ORIGINAL ARTICLE

Water Wheel Turbine Performance as a Power Plant in Waste Water Pit PLTU System

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ABSTRACT

Water wheel turbines can utilize the flow from wastewater from a generator (waste water pit) which has a large enough discharge. If the water wheel turbine is coupled with a generator, it will produce electrical energy. The application of water wheel turbines in the waste water pit can be utilized for lighting around the power plant. In addition, with the water wheel, the process of heat transfer by convection which generally occurs in the waste water pit. With this water wheel, it will help the process of decreasing the temperature of waste water in the waste water pit. This study aims to determine the performance of water wheel turbines that are applied as a power generator as well as an agitator in a waste water pit. The water wheel turbine model used in this study has dimensions which are: outer diameter of 40 cm; inner diameter of 24 cm; width 8 cm; blade width 8 cm, blade length 8 cm; and 16 spoons. Tests carried out with a temperature of 50°C, a flow rate of 38 l/min, 48 l/min, and 60 l/min. Furthermore, the measurement of water temperature before the water wheel (°C) is measured; water temperature after the water wheel (°C) of 6 points with a distance between points one meter; generator voltage (V); current generator (A); and generator speed (rpm). From the results of the discussion it can be concluded that the best operating condition of the water wheel turbine as a generator as well as a stirrer is the Re 18000 number with an efficiency of 36.5% and an average temperature reduction of 1.6°C/m. From this research, it is known the performance of water wheel turbines that are applied as a power generator as well as an agitator in a waste water pit.

Keywords: Fluid, turbine, water wheel, water pit

INTRODUCTION

The community's need for electricity continues to increase from year to year. To meet these needs, the Indonesian government built several power plants. One type of power plant that is widely used in Indonesia is the steam power plant. According to the Ministry of Energy and Mineral Resources (2019), until 2018, a power plant system with a capacity of 64.5 GW was built. Of this amount, 56.4% was generated from the PLTU system, which uses coal fuel. The data shows that power generation is significant in meeting electrical energy needs.

But on the other hand, the operation of power plants with coal fuel impacts the environment (Finkelman, Wolfe, & Hendryx, 2021). One type of waste generated from power plants is liquid waste from condenser coolers. This liquid waste contains chemicals and has a high temperature, so it cannot be discharged directly into the environment. There are three types of wastewater disposal processes often used in power plants with open loop cooling systems: surface disposal, subsurface disposal, and diffusion disposal. The surface disposal process is the most widely used of the three types of processes.

Figure 1 shows liquid waste discharge from the power plant into the sea using an open-loop system channel. One of the obstacles in the open loop cooling system is that the wastewater that will be discharged into the environment does not meet the quality standards of generation wastewater. As a result, it takes a waste water pit with long channel construction. The construction of a

long waste water pit channel is needed to allow convection heat transfer to occur. However, using long drains requires large construction costs.

On the other hand, there is the potential for wastewater flow energy to be utilized (Zhang & Ma, 2019). Therefore, technological innovation is needed to overcome the waste energy problem. One technological innovation that can be applied is the application of water wheel turbines as agitators. Aside from being an agitator, this water wheel can also generate electricity for lighting the PLTU area.

Fig. 1: Waste Water Pit (PT. Antam, 2016)

According to (Tamrakar, Pandey, & Dubey, 2015) and (G. Ibrahim, Haron, & Azhari, 2011), water wheel turbines can be applied as power plants for agricultural irrigation water supplies. From the two opinions, it can be interpreted that the water wheel turbine can also be applied to wastewater pit because it has a flow rate that is almost the same as the flow of irrigation. Water wheel turbines can be applied to channels with flow rates of 0.5 to 1.2 m^3/s (Emanuele Quaranta, 2015).

Water wheel turbines can utilize the flow from wastewater from a generator (wastewater pit) which has a large enough discharge (Kollmann et al., 2016). If the water wheel turbine is coupled with a generator, it will produce electrical energy. According to (Okamura, 2015) pycohydro scale power plants can be utilized for small-scale lighting in rural areas. This means that the application of water wheel turbines in the wastewater pit can be utilized for lighting around the power plant. In addition, with the water wheel, heat transfer by convection generally occurs in the waste water pit. With this water wheel, it will help the process of decreasing the temperature of waste water in the waste water pit. In this case the water wheel functions as an agitator so that the length of the waste water pit construction can be reduced. Thus, the cost of waste water pit construction is also getting lower.

