ISSN No:-2456-2165

Pressure Drop in an Axial Turbine System, Case Study of the Suction Line

Alifya Putri Askolani[1], Abrar Riza[2*], Didi Widya Utama[3*]
Department of Mechanical Engineering
Tarumanagara UniversityJakarta, Indonesia

Abstract:- The need for electricity today is generally still dependent on coal. However, the fact on the ground is that the amount of coal energy supply for power plants is in short supply. There must be steps to increase the supply of power plants that use New and Renewable Energy sources. Indonesia has the potential to build power plants that use New and Renewable Energy sources, namely water energy. In the field, water does not always have a strong enough discharge to drive a turbine. Therefore, this research will discuss the effect of variations in water discharge using a pump so that it can regulate the flow rate to be used to see the effect of motor rotation, pressure drop, and power generated. This research will be conducted at full valve opening, 3/4 intake valve opening, and 1/2 intake valve opening with variations in rotation from 700 rpm to 1000 rpm. From the research results, it is found that the higher the pump rotation, the higher the discharge produced. The valve opening affects the pressure drop value. Because the pressure drop has a relationship with cavitation, namely the formation of vapor in the fluid flow due to a decrease in pressure. Discharge has a directly proportional relationship with mechanical power. This can be said because motor rotation is also directly proportional to the resulting discharge.

Keywords:- *Suction, flowrate, pressure drop.*

I. INTRODUCTION

The current demand for electrical energy is mainly dependent on coal. The electricity sector accounted for 59% of all the coal used globally in 2021, together with 34% of natural gas, 4% of oil, 52% of all renewables and nearly 100% of nuclear power [1]. However, the facts on the ground are that the amount of coal energy supply for power plants is in short supply. The occurrence of a coal crisis for power plants can occur due to several things, including whether that affects coal excavation, the influence of high export (international) coal prices [2], and the low realization of the obligation to fulfill Domestic Market Obligation (DMO) coal from coal entrepreneurs [3]. The shortage of coal supply for power plants is not in line with the increasing electricity consumption. According to a report by the Ministry of Energy and Mineral Resources, Indonesia's electricity consumption per capita in 2022 reached 1,173 kWh/capita. This level of consumption increased by about 4% compared to 2021 and has been at a new record high in the last five decades [4]. Of course, there must be steps to increase the supply of power plants using New and Renewable Energy sources. Indonesia has the potential to build power plants that use New and Renewable Energy sources of water energy because the territory of Indonesia has abundant natural water resources.

Hydropower plants use natural resources such as waterfalls, which flow from high to low altitudes, and convert the resulting potential energy to generate electricity using turbines. A water turbine is a driving device that converts energy from kinetic to mechanical energy and utilizes fluid flow at high speed. Then the energy is used to rotate a generator to produce electrical power.

In the field, water does not always have a fast enough flow to move the turbine. Therefore, this study will discuss the effect of variations in water discharge by using a pump to determine the relationship of discharge between rotation and torque. In this study, a variable approach will be carried out on a series of axial turbines of the Kaplan turbine type at the Machine Performance Laboratory at Tarumanagara University.

Kaplan turbine is one type of reaction turbine that has propeller-shaped blades that can be adjusted to the load driven by the turbine to get maximum efficiency at a non-full load. In the turbine system, there is a venturi meter that functions to measure the discharge of fluid flow through a closed pipe. Venturi meters use the Bernoulli and continuity principles by relying on differences in a cross-sectional area that can lead to differences in velocity. The cross-sectional area can result in differences in velocity.

The problem that arises in this test is to identify the performance problems of the turbine with maximum and minimum discharge. In addition, it can also vary the torque used. This is sometimes a problem that occurs in actual circumstances when the Kaplan Turbine is operating.

In this test, several problem limitations are made with the intention of maintaining the focus of the tests carried out. The problem limitation is that the variables tested in the study are only water discharge flow data and torque given several variations.

The purpose to be achieved in the research is to get the effect of the performance of axial turbine characteristics with laboratory scale with variable parameters of discharge and torque. In addition, this research is also to get an overview of the relationship between motor rotation with discharge and torque on pressure drop and cavitation.

The benefit of the test is to know the parameters that play a role in testing the axial turbine characteristics in terms of water flow discharge, as well as a means of developing science.

