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The Performance of the Pico Scale Turgo Water Turbine Coconut Shell Blade with Variations in Nozzle Diameter and Distance

Muhammad Mizan[1], Warjito[1,*], Budiarso[1], Ridho Irwansyah[1], Muhamad Agil Fadhel Kurnianto[1], Muhammad Faridz Athaya[1]

[1] Department of Mechanical Engineering, Faculty of Engineering, University of Indonesia, Depok, Indonesia

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ABSTRACT

The Turgo turbine is a pico-scale water turbine that can produce less than 5kW electricity at low altitudes. Turgo turbines also have quite affordable investment and maintenance costs. Turgo turbine design is strongly influenced by the speed triangle and the size of the nozzle diameter. This study aims to compare the nozzle diameter with the nozzle distance on the coconut shell blade on the efficiency of the Turgo turbine. This turbine is designed with a height of 3.5 m, a flow rate of 32.5 l/m, with various diameters and nozzle distances. Variations in the diameter of the nozzle are 8,10,12 mm, and the nozzle distance is 100, 150,200 mm. based on the study results, the best diameter is 8 mm and a distance of 100 mm. The results of the computational efficiency of 49%.

1. Introduction

The problems of the energy crisis and environmental pollution are rapidly getting worse. Natural resources from the earth such as oil, coal, and natural gas are becoming limited [17]. Indonesia is committed to making efforts to be free of carbon emissions by 2060, which targets the phase-out of coal being replaced by NRE in 2056. The Government of Indonesia has issued a Business Plan for the Provision of Electricity (RUPTL) 2021 – 2030, which mentions an additional 40,600 MegaWatt (MW) power generation [1]. During the ten years, new and renewable energy obtained a share of 51.6% (20,949.6 MW), more significant than fossil energy, which was 48.4%. Indonesia's installed power generation capacity reaches 73,736 MegaWatt (MW) or 73.74 GigaWatt (GW) until November 2021 [2]. Technological advances in renewable energy continue to overgrow. One of them is renewable energy caused by water 14% [3]. Indonesia also has an area that is mainly filled with water. wind turbines are one solution if you get to increase the speed of the wind, then there is biodiesel [18], One of the benefits of using biodiesel is that it has a small negative impact on the environment because it produces less greenhouse gases, but still less for energy utilization in Indonesia [19]. The

* *Corresponding author.*
E-mail address: warjito@eng.ui.ac.id

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provision of energy access in Indonesia is also related to the quality of electricity received by the community. In addition to having difficulty reaching remote areas and areas, those who already have access to electricity have not fully experienced electricity of sufficient quality. Many people experience electricity, especially those in densely populated areas and eastern Indonesia.

Pico hydropower plant is used for hydroelectric power generation with a capacity below 5 kW (Kilo Watt). Pico hydro can be generated from a turbine rotated by a natural flow of water at an incline of at least one meter. Pico hydropower plants in areas with running water are small-scale power plants built for villages to get electricity and lighting. One impulse turbine type recommended for pico hydro applications in remote areas is the Turgo turbine.

