CHEMICAL ENGINEERING TRANSACTIONS
VOL. 45, 2015
A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet
Guest Editors: Petar Sabev Varbanov, Jiří Jaromír Klemeš, Sharifah Rafidah Wan Alwi, Jun Yow Yong, Xia Liu

ISBN 978-88-95608-36-5; **ISSN** 2283-9216 DOI: 10.3303/CET1545148

Experimental Investigation and Engineering Application of the Novel WX/U Desulfurization Equipment

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In this paper, a novel wet-flue gas desulfurization absorber including a venturi scrubber unit, a spraying section and a hydro-cyclone unit has been developed and investigated experimentally. A mixture of air and SO_2 was used to simulate flue gas and dilute sodium alkali was used as absorbent in the test. Test results indicated that the performance of WX/U desulfurization equipment was good, with the removal efficiency being much higher than that of a venturi scrubber. Furthermore, a full scale WX/U desulfurization equipment which employs dual alkali process has been set up in 2005. The monitoring results from local environmental protection bureau showed that sulfur dioxide of concentration has decreased from 2176 mg • Nm^{-3} to 298 mg • Nm^{-3}, while the mass concentration of dust has been decreased from 4027 mg • Nm^{-3} to 39 mg • Nm^{-3}. Overall results indicate that WX/U desulfurization equipment can be used for SO_2 absorption and dust collection in coal-fired boilers of either low or medium capacities. This document contains formatting instructions for preparing a camera-ready paper for CET. These formatting instructions comply with the rules set by AIDIC for the publication of the papers in a volume in the series: Chemical Engineering Transactions.

1. Introduction

Sulfur dioxide is a major atmospheric pollutant which could generate acid deposit; therefore its abatement in flue gases is a significant industrial concern (Vairo et al., 2014). In the past decades, many efforts have been made in SO_2 emission control, and wet scrubbing is the most commonly used approach (Xu et al., 2010). As a key component in wet flue gas desulfurization, the development and optimization of wet scrubber have received much attention. So far the most widely used wet scrubber types including spray scrubber (Brogren and Karlsson, 1997), packed tower (Gutiérrez Ortiz et al., 2006), jet bubbling reactor (Zheng et al.,2003), spheric O-element (Jecha et al., 2011), venturi scrubber (Taheri et al., 2010), slurry jet tower (He et al., 2002), PCF device (Gao et al., 2011), and two-stage hybrid scrubbers such as spray and bubble column (Bandyopadhyay and Biswasa, 2006). Venturi scrubber is one of the most prominent due to its simple structure, lower initial investment, and high removal efficiency. The first paper concerning the absorption of SO_2 was published in 1971 (Shah, 1971). Four Coners power plant has successfully transformed the dust-removal venturi scrubber into an integrated equipment of dust-removal and desulphurization by adding a lime slurry recycling system (Jason, 1981).Some novel desulphurization equipment have been developed based on the venturi scrubber, such as the two-stage ejector venturi scrubber (Xavier et al., 2012), the novel venturi scrubber (Mi and Yu, 2012) etc.
Since the application of desulphurization equipment was mainly meant for environment protection, its cost and performance are the most important factors need to be considered. To obtain a high-efficiency desulphurization equipment with lower cost, the WX/U desulfurization equipment have been developed by the authors successfully. In this study, the development, research course and structural features of the WX/U desulfurization equipment were introduced firstly. Then its performance was investigated experimentally. Finally, a full-scale WX/U desulfurization equipment was designed and applied for a low-capacity coal-fired boiler.

Please cite this article as: Duan Z., Huang W., Jia W., Zhang J., 2015, Experimental investigation and engineering application of the novel wx/u desulfurization equipment, Chemical Engineering Transactions, 45, 883-888 DOI:10.3303/CET1545148

2. Research and development of the WX/U desulphurization equipment

Due to the fact that the only significant deficiency of venturi was its huge pressure drop, investigations on the pressure loss of venturi scrubber were conducted firstly and the optimum structural size was obtained (Duan et al., 2004). Then the desulphurization performance of the venturi scrubber with optimized structure was investigated (Duan et al., 2008). To separate the residual dust particles and droplets from the flue gas effectively, the hydro-cyclone was chosen as gas and liquid separator. Based on the above factors, the novel equipment was developed as shown in Figure.1.

