

Effect of Vortex Finder Addition Modification on Cyclone Separator Performance in the Rice Milling Industry

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Abstract - A cyclone separator is a device used to separate particulates from gas streams by applying centrifugal force. Cyclone separators are used in the rice milling industry to overcome the effect of using a blower as a machine to push the bran through the pipeline to the storage room, where the bran flies, causing pollution, and the bran is not collected properly. This study aims to examine the effect of modification of the cyclone separator on a rice mill machine using the CFD simulation method. In this study, it was found that adding the length of the vortex finder to the top had an impact on increasing the particle collection efficiency value, which was quite significant at 8.83%.

Keywords: cyclone separator, vortex finder, bran, rice mill, pressure drop.

I. INTRODUCTION

The majority of Indonesian people's livelihoods are in the agricultural sector, which accounts for quite a lot of the community's economy and is able to improve the Indonesian economy [1]. Rice is the main agricultural commodity in Indonesia because rice, produced from paddy, is the staple food of most people in that country.

Rice produced in agriculture must go through several processes before it can become the staple food of the Indonesian people, one of which is the rice milling process. The rice milling industry is one of the agribusiness subsystems that plays an important role in processing grain as input into the rice and other side products. As an intermediary industry, the rice milling industry plays an important role in the national rice supply chain [2].

The rice milling industry also produces other products, namely bran or rice bran. The bran is separated from the rice because, in addition to shortening the shelf life of the rice, it can cause a rancid odour and make the colour of the rice ugly or not clean and white. On the other hand, rice bran is a part of

rice that has a high nutritional content, such as oil, vitamins, proteins, and minerals. The nutritional content of the bran is high; the bran is currently mostly used as an ingredient in animal feed [3], and partly with cleaner processing, the bran is sold as a food ingredient for humans.

The process of separating bran from rice in a rice mill machine currently only relies on the process of grinding. This resulted in the working environment of the rice grinding machine becoming dirty due to flying bran, not optimally collected rice bran even though it has quite a high economic value and a decrease in the quality of the rice bran. This causes several grinding machines to try to add blowers and pipes to take the bran and send it to a different room in the hope that the bran will be collected properly and not cause pollution in the milling workspace. At the end of the pipe, a cyclone separator is usually installed. A cyclone separator is a tool used to separate particulates (bran) from gas streams by applying centrifugal force [4].

A cyclone has two main parameters to describe its performance: pressure drop and particle separation efficiency. The pressure drop is the amount of energy required to move particles through the system. The pressure drop value is caused by losses in and out, friction, and kinetic energy in the cyclone [5]. Particle separation efficiency is the cyclone's ability to separate solid particles from gases of various sizes. The efficiency of separating cyclone particles is a function of the density of the solids, the size of the solid particles, and the design of the cyclone [6]. Cyclone performance can be maximized by adjusting the cyclone geometry, one of which is in the vortex finder section. The vortex finder functions to control the flow coming out of the cyclone [4].

Cyclone separators are widely used in the industrial world because they have a simple construction design, low operating costs, and the ability to adapt to high pressure and temperature conditions [7, 8]. In general, the main parts of the cyclone are shown in Figure 1 [9].

One characteristic of a cyclone is the presence of free vortex and forced vortex flows, which are better known as Rankine vortex [10]. The complexity of the cyclone separator flow pattern is often a problem in theoretical and experimental studies [11]. The rapid development of technology encourages people to use computational fluid dynamics (CFD) in solving cyclone separator simulation cases because it has the potential to predict fluid flow characteristics, particle trajectories, and pressure drops in cyclones, as well as save costs and time [12]. To obtain maximum cyclone performance, it can be done by modifying the cyclone geometry, one of which is the vortex finder. The vortex finder is a part of the cyclone that functions to control the flow leaving the cyclone. When a particle enters the cyclone separator, it will exert centrifugal force, drag force, and buoyancy force. Assume that the particle travels with a tangential velocity $U\theta$ and a radial velocity inward U_r , as shown in Figure 2 [13].

experiments with 8 variations in the length of a cylindrical vortex finder to determine the effect on pressure drop [16]. The experimental results show that increasing the length of the vortex finder causes an increase in pressure drop. Similar research results were found by Tian et al. in 2020 by simulating a vortex finder length ranging from 0 to 535 mm. The simulation results show that the efficiency value is always close to 100% with the addition of the vortex finder length [17].

