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ANALYSIS OF IMPACT VELOCITY OF RICE GRAIN ON IMPELLER SPEED VARIATION IN THE CENTRIFUGAL FLOW THRESHER BY USING CFD

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ABSTRACT

The use of a mechanical thresher could cause grain damage. This was due to friction, collision, and impact factors. The impact velocity of rice grain is one of the problems encountered by using the centrifugal flow thresher. Therefore, the aimed of this research to analyze the impact velocity of rice grain on the impeller speed variation in the centrifugal flow thresher by using CFD. The input parameter that applied of the CFD simulation is the impeller speed. While the output parameters are total pressure, impact velocity, and normal contact stress of rice grain. The simulation results indicated that the addition of the impeller speed caused the total pressure, impact velocity, and normal contact stress of the rice grain increased. The higher impact velocity and normal contact stress of the rice grain were obtained of 24.1 m s^{-1} and 27.28 MPa respectively at 960 RPM impeller speed at the wall of the fan housing. Based on approximating the critical stress of rice grain is 38.7 MPa so that could be predicted the critical impact velocity of the rice grain of 31.9 m s^{-1}.

Keywords: centrifugal flow thresher, CFD simulation, impact velocity, impeller speed, rice grain.

INTRODUCTION

Threshing is the other an important step of rice handling. That is usually done in order to produce rice grain and straw. At the first rice grain subjected to touch mechanically. A mechanical thresher acts by the rotating cylinder as a threshing unit. Referring literature [12] the mechanical thresher type consists of being cross flow, axial flow, and tangential-axial flow that based on the material flow. In reference [14] the other type of mechanical thresher uses a serrated blade impeller as a threshing unit with a modified centrifugal fan.

In principle, a centrifugal fan work through rotating impeller. It could increase the mass flow rate and move fluid radial outward due to the centrifugal action. At the same time, the fan generated kinetic energy. This energy would be converted to static pressure and produced pressure to use countering the resistance [4]. An impeller rotation could produce a suction pressure on the inlet side (negative pressure) and blow pressure on the outlet side (positive pressure). The impeller became an important component because it determines the performance of a centrifugal fan [3-11].

The centrifugal flow thresher that makes use of impeller rotation could generate an impact velocity of rice grain. This happens on the wall component of the fan housing. The high impact velocity might cause grain damage. Researchers [6] grain damage was due to friction, impact or collision factors. Impact damage was caused by a contact of mechanics during the threshing process. It's calculated as deformation, pressure or shock, and friction force so that grain becomes split and brittle. Researchers [10] the addition of the rotor speed caused the amount of damage grain increased.

Determining of the impact velocity of rice grain in the point of location in the thresher can be done by an experimental method. But it needs equipment that equipped with a more accurate sensor or detector. Referring literatures [5-9] analysis of fluid flow uses the experimental method needs a long time and high cost because complicated. On the other hand, the use of the CFD to analyze fluid flow becomes easier. Researcher [7] a design analysis by using the CFD is recent origin. It could analyze a complex flow and could improve of a flow pattern in the centrifugal fan system. Therefore, the aimed of this research to analyze the impact velocity of rice grain on the impeller speed variation in the centrifugal flow thresher by using CFD.

METHODOLOGY

Simulation design

The CFD simulation used the parameters that consist of the total pressure, impact velocity, and normal contact stress of the rice grain. This was focused to be predicted of the impact velocity of the rice grain to the impeller speed. It is observed that simulation results are related to the experimental results. The geometry is made according to the design results. This could be seen in Figure-1 and Table-1.

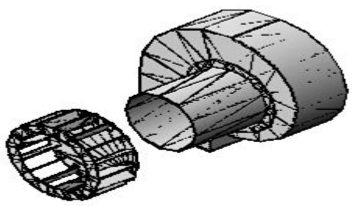

Figure-1. CAD-model.

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Table-1. Basic geometry of the centrifugal fan.

