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Gas flow optimization for Top Cyclone Preheater Cement Production

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Abstract:- Application of cyclone technology has been implemented in cement production since the construction because it is simple, low cost, reliability and stability both in high pressure environment and high temperature (900 oC). The ideal solution to improve the burning process is by optimizing the cyclone heat exchanger. The aim of this study is to see the effect of baffle plate for outlet duct to the outlet gas flow distribution in cyclone preheater CN1–A and CN1–B. Computational Fluid Dynamics is used for modelling the swirl turbulent flow inside the cyclone. The simulation shows It was found that by adding baffle plate (width between 250–300 mm) able to maximize the gas flow distribution and also improve the heat transfer and potentially to reduce the loss from heat loss by 0.9–1.3% (equivalent 588 – 722 billion Rupiah/year). Baffle plate also caused pressure drop in multicyclone system)

Keywords:- *Computational Fluid Dynamics, Efficiency, Cyclone Geometry, Pressure Drop, Dust Loss, Thermal Loss.*

I. INTRODUCTION

The modern clinker production system consists of a rotary kiln, a cyclone preheater (suspension preheater), and a calciner. Cyclone Preheater is the core equipment for cement production using kiln dry process technology. In this process, a raw mix with low water content (e.g., 0.5%) is used, to reduce the need for evaporation and reduce the length of the kiln. The raw mix is fed into the combined preheater and pre–calciner equipment, which heats and partially (almost completely) calcines the raw mix before reaching the rotary kiln. The calcination process involves the thermal decomposition of calcite and other carbonate materials to form metal oxides (mainly CaO) and carbon dioxide gas. Pre–calciner reduces fuel consumption in the kiln because the kiln no longer has to perform a calcination function. The use of the suspension preheater, which consists of a series of cyclone stages, also improves energy efficiency. The Cyclone Preheater regulates the raw mix temperature using the heat generated by the combustion of fuel or from hot gas fed from the kiln. This preheating removes carbon dioxide (up to 90%) and water in the raw mix before entering the kiln. Most suspension preheaters are equipped with four cyclones [1].

One of the solutions to increase the thermal efficiency of the combustion process is by optimizing the cyclone heat exchanger (suspension preheater). The efficiency of dust separation and heat utilization is highly dependent on the cyclone applied. It starts with using the suspension preheating method to preheat and partially decompose the feedstock to reduce the length of the kiln, and at the same time, make the raw material, and hot gas flow in the kiln in full. The Cyclone Preheater can fully utilize the heat from the kiln, reduce clinker combustion heat consumption, and reduce combustion equipment floor space [2].

The advantage of the cyclone preheater is that it has high productivity where the cyclone preheater adopts the multilevel suspension preheating cycle to increase the production rate, the low investment cost, due to the reasonable structure of the cyclone preheater, thus reducing equipment problems and low investment. Figure 1, illustrates the principle of operation of the cyclone suspension preheater.

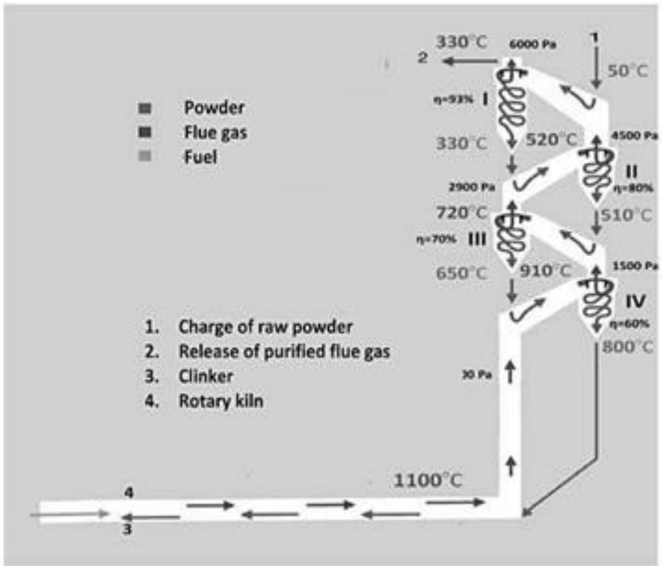

Figure 1. Operation principle of a cyclone Suspension Preheater [2]