Research related to the innovation of the vortex finder shape has also been carried out. Raoufi et al. in 2008, conducted a simulation study of an experiment conducted by Lim et al. in 2004 with 10 variations of cylindrical and conical vortex finders [18,19]. A convergent vortex finder shape (downward cone) has higher separation efficiency with an insignificant increase in pressure drop compared to a cylindrical vortex finder shape. The results of this study are linear with a simulation study on a square cyclone conducted by Fatahian et al. in 2021 [20].

Modification of the vortex finder can also be done by adding parts. Pei et al. conducted a study in 2017 on the addition of a metal cross-shaped to the vortex finder, which aims to change the local flow field [21]. The simulation results show that this addition can increase the tangential velocity as well as reduce the pressure drop. The addition of other parts was done by Zhou et al. (2018) by simulating the addition of a guide vane to the vortex finder. The simulation results show that the higher the number of vanes, the higher the peak value of the tangential velocity so the collection efficiency also increases [22].

Studies on the application of the cooling process to cyclones have also been carried out, such as those by Zhang et al. In 2021, cool down a conventional cyclone separator using the condensation method [23]. The results show that cooling is successful in reducing the pressure drop and increasing collection efficiency significantly. Safikhani et al., 2021: modelling uniform cooling of the cyclone separator body and obtaining a lower cyclone output temperature compared to the uncooled condition [24].

In this study, simulations were carried out using the Computational Fluid Dynamics (CFD) method on two cyclone models or designs, namely the actual cyclone design that operates in a rice mill and the design that the author has designed as an effort to optimize the performance of the existing design. The software used in the computational fluid dynamics (CFD) simulation in this study is Ansys Fluent 2021 R2. The research results are expected to be a theoretical guide for particle collection technology in cyclone separators, especially bran particle collection in the rice milling industry.

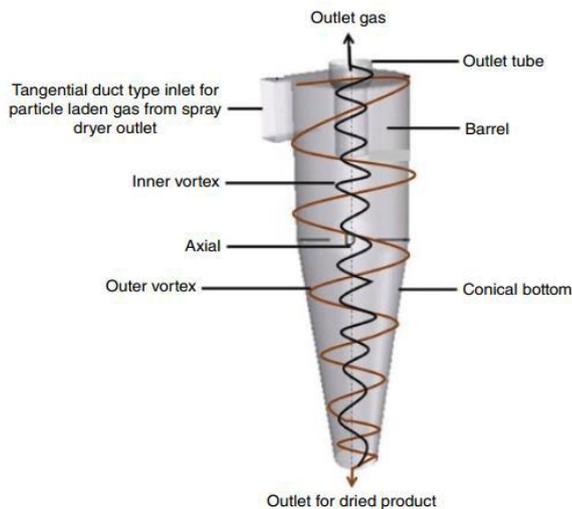


Figure 1: Cyclone separator

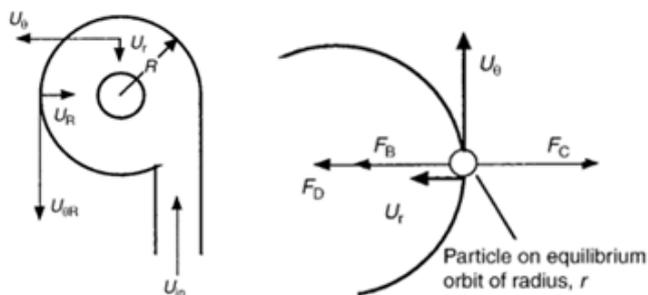


Figure 2: The free-body diagram of particles in a cyclone separator

Simulations of conventional cyclones with various diameters of cylindrical vortex finders have been widely carried out [12,14,15]. The results of their research showed that increasing the diameter of the vortex finder led to an increase in cyclone performance, both in terms of pressure drop and collection efficiency. Ficici et al. 2010 conducted