Several studies of water wheel turbine performance have been done before. (Khan, Ahmed, Khan, & Haider, 2015) reports that the power of a water wheel turbine can produce 0.6 kW at a water speed of 1.2 m / s. In terms of construction, the efficiency of water wheel turbines can be improved by modifying the curve / curved blade (Sule & Soenoko, 2014). This opinion is supported by (E. Quaranta & Revelli, 2017) that changing the blade shape of the water wheel turbine efficiency curve can be increased by 4%. Other research results reported (A. M. Ibrahim & Yoshihide, 2018) that water wheel turbines could be applied to irrigation channels with triangular blades. In terms of material, (Firman, Yunus, & Yusuf, 2017) reports that damage to the turbine blade material is affected by sediment dissolved in water. However, research on the application of water wheel turbines as power generators and agitators has not been done. Therefore, this research is significant because it relates to Indonesia's national problems in electricity.

METHOD AND EQUIPMENT

Discharge of heat using a long channel is one of the ways that can be used to achieve the requirements for the standard quality of wastewater. However, the disposal of heat with a long channel is not an effective way because it requires more cost so that new innovations are needed in the form of the application of the water wheel that serves to accelerate the reduction in temperature and the decomposition of chemicals that are still contained in wastewater. In addition to meeting the requirements for the generation of wastewater quality standards, this water wheel can also be used to generate power for lighting the power plant area.
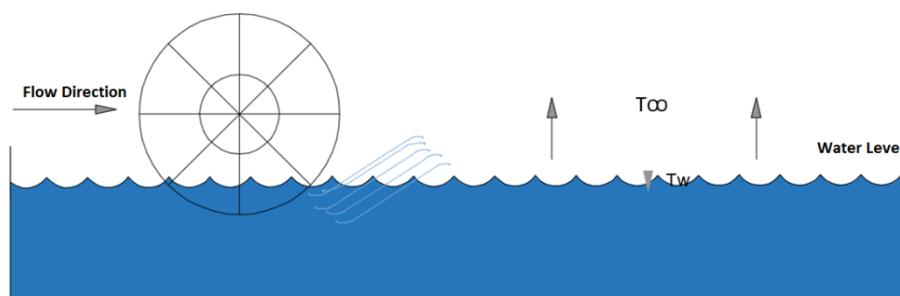

Fig. 2: Convective heat transfer over wastewater pit

An undershot water wheel is a wheel that works when the flow of water that flows hits the wall of the blade located at the bottom of the water wheel, which will cause the water wheel to rotate on its axis. This type is suitable for installing shallow waters in a flat area because the flow needed is flat flow. Here the flow of water is opposite to the direction of the blade, which turns the wheel (Sule & Soenoko, 2014).

In the turbine, the kinetic energy of water is converted into mechanical energy, where water turns the turbine wheel (Debler, 1990). The formula for determining hydraulic power is as follows:

$$P_h = \rho \times g \times Q \times h \tag{1}$$

Where P_h = Water power which moves the water wheel (Watt)
ρ = Fluid density (kg/m^3)
g = Gravitational force (m/s^2)
Q = Water discharge (m^3/s)
h = Water level (m)

The convection heat transfer rate is calculated by the equation (Holman, 1994):

$$q_c = \overline{h_c} A \Delta T \tag{2}$$

Where q_c = Convection heat transfer rate (W)
$\overline{h_c}$ = Convection heat transfer coefficient (W/m^2.K)
A = Heat transfer area (m^2)
ΔT = Difference between surface temperature Tw and fluid temperature T□ (ºC)

The hydrodynamic inlet length is the length that the inlet requires to reach the maximum speed of a fully developed flow. While the thermal length is the length needed from the beginning of the heat transfer area to reach the local Nusselt (Nu) number. If the transfer of heat to the fluid begins as soon as the fluid enters the channel, the heat and velocity boundary layer begins to develop rapidly, then both are measured from the front of the channel.
These laminar and turbulent flow conditions can be expressed by the Reynolds number.