A cyclone is a static device that applies centrifugal force to a mixture of gas and particles, to promote separation of the particles from the gas stream. A cyclone has been widely applied in various industries because of its main advantages of simple structure, low cost, and good adaptability to high pressure and high-temperature conditions, especially above 900ºC, which hardly includes the application of other separation technologies [3]–[5].

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The most important parameters that aim to assess the performance of the cyclone separator are the pressure drop and the efficiency of particle collection [6]. The overall collection efficiency is defined as the ratio of the mass of solids collected by the cyclone in time intervals to the mass flow rate of incoming solids. The pressure drop is given by the difference between the static pressure in the cyclone inlet and the gas out [7]–[9].

The case study at PT. XYZ shows that the material distribution is not balanced between CN1-A and CN1-B cyclones so that it has an impact on high thermal loss and dust loss. This also causes the work efficiency of one of the cyclones to decrease because it has to accept a larger dust load. Table 1 below shows the baseline mass flow distribution values for cyclones CN1-A and CN1-B.

Table 1. Mass flow distribution and design vs actual temperature

Operational	Mass Flow %			Temperature ºC			
	CN1-A, short	CN1-B, long	Diff	CN-A (short)	CN-B (long)	Diff	downcomer
Design	50	50	0	370	370	0	370
Actual	60	40	20	426	366	60	397

Table 1 shows that the mass flow distribution and temperature are not balanced between CN1-A and CN1-B, where the initial design values for CN1-A and CN1-B should be balanced. However actual current operating data for CN1-A and CN1-B are 60% and 40%. Meanwhile, the downcomer temperature according to the design is 370ºC, while the actual temperature is 397ºC. Table 2 shows the data on efficiency, dust loss, downcomer temperature, and heat loss.

Table 2. Efficiency, dust loss, downcomer temperature and heat loss

Operational	Efficiency Cyclone (%)	Dust loss (tpd)	Temperature Downcomer (ºC)	Heat Loss, (MJ/$t_{clinker}$)
Design	95.0	200	370	1,185.10
Actual	93.6	256	397	1,271.59

In table 2, the thermal loss value according to the design can be obtained by calculating the heat carried by air out of the preheater system. From the calculation results, the thermal loss value according to the design is 1185.10 MJ / t-clinker while in actual conditions it is 1271.59 MJ / t-clinker, there is an increase in heat loss of 86.49 MJ / t-clinker. The cyclone efficiency value is also directly proportional to the amount of dust loss in the preheater system. For a relatively new cyclone system, the efficiency is in the range of 95% so that the amount of dust loss has a value of 200 tpd. Meanwhile, in actual conditions, the efficiency of the cyclone was 93.6% and the dust loss value was 256 tpd.

The main objective of this study is to determine the effect of modification by adding baffle plates to the outlet duct cyclone preheater as a design optimization step to improve gas flow distribution at the outlet ducts coming out of the CN1-A and CN1-B cyclones using CFD simulation. So that the balance of gas distribution is expected to reduce heat loss.

The investigation is focused on the twin cyclone model for the 1st stage of the cyclone which operates in a cement factory in Indonesia [10]. Figures 2 and 3are cyclone preheaters with modern design features that have several advantages including:

1) Minimal power requirements due to the high heat recovery rate and low-pressure drop;
2) High efficiency - low heat consumption due to high cyclone collection rate and uniform meal distribution over the gas duct cross-section;
3) High validity and reliable design.

However, this model in its application has a different outlet duct length from the two cyclones to the downcomer duct as shown in Figure 1, causing an unbalanced distribution of gas outlets.

