Analysis and calculation of enclosed coal yard ventilation by using roof vortex flow natural ventilation

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Abstract. As the unsatisfied environment of the fossil fired power plant become more controversial and disputable, the current tendency of enclosed coal yard which helps to decrease air pollution gains more application than those open ones. In order to improve the indoor environment and ventilation effect as well as to achieve good energy conservation at the same time, this paper investigates the ventilation effect of the roof vortex flow natural ventilator. By using multivariate nonlinear regression analysis and the theoretical calculation of natural ventilation, this paper proposes an instructive natural ventilation model and calculation method of enclosed coal yard based on the indoor pollutants concentration control, which is highly recommended as a good design application in similar enclosed coal yard buildings.

1. Introduction
Coal yard, as one of the most important links of coal storage in fossil fired power plant, its economy effect, security and environmental friendliness has drawn worldwide attention [1]. Compared to open-air coal yard, the enclosed coal yard has the advantage of higher land use rate as well as better outdoor air condition [2]. While at the same time, bad thermal condition together with inferior air quality occurs [3-8]. Ventilation, one of the crucial methods to improve indoor environment in coal yard, helps to improve indoor thermal condition and decrease the combustible concentration [9-11]. In order to achieve better energy conservation effect, natural ventilation, especially air inlet through bottom louvers and air exhaust by roof vortex flow natural ventilator is commonly adopted. Currently, as there are no national standard or very few researches for designers to refer to, the ventilation design of enclosed coal yard is relatively limited. Therefore, this paper aims to investigate the ventilation volume under natural ventilation condition with the strategy of natural louvers inlet and roof vortex flow natural ventilator exhaust. By analyzing the design standard of roof vortex flow natural ventilator, a calculation method is established for controlling indoor air pollutants and providing better indoor environment.

2. Method
On the basis of the design standard of roof vortex flow natural ventilators, together with the multivariate nonlinear regression, an optimized calculation model is established. By adopting general
mass balance equation for the indoor combustible concentration, the total natural ventilation volume required is obtained. Then the number of roof vortex flow natural ventilators as well as the inlet louvers can be calculated to ensure ventilation performance. SPSS Version 21.0 is used during the data processing and statistical analysis procedure.

2.1 Total ventilation volume of enclosed coal yard
Since there are different volatile components of the coal pile in coal yard, methane, hydrogen and other gases will be released continuously. In a certain period, the mass quality of coal pile in coal yard will keep at a constant level. Given the internal environment of coal by interference basically remain unchanged, it could be assumed that the emission of combustible concentration released by coal pile remain stationary. Therefore, the steady state of general mass balance equation can be used to calculate the required ventilation volume to exclude combustible gas.

\[ Q = \frac{M}{c_2 - c_s} \]  

where:
- \( Q \) is the required ventilation volume, \( m^3/s \)
- \( M \) is the emission of indoor combustible gas, \( g/s \)
- \( c_s \) is the combustible concentration in supply air, \( g/m^3 \)
- \( c_2 \) is the indoor combustible concentration of daily steady-state conditions, \( g/m^3 \)

2.2 Calculation model of ventilation volume by roof vortex flow natural ventilators
According to China National Building Atlas Standard Design 06K105-Roof Natural Ventilation Device Selection and Installation, the ventilation volume \( Q_0 \) of one roof vortex flow natural ventilator depends on the throat area \( A \), the height difference \( h_{out} \) between tuyere center and neutral pressure level, temperature difference \( T_p - T_w \) between exhaust air temperature and outdoor air temperature, and outdoor wind speed \( v \) (m/s). Based on the multivariate nonlinear regression analysis, mathematical calculation model of ventilation volume \( Q_0 \) is established:

\[ Q_0 = 120.981 \times A + 152.817A \times h_{out} + 54.375A \times (T_p - T_w) + 1823.977A \times v \]  

where:
- \( Q_0 \) is the ventilation volume of one roof vortex flow natural ventilator, \( m^3/s \)

Table 1. Examples of calculated ventilation volume of roof vortex flow natural ventilator based on multivariate nonlinear regression m³/h.

| Size       | \( h_{out} \) | \( A \) | 3   | 5   | 10  |
|------------|---------------|--------|-----|-----|-----|
| QM400      |               |        |     |     |     |
| Throat size 0.4m |   |       |     |     |     |
| Throat area A 0.1256m² | |        |     |     |     |
| 1           | 455           | 532    | 628 | 724 | 519 |
| 2           | 684           | 761    | 857 | 953 | 748 |
| 3           | 913           | 990    | 1086| 1182| 977 |
| 4           | 1143          | 1219   | 1315| 1411| 1206|
| 5           | 1372          | 1448   | 1544| 1640| 1436|
| QM500      |               |        |     |     |     |
| Throat size 0.5m |   |       |     |     |     |
| Throat area A 0.1963m² | |        |     |     |     |
| 1           | 712           | 832    | 982 | 1132| 811 |
| 2           | 1070          | 1190   | 1340| 1490| 1169|
| 3           | 1428          | 1548   | 1698| 1848| 1528|
| 4           | 1786          | 1906   | 2056| 2206| 1886|
| 5           | 2144          | 2264   | 2414| 2564| 2244|
| QM600      |               |        |     |     |     |
| Throat size 0.6m |   |       |     |     |     |
| Throat area A 0.2698m² | |        |     |     |     |
| 1           | 1024          | 1197   | 1413| 1629| 1168|
| 2           | 1540          | 1713   | 1929| 2144| 1684|
| 3           | 2055          | 2228   | 2444| 2660| 2199|
In order

