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The Effect of 45° Upward Flow Straightener Position on Flow Uniformity in Sampling Point of Chimney

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Abstract. Air pollution is one of the factors that can cause the decreasing of air quality in urban areas, especially in areas close to the industry. The government made a policy for the industrial sector to conduct the emission quality measurements in their operating chimneys. Commonly, the quality of emissions from the chimney sampling point is still above the permissible threshold. This condition occurs due to the lack of uniform emission flow near the sampling point. Based on the EPA method, the exhausted gas flow condition near the sampling point must have uniform velocity and small helicity. Therefore in this study the author tried to modify the channel in the chimney by installing a flow straightener (FS) in order to reduce helicity and the degree of uniformity of the flow. The upward 45^0 FS was chosen. For further research, position of flow straightener at a chimney vertical distance was set at 0.75D, 1D and 1.25D from lower disturbance. Based on the computational results, the best KV value of 32.32% with FS 1.25 D and KV value of 35.52% with 0.75 D were obtained. The closer to the sampling point, the KV value will improve. This result indicated that the accuracy of measurement of emission quality at the sampling point can be improved.

1. Introduction

Based on the data of the Ministry of Health Republic of Indonesia No.1407 of 2002, the level of air pollution tends to increase every year. The occurrence of air pollution can be indicated when the quantities of dust, gas, smoke and even odors in air is more than its safe threshold [3]. Vehicles, industries, electricity generators, and forest fires or burning of the agricultural sector become some of the air pollution cause. In general, the major source of air pollution in the world comes from the transportation and the industrial sector. Exhausted gas emissions coming from the industry, especially those coming from the chimney, can decrease the air quality [9]. In industry, the exhausted gas commonly comes from fossil fuels [4] that are used as the production fuels. The fossil fuel is one of the major contributors of air pollution and greenhouse gas emissions on earth [2].

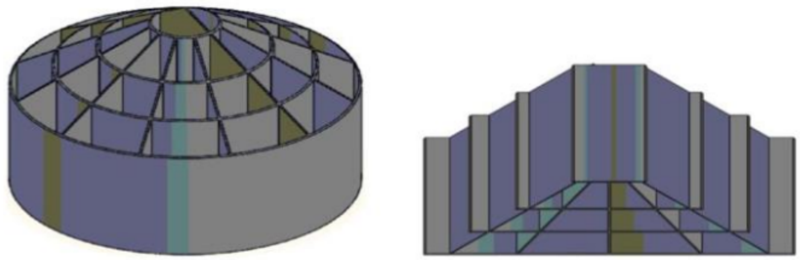
The air pollution, of course, has negative impacts to the environment and human health [5]. At certain concentration levels, air pollution substances can be dangerous for lung health. Therefore, the government through the Ministry of Environment and Forestry makes a policy for the industrial sector to conduct the emission quality measurements in the operating chimneys. According to the US EPA Method 1 [10], to obtain accurate emission quality measurement results, a measurement should be conducted using parameters, such as: i) measurements must use the reference point with a certain distance from the chimney outlet; ii) the emission flow velocity must be as uniform as possible; iii) the maximum slope of the emission flow is 5 degrees and should not form a helicity. To fulfill the requirement of these, it is important to install flow straightener inside the chimney properly [6].

This research relates to the improvement of the uniformity of flow in order to enhance the accuracy results of the chimney emissions quality measurement.

2. Research method

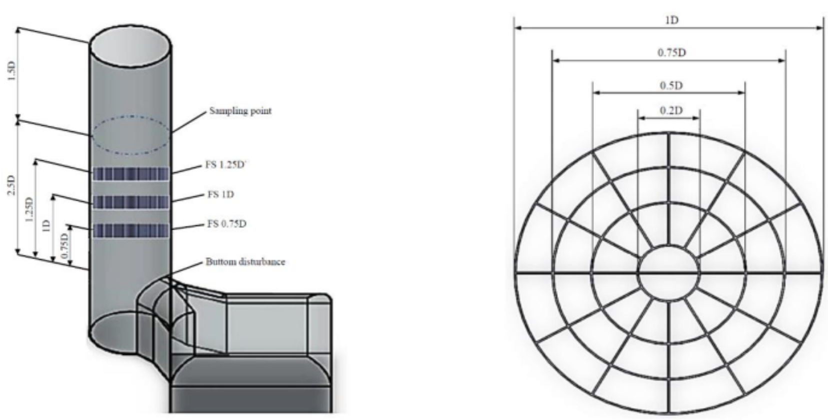
In previous works, a conical flow straightener upward and inverted cone downward with various degrees, i.e. 15, 30 and 45 degrees, has been designed. Based on these previous results, it was obtained that all geometric designs of flow straightener are effective in reducing the helicity. However, there is drawback of that design, such as: the flow rate of the gas emission in the area of the sampling point was not as uniform as expected. Therefore, in this study the flow straightener position will be set at a distance of 0.75D, 1D and 1.25D from the lower disturbance. This arrangement is expected to be able to improve the performance of flow straightener, so that the exhausted gas emission flow rate is more uniform.