ISSN No:-2456-2165

II. MATERIAL AND METHODS

The research method used in this test is the experiment, which is a quantitative research method used to determine the effect of independent variables (treatment) on dependent variables (outcomes) under controlled conditions.

The turbine used in this test is an axial turbine located at the Mechanical Achievement Laboratory of Tarumanagara University. With a piping system and sourced water power comes from a centrifugal pump. This Axial Turbine is equipped with a Venturi meter as a flow meter or water discharge.

The following is a table of specifications of the water turbine, centrifugal pump, and venturi meter which will be used as a reference in the calculation.

Table 1: Specifications of the centrifugal pump

Parameter	Description
Torque at 50 Hz	2,4 kg.m
Rotation	120-1200 rpm
Speed Generator 60 Hz	1500 rpm

Table 2: Specifications and Dimensions of Axial Water Turbines

Parameter	Description
Diameter of turbine (De)	0,14 m
Radius of turbine (re)	0,07 m
Diameter of hub (Di)	0,07 m
Radius of hub (Ri)	0,035 m

Table 3: Specifications and dimensions of the Venturimeter

Parameter	Description
Diameter of venturimeter (D1)	0,1217 m
Diameter of throat (D2)	0,075 m
Coefficient of discharge (Cd)	0,95-0,98
The cross-sectional area of venturimeter (A1)	0,0116324 m2
The cross-sectional area of the throat (A2)	0,00442 m2

Before processing the data, some basic information is needed, which is obtained from a venturi meter placed in the center of the pipe and connected to a mercury manometer as a measuring instrument, the rotation of the turbine shaft which produces the torque, and the rotation of the motor shaft.

All data taken relate to variation of motor speed from 700-1000 rpm with a 100 rpm interval controlled by motor speed. This axial turbine installation has five valves. As what is seen only in the suction section, there is only one valve, the suction valve, which can be seen in Figure 1.

Fig. 1: Plumbing Installation

In the first test, the condition of the intake valve is fully open, then in the second test the intake valve is opened ¾ and finally at ½ opening. In calculating the water discharge data on the venturimeter, variables such as Δh, or the difference in mercury level at the manometer and calculating the cross-sectional area of A1 and A2 are needed.

III. RESULTS AND DISCUSSION

In finding the amount of discharge value, you can use the formula for the discharge equation with a venturi meter measuring instrument. The way the venturi meter works uses the principles of Bernoulli and continuity by relying on differences in the cross-sectional area that can result in differences in speed. The difference in cross-sectional area from a larger diameter becomes smaller and then enlarges again which is done ideally to avoid the loss of compressive height due to expansion. The following are the known Bernoulli equation [5]:

$$p_1 + \frac{1}{2}\rho v_1{}^2 + \rho g h_1 = p_2 + \frac{1}{2}\rho v_2{}^2 + \rho g h_2 \quad (1)$$

Description:
p = Pressure (Pa)
ρ = Density (kg/m3)
v = Velocity (m/s)
Or it can be simplified to [5]:

$$p_1 + \frac{1}{2}\rho v_1{}^2 + \rho g h_1 = konstan \quad (2)$$

In the continuity equation for an incompressible fluid, the density or density of the fluid is always the same at every point it passes through. A mass of fluid flowing in a pipe having a cross-sectional area A1 (large diameter of the pipe) over a given interval of time [6]:

$$m_1 = \rho A_1 V_1 t \quad (3)$$

Similarly, the mass of fluid flowing in a pipe with a cross-sectional area of A2 (small pipe diameter) during a given time interval [6]:

$$m_2 = \rho A_2 V_2 t \quad (4)$$

For an incompressible fluid, the continuity equation is as follows [6]:

$$Q = A_1 V_1 = A_2 V_2 \quad (5)$$

The above equation shows that the volume flow rate or discharge is always the same at any point along the pipe or flow tube. When the cross-section of the pipe shrinks, the fluid flow rate increases, otherwise when the cross-section of the pipe becomes large, the flow rate is small.

