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EIGHT CURVED BLADED KINETIC WATER TURBINE PERFORMANCE

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ABSTRACT

The purpose of this research is to optimize the design of a new technology in the form of turbine that only relies on water flow rate to generate electricity to meet the needs of remote areas. This turbine is simple and has existed in some areas but has very low efficiency. A kinetic turbine is tested its prototype under a laboratory scale to get the turbine efficiency as the turbine performance. The results of this laboratory test will be verified with the turbine modeling implementing the CFD modeling software. In this modeling the observation focus is on the pressure distribution within the blade space which will produce the observation thrust. From the test results of this prototype, it is found that the highest kinetic turbine efficiency is 19% that is on a water flow rate of 45 m^3/hour and 80 rpm turbine rotation. From the modeling observations of every 5° runner movement, it appears that there is only one turbine blade that gets the greatest boost or momentum, although at certain runner angle positions there are two turbine blades that get a boost. This condition is suspected as one cause of the low turbine efficiency. From the modeling of this kinetic turbine the highest water pressure in the blade chamber is about 9.19e + 008 Pa, which occurs at 20° runner position, while the lowest pressure is 5.93e + 008 Pa which occurs at 45° runner position.

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

INTRODUCTION

At this time many researchers are less interested in developing a turbine that is used as a micro hydro drive. There are several reasons why micro hydro is still very competitive or important to observe. Some reasons why micro hydro turbines are still need to be developed, among other things is the cheap electricity prices, improve the function of flowing water stream freely that can actually generate energy. For example a direct mechanical energy for processing purposes such as pounding rice, processing in coffee plantation areas or operating simple rustic machinery, wood lathes. Electrical energy can also be produced even if the electricity quality is low for remote areas.

There are still many remote areas that have not enjoyed electrical energy. Some research done by Rudy are always doing with the turbine efficiency improvement. [1], [2], [3]. This type of turbine may have been considered a bit out of date, but this kinetic turbine is still very appropriate for remote areas, easy to build, easy to operate and does not require high head energy. Every human, every period of time in the presence of technology, will increase the electrical energy consumption as observed by Kautsari Anggun Karisma *et al*. [4].

Research on this micro hydro turbine began to be revived by some researchers such as Haurissa[5], Choi *et al* [6] and many more researchers.
Rispiningtati [7] observed the rules of water utilization in Sutami reservoir for possible utilization of irrigation system to remote areas to build a small water turbine in areas around the irrigation system included in the Sutami reservoir system (areas after Sutami).

Rispiningtati [8] also observed the bening reservoir operation that had excess water flow debit after being utilized for irrigation (areas after the clear dam). So that it is possible to build a micro hydro power plant on a river or irrigation network system.

The study of this turbine is then further explored by Brian Kirke [9], which is the development of a micro turbine called a kinetic turbine. This research is further observed by some researchers such as Lempoy [10], Boedi [11] and Monintja [12].

The kinetic turbine efficiency observed by some of the above researchers is generally low. The efficiency of this turbine is underestimated because it is assumed that the kinetic turbine only utilizes the remainder water flow. So this kinetic turbine is considered only a byproduct. Unfortunately, this opinion would mislead the actual issue that this kind of turbine has a low efficiency and should be observed to get a higher efficiency.

There are many efforts to increase the turbine efficiency, but it is not clearly explained how to solve the problem. There are several studies of kinetic turbines in terms of turbine blades number, curved blades shape, bowl blades and the influence of the steering angle which was done by Monintja [13] and the hinged blade system done by Lempoy [14]. The kinetic turbine was also optimization with the RSM system which was observed by Boedi [15] and there were some more research on this efficiency improvement effort.

Supriono, [16] mentioned in his research about the competitiveness of micro, small and medium enterprises, that one of the factor is electricity. Although it is possible to mention that electricity also plays an important role in determining the price of the product and the continuity of the production process. With the rise in the price of electricity, then this will be burdensome, especially for small entrepreneurs in the countryside. Therefore it is still necessary to have a cheap micro electric generator.

According to the National Energy Outlook 2011 [17], Indonesia in the period of 2000-2009 energy consumption increased from 709.1 million BOE (which is 555.88 million BOE in 2000) to 865.4 (961.39 million

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BOE on year 2014) million BOE (Barrel oil equivalent). Or increase on average by 3.99% per year. This energy consumption until the end of 2011 was dominated by the industrial sector as the largest consumer, followed by the household sector and the transportation sector.

