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HEIGHT OF THE CHIMNEY FOR AN INDUSTRIAL BOILER

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ABSTRACT

The quality of the surface and groundwater significantly change with the ash disposal from the flue gas stack. Atmospheric sulphur dioxide (SO2) and nitrogen dioxide (NO2) are caused for acid rain produced from fossil fuel combustion. The height of the flue gas stack is always essential to minimize the environmental impact of industrial flue gas emission. The wrong design of the flue gas stack height leads to ground-level air pollution, directly contributing to ecosystem failures and health impacts. The stack height depends on the sulphur content of the fuel or sulphur dioxide content, fuel firing rate, and the height of the tallest building within the affected area. Therefore, a new equation is developed to calculate the required minimum chimney height when sulphur content of the fuel and fuel consumption rate is known. Moreover, the equation is implemented to calculate the diameter of the flue gas stack. The new calculation steps are crucial for industrial applications such as for industrial boiler to minimize air pollution.

KEY WORDS: Air pollution, Chimney, Flue gas, Fuel firing rate, Sulphur content

INTRODUCTION

A boiler can be defined as an enclosed vessel that generates steam by the heat transfer mechanism. Industrial boiler flue gases consist of a sizable amount of recoverable energy. However, boiler flue gas contains several flue gases such as carbon monoxide (CO), Carbon dioxide (CO_2), Nitrogen dioxide (NO_2), Sulphur dioxide (SO2), and particulate matter (PM) (Williams *et al.,* 2012). Therefore, it is crucial to maintain the emission regulations to continue the boiler operation in an environment friendly way. The primary fuel sources of the industrial boilers are biomass, coal, furnace oil, and alternative fuels. Based on the fuel type, moisture content, sulphur content, and calorific values are varied (Udara and Sakuna, 2019). The hazard associated with the industrial boiler operation leads to environmental impact, ecosystem damage, personal safety and health, and the sustainable operation of the industrial process (Sajath, 2020). An excessive amount of flue gas emissions directly contribute to air pollution, which is accountable for the health of living beings.

Sulphur content of the fuel

The sulphur content and the calorific value of the varieties of fuel sources are given in Table 1. Most fossil fuels are having a significantly higher amount of Sulphur as well as the higher calorific value. The sulphur content of the biomass and derivatives of the alternative fuel or agricultural crop residue is almost negligible.

Table 1. Sulphur content and the calorific value of the fuel (Brian and Marty, 2008, Stanley, 2009)

Substance	% Sulphur	Calorific Value [MJ/kg]
Anthracite Coal	0.6-0.8	34.0
Bituminous Coal	0.7-4.0	25.3
Lignite Coal	1.5	23.0
Crude oil	0.5-3.0	Varies
Natural Gas	Traces	34.0
Bio mass	<0.2	18-21
Paddy husk	<0.1	13-16

There are several methods available for the reduction of sulphur related components which are directly contributing to air pollution. Some of them are categorized as (World Bank Group, 1998):

- Natural dispersion by dilution
- Using alternative fuels
- Removal of sulfur by desulfurization
- Control of SOx in the combustion process
- Process Modification
- Treatment of flue gases-Dry or Wet Methods

However, we are discussing the most economical and widely applicable method, which is natural dispersion by dilution. The control method is based on natural dispersion at high elevation so that the ground level concentrations are acceptable at all times.

Biomass Boilers

The use of biomass can potentially reduce the fuel cost as it is widely available and locally recoverable. Biomass is extensively used for domestic heating, cooking, and industrial boiler firing systems, which will directly reduce fuel expenses. However, the lack of particulate filters in the flue gas contributes to environmental issues and health issues, especially respiratory problems (Air Quality Expert Group, 2017).

It is a common practice nowadays to use more alternative fuel to replace the biomass. Some of the alternative fuel sources are paddy husk, sawdust, briquette, organic waste, agricultural crop residue. However, the combustion of biomass will be responsible for air quality fluctuations. The regulations for the prevention of air pollution from industrial boilers are defined with multiple protocols. However, the threshold limits are varied according to the own administrative control mechanisms and standards.

MATERIALS AND METHODS

It is essential to have a proper chimney design to prevent combustion products such as soot, low-flying smoke, dust, and gasses emitted at low elevation (CSFE, 2020). The chimneys are designed to take care of its pressure drop based on the density difference of hot flue gas and air. Flue gas duct has to be created based on the minimum pressure drop between equipment and chimney. The following precautions should be followed when the flue gas duct is designing. The chimney with smaller diameter and chimneys with long duct piece between the flue gas outlet of equipment and the main chimney should not be used. The duct connection between equipment outlet and chimney should be connected at an angle not less than 45. There should be a removable piece between the equipment and chimney. Whenever it is going to shutdown without disturbing the boiler, the removable piece can be separated to disconnect the boiler from the chimney. Chimney with more than two bends should be avoided.