II. METHODOLOGY

Table 3: Actual and Modified Cyclone Dimensions

The cyclone separator currently in use has a problem, namely the low efficiency of collecting rice bran particles, where the rice bran that should be collected still flies through the exhaust ducts, polluting the room and the air. The CFD simulation approach on an actual cyclone separator will be used as a reference for creating a new cyclone separator modification in an effort to optimize cyclone separator performance.

Geometry	Dimensi (mm)	
	Actual Cyclone	Modified Cyclone
CycloneBody Height	1350	1350
Cone Height	1020	1020
Outlet Dustbin Height	50	50
Vortex Finder Length	300	450
Vortex Finder Diameter	200	200
Inlet Diameter	130	130
Outlet Dustbin Diameter	140	140
Body Diameter	410	410

2.1 Characteristics of Bran Particles

Table 1 shows the characteristic data of bran, including particle size, density, and specific heat, which will later be used as input data in the simulation process.

Table 1: Characteristics of Bran Particles

No	Parameters	Value	Unit
1	Particle size	1,19	mm
2	Density	1,33	kg/l
3	Specific heat	0,4038	cal/g°C

2.2 Airflow Measurement

In this airflow measurement, an anemometer is used to measure the airflow velocity, which is calculated per 5 seconds with a time span of 25 seconds to get the average velocity. The results of airflow measurements can be seen in Table 2 below.

Table 2: Airflow Measurement Results

Time	Inlet Cyclone Temperature (°C)	Inlet Cyclone Velocity (m/s)	Outlet Cyclone Velocity (m/s)
5 th second	35	11,1	9,0
10 th second		11,3	8,9
15 th second		10,8	8,6
20 th second		10,9	8,8
25 th second		10,9	8,4
Average	35	11,0	8,7

2.3 Actual and Modified Cyclone Dimensions

Cyclone dimension data was obtained from direct measurements on a rice mill machine, and then modifications were made to the vortex finder section based on considerations from various literature. The real dimension data of the cyclone is shown in Table 3. Figure 3 shows the actual design and the design modifications made.

