

Simulation of CO₂ Gas Adsorption Process Flow at Cyclone Gas Outlet in Palm Oil Mills Using Computation Fluid Dynamic Simulation

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Abstract

Cyclone separator is equipment used to control emissions from gas flow in industrial processes. The principle of removing particulates from the gas flow in this tool is to use the centrifugal force. The centrifugal force generated from the rotating flow will make dust particles wasted into the cyclone wall where the dust will then fall into the hopper. Adsorption is a series of processes for the accumulation of a substance (adsorbate) on the surface of another substance (adsorbent). Adsorption can occur because of the energy on the surface and the attraction force on the surface. This study aims to obtain a good CO2 adsorption efficiency from modifying the cyclone separator using an adsorption column, analyzing the CO2 gas adsorption process produced from the biomass system at the utility unit boiler station at the Palm Oil Mill (PMO) using a modified cyclone. This simulation was carried out using the Autodesk Inventor Professional 2017 (Student Version) application for the descripction of the tool as a preprocessor and Ansys 2019 R3 (Student Version) applications as a processor and post processor. The variations that were applied included the adsorption column bed height of 3100 mm and 4650 mm, respectively, CO₂ gas flow rates of 10, 12.5, 15, 17.5, 20, 22.5 dan 25 m/s and mass loading 0,001 kg/s. The results obtained in the most optimal modification of the cyclone separator are at a bed height of 3100 mm with the highest adsorption percentage 93.437%, the highest flow 91.974% with a pressure drop of 1000 Pa.

Keywords: Cyclone, Adsorption, Efficiency, Bed Height, CO2

1. Introduction

Indonesia is one of the countries in the world that has a large palm oil industry. Support from Indonesia's strategic location has made Indonesia the first largest crude palm oil (CPO) producer in the world with a production of 43 million tons in 2019 [1]. CPO is an Indonesian export commodity that is a mainstay for state visa revenues. However, this has side effects for the existing environment, because the development of the CPO industry in Indonesia is not always supported by the development of the process of overcoming the pollution produced by palm oil mills. One of the dominating air pollution from palm oil mills is carbon dioxide gas which can cause the greenhouse effect. CO2 is produced from the combustion of biomass in the boiler. However, the air emissions released are not only in the form of a gas phase, but also a solid phase, namely fly ash[2]. The percentage of total CO2 emissions originating from the stationary combustion unit is around 38.39% [3].

So far, the tools used by palm oil mills to reduce pollution emissions are cyclones [4]. The advantage of using a cyclone as a particle separator is that no part of the cyclone moves during the separation process. In addition, investment and maintenance costs are more economical so that the use of cyclones is preferred [5]. However, in general, cyclones are only used to separate fly ash contained in the boiler output gas [6]

Therefore, the researchers modified the cyclone separation device in order to reduce the CO_2 content along with particulates in the form of fly ash which was dispersed in the boiler exhaust flue gas stream. Modifications made by adding adsorbents are placed at the gas outlet, which is expected to be able to absorb CO_2 . So that the content of fly ash and CO_2 coming out of the exhaust gas from the boiler can be reduced.



2. Literature Review

Several studies that have been conducted regarding the absorption of CO_2 by adsorption method using adsorbents explain that the adsorbents capable of absorbing CO_2 are zeolite, activated carbon and silica gel [7-10]. Singh and Kumar [11] investigated that adsorption on activated carbon is a simple and relatively more economical CO_2 separation method compared to other CO2 separation techniques. It has been analyzed by Rashidi and Yusup [10] and Yunardi et al. [12] that palm shells can be used as adsorbents that have the potential to capture CO_2 from gas streams. This is very useful because it can maximize the use of solid waste sourced from the PKS itself. This is because palm kernel shells are a fairly large solid waste, reaching 60% of oil production [13].

2.1. Cyclone

Cyclones have the advantages of high separation efficiency, low energy consumption, small structure size, large processing capacity, and easy operation and maintenance, and are suitable for continuous long-term operation. Therefore, cyclones have been widely used in particle separation and grading, gas purification, atmospheric pollution prevention and treatment in refining, chemical, environmental protection, food, mining, textile and other fields. With the development of cyclone separation technology, especially the discovery and quantitative characterization of the highspeed self-rotation of particles in the cyclone field, the separation precision of cyclones has evolved from the micron to nanoscale, and even ion-separated contaminants have been achieved [14].

