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Research Paper

Analysis of the Influence of Center tube on Cyclone Preheater Efficiency in Production Units in the Cement Industry

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ABSTRACT: *Cyclone Suspension preheater is an important part of the kiln unit which aims to separate materials and hot gases. The Suspension preheater consists of two strings, namely strings A and B and consists of 4 stages with stage 4 and stage 3 of string B not having a center tube. The efficiency calculation is carried out to determine the ability of the cyclone to separate material and gas and compare the efficiency of the cyclone which has a center tube with a cyclone without a center tube. The efficiency calculation is calculated using the Bohnet calculation. The efficiency calculation was obtained at stage 1 string A of 92.15%, stage 1 string B of 92.16%, stage 2 string A of 87.71%, stage 2 string B of 87.627%, stage 3 string A of 81.987%, stage 3 string B of 78.008%, stage 4 string A of 72.877%, and stage 4 string B of 73.459%. There was a decrease of 4% from stage 3 string A to stage 3 string B. A reduction in efficiency was observed in cyclones without a center tube. The gas flow in the cyclone is more regular with the presence of a center tube and has a longer residency time compared to a cyclone without a center tube. A cyclone without a center tube has a chaotic flow and turbulence can increase so that the separation between particles and gas is inefficient. The presence of a center tube effectively improves both separation efficiency and gas flow stability in the cyclone.*

Keywords: *Cyclone, separation efficiency, center tube, cut off diameter, gas flow.*

1. INTRODUCTION

A cyclone separator is a device used to separate solid particles from a gas or liquid stream by utilizing centrifugal force [1]. This tool is often used in industry to reduce air pollution and improve the efficiency of the production process [2]. Its working principle is based on a vortex flow that forces heavy particles to move outward, towards the cyclone wall, while clean gas or air exits the top of the device. The workings of a cyclone separator begin when a gas or liquid mixture containing solid particles enters the separator through a spiral-shaped inlet. The flow is then forced to rotate inside the cylinder or cone of the separator, creating a centrifugal force that pushes the solid particles to the outer wall of the device. The particles then fall to the bottom of the separator and are collected, while the gas or liquid that has been cleared of solid particles exits through the upper channel.

In the cement industry, cyclones are used as preheating before entering the calciner [3]. This cyclone is also used to increase thermal efficiency by utilizing the heat of the exhaust gas from the kiln to heat the raw material that has been fed. The suspension preheater has four stages and two strings (strings A and B) that work simultaneously. In the fourth stage, strings A and B and the third stage B string do not have a center tube which will affect the effectiveness of the cyclone work. Vortex finder or Center tube is one part of the cyclone that can affect the vortex flow and also control the output flow of the cyclone [4]. Center tube plays an important role in keeping the gas flow directed, optimizing centrifugal force, and ensuring clean gas comes out with minimal solid particles. Gas flow in the cyclone can also affect the separation efficiency of the

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cyclone. Gas flow refers to the gas flow that occurs in a particle separation system using the principle of cyclone separation [5]. By paying attention to factors such as the geometry of the cyclone, characteristics and flow velocity in the cyclone will be able to improve the separation efficiency and performance of the cyclone.

Research conducted by Zheng, Y., et al [6] on the effect of center tube length on ECSD separation performance through numerical simulation found that increasing the center tube length can increase the separation efficiency, where the center tube length of 1.5 times the cylinder cross-sectional length produces an efficiency above 80%.

The efficiency of the cyclone also depends on the equilibrium between the length and diameter of the center tube [7]. A good and ideal arrangement will allow an increase in the centrifugal force generated and reduce turbulence, thus increasing the separation efficiency. Without a center tube, there will be a decrease in efficiency, an increase in dust emissions, as well as an increase in pressure drop and turbulence within the cyclone, all of which will negatively impact the cyclone's overall performance and operating costs. The absence of a center tube will certainly affect the effectiveness of the cyclone's work, therefore it is necessary to review the effectiveness of the cyclone's performance. The parameters that affect this are cyclone design, temperature, pressure, gas flow, and density.

2. RESEARCH METHOD

The analysis method in this calculation includes several important data in the form of design data and actual data in the field. This design data contains gas flowrate, gas viscosity, gas density, solid density, diameter, cyclone body length, cyclone cone length, center tube length, center tube diameter, down pipe diameter, inlet width, inlet length and inlet width. While the actual data in the field used are the pressure in the cyclone, the temperature in the cyclone and the weight of the clinker product.