Based on the environmental regulations, the chimney's height and diameter have to be calculated for flue gas airflow. Flue gas ducting and the chimney plays a vital role in air pollution control. Flue gas emission test has to be performed to identify the emission levels. Those levels should be maintained as much as possible below the regulation levels.

The following points should be considered while designing the chimney for an industrial boiler. The emission regulations have to be considered for proper designing as it is important to get the approval from the Environmental Department. The chimney height and diameter have to be calculated based on the fuel flow rate, the sulphur content of the fuel, operating hours, flue gas temperature, and the velocity of the flue gas. Therefore, the velocity of the flue gas has to be calculated based on the flow rate of the flue gas and the diameter of the duct. The chimney drawings and dimensions should be carefully approved by the environmental regulatory authorities. The main chimney should be erected on the ground outside the boiler house with proper foundation bolts.

The chimney can be connected vertically and supported on the roof (Fig. 1) or attached as cross-

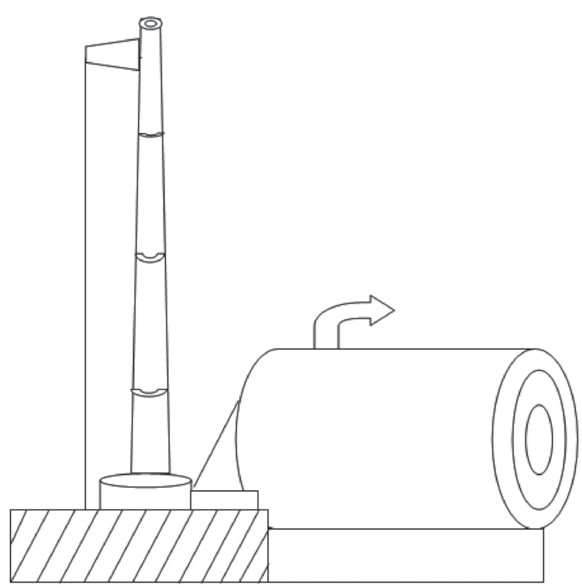

Fig. 1. Chimney connected vertically and supported on the roof.

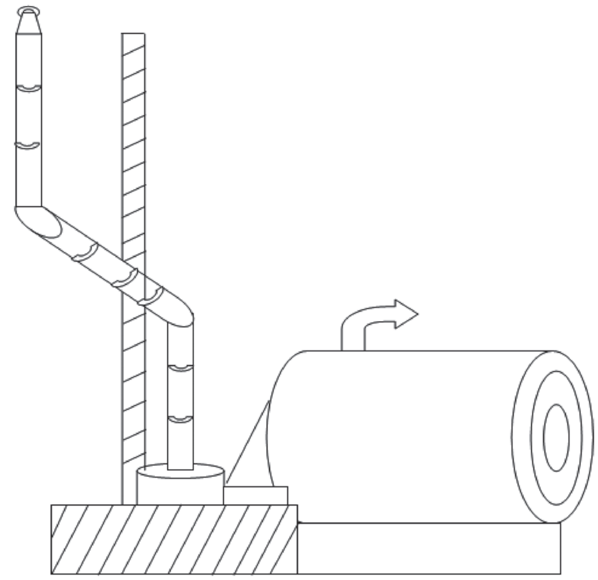

Fig. 2. Chimney with cross-connection and clamped to the wall.

connection and clamped to the wall (Fig. 2). However, for the cross-connection system, angles of 45 degrees or higher values should be maintained to avoid dust fouling in the ducting.

The most critical parameter of the chimney design is considered as the height of the chimney. The height of the chimney is crucial to maintain to get the environmental authority approval for boiler operation and for achieving the emission regulations. Lower height than the required is contributing to low-flying soot and smoke to spread in the atmosphere and exceeds the emission levels by creating an unhealthy environment.

Height of the Chimney

Minimum stack height of any combustion point source shall be determined by the following equation (The Gazette of the Democratic Socialist Republic of Sri Lanka, 2019).

(1)

Where,
C = Minimum stack height in meters.
H = The height in meters of the tallest building within 5U radius of the point source.
U = Uncorrected stack height in meters.
U shall be determined by following equation (2), (The Gazette of the Democratic Socialist Republic of Sri Lanka, 2019),

(2)

Where,
Q = Gross heat input in Mega Watt (MW)

- This rule shall be applied for the combustion source with gross heat input greater than 0.620MW
- In any case, stack height shall not be less than 20 meters except for the combustion sources with gross heat input less than 0.620 MW.

For the Thermal Power Plants, minimum stack height is given by Equation (3),

$$H = 14Q^{0.25} \quad (3)$$

- Where, Q is sulphur dioxide emission rate in kg/hour.