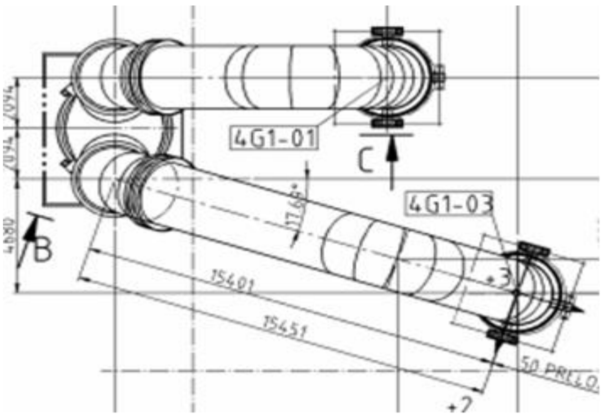

Figure 2. Top cyclone preheater and outlet duct design drawing [11]

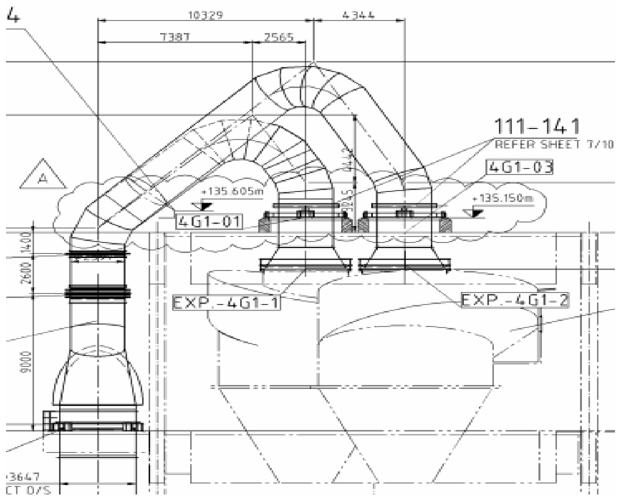

Figure 3. Outlet duct from top cyclone preheater design drawing different length [11]

This cyclone design has a difference on the top roof compared to the cyclone design in general, where the cyclone roof is sloping. The advantage of this cyclone model is that it has a lower pressure drop compared to the cyclone design with a flat top roof [12].

II. METHODS

In previous research conducted by Feri, et al [2], CFD analysis was carried out on a single cyclone, but in this case, CFD analysis was carried out on a twin cyclone, to find out how much influence the imbalance of gas outlet distribution due to the lengths of the two different duct outlets on temperature, against thermal loss and mass flow. Then, determine the corrective steps that need to be taken to optimize the cyclone design so that thermal loss can be reduced.

The methodology in this study is an analysis of the gas flow conditions in the cyclone preheater with the CFD (Computational Fluid Dynamics) simulation method to determine the effect of modification with the addition of baffle plates and steps to improve it. There are 4 (four) steps in conducting a CFD simulation, namely:

2.1 Identification of the Problem

a. This process is the first step to determine the cause of the imbalance in the efficiency of the two top cyclone preheaters;
b. This research was conducted through the process of collecting operational data and clinker production reports;
c. The fluid domain is the raw mix dust that goes through the calcination process.

2.2 Pre-Processing Stage

a. Creating geometry with geometry build facilities using SolidWorks software

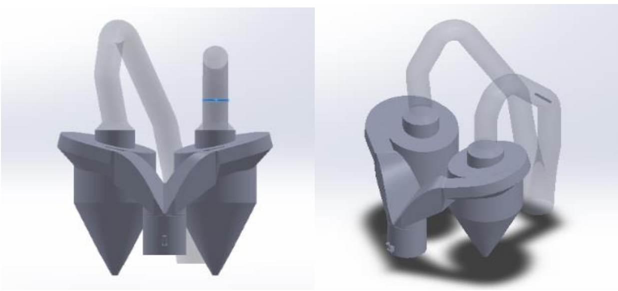

Figure 4. 3D Modeling on Multicyclone Preheater with Solidworks

b. Meshing. Determine the type of mesh that will be used. In this simulation, tetrahedron type meshing is used. Figure 5 shows the meshing used in this simulation

