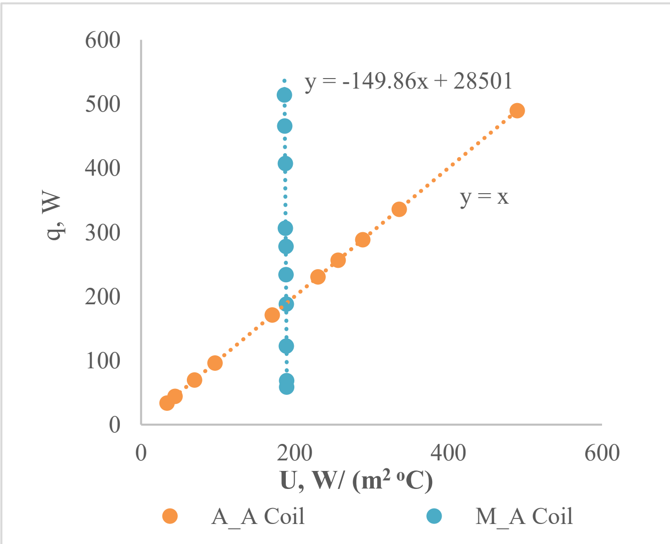

Figure 7. U vs. q on HE Coil

V. CONCLUSION

The results of laboratory improvement studies on various fluid testing systems on HE equipment are as follows:

1. The construction of the testing system has been successful, namely, HE types double pipe and coil.
2. The Reynolds number results obtained in the highest coil type Heat Exchanger is 2649 Methanol fluid Twenty-five percent, and in the Double pipe type, HE is 2367 for 25% Methanol fluid.
3. The highest heat transfer rate is obtained by 507 W in the coil type HE for 25% methanol and the lowest 34 W for Water in the Double pipe type HE.

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