The result of the combination of the Bernoulli and continuity equations in equations (1) and (5) will produce a discharge calculation equation for the venturi meter, as follows [5]:

$$Q = C A_T \sqrt{\frac{2(p_1 - p_2)}{\rho_{raksa}(1-\beta^4)}} \quad (6)$$

Description:
Q = Water discharge (m^3/s)
C = Coefficient of Discharge
A_T = Venturimeter Cross-Sectional Area (m^2)
$(p1 - p2)$ = Pressure Difference (Pa)
ρ = Density (kg/m^3)
β = d/D (m)

In the flow equation used, some variables cause pressure drop, namely variables (p1-p2). The occurrence of pressure drop can be influenced by several factors including pipe roughness, pipe length, pipe diameter, fluid type, fluid flow velocity, and fluid flow shape. In this test, the pressure drop can be seen from equation (6), which has a directly proportional relationship to the water discharge due to the diameter of the Venturi meter in the pipe installation, and the influence of various factors on the major and minor head losses in equations (7) and (8) [5].

$$h_{L\,major} = f\frac{l}{D}\frac{V^2}{2g} \quad (7)$$

$$h_{L\,minor} = K_L \frac{V^2}{2g} \quad (8)$$

Description:
f = Friction factor
l = Pipe length (m)
D = Pipe diameter (m)
V = Flow velocity (m/s)
g = Acceleration of gravity (m/s^2)
K_L = Loss coefficient on fittings

In the major head loss, there is a value of f which is the friction factor, the length of the pipe is l, and the diameter of the pipe is D. These three values are what distinguish major head loss from minor. Head loss calculations can be used in determining the power of water pumps needed in piping installations before determining the amount of pump power by calculating the amount of pressure needed plus the amount of head loss.

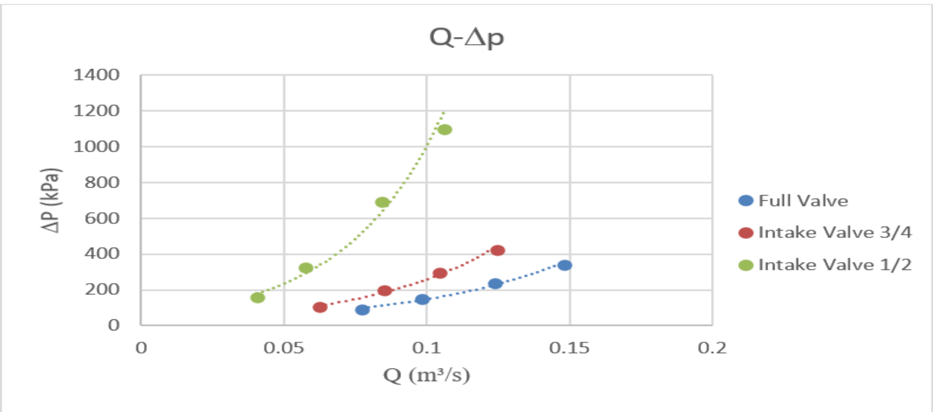

Fig. 2: Graph of Discharge against Pressure Drop

ISSN No:-2456-2165

Based on the tests that have been carried out, it can be seen in Figure 2 that the higher the discharge produced, the higher the pressure drop that occurs. The lowest value of Q at the full opening is 0.077 m3/s with a value ΔP of 92 kPa. The highest value of Q at the full opening is 0.148 m3/s with a value of 340 kPa ΔP. These results also show the same trend in the variation of the intake valve openings.

The graph of the relationship between flow and pressure drop resulting from the tests described is similar to that in the research paper by Nurnawaty and Sumardi [7]. The study explains that the higher the flow, the higher the pressure drop will be for a variety of turns. The following graph from the research journal is shown in Figure 3.