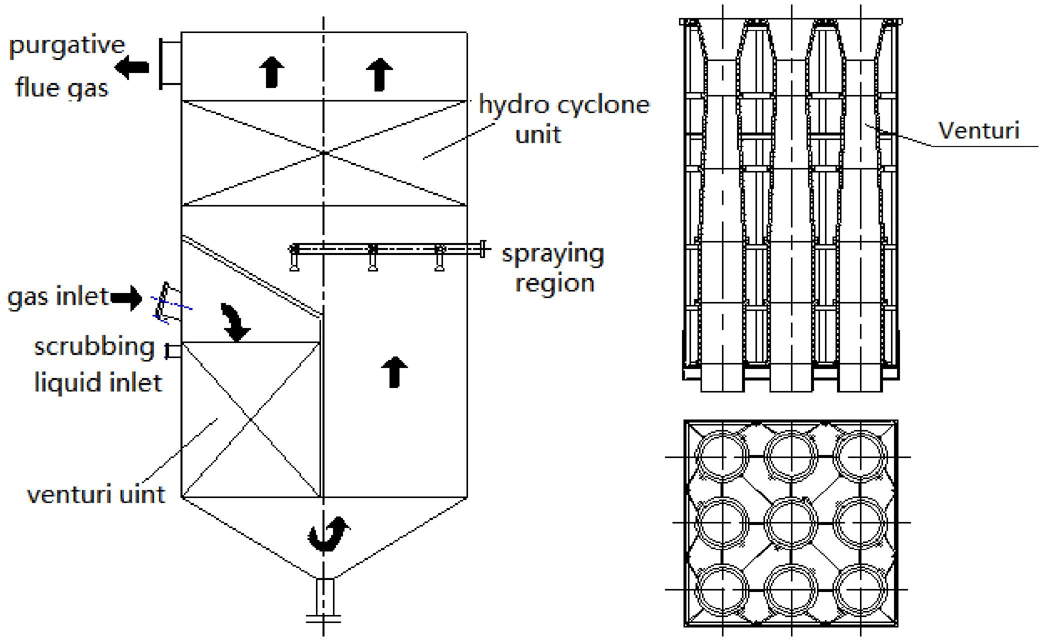


Figure 1: Schematic diagram of WX/U desulfurization equipment

As shown in Figure.1, the overall absorption zone consists two parts. First is the venturi unit through which flue gas enters in the middle part of the device and be distributed uniformly to the inlet of each single venture afterwards. The second is the spraying section in which the recycled liquid sprays from the top to bottom and absorbs the flue gas by counter-current contact reaction. Subsequently, the flue gas flows upwards into the hydro-cyclone unit to be separated from liquid and then was emptied. The novel equipment was named as WX/U desulphurization equipment and has the following features:

(1) Unique main structure with no concerns of engineering amplification effect

It has been found that it is impossible to get a uniform droplet distribution over the throat if the throat diameter exceeds 420 mm (Val'dberg and Dubinskaya, 2002). Therefore the venturi unit was designed to be composed of many small-sized individuals assembled in parallel as shown in Figure.1. The hydro-cyclone unit was similar to the venturi unit. Due to this unique structure design, the number of small-sized individuals could be adjusted conveniently according to changes in actual operating conditions, which helps to reduce concerns about the engineering amplification effect.

(2) Lower investment of the core equipment

Since the structure is relatively simple, both the small-sized venturi and hydro-cyclone could be made by firing the chemical clay, which has an excellent anti-corrosive property but costs much less than stainless steel such as Cr18Ni9Mo2Ti. It could not only prolong the service life but also reduce the cost of core equipment due to the rich resources of high quality chemical clay and world-famous firing technology in China.

(3) Hydro-cyclone employed in the WX/U desulfurization equipment was the inverse installation. That is to say, the conventional upper-lower flow direction was abandoned and instead the lower-upper pathway was used. Consequently liquid droplets in cyclone separator are separated from gas and then flows down along the wall while gas flows in upward direction. This structure avoids the gas liquid back-mixing phenomenon existed in the traditional hydro-cyclone because of gas-liquid motion. The separation efficiency is improved consequently.