During 2000-2014, final energy consumption declined especially in 2005 and 2006. This was caused by the increase in the fuel price that led to the decrease in industrial productivity and the decline of final energy consumption in industrial sector at 2005 and in transportation sector at 2006. The policy on increasing domestic fuel prices encouraged the increase in inflation. Based on data from Bank Indonesia, inflation in January 2005 reached 7.32% and rose to 17.1% in December 2005. This data could be seen in the Indonesia Energy Outlook 2016 [17].

In this study, the performance of the kinetic turbine will be reviewed from the flow behavior performed in the fluid mechanics laboratory and will be compared with its flow behavior with a computer fluid dynamic, especially to determine the causes of low turbine efficiency.

MATERIAL AND METHODS

The research will be conducted under a laboratory test and the laboratory result will be verified by a computer fluid dynamic simulation modeling. The purpose of this verification modeling is to know the behavior of the water flow in the kinetic turbine and evaluate the water turbine performance.

Figure-1. Turbine test bed.

The laboratory used is the fluid mechanics laboratory, Brawijaya University which is located in the Mechanical Engineering Department, Engineering Faculty. This laboratory has a number of equipment to support compressible and incompressible fluid research topics.

One of the equipment in this laboratory, used in this research, is the turbine test bed equipped with a 1.5 m^3/hour pump capacity (Figure-1).

Research installation

In this research, the testing installation used is a vertical axis kinetic turbine which is installed on an open channel water duct as shown in Figure-2.

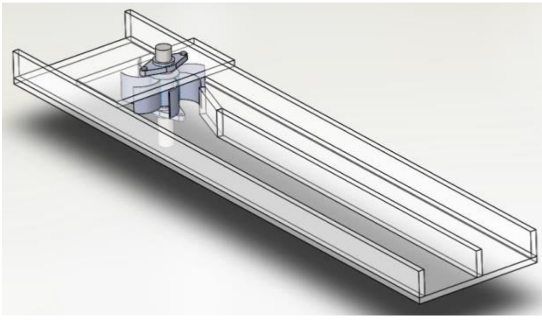

Figure-2. Research duct system.

Figure-3. Turbine experimental test.

The turbine dimension used in the experimental test could be seen in Figure-4. The turbine blade has a height of 11 cm, a drum diameter of 12 cm and a shaft diameter of 6 cm. The experimental kinetic turbine blade was equipped with eight similar blades. The experimental turbine runner could be seen in Figure-5.

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.

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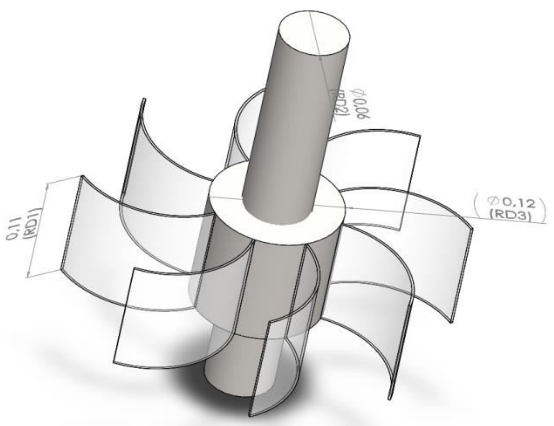

Figure 4. Research turbine runner dimension

In order to get the optimum design, it is necessary to improve this research under the experimental and compare it with the modeling simulation result.

Figure-5. Turbine runner for the experimental testing.

To obtain the turbine torque data, break system equipment is mounted on the turbine shaft (Figure-6). This brake system is equipped with two scales to measure the breaking system of forces difference to get the turbine torque result.

$$T = (F_2 - F_1).l \quad (1)$$

Figure-6. Break system and Tachometer.

Kinetic turbine

A kinetic turbine is a turbine that works by implementing water flow velocity, so that this type of turbine does not require high water head. This turbine type is very suitable for river flows in flat areas, especially rural areas. Until now this type of kinetic turbine is called as a waterwheel. A waterwheel is a very simple kinetic turbine. This waterwheel is still widely found in Indonesia, such as waterwheel in Pronojiwalumajang used as a small generator for motor vehicle battery charger.

Currently there are three types of kinetic turbines, namely the flat kinetic turbine, the upright kinetic turbine and the third is the horizontal kinetic turbine which is used in this study. This type of turbine is placed on a flat position and the turbine axis is on a vertical position.