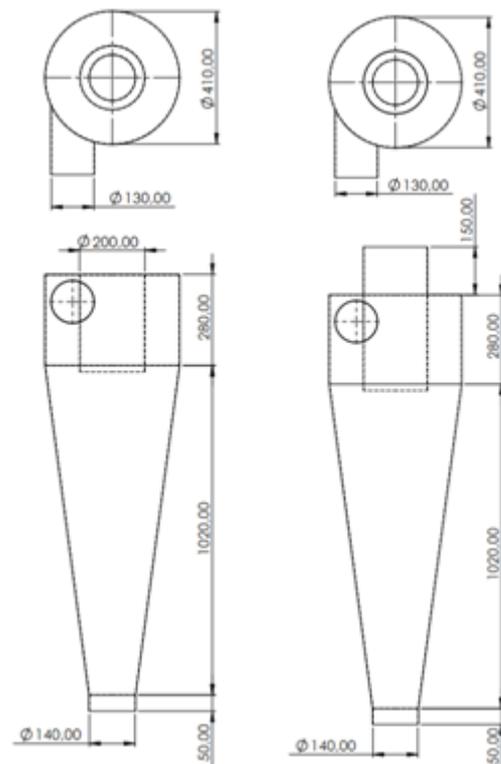


Figure 3: Actual (left) and Modified (right) Cyclone Designs

2.4 Boundary Conditions and Numerical Schemes

In this study, the boundary condition at the inlet is defined as the inlet velocity. Rice bran particles with a density of 1.33 kg/l (1330 kg/m³) and air with a density of 1,225 kg/m³ enter simultaneously at a temperature of 308 K with a speed of 11 m/s according to the average measured inlet velocity. Hydraulic diameter: 0.13 m, turbulence intensity: 3.804%. For the surface of the cyclone, the wall boundary conditions are used with the following settings: "DPM reflects" and "no-slip" on the cyclone wall surface, and "trap" on the dustbin (outlet) surface. The collision between the particles and the cyclone wall is assumed to be perfectly elastic (recovery coefficient equal to 1). The Rosin-Rammler distribution is assumed to model the particles entering the

cyclone. In order to accurately represent the distribution, the diameter distribution function is randomly sampled. Particle collection efficiency is obtained by releasing a certain amount of monodispersed particles at the cyclone inlet [11,24].

2.5 Simulation Validation

Validation is used to determine the correctness of the condition settings and results in this simulation. Validation is carried out by comparing the velocity of air flowing out of the outlet based on the simulation results and direct measurements using an anemometer. The calculation of the error value in validation uses Equation 1. The comparison results show an error value of 3.4%, where the value is valid because the error value does not exceed 10%. Figure 4 shows the outlet flow velocity profile and error value calculation.

$$Error = \frac{V_{actual} - V_{simulation}}{V_{actual}} \times 100\% \quad (1)$$

$$Error = \frac{8,7 - 8,4}{8,7} \times 100\%$$

$$Error = 3,4\%$$

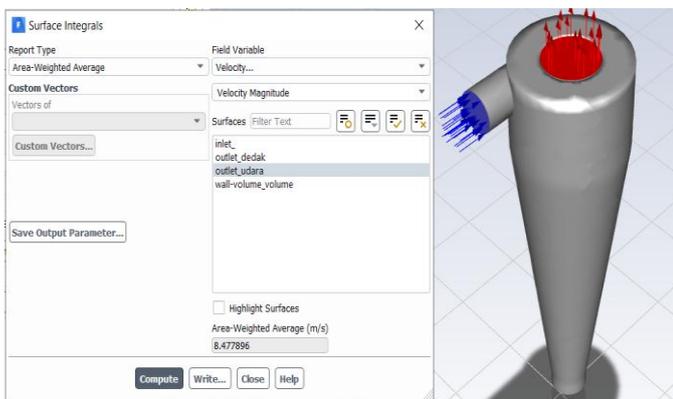


Figure 4: Outlet Flow Velocity Validation Results

III. RESULTS AND DISCUSSION

The results and analysis of the simulation will be explained in this study. The analysis to be carried out is the effect of adding a vortex finder on the velocity, pressure drop, and efficiency of particle collection.

3.1 Influence on Velocity

The velocity flow field is also known as the flow characteristic of the cyclone separator. The following is a simulation result of the effect of the length of the vortex finder and additional cooling on the cyclone body on the velocity flow field.

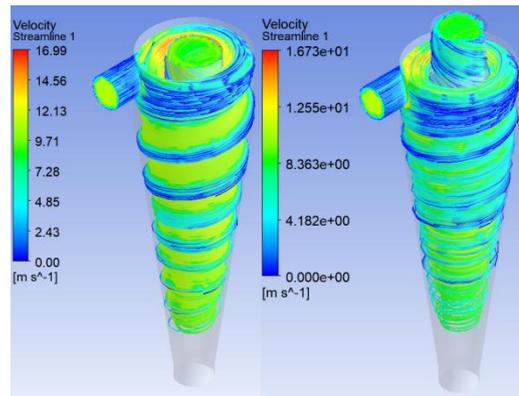


Figure 5: Actual Cyclone Flow Speed Streamline (Left) and Modified Cyclone (Right)

Visually, we can see in Figure 5 that the velocity value near the cyclone wall is smaller, which is marked in blue-to-tosca. This is because in this area there is a downward flow that is responsible for carrying the particles to the separation area to be captured by the dust bin.