The Reynolds number for open channel flow can be defined by (Holman, 1994):

$$Re = \frac{\rho \, v \, D_h}{\mu} \tag{3}$$

Where ρ = Fluid density (kg/m^3)
v = Flow velocity (m/s)
D_h = Hydraulic diameter (m)
μ = Dynamic viscosity (kg/m.s)

A small Reynolds number (<2000) indicates a laminar flow while a large value indicates turbulent flow (> 4000). The hydraulic diameter equation for non-circular cross sections is as follows:

$$D_h = \frac{4 \, A}{P} \tag{4}$$

Where D_h = Hydraulic Diameter (m)
A = Cross-sectional area (m^2)
P = Channel lenght(m)
While the Pr and tl number is the ratio between the thickness of the velocity boundary layer and the thickness of the thermal boundary layer, written in the equation below:

$$Pr = \frac{\mu \, Cp}{K} \tag{5}$$
Where μ = Dynamic viscosity (kg/m.s)
Cp = Specific fluid heat at constant pressure (KJ/kg.K)
K = Thermal conductivity (W/m.K)

Then the Nusselt number for a fully developed turbulent flow is obtained, it can be written with the equation:

$$Nu = 0.023 \times Re^{0.8} \times Pr^{0.4} \tag{6}$$

Where   Re = *Reynolds*number
          Pr = Prandtl number

After the Nusselt number is known, the coefficient of heat transfer by convection can be described as follows:

$$\overline{h_c} = \frac{N_u K}{D_h}$$ (7)

Where Nu = *Nusselt*number
          K = Thermal conductivity (W/m.K)
          D_h = Hydraulic diameter (m)

The formula for heat transfer per unit length is as follows:
$$\frac{q}{L} = h\pi d \ (T_w - T_b)$$ (8)

Where h = Heat transfer coefficient (W/m^2.K)
          L = Channel length (m)
          d = Channel diameter (m)
          T_w = Wall temperature (ºC)
          T_b = Channel average temperature (ºC)

Forced convection that occurs on the surface of an object is part of the convection heat transfer for external flow or called external flow that is observed is the change in flow that comes in contact with the surface of the object. The formula for forced heat transfer is as follows:

q = h A(T$_w$-T$_\square$)av

         (9)

Where   q = Convection heat transfer rate (W)
          h = Cconvection heat transfer coefficient (W/m^2.K)
          A = Surface area (m^2)
          T$_w$ = Surface temperature through which the fluid passes (°C)
          T$_\square$ = Fluid temperature (°C)

The water wheel turbine model (Fig. 3) used in this study has dimensions: outer diameter of 40 cm; inner diameter of 24 cm; width 8 cm; blade width 8 cm, blade length 8 cm; and 16 spoons. The following is the perspective of the water wheel turbine used in this study:
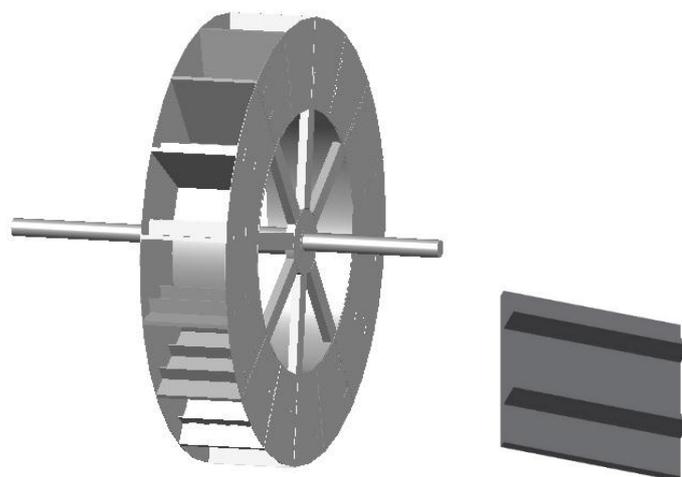

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Fig. 3: Perspective of water wheel turbine and blade

The test is carried out using an open channel device (Fig. 4) with dimensions including channel width of 10 cm; length 7 m, height 1.3 mm, fiber thickness 5 mm; and the dimensions of the triangle foot 4 x 8 cm. This tool has a flow meter, heater with temperature control, instrument temperature system data acquisition.
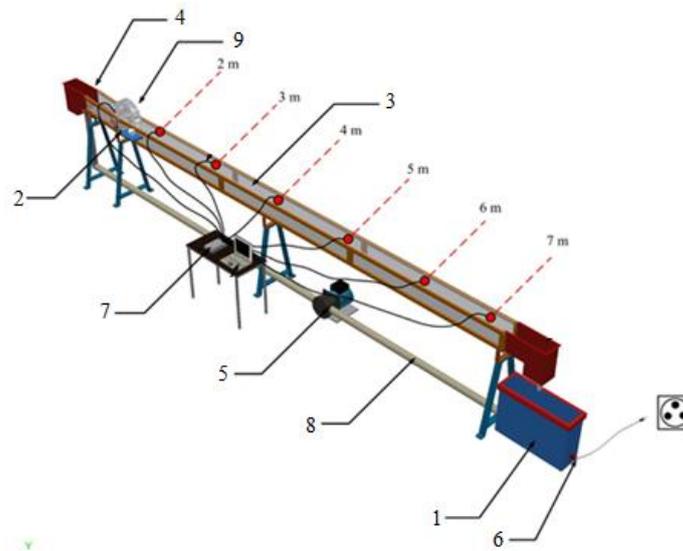
Fig. 4: Testing Scheme

