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BOWL BLADED HYDRO KINETIC TURBINE PERFORMANCE

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ABSTRACT

In this study, the activity undertaken is to develop a kinetic turbine that has been studied previously with the modification of the turbine blade shape, so that the momentum of the resulting blade becomes larger. Some researcher mentioned in some studies, that a kinetic turbine is a simple turbine and has a low efficiency. As previous studies of turbines to be observed are a laboratory-scale prototype turbine and what is sought is the turbine efficiency as a representative of a turbine performance. The results of this turbine performance measurement will be compared with the result of the kinetic turbine modeling on the Computer Fluid Dynamic system. In order that the modeling results comparable to be valid, it was then compared with the previous studies result. Then what was done was observing the pressure distribution occurred in the turbine. For the bowl bladed kinetic turbine it was found that the highest efficiency achieved was 21% at a water flow rate of 45 m^3/ h and a turbine rotation of about 80 RPM. The simulation results with CFDs that observe every movement of rotating runner appear that there are at least two turbine blades that experience great momentum in the modeling. Compared with previous research, the kinetic turbine with a curved blade, the turbine bowl bladed efficiency has a higher efficiency and a more stable turbine rotation. The largest water flow, pressure occurs on the 45 (runner position as big as 1.02e+010 Pa and occurs in its two-blade area. On the 40°runner position, the water flow pressure is slightly lower as big as 9.34e+009 Pa and also occurs in the two blades regions. While at the 5°, 10°, 15°, 20°, 25° and 30 runner position the water pressure is the lowest but still high enough with a value of about 8.63e+009 Pa. Thus, based on the water pressure between the blades which produces the same relative momentum in the kinetic turbine with the bowl blade, it can be concluded that this turbine rotation is more stable. The water pressure produced is higher than that on the curve bladed kinetic turbine observed in the previous research.

Keywords: Kinetic turbine, efficiency, thrust, remote area, computer fluid dynamic.

INTRODUCTION

From the previous research on the curved blade kinetic turbine [1], based on the Computer Fluid Dynamic contour produced result, it can be concluded that this kinetic turbine can be developed further by increasing the momentum that occurs on every kinetic turbine blade. As it is well known that there are still many places in remote areas that have a micro-hydro potential, this is one of the reasons that kinetic turbines can still be developed, especially if there is an opportunity to improve turbine performance. The information that needs to be added here is that increasing the turbine performance, which is defined as turbine efficiency, power generation, production, turbine torque and some other more, more importantly, is the electricity quality. One of the parameters that could influence the electricity quality is the turbine rotation. The turbine rotation quality is talking about the kinetic turbine rotation stability. A good electricity quality, low price electricity, the ease of erecting a turbine and utilizing the existing water, energy source is a very profitable project, especially in remote areas. Boedi [2] also mentioned that the turbine rotation can be utilized directly without going through a process of converting turbine rotation to a generator to generate electricity. In a recent study, Soenoko [3] mentioned that there are still many remote areas that have not enjoyed electrical energy. Recently, turbine efficiency research and observation is still conducted to get the best turbine efficiency [4], [5]. Rudy also mentioned that the kinetic turbine is still reliable for remote areas that have the potential water energy [1].

From some observations in several places conducted by Rispiningtati [6], [7] it can be stated that locations with a long irrigation networks have always the potential to build a power plant, whether it is a micro scheme, small or medium-sized scheme. So the need of micro-water turbine until to the medium size water turbine is very high. It should also be conveyed that turbine design for micro-hydro turbines and medium-sized turbine has a high difficulty level because each region has their own specification of electricity generation. So this turbine variation should be adjusted to the place where the turbine water will be installed. What is meant by the specific nature of an area include the head energy (waterfall), water flow rate, water flow speed and the water channel slope. These specifications would affect the turbine design and specification (Cross flow, kinetic turbine or others).

Several studies have also been developed at Fluid Mechanics Laboratory Brawijaya University, such as was done by the Mechanical Engineering Doctoral Students. For the kinetic turbines, some topics are observed and discussed for its performance development [8], [9], [10] and another Archimedes turbine done by Saroinsong [11]. These studies have observed further supporting the work of turbine kinetic by considering all factors that could increase the momentum of a kinetic turbine. Monintja [12] observed the flow steering device enters the turbine blade. Later it has also been mentioned that Lempoy [13] conducted a study of hinged blades aimed at reducing the back pressure that occurs in the other half-section of the turbine runner. All attempts are made to get the best kinetic turbine performance. As Boedi did [9] is to analyze the kinetic turbine performance using the RSM analysis, to get the best kinetic turbine design. Like for example, what is the best turbine blade height, what is the best turbine blade number and probably by using RSM analysis the other kinetic turbine parameter could be optimized too.

