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Research article

The synergetic particles collection in three different wet flue gas desulfurization towers: A pilot-scale experimental investigation

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ABSTRACT

The synergetic removal of particulate matters (PM) in different wet flue gas desulfurization (WFGD) towers was investigated on a pilot-scale experimental setup with the gas flow up to 6372 m^3/h. Three types of scrubbing tower, i.e. open scrubbing tower (OST), scrubbing tower with porous tray (TST), and scrubbing tower with a flow pattern control device (FST) were used in this study. The multiphase flow is a counter-current liquid-dispersed flow in OST, while it is an insufficient developed and fully developed bubble flow in TST and FST, respectively. The PM collection efficiency was significantly increased after adding internals (porous tray or flow pattern control device). The total collection efficiency for TST and FST was ~84.3% and ~87.2%, respectively, when using gypsum slurry as recycle liquid at a superficial gas velocity of 3 m/s and $L/G = 10$ L/m^3. Comparing to that of OST, the improvement of the efficiency was ~9.2% and ~13% for TST and FST, respectively. Interestingly, even though the pressure drop of FST is lower than that of TST, the particle removal efficiency of FST is the highest among three scrubbing towers, which means FST is much more cost-effective. The performance index (*PI*) is introduced in this study to evaluate the particle removal effect of different internals. The *PI* for FST is approximately 4 times larger than that of TST at $L/G = 10$ L/m^3, indicating a much better effect of FST for WFGD, especially for low-load operation in power plant.

1. Introduction

SO_x, NO_x and particles matters (PM) are the main pollutants released from coal combustion, leading to various environmental problems [1]. The emissions are more serious in China, because over 60% of the energy supplies in China come from the combustion of coals [2]. Chinese government has made great effort to reduce environmental pollutions by formulating specific policies, laws and regulations to address the emissions from coal-fired processes, including power plant boilers and industrial boilers [3]. In 2014, a new term with an aim of energy-saving and emission-reduction called “Ultra-Low Emission (ULE)” was proposed for coal-fired power plants in China, with SO_x, NO_x and PM emission limiting to 35, 50, and 10 mg/Nm^3, respectively. In the near future, this emission limit will be applied to all coal-fired boilers, not just for coal-fired power plants.

In terms of particles removal, although some advanced technologies [4], such as wet electrostatic precipitators, low-low temperature electrostatic precipitators, and electrostatic-bag dust collectors, showing a predominant performance for particle removing, the total costs are growing in order to meet the increasingly stringent standards of emission in China [5]. On the other hand, wet limestone-gypsum flue gas desulfurization (FGD) tower, as the most widely used desulfurization technology for coal-fired power plants [6], has a scrubbing removal effect for particulate matters [7]. According to previous studies, more than half of original fly ash (even > 70%) was removed in wet FGD process, while most of the fine particles (with size < 2.5 μm) escaped [8–10]. As a result, alternative to developing novel technologies for particulate matter removal, it is necessary to take full advantage of the existing flue gas purification devices, especially for Wet flue gas desulfurization (WFGD), in order to lower the PM emission synergistically.

Since 2004, many studies have been carried out to investigate the PM removal performance in WFGD as shown in Table 1. Various scrubbers are proposed and designed to improve the PM removal efficiency, such as multi-stage tray scrubber [11], multi-stage bubble column [12], swirl cyclone scrubber [13,14], spray-cum-bubble scrubber [15], modified turbulent scrubber [16], fixed valve tray column [17]. For most of the cases mentioned above, the particle removal efficiency for $d_p > 2$ μm was reported to be larger than 95%. As a result, adding some internals to control the flow pattern in the column is the most common and effective method for synthetic particles collection. However, the available internals mentioned above are difficult

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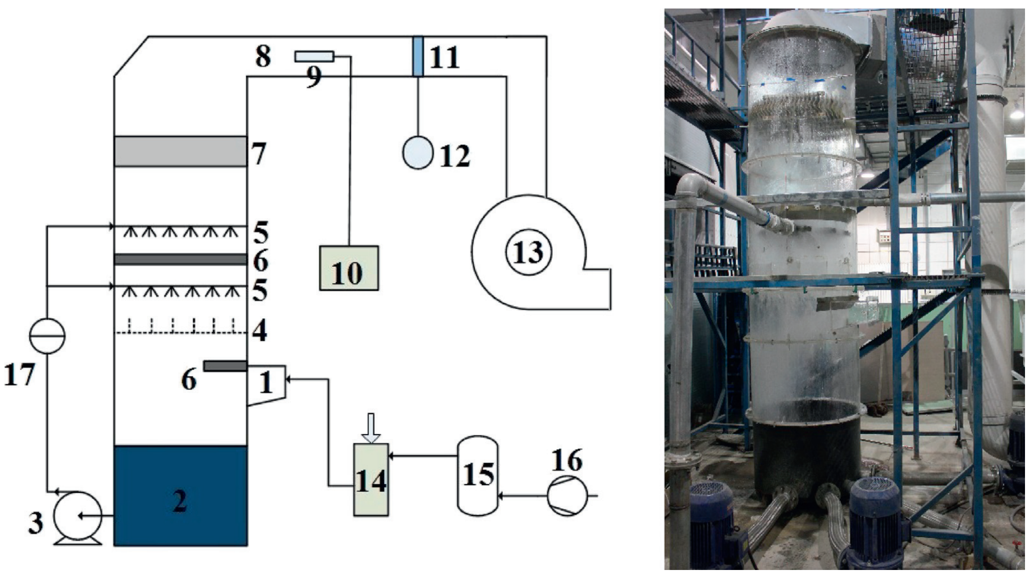
Table 1
Literature survey.

