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Experimental investigation on gas–liquid flow, heat and mass transfer characteristics in a dual-contact-flow absorption tower

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ABSTRACT

As a kind of chemical reactor, the dual-contact-flow absorption tower has been widely used for SO_2 absorption in recent years. However, studies on heat transfer characteristics of the absorber have been rarely carried out. There is also lack of an integrated partition map of flow pattern in the dual-contact-flow absorption tower. In this paper, the gas–liquid flow, heat and mass transfer characteristics in the dual-contact-flow absorption tower have been experimentally investigated. Direct observation, probability density function (PDF) and power spectral density function (PSD) methods are comparatively adopted in the flow pattern analysis. The partition map of flow pattern in the dual-contact-flow absorption tower is obtained through integrating a large quantity of experimental data. In addition, empirical formulas of both heat and mass transfer performances have been developed. Application of empirical formulas has also been stated. The research results obtained in the present study can provide guidance for estimating the practical application performance.

Keywords: Absorption; Chemical reactors; Heat transfer; Mass transfer; Multiphase flow; Partition map

1. Introduction

SO_2, mainly generated from fossil-fuel combustion in power plants, is one of the main threats to social and environmental sustainability because of its harmful effect on human health and the ecosystems (Fang et al., 2011) Hence, numerous flue gas desulfurization techniques, such as dry, semi-dry and wet flue gas desulfurization, have been extensively developed and investigated to achieve the reduction of SO_2 emission. The wet flue gas desulfurization (WFGD), due to its high utilization rate of sorbent and low operation cost, has been widely used in most power plants worldwide (Kiil et al., 1998; Neveux and Le Moullec, 2011). In the past 30 years, different WFGD systems, such as the bubbling tower (Lancia et al., 1994; Meikap et al., 2002), the spray tower (Bandyopadhyay and Biswas, 2007; Eden and Luckas, 1998; Klingspor and Bresowar, 1995; Weiss and Wieltsch, 2005; Zhong et al., 2008), the grid packed tower (Kiil et al., 1998; Rejl et al., 2009), and the impinging stream reactor (Berman et al., 2000; Wu et al., 2007; Yan et al., 2011), have been proposed and studied to improve desulfurization efficiency and decrease operation cost.

The dual-contact-flow absorption tower designed for WFGD is one of the most promising reactors for SO_2 reduction (Fujimori and Nakashoji, 2003; Li et al., 2010; Naohiko et al., 1995; Sun et al., 2010). Due to the simple absorption setup, long contact time between the gas and liquid phase, large quantity of holding liquid, and intensive mixture (Li et al., 2010), the dual-contact-flow absorption tower certainly has versatile application prospect in the chemical process. By adding different additives, it can also be used to achieve integrated removal of pollutants in flue gas, such as SO_x, NO_x, CO_2, heavy metal, and particulates (Fang et al., 2011; Gao et al., 2010; Jin et al., 2006; Li et al., 2009; Raj Mohan and Meikap, 2009; Roy and Rochelle, 2004; Sun et al., 2011).

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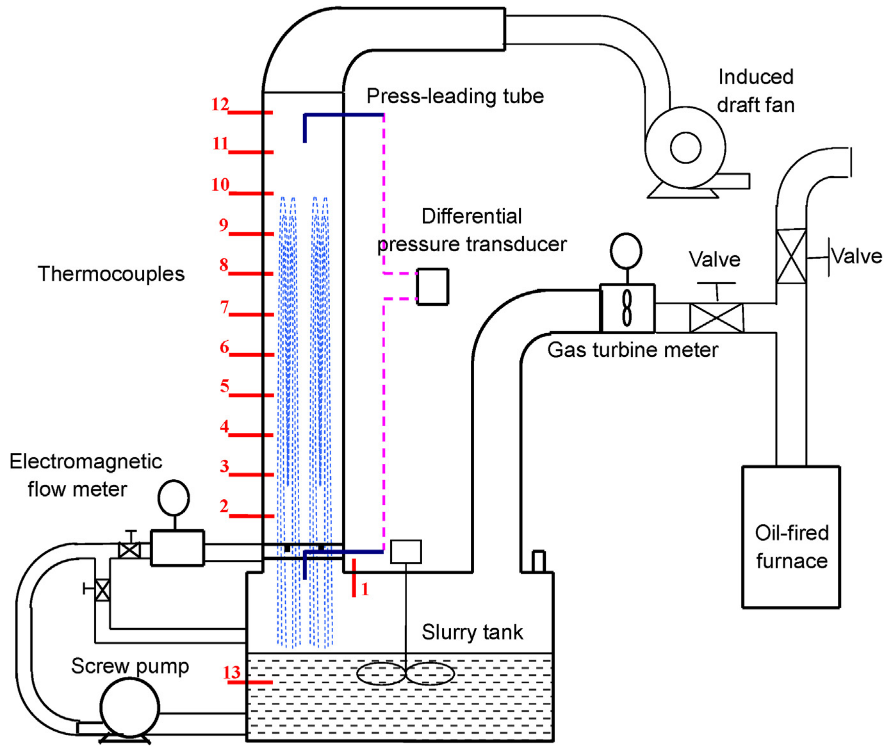