In this research, a conical flow straightener (upward) with a slope of 45 degrees is used (**Figure1**). Based on previous research, this slope size is believed to be the best one. Basically, the cone-shaped flow straightener has two functions, i.e. i) reducing the helicity; and ii) distributing the flow from the side to the center of the chimney. The distribution of the flow happens due to the different pressure occurred between the sides and the center of the chimney. Commonly, the pressure on the edge of the chimney is greater than the center of the chimney.



(a) (b)

Figure 1. Isometric flow straightener 45° upward (a) Isometric view (b) side view



(a) (b)

Figure 2. (a) dimension of chimney (b) geometry of flow straightener 45° upward

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3. Geometry
The dimension of chimney and the flow straightener in this study was designed based on the previous research. From sampling point, the height of chimney was set at 4D, the top of the chimney was 1.5D and the bottom of the chimney was 2.5D. Based on that chimney geometry, a numerical simulation was then conducted in order to justify whether the properties of flue gas streamline has been closed to the previous research or not. **Figure 2** describes the redesigned dimension of the chimney. In this research, the vertical distance of flow straightener with three positions (0.75D, 1D and 1.25D) was then installed.

4. Simulation
In this research, a CFD simulation was used. Before operating the CFD simulations, the solver, the model and the boundary conditions input were determined, namely: i) the solver was pressure based, with emissions that was assumed as compressible flow and steady state; ii) the viscous model was K-ε realizable with standard wall treatment; iii) the boundary conditions were the emission in the chimney area which were assumed to flow at velocity of 17.5 m/s; iv) chimney temperature was set at 190^{o} celcius and it was assumed that there was no temperature difference between the output and the input side, so that there will be no heat transfer on the chimney wall [10]; v) chimney was assumed to operate in a standard environment with 1 atm air pressure; vi) Emission was also assumed to be the result of burning fuels, i.e. coal [7]; and vii) emission composition was shown in the **Table 1**:

Table 1. Flue gas composition; source [11]

Name of Substance	Fraction of Volume (%)
Carbon Dioxide (CO2)	11
Argon (Ar)	1
Water Vapor (H2O)	6
Oxygen (O2)	6
Nitrogen (N2)	75.821
Nitrogen dioxide (NO2)	0.069
Sulfur Oxide (SO2)	0.063
Carbon Monoxide	0.047

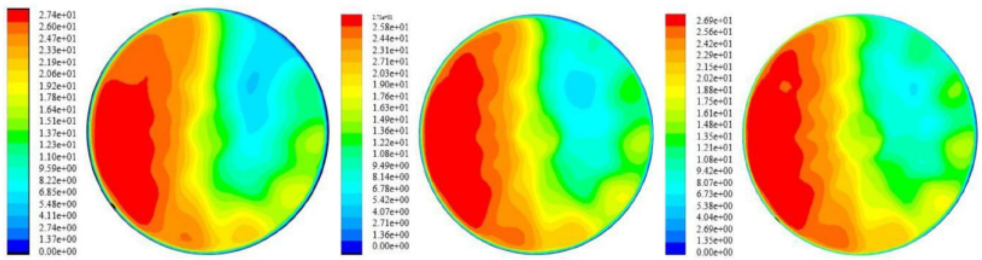
In this study, 3 CFD simulations were conducted, namely 45^{o} flow straightener upward simulation with three different positions (0.75D, 1D and 1.25D) measured from the bottom disturbance (**Figure 2**).

5. Results and discussion

5.1. Velocity Contours
The isokinetic method is used to measure the emission quality at the sampling point. The position of the sampling point is at a distance of 1.5D from the outlet side of the chimney [8]. One of the conditions that should be fulfilled in order to obtain accurate quality measurement results is that the flow velocity of emission at the sampling point must be as uniform as possible. By using CFD simulations, the contours of velocity were obtained at the sampling point area (**Figure 3**).