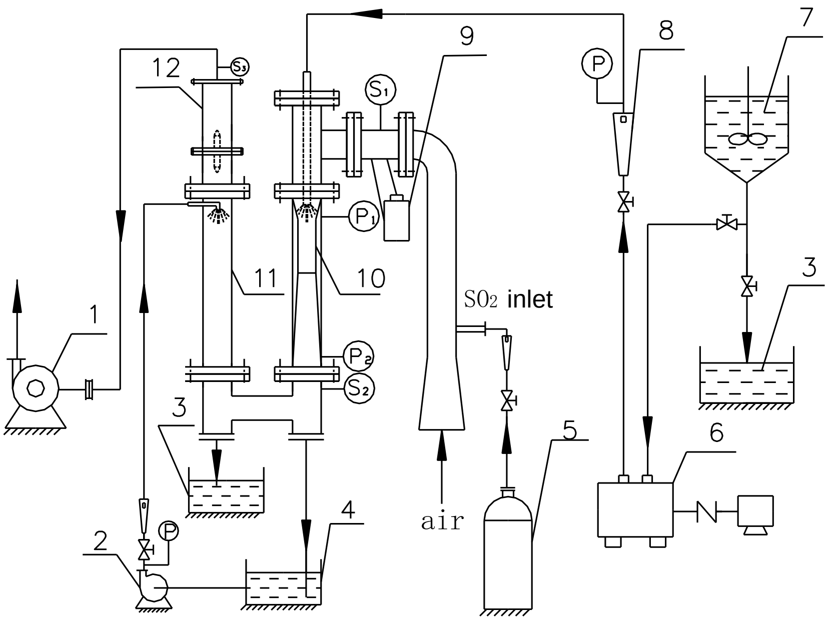
(4) The WX/U desulfurization equipment is an integrated equipment of de-dust and desulfurization.

3. Experimental Section

3.1 Experimental setup and measuring methods

The experiment set-up was schematically shown in Figure 2. Since there was no amplification effect in the present equipment, a single venturi scrubber and a single hydro-cyclone were employed instead of venturi scrubber and hydro-cyclone units to reduce test cost. Na_2CO_3-$Ca(OH)_2$ dual alkali process was adopted and sodium solution was used as scrubbing liquid. The optimal geometric parameters of a venturi were: convergence angle (24 °), throat length (100 mm), throat diameter (50 mm), divergence angle (7 °), second-spraying duct diameter (80 mm), and height (350 mm).

The concentrations of SO_2 at the inlet (S_1) and outlets (S_2 and S_3) were measured simultaneously by three single phase gas analyzers, i.e. SGA94-SO_2. More detailed description of experimental procedure and measuring methods can be found in literature (Duan et al., 2010).



1.draught fan; 2.recycle pump; 3.reservoir tank; 4.recycle tank; 5.SO_2 cylinder; 6.peristaltic pump; 7.fresh solution tank; 8.rotameter; 9.chattock gauge; 10.venturi scrubber; 11.second-spraying duct; 12.hydro cyclone

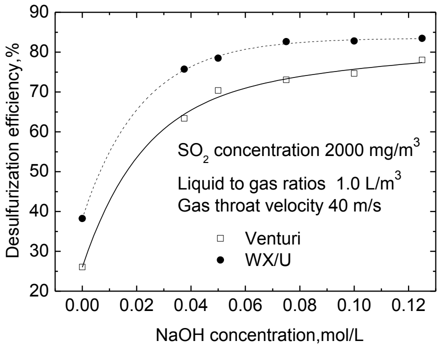
Figure 2: Schematic diagram of experimental set-up for the WX/U desulfurization equipment

3.2 Experimental results and discussion

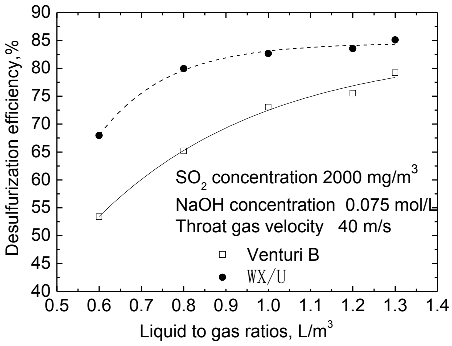
Figure 3 shows that the desulfurization efficiency of the WX/U desulfurization equipment is higher than that of a single venture due to the fact that the addition of a second-spraying section increases the contacting and reacting time. For example, under the given operational conditions, the desulfurization efficiency of a single venturi was only 73.05 % while then it was up to 82.65 % in the WX/U desulphurization equipment, which had been increased by 9.6 % obviously.