Information:
1. Heater container   6. Heater with temperature control
2. Generator   7. Data acquisition system
3. Open channel   8. Pipe
4. Reservoir   9. Water wheel turbine
5. Pump

Data collection procedures performed on this test are as follows: Water is heated to a temperature of 50ºC and maintained during the test. Open the control valve so that the water flows at 38 l / min flow rate. Furthermore, the measurement of water temperature before the water wheel (° C) is measured; water temperature after the water wheel (° C) of 6 points with a distance between points is one meter; generator voltage (V); a current generator (A); and generator speed (rpm). Furthermore, the test was repeated with a variation of water flow that is 48 l / min, and 60 l / min.

RESULT AND DISCUSSION

Figure 5 shows that turbine efficiency tends to increase to 36.5% in Reynolds numbers 14000 to 18000, but after that, it decreases to 33.5% in Re 22000 numbers. This is in line with the theory of (Holman 1994) and supported by the results of research by (Emanuele Quaranta, 2018) that the number Re influences the turbine's efficiency.
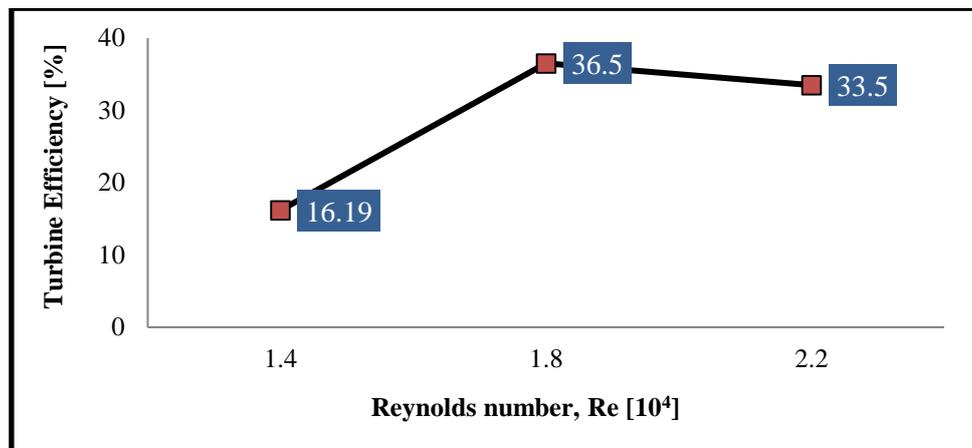

Fig. 5 : Turbine efficiency vs Reynolds number

Figure 6 shows a decrease in water temperature slowly just after exiting the turbine to the end of the channel. The greater the Re number, the greater the temperature change. However, drastic temperature changes occur before entering and after the turbine. This means that the water turbine significantly influences the convection heat transfer process. This phenomenon shows that the wheel turbine can function as a mixer and its main function as a power plant.
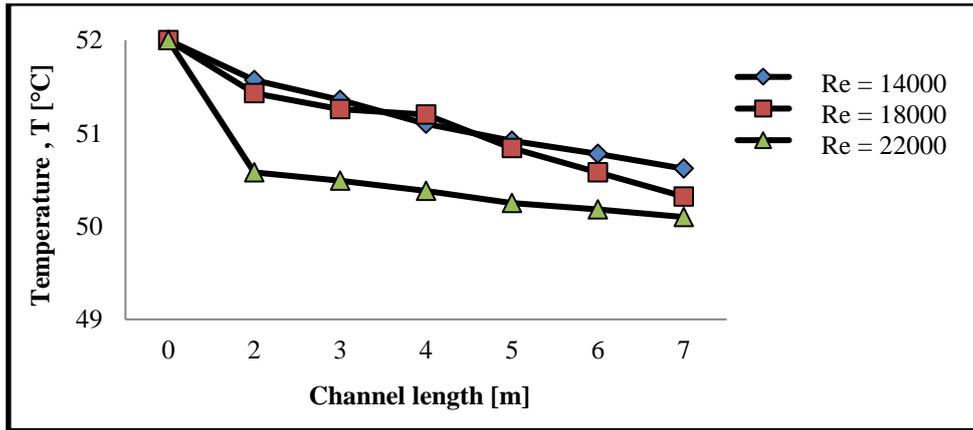
Fig. 6: Temperature decrease along the channel