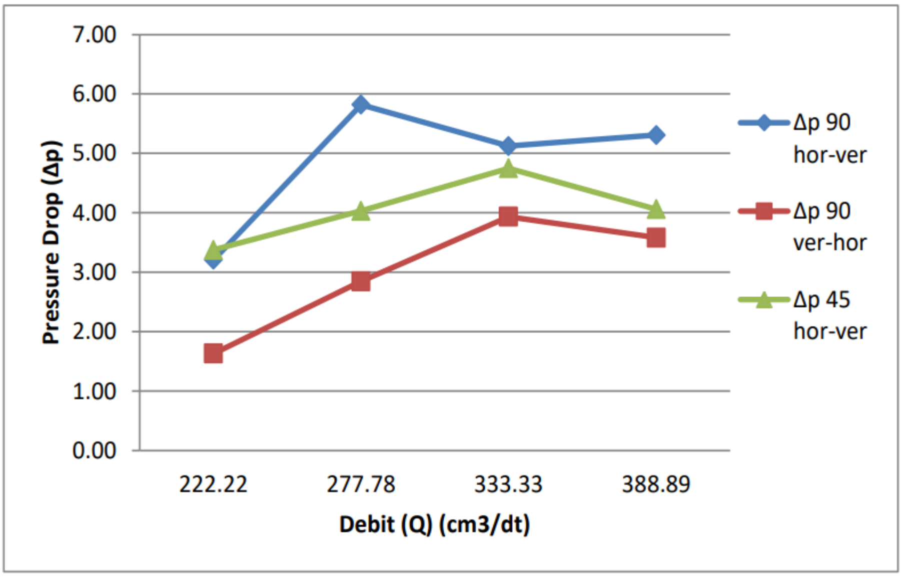

Fig. 3: Test Comparison Results [7]

In addition, Figure 2 also shows that the smaller the valve opening, the higher the value ΔP produced. In other words, the valve opening has an indirect effect on the pressure drop value obtained. This is due to the different K values in equation (8) for each valve orifice.

This is because pressure drop is related to cavitation in the suction line area of the test equipment installation, which is the formation of vapor at room temperature in a fluid flow as a result of pressure drop. Therefore, it can be concluded that the higher the pressure drop, the greater the possibility of cavitation (reaching Pv). This is supported by a research journal by Anisa Aulia [8]. The research journal has a graph of valve openings against cavitation values, which can be seen in Figure 4.

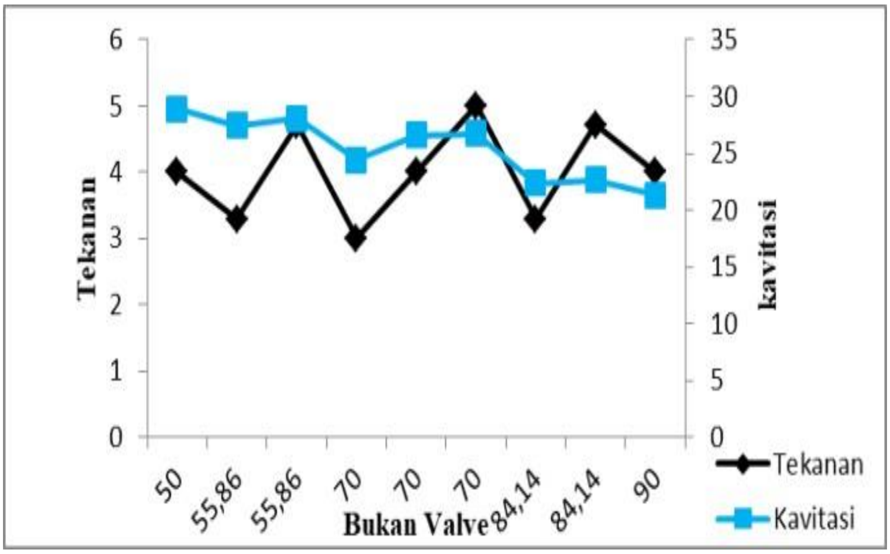

Fig. 4: Journal Graph Comparison Testing [8]