According to National Energy Outlook 2016 [14], energy demand will increase from 144 million TOE (Tonnes Oil Equivalent) in 2016 to 1049 million TOE (BaU, Business as Usual) by 2050 with a growth a rate of 5.7% per year. By controlling the turbine efficiency, the final energy requirement in 2050 can be reduced to 652 million TOE (EFF-efficiency) with 4.3% annual growth rate and 543 million TOE (EFF_HIGH, high efficiency) with a growth rate of 3.8%. By implementing the energy saving technologies in industry, transportation, household and commercial sectors as well as transport mode shifts in EFF and EFF_HIGH scenario results a lower energy requirements. The industry sector energy need which is the largest energy consumer grew 5.7% (BaU), 4.2% (EFF) and 3.6% (EFF_HIGH) per year respectively. Currently, energy sector industry consumption is 41%, dominated by coal, natural gas and electricity. The next largest consumption is transportation. The energy needs of the transportation sector increased by 5.3% (BaU), 3.5% (EFF) and 2.8% (EFF_HIGH) per year respectively. The share of energy consumption in the transportation sector is currently 34%, which is still dominated by fuel oil (BBM) although the fuel subsidy for transportation has been revoked.

MATERIAL AND METHODS

The research method is the same as done on the previous research. The research method is comparing the prototype kinetic turbine test result, taken from the fluid mechanics laboratory, with the Computer Fluid Dynamic simulation software result.

Figure-1. Turbine test bed.

As mentioned above that the laboratory used for the research is the Fluid Mechanic Laboratory, which is located in the Mechanical Engineering Department, Brawijaya University. Many research topics were conducted in this laboratory, such as the development research of wind turbines by utilizing a wind tunnel. Other research is pump development research, compressor development research and of course the water turbine development research. The water turbine test bed was equipped with a 1.5 m^3/h flow rate pump.

Research installation

As mentioned above that in this study, the test installation used is a vertical axis kinetic turbine blade bowl bladed kinetic turbine, installed on a special wooden open channel water duct as seen in Figure-2.

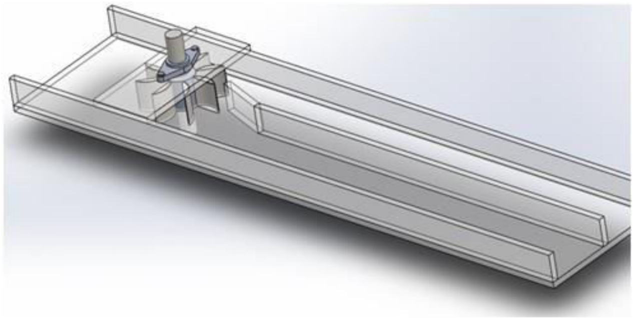

Figure-2. Research duct system.

The bowl bladed hydrokinetic turbine prototype is mounted in a duct that has been fitted with a bearing cradle at the duct top end to hold the upper turbine shaft and another bearing on the duct bottom side, to hold the lower turbine shaft. On the upper side, a wooden base is mounted on the top bearing support plate as a torque load measuring holder. This wooden base would hold the disc pulley installed at the end of the turbine shaft so that the turbine braking can be done directly on the runner turbine. The bowl bladed hydrokinetic turbine research installation could be seen in Figure-3.

Figure-3. Turbine research installation.

The bowl bladed kinetic turbine dimension for the experimental observation could be seen in Figure-4. The blade height is 120 mm, the runner drum diameter is 110 mm and the turbine shaft diameter is 30 mm. The experimental bowl bladed kinetic turbine was equipped with eight similar blades as seen in Figure-5.

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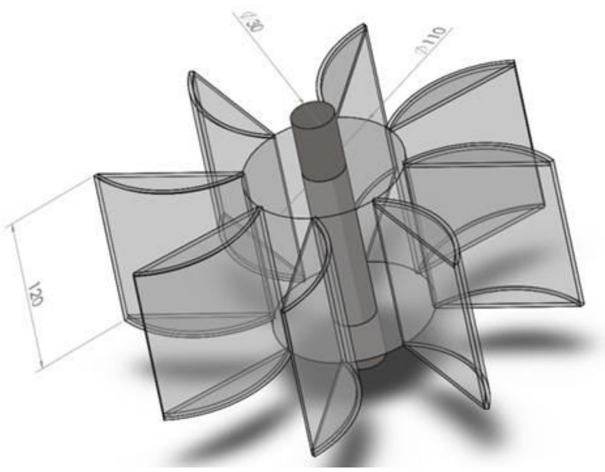

Figure-4. Runner dimension.