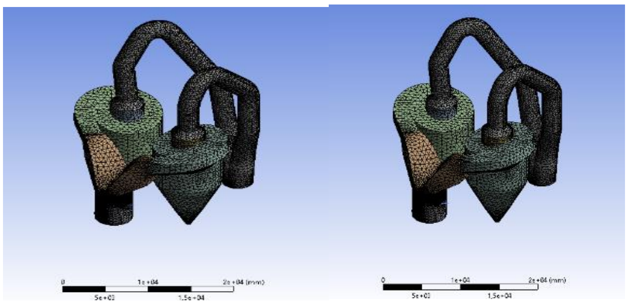

Figure 5. Meshing Baseline on Multicyclone Preheater

2.3 Solution stage (Solver Execution)

At this stage, the equations used in the CFD simulation will be solved iteratively until they reach a convergent condition. The level of accuracy of this solver execution is influenced by: the level of accuracy of the limitations or assumptions used, meshing, and numerical errors (either due to software limitations or due to errors in software users).

2.4. Post Processing Stage

At this stage, the results of the CFD simulation that has been performed will be obtained. The results of this CFD simulation can be in the form of velocity vector plots, pressure distribution contours, the magnitude of aerodynamic forces, etc. The results we get at this post-processing stage need to be tested again to get more accurate results.

III. RESULT AND DISCUSSION

The design optimization carried out in this study is by adding a baffle plate to the outlet duct to balance the gas flow from the top cyclone preheater. To make this research-focused, it is necessary to limit the problems including:

1. The simulation is carried out from before the gas is split from CN2 to CN1-A and CN1-B until the meeting of the two exhaust gases from CN1-A and CN1-B
2. Operating conditions are taken at a steady-state kiln with an average production rate of 95%
3. Modifications are made by adding a baffle plate at one of the duct outlets with a variable baffle plate width of 210 mm, 250 mm and 300 mm.

The first step in the simulation is to determine the parameters that will serve as the baseline. In table 1, several parameters that can be used to determine this simulation according to actual conditions are the gas mass flow at the output of each cyclone and the gas temperature in the downcomer. These two parameters were chosen because the actual data could be taken and also had a big effect on unbalancing conditions in the multi-cyclone system.

Table 3. Mass flow distribution and actual & baseline temperature

Operational	Mass Flow %			Temperature °C			
	CN1-A, short	CN1-B, long	Diff	CN-A (short)	CN-B (long)	Diff	downcomer
Actual	60	40	20	426	366	60	397
Baseline (simulation)	62.45	37.55	24.9	452.1	406.9	45.2	400.5

In table 3, quantitatively CN1-A has a mass flow of 62.45% and CN1-B of 37.55% from the inlet. This value is comparable to the actual conditions where CN1-A has a mass flow of 60% and CN1-B has a mass flow of 40%. From these results, it can be concluded that this baseline can represent the actual conditions. Furthermore, the data used to run this baseline simulation will be used to simulate CFD Cyclone with the condition of the outlet ducts installed with baffle plates of different sizes.

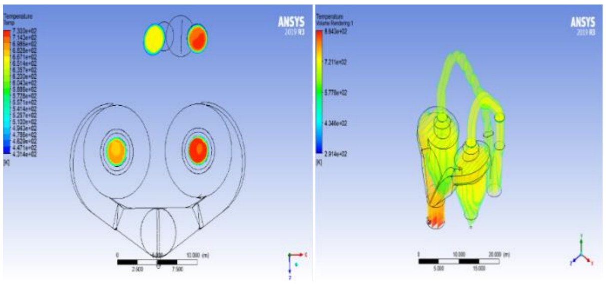

Figure 6. Temperature profile at baseline conditions

From Figure 6, it can be seen that the gas temperature in the cyclone with a shorter outlet duct (right side) is brighter, which qualitatively indicates that the cyclone temperature is hotter. Quantitatively, it is found that the temperature of the CN1-A cyclone for the short outlet duct is 452.1 °C, while the temperature in the CN1-B cyclone for the long outlet duct is 406.9°C.

