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The Calculation of Expense Reduction based on the Efficiency of Cyclone by Computational Fluid Dynamic

The rotary kiln in cement industries used hot air (temperature 1450°C) for doing a reaction to form a clinker. The outlet hot air from the combustion reaction in the kiln is reused to decrease the water content of coal in the coal mill. However, the hot air that contained ash will affect the drying process in the coal mills will not reach the maximum point. Therefore, the hot air needs treatment to separate the hot air and particle. The hot air is carried out to the cyclone. The goal of this study is to investigate the efficiency work of cyclones in cement industries using the CFD method. Besides, the other goal of this research will convey the expense that is reduced in decreasing the ash content in hot air. In general, the good cyclone has the low-pressure drop, the turbulence model using Reynold Average Navier Stokes (RANS) simulation, $k-\epsilon$ standard, with the Lagrangian model to solve the problem in particle lane. The result of this study is showing the pattern of the ash in cyclones, the pressure in cyclones, and the efficiency of cyclones. The number of efficiencies will affect the reduction of expense in this section.

Keywords : Ash, Cyclone, Efficiency.

1. INTRODUCTION

Indonesia is one of the world's fastest levels of economic growth. The cement industry's growth pattern will be the same as or above national economic growth as demonstrated by the emergence in Indonesia of different types of cement industries. PT Semen Indonesia is one of Indonesia's largest cement industries, with the Proper Gold award meeting the highest environmental management standards. Cement production process at PT Semen Indonesia includes the process of preparing raw materials, crushing, storing and feeding raw materials, grinding and drying raw materials, mixing and homogenization, pre-heating, firing, cooling, final milling, filling. In order to achieve high economic value, it is necessary to integrate process units. Cement industry is one of the most energy-intensive industries in the system of kilns. Kiln is a cement factory's main equipment that plays an important role in deciding the plant's overall performance parameters. There is heat loss in the kiln that is used as a heater with counter current flow in calciner and multi-stage preheater. There is combustion process in kiln and it will produce hot air which is still used to reduce the water content in coal. The outlet hot air is still contained ash which must be separated before being sent to the coal mill. Cyclones are one of industry equipment that have function to separate gas and solids. This equipment is used in many industries because it has relatively low installation and maintenance costs, high separation efficiency for small particles, and be able to operate it at high temperatures. Inside the cyclone, inlet of particles and gases go through the tangential direction into the top of the cyclone [1,2]. Therefore, evaluation of preduster efficiency is needed. Many researchers have been looking for cyclone efficiency both in operating cost and collection efficiency by experiment or theoretic. Chuah et. al. [3] compared experimental and theoretical pressure drop in cyclone by Shepherd and Lapple (1939), Casal and Martinez (1984), Dirgo (1985) and Coker (1993) model. Their study

shows Coker model predicted cyclone pressure drop, which is related to operating cost and collection efficiency. Bogodage and Leung [4] estimated overall collection efficiency of cyclone by experimental method, then improve the cyclone separator performance by variation of down-comer tubes. Many researchers examine the performance of cyclones to find good cyclone efficiency, both in operating costs and collection efficiency through experiments or theories. Computational Fluid Dynamics (CFD) methods are currently used to theoretically evaluate cyclone efficiency. CFD was first presented by Boyson et. al. the results of the presentation were reported that pressure drop that is predicted by CFD has a great agreement with measured data. CFD offered momentum, heat, and mass transfer data to simulate cyclone operation which is based on combination of mass rotational forces, drag forces, and other forces [5]. Brennan et. al [6] validated performance of industrial cyclone separators by CFD modelling. Their study compared Differential Reynold Stress (DRSM), Large Eddy Simulation (LES), and Laminar flow model. They reported that DRSM and LES model predicted well. Kepa [7] also reported that CFD modelling allows the analysis of large-size cyclones that are very difficult to analyze in experimental studies by RSM turbulence model. Since LES and RSM method burdened with a lot of computational effort [8-10] although let the result that closed to experimental measurement, Reynold Average Navier Stokes (RANS), the simpler model gave accurate estimation [11], may be considered to provide this present study. For particles tacking is defined by Lagrangian calculation that have been commonly used. Since collection efficiency is affected by velocity inlet [12] and the rate of hot air is can't be changed, here the influence of inlet dimension in Le/D ratio to pressure drop and collection efficiency of the preduster was examined.