The bowl bladed kinetic turbine was tested with several variables. Variables that are used in this experimental observation are the turbine torque, turbine rotation and the water flow rate. The purpose of this test variable is to get the bowl bladed kinetic turbine performance. From the test result data, it could be found the relationship between the water flow rate and turbine efficiency and momentum that occurs in each blade. These data are then compared with the data from the computational fluid dynamic software prediction flows based on the partial differential equation representing the momentum and energy law.

Figure-5. Turbine runner for the experimental testing.

A braking system is implemented on the kinetic turbine shaft. The purpose of this braking system is to apply a braking force to get a kinetic turbine torque value. (Figure-6) To get an easy breaking force, two scales were equipped to get a force difference as a total torque force value. This force value is known as the force to get the shaft moment or the turbine shaft torque.

Figure-6. Torque break system.

After getting the experimental turbine performance, the next step is implementing the computational fluid dynamics (CFD) software to develop a turbine design. The CFD software will predict flows based on partial differential equations representing the momentum and energy laws.

As mentioned above that the braking system is a system used to get a torque value of a rotating shaft. By adding the left and right scale value then the total force of the shaft could be obtained to calculate the shaft torque which is expressed as in equation (1).

$$T = (F_2 - F_{1)}.l \tag{1}$$

Kinetic turbine

The hydrokinetic turbines share the same principle as wind turbines and tidal turbines. The kinetic turbine energy conversion system utilizes the kinetic energy of a flowing water stream with little or no reliance on the energy head to produce another form of energy that can be utilized. Much research and development about turbine kinetic is to produce this technology from the concept stage of proof and to demonstrate the technical feasibility and potential of micro-hydro power generation. It is also a variant of the micro power generation scheme, which adapts to local conditions. Micro-hydro program with turbine kinetic generator is adapted to local conditions and local hydrological conditions [7]. So in this research, new technologies are being developed for challenges, potentials, prospects and frameworks for remote areas.

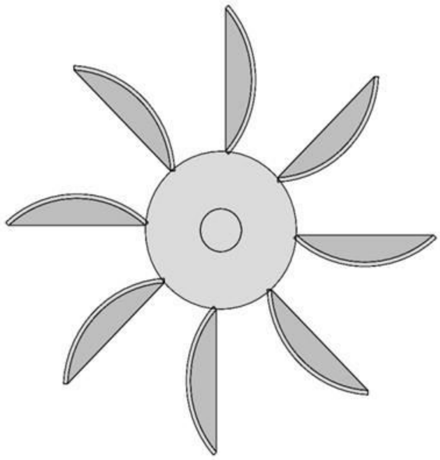

Figure-7. Bowl bladed kinetic turbine runner.

Hydrokinetic turbine working principle

The working principle of turbine hydrokinetic is a blade that gets a direct boost in the absence of head energy. The turbine blade gets the energy from the water flow velocity flowing into the turbine chamber. In this type of turbine, half of this turbine will experience a boost from the water flow entering the turbine, the other half also experiencing a push, but because of its blade convex shape, the water push becomes smaller. To reduce the effect of a water boost that will provide a negative torque, a steering plate was installed. The runner's impulse is also influenced by this hydrokinetic turbine blade. This negative torque will inhibit the runner spin so that the torque will be smaller.

The hydrokinetic turbine form in this study is a runner equipped with eight bowl-shaped blades. The hydrokinetic turbine is a vertical type. As mentioned above that, this kind of hydrokinetic turbine gets the rotational energy from the water flow rate and water velocity. So the hydrokinetic turbine performance depends only on the water flow rate, water velocity, and the water flow direction.

The hydrokinetic turbine power

The hydrokinetic turbine power (E_a-joule) is determined by the amount water mass ($\dot{m}$-kg/s) and Water flow velocity (m/s), as expressed in equation 2.

$$E_a = \frac{1}{2} \cdot \dot{m} \cdot V^2 \tag{2}$$

Equation (3) is used to calculate the power (P_a–watts) passing through a cross-section (A-m^2), with a water specific gravity ρ(kg/m^3).

$$P_a = \frac{1}{2} \cdot \rho \cdot A \cdot V^3 \tag{3}$$

With $\omega = \frac{2 \cdot \pi \cdot n}{60}$ and torque T, the turbine power generated (Pt-watt) could be calculated as follows:

$$P_t = T \cdot \omega \tag{4}$$

Where:

$$\omega = \frac{2 \cdot \pi \cdot n}{60} \tag{5}$$

Hydrokinetic turbine efficiency

The hydrokinetic turbine efficiency is determined by the ratio of the incoming water power (WHP) to the amount of power generated (HP) by the kinetic turbine, as shown below.

$$\eta = \frac{BHP}{WHP} \tag{6}$$

The hydrokinetic turbine efficiency is the efficiency in which the hydrokinetic turbine converts the water mechanical power into the electrical power. This value is used to calculate the nominal hydrokinetic power and the actual hydro turbine output in each time step.