A Pico hydro turbine can be an alternative to rural electrification in Indonesia due to its lower cost of manufacture and maintenance. impulse turbines are recommended at high and medium fall heights [4]. One type of impulse turbine recommended for pico hydro applications in remote areas is the Turgo turbine [5]. Low construction costs and ease of maintenance make this turbine suitable for use in remote areas. Several studies have been made regarding the Turgo turbines. Myat myat Soe *et al*., [6], Experimental analysis of the performance of a pico-hydro Turgo turbine with Response Surface Methodology to determine the optimal operating conditions of the referred geometric factors aiming at the maximization of the turbine efficiency, as well as to investigate the effect of each parameter on the turbine efficiency. Dendy *et al.,* [7]*,* studied the effect of jet angle on the performance of a Turgo turbine. Edwin *et al.,* [12]*,* assessment of turbulence modelling for numerical simulations into Pico Hydro Turbine to explain flow characteristics and determine whether turbulent flow would occur and recommends a turbulent model that may be applied to a pico hydro turbine. Hnin *et al.,* [13]*,* Optimized Flow Analysis of Turgo Impulse Turbine for Low Head Power Plant. Lubis *et al.,* [14]. investigate the performance of a low-cost spoon-based Turgo turbine wheel under several operating conditions, and they make variations on the valve. Warjito *et al.,* [15]*,* Sim simple bucket curvature for designing a low head Turgo turbine for pico hydro application. Dendy *et al.,* [8]. Feasibility Analysis of a Pico-Scale Turgo Turbine Bucket using Coconut Shell Spoons for Electricity Generation in Remote Areas in Indonesia. Budiarso *et al.,* [16]*,* Determine the ratio of D/d for a pico hydro Turgo turbine that can produce maximum electric power.

In this study, the analysis is done to various nozzle diameters and distances between the nozzle and the spoon with coconut shell spoon to analyze the effect of different diameter nozzle and distance between the nozzle and the blade on the efficiency of turbines designed with coconut shell spoon.

2. Numerical Methodology

2.1 Model Specification and Parameters

This study follows the specification model from the specifications of length, width, and depth for coconut shell spoon [8]. The CFD refers to governing equation Volume of fluid, because the Turgo turbine has 2 phases namely water and air, the surrounding conditions are air and when the nozzle sprays water, by applying transient state and k – $\boldsymbol{\omega}$ turbulence model. In fluid dynamics, radiative heat either nonlinear or linear plays major impact in diverse enormous temperature processes because of it several applications in power plant and industries [22]. This property exhibit both viscous and elastic characteristics when thermal motion occurs [20]. there are several conditions used in CFD simulation using Ansys Fluent according to Table 1.

Table 1
Boundary conditions of Turgo Turbine simulation model

Boundary Conditions	Values
Inlet Velocity	8,08 m/s
Outlet Pressure	0 Pa
The Density of fluid	998,2 kg/m^3
Convergence Absolute	1.00 E-5
Phases	Water and Air

The specifications of the size of the coconut shell blade greatly affect the power produced by the turbine, therefore the size of the coconut shell blade can be seen in Table 2, and for the specifications mentioned in Table 2, Figure 1 model of a coconut shell spoon.

Table 2
The dimensions of the coconut shell spoon used

Dimension	L, mm	B, mm	T, mm
Spoon 40 ml	84±0,6	70±0,5	11±0,7
Spoon 70 ml	95±1,5	83±1,3	18±1,2

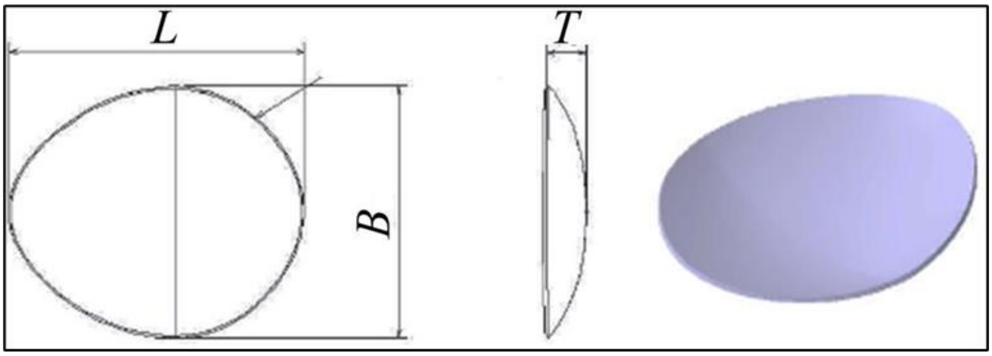


Fig. 1. Coconut shell spoon size of numerical design

For the size of the turgo turbine used in this study is 315 mm for the outer diameter and inner diameter 150 mm, the thickness of the turgo turbine itself is 30 mm it can be seen in Figure 2. for variations and several other parameters can be seen in Table 3 below.

