Flue Gas Desulphuriation Using Jet Bubbling Reactor

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Abstract: - This paper deals with a very important topic of environmental protection: flue gas desulphurization. By burning sulfur-containing fuels (oil, coal) sulfur oxides are released into the atmosphere, causing acid rain, which is very harmful for both humans and the environment. Desulphurization technologies are very expensive, both in terms of investment, and operation. This paper aims to study the retention of sulfur oxides from flue gas by wet method using the jet bubbling reactor

Key-Words: - flue gas, desulphurization, sulfur oxides, mass transfer, reactor, bubbling, jet

1 Introduction

Of the various gases that pollute the atmosphere, first, because higher concentrations are carbon monoxide, nitrogen oxides and sulfur oxides, particularly sulfur dioxide.

Sulfur dioxide smell and attract attention by irritating action on the mucous membranes, causing spasm and contraction of upper airway muscles. Action of sulphur dioxide is potentiated both by the presence and by the possibility of formation of sulphuric acid aerosols; synergic action of sulphur dioxide and sulphuric acid aerosols cause lung damage much worse than these substances separately. Besides the action on living beings, sulphur dioxide is negative action and on plants, reducing crop yield proportional to its concentration.

Oxidation of sulphur dioxide to sulphur trioxide occurs through catalysis phenomena that occur in the atmosphere and water in the presence of transition metals, iron, manganese, cobalt fine particles of fog and clouds

2 Desulphurization methods

Three solutions are known flue gas desulphurisation: dry, spray drying and wet. Among them, the wet method has the highest yields.

Remove SO2 from flue gases is achieved by complex systems desulphurization, where the reactor is in the lead; it has plenty of options, with the disadvantage of investment and operating costs very high.

Wet FGD processes are classified as neregenerative and regenerative. Most absorbents used are compounds of calcium: CaCO3 and Ca (OH) 2. Neregenerative wet processes are the most popular, most having gypsum as by product. Wet regenerative processes eliminate the formation of by products, by consuming large amounts of reactants. Product obtained by these methods can be concentrated sulphur or concentrated sulphur dioxide and regenerate reactant.

Mathematical Equations must be numbered as follows: (1), (2), …, (99) and not (1.1), (1.2),…, (2.1), (2.2),… depending on your various Sections.

2.1 Wet desulphurization reactors

The basic equipment for both spray drying and wet flue gas desulphurization is the reactor. In spray drying desulphurization, reactant solution is sprayed, as shown in Figure 1.
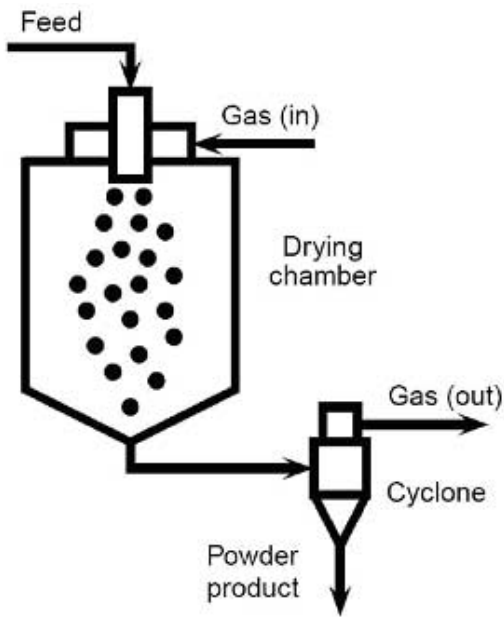
Figure 1

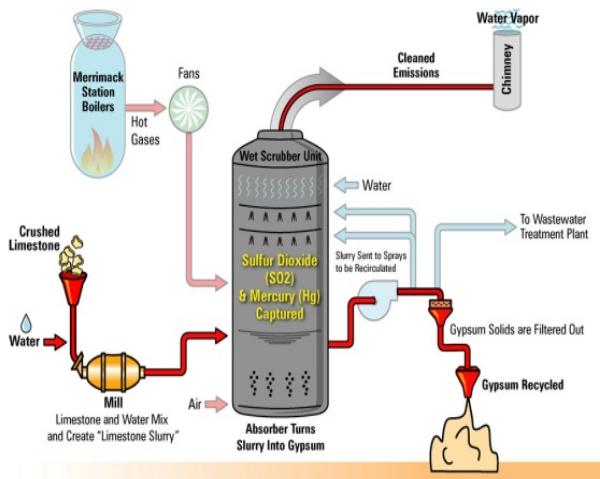The type of reactor used most widely in wet desulphurization is wet scrubber unit (Fig. 2)