Blade tangible velocity and stream velocity ratio (u/v)

A formula to determine the blade tangential velocity and water flow velocity [15] is as follows:

$$\frac{u}{v} = \frac{\omega \cdot R}{V} \tag{7}$$

Force and momentum

The force generated by a fluid velocity pushing the turbine blade and will produce a momentum with a magnitude determined [16] as follows:

$$M = \rho .\ Q \cdot v \tag{8}$$

In accordance with Newton's statements of law, force magnitude is the fluid mass multiplied by fluid acceleration as follows:

$$dF = dm \cdot a = \rho . v . dA \cdot dt \left(\frac{dv}{dt}\right) = \rho \cdot dA \cdot dV \tag{9}$$

Power (watts) available in a water stream could be calculated based on the turbine efficiency (η), water density (ρ = kg/m^3), head (m), water flow rate ($\dot{q}$ = m^3/s) and gravity g (Equation 10).

$$P = \eta \cdot \rho \cdot g \cdot h \cdot \dot{q} \tag{10}$$

The method used for the result validation is the same as used in the previous research, which utilizes Computer Fluid Dynamic software to see the water movement behavior between hydrokinetic turbine blades. What is observed is the large water pressure that generates the momentum between every blade. As in previous studies that observed hydrokinetic turbine with curved blade, then the observed and simulated is hydrokinetic turbine with bowl bladed. The flow configuration between the blades and the water pressure that occurs inside the runner will be modeled for each 5°rotational blade motion. Since the number of blades is eight pieces, the

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angle between two blades is 45°, which means that there are nine blade modeling.

RESULT AND DISCUSSIONS

To get the test results on the test bed in the laboratory, the prototype turbine is placed on the available channels on the test bed. The data taken are turbine spin which varied between 20 RPM to 100 RPM with a variation of flow rate between 40 and 60 m^3/h. Then the data of this test result in the plot in some graph relation. One of these performance graphs is the relationship between flow rate and hydrokinetic turbine efficiency (Figure-8).

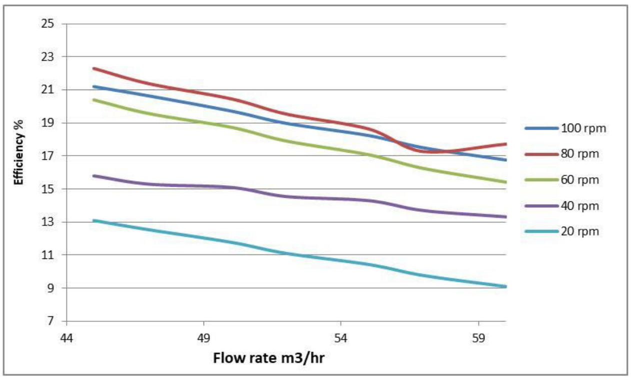

Figure-8. Turbine flow rate vs turbine efficiency.

From the turbine test results shown in Figure-11, it can be seen that maximum efficiency occurs at a rotation between 60 RPM and 100 RPM. Precisely, turbine efficiency is 20.4% at 60 RPM turbine rotation and at a 46 m^3/h water flow rate. For the 80 RPM turbine rotation the turbine efficiency is about 22.6% under a 46 m^3/h water flow rate. While at 100 RPM turbine rotation, the maximum turbine efficiency is 21.2% occurs at a 46 m^3/h water flow rate.

