The Effect of Water Spray upon Incineration Flue Gas Clean-up

Haigang Wang Bin Li Shi Liu Zhonggang Pan Guizhang Yan
Institute of Engineering Thermophysics, Chinese Academy of Sciences
P O Box 2706, Beijing 100080, P R China

The existence of liquid water was found very important in incineration flue gas clean-up systems for enhancing the absorption of acid components contained. In a newly developed incineration flue gas clean-up tower, which works in a semi-dry mode, the water is injected in the form of spray to maximum its contact surface with the gas. The criteria for the design of the water nozzles would be high water concentration but no liquid impinging on the solid wall and complete evaporation inside the tower. In order to optimize the atomizer design, the effects of the spray type (hollow or solid cone), their initial droplet size distribution and water flow rate on the performance of the acid gas absorption were investigated. The liquid behaviour was studied with a fluid dynamic simulation code, and the overall performance was checked experimentally. This paper presents the use of a commercial CFD code, FLUENT, and some modifications made during such investigation. The modification includes the viscosity of the flue gas defined as a function of the temperature, and the initial mass fraction of different droplet size group described with an exponential distribution formula of Rosin-Rammler. The investigation results (the optimal spray parameters) were used to guide the water nozzle design. The general performance of the flue gas clean-up system measured during the plant operation complied with the design criteria.

Keywords: spray evaporation, fluid simulation, flue gas clean-up system.

Introduction

The rapid increase of municipal solid waste (MSW) generation in recent decades has resulted in huge piles of wastes in China especially in its south-east and other areas of dense population and fast economy developing. Due to the land occupation and air commitment, it has induced throat to the further development of these concerned areas. Effective MSW management technology must be developed, therefore, to remove these MSW piles, and the incineration technology would be the most prospective approach. A consequent issue of incineration flue gas has arisen and attracted the public concerns. Wet scrubber has been commonly used and proven to be effective for some pollutant spices clean-up, including some acid gases as HCl, SO_2 etc. Such wet scrubber generally uses hydrated lime slurry as the acid gas absorption agent since the liquid form water contained in slurry helps the neutralization reaction. This process, however, has some limitation in application because the difficulty of wet by-product handling and high water consumption.

In order to overcome such problem, a new process with powder feeding and dry by-product is under development in Institute of Engineering Thermophysics. In this process, the concept of circulating fluidized bed is adapted to ensure good contact of gas and $Ca(OH)_2$ powder. Water, the reaction promoter, is added into the scrubber tower separately by means of atomization to maximum the contact surface. This water droplets should evaporate completely before leaving the tower and not impinge onto the side wall to avoid the slurry formation. If such situation appears the slurry may flow down, accumulate at the bottom and block the gas entrance on the distribution plate. The behaviour of the water spray, therefore, must be investigated carefully.

The present study investigates the effect of initial parameter of the water spray upon its behaviour inside the scrubber tower. Computational fluid dynamics will be a good tool since this has many advantages over experimental approach, such as supplying detailed information about spray droplets with relatively less

Received 2000.

time and low monetary costs.

Modification on Calculation Process

The calculation was performed using Fluent 5.1, a computer program that is capable to efficiently solve multiphase flow using Discrete Phase Model. There have been two main changes adopted during the calculation, one is the droplet's drag law, the other is the material viscosity. These are defined as:

1. The relationship between C_D and Re_p for a droplet can be expressed by [1]:

$$C_D = \begin{cases} \dfrac{24}{\mathrm{Re}_p} & \mathrm{Re}_p < 1 \\ \dfrac{24}{\mathrm{Re}_p}(1.0+0.15\mathrm{Re}^{0.687}) & \mathrm{Re}_p < 800 \\ 0.424 & \mathrm{Re}_p < 2.0\times10^5 \end{cases} \quad (1)$$

2. Because the temperature of the fluid varies in the range from 283K to 523K, the viscosity can not be considered as a constant. The relationship between μ and T (temperature) can be expressed by:

$$\mu = 1.0\times10^{-5}\times[17.2+a_1(T-273.5)+ a_2(T-273.5)^2+a_3(T-273.5)^3] \quad (2)$$

In the above equation, the coefficients are deduced by the curve fitting method, and they are:

$$a_1 = 0.050667, a_2 = -0.00004, a_3 = 3.3\times10^{-7}$$

This relationship is therefore used as a function of the material property in Fluent 5.1 in the form of UDF (user defined function).

3.The spatial mass distribution of the water spray:

In the calculation, the mass fractional distribution of the water droplets is defined by the Rosin-Rammler equation, this distribution function is based on the assumption[2] that an exponential relationship between the droplet diameter, D, and the mass fraction of droplets with diameter greater than D, M_D, exists as:

$$M_D = \exp(-(D/\overline{D})^n) \quad (3)$$

in the equation $\overline{D}$ is a kind of mean diameter, n is called the Spread Parameter . In the calculation n is taken to be 2.3.