During the experiment, through the observation of the flow pattern of droplets in the hydro-cyclone, it was found that the number of droplet entrained into the hydro-cyclone by flue gas was reduced substantially as most liquid droplets were separated by gravity and fell into the second-spraying section before entering the hydro-cyclone, even when the flue gas flow reached the maximum. All these results indicate that the inversed structure of hydro-cyclone could reduce operational load and consequently its pressure loss.

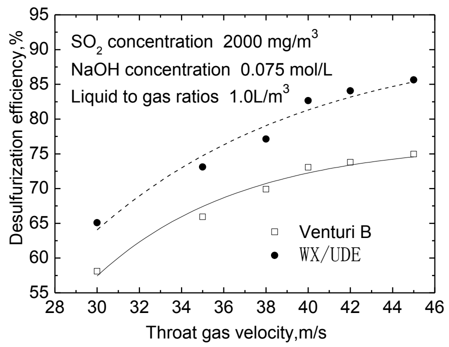
Figure 3 also shows that, if the concentration of NaOH is up to 0.1 $mol \cdot L^{-1}$ or the liquid to gas ratio reaches 1.2 $L \cdot m^{-3}$, the concentration of SO_2 in flue gas after going through venturi scrubber had been reduced to a quite low level due to the fact that the OH^- concentration was higher than that needed for absorbing SO_2. Then the function of the spraying counter-current absorption was decreased. Furthermore, the mixture and turbulence levels of liquid and gas could be increased by speeding up the gas throat velocity. As a result, the desulfurization efficiency difference between WX/U desulfurization equipment and venturi enlarges by increasing the throat gas velocity.



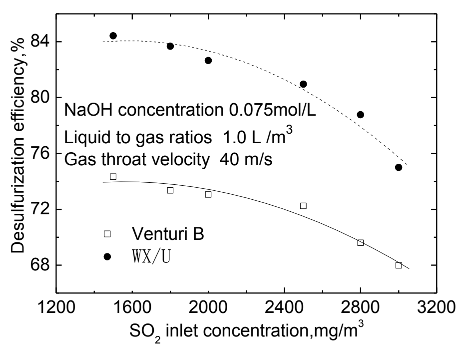
(a) Effect of NaOH concentration



(b) Effect of liquid to gas ratios



(c) Effect of gas throat velocity



(d) Effect of SO_2 inlet concentration

Figure 3: Effect of operational parameters on the desulfurization efficiency of WX/U

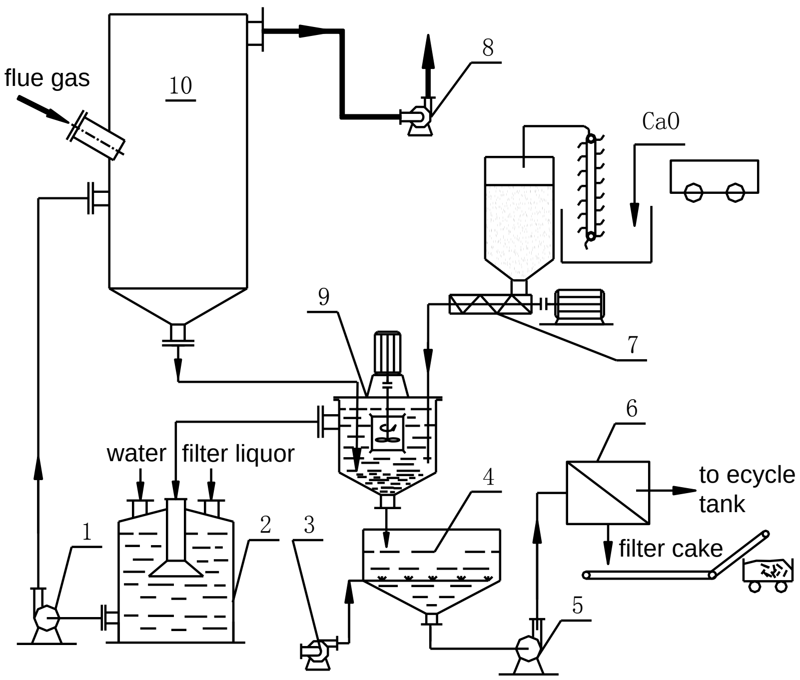
4. Industrial application of the WX/U desulfurization equipment

A central heating boiler was a chain furnace of 20 t·h^{-1}. Based on the investigation of the WX/U desulfurization equipment, a flue gas desulfurization system was designed by the authors in 2005. Dual alkali process was commonly applied in integral wet desulfurization and de-dusting facility (Mazziotti di Celso et al., 2013). In the present process, the key absorbent is sodium alkali solution with high neutralization capacity for SO_2, and the waste solution can be regenerated by reacting with lime.