To calculate the level of uniformity of the emission flow velocity, the equation with Coefficient Variation (KV) was used, as shown in equation (1).

$$KV = \frac{|v-\bar{v}|}{\bar{v}} \times 100\% \quad (1)$$



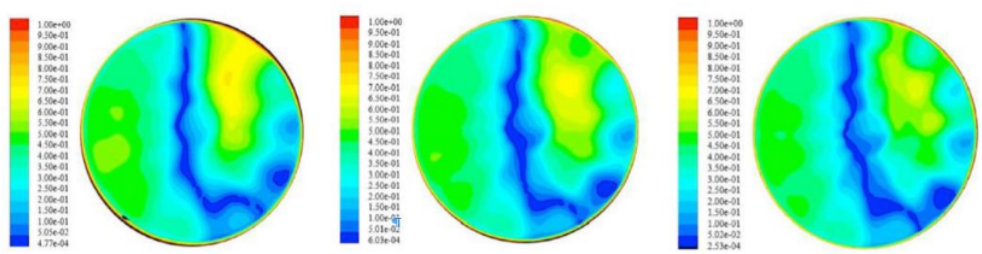
(a) (b) (c)

Figure 3. Contours of flow velocity at the sampling point of (a) 0.75D (b) 1D (c) 1.25D

The KV values for the 3 simulations can be seen in **Table 2**. The smaller the coefficient of variation (KV), the more uniform the emission flow velocity at the sampling point. At the position of 1.25D, the value KV was 32.323 %. If this value 32.323 %, (flow uniformity near the sampling point as required by US EPA), is compared to the KV value at position 0.75D, it shows an improvement. **Figure 4** (c) shows a reduction that occurred in the non-uniform area of the cross section of sampling point (marked in green and light yellow). This condition indicated that the fluctuations of velocity would decrease when it approached the sampling. Therefore, the emission measurement results provided more accurate results.

Table 2. The value of KV under variation position of flow straightener

Flow straightener 45° upward position	Average velocity (m/s^2)	Coefficient of variation (%)
0.75D	18.0529	35.516
1D	18.0534	34.285
1.25D	18.0528	32.323



(a) (b) (c)

Figure 4. Coefficient of contour variation (a) 0.75D (b) 1D (c) 1.25D

5.2. Pressure Drop

Commonly, the addition of a flow straightener to improve the quality of the exhausted gas can improve the uniformity of the flow. However, the installation of flow straightener can also cause the increasing of the resistance that can allow a pressure drop. The pressure drop is expressed as the pressure drop coefficient (K) as shown in equation (2):

$$K = \frac{\Delta P_T}{0.5\,\rho_{ch} V_{ch}^2} \quad (2)$$

Table 3. Pressure drop under variation of flow straightener position

Simulation conditions	Pinlet-Poutlet (Pa)	Velocity (m/s)	Density Kg/m^3)	K	
				Total	*F S*
Chimney without flow straightener	191.272	12.369	0.773	6.604	0
Flow straightener position 0.75D	224.315	12.647	0.752	7.318	0.713
Flow straightener position 1.00D	219.662	12.605	0.752	7.165	0.560
Flow straightener position 1.25D	219.518	12.573	0.752	7.136	0.531

Table 3 shows that the flow straightener at the distance 1.25D has the lowest pressure drop of 0.531, while the flow straightener at 1.00D has the second lowest pressure drop of 0.560 and for 0.75D has the biggest pressure drop of 0.713 compared to the others. The addition of pressure drop for all positions can still be tolerated.

6. Conclusion
Based on the CFD simulation that has been conducted, by focusing on the parameters of uniformity of emission flow velocity and pressure drop, it was obtained that setting the flow straightener position 45^o upward can improve the uniformity of the emission flow velocity during the sampling point. The position of 45^o upward flow straightener with a distance of 1.25D has the best emission flow uniformity with the lowest coefficient of variation (KV) of 32.323%. Flow straightener with a distance of 1.00D has the second best gas emission uniformity, namely 34.285% and distance of 0.75D has the largest value, i.e. 35.516%. The pressure drop was directly proportional to the uniformity of the emission flow velocity expressed by the coefficient of variation (KV). The lower the pressure drop, the smaller the coefficient of variation (KV). It indicated that the more uniform the velocity of the emission was.

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