2. MATERIALS AND METHODS

In this study calculation, the commercial software is needed for doing CFD. ANSYS FLUENT 16.2 is used in this simulation and the 3-D calculation domain was defined as a geometry.

Figure 1: (a) Preduster Geometry, (b) Name Section and Preduster grid of Le/D = 0.5 (current preduster), (c) Peduster grid of Le/D = 0.3, (d) Preduster grid of Le/D = 0.2.

It shows in Figure 1(a). the sketch of preduster dimension in millimeter size. The geometry was made by Workbench Design Modeller software and divided by meshing software into several grids. The grids of current preduster were generated in 84,148 grids with skewness 0,153 as can be seen at Fig. 1(b). While for Le/D = 0.3 was divided by 85,734 grids with skewness 0,159 and for Le/D = 0.2 the grids are 84,914 with skewness 0.158. It means the calculated domain has relatively high accuracy. Reynold Average Navier Stokes model is used to describe turbulence model by assuming fully turbulence flow. This model solved two equation[5,13], which are turbulence kinetics energy (k) and dissipation rate (ϵ), here

$$\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_i} (\rho k u_i) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \right] + G_k + G_b - \rho \epsilon - Y_m + S_k \quad (1)$$

$$\frac{\partial}{\partial t} (\rho \epsilon) + \frac{\partial}{\partial x_i} (\rho \epsilon u_i) = \frac{\partial}{\partial x_i} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial \epsilon}{\partial x_i} \right] + C_{1\epsilon} \frac{\epsilon}{k} (G_k + C_{3\epsilon} G_b) - C_{2\epsilon} \rho \frac{\epsilon^2}{k} + S_\epsilon \quad (2)$$

$$G_k = -\rho \overline{u_i' u_j'} \frac{\partial u_j}{\partial x_i} \quad \mu_t = \rho C_\mu \frac{k^2}{\epsilon} \mu_t \cdot C_\mu$$

Dimana, nilai viscositas dapat dihitung dari persamaan adalah tetapan 0.09 $C_{1\epsilon}$, $C_{2\epsilon}$ adalah 1.44; 1.92. σ_k , σ_ϵ adalah Prantdl Number 1, 1.3. S_k , S_ϵ adalah nilai yang dimasukkan peneliti. Sementara itu, persebaran partikel dihitung dengan menggunakan pemodelan Langrangian, Dicrete Phase Model (DPM), keduanya digunakan untuk menghitung keseimbangan gaya persebaran partikel dengan persamaan sebagai berikut :

$$\frac{du_p}{dt} = F_D (\vec{u} - \vec{u}_p) + \frac{\vec{g}(\rho_p - \rho)}{\rho_p} + \vec{F} \quad (3)$$

$\vec{F}$ adalah pertambahan percepatan, $F_D(\vec{u} - \vec{u}_p)$ adalah gaya tarik antar partikel, and F_D presented by $F_D = \frac{18\mu}{\rho_p d_p^2} \frac{C_D Re}{24}$ dimana $\vec{u}$ and $\vec{u}_p$ adalah viskositas fluida [5]. Kontur tekanan dalam preduster diamati dari bidang horizontal yang ditunjukkan pada Gambar. 1 (b). Effisiensi keseluruhan dihitung dari

$$\eta_o = \sum \eta_j m_j \quad (4)$$

$$\eta_j = \frac{1}{1 + \left(\frac{d_{pj}}{d_{pj}} \right)^2} \quad (5)$$

$$d_{pj} = \left[\frac{9\mu W}{2\pi N e V i (\rho_p - \rho_g)} \right]^2 \quad (6)$$

m_j adalah fraksi partikel pada range ukuran partikel jth. d_{pj} adalah diameter dari range ukuran partikel jth dalam satuan (μm). Ne adalah bilangan pengganti dan Vi adalah kecepatan masuk cyclone.

