ANALYSIS OF OUTLET FLUE GAS MOISTURE CARRYOVER IN WET LIMESTONE--GYPSUM FLUE GAS DESULPHURIZATION INSTALLATION

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1. Introduction

China is one of a few countries throughout the world that its energy production and consumption structure is dominated by coal--a type of fossil fuel with high dust, SO_2 and NO_X pollution. Large amounts of coal combustion directly have caused severe SO_2 and acid rain pollution in China. In 2000, the total SO_2 emissions in China were about 19.95Mt, and 5.54Mt of which came from thermal power plants. Areas with precipitator pH value of lower than 5.6 have occupied more than 30% of Chinese total territory.

In order to comply with the requirements of newly revised Emission Standards for Thermal Power Plants in 2003, newly built coal-fired power plants in China must adopt effective desulphurization installations to reduce SO_2 emissions. By now, among all the desulphurization installations in the world, wet flue gas desulphurization (FGD) is the most widely used process, and wet forced-oxidation limestone-gypsum FGD was especially widely applied in thermal power plants. This process has been selected by utility companies because it is the most economical process among the many process developed and used. It is characterized by high SO_2 removal efficiency, low cost, wide availability of the absorbing reagent, useful gypsum by-product, and does not require a great knowledge in the management of chemical processes.

In a forced-oxidation limestone-gypsum wet FGD installation, limestone slurry is the wet desulphurization absorbent. Limestone reacts with SO_2 which is in flue gas in absorber through spraying, and gypsum($CaSO_4 \cdot H_2O$) is produced. In this way, SO_2 is eliminated. During the process of reaction, the temperature of flue gas entering into absorber is rather high, which will make water in slurry atomize into steam while contacting with limestone slurry. Then the atomized steam is discharged into the air along with disposed flue gas. As a result, the moisture degree is high and there is a certain extent of moisture carryover in purified outlet flue gas, and the magnitude of moisture carryover increases with the unit consuming slurry. In such circumstance, ash will deposit on the impeller in the fan, so much as making the fan vibrate abnormally and run away. At the same time, the entrained water reacts with untreated SO_2 in flue gas and produces sulfurous acid, which erodes metal equipments and accessories such as tail flue duct and fan vane.

In this paper, the common problem of flue gas moisture carryover, which is produced in wet flue gas desulphurization installation, is studied. Based on the mass balance and energy balance in a typical wet FGD scrubber, the calculation formula of moisture carryover is deduced and analyzed in detail. Further, relation between outlet flue gas moisture carryover with the inlet flue gas temperature and inlet slurry temperature.

2. Methodology

In this paper, the mathematical model of flue gas moisture carryover was developed by using mass and energy balance in the wet FGD absorber. The sketch drawing of mass and energy balance of a typical FGD absorber was shown in **Figure 1**.

2.1 Calculation of flue gas moisture carryover

In a wet flue gas desulphurization system, there are two mass balances and one energy balance [1].

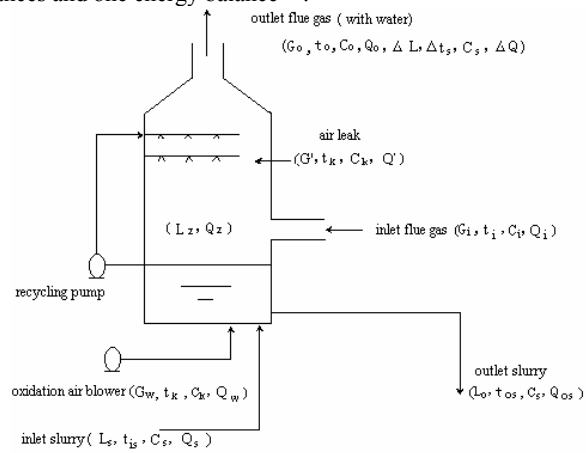

Figure 1 The mass and energy balance in a wet FGD absorber

Balance of gas flow rate. Under the standard conditions, sum of the inlet flue gas rate, air leak rate, and supplying air flow rate equal to the outlet flue gas rate of absorber:

$$G_i + G' + G_w = G_o \quad (1)$$

Balance of water flux. The total ingoing water flux of absorber is equal to the total discharging water flux of absorber:

$$L_s = L_o + \Delta L + L_z \quad (2)$$

Balance of energy. In order to deducing the energy balance in the absorber, some hypotheses as follows were made firstly:

(1) Moisture vaporizing in absorber was considered.