Table 3
Parameter value of turgo turbine simulation model

Parameter	Dimension
Head, H	3.5 m
Distance between Nozzle and Spoon	100,150,200 mm
Diameter Nozzle	8,10,12 mm
Spoon, $\mathbf{z}$	8

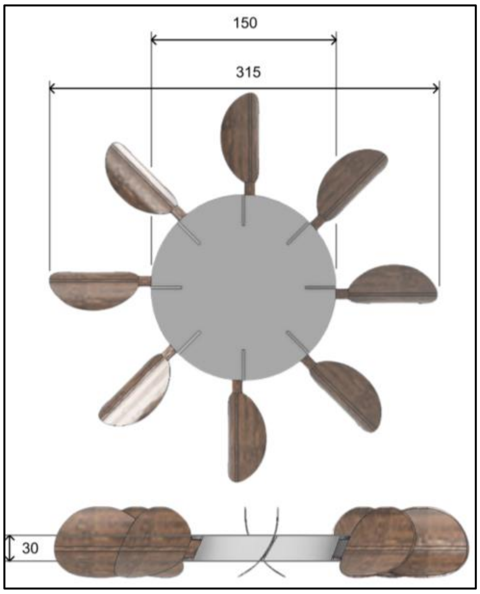


Fig. 2. The dimensions of the blade and the runner

Meshing affects the results of the simulation, namely in terms of precision, convergence, and the length of time required for simulation. The meshing process aims to get a good skewness value, where skewness itself is used to indicate how skewed a mesh is. The more angled an element is, the better the data transfer from one element to another. Therefore, if the shape of the elements is not aligned, it will require a lot of corrections during the calculation process, which will reduce the quality of the calculations and slow down the calculation process and sometimes make the calculations not converge [9].

This study uses the tetrahedron method on all parts of the workpiece with the consideration that the tetrahedron method is more adaptive to adapt to extreme workpiece shapes or has a relatively small radius compared to the mesh size Figure 3. However, even though the tetrahedron is more adaptive, this mesh requires a longer time to converge because it has a larger number of meshes than other mesh types [9].

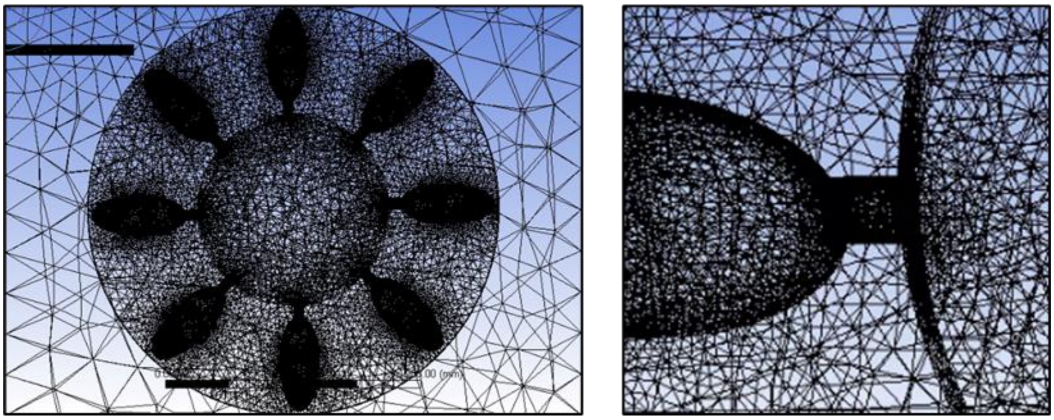


Fig. 3. The meshing results of the turgo turbine of coconut shell blades

Next, the edge sizing method is used on the blades and runner Edge Sizing itself is one of the sizing methods in Ansys which aims to be able to distribute the number of meshes along the corners of the workpiece. The use of Edge Sizing in the workpiece meshing is because each edge of the blade and runner has poor quality mesh which can affect skewness. In the area used by Edge Sizing, the mesh size is much smaller than the mesh in other areas which aims to keep the quality of the mesh at the edges good and have good skewness. From the meshing process that has been carried out, the average skewness of the workpiece is 0.23412 and the maximum skewness of the workpiece is 0.87888.

