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Research Article

CFD Analysis Of Flue Gas Streamline Through Varied Of Flow Straightener Inclination

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ABSTRACT

Air emission, generated by industrial sector, is one of the main contributors of ambient air quality degradation. In order to minimize the impact to its surrounding, the company regularly should conduct an air emission monitoring activity by measuring the hazardous compound concentration. The sample should be taken in a reference plane located two diameter from the outlet. The sampling of air emission by using isokinetic method cannot be conducted when the swirling flow is existed; the streamline is also should be uniform and vertical. Flow straightener with difference inclination angles, 0°, 15°, and 30°, are suggested to condition the streamline and fulfill the requirements. A computational simulation conditions with no flow straightener and with three flow straighteners are conducted to overview the influence of flow straightener inclination. Based on the analysis these inclinations are effectively improving the uniformity of velocity at reference plane. In other side these inclinations are causing the increasing of helicity as well as streamline inclination.

Keyword: Flow Straightener, Inclination angle, Helicity

1. INTRODUCTION

Industrial sector is one of the main emission contributors in Indonesia. One of processes is generated by the combustion process. The amount of emission load is determined by the amount of fuel and the quality of equipment used. In 2014 industrial sector is became the largest consumer of energy with a percentage of 48% [1]. Considering the significant impact, the government has been regulating the industrial sector to implement the monitoring/ measurement of air emission quality. This study is aimed to analyze the chimney which it's sampling point does not meet the 8D-2D criteria, where the chimney has 6D of height. The sampling point/reference plane is measured at some distances from the outlet, they are: 2D, 1.5D and 1D from flue outlet.

Particulate emission is measured by isokinetic method, where the sample is taken at some points along two traverse points in the reference plane [2][3]. This method cannot be used when a swirling flow is occured. Because of that a vertical flue gas flow with small angle streamline is required. This swirling flow can lead an error for the measurement of exhaust emissions, particularly related to the increasing of measurement deviation which is reaching of -7.05% [4]. In addition, the uniformity of flow should also be a concern, because the uniformity of velocity is influencing the measurenment result.

2. EXPERIMENTAL SECTION

2.1.Geometry

The geometry of chimney and flow straightener are created with the dimension is resemble to the previous research [5]. The flue gas is flowing through the inlet of chimney in a certain angle which produces a swirling flow. The flow straightener is designed with the height of 0.45 D stack diameter. The detail of dimension is shown in Figure 1. The modification of flow straightener dimension is focused on the inclination angle of flow straightener. So the flow straightener is designed with inverse conical shape (downward position) with the angle of 0°, 15° and 30° as shown in Figure 2.

2.2. CFD Simulation

Having created the geometry, the next process is creating the hexahedron mesh. The size of mesh inside the flow straghtener is arrenged to be 0.015 D, while the others is arranged to be 0.05-0.1D. The flue gas flow and the influence of flow straightener installation was analyzed computationally by using software of fluent. The flue gas temperature is assumed 190°C and with the composition as shown in Table 1 [6]. The average velocity of flue gas at the reference plane is set to be 17.5 m/s [7]. This simulation is using K-Epsilon (reliazable) viscous model with pressure based solver.

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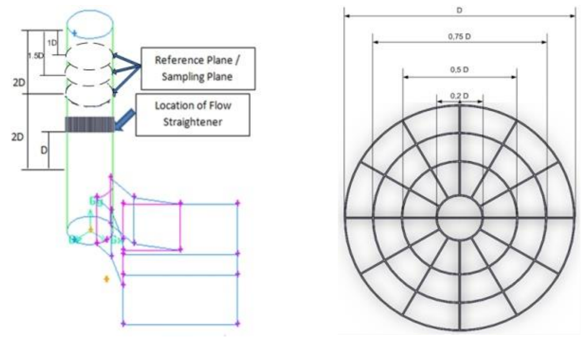
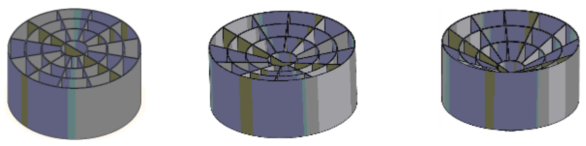


(a) (b)

Figure 1. Fixed dimensions of the geometry (a) Chimney (b) Flow Straightener



(a) (b) (c)

Figure 2. isometric figure of flow straightener (a) with 0o angle (b) with 15o angle, (c) with 30o angle.