(2) Heat radiating outwards of the system was considered

(3) In the whole system, the specific heat of flue gas, water, and air, is constant.

(4) $C_i = C_o = C_y$, $\Delta t_s = t_0$

Thus, the formula of energy balance can be given as follows:

$$Q_w + Q_i + Q_s + Q' = Q_0 + Q_{os} + \Delta Q + Q_z + Q_d \quad (3)$$

viz. $G_w C_k t_k + G_i C_y t_i + L_s C_s t_{is} + G' C_k t_k$
$= G_o C_y t_o + L_o C_s t_{os} + \Delta L C_s t_o +$
$L_z[C_s(t_o - t_{is}) + 595 \times 4.187] + (G_i + G_o + G_w) C_y \Delta t/2 \quad (4)$

Incorporating equations (1) and (2) into (4), it can be derived:

$$\Delta L = \{G_i C_y (t_i - t_o - \Delta t) + G_w (C_k t_k - C_y t_o - C_y \Delta t) + G'(C_k t_k - C_y t_o - C_y \Delta t/2) + L_s C_s (t_{is} - t_{os}) + L_z[C_s t_{os} - C_s(t_o - t_{is}) - 595 \times 4.187]\}/C_s(t_o - t_{os}) \quad (5)$$

Revising G_i ,G_w and G' into flux of flue gas, supplying air flow rate and air leak rate in actual conditions, respectively:

$$G_i = G_i(273 + t_i)/273 \quad (6)$$

$$G_w = G_w(273 + t_k)/273 \quad (7)$$

$$G' = G'(273 + t_k)/273 \quad (8)$$

introducing equations (6), (7) and (8) into (5), thus:

$$\Delta L = \{G_i C_y (t_i - t_o - \Delta t)(273 + t_i)/273 + G_w (C_k t_k - C_y t_o - C_y \Delta t)(273 + t_k)/273 + G'(C_k t_k - C_y t_o - C_y \Delta t/2)(273 + t_k)/273 + L_s C_s (t_{is} - t_{os}) + L_z[C_s t_{os} - C_s(t_o - t_{is}) - 595 \times 4.187]\}/C_s(t_o - t_{os}) \quad (9)$$

2.2 Calculation of vaporizing quantity in absorber (L_z)

The vaporizing water quantity can be obtained by the formula as follows[2]:

$$L_z = \frac{\left[\Delta t_w - \frac{L_s(t_{os} - t_{is})}{G_i C_p}\right] G_i C_p}{595 + 0.47(t_i - \Delta t_w) - t_{os}} \qquad L_s = \frac{G_i l_w \rho}{1000} \quad (10)$$

Where:

G_i--inlet flue gas rate in absorber (Nm^3/h),

l_w--the unit consuming slurry rate in absorber ($m^3/K \cdot Nm^3$),

ρ--slurry density ($1000kg/m^3$),

Δt_w--fall of flue gas in absorber (℃),

t_{os}--outlet slurry temperature (℃),

t_{is}-- initial slurry temperature (℃),

t_i--inlet flue gas temperature (℃),

C_p--volume specific heat of flue gas, commonly 0.325kcal/km^3·□.

3. Results and Discussion

From equation (9) and (10), it can be seen that all input parameters for calculation of outlet flue gas moisture carryover were measurable. Therefore, flue gas moisture carryover can be calculated if giving all the measurable parameters by field tests.

According to the experiences in the real wet FGD system, some parameters and their range are assumed. Thus, we can obtain the relation curves between flue gas moisture carryover with outlet flue gas temperature and inlet slurry temperature.

3.1 Relation between flue gas moisture carryover with outlet flue gas temperature

As G_i=1.0(Nm3/h), l_w=0.29($m^3/K \cdot Nm^3$), ρ=1000($1000kg/m^3$), G'=0.045(Nm^3/h), G_w=0.05(Nm^3/h), C_y=0.25×4.187=1.047(kJ/kg·□), C_s=4.187(kJ/kg · □), C_k=0.716(kJ/kg · □), C_p=0.325 (kcal/km^3 · □), Δt=4.0(□), t_k=20.0(□), t_{is}=20.0(□), respectively, and selecting t_i=130, 140, 150(□), we can get the trend of flue gas carry-over(ΔL) with outlet flue gas temperature (t_i), as is shown in **Figure 2**.