2.2 Grid Convergence Study

After the geometric model has been designed, the next step is to form a grid or mesh. The results of this numerical calculation are highly dependent on the size, shape, and number of mesh used. The small mesh size results in an increase in the number of mesh formed. Generally, the smaller the mesh size, the more accurate the numerical calculation results will be. In addition to size, the shape of the mesh greatly determines the success and accuracy of the simulation. Before determining the size and number of mesh to be used for all study conditions, it is necessary to do a Grid Independence Test. This test aims to determine the optimal mesh conditions with a minimum number of meshes without causing significant differences in numerical results. This test generally uses the Richardson Extrapolation method because it is the most reliable method at present. Richardson Extrapolation is an extrapolation method that is used to find the value of a variable in the mesh size value with a grid spacing equal to zero [10]. To obtain this value, at least two different mesh sizes are required. As the grid is refined by becoming smaller grid cells thereby increasing the number of cells in the flow domain, the time step is reduced. Temporal and spatial discretization errors must be asymptotically close to zero, excluding computer rounding errors.

First, the representative cell, mesh, or grid size is determined by calculating the grid repair ratio with Eq. (1), namely:

$$r = \left(\frac{N_{fine}}{N_{coarse}}\right)^{\frac{1}{d}} \tag{1}$$

The value must be greater than 1.1 to allow discretization errors to be distinguished from other error sources. N is the number of lattice points used for the lattice; d is the dimension of the flow domain. Next, three significantly different grid sets were simulated to determine the objective values. In this study, the torque value of the turbine blades is reported to the conclusion of the CFD analysis. The flow field is calculated on three grids with nice default mesh settings.

After getting r_{21} and r_{32}, the order p of the method is calculated using the Eq. (2)

$$p = \frac{1}{ln(r_{21})} \ln \left|\frac{\tau_{3-}\,\tau_2}{\tau_{2-}\,\tau_1}\right| \tag{2}$$

Fine Grid Convergence Index (GCI) calculated using the Eq. (3) and Eq. (4),

$$GCI\,_{fine}^{21} = \frac{1.25\,|(\tau_{1-}\,\tau_2\,)/(\tau_1\,)|}{\left(r_{21}^{p} - 1\right)} \times 100\% \tag{3}$$

$$GCI\,_{fine}^{32} = \frac{1.25\,|(\tau_{2-}\,\tau_3\,)/(\tau_2\,)|}{\left(r_{32}^{p} - 1\right)} \times 100\% \tag{4}$$

Table 4 shows the results of the CGI used, namely for the acceptable size, namely 3756998 with a GCI of 0.9%, therefore for the fine mesh with that size, it is used with a reasonably small error rate.

Table 4
The result of grid convergence study

Mesh	Normalized Grid Spacing	Torque	GCI (%)
2878499	2.00	0,82567	3.9
3222998	1.41	0,88124	1.2
3756998	1.00	0,90261	0.9

2.3 Governing Equation

At VoF (Volume of Fluid), the single momentum equation is solved in the domain so that, the velocity field is divided between the phases. Based on the volume fraction of all phases through the mixed density and viscosity properties, the momentum equation [11] is

$$\frac{\partial}{\partial t}(\rho\,\vec{v}) + \nabla\,.(\rho\,\vec{v}\,\vec{v}) = -\nabla p + \nabla\,[\,\mu\,(\nabla\vec{v} + \nabla\vec{v}^{T})] + \rho\,\vec{g} + \vec{F} \tag{5}$$