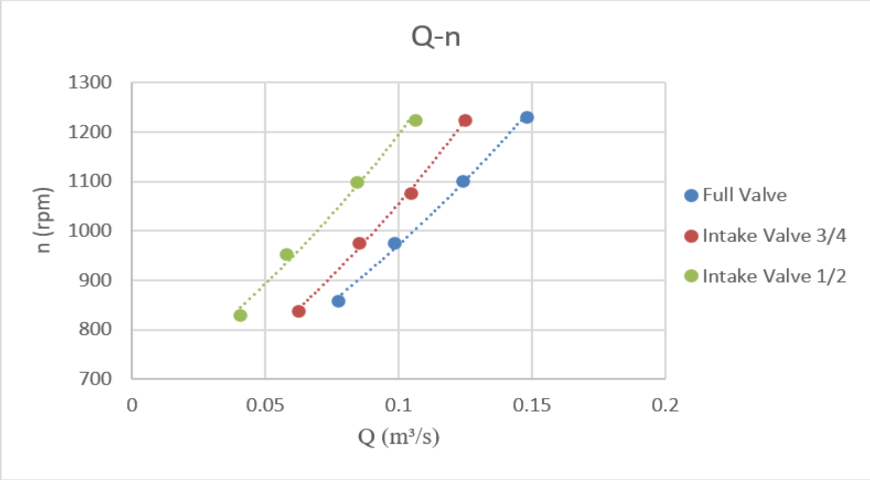

Fig. 5: Graph of Discharge Against Rotation

As well as affecting pressure drop, the amount of flow can also affect engine rotation. This can be seen from the graph in Figure 5, which explains that all variations of intake valve opening have increased, or it can be said that the results are directly proportional. The higher the discharge value, the greater the engine rotation produced. The difference between the highest and lowest values in each variation of intake valve opening can be said to be very small. Comparing the full opening with the ¾ opening has a range of 1.8% - 2.2%. While the ½ intake valve opening has a range of 0.7% - 3.4%.

The graph of the relationship between the motor rotation and the discharge generated from the tests described is comparable to the research journal of Didik Sugiyanto [9]. The journal also explains that the higher the discharge, the higher the rotation produced. The following graph from the research journal is shown in Figure 6.

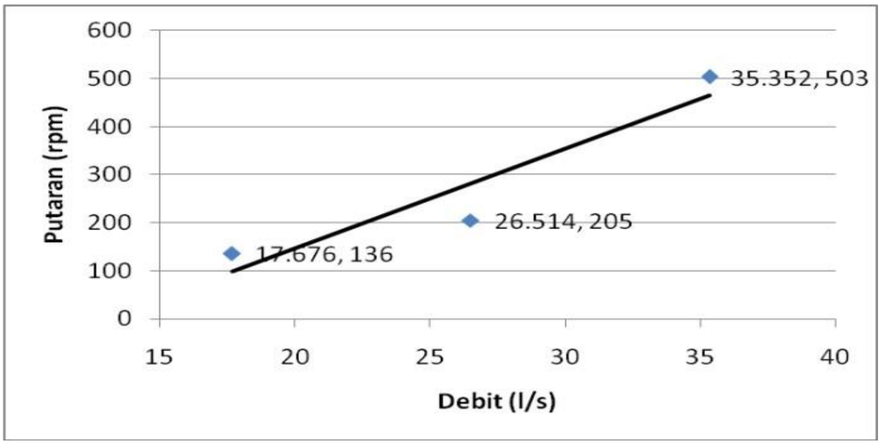

Fig. 6: Testing Comparison Chart [9]

The existence of a water turbine as a tool to convert water potential energy into mechanical energy is expected to produce sufficient power. In this test, the discharge analysis is carried out on the mechanical power (Pm) produced.

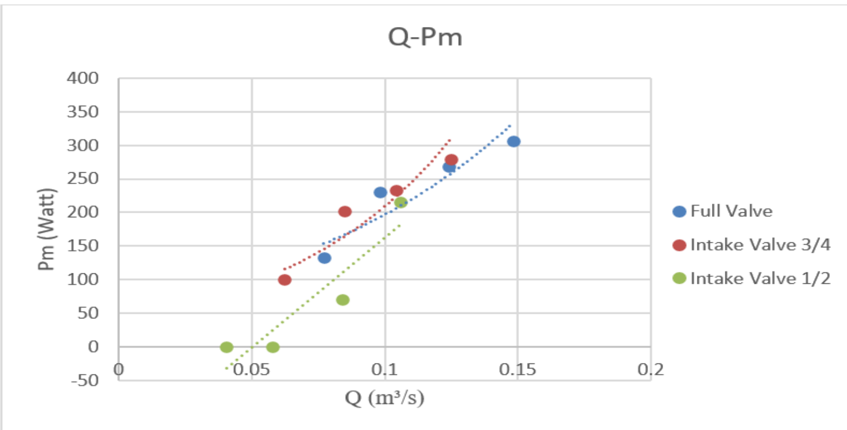

Fig. 7: Graph of Discharge against Mechanical Power

ISSN No:-2456-2165

Discharge and power are linked. Where there is no discharge, there is no turbine rotation to generate electricity. This relationship can be seen in Figure 7, which explains that the higher the discharge value, the higher the power generated. This is related to the mechanical power equation (9) which has a value of ω derived from motor rotation and the relationship between discharge and rotation [5].

$$P_{mekanis} = \omega . T \quad (9)$$

From the equation above, it can be seen that the value of ω is directly proportional to the mechanical power. This can be said because the rotation of the motor is also directly proportional to the resulting discharge. In line with this, the higher the Q value, the higher the mechanical power value.