Description	Dimension
Number of impeller blades Number of serrated blades Impeller diameter	16 pieces 4 pieces 0.35 m
Inlet diameter	0.27 m
Outlet cross sectional	0.2 x 0.2 m
Volute diameter	0.4 m
Volute tongue diameter	0.22 m

The design was continued with making of the Grid/Mesh. It was done using software GAMBIT 2.4.6. Mesh or Grid used unstructured element model Tetra/Hybrid and T-grid type, size interval of 1. Checking the mesh quality is good, then that should be done with far value Equal-Angle Skew not exceeding of 0.9, as in reference [13]. The examination results obtained the value of 0.807 mesh quality with values still going down on FLUENT program. With a high quality mesh will result in a more accurate solution and faster convergence times. The result of mesh-model with the number of node and element are 68,441 nodes and 466,196 elements respectively. This can be seen in Figure-2.

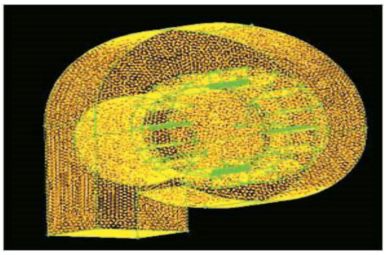

Figure-2. Mesh-3D models**.**

Table-2. The boundary conditions and case setup.

Boundary conditions	Value
General settings	3D, scale in cm, pressure-based type, velocity formulation, and time steady.
Alternative model	Model k-epsilon (2–eqn) standard and multiphase (Eulerian) with interaction model of Schiller and Nauman.
Materials	Air density of 1.125 kg m^{-3} and paddy grain density of 577 kg m^{-3} and grain kinematic viscosity of 1.49 E-03 Pa s
Setting of boundary conditions	Velocity inlet, pressure outlet, impeller (moving wall), wall, fluid zone, and interior default
Solution of Navier Stokes equation	Simple algorithm
The impeller speeds	400; 600; 800; and 960 RPM

The important stages of the simulation are geometry completion, meshing and determining of the boundary condition. The next stage is to determine the boundary condition (Table-2). This is done to limit the portion to be analyzed by the software. The final stage is to export the mesh. If the geometry file with Gambit software then could be exported to FLUENT program.

The design of the process simulation was performed using the ANSYS FLUENT 6.3.26. The analysis process consists of several of the stages. The final stage is solution run calculation till reaching convergent.

Input and output parameters

The simulation analysis gives the input parameters of the impeller speeds (400, 600, 800, and 960 RPM). The output parameters consist of impact velocity, total pressure, and normal contact stress of rice grain in the centrifugal flow paddy thresher. The output parameters consist of an impact velocity and total pressure were obtained from the plot on the CFD diagram. Whereas the normal contact stress of rice grain (σ) was determined by using the equation as follows [6]:

$$\sigma = \frac{3F_c}{2\pi ab} \quad (1)$$

Where: σ is normal contact stress (Pa), F_c is centrifugal force (N), a is length of grain (m) and b is width of grain (m).

A centrifugal force was determined by using the equation as follows [8]:

$$F_c = \rho R^2 v^2 \quad (2)$$

Where: ρ is grain density (kg m^{-3}), R is a radius of the impeller (m) and v is linear velocity of the impeller (m s^{-1}).

RESULTS AND DISCUSSIONS

Total pressure

The simulation results show that there is the extreme of the total pressure at high impeller speed at 960 RPM. This is indicated by the red color on the left side of the fan housing wall. This could be seen in Figure-3. This occurs as a result of the impeller rotation generated value of the centrifugal force at each point of the location in the fan housing.

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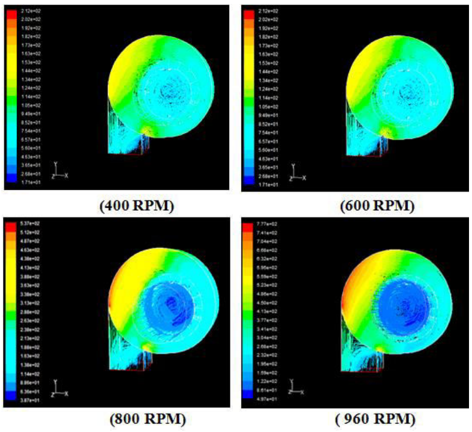

Figure-3. The plot of the total pressure on the impeller speed variation.