3. RESULTS AND DISCUSSION

3.1. Helicity

Helicity is a scalar value obtained by projecting the vorticity to axial velocity of flue gas as shown by the equation (1). The magnitude is directly proportional to the rotational / vortex movement that is occured inside the chimney.

$$H = (\bar{V} x \vec{V}) \cdot \vec{V} \qquad (1)$$

The resume of helicity value for four-simulation conditions is shown in Table 2. While contour of helicity inside the chimney is shown in Figure 3. According to simulation results, the installation of flow straightener is able to reduce helicity. The helicity reduction is inversely proportional to the increase of flow straightener inclination. This relation is occured due to the flow straightener inclination which tends to direct the flue gas to be rotated in counter-clockwise direction.

3.2 Streamline Inclination

The streamline inclination of flue gas is shown by the angle between radial velocity and vertical velocity. The smaller angle indicates the more vertical streamline which is influencing the measurement accuracy as shown in Table 3. The results show that 30° flow straightener produces the largest streamline angle with a maximum and average value of 8.01° and 1.62°. These results show that the more angle of flow straightener inclination, the more angle of flue gas streamline occured. These streamline inclinationss are directly proportional to the value of helicity. Based on the contour of streamline inclination, the largest streamline angle is occured on the left side of chimney (x-negative axis) which generally has a lower vertical velocity. Details of streamline inclination can be seen in Figure 4.

Table 1. Composition of flue gas [8]

Substance	Volume fraction (%)	Mass fraction (%)
Carbon Dioxide (CO2)	11	16,66
Argon (Ar)	1	1,32
Water vapor (H2O)	6	3,97
Oxygen (O2)	6	6,57
Nitrogen (N2)	76	72,81
Other substances	Near zero	Near zero

Table 2. Helicity values at the reference planes

Simulation Condition	Maximum Helicity (m/s2)	Average Helicity (m/s2)
With no flow straightener	733.37	385.32
With 0° flow straightener	667.58	45.42
With 15° flow straightener	717.81	53.59
With 30° flow straightener	873.72	67.18

Table 3. The Maximum and Average Streamline Inclination in reference plane

Simulation Condition	Maximum (°)		
	2D from outlet	1.5D from outlet	1D from outlet
With no flow straightener	43.34	38.84	35.57
With 0° flow straightener	6.42	5.16	2.97
With 15° flow straightener	7.09	3.98	3.07
With 30° flow straightener	8.01	4.6	3.29
Simulation Condition	Average (°)		
	2D from outlet	1.5D from outlet	1D from outlet
With no flow straightener	17.47	16.46	16.05
With 0° flow straightener	1.41	0.97	0.78
With 15° flow straightener	1.45	0.98	0.78
With 30° flow straightener	1.62	1.01	0.82

3.3 The Uniformity of Velocity

Figure 5 shows the velocity profile of flue gas from inlet to outlet of chimney and the velocity profile in the reference plane where located at 2D, 1.5D and 1D from the outlet. This pictures show that by increasing the inclination angle of flow straightener, it will cause the increasing of velocity in the right side of chimney (x-positive axis). Then it increases the uniformity of velocity. The method used to calculate the uniformity of velocity is taken by calculating the Coefficient Variation (CV). The coefficient of var-