The methodology used in this completion includes literature study, data collection, data processing with Bonet 1997 [8] calculations with the following steps:

1) Calculating the K rasio

The K ratio consists of K_H, K_B, K_S, K_i, K_L, K_D, K_Z from the dimensions of the cyclone in the cement industry. K_H is the quotient of the height of the inlet feed with the diameter of the cyclone, K_B is obtained from the quotient between the length of the inlet feed cyclone and the diameter of the cyclone. K_S is the quotient of the length of the center tube with the diameter of the cyclone, K_i is obtained from the quotient between the diameter of the center tube with the diameter of the cyclone. K_D is obtained from the quotient between the diameter of the cyclone material output and the diameter of the cyclone, K_Z is the quotient of the length value of the bottom of the cyclone (the sloping part of the cyclone body) with the diameter of the cyclone. While K_L is obtained from the quotient between the length of the top cyclone (the upright part of the cyclone body) and the diameter of the cyclone.

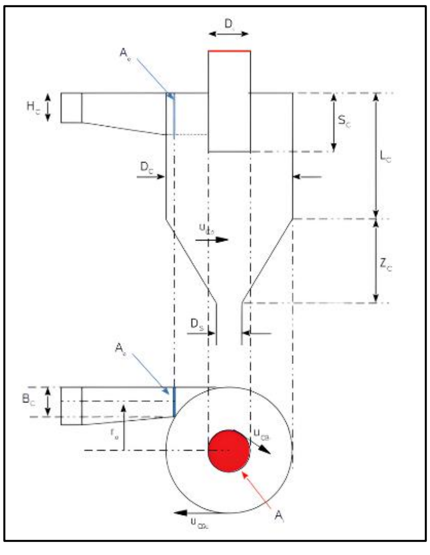

Figure 1. Image of a cyclone and it is characteristic geometry name

$$Hc/Dc=K_H \quad (1)$$
$$Bc/Dc=K_B \quad (2)$$
$$Sc/Dc=K_S \quad (3)$$
$$Di/Dc=K_i \quad (4)$$
$$Lc/Dc=K_L \quad (5)$$
$$Zc/Dc=K_Z \quad (6)$$
$$Ds/Dc=K_D \quad (7)$$

2) Calculating Geometrical Dimensions

$$\frac{Ae}{Ai} x \frac{Ri}{re} = \frac{4}{\pi}\frac{K_B K_H}{{K_I}^2}\frac{K_I}{1-K_B} \quad (8)$$

$$\frac{Af}{Ai} = 1+4\frac{K_S}{K_I} + \frac{1}{{K_I}^2}(1 + 4K_L + 2K_Z(1 + K_S)) \quad (9)$$

3) Calculating the Inlet and Outlet Velocity

$$\mathrm{U}ce = \frac{Vc}{K_B K_H Dc^2} \quad (10)$$

$$\mathrm{U}ci = \frac{4Vc}{Ki^2 \pi Dc^2} \quad (11)$$

4) Calculating friction coefficient

- Coefficient of contraction at inlet

$$\mathrm{Ce} = 1\text{-}(0.680\text{-}0.151\frac{Ki^2}{K_B K_H}){K_B}^{1/3} \quad (12)$$

- Cyclone walls velocity (m/s)/inlet velocity (m/s)

$$\frac{ucc}{uce} = (0.889 - 0.408KB)^{-1} \quad (13)$$

- Reynolds number

$$\mathrm{Rec} = \frac{\rho c\, ucc\, \mathrm{Dc}}{\mu c} \quad (14)$$

- Coefficient of friction

$$\mathrm{C}f = 2.5\mathrm{x}10^{-3} + \frac{144}{\mathrm{Rec}} \quad (15)$$

5) Calculate Characteristics Velocities

$$u_{Cri} = \frac{Vc}{\pi D^2 K_i (K_L + K_z - K_S)} \quad (16)$$

$$\frac{u_{C\theta i}}{u_{Ci}} = \left[C_e \frac{A_e}{A_i}\frac{R_i}{r_e} + C_f \frac{A_f}{A_i}\sqrt{\frac{R_i}{r_e}}\right]^{-1} \quad (17)$$

- Cut off diameter

$$d_C = 2.846\sqrt{\frac{u_{Cri}\mu_C K_i D_C}{\Delta\rho u_{C\theta i}^2}} \quad (18)$$