2.2. Carbon Dioxide Gas

Carbon dioxide (CO2) is a chemical compound consisting of two oxygen atoms (72.7 wt %) covalently bonded to a carbon atom (27.3 wt %). It is a gas at standard temperature and pressure and exists in the atmosphere. Carbon dioxide is also a non-reactive and non-toxic gas. The gas is not flammable (non-flammable) and can not trigger combustion). Nearly 97% of CO2 gas is produced from the combustion of fossil fuels, such as from coal, oil, natural gas, and biomass sources. The presence of CO2 in the natural gas industry can reduce the heating value of gas and acidic components can cause corrosion of equipment. In natural gas pipelines, the permissible CO_2 content is about 1-2% mol [9].

2.3. Adsorption

Adsorption is a separation process in which certain components of a fluid phase move to the surface of the solid adsorbent (adsorbent). Usually the small particles of the adsorbent are placed in a fixed bed, and the fluid is then flowed through the bed until the adsorbent approaches saturation and the desired separation can no longer take place. The stream is then transferred to a second bed until the saturated adsorbent can be replaced or regenerated [15]. Adsorption is usually carried out on fixed bed vertical beds of porous granular adsorbents [16].

3. Methods

This research was conducted by simulating a modified cyclone with an adsorption column at the gas outlet. The materials to be separated are CO2 and dust (particultate matter) using activated carbon adsorbents derived from palm oil shells. Simulations were carried out using commercial software Autodesk Inventor Professional 2017 (Student Version) and ANSYS 2019 R3 (Student Version).

The research variable is a data parameter that will be analyzed and measured in the right way. In this study, the object of research is the percent CO2 absorption, CO2 absorption capacity, cyclone collection efficiency and pressure drop in the cyclone separator, while the independent variables are CO2 gas flow rates of 10, 12.5, 15, 17.5, 20, 22.5 and 25 m. /s, particle mass loading of 0.001 kg/s, and adsorption column bed height ratios of 3100 and 4650 mm, respectively. The geometry of the cyclone is shown in Figure 1. Diameter of adsorbent particles is 0.0029 m, Bed Porosity of activated carbon (ϵ): 0.4, Bulk Density of activated carbon 0.1064 gr/cm3, cyclone inlet temperature 573 K, Operating pressure 11.72 Bar (170 psi).



Fig 1. Modified cyclone geometry (mm)

4. Results and Discussion

This study discusses the effect of variations in bed height and particle velocity on the percent absorption of CO2 and the efficiency of collection in the modified cyclone shape with an adsorption column added to the gas outlet. Geometry drawing is done on autodesk fusion 360 layers with IGES storage model export. The core simulation is carried out using the ansys Fluent R3 2019 Computational Fluid Dynamic (CFD) application. The geometry is defined into 4 important parts, namely Inlet cyclone, Outlet bottom cyclone, outlet top cyclone, Porous zone, and outlet gas. The mesh density is made as much as possible to minimize the percent error in the geometry runner to be simulated. The maximum number of mesh is 950 mm with the number of nodes 107644 and elements 450074.

4.1. Effect of Variation of CO₂ Gas Flow Rate on CO₂ removal efficiency

Percentage of absorption is the ratio between the substance that has been absorbed and the quantity of the substance fed or CO_2 removal efficiency[15]. Based on Figure 2, the highest absorption percentage of 95.58% was obtained in the bed which has a higher size of 4650 mm with a CO_2 gas flow rate of 10 m/s. The lowest percent absorption of 93.13% was obtained at a bed height of 3100 mm with a CO_2 gas flow velocity of 25 m/s. These results show that the higher the adsorption column bed, the higher the percent absorption obtained. However, this is inversely proportional to the effect of the flow rate of CO_2 gas entering the cyclone separator. This result is in line with the previous study conducted by Sylvia et al [16], where the height of the adsorption column was proportional to the percent absorption obtained. This result is because the mass of the adsorbent is getting bigger so that the place of contact between the gas fluid and the adsorbent is also getting bigger, but the greater the inflow rate, the lower the absorption percent.