Figure 2

Washer fluid is sprayed through several nozzles, made of corrosion resistant material. There are desulfurization solutions using the jet bubbling reactor (JBR) (Fig. 3)
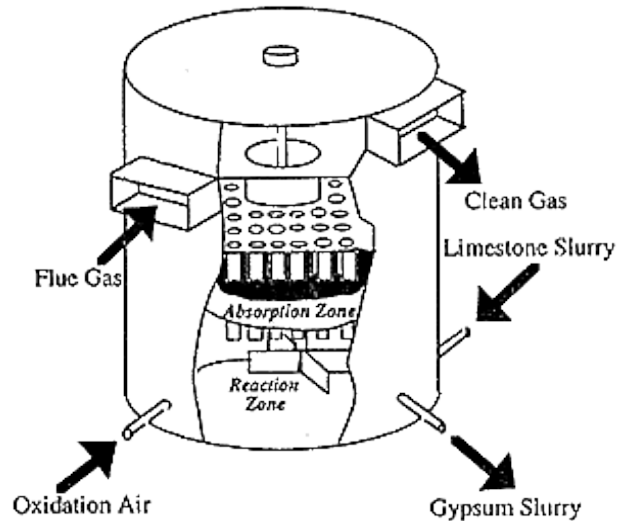

Figure 3

## 2.2 Mass transfer with chemical reaction in gas-liquid surface

In the absorption of a gas by a liquid, mass transfer takes place in three steps: the diffusion of the gas from the gas mixture to the liquid surface, its dissolution in liquid, diffusion of liquid inside. The basic theory used in the standard is the well-known "Two-Film Theory" from Lewis and Whitman (1924), which states that can be expressed transfer rate in terms of year overall transfer coefficient and resistances on either side of the interface. Mass transfer resistances in the stagnant layer of gas and liquid are expressed through partial mass transfer coefficients kG=DAG/δG that kL=DAL/δL. Effect of chemical reaction on mass transfer is presented by a parameter called synthetic intensification factor:

(1)

$$\Phi = \frac{reactant\ flow\ transported\ from\ the\ interface\ in\ the\ volume\ of\ liquid\ in\ chemical\ reactions}{eactant\ flow\ would\ be\ transported\ from\ the\ interface\ in\ the\ liquid\ volume\ in\ the\ absence\ of\ chemical\ reaction}$$

Rate mass transfer process in gas-liquid interface at the instantaneous reactions of the form:

$$A+bB \rightarrow products \quad (2)$$
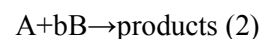
It is considered to occur in the liquid film, which consists of two parts: one containing only A, the other containing only B.Henry's law is written for A's balance at the interface:

$$PAi=HAcAi \quad (3)$$

It will still get : (4)

$$N_A = \frac{1}{\frac{1}{k_G} + \frac{H_A}{k_L}}\left(P_A + \frac{1}{b}\frac{D_B}{D_A}H_A c_B\right)$$

It will be introduced global mass transfer coefficient relative to the gas phase : (5)

$$K_G = \frac{1}{\frac{1}{k_G} + \frac{H_A}{k_L}}$$

In this way, the process rate the quantity measured will be: (6)

$$N_A = K_G\left(P_A + \frac{1}{b}\frac{D_B}{D_A}H_A c_B\right)$$

If we write according relationship of mass transfer coefficient in liquid phase K_L we obtain (7)

$$N_A = K_L\left(\frac{P_A}{H_A} + \frac{1}{b}\frac{D_B}{D_A}c_B\right)$$

Where (8)

$$K_L = \frac{1}{\frac{1}{H_A k_G} + \frac{1}{k_L}}$$

As seen in (6) and (7) relationships rate of the process is determined by mass transfer processes, and the size of the concentration in the liquid phase. If it reaches the $CB \geq cB$ 'equation becomes:

$$N_A = k_G p_A \quad (9)$$

This allows to rate the process simpler expression, independent of the B concentration. Critical concentration is expressed (10) and change with changing partial pressure of A:

(10)

$$c'_E = b\frac{k_G}{k_L}\frac{D_A}{D_B}p_A$$

Slow chemical reactions, reactant A is consumed in a negligible share in the film, the liquid phase is viewed as a process of mass transfer in the film, followed by chemical reaction in the convective zone, the concentration of B in the film remain constant.