6) Efficiency

$$\eta\left(\frac{d_i}{d_C}\right) = \frac{1}{2} + \frac{1}{2}\cos\left(\pi\left[1 - \frac{\ln\left(\Gamma\frac{d_i}{d_C}\right)}{\ln\Gamma^2}\right]\right) \quad (19)$$

With the data obtained, the geometry ratio for each stage of the cyclone is shown as follows:

Table 1. Geometry Ratio of Each Stage Cyclone

Cyclone	***Stage* 1**	***Stage* 2**	***Stage* 3**	***Stage* 4**
	***String* A and B**	***String* A and B**	***String* A and B**	***String* A and B**
KH	0.523	0.3212	0.3212	0.3212
KB	0.240	0.200	0.2000	0.2000
KS	0.765	0.5121	0.5121	0.6204
KI	0.544	0.588	0.5883	0.5882
KL	2.059	1.1913	1.1889	2.409
KD	0.098	0.1493	0.1493	0.1637
KZ	0.982	0.9167	1.1399	1.1311

(Source: Personal calculation with design data, Cement Factory)

For calculations on cyclones without center tube, the Ks value is 0.

3. RESULTS AND DISCUSSION

3.1. Effect of Center tube on Cyclone Efficiency

The cyclone is located in the preheating unit, namely the suspension preheater. Suspension preheater is a series of several cyclones that are used as preheating before entering the kiln in the cement industry [9]. In the suspension preheater there are two strings, namely string A (SA) and string B (SB). Each string has 5 cyclones, of which there are two A51 cyclones with smaller sizes than the A52, A53, and A54 cyclones. Likewise with cyclone B51 there are two with smaller sizes than cyclone B52, B53, and B54. The suspension preheater uses heat from the recovery of hot air coming out of the rotary kiln, which then flows through the cyclone to heat the raw material before entering the rotary kiln [10].

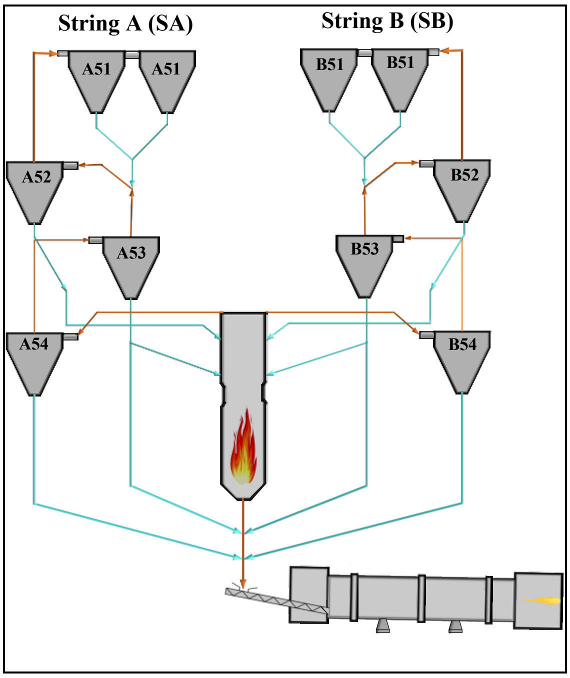

Figure 2. Suspension Preheater

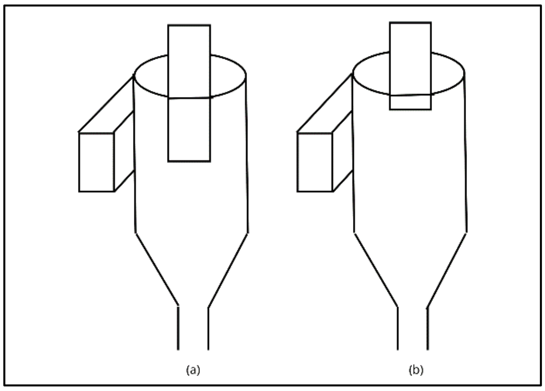

Figure 3. (a) cyclone with center tube and (b) cyclone without center tube

The process in the suspension preheater begins with the raw mix entering from the top of cyclone A51 and B51 on the side. The heat transfer process occurs in the riser duct in a co-current and counter current manner and then enters the cyclone. In the cyclone there is centrifugal force, gravity, and lifting force [11], [12], [13]. Centrifugal force causes the material to rotate and stick to the cyclone wall. Gravity causes the material to fall and enter the next cyclone. In the cyclone, raw mix material enters through cyclone A51 and A51, along with hot air from A52. The material then falls towards cyclone A52 to meet the hot air from cyclone A53. The material then falls, partly towards cyclone A53 which meets the hot gas from cyclone A54, partly towards the calciner. Material from cyclone A53 goes directly into the calciner and undergoes a calcination process, while material A54 goes to the kiln, the process also occurs in string B.