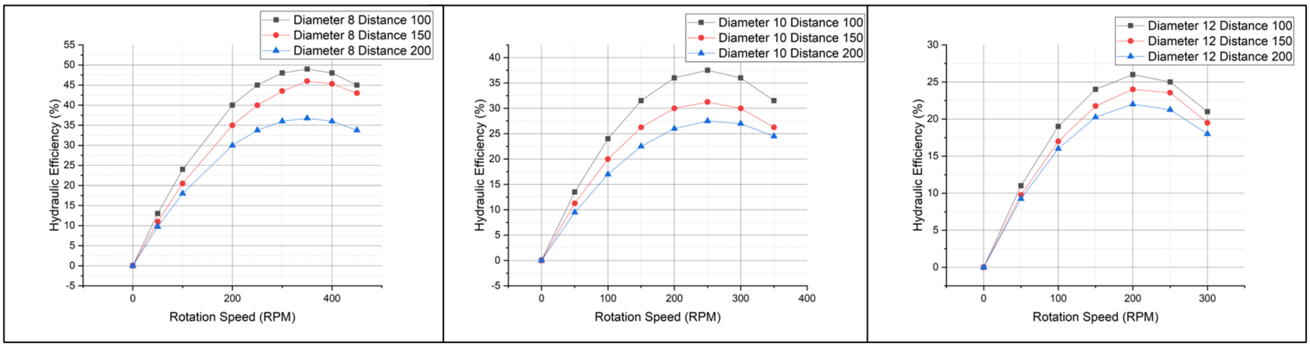
To incorporate surface tension into the calculation of the VOF model, the source term is added to the momentum equation. If there are only two phases in the cell, the source term can be expressed as the volume force equation and can be written as follows [11]

$$F_{\mathrm{vol}} = \sigma_{ij}\,\frac{\rho k_i\,\nabla\alpha_i}{\frac{1}{2}(\rho_i + \rho_j)} \tag{6}$$

3. Results and Discussion

In this study, the purpose of CFD simulation is to determine how the performance of the Turgo turbine is affected by the diameter of the nozzle and the distance from the nozzle to the blades. At this stage, the results of the computed CFD simulation are obtained. Numerical calculations give results before entering into the experiment.

Shows the simulation results for variations in the diameter of 8, 10, and 12 mm and distances of 100, 150, and 200 mm Figure 4 is a comparison graph between rotational speed and hydraulic efficiency, which shows a peak of the efficiency according to the existing variations. Figure 4 also shows that the smaller the nozzle diameter, the Turgo turbine guarantees a higher rotational speed. It can be seen in Figure 4 that the highest rotating speed is obtained with a nozzle diameter of 8. Over time (steady conditions), the rotational speed of 8 mm diameter gets a higher value than the variation in the number of other diameters. The rotating speed of 8 mm diameter has a higher value because the diameter of the eight nozzles has a higher water velocity than the other nozzle diameters. Figure 4 shows that the best efficiency is obtained at a nozzle diameter of 8 mm with a distance between the blade and the nozzle.



(a) (b) (c)

Fig. 4. Numerical results graph (a) Diameter 8 mm (b) Diameter 10 mm (c) Diameter 12 mm

The data in the graphic above shows that the best efficiency is obtained at a nozzle diameter of 8 mm with a nozzle distance of 100 mm, resulting in a hydraulic efficiency of 49%, for a 10 mm nozzle diameter variation has the best hydraulic efficiency of 37%, with the lowest efficiency obtained at a nozzle diameter of 12 mm with a length of 200 mm by 22%.