In this case the process rate can be written as follows: (11)

$$N_A = k_L(c_{Ai} - c_{AL}) = v_R(c_{AL}, c_{BL})\frac{V_L}{S_t} \quad [kmol/m^2.s]$$

Where V_L is the total volume of liquid, practically equal to the volume of the convective zone, and S_t is the total interfacial area. If we take into account the gas phase mass transfer resistance is obtained: If we take into account the gas phase mass transfer

resistance is obtained: (12)

$$v_p = k_G(p_A - p_{Ai}) = k_L(c_{Ai} - c_{AL}) = v_R(c_{AL}.c_{BL})\frac{V_L}{S_t}$$

3 Characteristics of JBR

JBR generally used for slow reactions (oxidation, hydrogenation, chlorination) because the specific interfacial area relative to volume of liquid is small compared to other reactors. Also, the rate of penetration of gas into liquid at JBR unlike conventional bubbling reactor is about 10 times higher, ie obtain a superficial gas velocity of the order of several thousand cubic meters per square meter and time. Gas jet generates a bubbling zone, where liquid is mixed by violent gas and fine gas bubbles are broken by moving liquid.

### 3.1 Characteristics of gas-liquid horizontal jets

Thanks to simplify the study, the literature usually take into account vertical jets of gas in liquid. But taking into account that this paper addresses an engineering issue, where technical efficiency is important, she was directed to study horizontal gas jets in liquid.
Horizontality very little is actually stored as Archimedes force is in this case very little preserved.
Both width (l) and thickness (b) depending on the

speed of the jet are input gas in liquid, gas flow, the depth of immersion and physical properties of gas and liquid

The jet considered in this paper has the following configuration (Figure 4) :
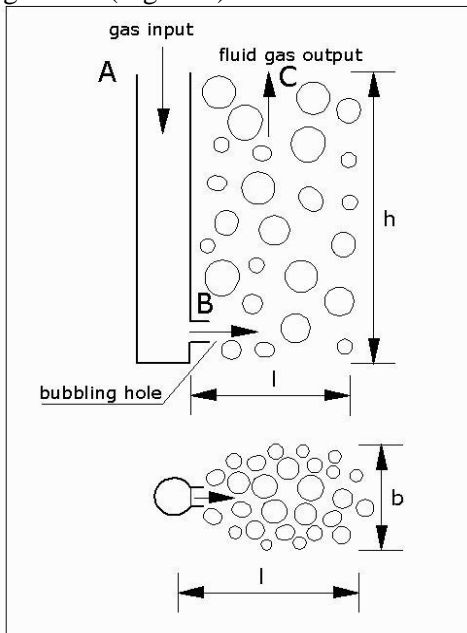
Horizontal flow structure of gas in the liquid.
h - depth of bubbling   l - jet width   b - jet thickness

Figure 4

Gas, which comes with a high speed in the liquid layer has a high relative impulse in the B zone. This, considering the properties of gas and liquid, the liquid is transferred quickly, so soon gas stream breaks into bubbles, which get a move upward.

An important characteristic for horizontal jets is that in the initial buoyancy B is zero.(Figure 5)
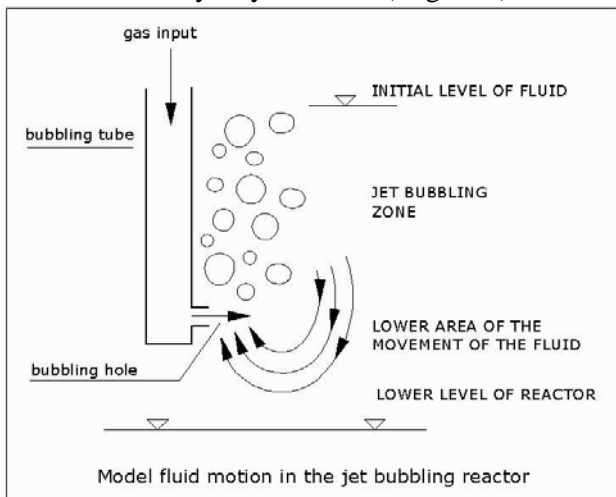

Model fluid motion in the jet bubbling reactor

Figure 5

3.2 Structure of two-phase flow

Formation of gas-liquid two-phase flow is due to

drive the liquid gas bubbles. Drive phenomenon has in this case these main causes:

-a portion of the motion of bubbles due to Archimedes force is transferred to the surrounding fluid. Initial impulse leads to the initial training of the liquid.

-a dissolution of the gas in liquid, produce lower density fluid jet, in relation to fluid flow outside. Thus creating conditions for the emergence of a strong upward free convection type.