Table 2. Efficiency of cyclone with center tube

Cyclone	Stage 1	Stage 2	Stage 3	Stage 4
String A	92.150%	87.710%	81.987%	75.969%
String B	92.160%	87.627%	82.410%	76.519%

Table 3. Efficiency of cyclone without center tube

Cyclone	Stage 1	Stage 2	Stage 3	Stage 4
String A	92.150%	87.710%	81.987%	72.877%
String B	92.160%	87.627%	78.008%	73.459%

The cyclone serves as a place of separation between material and gas and preheating. The cyclone design plays an important role in this separation process, the more efficient the cyclone, the less dust lost [14]. Excessive dust loss causes losses because the material losses to the BHF must re-enter the cyclone and experience the separation process again. This process involves a lot of equipment which causes more energy to be used.

The part of the cyclone that plays an important role in this process is the center tube, where the center tube functions in keeping the clean gas flow separated from the particles that are still in the separation process. When you lose the center tube, the gas flow in the cyclone becomes more unstable and allows the gas to go to the outlet before it has time to go to the particle outlet. Therefore, it is necessary to calculate the effect of the absence of a center tube on cyclone efficiency.

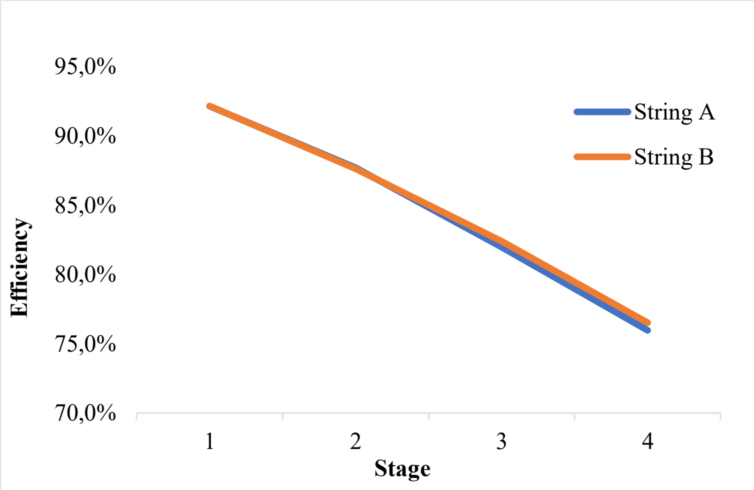

Figure 4. Efficiency of Cyclone with Center tube

The figure above is a comparison of cyclone efficiency when there is still a center tube. In the figure it is found that the cyclone efficiency in string A stage 1 is 92.15%, stage 2 is 87.71%, stage 3 is 81.987% and stage 4 is 72.877%. In string B stage 1 is 92.160%, stage 2 is 87.627%, stage 3 is 78.008% and stage 4 is 73.459%.

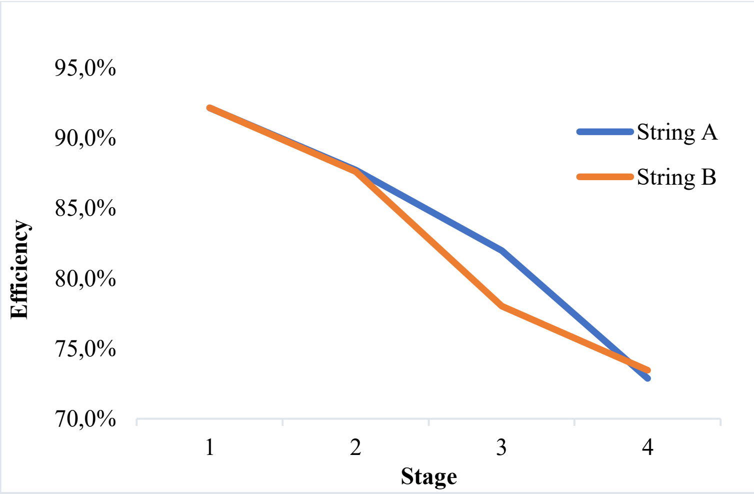

Figure 5. Cyclone efficiency without center tube

Cyclones that do not have a center tube will experience a significant decrease. After the absence of the center tube, cyclone stage 3B decreased by 6% from 81.987% to 78.008%. In cyclone stages 4A and 4B also experienced 3% and 2% respectively. This decrease causes dust loss from the stage that has decreased to increase and causes an increase in the load on the next stage and more output at the BHF. In addition, in the absence of this center tube, the thermal comsumtion energy increases due to the greater pressure required by the cyclone.