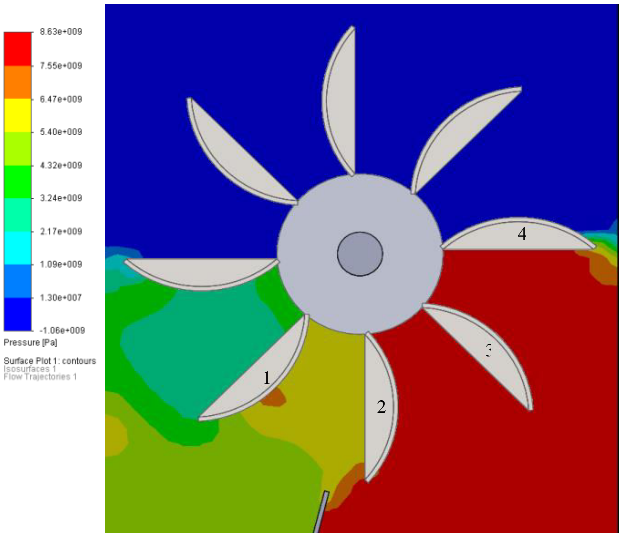

Figure-9. Turbine runner at 5°.

In the first 5° runner position it is apparent that the highest pressure occurring is on the two blade regions with a water pressure of about 8.63e+009 Pa. Occurring in the space between the 2nd and 3rd blades and also between the 3rd and 4th blades. While in the space between the 1st and 2nd the water pressure occur is slightly lower, which is around 5.40e+009 Pa. In the section before the 1st water pressure is about 2.17e+009 (Figure-9). In the chamber after the blade 4, there is the lowest water pressure which is 1.30e+007. So it can be concluded that this turbine is spinning because there is a large momentum in the two spaces between the 2nd and 3rd blades and the other momentum in the space between blade 3 and blade 4 and the water pressure between blade 1 and blade 2 are slightly lower. But the momentum generated in this section can add a boost to the runner turbine.

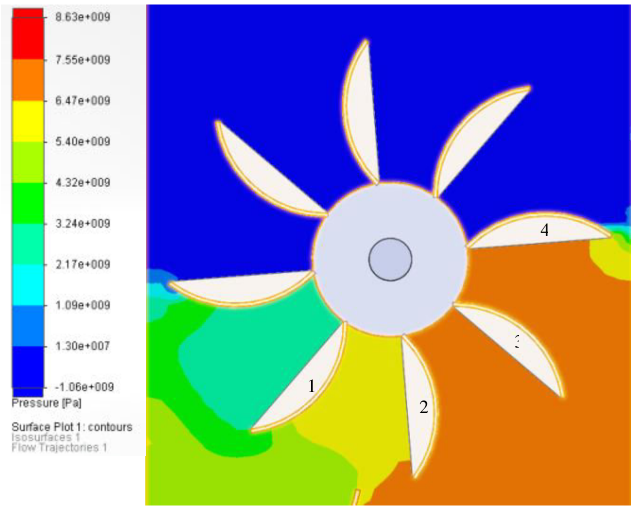

Figure-10. Turbine runner at 10°.

For the working through the 10° runner position, it is seen that the highest pressure is 8.63e+009 Pa. The highest pressure still occurs between blades 2 and 3 and between blade 3 and blade 4 as what happened in the 5° runner position observation. The water pressure between blade 1 and blade 2 is slightly lower at around 6.47e+009 Pa (Figure-10). In part after the blade 4, there was a significant decrease of pressure that is equal to 1.30e + 007. Meanwhile, water pressure in the space before blade 1, there was a pressure of 2.17e+009. So it can be concluded that this turbine is rotating still as in the 5° runner position, condition because there is a great momentum between blade 2 and blade 3 as well as large momentum between blade 3 and blade 4 and an additional momentum of water pressure between blade 1 and blade 2.

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Figure-11. Turbine runner at 15°.

The next runner position in this CFD observation is 15°, shows that the highest water pressure is 8.63e+009 Pa occurs between blade 2 and blade 3, while between blade 3 and blade 4 the water pressure is slightly lower around 6.47e+009 Pa (Figure-11). While in the space before blade 1 the water pressure is about 2.17e+009. So in this position, this turbine is spinning because there is a big momentum between blade 2 and blade 3 and another momentum with a slightly lower momentum value between blade 1 and blade 2 and lastly a little additional momentum due to the water pressure between blade 3 and blade 4. At a glance, it appears that at the 15° runner position there a slight turbine rotation decrease compared with the turbine rotation at the 10° runner position.

