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# Experimental study on particle removal with gas-liquid cross-flow array system ☆

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## ABSTRACT

It is considered to be a valid method for using the waste water of an industrial plant in a wet scrubber to control the air pollution of the exhaust gas of the same plant. A new Gas-Liquid Cross-flow Array (GLCA) wet scrubber system is proposed to reduce the particulate matters of the exhaust gas. Thereby, the plant's waste water is formed into a continuing and regular liquid columnar array to separate the exhaust gas particles. The principle of this method is that many continually falling waste water liquid columns act as dust collectors. These dust collectors are perpendicularly streamed by the dusty gas flow and particles can be captured by the water stream due to inertial, diffusion and interception mechanisms.

Generally the GLCA system is applied to exhaust gas purification with hot temperatures, where inertial, interception, diffusion, condensation, and thermophertic mechanisms could occur. However, in the first scientific investigation the gas temperature was fixed close to the water temperature. So the condensation and thermophertic effects can be nearly excluded.

A model approach for this "cold version" was developed to optimize the design and operating parameters. Experiments on a lab-scale test rig are shown, by which the pressure drop and the grade penetration efficiency were measured for different parameters (number of unit rows, geometric parameters and gas velocities...). To get the optimal GLCA parameters for a high separation efficiency with lowest pressure drop the quality-factor is used. Further a method is presented to calculate the single unit row grade penetration and pressure drop from measurements of the total grade penetration and total pressure drop of a high number of unit rows. With these method it was possible to calculate for a certain given particle size separation efficiency, the needed number of unit rows, respectively the length of the GLCA filter apparatus and the expected total pressure drop.

## 1. Introduction and goal of the work

The methods of air purification for fine particle removal are well documented, and they are generally based on filtration, electrostatic precipitation and wet scrubbing. Filters, such as cleanable filters (bag house) [1], granular beds filters [2], simply capture those particles, but the main problems arise from the cleaning of the clogged filter medium. Meanwhile, electrostatic precipitator (ESP) utilize electrostatic forces to attract particles to a collection surface. However, the separation of the particles from the gas stream is sometimes not secure and the investment cost of an ESP and energy consumption are relatively high [3]. In terms of wet scrubbers [4–7], there are two common systems--the liquid dispersing system and the gas dispersing system. Normally they need extra operating cost to purify recycling water, which may be expensive.

Generally speaking, many industrial processes produce substantial amount of waste water and it is uneconomic to be treated separately. Based on the conception that, the waste water and the exhaust gas could be treated simultaneously, a Gas-Liquid Cross-flow array (GLCA) system was proposed, in which the waste water serves as the medium for separating the particles from the exhaust gas. Zhu et al. [8,9] proposed to utilize a GLCA system, which uses drilling waste water to separate fine particles from diesel engines exhaust gas. This approach was proven to be highly cost-effective.

This GLCA system can be categorized into wet scrubbers, but the main distinction from the traditional scrubbers, where droplets are used, is the collecting surface. The collecting surfaces of the GLCA system consists of the outer surfaces of the falling water columns. A continuous and regular liquid column array is formed under the force of gravity with a holed distributor, by which the particles will be captured when the dusty gas flows through the

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column array. There are two main advantages of this approach. Firstly, the separation surface of these columns will be continuously cleaned and the initial low pressure drop will be kept constant over the whole operation time. On the other hand, the waste water has to be treated anyway later in the waste water treatment section, so it can help to omit the purifying cost of the washing liquid.

So far, the research related to GLCA system is very limited and only few data are available. In order to improve the separation and pressure drop behaviour, it was the goal of this paper to develop a suitable optimization method for the design and operating parameters. Usually, the application of the GLCA system will be used for hot gas purification, where a temperature difference occurs between waste water and the gas. There, besides inertial, interception, diffusion, condensation and perhaps also thermophoretic effects will act as separation mechanisms. But within the first scientific investigation steps, the temperature of the gas was fixed nearly to the temperature of the water, so the condensation and thermophoretic mechanisms could be nearly excluded. A lab-scale apparatus was built up, by which the separation efficiency and the pressure drop can be measured for different design parameters (like geometric arrangements, number of columns) and operating parameters (gas velocities). To find out the right design and operating parameters, an optimization method has been developed within this paper.