Figure 7 shows the change in temperature affected by the Renumber. The temperature change goes up to Re 18000 and after that it drops to Re 22000.
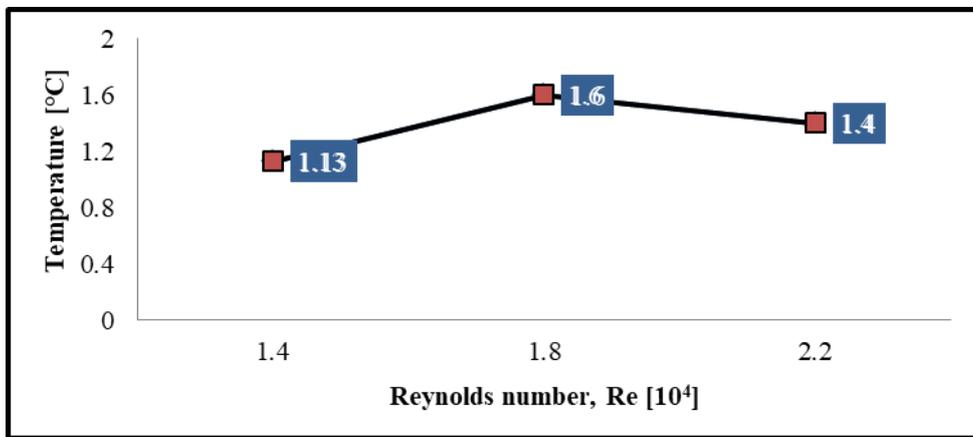

Fig. 7: Mean temperature decreasing vs Re

Figure 8 shows that the higher the Re number, the higher the Pr. number. This is in line with the opinion of (Holman, 1994) and (Incropera & DeWitt, 2005).
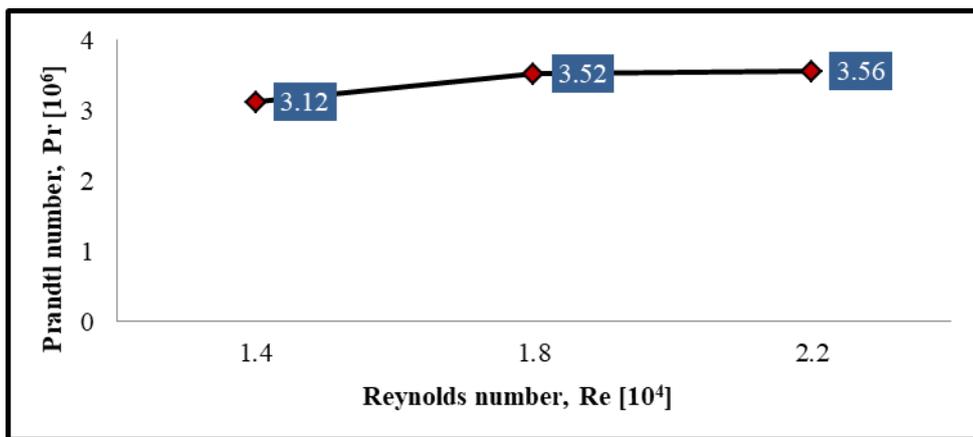

Fig. 8: Prandtl number vs Reynolds number

Like the graph in Figure 8, Figure 9 also shows the same tendency that the higher the Re number, the higher the Nu number. This is in line with the opinion of (Holman, 1994) and (Incropera & DeWitt, 2005).
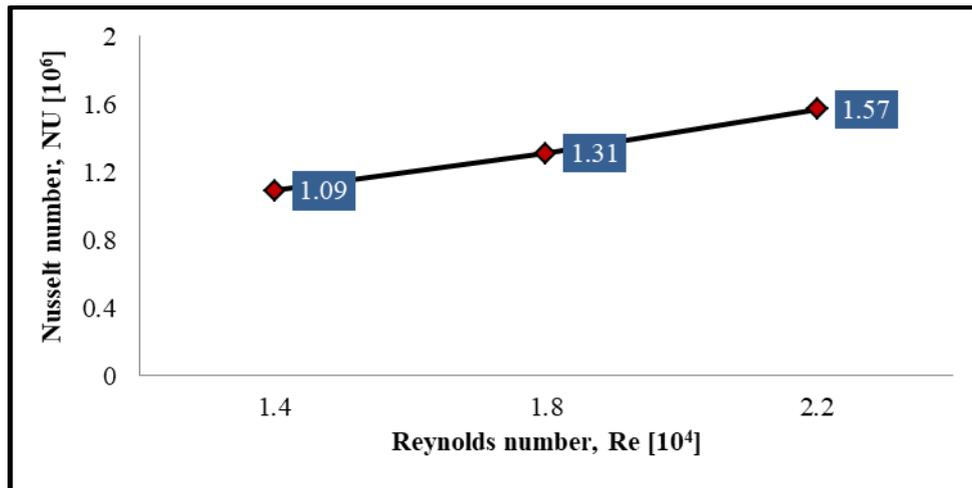
Fig. 9: Nusselt number vs Reynolds number

