

The Flue Gas Desulphurisation at The First Stage of The Absorber - O-element

David Jecha^{*,a}, Pavel Leštinský^b, Vladimír Brummer^a, Jaroslav Jícha^a

^aBrno University of Technology, Faculty of Mechanical Engineering, Technická 2896/2, 616 69 Brno, Czech Republic

^bVSB – Technical University of Ostrava, Institut Enviromental Technology, 17. listopadu 15/2172, 708 00 Ostrava-Poruba, Czech Republic
 jecha@fme.vutbr.cz

Pilot plant wet scrubber is comprised of first stage and second stage. In our experimental setup, O-element is used as a first stage. O-element replaces venturi scrubber that is currently used in practice. O-element is a device used to homogenise the gas-liquid mixture. Upon contact of flue gas and liquid, the hot flue gas is cooled and pollutants are being removed from flue gas. As a second stage a packed column with the structured packing is designed. By a gradual transition from the planar embodiment of the O-element (the O-element 2R) to the spatial arrangement, the four branched O-element - the O-element 4R originated. The design of equipment for the larger flue gas flow rate is necessary, because the waste to energy plants incinerating the municipal and hazardous waste commonly produce flue gas with flowrates in the tens of thousands m³/h. For such flue gas flow rate would the originally designed device O-element 2R be too space-demanding. Spraying a liquid in the four-branched-O element can be performed in two ways. Firstly, it could be managed in the same manner as in two-branched O-element, i.e. through the orifices in the bottom arcs of the equipment, or by spraying of the liquid around the circumference of the inlet pipe. Experiments were performed with the two O-4R elements with liquid spray positioned around the perimeter of the inlet pipe and with the liquid spray through the nozzles in the lower arcs of the equipment. The main observed parameter was the SO₂ removal efficiency depending on the L/G ratio. In addition even more important indicator as SO₂ removal efficiency was monitored - O-element pressure loss.

1. Introduction

Processes of thermal decomposition are necessary not only for removal of pollutants, but also for reduction of the negative impacts on the environment. At the same time, waste serves as secondary source of energy. However, thermal processing has its drawbacks as well, including release of emissions into the atmosphere, residual waste formation and water pollution. Emissions are formed by the polluting substances in the flue gas which are produced by the waste combustion and are of a harmful and toxic nature. Flue gas contains PAHs, CO, SO₂, HCl, PM etc.

Regarding structure of waste, incineration plants are usually divided into two categories, i.e. municipal solid waste incineration plants and hazardous waste incineration plants. Hazardous waste comprises various components of different concentrations (Chohey, 2004). Hazardous waste incineration plants have to engage more sophisticated procedures and technologies for reduction of these hazardous materials than municipal solid waste incineration plants.

Dry, semi-dry and wet flue gas cleaning methods are used for capture of gaseous components of acidic nature (SO₂, HCl). Pilot plant of flue gas wet scrubber was implemented at the Institute of Process Engineering (IPE), see Figure 1. Experimental equipment of two-stage flue gas cleaning consists of "O-element" first stage (Filip, 2009) and second stage: packed column (Jecha, 2010). O-element (Figure 2) device substitutes venturi scrubber which is commonly used as a first stage of absorption in practice. Design of packed column counts with structured packing as filling.