Setelah melalui simulasi didapatkan hasil effisiensi cyclone maka dapat dilakukan perhitungan biaya yang dapat dihemat dibandingkan desain awal sebelum dilakukan effisiensi yaitu dengan persamaan :

$$E = L - M \quad (7)$$

$$F = A \times B \quad (8)$$

$$G = \frac{F}{C} \quad (9)$$

$$H = D \times G \quad (10)$$

$$J = \frac{E}{0.02} \times 0.05 \quad (11)$$

$$K = A - (J \times A) \quad (12)$$

$$O = H - N \quad (13)$$

E adalah pengurangan kandungan abu antara $Le/D = 0,05$ and $Le/D = 0,03$. L adalah kandungan abu dari cyclone dengan $Le/D = 0,5$. M adalah kandungan abu dari cyclone dengan $L3/D = 0,3$. F adalah total kebutuhan panas. A adalah kebutuhan panas untuk produksi yaitu 869,61 kcal/kg klinker [14] . B adalah data acuan produksi 344 kg/h [14]. G adalah kebutuhan batubara. C adalah kandungan panas dari batubara yaitu 4670 kcal/kg batubara [14]. H adalah biaya kebutuhan panas dari cyclone dengan $Le/D 0,5$. D adalah harga batubara yaitu 57000/kg batubara [14]. J adalah pengurangan panas. K adalah kebutuhan panas setelah effisiensi. O adalah pengurangan biaya. N adalah biaya kebutuhan panas dari cyclone dengan $Le/D 0,3$.

3. RESULTS

CFD method predicted the current outlet pressure is -3205 Pa.

Figure 2: (a) flow pattern of dust-laden air in the preduster by velocity (m/s) path line, (b) Pressure contour in Horizontal plane (Pa)

The calculation to find out the efficiency for preduster used the equation. (4) is 47.59%. The Le/d decreases to be 0.3 , the efficiency will rise until 66.95%.

Figure 3: Particle distribution in cyclone

Table 1: Pressure drop comparison between Shepherd and Lapple and Standard k- ϵ method

No	Le/D	Pressure Drop		Velocity Inlet
		Shepperd Lapie Model	Standard k- ϵ Model	
1	0,5	235	145	12
2	0,3	447	430	24

Graph 1: Particle distribution in cyclone

Table 2: Cost Reduction Calculation

Information	Le/D		Unit
	0,3	0,5	
By Data			
Ash content	0.07006	0.1111	

Reduction of ash content	0,041039802		
Heat requirement	780,3884	869,61	kcal/kg clinker
By calculation			
Total heat requirement	268453,6	299145,8	kcal
Coal requirement	57,48472	64,05693	kg
Coal Expense	32766288	36512447	Rupiah
Cost reduction	3746158,978		Rupiah