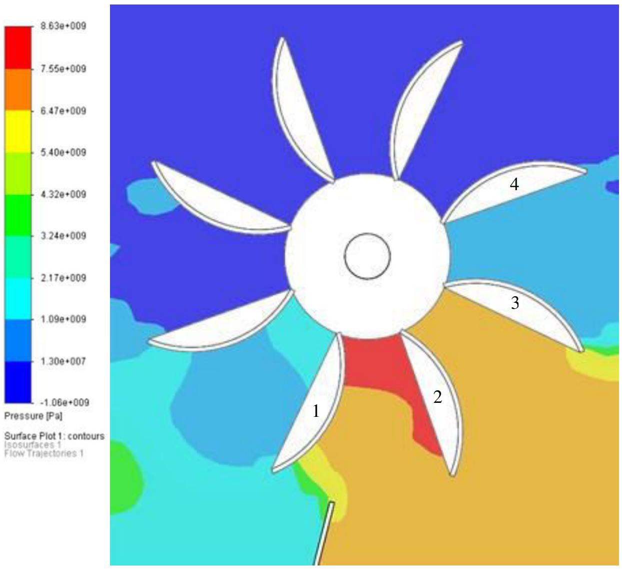

Figure-12. Turbine runner at 20°.

Furthermore, at the 20° runner position, it is seen that the highest pressure occurred between blade 1 and blade 2, as big as 8.63e+009 Pa and partly with a lower water pressure about 7.51e+009 Pa. (Figure-12). This happens because there is a huge vortex. This phenomenon can be seen from the path of water flow in kinetic turbine modeling. While in the space between blade 2 and blade 3 the pressure is a little bit lower which is about 7,51e+009 Pa. The pressure on the part before the 1st blade is very low at about 1.30e+009 Pa, so it is clear that in this section the momentum is very small. It is estimated that there is a slight decrease in the turbine rotation. This is what is thought to be the cause of the unstable turbine rotation.

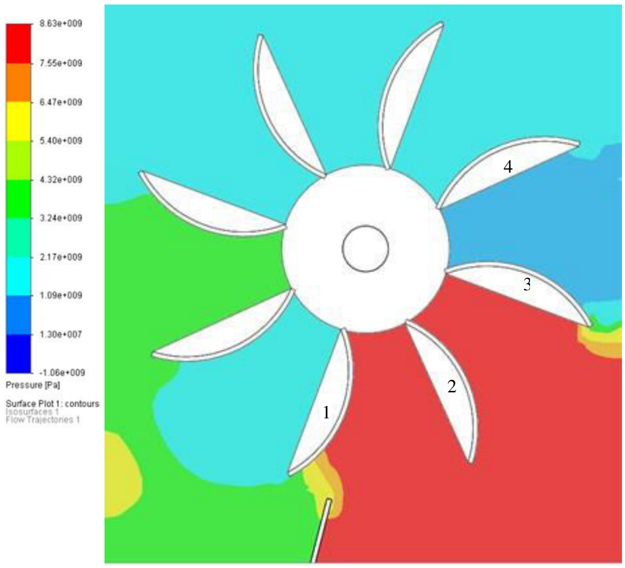

Figure-13. Turbine runner at 25°.

In Figure-13, for the 25°runner position, it appears that the highest pressure is 8.63e+009 Pa occurs between blade 1 and blade 2 and between blade 2 and blade 3. While the water pressure at the area between blade 3 and blade 4 the water pressure is about 1.09e + 009 Pa., while the pressure between the blades before blade 1 is about 2.17e+009 Pa. It can be assumed that the runner turbine rotation for the 25°angle increases again due to the bigger magnitude of the momentum between blade 1 and the blade 2 and between the blade 2 and the blade 3. Surely there is an additional momentum from the other blades though not very large. Refer to the water path of motion observed in the modeling it is clearly a pretty much vortex among the blades.

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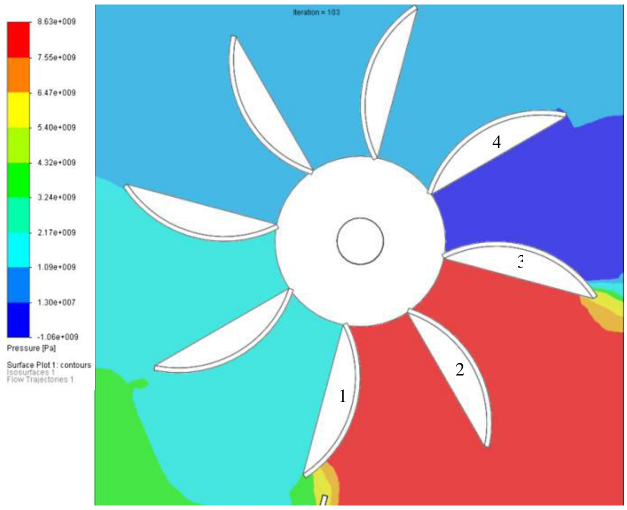

Figure-14. Turbine runner at 30°.