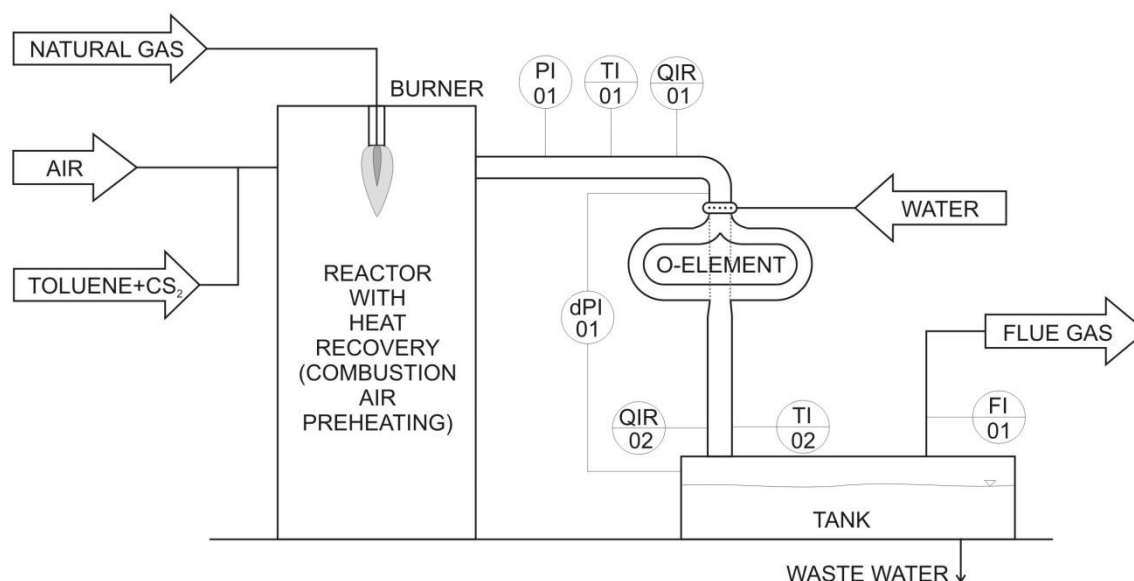


Figure 1: Overall view of experimental unit for flue gas cleaning

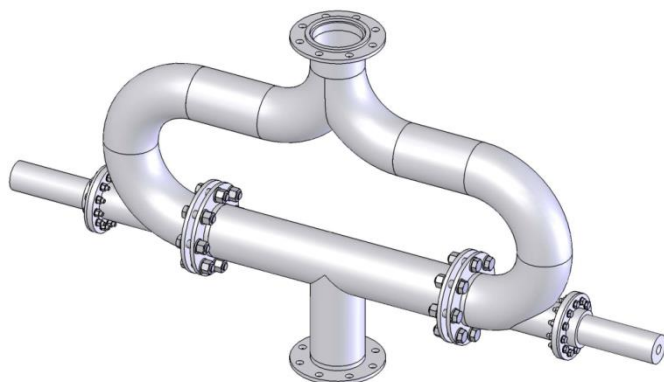


Figure 2: Visualization of the O-element 2R

2. New prototype of first stage – O-element

Proposed first stage of wet flue gas cleaning (O-element) substitutes device for intensive contact between gas and fluid which is called venturi scrubber. Homogeniser called O-element is a device which serves for homogenisation of gaseous-liquid mixture and was already used for similar purposes (Bébar et al., 1975).

Main objective of the O-element (Figure 2) is a perfect mixing of individual flows and formation of large mid-phase area which is secured by formation of dispersed flow. This further enables increase of mass transfer intensity during absorption. Other objective is the minimisation of hydraulic resistance.

In place where streams are mixed together, the creation of mist flow is occurring with a much dispersed liquid. This phenomenon is referred to a "transition jump" manifesting itself in a situation where the two-phase liquid-gas flow forms a pressure drop equals to the dynamic pressure component.

Other research organisations also dealt with the replacement of the first stage of flue gas cleaning. Some of them are mentioned below:

Very interesting technological solution of first stage wet scrubber using new type umbrella plate scrubber is presented by (Li et al., 2008). Similar solution was applied for absorption in PCF device (Gao et al., 2011). Further on, already implemented methods of acid components reduction using venturi scrubber are being improved (Gamisans et al., 2002). Combined NO_x and SO_2 removal from flue-gas mixture in an integrated wet scrubber-electrochemical cell system (Chandrasekara Pillai et al., 2009) is not that commonly used.

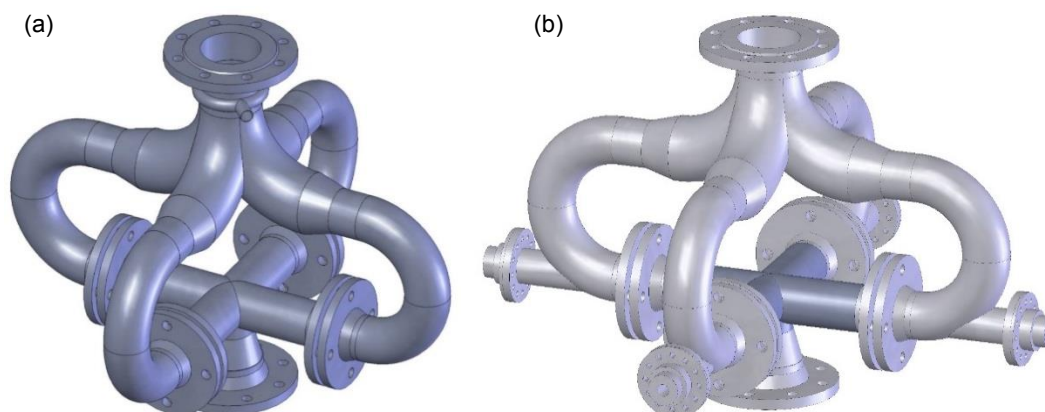


Figure 3: Development of O-element prototype with (a) atomizer injection and (b) injection of fluid by nozzles

Gradual change from plane type O-element (further on as O-element 2P) to special arrangement gave rise to 4 piped O-element (further on as O-element 4P). Final product is an O-element prototype (Figure 3) with the main goal to minimise dimensions because municipal solid waste incineration plants and hazardous waste incineration plants produce flue gas of flow rates reaching dozens of thousands of m³/h. O-element 2P is too space demanding for this flows of flue gas. The design of individual prototypes required maintaining the high efficiency for reduction of harmful substances along with the preservation of the lower hydraulic resistance comparing to the conventional Venturi scrubber.