Literatures	Set-up scale (mm)	Gas flow (m^3/h)	Structure types	Technical route for particles removal
Meikap et al. (2004) [15]	Φ190.5 × 2000	10.8–21.6	Multi-stage bubble column	Flow pattern controlling by internals
Mohan et al. (2008) [25]	Φ12.5 × 2400	~11	Open scrubbing column	Scrubbing by atomizing droplets
Lee et al. (2008) [16,17]	–	1008	Swirl cyclone scrubber	Flow pattern controlling by internals
Mohan et al. (2008) [18]	Φ12.5 × 2410	11–20	Spray-cum-bubble scrubber	Flow pattern controlling by internals
Yang et al. (2010) [22]	Φ150 × 2500	~70	Open scrubbing column	Heterogeneous condensation and scrubbing
Byeong et al. (2012) [19]	600 × 220 × 1000	210–270	Modified turbulent scrubber	Flow pattern controlling by internals
Wang et al. (2013) [20]	Φ90 × 1350	0–18	Fixed valve tray column	Flow pattern controlling by internals
Wu et al. (2016) [21,26]	Φ200 × 5150	350	Open scrubbing column	Heterogeneous condensation and scrubbing
Bianchini et al. (2016) [13]	–	~28.5	Various scrubbers	Flow pattern controlling by internals
Kurella et al. (2016) [14]	Φ152 × 2600	3–7	Multi-stage tray scrubber	Flow pattern controlling by internals
Yan et al. (2017) [24]	Φ200 × 1500	~80	Open scrubbing column	Acoustic agglomeration and condensation
Luo et al. (2017)	Φ99 × 1500	–	Open scrubbing column	Pulsed corona discharge and acoustic agglomeration
Meij et al. (2004) [8]	600-MW power plant	1.9×10^6	Open scrubbing column	Scrubbing by droplets
Wang et al. (2014) [27]	300-MW power plant	–	Open scrubbing column	Scrubbing by droplets
Sui et al. (2016) [7]	300-MW power plant	–	Open scrubbing column	Scrubbing by droplets



(a) Schematic diagram (b) Pilot-scale system

Fig. 1. Experimental setup. 1. Inlet; 2. Slurry tank; 3. Circulating pump; 4. Internals (Porous tray or FPC device); 5. Spraying layers; 6. Deflectors; 7. Demister; 8. Outlet; 9. Sampler; 10. Flue gas analyzer; 11. Pitot tube; 12. Micro-manometer; 13. Centrifugal fan; 14. Powder feeder; 15. Gasholder; 16. Air compressor; 17. Flowmeter.

to apply into practical WFGD system due to various reasons, e.g. high resistance or easy to be blocked. Currently, the most frequently installed towers for WFGD are still open scrubbing tower (OST) and tray scrubbing tower (TST) [18,19]. The major difference between OST and TST is that a porous tray is applied in TST as an internal, which can change the local flow field in the tower to improve the desulfurization performance [18,19]. The scrubbing tower types and gas-liquid flow condition have a significant influence on particles removal performance [20]. Due to the effect of porous tray, a foam layer can be developed above the tray in the tower, which has a positive effect on desulfurization and PM removal [11].

Based on that, making the utmost of internals in tower to change the flow condition is still the most convenient and effective method for enhancing the desulfurization and PM removal performance. However, there are few researches focusing on the flow condition and PM removal in TST, which is one of the most frequently installed tower types. As shown in Table 1, the only work carried out by Kurella et al. in 2016 [11] is related with porous tray, but the structure parameters of tray and operation conditions were different from that of the practical TST, which failed to fully reflect the flow condition and particles collection process in actual process.

In addition, it is worth noting that most of the experiments mentioned above were done on a bench scale platform, with most of set-up diameter < 200 mm and flue gas flow < 1000 m^3/h, which lacks of practical guide for large scale application. Although some work (listed in Table 1) was carried out on the practical desulfurization plants, these investigations focused on open scrubbing tower without taking consideration of the internals. As a result, it is necessary to investigate the influence of internals on the synergetic removal of particles with a pilot-scale setup in order to provide practical guides for real applications.

In our previous study [21], a novel flow pattern control (FPC) device, as internal of spraying tower, was proposed to change the flow pattern in a widely used scrubbing tower. The developed FPC exhibited a better performance in bench scale experiments for both desulfurization and fine particles removal than that of the OST. To further study its applicability for industrial application and its superiority over the widely used OST and TST, pilot scales experiment were conducted with OST, TST, and FST (the scrubbing tower with FPC device).

Thus, the objective of this study is to investigate the synergetic removal performance of particulate matters in a pilot-scale WFGD tower with three different internal types. The total particles removal efficiency under different operation conditions, including superficial gas velocity, liquid to gas ratio, and the circulating liquid component, are measured by weighting method. The pressure drop caused by the adding of internals was compared with that of open scrubbing tower. The gas-liquid flow condition in different scrubbing towers and the