The dimensions of the cyclone design greatly affect the efficiency of the cyclone produced. The higher the cyclone , the more time will be available for particles to rotate and collide with the walls, so that more particles are collected [15]. In addition, the width of the inlet also affects the speed of gas entry into the cyclone. A largerinlet will provide an increase in input velocity and cause greater centrifugal force, so that particles are pushed faster to the cyclone wall. The length of the center tube is related to the probability of particle separation, longer center tubes are associated with higher efficiency.

The expected cyclone efficiency will be achieved with the center tube. However, the absence of a center tube on the cyclone now causes a decrease in the efficiency of the cyclone . If the center tube is also too short, it will cause short circuit flow which reduces the intensity of the vortex and causes particles to separate poorly [16]. Therefore, the absence of a center tube will greatly affect the intensity of the vortex in the cyclone. The absence of a center tube also affects the cut off diameter value produced. Cut off diameter is the particle size that can be effectively separated by the cyclone, this diameter is the smallest particle size that can theoretically be captured by the cyclone with 50% efficiency [17]. Cut off diameter will increase if the cyclone has no center tube. A longercenter tube provides a longer time for particles to be pushed towards the cyclone wall, thus increasing the capture efficiency of smaller particles. If there is no center tube , the capture efficiency of smaller dust particles will decrease, so that larger dust particles will be captured.

3.2. Effect of Using Cyclone Center tube on Gas Flow

The center tube in the cyclone has a very important role in directing the gas flow and separating solid particles from the gas flow. The center tube helps in creating a more stable gas flow by reducing turbulence in the cyclone [18]. With this center tube, the gas flow velocity in the cyclone is more controlled. The impact of cyclone cone length on the gas flow field indicates that both the cone length and cone angle significantly influence the flow pattern inside the cyclone [19]. The gas flow value is in units of Nm^3/ kg clinker which refers to the volume of gas under standard conditions (Nm^3) flowing per kilogram of clinker. In the calculation process used, the gas flow value is first converted into m^3/h or m^3/h units by using calculation components such as environmental pressure, actual pressure, environmental temperature, actual temperature, feed amount, and clinker factor. The amount of feed is taken from the average incoming feed in 7 days, which is 549,299.11 kg/hour, while the clinker weight is obtained from the quotient of the clinker factor of 1.65 with the amount of incoming feed, so that the clinker weight is 332,908.5486 kg of clinker. This gas flow unit change is needed to find the efficiency of the cyclone.

Table 4. Supporting data for converting gas flow units from Nm^3/kg clinker to m^3/h.

Cyclone	Ambient Pressures (Pa)	Actual Pressure (Pa)	Ambient Temperature (K)	Actual Temperature (K)
A51	101,325	97,071.51	303.15	723.11
B51	101,325	97,033.99	303.15	722.46
A52	101,325	97,900.86	303.15	901.34
B52	101,325	97,711.14	303.15	902.68
A53	101,325	98,149.00	303.15	1,060.94
B53	101,325	98.149.00	303.15	1,045.27
B53 with center tube	101,325	98,149.00	303.15	1,045.27
A54	101,325	99,284.77	303.15	1,204.68
B54	101,325	99,459.96	303.15	1,186.26
A54 with center tube	101,325	99,284.77	303.15	1,204.68
B54 with center tube	101,325	99,459.96	303.15	1,186.26

The following are the gas flow values in units of Nm^3/kg clinker per stage in string A and string B.