From Figure-14, at the 30° runner position, it is seen that the highest water pressure occurs is about 8.63e + 009 Pa in the space between blade 1 and blade 2. Between blade 2 and blade 3 there is also a same water pressure magnitude about 8.63e+008. While the pressure on the area before blade 1 is about 2.17e+009 and the water pressure between blade 3 and the blade 4 is about 1.30e+009.

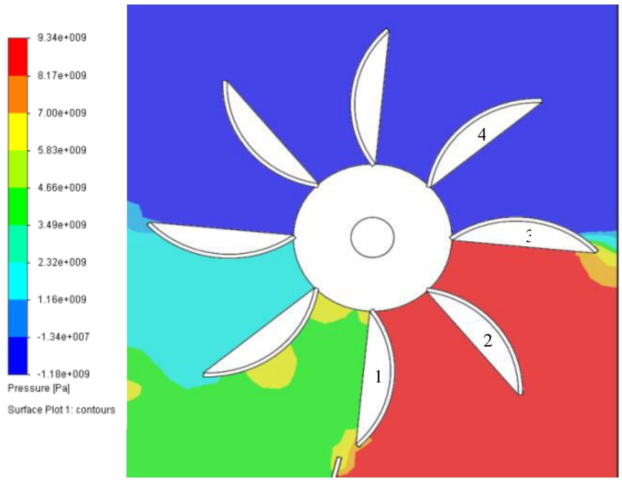

Figure-15. Turbine runner at 40°.

From the flow modeling path it appears that the water rotation occurring in the blade space is very large, this area has the highest pressure value, but it is similar to that of the same position at 25° runner position. At the 30° runner, the two blade regions gain considerable momentum coupled with a small momentum in the area before the 1st blade and between blade 3 and blade 4. So at the 30° runner, the turbine rotation is strong enough. It is estimated that from this simulation result the runner gets a same boost compared to when the runner is in the 25° position.

In the 40° runner position, it is seen that the highest water pressure is 9.34e+009 Pa occurs in the area between blade 1 and blade 2 and also occurs between blade 2 and blade 3. Water pressure before blade 1 is 5.83e+009 which will give a momentum addition on the runner turbine. The pressure between blade 3 and blade 4 drops drastically to as big as 1.16e+009 Pa. At this 40°runner position the runner drive is big enough.

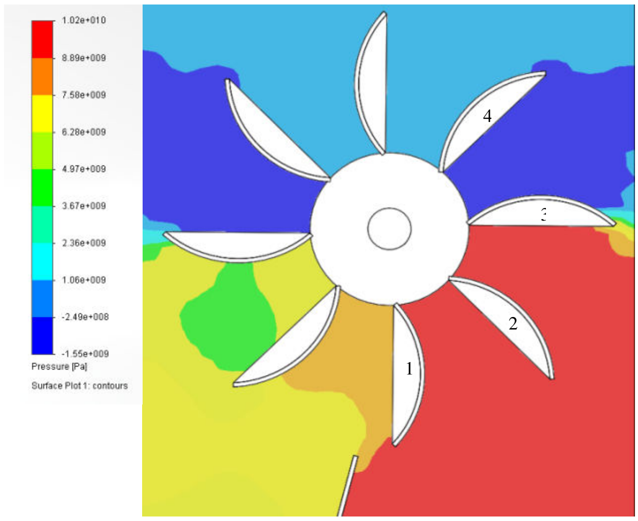

Figure-16. Turbine runner at 45°.

In the 45° runner position, it appears that the highest pressure is 1.02e+010 Pa occurs mostly in the area between blade 1 and blade 2. The same water pressure also occurs between blade 2 and blade 3. Compare to the pressure that occurs when the runner is at a 40° position, the pressure on the area between blade 1 and blade 2 in the 45°runner position is higher than the pressure on the same area at the 40°runner position. The pressure on the area between blade 2 and blade 3 is higher compared with the pressure on blade 2 and blade 3 for the 40°runner position. While in the area between blade 3 and blade 4 the water pressure is about 1.06e+009 Pa and the water pressure before blade 1 is 8.84e+009. So it can be concluded that this turbine is rotating because there is a considerable momentum in the area before blade 1, the area between blade 1 and blade 2, the area between blade 2 and blade 3 and a little extra momentum after blade 4. The overall momentum of the 45° runner position may have the same or slightly higher than the overall momentum at the 40° runner position. The magnitude of the same momentum in the runner's movement since 40° to 45° will ensure the stability of the kinetic turbine rotation. It should also be slightly reviewed the shape of the water flow path that occurs in the turbine runner. From the water flow path on the 40° runner indicates that there is a vortex in the area between blade 1 and blade 2. This vortex generates momentum or thrust force in the turbine runner so there is a recurring momentum that pushes the blade to rotate the runner.