In this study, there is a visualization of the flow that is fired from the nozzle to the turgo turbine blade. There is a speed difference resulting from a predetermined speed from a distance of 0-4 m/s. from Figure 5 variations in diameter 8 mm with a distance of 100, 150,200 mm. it can be seen in the image (a) a distance of 100 mm emits a more incredible speed can be seen from the results of hitting the blade, seen in the image (c) the distance away, the speed decreases along with the beam that becomes wider which makes the water splash widen. seen from the image that the speed begins to decrease as the distance away, and it affects the specific speed, where the specific speed is influenced by the basic dimensions of the turbine, especially the shape of the blades given to be optimal. for diameter 8 with a distance of 100 mm has the best results compared to other variations, but for a distance of 100 mm, it has not been tried to reach the closest point of the coconut shell blade turbine to see the most optimum in that section. The difference in color gradation is caused by the middle point experiencing a more significant speed because the point is coming out of the nozzle, so from the picture, it can be seen that the red color is always in the middle.

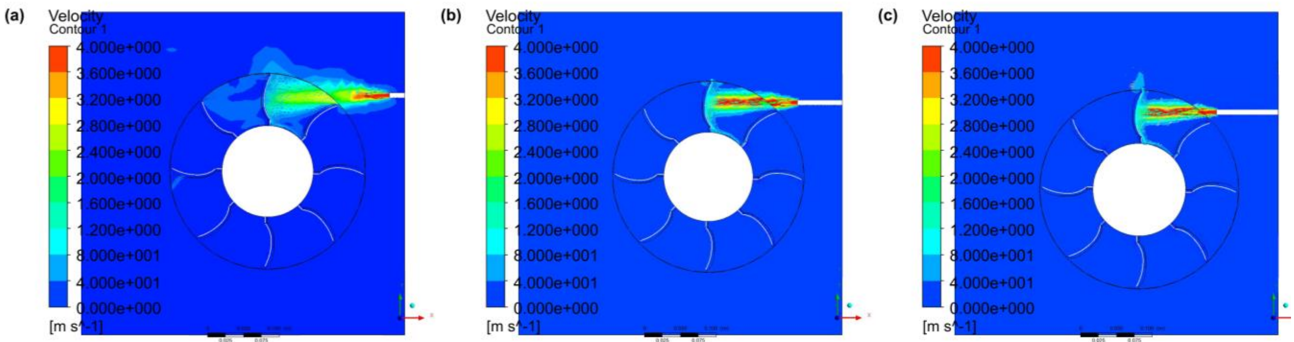


Fig. 5. Visualization results with diameter 8 mm (a) Nozzle distance 100 mm (b) Nozzle distance 150 mm (c) Nozzle distance 200 mm

Figure 6 shows the diameter of 10 mm with a distance of 100, 150, 200 mm, it can be seen that the speed is still below 8 mm so the water splash is not the same as with 8 mm, from the width of the spout is larger so that the speed decreases, and results in decreased efficiency. for diameter 10 with variations in the distance not too different from a diameter of 8 mm but diameter 10, there is a decrease in velocity resulting in decreased momentum of water touching the blade compared to a diameter of 8 mm and the size of the spray area is also more prominent, so the specific speed is lower