Figure 10. Shows the heat transfer characteristics of a water wheel turbine. The higher the Renumber, the higher the Pr and Nu Numbers. However, the highest temperature reduction was obtained at the Re number 18000. This is in line with research by (Al-Kayiem & Ibrahim, 2015) and (Yah, Mat Sahat, & Oumer, 2016) that the nature of fluid flow influences the optimum conditions of undershot type water wheel turbines.
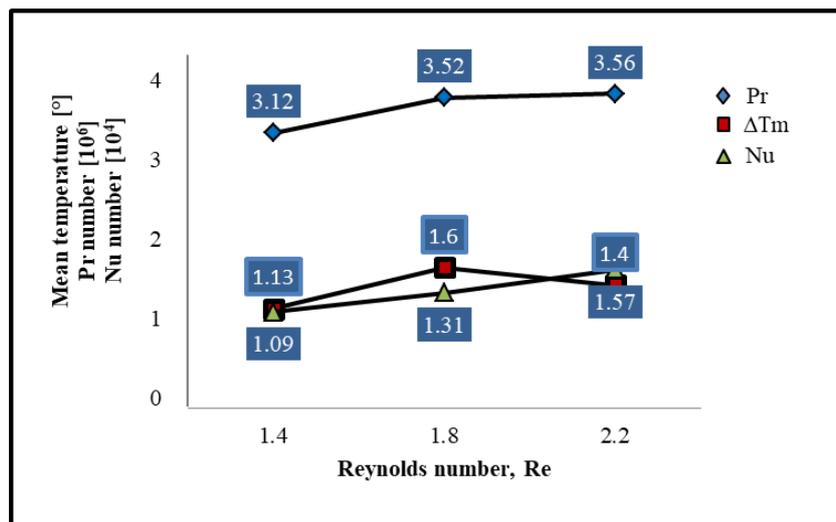

Fig. 10: Heat transfer characteristics

Figure 11 shows that both turbine efficiency and water temperature drop are obtained at the Re number 18000. Therefore, it can be concluded that the best performance of the water wheel turbine at the Re number 18000 if operated as a power generator and a mixer in the wastewater pit.
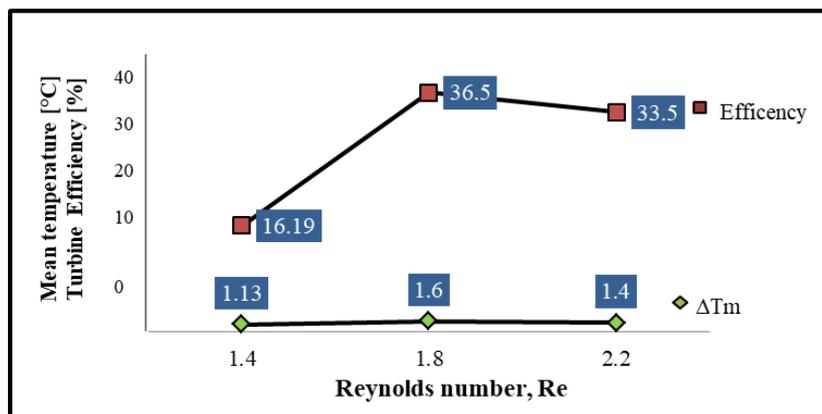

Fig. 11: Water wheel turbine performance

CONCLUSION

From the discussion results, it can be concluded that the best operating condition of the water wheel turbine as a generator and a stirrer is the Re number 18000 with an efficiency of 36.5% and an average temperature reduction 1.6oC/m. From this research, it is known the performance of water wheel turbines that are applied as a power generator and an agitator in a wastewater pit.

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