The modification made to balance the gas flow in this CFD simulation is to install the baffle plate on the shorter duct outlet. Position the baffle plates in an easily accessible area for installation and maintenance considerations. Figure 7 shows the position of the baffle plate in the simulation.

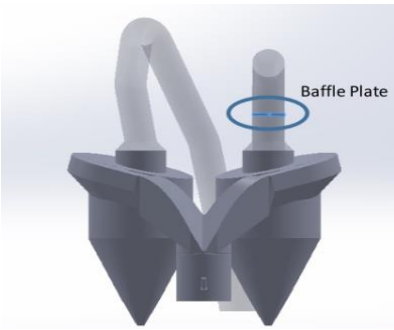

Figure 7. Position of baffle plate on the shorter outlet duct

3.1 Modification with 210 mm Baffle Plates

Figure 8 shows the temperature conditions of the simulation results after adding a 210 mm wide baffle plate to the short duct of CN1-A. From the simulation data, it is found that CN1-A temperature is still higher than CN-B at 21.18°C and mass flow distribution is still large CN1-A than CN1-B is 15.66%.

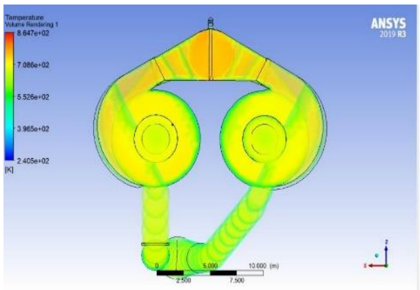

Figure 8. Temperature profile with the addition of 210 mm baffle plate

3.2 Modification with 250 mm Baffle Plates

Figure 9 shows the temperature conditions of the simulation results after adding a baffle plate with a width of 250 mm on the short duct side of CN1-A. The temperature difference was around 16.94°C and the mass

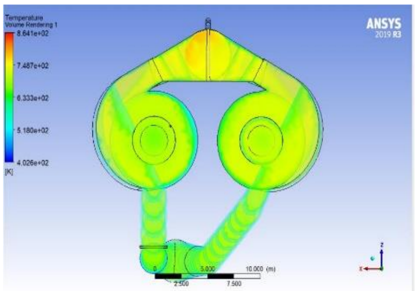

Figure 9. Temperature profile by adding 250 mm baffle plate

3.3 Modification with 250 mm Baffle Plates

In a simulation with a baffle plate size of 300 mm, the temperature difference is the same as the baffle condition of 250 mm, but the mass flow balance has shifted from CN-A to CN-B by 5.39%.

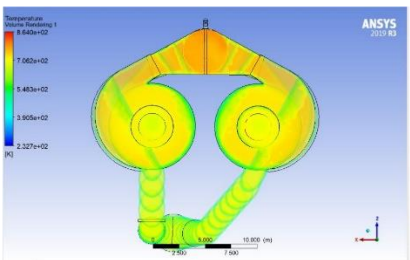

Figure 10. Temperature profile by adding 300 mm baffle plate

Table 4. Mass flow distribution and temperature before and after simulation

Operational	Mass Flow %			Temperature				Pressure mbar
	CN1-A, short	CN1-B, long	Diff	CN-A (short)	CN-B (long)	Diff	downcomer	
Baseline	62.5%	37.5 %	25%	452	407	45	400.5	0
Add Baffle Plate								
210 mm	57.83 %	42.17 %	15.66%	434.2	413.1	21.18	398.1	0.99
250 mm	51.88 %	48.12 %	3.77 %	429.5	412.6	16.94	396.3	1.40
300 mm	47.30 %	52.70 %	-5.39 %	415.1	431.5	16.38	397.1	2.02

Based on the simulation results in table 4°, heat loss can be calculated using the equation in point 2.2.1 and converted into rupiah according to the specific thermal cost for the use of existing coal. Assuming the material heat capacity value (Cp) is considered constant, the production rate is 95% of the design capacity, the operating time is 310 days in 1 year, then the heat loss value and potential savings per year can be seen in table 5.