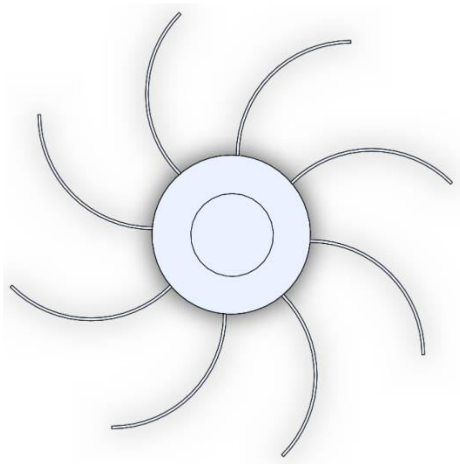

Figure-7. Eight blades kinetic turbine.

Kinetic turbine working principle

The kinetic turbine works, in which the direct current flow pushes the turbine blades without passes through a nozzle. Energy is given to the blade as a kinetic energy or velocity energy. On a vertical kinetic turbine, the water directly pounds the turbine blade on the half part of the turbine wheel, while the other half also gets a collision but not as big as the first half so the turbine can still spin. Surely the success of this turbine to rotate depends on the blade shape and blade number, if the shape and number of the blade is inadequate then the turbine rotation will be slower, even stop spinning. Therefore based on this working principle and based on the theory of speed triangle it will get the appropriate shape and number of blades.

Kinetic turbine performance

The kinetic turbine under this study is a mechanical wheel-shaped device with some curved blades attached on a vertical shaft. This water turbine utilizes the natural height difference from the surface of a small stream or flow velocity. Water that goes into and out of the turbine has no pressure differences. In this study, the water turbine is placed axially and utilizes natural river velocities. The performance of this water turbine depends

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on the water flow conditions (water velocity and water discharge), solidity and the blade angle [18].

Kinetic turbine power

The kinetic turbine power is determined by the amount of kinetic energy and power generated by that stream. The amount of energy produced by the water flow is determined as follows:

$$E_a = \frac{1}{2} . \dot{m} . V^2 \quad (2)$$

where:
E_a = Water Energy (joule)
$\dot{m}$ = Water Mass (kg/s)
V = Water flow velocity (m/s)

For the power of water flowing in a particular cross section the equation used is as follows:

$$P_a = \frac{1}{2} . \rho . A . V^3 \quad (3)$$

Where:
P_a = Water power (watts)
ρ = Water specific gravity (kg/m^3)

The equation used to calculate the turbine power generated form a kinetic energy result is as follows:

$$P_t = T . \omega \quad (4)$$

Where:

$$\omega = \frac{2 . \pi . n}{60} \quad (5)$$

where:
Pt = Turbine power (watt)
T = Torque (Nm)
l = Arm length (m)
n = Turbine rotation (rpm)
F = Force (N)

Turbine efficiency

The kinetic turbine efficiency is determined by the ratio of incoming water power to the amount of power generated by the kinetic turbine, as shown in Equation. (6).

$$\eta = \frac{BHP}{WHP} \quad (6)$$

The hydro turbine efficiency is the efficiency with which the hydro turbine converts the mechanical power of the water into electrical power. This value is used to calculate the nominal hydro 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 [19] is as follows:

$$\frac{u}{v} = \frac{\omega . R}{V} \quad (7)$$

Force and momentum

The force generated by a fluid velocity pushing the turbine blade and will produce a momentum with a magnitude determined [20] as follows:

$$M = m . v \quad (8)$$

Where:

$$m = \rho . Q \quad (9)$$

Then:

$$M = \rho . \; Q . v \quad (10)$$

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

$$dF = dm . a = \rho . v . dA . dt \left(\frac{dv}{dt}\right) = \rho . dA . dV \quad (11)$$

Power available in a water stream:

$$P = \eta . \rho . g . h . \dot{q} \quad (12)$$

P = power (watts)
η = turbine efficiency
ρ = water density (kg/m^3)
g = acceleration of gravity (9.81 m/s^2)
$\dot{q}$ = flow rate (m^3/s)
h = head (m).

For still water, this is the difference in height between the inlet and outlet surfaces. Moving water has an additional component added to account for the kinetic energy of the flow. The total head equals the pressure head plus velocity head.