The Calculation Results

In this study the investigated spray structure is characterized by the following parameters: the semi-cone angle (θ), its origin position (x,y,z) or cone diameter (r), water flow mass ratio, droplet's diameter (D_p), initial velocity and temperature, as showed in Fig.1.

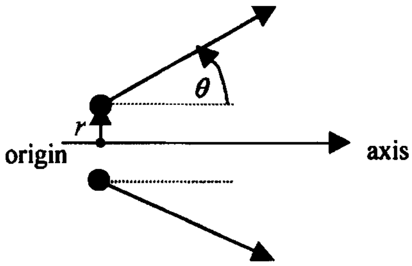

Fig.1 The initial structure parameters of a spray cone

The initial velocity of droplet is a function of the differential pressure across the nozzle and can be calulated using the following equation:

$$V_{p,\mathrm{int}} = c_s[\frac{2(P_{in}-P_b)}{\rho_p}]^{0.5} \quad (4)$$

where P_{in} is the water supplying pressure, P_b the main flow (flue gas) pressure and ρ_p is the water density. The coefficient c_s usually takes the value of 0.97.

Fig.2 and Fig.3 show two typical cone spray structure: hollow and solid cone spray. The hollow cone spray can be directly defined in the Fluent code menu, but the solid cone spray can not. Therefore it must be defined by an input file, in which all the input parameter described above need to be defined in the full plane of the droplet's initial position.

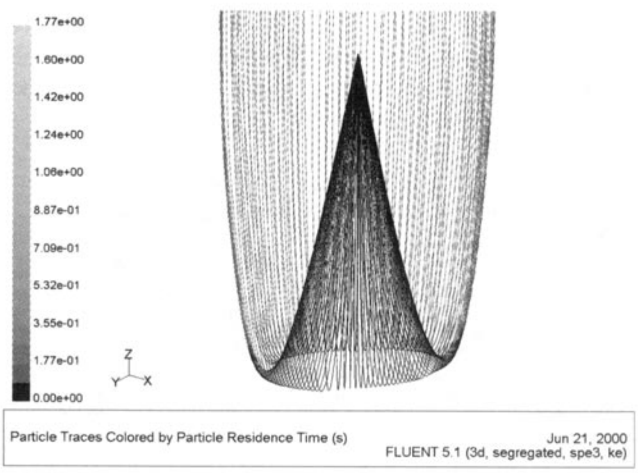

Fig.2 Hollow cone spray

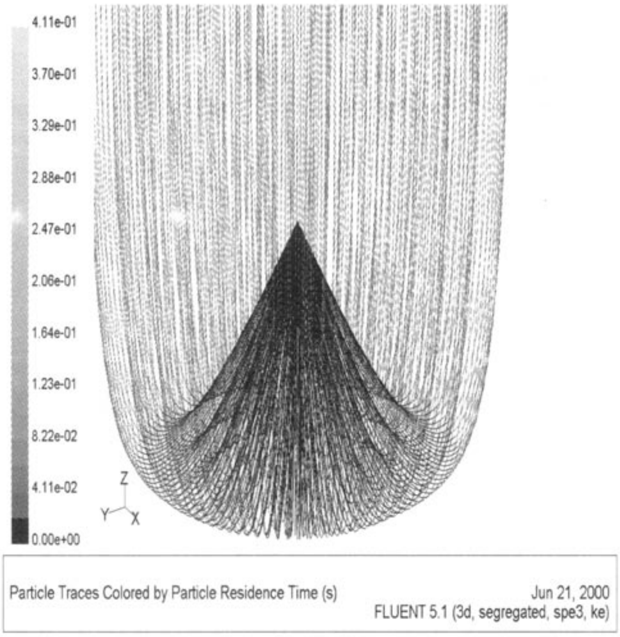

Fig.3 Solid cone spray

The droplets Reynolds number varies between 0 and 300, so the droplet drag coefficient law takes the relationship (1) to replace the original relationship in the Fluent code.

In Fig.4, two different calculation results are compared, in the first group the main fluid viscosity remains constant ($1.72*10^{-5}$ kg/m-s), while in the second case the viscosity was taken according to the formular (2). The difference of Reynolds number and mass fraction of H_2O in gasous phase between the two cases is very clear (refer to Fig.4 a,c,d,f).

Figs.5 and 6 give the average temperature and evaperatured rate at the plane of Z=12 m with three different initial droplet velocities as listed in Table 1. These sprays are all hollow cone type. In this calculation the gas viscosity is varing simultaneously with the local temperature. These curves show that the average temperature at z=12 plane decreases with the droplet initial velocity increase.