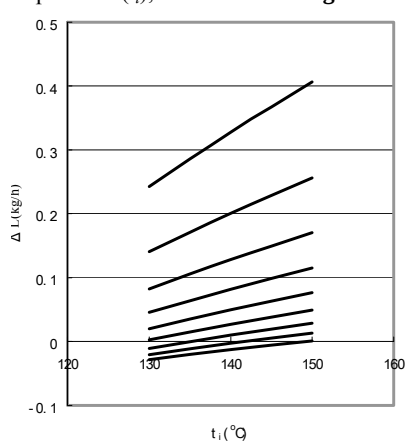

Figure 2 The relation between flue gas moisture carryover with outlet flue gas temperature

Note: Nine curves from the top to down represent the running situations when t_0 at 60□、65□、70□、75□、80□、85□、90□、95□ and 100□, respectively. It can be seen that, flue gas moisture carry-over increase along with the decrease of outlet flue gas temperature.

3.2 Relation between flue gas moisture carryover with inlet slurry temperature

As G_i=1.0(Nm^3/h), l_w=0.29($m^3/K \cdot Nm^3$), ρ=1000($1000kg/m^3$), G'=0.045(Nm^3/h), G_w=0.05(Nm^3/h), C_y=0.25×4.187=1.047(kJ/kg·□), C_s=4.187(kJ/kg · □), C_k=0.716(kJ/kg · □), C_p=0.325 (kcal/km^3 · □), Δt=4.0(□), t_k=20.0(□), t_o=80.0 (□), respectively, and selecting t_i=130, 140, 150(□). Thus, we can get the relation of flue gas moisture carryover (ΔL) with inlet slurry temperature (t_{is}), as is shown in **Figure 3**.

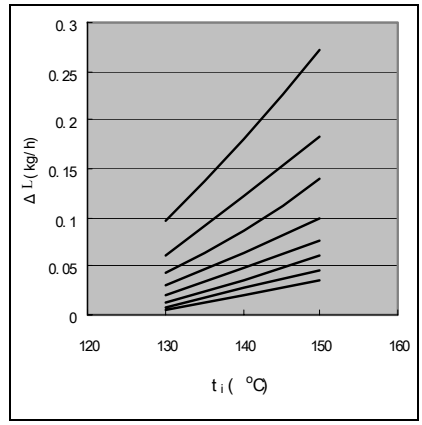

Figure 3 Relation between outlet flue gas moisture carryover with inlet slurry temperature

Note: Eight curves from the top to down represent the running situations when t_{is} is 40.0(□)、35.0(□)、30.0(□)、25.0(□)、20.0(□)、15.0(□)、10.0(□)and 5.0(□), respectively. It can be seen from Fig.3, that flue gas moisture carryover decrease along with the decrease of inlet slurry temperature when other parameters are constant.

Conclusions

According to mass and energy balance in a wet limestone-gypsum desulphurization absorber, the calculation formula of outlet flue gas carryover is deduced and analyzed. It shows that the variety of moisture carryover is consistent with the reality, which proves that the derived calculation formula is credible and feasible. With the formula, flue gas moisture carry-over of all types of wet flue gas desulphurization installations can be estimated.

References

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Notation

G_i, G_o, G', G_w-- quantity of inlet, outlet flue gas, air leak and supplying oxygen, respectively (Nm^3/h）

t_i, t_o, t_k-- temperature of inlet, outlet flue gas and air, respectively (℃)

C_i, C_o, C_k--specific heat of inlet, outlet flue gas and air, respectively (kJ/kg. □)

L_s, L_o--flux of inlet and outlet slurry, respectively (kg/h)

t_{is}, t_{os}--temperature of inlet and outlet slurry, respectively (□)

C_s -- specific heat of slurry (kJ/kg.□)

ΔL—moisture carry-over in flue gas (kg/h)

L_z--vaporizing quantity in absorber (kg/h)

Δt_s--temperature of water in flue gas(□)

Δt--temperature difference by external diffusion heat of flue gas(□)

Q_i—quantity of heat of inlet flue gas (kJ)

Q'—quantity of heat of air leak (kJ)

Q_w—quantity of heat of supplying oxygen in oxidation air blower (kJ)

Q_s —quantity of heat of absorbent (limestone slurry) (kJ)

S_o—quantity of heat of outlet flue gas (kJ）

Q_{os}—quantity of heat of outlet slurry (kJ）

ΔQ—quantity of heat of water in flue gas (kJ）

H_z—quantity of heat of vaporizing in absorber (kJ)

Q_d—external diffusion heat in absorber (kJ）