When the resulting momentum is the result of a non-uniform flow then the momentum is determined by the momentum correction coefficient (f)

$$M = f . \rho . V . A . v \quad (13)$$

The force magnitude that occurs is [21]:

$$F = \rho . A . V = (fv2 - fv1) \quad (14)$$

Where:
f = 1.33 for laminar flow
f = 1.02 - 1.04 for turbulent flow

Modeling with computer fluid dynamic software in this study is to review the flow forms that occur in each blade rotating motion because of the water flow pushes the blade that generates momentum on each of the blades.

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In this model the flow forms in the blades and the water pressure occurring within the runner will be modeled for every 5°rotation blade movement. The turbine blade number in this study is eight with a same distance between one to the other, so that one blade with the other blade is separated by 45°. So the total modeling is 45° divided by 5°which are equal to nine blade position modeling.

RESULT& DISCUSSIONS

In the turbine performance test, the observed and captured data is the turbine rotation data with a turbine rotation variation between 20 rpm to 100 rpm. The water flow rate variation is between 40 and 60 m^3/hour. From the turbine test the data obtained was the turbine power, turbine torque and turbine efficiency. All data and calculated data are plotted in some relationship graphs. One of these performance graphs is the flow rate and turbine efficiency relationship graph (Figure-8).

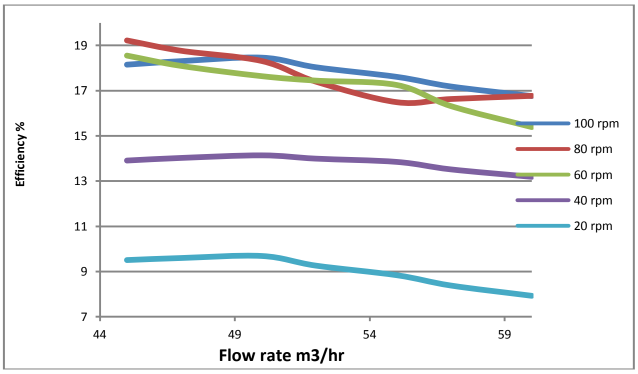

Figure-8. Kinetic turbine flow rate vs turbine efficiency.

From the turbine test results shown in graph 1, it is could be seen that the maximum efficiency occurs on the rotation between 60 rpm and 100 rpm. Precisely, the turbine efficiency is 18% at a 60 rpm turbine rotation and at a 50 m^3/hour water flow rate. The turbine efficiency of 19% is at 80 rpm turbine rotation and at a 46 m^3/hour water flow rate. While at the 100 rpm turbine rotation, the maximum turbine efficiency of 18.7% occurs at a 50 m^3/hour water flow rate. It should also be noted that in this study it is found the instability of turbine rotation, especially at low runner rotation.

As mentioned above that the blade number in this modeling are 8 blades It is expected that these eight blade turbine model will address to the kinetic turbine weakness.

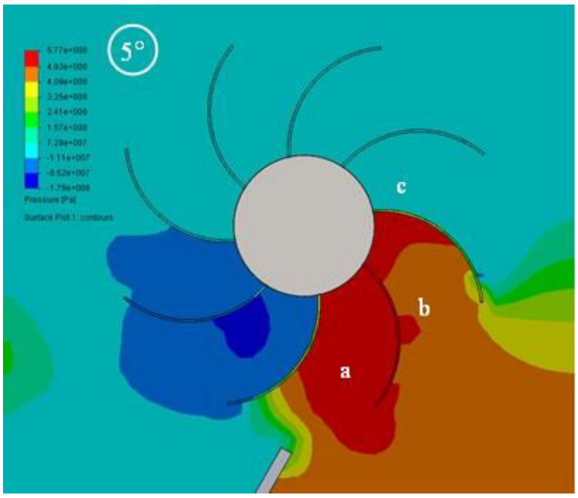

Figure-9. Turbine runner at 5°.

On the first 5° position it is seen that the highest pressure is 5.77e + 008 Pa which occurs in space *a* while in space *b* the pressure is slightly lower around 4.09e + 008 Pa. In section *c* there is a decrease in pressure to about 7.29e + 007 (Figure-9). While in the space before space *a*, occurs the lowest pressure. So it can be concluded that this turbine is spinning because there is large momentum in space *a* and another momentum in space *b* which is slightly lower than the momentum in space *a* and there is still an additional impetus in space *c*.