The main drawback of this calculation procedure is that it includes energy input, which is hard to calculate. Simultaneously, for the biomass boilers, the sulphur content of the fuel is not considered for the chimney height evaluation. Therefore, the new equation is developed with the proper parameter evaluation to calculate the chimney height. In that equation, sulphur content of the fuel and the fuel firing rate or fuel consumption rate are also included. To avoid the drawbacks of the above method, the new equation is developed to calculate the flue gas stack height and the diameter. The sulphur content of the fuel is also included in the new equation. The sulphur content of the fuel is essential to calculate the chimney height as that will directly contribute to SO_2 formation. The following method of calculation introduces to design the chimney for the industrial biomass boiler. However, that can be even used for coal-fired boilers. The main variables responsible for the height of the chimney variations are sulphur content of the fuel, fuel consumption rate, and height of the tallest building around the pollution source. If the stack height is lower than the tallest building within the responsible zone, then the lower level soot, dust, and smoke will enter that building with a ventilation system. Therefore, the minimum height of the flue gas chimney should always be higher than the height of the tallest building in that area.

$$H = H_0 + H' \quad (4)$$

$$H' = 0.31 \times (S\% \times FF)^{0.3} \quad (5)$$

$$H = H_0 + 0.31 \times (S\% \times FF)^{0.3} \quad (6)$$

If 1. H ≥ 2 then H should consider as 20m.
H = Minimum height of the Chimney [m]
H_0 = Height of the tallest building in meters within the radius of 5R, R = $H' / 0.31$

The R value calculated and then five times R considered as the effective radius to identify the tallest building.
S% = Sulphur percentage in the fuel [-]
FF = Fuel consumption flow rate [kg/hr]
The 0.31 factor is calculated based on the SO_2 emission flow rate which is experimentally tested with the actual boiler flue gas emissions. It is assumed that the SO_2 is produced from the fuel sulphur only and follows Equation (7),

$$S + O_2 \rightarrow S \qquad (7)$$

As an example, let's consider biomass (Assume 18 MJ/ kg heat capacity), boiler which has Fuel consumption rate (FF) of 1000 kg/hr, 0.2% Sulphur content of the biomass, and as a nearest tallest building height 20m within the respected radius. Then, Equation (1),

$C = 20 + 0.6 \times 1.36\, Q^{0.6}$

$Q = 18 \times 1000 \times \; = 5$ MW

$C = 20 + 0.6 \times 1.36 \times 5^{0.6} = 21.14$m

Equation 6,

$$H = H_0 + 0.31 \times (S\% \times FF)^{0.3}$$

$H = 20 + 0.31 \times (0.2 \times 1000)^{0.3} = 20 + 1.519 = 21.519$ m

Difference = (21.519 - 21.14) ×100% / 21.519 = 1.76% < 2

Diameter of the Chimney

The diameter of the chimney can be calculated by Equation (8) given below. Similar to the height of the chimney, the diameter of the chimney also important. The flue gas velocity is varying with the diameter of the chimney. Equation 8 consist with fuel firing rate, stack temperature, the carbon content of the fuel, and carbon dioxide content of the flue gas, the density of the flue gas as well as the velocity of the flue gas. Based on those factors, the diameter of the chimney will be varied.

$$\frac{\pi}{4} \times D^2 = \frac{FF \times \left(\frac{T_S + 273.15}{273.15}\right) \times C\% \times \frac{44}{12} \times \frac{1}{CO2\,\%}}{\rho_{flue\,gas} \times V_{flue\,gas} \times 3600} \qquad (8)$$

D	=	Diameter of the Chimney [m]
FF	=	Fuel firing rate [kg/hr]
Ts	=	Stack Temperature [°C]
C%	=	Carbon content of the fuel [-]
CO_2%	=	CO_2 content of the flue gas
P flue g	=	Density of the flue gas [kg/m^3]
V flue g	=	Velocity of the flue gas [m/s]

However, it can be assumed that density of the flue gas (1.98 kg/m3), C content (80%) and CO_2 % of the flue gas (14%) are almost equal with the fuel type. Therefore, above equation 8, can be simplified as Equation (9),

$$D = \sqrt{13.48 \times \frac{FF \times \left(\frac{T_S + 273.15}{273.15}\right)}{V_{flue\,gas} \times 3600}} \qquad (9)$$

Both height and the diameter of the chimney are essential for designing an industrial boiler with emission regulations. This has been applied practically, and calculated the theoretical chimney height and diameter based on those two equations and validated with the actual designs. The deviation between theoretical calculation and exact measurement is 2-5% only. However, it all depends on the tallest nearest building height, as included in the equation to be considered for air quality monitoring.

CONCLUSION

The flue gas stack can be designed in one of the two ways, which are vertically and supported on the roof or attached as cross-connection and clamped to the wall. However, for the cross-connection system, angles of 45 degrees or higher values should be maintained to avoid dust fouling in the ducting. The developed equations can be used to calculate the required chimney stack height and the chimney diameter, which are vital to prevent ground-level air pollution caused by sulphur dioxide and nitrogen oxide. The height and the diameter of the chimney, both values depend on the fuel consumption rate. The height of the chimney can be calculated by considering the sulphur content of the fuel and the height of the nearest tallest building within the specified radius. Therefore, it always most towering building height should be taken into account for the calculation. Then there is no issue with the height of the tallest building nearby.

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