The total pressure at the fan location point generally increases with the addition of the impeller speed. The increase of total pressure occurs in the fan housing wall and the outlet wall quadratic. The total pressure between 800 to 960 RPM increased sharply. The higher total pressure occurred on the fan housing wall of 375.93 Pa at 960 RPM impeller speed (Figure-4).

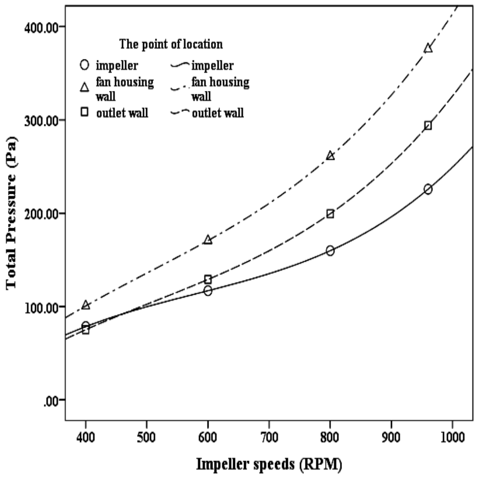

Figure-4. The total pressure on the impeller speed variation in the wall components.

The total pressure of flow is the sum of the static and dynamic pressure on the point. Change dimension of an inlet or outlet duct and impeller speed could affect static and dynamic pressure. Finally, it affect of total pressure. Total pressure depends on resistance and pressure losses in a fan and blower [1]. The total pressure could affect the impact velocity on the fan housing wall.

Impact velocity

The grain velocity that occurred right on the wall was recognized as the impact velocity. The higher impact velocity of 24.1 m s^{-1} is achieved in the fan housing wall at 960 RPM impeller speed. The extreme velocity was indicated by the red color on the left side of the fan housing wall. This could be seen in Figure-5.

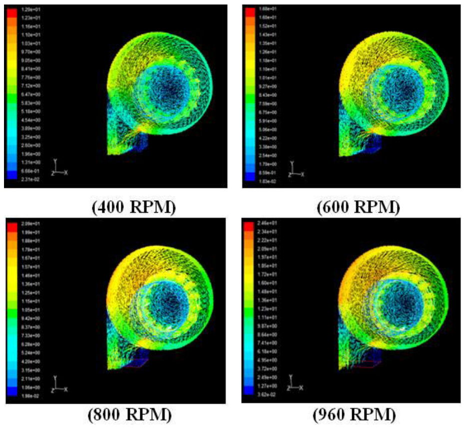

Figure-5. The plot of grain velocity on the impeller speed variation.

The simulation results show that the impact velocity increases linearly with increasing of the impeller speed. Whereas increasing of the impact velocity at the wall of the outlet is a small relatively (Figure-6). The addition of impeller rotation obtained the impact velocity of grain from 0.64 to 1.64 m s^{-1}. On the outlet wall, the impact velocity gets diminished with decreasing of blow pressure due to direct contact with the outside air.

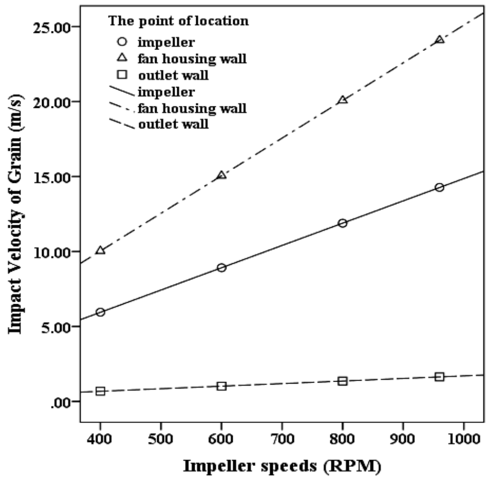

Figure-6. The impact velocity of rice grain on the impeller speed variation.