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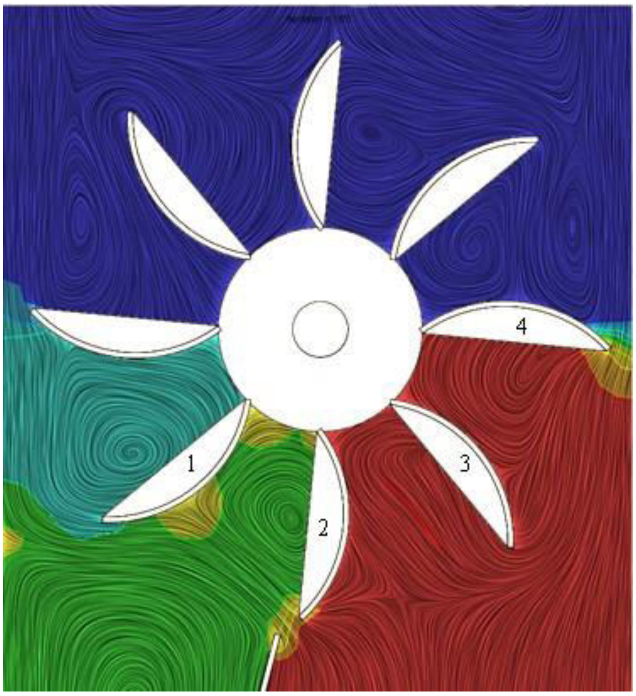

Figure-17. Trajectory on 5° runner position.

At a glance, it appears that there is a little improvement on this bowl bladed hydrokinetic turbine compared with the previous studies [1]. In the bowl bladed hydrokinetic study the turbine efficiency, increased by 3% compared to research on curved bladed hydrokinetic turbine. On the curved bladed hydrokinetic turbine observation, it is clear that there is a water flow that leaves the runner without contributing a water pressure on the blade, while in the bowl bladed hydrokinetic turbine there is still an amount of water that leaves the runner directly but not too large. So it is still needed a further research to optimize that more water pounding the blade will increase hydrokinetic turbine performance.

CONCLUSIONS

From the bowl bladed hydrokinetic turbine research, it was found that the performance of bowl bladed hydrokinetic turbine is better than the curved bladed hydrokinetic turbine performance observed in the previous research. Like, the research process on curved bladed hydrokinetic turbine, the research procedure is entirely the same, with an expectation that the research result could be compared. From the laboratory results, it is shown that there is an increase in the bowl bladed hydrokinetic performance about 3% compared to the curved bladed hydrokinetic turbine performance. From this prototype test results, the highest bowl bladed kinetic turbine efficiency is 21% that occurred on the 80 RM turbine rotation and a 45 m^3 / h water flow. From the modeling, observations, from every 5° runner position, it appears that there are two turbine blades that get the greatest boost or momentum, although at certain runner angle positions there are just one turbine blades that get a boost. This study was conducted by a kinetic turbine experimental testing on a laboratory scale and verified virtually with CFD software. In this modeling, the focus of the observations is on the pressure distribution in the blade space which will generate a boost from the turbine runner. By looking at the rotation of water in the turbine runner, in this case, is the water flow movement that occurs in the impeller chamber, it appears that there is a big boost on the two blade areas, while in the other blade it produces a smaller boost. Furthermore, by looking at the behavior of the water path there is a decrease in the amount of water that does not enter the blade area which directly leaving the channel output compared with what happens to the curved bladed hydrokinetic turbine. This condition is thought to cause a slight increase in the performance of hydrokinetic turbines. So there is still a chance to increase the amount of water flow that can maximally enter the turbine blade chamber, to generate a maximum momentum and how to minimize the flow rate of the waste water directly to the output channel. From the modeling of bowl bladed hydrokinetic turbine, this highest water pressure occurs at the 45° runner position with a water pressure of 1.02e+010 Pa. The water pressure at the 40°runner position is slightly lower at 9.34e+009 Pa and occurs in two spaces between the blades. While at a runner position of 5°, 10°, 15°, 20°, 25° and 30°, the water pressure is about 8.63e + 009 Pa. So because of the prevalence of water pressure in most runner positions then the turbine rotation becomes more stable than that on the curved bladed hydrokinetic turbine. The water pressure produced is higher than the water pressure on the curve bladed kinetic turbine observed in the previous research.

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