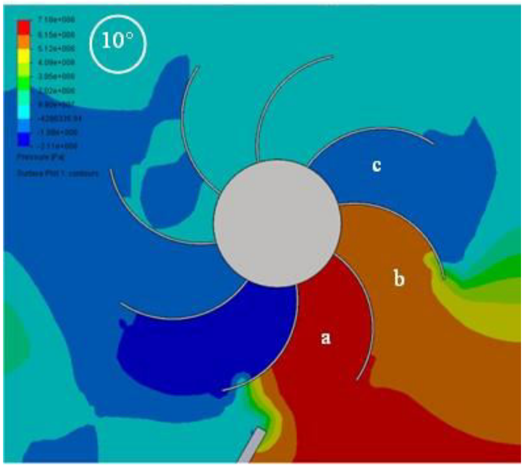

Figure-10. Turbine runner at 10°.

For the 10° runner position, it is seen that the highest pressure is 7.18e + 008 Pa occurs at space *a* while in space *b* the pressure is slightly lower which is around 6.15e + 008 Pa (Figure-10). In section *c* there is a significant pressure drop to -1.08e + 008. While in space before *a*, occurred the lowest pressure. So it can be concluded that this turbine is spinning because there is large momentum in space *a* and the addition of another momentum in space *b* although it is slightly lower than the momentum in space *a*.

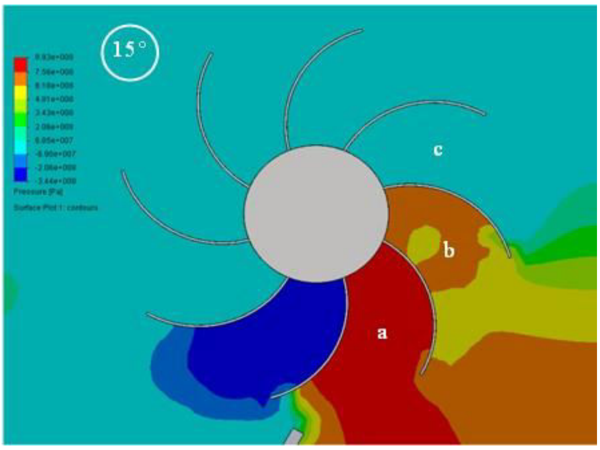

Figure-11. Turbine runner at 15°.

The momentum in space *a* at position 10° is larger than the momentum in the same space at the 5° runner position. Similarly the momentum in space *b* in the 10°runner position is larger than the momentum in space *b* at the 5° runner position. Probably the overall momentum at 10° will be higher than the overall momentum at the 5°runner position. This is probably the cause of the turbine rotation instability.

The next runner position, which is 15°, it appears that the highest pressure is 8.93e + 008 Pa occurs at space *a* while in space *b* the pressure is slightly lower which is around 6.18e + 008 Pa (Figure-11). In section *c* there is a significant pressure drop to 6.85e + 007. While in space before *a*, there is the lowest pressure. So it can be concluded that this turbine is spinning because there is great momentum in space *a* and the addition of another momentum in space *b* though it is slightly lower than momentum in space *a*. The momentum in space *a* at position 15° is larger than the momentum in the same space at the 10° runner position. Similarly the momentum in space *b* in the 15°runner position is larger than the momentum in space *b* at the 10° runner position. Probably the overall momentum at 15° will be slightly higher than the overall momentum at the 10° runner position. So in this position the runner will get a stronger water push.

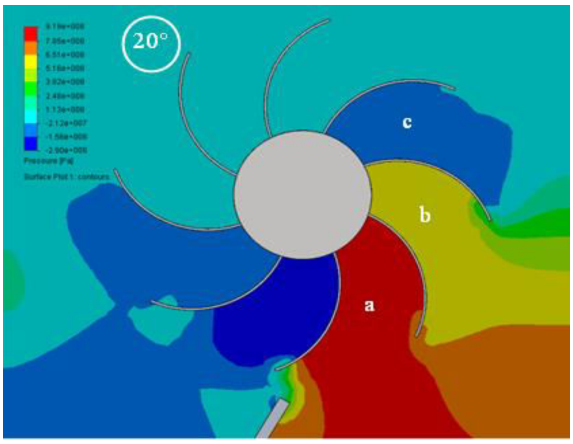

Figure-12. Turbine runner at 20°.