The injection of the fluid into four piped O-element can be done by two ways. Firstly, it can be done by same way as in the two piped O-element – by nozzles in the lower arc of the device, or by the injection of the fluid around the circumference of the inlet pipe. Second mentioned type of liquid injection allows to dose the fluid into the pipe even with bigger diameter. O-element 4R with liquid injection around the circumference the inlet pipe was manufactured for the experiments. By dosing of the fluid in the upper part of the device, the time of flue gas and absorbent contact is prolonged.

2.1 Experimental conditions

A mixture of carbon disulfide (CS₂) and toluene in a volume ratio of 1 : 1 was prepared for the formation of flue gas. This mixture was injected (800 cm³/h) into the air, which was driven by the fan to the reactor with the burner. This reactor contains a heat recovery for easier heating of the flue gas with minimal natural gas consumption. SO₂ is formed by burning of CS₂. Generated flue gas containing SO₂ with a temperature of 150 °C are transported from the reactor into the O-element in a slightly under pressure created by the fan at the end of the pipeline. SO₂ concentration at the inlet of the O-element was in the range of 360 - 560 ppmv.



Flue gas enters O-element by a pipeline with diameter - DN 100. Flue gas stream is divided in the inlet pipe into the four arms with a diameter - DN 70. In the lower part of the arms, the water is sprayed into the flue gas. The mixing of all four streams back into one with the diameter DN 100 is following. At this point there is known transient jump described above. This phenomenon is a major advantage of the O-element.

As an absorption liquid was used water from water supply system without reflux (downstream the O-element has been released into the waste). For the experiment two exhaust flow rates: 500 and 600 m³/h were used. Water flow was in the range of 0.2 m³/h to 1.0 m³/h.

Simplified flow sheet of experimental unit with measuring elements is shown in Figure 1. Measurement of flue gas composition was carried out simultaneously at the input and at the output of the O-element. The composition was measured using a flue gas analyser ABB EL 3020 (spectrometer). Concentrations of SO₂, NO_x (NO), CO₂, CO and O₂ were measured. Data (flue gas composition at the inlet and outlet) for the given experimental conditions were recorded for 30 min with a frequency of 1 Hz. Inlet and outlet concentrations were then determined as the medians of data series. Data such as temperature, pressure, flow rate and pressure drop were read once roughly in the middle of the experiment.

3. Results and discussion

During the tests, two modifications of the four-arm O-element were verified (see Figure 3).

On this devices, SO₂ was removed from the flue gas by absorption into water. Other components such as CO and CO₂ were also adsorbed into the water, however their concentrations were under the limit of quantification (LOQ), so that these components removal can be neglected. SO₂ removal efficiency is depending on the proportion of the L/G which is the proportion of the normal water flow and normal flue gas flow, shown in Figure 4. SO₂ removal efficiency increases linearly with an increasing of L/G ratio (L/G was changed by increasing flow of absorption liquid). When using the water flow rate of about 1,000 times lower than the flue gas flow rate (L/G = 0.001), the SO₂ removal efficiency still exceeds 60 %. Flue gas temperature at the outlet of the O-element (see Figure 5) also shows a linear dependence on the L/G ratio.

The main defining parameter of the first stage of sulfur dioxide removal is its effectiveness. SO₂ removal efficiency was observed in a large range of ratios of liquid and gas (L/G), from 0.0001 to 0.0016 (see Figure 4). During a large surplus of gas, greater efficiency was observed for O-element with a top injection, but with the conventional flow rates and larger feed of fluid, the greater efficiency was observed for O-element with the liquid injection through the nozzles. This effect is caused by the main factors that influence the absorption, namely size of the interfacial area and the residence time.

At low flow rates of the liquid injected into upper inlet (Figure 3(a)), has a longer residence time in the O-element and this has the prevailing influence on the mass transfer. At higher flow rates of the liquid injected by nozzles (Figure 3(b)) larger number of smaller drops are formed, and thus the interfacial area has the predominant influence for the efficiency of mass transfer. Output temperature for both models match very well the material balance and the liquid evaporation, where steady state after saturation of the flue gas with liquid is anticipated as shown in Figure 5 (Lestinsky, 2015).