Table 1 Case study on initial droplet velocity

	Cone angle	diameter	Velocity	Mass flow rate
1	20.0	200 μ m	14.7 m/s	0.05 kg/s
2	20.0	200 μ m	24.7 m/s	0.05 kg/s
3	20.0	200 μ m	34.7 m/s	0.05 kg/s

The effect of the water injection rate of solid cone spray on the average temperature and evaporated rate

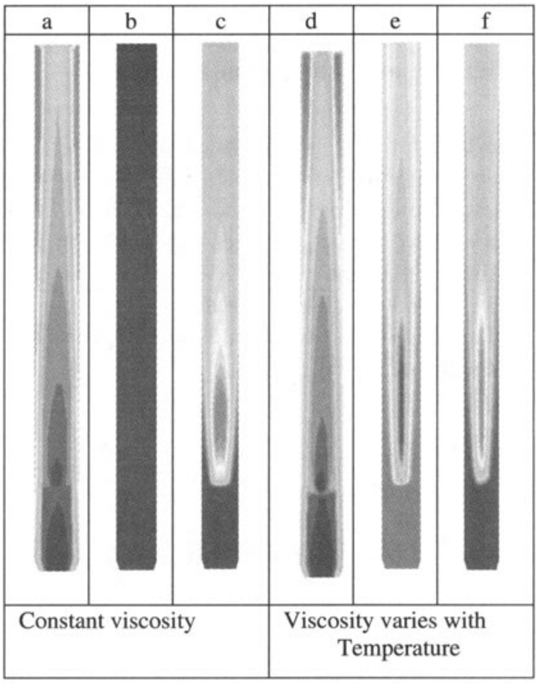

Fig.4 Results from different settings of gas viscosity (a and b are cell Reynolds number, b and e are Molecular viscosity, c and f are the fraction of H_2O)

at the Z=12 plane is showed in Figs.6 and 7. The parameters in these three cases are listed in Table 2. Calculation provided that all the droplets evaporated completely at z=11.6737m in case 1, 12.2571m in case2, 12.3807m in case 3 and 13.5139m in case 4. From these figures, we can conclude that with the mass flow rate of water increase the average temperature is decreased, and consequently the position of the last droplet evaporated is delayed.

Table 2 Case study on injected water mass flow rate

	Cone angle	Diameter	velocity	Mass flow rate
4	20.0	200 μ m	34.7m/s	0.05kg/s
5	20.0	200 μ m	34.7m/s	0.08kg/s
6	20.0	200 μ m	34.7m/s	0.10kg/s
7	20.0	200 μ m	34.7m/s	0.12kg/s

The cases 8 ~ 10 investigated the effect of the initial droplet size distribution on the spray behaviour. The size distribution, or the initial mass fraction, is expressed by the Rosin-Rammler formula (eqtn 2). Figs. 7, 8 are the calculation result. From the result, we can see that the droplet evaporation becomes slower when the mean diameter increases.

Table 3 Case study on mass distribution using Rosin-Rammler expression

	Cone angle	Mean diameter	velocity	Mass flow rate
8	20.0	60 μ m	34.7m/s	0.12kg/s
9	20.0	80 μ m	34.7m/s	0.12kg/s
10	20.0	100 μ m	34.7m/s	0.12kg/s

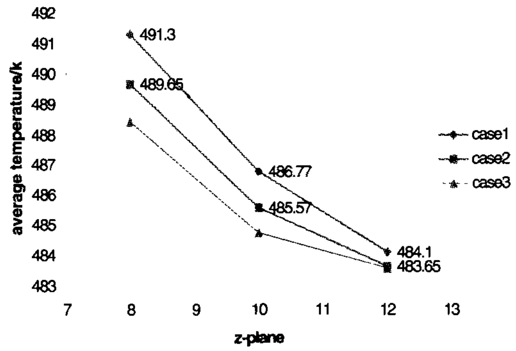

Fig.5 Average temperature

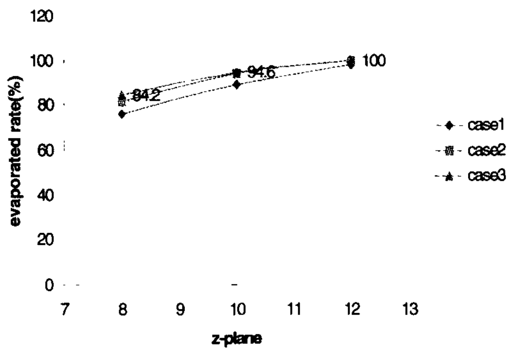

Fig.6 Droplet evaporated rate

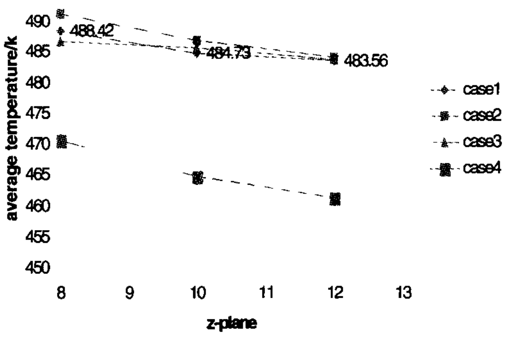

Fig.7 Average temperature

The nozzle design and plant operation

According to the numerical investigation of the spray behaviour and the existing gas clean-up tower's geometry, a set of spray parameters were outlined as the required water nozzle design criteria. These includes:

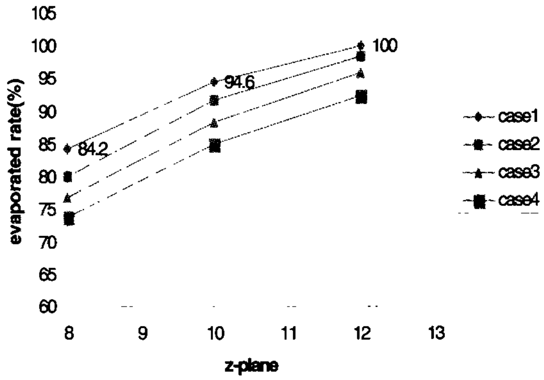

Fig.8 Droplet evaporated rate

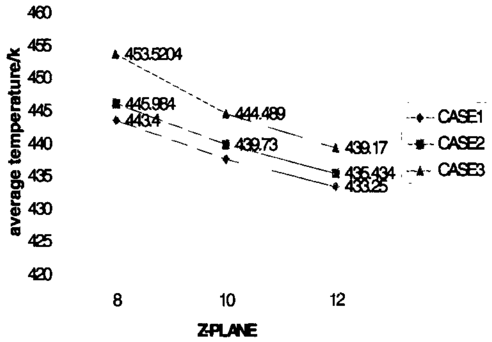

Fig.9 Average temperature

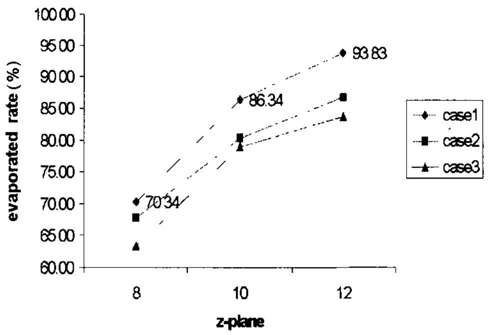

Fig.10 Droplet evaporated rate

Initial cone angle	30 degree
Initial droplet size (mean)	60 μm
Initial droplet size (max.)	100 μm
Spray type	solid cone
Water injection flow rate	450 kg/hr
Maximum initial droplet velocity	55 m/s

Because the required initial droplet size is fairly small, an air-assisted type nozzle would be preferred. For simplifying the water spray system, however, the mechanical type nozzle(s) was selected. Because the tiny droplet size and the relatively high water injection rate could not be realized with a single mechanically atomizing nozzle, two identical nozzles were designed and manufactured. Tested in the laboratory, the following parameters of the nozzles were obtained:

Initial cone angle	45 degree
Initial droplet size (mean)	43 μm
Initial droplet size (below 95 %)	100 μm
Spray type	solid cone
Water injection flow rate	232 kg/hr
Initial droplet velocity	35 m/s (with nozzle inlet pressure of 15 bar)

The gas clean-up tower is a 10 m high column. The two nozzles are located at the height of 1.75 m and 2.50 m from the bottom, where the gas flows in through a distribution plate. Over a range of plant operation, no signs of any water drop elutriation and impinging onto the wall were found. The concentration of acid spices in outlet gas was reduced and well met the EPA regulation.

Summary

Ten different spray structure were studied using the CFD code Fluent. From the calculation result and measured data, we can summarized below:

- The main flow temperature is strongly affected by the water spray mass flow rate. When the total mass flow rate increase , the drop of the temperature is increase, but there were some droplets which did not completely evaporated.
- The droplet initial velocity also affect the flow temperature. When the droplet initial velocity increase, the droplet can move more close to the inlet boundary, so it take away more heat of the main flow.
- When the droplet diameter increase, the drop of temperature increase, but it can not evaporated completely. Compared with the experience, the most optimial droplet diameter is between 150 *μm* and 10 *μm*.
- The fact that the concentration of acid spices in outlet gas were reduced and well met the EPA regulation suggests the success of the investigation and the system design.

References

[1] Schliching, H, "Boundary Layer Theory," 7th ed, New York: McGraw-Hill, (1979).

[2] Liang-Shi Fan and Chao Zhu, "Principles of Gas-Solids Flows," Cambridge University Press, pp.6-8, (1998).