Improving of the impact velocity caused by the centrifugal force to be increased. It depends on density of grain, velocity of grain, and speed of the impeller. It might affect to the grain breakage, when exceed from the strengthening force of the rice grain.

The addition of the impact velocity cause increasing the damage ratio of rice kernels [10]. By using the axial type thresher with the normal velocity, relative velocity, and tangential velocity of 6.7; 20; and 18.84 m s^{-1} respectively, produce the impact between the rice kernel and the threshing tooth. When the relative speed exceeds of 30 m s^{-1} causes the rice grain to become broken shell ratio more than 88 % [6].

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Normal contact stress

Rice variety that use is "Santana" variety. Santana had the dimension of length of 2.6 mm and width of 9.2 mm. By using Eqn. (1) and Eqn. (2) then obtained the average surface area of a rice grain that impacted of 50.07 mm^2. This value used to determine the normal contact stress of the rice grain.

The calculation result indicated that increase the impeller speed causes the normal contact stress increased (Table-3). The higher normal contact stress obtained of 27.28 MPa at 960 RPM impeller speed. This is due to impact velocity with throw distance between the blade tips to left side of the fan housing more than the other.

The addition of the impact velocity in the horizontal direction caused the increase of the normal contact stress linearly. The experimental test was obtained the critical stress of the rice kernel is 38.7 MPa. The critical stress was depended on modulus of elasticity, Poisson ratio, yield of strength, and collision position of rice kernels [6]. This value would be disparate at each rice variety and condition of a rice grain at the time of threshing.

Table-3. The calculating results of the normal contact stress of the rice grain.

Impeller speeds (RPM)	Grain surface area impacted (mm^2)	Centrifugal forces (N)	Normal contact stress (MPa)
400	50.07	237.14	4.74
600	50.07	533.56	10.66
800	50.07	948.56	18.94
960	50.07	1365.93	27.28

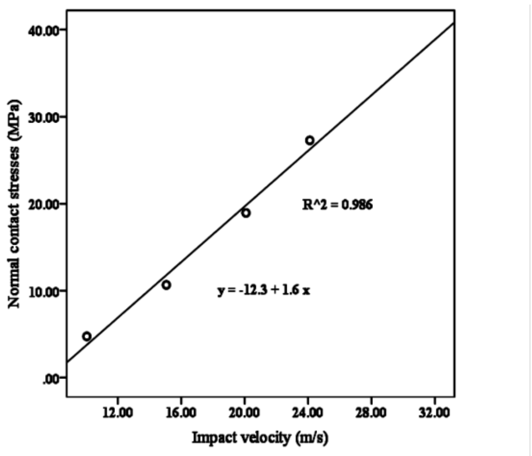

Figure-7. Relationship between impact velocity and normal contact stress of the rice grain.

Based on the approximating the critical stress of the rice kernel of 38.7 MPa [6]. By method plotted the curve from the Y-axis to X-axis in Figure-7 or by calculating of the value of the X-axis on the linear equation is y = -12.3 + 1.6 x so that obtained prediction of the critical impact velocity is 31.9 m s^{-1}. Operating the centrifugal flow threshed exceed the critical impact velocity could cause impact damage of rice grain.

CONCLUSIONS

The simulation results indicated that the addition of the impeller speed causes the total pressure, impact velocity, and normal contact stress of the rice grain increased. The impact velocity of 24.1 ms^{-1} and normal contact stress of the rice grain of 27.28 MPa is higher at 960 RPM impeller speed.

Based on approximating the critical stress of rice grain is 38.7 MPa so that could be predicted the critical impact velocity of the rice grain of 31.9 m s^{-1} by using the centrifugal flow thresher.

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