Based on Figure 7, the decrease in power from the initial rotation of 700 rpm is very high when given a variation in intake valve opening. At full opening, the power generated is 133.067 Watt, while for the intake valve opening ¾ is 99.959 Watt, and at ½ intake valve opening does not produce power because the turbine does not rotate. This also applies at 800 rpm and 900 rpm.

IV. CONCLUSION

The relationship between flow and pressure drop is directly proportional, i.e. the higher the flow produced, the higher the pressure drop. These results also show the same trend for the variation of the inlet valve openings. Where the lowest value of Q at the full opening is 0.077 m3/s with a value ΔP of 92 kPa. The highest value of Q at the full opening is 0.148 m3/s with a value ΔP of 340 kPa.

From the relationship between displacement and rotation, it can be seen that all variations of intake valve opening have increased, or it can be said that the results are directly proportional. In other words, the greater the discharge, the greater the engine rotation. Comparing the full opening with the ¾ opening has a range of 1.8% - 2.2%. While the ½ intake valve opening has a range of 0.7% - 3.4%.

From the relationship between discharge and power, it can be seen that the higher the discharge value, the higher the power generated. This is related to the mechanical power equation, which has a value of ω derived from motor rotation and the relationship between discharge and rotation.

ACKNOWLEDGMENT

The authors would like to thank the Mechanical Engineering Department of Tarumanagara University as an institution that has helped facilitate the research and several other parties who have helped in the research until the preparation of the paper.

REFERENCES

[1.] "Outlook for electricity – World Energy Outlook 2022 – Analysis - IEA." https://www.iea.org/reports/world-energy-outlook-2022/outlook-for-electricity (accessed Jun. 07, 2023).
[2.] "Duh Duh.. Ternyata Ini Biang Keladi Kritisnya Batu Bara PLN!" https://www.cnbcindonesia.com/news/20220104131240-4-304456/duh-duh-ternyata-ini-biang-keladi-kritisnya-batu-bara-pln (accessed Jun. 07, 2023).
[3.] "Krisis Listrik di Negeri Gelimang Batu Bara." https://www.cnnindonesia.com/ekonomi/20221221143521-85-890305/krisis-listrik-di-negeri-gelimang-batu-bara (accessed Jun. 07, 2023).
[4.] "Konsumsi Listrik Penduduk Indonesia Naik pada 2022, Capai Rekor Baru." https://databoks.katadata.co.id/datapublish/2023/02/23/konsumsi-listrik-penduduk-indonesia-naik-pada-2022-capai-rekor-baru (accessed Jun. 07, 2023).
[5.] Munson, Young, Okiishi, and Huebsch, "FUNDAMENTALS OF FLUID MECHANICS (sixth edition)," pp. 1–23, 2016.
[6.] F. ARIZA, "Analisa Numerik Aliran Melalui Venturimeter Dengan Variasi Ukuran Leher Untuk Menentukan Koefisien Kecepatan Dan Penurunan Tekanan," Ariza Fiki, pp. 1–77, 2019.
[7.] dan Sumardi, "Fluid Friction Apparatus," J. Tek. Hidro, vol. 13, no. 1, pp. 28–37, 2020, [Online]. Available: https://journal.unismuh.ac.id/index.php/hidro/article/viewFile/3980/2716
[8.] S. B. Anisa Aulia, Nasrul ZA, Novi Sylvia, Lukman Hakim, "KAJIAN TERHADAP KAVITASI DAN PRESSURE DROP PADA BUKAAN CONTROL VALVE TIPE GLOBE VALVE DENGAN MENGGUNAKAN SOFTWARE AUTODESK CFD (COMPUTATIONAL FLUID DYNAMICS)," vol. 4, no. April, pp. 1–23, 2016.
[9.] D. Sugiyanto, "Potensi Pembangkit Listrik Tenaga Mikrohidro Turbin Kaplan Dengan Variasi Debit Air," J. Kaji. Tek. Mesin, vol. 1, no. 1, pp. 31–42, 2016, doi: 10.52447/jktm.v1i1.331.