Fig. 1 – Experimental system schematic.

In our previous studies, Hou et al. (2006) carried out the flow pattern identification and their transition inside the dual-contact-flow absorption tower by probability density function (PDF). Li et al. (2010) experimentally investigated the mass transfer characteristics in the double-contact-flow absorber and proposed a method which could effectively describe and predict the mass transfer process. Sun et al. (2010) investigated the desulfurization efficiency in the liquid-screen desulfurization system. However, few studies on heat transfer process have been carried out and there is also lack of an integrated partition map of flow pattern in the dual-contact-flow absorption tower.

In this paper, the corresponding experimental investigation on gas–liquid flow, heat and mass transfer characteristics in the dual-contact-flow absorption tower has been carried out comparatively. We also present further research on the flow pattern identification in the dual-contact-flow absorption tower with direct observation, probability density function (PDF), and power spectral density function (PSD) methods comparatively. The PSD method has been successively applied in the flow pattern identification which was rarely utilized in the flow pattern identification in the WFGD systems previously. The partition map of flow pattern in the dual-contact-flow absorption tower has been obtained by integrating a large quantity of experimental data, which is of great benefit for determination of the optimal heat and mass transfer condition. In addition, different factors influencing the performance of the absorber have been analyzed and the empirical formulas of heat and mass transfer coefficients are also derived. All the work above is indispensable for the further application of the dual-contact-flow absorber and will provide valuable guidance for further work on flue gas treatment.

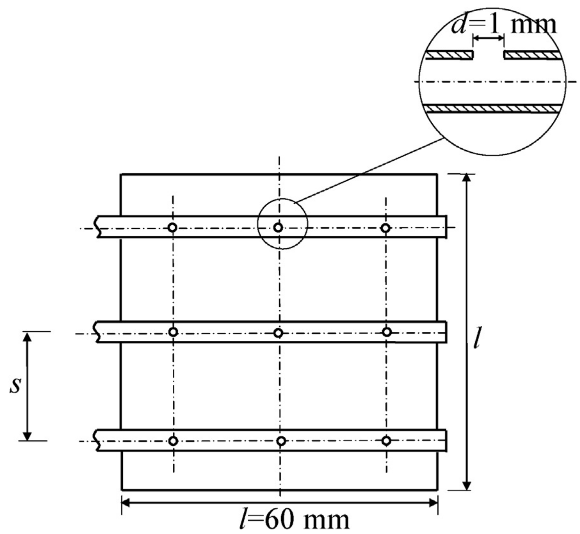

Fig. 2 – Configuration of nozzles in the experiment ($s/d = 20$, $d = 1$ mm, 3 × 3).

2. Experimental apparatus and procedure

The dual-contact-flow absorption tower has been developed on the basis of advantages of the traditional spray tower (Klingspor and Bresowar, 1995), the grid packed tower (Kiil et al., 1998) and the bubbling tower (Lancia et al., 1994). Fig. 1 shows the schematic representation of the dual-contact-flow absorption tower experimental apparatus. The test system, consisting of the absorption tower system, the slurry circulation system and the flue gas generating system, was designed on the basis of the principle of similitude and modeling.

As shown in Fig. 1, circulation slurry was sprayed upwards from a set of nozzles fixed at the bottom of the absorption tower. The slurry liquid columns scattered and then fell back, forming a dual-contact flow. The pseudo-flue gas generated by an oil fired furnace entered the absorption tower with the assistance of an induced draft fan. The two phases of gas and liquid contacted with each other the first time as the