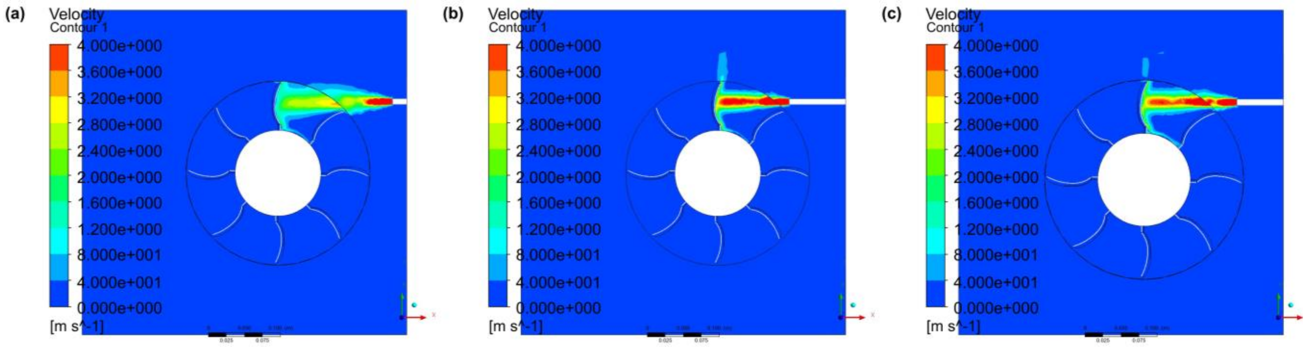


Fig. 6. Visualization results with diameter 10 mm (a) Nozzle distance 100 mm (b) Nozzle distance 150 mm (c) Nozzle distance 200 mm

Figure 7 shows the 12 mm diameter variation, it can be seen that the speed visualization is less because the nozzle diameter is getting bigger, and it can be seen that the water jet is larger than the diameter of 8 and 10 mm. The 12 mm diameter speed is the smallest compared to others because it decreases the Turgo turbine's hydraulic efficiency. For diameter 12, which has the largest spray area, optimizing diameter 12 requires a change in the dimensions of the desired blade because the speed decreases drastically compared to the two variations above, which results in lower specific speed and momentum.

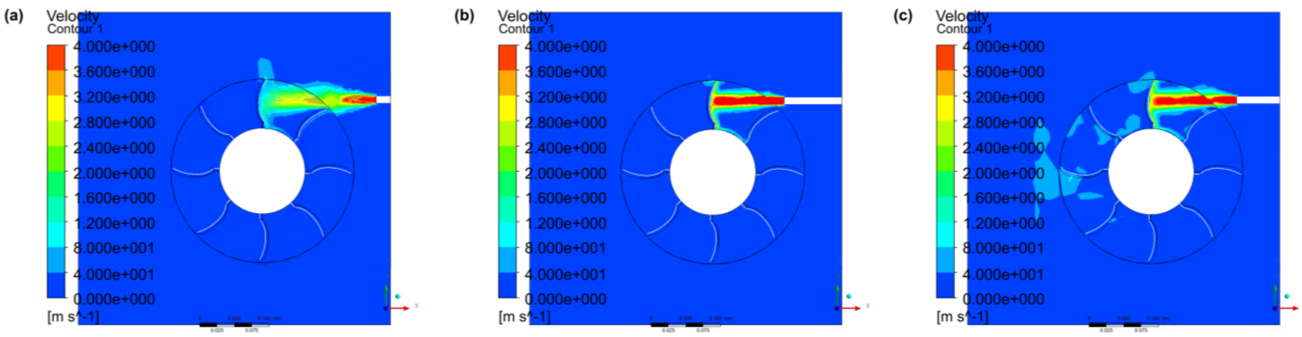


Fig. 7. Visualization results with diameter 12 mm (a) Nozzle distance 100 mm (b) Nozzle distance 150 mm (c) Nozzle distance 200 mm

4. Conclusions

This study analyses the nozzle diameter and distance between the nozzle and the spoon performance of Turgo pico hydro turbines designed with coconut shell spoon. The diameter and distance of the nozzle to the blade greatly affect the efficiency of the turgo turbine, under these conditions, the variation with the smallest diameter causes the speed to increase and the spray area decreases. and the distance that affects the specific speed at a turbine rotation because the momentum affected is different with different distances. Concluding points of this work are summarized as

i. The variation of nozzle diameter 8 mm the hydraulic efficiency of the turbine got a maximum value of 49% with a distance variation of 100 mm.
ii. The variation of nozzle diameter 12 mm the hydraulic efficiency of the turbine got a minimum value of 22.5%, with a distance variation of 200 mm.

The result shows that the variation of nozzle diameter 8 mm the hydraulic efficiency of the turbine got a maximum value of 49%, with a distance variation of 100 mm.

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