Table 5. Gas flow cyclone with center tube

Cyclone	Stage 1	Stage 2	Stage 3	Stage 4
String A	0.7075	1.371	1.340	1.338
String B	0.7075	1.371	1.340	1.388

Based on the gas flow, a graph of gas flow and efficiency of cyclone string A and string B is obtained as follows:

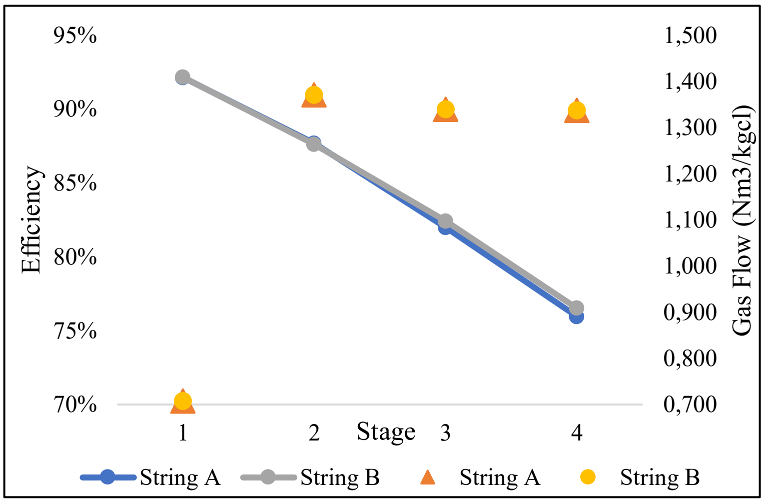

Figure 6. Comparison graph of gas flow (Nm^3/kgcl) with center tube cyclone efficiency

The figure above shows the relationship between gas flow and cyclone efficiency in the presence of a center tube. The data used is design data taken from the cement industry. Stage I cyclone has the lowest gas flow value compared to the others, this is because the design of the stage I cyclone has smaller dimensions compared to other cyclones. However, at stage I, the cycone has the highest separation efficiency compared to the others. The flow velocity and flow pattern in the cyclone are determined by the geometry of the center tube in the cyclone [20]. Gas flow in the cyclone with the center tube will be more stable and more regular movement so that the separation between particles and gas is better because the regular flow causes a long enough residence time until the solids come down through the bottom cyclone output or solids output. The length of the center tube on the cyclone can help reduce flow disturbances around the outlet and ensure that a clean stream of gas exits the cyclone without disturbing the flow of the rotating cyclone. Optimal center tube length can improve separation performance by extending the contact time between gas and particles, however excessive length can lead to increased pressure drop [21]. The center tube length needs to be optimized in order to maintain the pressure drop value. Stagnation pattern in the context of a cyclone refers to a condition where the gas flow slows down or even stops (stagnates) in a certain region within the cyclone. This mainly occurs near the center of the cyclone or on its axial axis, where the axial velocity becomes very low or zero [22].

3.3. Effect of Using Cyclone Without Center tube on Gas Flow

The following are the gas flow values in units of Nm^3/kg clinker per stage in string A and string B.

Table 6. Gas flow cyclone without center tube

Cyclone	Stage 1	Stage 2	Stage 3	Stage 4
String A	0.7075	1.371	1.340	0.802
String B	0.7075	1.371	0.804	0.802

Based on the gas flow, a graph of gas flow of cyclone string A and string B is obtained as follows :