Furthermore at the 20° runner position, it is seen that the highest pressure is 9.19e + 008 Pa occurs in area *a* (Figure-12). This happens because there is a large swirl. This phenomenon can be seen from the water flow trajectory in the kinetic turbine modeling. Whereas in chamber *b* the pressure that occurs is lower than the pressure in area *a* which is about 6.51 pm + 008 Pa. Pressure on part *c* and space before area *a* is very low, so it is clear that in these two sections there is no momentum produces torque addition. So it can be concluded that this turbine is spinning because there is a large momentum in are*a* and the *a* momentum addition in are *b*. The momentum of space at 20° runner position is greater than the momentum in the same place at the 15° runner position. Similarly the momentum in area *b* in the 20°runner position is greater than the momentum in area *b* at the 15°runner position. Probably the overall momentum at 20° will be slightly higher than the overall momentum in the 15°runner position. So at this position the runner will get a stronger boost.

In Figure-13 for the 25°runner position, it appears that the highest pressure is 7.91e + 008 Pa occurs in area *a*. From the modeling flow trajectory it appears that the swirl that occurs in area *a* is very few, so that although the pressure in this area is the highest but it is still lower than the same position in the 20° runner position.

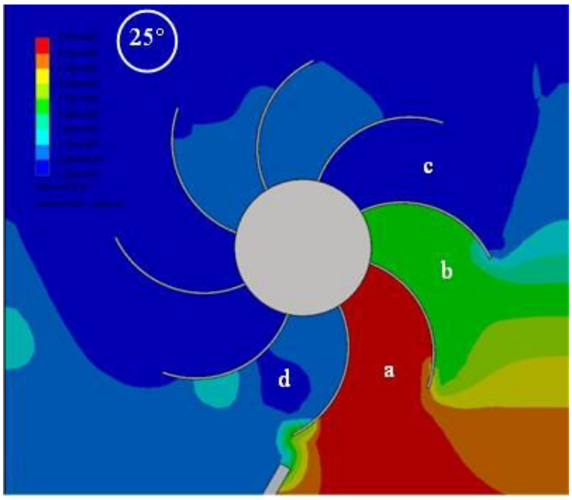

Figure-13. Turbine runner at 25°.

In Figure 13 for the 25°runner position, it appears that the highest pressure is 7.91e + 008 Pa occurs in area *a*. From the modeling flow trajectory it appears that the swirl that occurs in area *a* is very few, so that although the pressure in this area is the highest but it is still lower than the same position in the 20° runner position. While in area *b* the pressure is also lower than the pressure in area *a*, which is 4.96 pm + 008 Pa. Water pressure on part *c* and part *d* is very low, so it can be concluded that in these two sections there are no momentum to produce an additional torque. So at the 25° runner position the turbine rotates due to the momentum in area *a* and another additional momentum in area *b*. Momentum in area *a* at 25° runner

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position is lower than momentum in the same part at 20° runner position. Similarly the momentum in area *b* in the 25°runner position is lower than the momentum in area *b* in the 20°runner position. Perhaps the overall momentum at 25° will be lower than the overall momentum in the 20°runner position. So at this position the runner will get a smaller boost than that in 20° runner position.

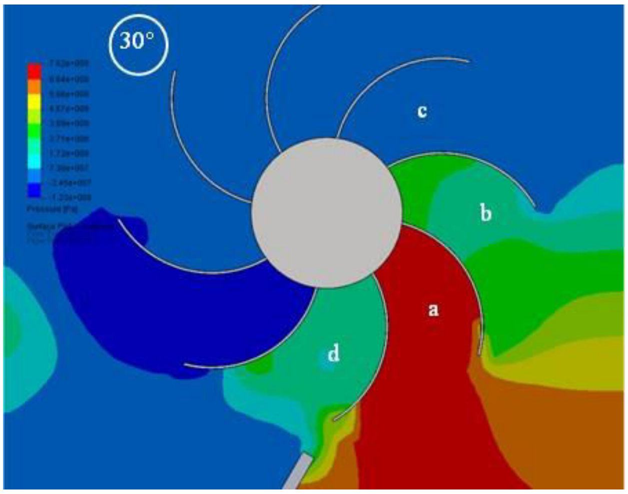

Figure-14. Turbine runner at 30°.