Therefore, visually, it can be seen that increasing the length of the vortex finder upwards results in a decrease in velocity in the area near the walls of the vortex finder, which is shown in a bluer color on the modified cyclone, so that the particles descend down in a downward flow.

3.2 Influence on Pressure Drop

Pressure drop is a cyclone performance parameter that indicates the amount of energy required to move particles through the system. The pressure drop is a function of the inlet gas velocity and cyclone diameter. The total pressure drop in a cyclone is due to the losses in and out, friction, and kinetic energy in the cyclone. Usually the most significant pressure drop occurs in the body due to the swirl and energy dissipation as shown in Figure 6. The pressure drop can be calculated by comparing the difference between the pressure in the inlet area and the outlet area.

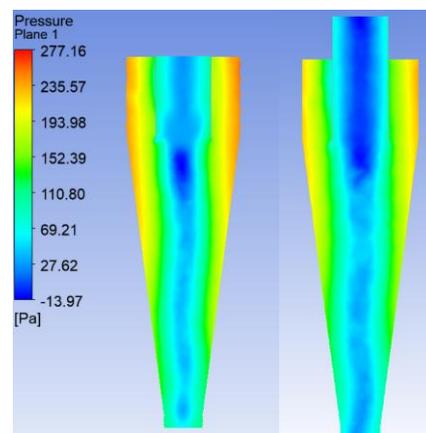


Figure 6: Contour of Actual Cyclone Pressure (Left) and Modified Cyclone (Right)

3.3 Influence on Particle Collection Efficiency

To obtain particle collection efficiency, the distribution of particles is injected at the cyclone inlet. Particles that have been injected into the cyclone are then tracked using the lagrangian approach. The particle collection efficiency is determined in Equation 2 below.

$$\eta = \frac{n_{injected} - n_{escaped}}{n_{injected}} \times 100\% \quad (1)$$

Table 4: Simulated Results of Bran Particles in Ansys Fluent

Parameters	Actual Cyclone	Modified Cyclone
Particle Tracked	1360	700
Particle Escaped	602	248
Cyclone Particle Collection Efficiency	55,74 %	64,57 %

A visualization of the collection of rice bran particles in the cyclone separator is shown in Figure 7 below.

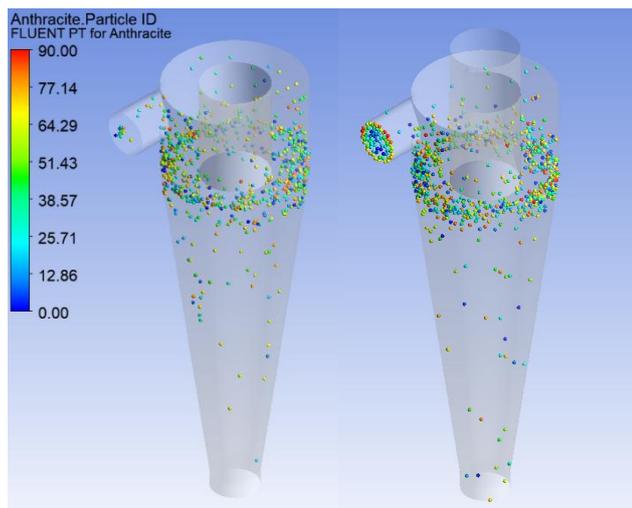


Figure 7: Visualization of the Movement of Rice Bran Particles in the Actual Cyclone Separator (left) and Modified Cyclone Separator (right)

IV. CONCLUSION

From the manufacture of the two designs that have been analyzed, it can be concluded that adding the length of the vortex finder has an impact on increasing the particle collection efficiency value, which is quite significant at 8.83%. The effect of increasing the length of the vortex finder upwards also results in a decrease in velocity in the area near the wall of the vortex finder on the cyclone separator, so that the particles fall down by downward flow.

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