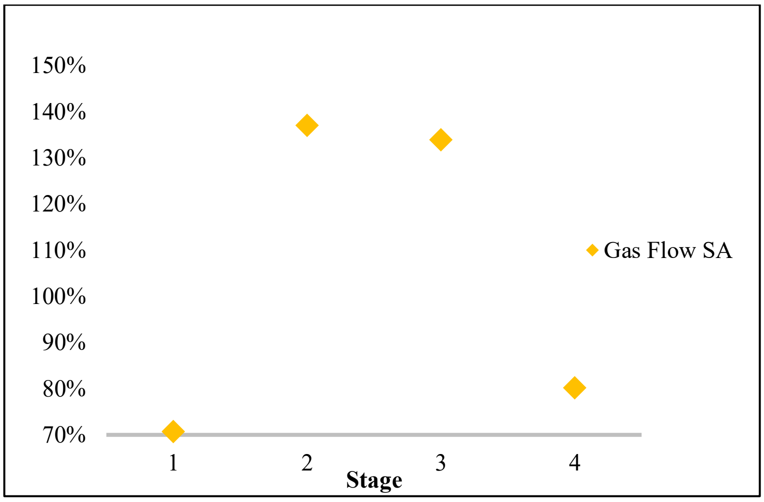

Figure 7. Comparison graph of gas flow in string A

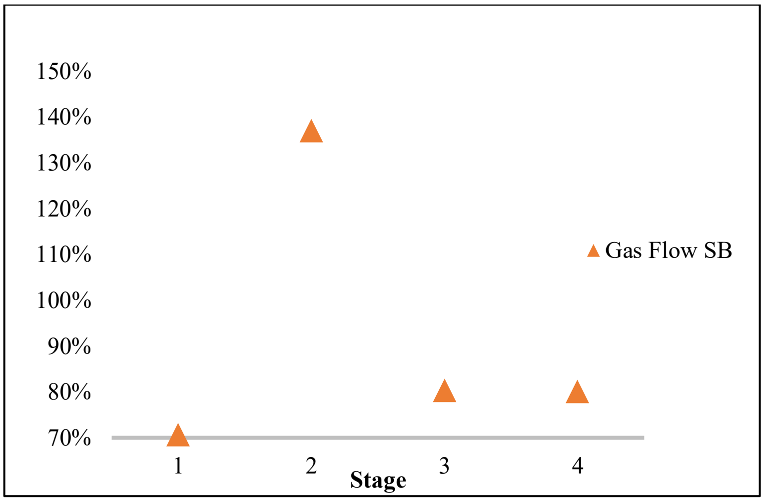

Figure 8. Comparison graph of gas flow in string B

The figure above shows the relationship between gas flow and cyclone efficiency without center tube. Cyclone that lost the center tube is found in the String B stage III and IV cyclone and string A stage IV. Stage III experienced a decrease in efficiency due to the absence of a center tube, but in the stage III string B graph experienced a decrease in the value of gas flow, as well as stage IV, Figure 6 shows the efficiency of the stage IV cyclone is in the range of 74% - 77% with the center tube and gas flow at a value of 1.338 Nm3/kg clinker. Figure 7 shows a decrease in efficiency in the range of 72%-74% with the gas flow value dropping to 0.802 Nm3/kg clinker. It has not been proven that the absence or absence of a center tube on the cyclone causes the gas flow value of the cyclone to drop. The absence or presence of a center tube will certainly affect the shape of the flow and residence time of the gas with the solids to be separated in the cyclone [23].

Generally, larger particles will have a longer residence time inside the cyclone body [24]. A cyclone that does not have a center tube residence time will be shorter due to the formation of irregular flow so that the centrifugal force created is not better than a cyclone that has a center tube. This residence time means that how long the mixture of gas and solids in the cyclone experiences centrifugal force, where the center tube plays a role in regulating and creating this centrifugal force. Gas and solids entering from the inlet of the cyclone will form a centrifugal force and swirl a little in the cyclone which then the gas will go up and the solid particles go down to the outlet of the cyclone a little. Gas flow that occurs is irregular or turbulence increases.

Research has been conducted by Wojtowich, R., et al [25] where he compared gas flow using flow patents on 5 types of cyclone with different dimensions of vortex finder or center tube. It was found that the gas flow on the short center tube was turbulent and irregular when the initial part of the gas outlet passed through the center tube. Without the center tube, the centrifugal force created is not strong enough to push the particles towards the cyclone wall to capture the solid particles, so this will make the cyclone separation efficiency reduced. The gas flow pattern inside the cyclone will not be well controlled, because the center tube function as a flow director does not work. The absence of a center tube causes the flow to be chaotic and turbulence will increase. The gas flow is likely to shift faster from downward spiral flow to the top of the cyclone, making it possible for the solids to be separated from the carrier gas to be carried back to the next cyclone.

4. CONCLUSION

Based on the calculations carried out, it can be concluded that the absence of a center tube on the cyclone causes a decrease in efficiency on the cyclone. Cyclones that experience a decrease in efficiency will increase the cyclone load and cause losses. Currently, the cyclone in stage 3 string B and stage 4 string A and B does not have a center tube so that the efficiency drops by 2% to 4%. This decrease causes the function of the cyclone as a material separator and hot gas carrier to be reduced. The absence of a center tube on the cyclone will certainly be able to affect the gas flow in the cyclone. Gas flow in a cyclone that has a center tube is more regular so that the separation of particles and gas is better due to the longer residence time of gas and particle flow in the cyclone. Gas flow in a cyclone that does not have a center tube is irregular, causing turbulence to increase and the separation between gas and particles is also not good because the residence time in the cyclone is small and the gas only forms centrifugal force in a short time.

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