The desulfurization process designed for this heating centre is shown in Figure 4. The boiler flue gas is inhaled into the core unit of the WX/U desulfurization equipment by a fan, in which SO_2 gas reacts with aqueous NaOH solution and dust is removed simultaneously. The scrubbed flue gas subsequently enters into the hydro-cyclone unit, in which droplets entrained by the flue gas are withdrawn while the flue gas flows into the chimney. After being absorbed with SO_2 and dust, the scrubbing liquid is conveyed from the WX/U desulfurization equipment to a neutralization reactor and reacts with lime slurry to generate NaOH solution and calcium sulfite. Calcium sulfite is oxidized subsequently into calcium sulfate in an oxidation tank. The slurry containing calcium sulfate and dust is pumped into the filter press and is handled afterwards. Solid waste could be used as building material while the filtered solution was recycled. The main design parameters are listed in Table 1.

Table 1: Main design parameters of the WX/U desulfurization equipment

Parameters	Value	Parameters	Value
Boiler Capacity/t·h^{-1}	20	Lime Consumption/kg·h^{-1}	85.68
Initial Mass Concentration of SO_2/mg·m^{-3}	2,801	Dust Concentration /mg·m^{-3}	3,475
Design Requirement of SO_2/mg·m^{-3}	≦400	Design Requirement of Dust/mg·m^{-3}	≦100
Flow rate of Flue Gas/m3·h^{-1}	33,987	Liquid to Gas Ratio/L·m^{-3}	2.0
（2OH^-）/SO_2	1.2：1	Gas Throat Velocity /m·s^{-1}	40



1.recycle pump; 2.recycle solution tank; 3.oxidation fan; 4.oxidation tank; 5.centrifugal pump; 6.plate-frame press; 7.spiral feeder; 8.fan; 9.neutralization reactor; 10.core unit of WX/U

Figure 4: Flow diagram of the industrial scale WX/U-desulfurization equipment

After a four-month heating span, the effect of WX/U desulfurization equipment has been tested by the local environmental protection bureau and testing results are listed in Table 2. It can be seen by comparing Table 1 and Table 2 that the actual flow rate of the flue gas is much higher than the designed value. However, test results show that sulphur dioxide concentration is reduced from 2,176 mg • Nm^{-3} to 298 mg • Nm^{-3} while dust concentration dropped from 4,027 mg • Nm^{-3} to 39 mg • Nm^{-3}. Both SO_2 and dust concentrations in the outlet of the WX/U desulfurization equipment meet design requirements.

Table 2: Measured results of WX/U desulfurization equipment

Parameters	Entrance	Exit	Note
Local Atmospheric Pressure/ KPa	101.5	101.5	
Flue Gas Temperature/℃	143	46	
Sectional Area of Flue Gas Duct/m^2	1.131	1.131	
Flow Rate of the Flue Gas /m^3·h^{-1}	51,634	52,108	
Oxygen Content/%	8.6	9.3	
Air Excess Coefficient	1.7	1.8	
Mass Concentration of Dust/mg·m^{-3}	4,027	39	99.0%
Mass Concentration of SO_2/mg·m^{-3}	2,176	298	86.2%

5. Conclusions

WX/U desulphurization equipment was an integral wet de-dusting and desulphurization facility. The most competitive advantage was its low equipment cost, which was a critical factor for SO_2 and dust emission control from low and medium-capacity coal-fired industrial boilers widely existed in China. In this study, the development and geometric characteristics of WX/U desulphurization equipment were introduced briefly. In addition, the effects of various operational parameters on desulfurization efficiency were investigated experimentally. Finally, a full scale WX/U desulfurization equipment for a 20 t·h^{-1} coal-fired boiler was set up in 2005. Test date showed that SO_2 and dust concentration in the outlet of the WX/U desulfurization equipment were 298 mg • Nm^{-3} and 39 mg • Nm^{-3} respectively when the liquid to gas ratio was 2.0, which could meet the emission standard in 2005, i.e. 400 mg • Nm^{-3} for SO_2 and 50 mg • Nm^{-3} for dust. Though the emission standard of air pollutants is becoming more and more stringent, i.e. the upper limit of sulphur dioxide has decreased to 200 mg • Nm^{-3}, the removal efficiency of the WX/U desulfurization equipment could be improved by using higher liquid to gas ratio to meet the requirement of new standards. Results from this study are important for the development of efficient SO_2 and dust emission control technology for low and medium-capacity coal-fired industrial boilers.