4. DISCUSSIONS

The result for this research indicated well prediction. It is shown in Fig. 2(a), the hot air that contained with particles go through preduster inlet in the top of cyclone. The dust-laden air flow in a downward spiral against the cyclone body's of the outer wall. It causes the separation between the gas and particles by centrifugal force. The outer vortex will get smaller when the air flows downward along the cone. For the further, the vortex will hopped up in spiral flow, it is called inner vortex, leaves the preduster by the vortex finder to pass the outlet in the top of cyclone. It can be seen in Fig. 2(b) similarly approximated pressure outlet to measure pressure in plant. CFD method predicted the current outlet pressure is -3205 Pa, meanwhile the actual hot air inlet pressure in the coalmill is -2546,5 Pa. The differences number is caused the amounts of mesh geometry, besides the friction loss by the pipe and elbow which have length about 10 meters. In the CFD model happens the pressure drop which give well comparison with the most accurate empirical model, Shepherd and Lapple, as can be seen in fig 3. It can be noted if the increasing inlet velocity due to reduce Le/D ratio will rise the pressure drop in preduster. For knowing the approximation of particle contained in hot air by Rosin Rammler distribution in particle range between $0,5 \mu m$ dan $25 \mu m$ with 10% of hot air flow rate. The condition of particles that is going out through both the clean air discharges and the collected dust discharged is considered in steady state condition. The calculation to find out the efficiency for preduster used the equation. (4) is 47.59%. The relatively low efficiency may be affected by the dimension of preduster so the particle is available to swirl in the inner vortex from the bottom to the gas outlet and the largest number of particles loading in which smaller than $5 \mu m$. While the Le/d decreases to be 0.3, the efficiency will rise until 66.95%, it can be caused by some particles go down directly without flowing in the inner vortex from the bottom as can be seen in Fig. 3(b). It shows in Fig.4 the particle size distribution data at the gas inlet and outlet. On the inlet line, there are two peaks which have meaning the most showing number of particle size. The most showing size are less than 10 micrometers and particle in range of 25-30 micrometers. However, after separation in the gas outlet line preduster was just showing one high peak. This peak is related with the size that is still carried out in the range diameter less than 10 micrometers. This shows that larger particle is more easily separated from the carrier air in the preduster (cyclone) than the small one. It is because relatively small particles are still carried by air into the air flow out through the top of the preduster. This phenomenon is according with the characteristics of the cyclone weakness which can not separate particles in very small size. The amount of particles that can be separated will affect the efficiency of the cyclone's performance. To find the expense reduction that can be saved from cyclone efficiency data through this CFD method was calculating the cost for heating process in the kiln. The capacity production of clinker is 344 kg / hour. Based on study before said that the increasing of 2% ash content in hot air will also cause the increasing 5% coal needs in coalmill. It will reduce the heat needed 869.61 kcal / kg of clinker and the content heating of coal is 4670 / kg. The first thing was calculating the efficiency of the cyclone with the original dimension in PT. Semen Indonesia or $Le / D = 0.5$ with a yield is 47% and ash content in hot air is 11%. Based on the equation (8), the total heat requirement for the production is about 299145.8 kcal. Based on equation (9), the amount of coal is 64.06 kg. Based on equation (10) by using general coal price of Rp. 570,000 / kg, the total cost for coal is Rp. 36,512,447. After simulating the CFD method, the efficiency increases to 67% after changing the Le / D variable to 0.3 with a ash content of 7%. Based on the increasing efficiency, it is obtained a reduction in ash content by 4%. Then the heat reduction can

be known by the equation (12). And the results obtained heat reduction results of 10.26%. With these savings, the current heat requirement according to the equation is 780.3884 kcal / kg. Using the same method, it was found that the cost of coal was reducing to Rp. 32,766,288. It means it is able to save cost about Rp. 3,746,159 per production (base 344 kg / hour) after applying the results of this CFD cyclone simulation.

5. CONCLUSIONS

This study showed that CFD can provide a good prediction of the performance and efficiency of the cyclone as demonstrated by the flow pattern of hot air containing dust, approximation of the pressure outlet in the current preduster, and a good drop in the comparison pressure to the Shepherd and Lapple model. The current preduster still has an overall collection efficiency that is relatively low. The increase in speed is attributed to a 0.3 Le / D ratio that increases the overall efficiency of collection. This simulation had a higher efficiency than before, 0.5 and was affected by the reduction of expenses.

6. ACKNOWLEDGMENTS

PT Semen Indonesia (Persero) Tbk. is acknowledged for giving the necessary data. This calculation research allowed by LPPM-UIIS is also gratefully acknowledged.

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