Fig 2. Effect of inlet velocity on CO2 on removal efficiency with various bed height of adsorbent

4.2. Effect of Variation of CO₂ Gas Flow Rate on Cyclone Collection Efficiency

Variations in CO_2 gas flow velocity were carried out in cyclones with different adsorption column heights of 3100 mm and 4650 mm. The results of cyclone collection efficiency obtained from each bed height and variations in CO_2 gas flow velocity of 10, 12.5, 15, 17.5, 20, 22.5 and 25 m/s are shown in Figure 3. Cyclone collection efficiency can be defined as the ratio of the mass of solids that can be separated to the mass of solids before entering the cyclone [17]. The efficiency of the cyclone separator has an influence on the number of trapped particles and escaped particles. In addition, the inlet velocity also affects the percentage of particle separation from the gas [18].

Based on Figure 3, the highest cyclone collection efficiency of 92.15% was obtained in the bed which has a higher size of 4650 mm with a CO₂ gas flow velocity of 25 m/s. The lowest cyclone collection efficiency of 79.74% was obtained at a bed height of 3100 mm with a CO₂ gas flow velocity of 10 m/s. This fluctuating trend of cyclone collection efficiency proves that the efficiency of separating solid particles in a cyclone separator depends on several parameters including inlet velocity [19] and dust loading [20]. The inlet velocity has a direct linier ratio to the cyclone collection efficiency. This is because the carried particles will collide with the cyclone wall so that the particles can easily go to the dust hopper section of the cyclone. In addition, dust loading also has a linier effect on the efficiency of cyclone collection. If the dust loading has a high value, then the collision between the particles and the cyclone wall will be maximal [21].



Fig 3. Effect of inlet velocity of CO2 on separation efficiency of cyclone with various of bed height of adsorbent

4.3. Effect of Variation of CO2 Gas Flow Rate on Pressure Drop

This observation of the cyclone pressure drop is closely related to the energy used by the cyclone to separate the dispersed particles in the gas stream. The expected pressure drop is low because in this way, energy consumption is also low. This will have an impact on saving the required energy. Therefore, pressure drop is also a measure of the performance of a cyclone in the process of separating particle [22-24].



Fig 4. Effect of inlet velocity of CO₂ on pressure drop of cyclone with various of bed height of adsorbent

Based on Figure 4, that the pressure drop that occurs in the cyclone body with a bed height of 4650 mm has a higher pressure drop than a bed height of 3100 mm. This is due to the large resistance that occurs in the adsorption column. Apart from that, the magnitude of the mass loading of particles fed into the cyclone separator also affects the pressure drop because it will increase the friction in the cyclone separator material. The higher the velocity, the higher the pressure drop, as well as the effect of bed height affects the pressure drop [17].



Fig 5. Contour pressure drop of cyclone with various of bed height of adsorbent in 10 m/s velocity inlet (left=3100 mm, right=4650 mm)

Based on the pressure drop contour in Figure 5, the maximum pressure occurs in the cyclone wall area and the minimum pressure occurs in the cyclone separator outlet area. This happens because of a collision between the input cyclone which is CO2 gas and the dust loading which collide with the cyclone wall, creating friction which causes a pressure drop. It is also supported by the velocity contour in Figure 6. which shows that the higher the adsorbent bed, the lower the CO2 velocity. The decrease in velocity occurs in the porous zone caused by contact between the adsorbent and the incoming CO2 so that some of the CO2 will be retained on the surface of the adsorbent [25].



Fig 6. Contour velocity of cyclone with various of bed height of adsorbent in 10 m/s velocity inlet (left=3100 mm, right=4650 mm)

5. Conclusion

The conclusion of the paper in this simulation study that the optimal modified Cyclone separator is obtained from the simulation that has been carried out, namely a cyclone separator with the addition of an adsorption column that has a bed height of 3100 mm by reviewing the absorption percent, cyclone collection efficiency, and pressure drop. The most optimal modification of the cyclone separator was at a bed height of 3100 mm with the highest adsorption percentage of 93.437%, the highest flow of 91.974% with pressude drop of 1000 Pa.

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