Table 5. Heat loss simulation results and potential savings

Baffle Plate Width	Temp. downcomer, °C	Heat Loss, MJ/s	Heat Improvement, MJ/s	Heat Improvement, %	Potential saving, IDR/year
Base line	400.5	52.88	0	0	0
210 mm	398.1	52.54	0.34	0.64	412,430,381.10
250 mm	396.3	52.29	0.59	1.13	**721,753,166.93**
300 mm	397.1	52.40	0.48	0.92	584,276,373.23

Based on the three tests carried out on the twin cyclone, the following CFD simulation results are obtained:

a. The addition of a 210 mm baffle plate to the CN1-A duct outlet did not have a significant effect on temperature and mass flow. Where the cyclone CN1-A temperature was 21.18°C higher and the CN1-A velocity was 15.66% higher. However, from the heat loss, there is a decrease of 0.33 MJ / s or 0.64% from the baseline, so there is a potential savings of 421 million Rupiah per year.
b. The addition of a 250 mm baffle plate to the CN1-A duct outlet has a positive effect on temperature and mass flow. Where the cyclone CN1-A temperature was 16.94°C higher and mass flow was 3.77% higher. Judging from the heat loss value, there is a decrease of 0.59 MJ / s or 1.13% of the baseline and a potential savings of 722 million rupiahs per year.
c. The addition of a 250 mm baffle plate to the CN1-A duct outlet has a positive effect on temperature and mass flow. Where the cyclone CN1-B temperature was 16.38°C higher, but CN1-B mass flow was 5.39% higher. Judging from the heat loss value, there is a decrease of 0.48 MJ / s or 0.92% and a potential savings of 584 million rupiahs per year.

From the three tests, the gas flow balance position is achieved when the baffle plate is installed with a width of between 250 - 300 mm inside the duct outlet of CN1-A.

According to the simulation results in table 4, with the addition of baffle plates, the mass flow experienced a significant improvement from 25% to 3.77% and the difference in temperature difference decreased from 45°C to 16°C. The downcomer temperature has also decreased by approximately 2-4°C, which indicates that the more balanced flow in the two multi cyclones can increase heat transfer.

A decrease in downcomer temperature will also have a positive effect on ID Fan and maintenance. However, the addition of baffle plates also had a negative impact, namely an increase in pressure drop in the multi-cyclone system by 1.40 - 2.02 mbar. This increase in pressure drop needs to be compensated by the ID fan, which in turn will increase the load on the ID fan and increase the power consumption of the ID fan (in good accordance with [13]). Further research is still needed to be able to analyze the effects of this problem.

IV. CONCLUSION

The simulation process uses CFD for twin cyclones with different outlet duct lengths between CN1-A and CN1-B. From the simulation can be concluded that the gas flow balance is achieved when the baffle plates are installed with a width between 250 - 300 mm, and causing difference in mass flow and temperature, Mass flow has decreasing significantly from 25% to the range of 3.77%, as well as the temperature has decreasing from the previous 45°C to 16°C. Judging from the value of heat loss, the potential savings that can be obtained range from 0.9 - 1.3% or equivalent to 584 - 722 million rupiah per year. However, this simulation result will certainly provide its own challenges for the next researchers, to find out the effect of unbalance gas flow on cyclone efficiency and the effect of increasing pressure drop and steps to anticipate it.

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