3. Case analysis

This paper chose an enclosed coal yard of summer condition in Henan Shangqiu area as an example, and the size of the coal yard to 96 m×m 54×10 m. For roof vortex flow natural ventilators, the premise of using multivariate regression model is to determine three variables, namely the height difference \( h_{out} \), temperature difference \( T_p-T_w \), and outdoor wind speed \( v \).

\[
Q_0 = 1335.8 + 43.2 \times h_{out}
\]  
(3)

For natural ventilation, air inlet area:

\[
F_{in} = \frac{Q}{\mu_{in} \times \sqrt{\frac{2}{\Delta p_{in} / \rho_{in}}}} = \frac{Q}{\mu_{in} \times \sqrt{\frac{2 \times h_{in} \times g \times (\rho_{in}-\rho_{np})}{\rho_{in} \times \rho_{np}}} \times \rho_{in}}
\]  
(4)

Air exhaust area:

\[
F_{out} = \frac{Q}{\mu_{out} \times \sqrt{\frac{2}{\Delta p_{out} / \rho_{out}}}} = \frac{Q}{\mu_{out} \times \sqrt{\frac{2 \times h_{out} \times g \times (\rho_{in}-\rho_{np})}{\rho_{out} \times \rho_{np}}} \times \rho_{out}}
\]  
(5)

\( \Delta p_{in}, \Delta p_{out} \)———air pressure difference between air inlet and air exhaust, Pa

\( Q \)———total ventilation volume, kg/s

\( \mu_{in}, \mu_{out} \)———flow coefficient of air inlet and air exhaust

\( \rho_{in} \)———outdoor air density, kg/m³

\( \rho_{out} \)———exhaust air density, kg/m³

\( \rho_{np} \)———indoor air density under indoor average temperature, kg/m³

\( h_{in}, h_{out} \)———the height difference between air inlet and neutral pressure level; the height difference between air outlet and neutral pressure level, m

\( \Delta T = T_p - T_w \)

Tab. 1 shows that the number of points with deviation ratio exceeding 10% is no more than 5% of all the calculated points. Therefore, the assumed multivariate nonlinear regression model is quite accurate and reliable. When the size of natural ventilator is selected, this calculation model can be converted into the linear regression model, only decide by three independent variables: the height difference \( h_{out} \), temperature difference \( T_p - T_w \), and outdoor wind speed \( v \).
Because the lack of testing and empirical data of flow coefficient of roof vortex flow natural ventilator currently, according to the internal structure of roof vortex flow natural ventilator, it is assumed that $\mu_{out}=0.75$, $\mu_{in}\approx\rho_{in}\approx\rho_{out}$, then:

$$F_{in} = 0.75 \sqrt{\frac{h_{out}}{h_{in}}}$$  \hspace{1cm} (6)

$$F_{out} = n \times A$$  \hspace{1cm} (7)

$$Q = 3600 \times \mu_{in} \times v_{in} \times F_{in} = n \times Q_{0}$$  \hspace{1cm} (8)

From Equation (6)~(8) then get:

$$Q_{0} = \frac{3600 \times \mu_{in} \times v_{in} \times A}{0.75 \sqrt{\frac{h_{out}}{h_{in}}}}$$  \hspace{1cm} (9)

Where,
- $n$ ———— Design number of roof vortex flow natural ventilator
- $v_{in}$ ———— Air inlet velocity of louvers, m/s
- $A$ ———— Throat area A of a QM600 ventilator, m$^2$
- $Q_{0}$ ———— Ventilation volume of a QM600 ventilator, m$^3$/h

For QM600 type roof ventilator, throat area $A=\pi r^2=0.2826$ m$^2$. Assuming that the design height of center line of the air inlet louvers is 0.5 meter, so the height difference between air outlet and air inlet $h_{out}+h_{in}=10-0.5=9.5$ m. To prevent dust pollution in coal yard, the inlet air velocity $v_{in}=2.5$m/s, flow coefficient of inlet $\mu_{in}=0.85$ [13].

From Equation (3) and data above into Equation (9):

$$\frac{1335.8+43.2 \times h_{out}}{3600 \times 0.8 \times 2.5 \times 0.2826} = 0.75 \sqrt{\frac{h_{out}}{9.5-h_{out}}}$$  \hspace{1cm} (10)

Then get: $h_{out}=4.8$ m

Substitutes $h_{out}=4.8$ m into Equation (3) then get:

$$Q_{0}=1543.1 \text{ m}^3/\text{h}$$

According to the Equation (1) and local coal quality information, $c_0 = 0$ g/m$^3$ and $c_2$ shall not exceed 25% of the detonation of the chosen combustible [14-15]. Therefore, the Q can be calculated. The number of QM600 roof ventilators as well as total louvers area can be calculated.

$$n = \frac{Q}{Q_{0}} = \frac{Q}{1543.1}$$  \hspace{1cm} (11)

$$F_{in} = \frac{Q}{3600 \times \mu_{in} \times v_{in}} = \frac{Q}{3600 \times 0.8 \times 2.5} = \frac{Q}{7200}$$  \hspace{1cm} (12)
When changing the selected size of roof vortex flow natural ventilator, design height of center line of the air inlet louver, or inlet air velocity similarly etc., the number of ventilators and the total area of design inlet louvers can be calculated correspondingly.

4. Conclusions and discussions
The research establishes a ventilation volume mathematical model of roof vortex flow natural ventilators by using multivariate nonlinear regression analysis. Then based on the theory of natural ventilation, combined with general mass balance equation, together with the stability of combustible pollutants, this paper puts forward an applicable calculation method of natural ventilation design in enclosed coal yard, to help maintain good ventilation effect and indoor air quality in enclosed coal yard. Therefore, the result of this paper provides guidance for the natural ventilation design scheme of the enclosed coal yard. Meanwhile, it is of great important theoretical and realistic significance to guarantee the safe operation of coal yard.

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