## 2. Experimental setup

The experimental setup is shown schematically in Fig. 1 [10]. Instead of a through-going waste water, which will not be circulating in industrial scale, circulating tap water was used in order to save the water consumption of the test unit. The circulating tap water was pumped from the water tank onto the top of dust purification chamber where the volume flow was measured by an orifice meter. Thereafter the water formed a regularly arranged columnar array under the force of gravity over a holed distributor. The structure of purification chamber can be found in Fig. 2. There are 6 channels in series, and each channel is connected to the other by an elbow. The water will be gathered at the bottom of every channel, and then it will be redisposed by a distributor at the top of the channel below. Ambient air was used as carrying gas which was sucked in by the blower and the dust was dispersed by a powder dispersion generator (RBG 2000, Pales GmbH). The volume flow of the gas and the corresponding particle concentration can be adjusted by varying the suck-in rate of the blower and the dispersing rate of the dust generator. During the experiments, the pressure drop and the particle size distribution were measured in front of the first channel and after each other channel.

The section profile of the purification chamber is illustrated in Fig. 2. The particle size distribution and the concentration were measured by a Welas digital 2000 (Palas GmbH) device. And a series of sampling probes for particle size distribution were measured isokinetically [11]. In order to get the right dust concentration for the Welas digital 2000, a dilutor (VKL 10, Palas GmbH) was used.

## 3. Varied test parameter

Tests were executed for different liquid column arrangements and different gas velocities.

The schematic diagram for one channel of GLCA is shown in Fig. 3. The cross area of the gas is a 150 × 80 mm rectangle. The arrangement of liquid columns can be easily changed by replacing the distributor at the top of each channel. The total opening area for all tested distributor arrangements was almost kept constant ($77\ \mathrm{cm}^2 \pm 2\%$) and the volume flow of recycling water was fixed to $13.4\ \mathrm{m}^3/\mathrm{h}$. This ensures a nearly constant water velocity for each distributor arrangement in the columns of 0.48 m/s. Preliminary tests have shown that a water volume of $13.4\ \mathrm{m}^3/\mathrm{h}$ shows a steady cylindrical downward flowing shape and will not become unsteady for different tested cross flow gas velocities. Also experiments with different column heights [12] show that 20 times of the hole diameter ($4 \times 20 = 80$ mm) is sufficient to have a steady downward flow of the water columns. So, for this setup, the height of all the columns was designed to be 80 mm.

6 different column arrangements were considered to be tested. Among them 3 arrangements have 4 mm and 3 arrangements have 5 mm column diameter (Fig. 4). For each arrangement, two subsequent rows of liquid columns in the gas flow direction will be treated as one unit row in order to have equal elements with increasing unit numbers $n$ (Fig. 5). There were 15, 19 and 21 unit rows in each channel for the arrangements of $d = 5$ mm and 18, 24 and 27 unit rows in each channel for that of $d = 4$ mm, respectively. In Eq. (1), a dimensionless column distance factor $Z$ is defined to relate the distance between the columns $t$ to the channel width $w$. In that condition, $Z$ varies from 0.5 to 1.0.

Further different gas velocities between 0.4 and 1.0 m/s were tested. All configuration, operating and fluid property parameters are listed in Table 1.

$$Z = \frac{t}{w} \tag{1}$$

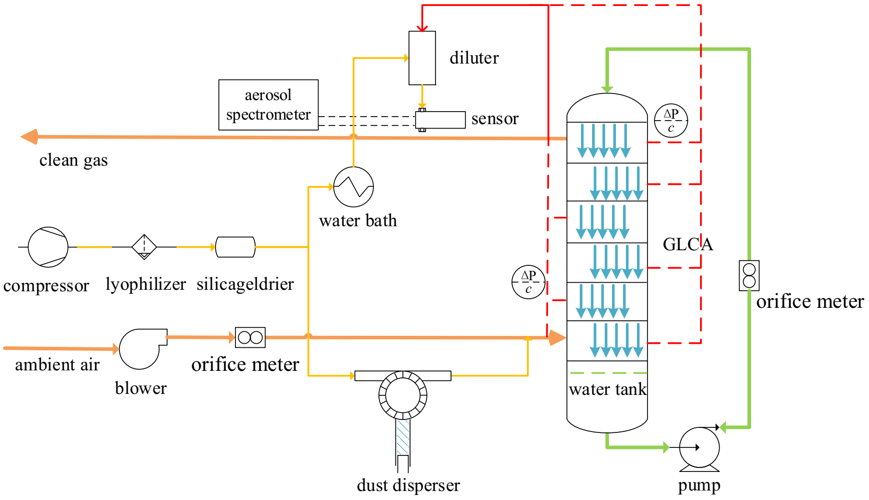

**Fig. 1.** Scheme of the experimental setup.