References

Bandyopadhyay A., Biswasa M.N., 2006, Prediction of the removal efficiency of a novel two-stage hybrid scrubber for flue gas desulfurization, Chemical Engineering Technology, 29(1), 130−145.

Brogren C., Karlsson H.T., 1997, Modeling the absorption of SO_2 in a spray scrubber using the penetration theory, Chemical Engineering Science, 52(18), 3085−3099.

Duan Z.Y., Hu J.B., Zong R.K., Wang S.X., 2004, Model for the prediction of pressure drop in venturi scrubbers, Chemical Engineering, 32(6), 31−35 (in Chinese).

Duan Z.Y., Shi W.M., Hu J.B., 2010, Experimental study on enhancement of inorganic additives for WX/U desulphurization equipment, Chemical Engineering, 38 (9), 70−73 (in Chinese).

Duan Z.Y., Zhang J.M., Zhang W.X., 2008, Experimental investigation on the desulfurization characteristics of venturi scrubbers, Petro-Chemical Equipment, 37 (1), 24−27 (in Chinese).

Gao H.L., Li C.T., Zeng G.M., Zhang W., Shi L., Fan X.P., Zheng Y.N., 2011, Experimental study of wet flue gas desulphurization with a novel type PCF device, Chemical Engineering Process, 50 (2), 189−195.

Gutiérrez Ortiz F.J.,Vidal F., Ollero P., Salvador L., 2006, Pilot-plant technical assessment of wet flue gas desulfurization using limestone, Industrial and Engineering Chemistry Research, 45 (17), 1466−1477.

He S.H., Xiang G. M., Li D.K., 2002, Commercial test of a slurry jet FGD system, Environmental Progress, 21 (2), 131−136.

Jecha, D., Dvořák, R., Bébar L., Stehlík, P., 2011, Absorption flue gas cleaning - "Spheric O-element" new prototype of first stage and HCl reduction, Chemical Engineering Transaction, 25, 327-332.

Jason M., 1981, Wet venturi doubles as an SO_2 scrubber, Power, 125(12), 71−72

Mazziotti di Celso G., Karatza D., Karatza D., Lancia A., Musmarra D., Prisciandaro M., 2013, Limestone-gypsum flue gas desulfurization processes: modeling of catalyzed bisulfite oxidation, Chemical Engineering Transaction, 32, 781-786.

Mi T., Yu X.M., 2012, Dust removal and desulphurization in a novel venturi scrubber, Chemical Engineering Process, 62 (7), 159−167.

Shah I.S., 1971, Removing SO_2 and acid mist with venturi scrubbers, Chemical Engineering Process, 67(5), 51−56.

Taheri M., Mohebbi A., Taheri A., 2010, Simulation of SO_2 absorption in a venturi scrubber, Chemical Engineering Communications, 197(7), 934−952.

Vairo T., Curro' F., Scarselli S., Fabiano B., 2014, Atmospheric Emissions from a Fossil Fuel Power Station: Dispersion Modelling and Experimental Comparison, Chemical Engineering Transaction, 36, 295-300.

Val'dberg A.Yu., Dubinskaya F.E., 2002, Design and operational aspects of venturi scrubbers, Chemical and Petroleum Engineering, 38 (7-8), 485−489.

Xavier G., Montserrrat S., Javier L.F., 2012, Gas pollutants removal in a single and two stage ejector venturi scrubber, Journal of Hazardous Materials, 20(3), 251−266.

Xu J., Liu P.Y., Zeng M., Wang Q.W., 2010, Numerical study on the effects of flue-gas inlet type for the flue-gas-desulfurization wet scrubber, Chemical Engineering Transaction, 21, 241-246.

Zheng Y.J., Kiil S., Johnsson J.E., 2003, Experimental investigation of a pilot-scale jet bubbling reactor for wet flue gas desulphurization, Chemical Engineering Science, 58(20), 4695−4703.