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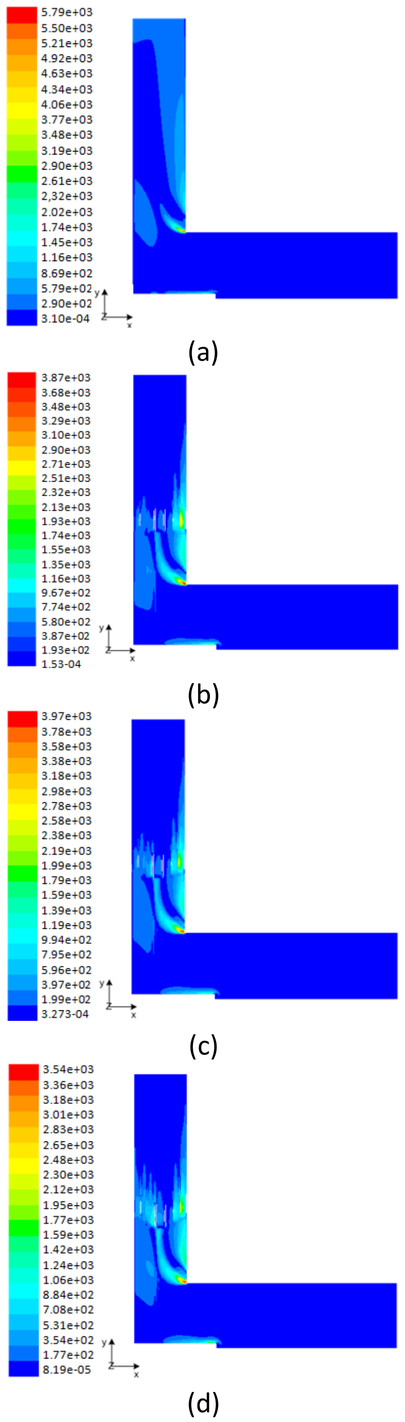

Figure 3. The helicity contours from inlet to outlet of chimney (a) with no flow straightener, (b) with 0o flow straightener (c) with 15o flow straightener, (d) with 30o flow straightener.

iation is calculated by the following formula:

$$CV = \frac{|v-\bar{v}|}{\bar{v}} x100\% \quad \text{.................................(2)}$$

By taking the average value of CV, then it obtain the CV value of each simulatin as shown in Table. 4. Based on the result, the 30° flow straightener is able to generate the most uniform velocity at the reference planes. These results also show that the closer plane to the chimney outlet, the more uniform velocity is obtained.

CONCLUSION

Computational simulations have been performed to exemine the effect of flow straightener inclination to the flue gas flow at the reference plane. The reference planes are located at a distance of 2, 1.5 and 1 times diameter of flue outlet. The velocity profile and streamline inclination are presented in contour form. Meanwhile the uniformity of velocity is determined by calculating the average value of the coefficient of variation.

Based on the results, these modifications are effectively improving the uniformity of velocity in some reference planes. The best variation coefficient is generated by 30° flow straightener with value of 35.05% located 2D before outlet, 33.58 % located 1.5D before outlet and 32.37% located 1D before outlet. On the other hand the increasing of flow straightener inclination is causing the increasing of helicity. Where this increasing of helicity is proportional to the increasing streamline inclination. The highest streamline inclination which is generated by 30° flow straightener is located in the area near chimney wall. Since the inclination angle is relatively low and the emission measurement do not be taken in the area near to the wall, it is predicted that the stremline

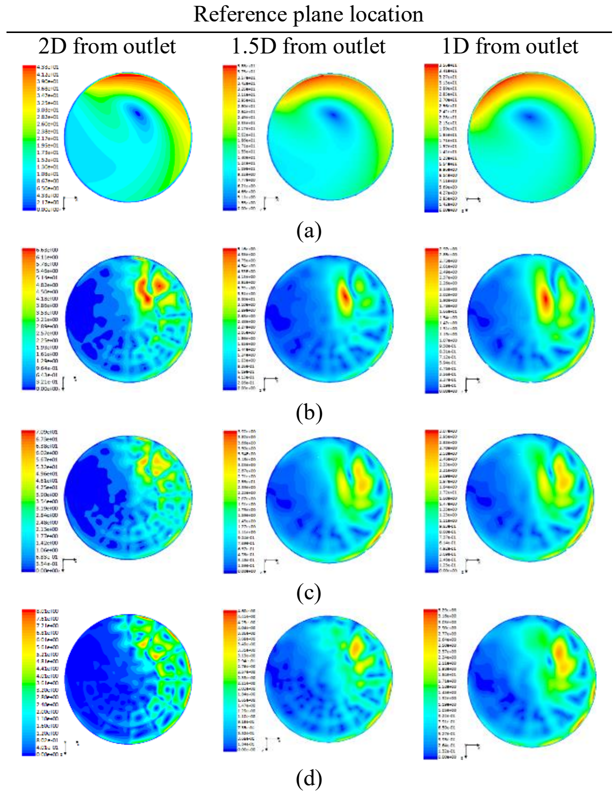

Figure 4. The contour of streamline inclination at reference plane (a) with no flow straightener, (b) with 0o flow straightener (c) with 15o flow straightener, (d) with 30o flow straightener