From Figure-14, at a 30°runner position, it is seen that the highest pressure is 7.62e + 008 Pa occurs in space *a*. From the modeling flow trajectory it appears that the water swirl that occurs in space *a* is very few, so that although the pressure in this area has the highest pressure value, but it still lower than the same position at the 25°runner position. Whereas in space *b* the water pressure is also lower, which is about 4.67 pm + 008 Pa. Water pressure on part *c* is very low, while the pressure in space *d* reaches 4.67 pm + 008 Pa. In this 30° runner position, three blades gain a momentum boost, so the impulse at these three blades will provide a considerable torque, which may be equivalent to the impulse at the 10 ° runner position. So at the 30° runner position, this turbine spins due to the momentum in space *a*, momentum in space *b* and momentum in space *d*. Momentum in space *a* at 30° runner position is lower than momentum in the same place at 25°runner position. Similarly the momentum in space *b* in the 30°runner position is lower than the momentum in space *b* at the 25°runner position. Perhaps the overall momentum at 30° will be higher than the overall momentum in the 25°runner position. So at this position the runner will get a larger boost (3 blades) compared to 25° runner position.

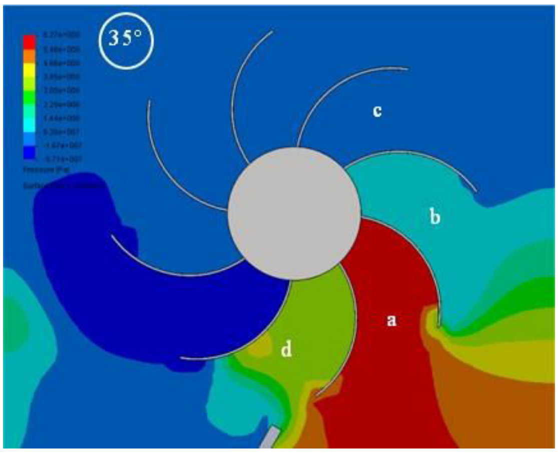

Figure-15. Turbine runner at 35°.

In Figure-15, at a 35°runner position, it is seen that the highest pressure is 6.27e + 008 Pa occurs in space *a*. From the modeling flow trajectory it appears that the water swirl that occurs in space *a* is very few, so that although the pressure in this area has the highest pressure value, but it still lower than the same position at the 30°runner position. Whereas in space *b* the water pressure is also lower, which is about 2.25 pm + 008 Pa. Water pressure on part *c* is very low, while the pressure in space *d* reaches 3.85 pm + 008 Pa. In this 35° runner position, three blades gain a momentum boost, so the impulse at these three blades will provide a considerable torque, which may be equivalent to the momentum at the 15° runner position. So at the 35° runner position, this turbine spins due to the momentum in space *a*, momentum in space *b* and momentum in space *d*. Momentum in space *a* at 35° runner position is lower than momentum in the same place at 30°runner position. Similarly the momentum in space *b*in the 35°runner position is lower than the momentum in space *b* at the 30°runner position. The overall momentum at 35°probably, will be higher than the overall momentum in the 30°runner position. So at this position the runner will get a boost from 3 blades.

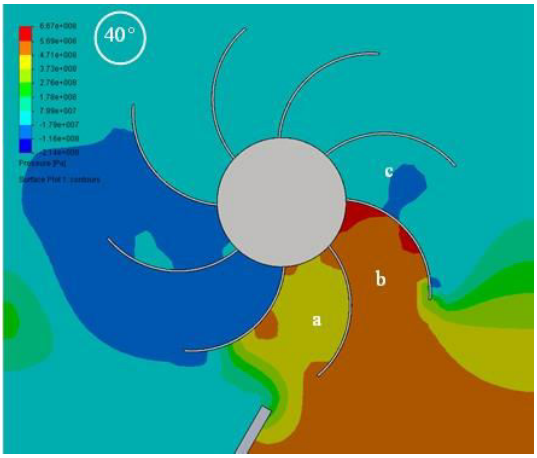

Figure-16. Turbine runner at 40°.

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At the 40° runner position, it is seen that the highest pressure is 6.67e + 008 Pa occurs in area *a*. This happens because there is a large swirl. This phenomenon can be seen from the water flow trajectory in the kinetic turbine modeling. Whereas in area *b* the pressure that occurs is higher than the pressure in area *a* which is about 6.67e + 008 Pa. Pressure on part *c* is about 7.99e + 007 Pa. So it can be concluded that this turbine is spinning because there is a large momentum in area *a,* area *b* and area *c*. The momentum of space at 40° runner position is greater than the momentum in the same place at the 35° runner position. Similarly the momentum in area *b* in the 40°runner position is greater than the momentum in area *b* at the 35°runner position. Probably the overall momentum at 40° will be slightly higher than the overall momentum in the 35°runner position. So at this position the runner will get a stronger boost.