The question is: when bubbles lifting to subscribe to "the isolated bubble" and when it comes to "jet-phase" of gas in liquid. For this in [40] to obtain volumetric flow limit between the two cases, the relationship (13)

$$V_{G_{lim}} = \left[\frac{2,14\sigma d_0}{(\rho_L - \rho_G)g^{2/5}} \right]^{5/6}$$

3.3 Definition of gas-liquid contact area at the horizontal jets

This paper deals with the study of mass transfer in situations where gas volumetric flow rate is higher than the limit defined flow relation (13). In this context, taking into account the study of mass transfer of gas-liquid interfacial area specific a_b [m2/m3] and upward velocity of gas bubbles w_b [m / s] is inappropriate for the following reasons:

-to define specific interfacial area is needed so the amount of gas in contact with the reactor volume or the reactor volume [m3]. The approach of this paper will follow the transfer of ownership (by mass) of gas from a solid to a liquid jet considering that gas escapes in a volume of liquid indefinitely.

-also for defining a_b size would require an average diameter of gas bubbles d_b, difficult notion also introduced, due to the complexity the phenomenon

-lifting speed-on bubbles, considering that there are initial horizontal momentum,which makes the gas jet have a very complex evolution, is impossible to define an average speed. Can instead define a gas-liquid contact time τ as follows:

$$\tau = V_G^*/V_G \ [s] \quad (14)$$

V_G^*-volume occupied by the gas that comes in contact with liquid [m3]

V_G-gas volume flow [m3 / s]

For the case of horizontal flow of gas in a volume of liquid indefinitely, it introduces the notion of gas-liquid interfacial total area (S_t).

Intuitively, it can be defined as follows:

$$S_t = V_G/w_G = V_G^*/V_G \ \tau \ [m^2] \quad (15)$$

Total interfacial area is easily intuited size. This is defined for a gas jet in liquid, the total area of gas-

liquid contact, Total interfacial area is easily intuited size. This is defined for a gas jet in liquid, the total area of gas-liquid contact, which property is exchanged in a two-phase jet. This size is one of the parameters that were studied in this paper using similarity theory and dimensional analysis.

3.4 Using Two-film Theory of mass transfer in the Jet Bubbling Reactor (JBR)

Since the mass transfer accompanied by chemical reaction at JBR is an extremely complex phenomenon, this study can not be done analytically .The most appropriate method for this is the similarity theory, accompanied by dimensional analysis.

It will study the gas-liquid mass transfer in the jet bubbling reactor using two-film theory

Mass transfer process rate is obtained to the relationship (16)

$$M_A = N_A S_t = (K_G / (\Re T)) S_t (p_A - p_A^*) \quad [kmol/s]$$

where K_G is shaped relationship on (17):

$$K_G = \cfrac{1}{\cfrac{1}{k_G} + \cfrac{H}{\Phi k_L}} \quad [m/s]$$

So you have to determine total interfacial area, St, and the two mass transfer coefficients, k_L liquid side and gas side k_G

3.4.1 Determination of criteria relationship for finding the total interfacial area

Based on a synthesis of works dealing with specific interfacial area a_b to bubbling, similarity that we can state the total gas-liquid interfacial area to JBR depends in particular: liquid and gas density, liquid viscosity, surface tension of the liquid, and the structural parameters of the jet bubbling reactor diameter and depth hole bubbling immersion

The theory of π we have the following relationship:

$$\pi = C \; S_t^{v1} \; \rho_L^{v2} \; (\rho_L - \rho_G)^{v3} \; \nu_L^{v4} \; V_G^{v5} \; d_0^{v6} \; h^{v7} \; g^{v8} \; \sigma_L^{v9}$$
(18)

Thus reach the following relationship criteria (19)

$$\frac{S_t(\rho_L - \rho_G)g}{\sigma_L} = C_x \left(\frac{V_G \rho_L}{\mu_L d_0}\right)^{x_1} \left(\frac{gh^3 \rho_L^2}{\mu_L^2}\right)^{x_2} \left[\frac{V_G^2(\rho_L - \rho_G)}{\sigma_L d_0^3}\right]^{x_3} \left(\frac{h}{d_0}\right)^{x_4}$$

The relationship of similarity meet the following criteria:

Bo defines Bond criteria adapted to JBR and represents the ratio of gravitational forces and the surface tension data. (20)

$$\frac{S_t(\rho_L - \rho_G)g}{\sigma_L} = Bo$$

$(Re)_L$- Reynolds criterion is related to the liquid (21)

$$\frac{V_G \rho_L}{\mu_L d_0} = \frac{V_G}{d_0 \nu_L} = (Re)_L$$

Ga is Galileo's criterion (22):

$$\frac{gh^3 \rho_L^2}{\mu_L^2} = \frac{gh^3}{\nu_L^2} = Ga$$

We-Weber's criterion is adapted to JBR. Weber criterion is the ratio of inertial forces and those due to surface tension. (23):

$$\frac{V_G^2(\rho_L - \rho_G)}{\sigma_L d_0^3} = We$$

G is geometric criterion for the jet bubbling reactor(24):

$$\frac{h}{d_0} = G$$

Thus, to calculate the total interfacial area can write the following criterial relationship (25):

$$Bo = C_x (Re)_L^{x_1} Ga^{x_2} We^{x_3} G^{x_4}$$

Sizes C_x, x_1, x_2, x_3 and x_4 be determined by experimental measurements.

3.4.2 Determination of criteria relationship for finding the mass transfer coefficient on the liquid k_L

Since the fluid movement occurs due process gas bubbling through it, mass transfer through the liquid film also depends on the speed at which gas enters the liquid. Also, mass transfer depends on the size of the reactor geometry (h and d_0).Properties of the liquid (ρ_l, m_l) should be considered, It's also A diffusion through liquid film (D_L), and the acceleration of gravity.

With those shown we can write: π (26)

$$\pi = C\, k_L^{\,y_1} d^{\,y_2} h^{\,y_3} \rho_L^{\,y_4} \mu_L^{\,y_5} g^{\,y_6} D_{vG}^{\,y_7} D_L^{\,y_8}$$

We obtain a relation of the form (27):

$$\frac{k_L \cdot d_0}{D_L} = C_y \left(\frac{V_G \rho_L}{\mu_L d_0}\right)^{y_1} \left(\frac{\mu_L}{\rho_L D_L}\right)^{y_2} \left(\frac{g h^3 \rho_L^2}{\mu_L^2}\right)^{y_3} \left(\frac{h}{d_0}\right)^{y_4}$$

Similarity criteria are involved in (27):
Sherwood (28):

$$\text{Sherwood} = Sh = \frac{k_L d_0}{D_L}$$

Reynolds defined to (21)

$$\frac{V_G \rho_L}{\mu_L d_0} = \frac{V_G}{d_0 \nu_L} = (Re)_L$$

Schmidt $= Sc = $ (29)

$$\frac{\nu_L}{D_L} = \frac{\mu_L}{\rho_L D_L}$$

Galileo defined with relationship (23):

$$\frac{g h^3 \rho_L^2}{\mu_L^2} = \frac{g h^3}{\nu_L^2} = Ga$$

(24) defined with geometric relationship:

$$\frac{h}{d_0} = G$$

In this way, the criteria relationship for determining of k_L is written as follows: (30) :

$$(Sh)_L = C_y (Re)_L^{y_1} (Sc)_L^{y_2} (Ga)_L^{y_3} G^{y_4}$$

C_y, Y_1, Y_2, Y_3, Y_4 values are to be determined experimentally.

3.4.3 Determination of criteria relationship for finding the mass transfer coefficient on the gas k_G

It will seek to determine the mass transfer coefficient not depending on the size of the gas bubbles, however unknown parameters when addressing the problem, but according to the geometric characteristics of the reactor (depth of immersion h, bubbling hole diameter d_0) and physical characteristics of the gas bubbled.
It easily recognize these criteria of similarity:
(28) Sherwood :

$$\text{Sherwood} = (Sh)_G = \frac{k_G d_0}{D_G}$$

Reynolds for gas (31):

$$\text{Reynolds} = (Re)_G = \frac{V_G \rho_G}{\eta_G d_0}$$

Weber (23):

$$\frac{V_G^2 (\rho_L - \rho_G)}{\sigma_L d_0^3} = We$$

Geometric (24): $G = H/d_0$
In this way, the criterial relationship for mass transfer through the gas film can be written (32):

$$(Sh)_G = C_z (Re)_G^{z_1} We^{z_2} G^{z_3}$$

4 Conclusion

Flue gas desulphurisation is a necessity in power plants burning sulfur fuels. This paper aims to study the gas-liquid mass transfer to the jet bubbling reactor. We studied a reactor with horizontal gas jet. Mass transfer was studied using double film theory. Added a new size to mass transfer in jet bubbling reactor called total interfacial area, S_t. With this new concept introduced relationships were determined criteria for determining measurements St, k_L and k_G. In this way everything is ready for the experimental determination of JBR, and find related measurements criterial relations which can cause mass transfer to JBR.

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