Tabel 4. Average of variation coefficient for each simulation

Simulation condition	Reference plane location (%)		
	2D from outlet	1.5D from outlet	1D from outlet
With no flow straightener	21.61	18.54	16.4
0° With flow straightener	36.91	35.11	33.78
With 15° flow straightener	36.33	34.73	33.4
With 30° flow straightener	35.05	33.58	32.37

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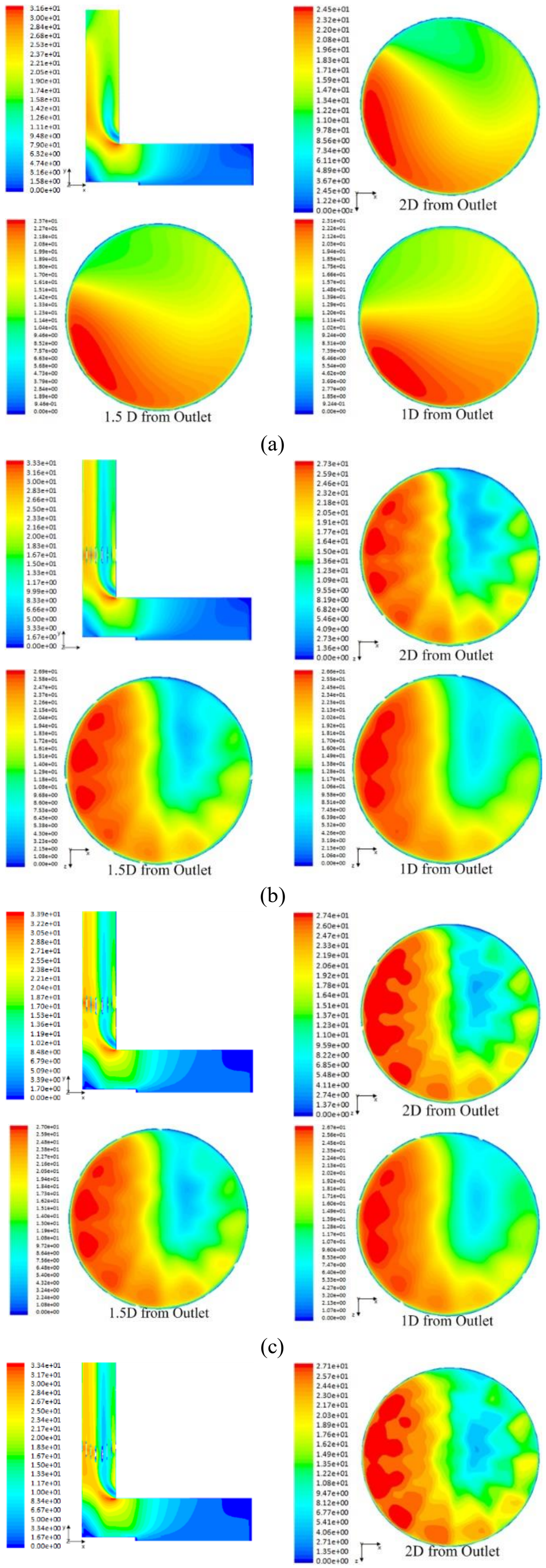

Figure 5. Contour of velocity profile (a) with no flow straightener, (b) with 0o flow straightener (c) with 15o flow straightener, (d) with 30o flow straightener

inclination do not give a significant impact on the measurement results. Finally, experimental analysis is still needed to determine the accuracy of these particulate emissions measurements.

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