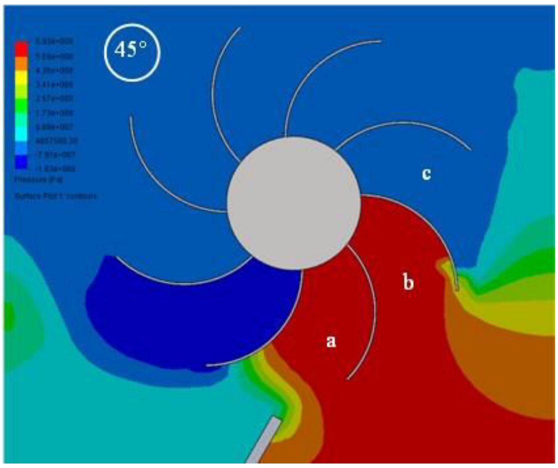

Figure-17. Turbine runner at 45°

At the 45° runner position, it is seen that the highest pressure is 5.93e + 008 Pa occurs mostly in area *a* and area *b*. Compare with the pressure in 40° runner position the pressure on area *a* in the 45° is lower than the pressure at the same area on 40°, but on 45° runner position the pressure on area *b* is higher than the pressure on area *b* for the 40° runner position. While on area *c* the water pressure is about 4857580.28 Pa. So it can be concluded that this turbine is spinning because there is a large enough momentum in area *a,* area *b* and area *c*. The overall momentum of the 45° runner position probably has the same value with the overall momentum of the 40° runner position. The same momentum value on the runner transfer movement from 40° to 45° would guaranty the kinetic turbine rotation stability.

It should also be slightly reviewed the water flow trajectory form that occurs within the turbine runner. The water flow trajectory at 5°runner position indicates that there is a swirl in area *a* (red trajectory). This is what generates momentum or force motion thrust in the turbine runner so that there is a repetitive momentum that pushes the blade to rotate the runner.

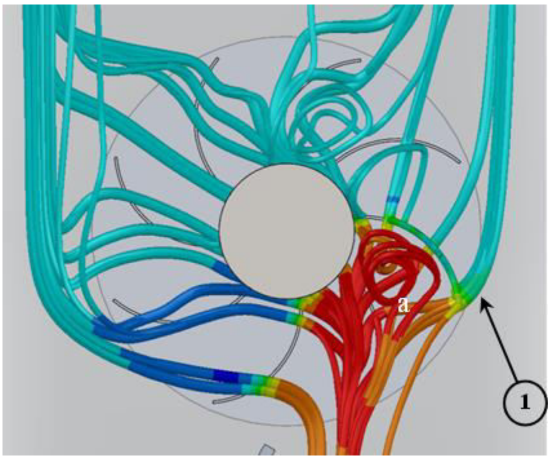

Figure-18. Trajectory on 5° runner position.

There are a few additional explanations that may be associated with the low turbine efficiency. When considered in section 1 (Figure-18) the water pressure drops drastically and the water flow directly leaves the turbine runner. So it can be concluded that the flow of water is not utilized optimally, because there is a flow of water that immediately left the runner and did not produce momentum.

CONCLUSIONS

This research was conducted by testing a kinetic turbine experimentally under a laboratory scale and verified virtually with CFD software. It is suspected that there are several causes that result in low turbine efficiency and unstable turbine rotation. In this modeling the focus of the observation is on the pressure distribution within the blade space which will produce the thrust of the turbine runner. From this prototype test results obtained that the highest kinetic turbine efficiency is 19% that is on 80 rpm turbine rotation and 45 m^3/hour water flow rate. From the modeling observations, from every 5° runner movement, it appears that there is only one turbine blade that gets the greatest boost or momentum, although at certain runner angle positions there are two turbine blades that get a boost. This condition is suspected as one of the cause of the low turbine efficiency. By looking at the water swirl in the turbine runner, in this case the water flow trajectory movement that occurs in the blade space, then it appears that there is a big boost, while on the other part produces a small boost. Furthermore, by looking at the water trajectory behavior there is a big amount of water flow rate that drastically dropped their pressure because it does not enter the turbine blade area but directly move to the duct output. This is suspected as one of the cause of low turbine efficiency and turbine rotation instability. In conclusion, it should be considered how the water flow can maximally enter the turbine blade space, to generate maximum momentum and how to minimize the wasted water flow rate directly to the output channel. From the modeling of this kinetic turbine the highest water pressure in the blade chamber is about 9.19e + 008 Pa, which occurs at 20° runner position, while the lowest pressure is 5.93e + 008, which occurs at 45° runner position.

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