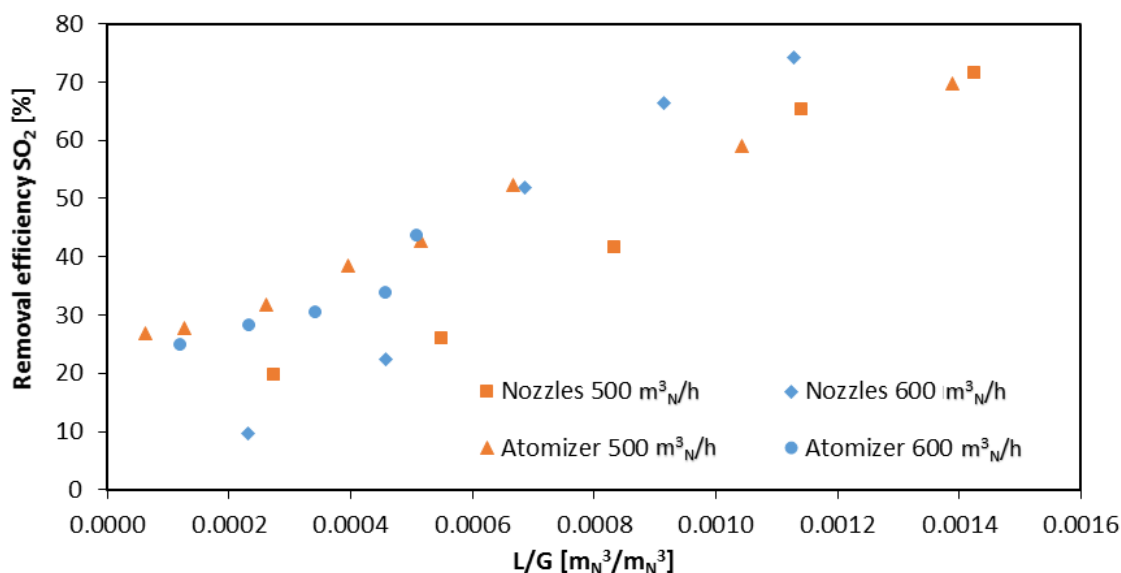


Figure 4: Dependence of the SO₂ removal efficiency on the L/G ratio (ratio of liquid to gas flow rate)

Also other important indicator - pressure loss of the O-element was monitored as well. The measurement results are shown in Figure 6. This Figure shows that the pressure loss is increasing slightly with increase in liquid flow. The pressure drop of about 2.0 - 2.5 kPa equals the pressure drop at the Venturi scrubber at similar conditions (L/G) for the flow of 500 m³/h.

Pressure loss, which was measured in both types of O-element has an increasing character with an increase in the liquid injection. As shown in Figure 6, higher pressure loss was measured for the O-element with liquid injection in the input pipe. This is due to the fact that throughout the entire flow of the O-element the flow is characterised as a two-phase flow which has a greater pressure resistance than a single-phase flow.

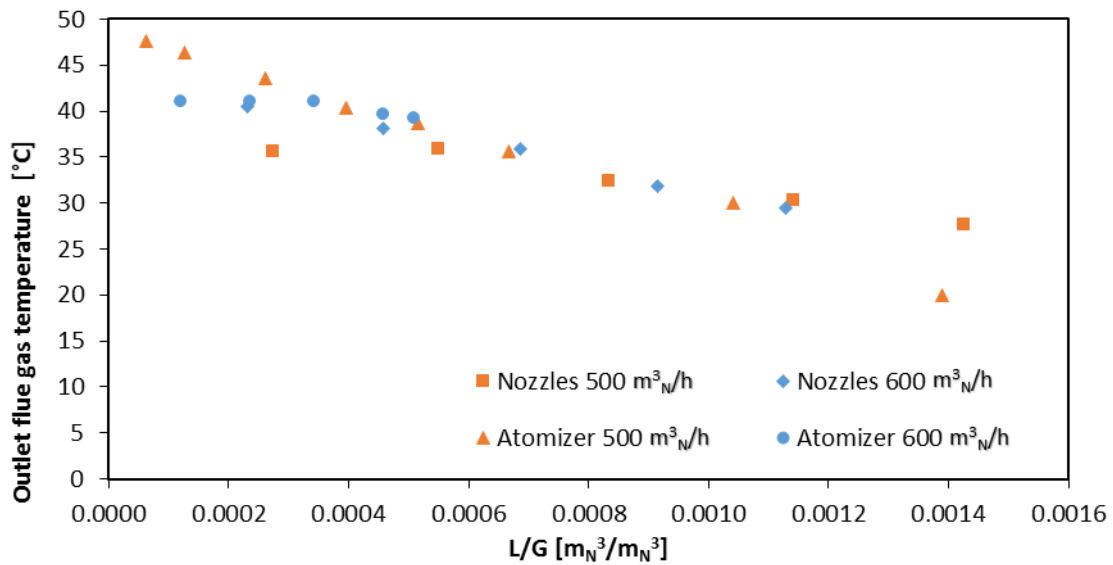


Figure 5: Dependence of the outlet flue gas temperature on the L/G ratio (ratio of liquid to gas flow rate)

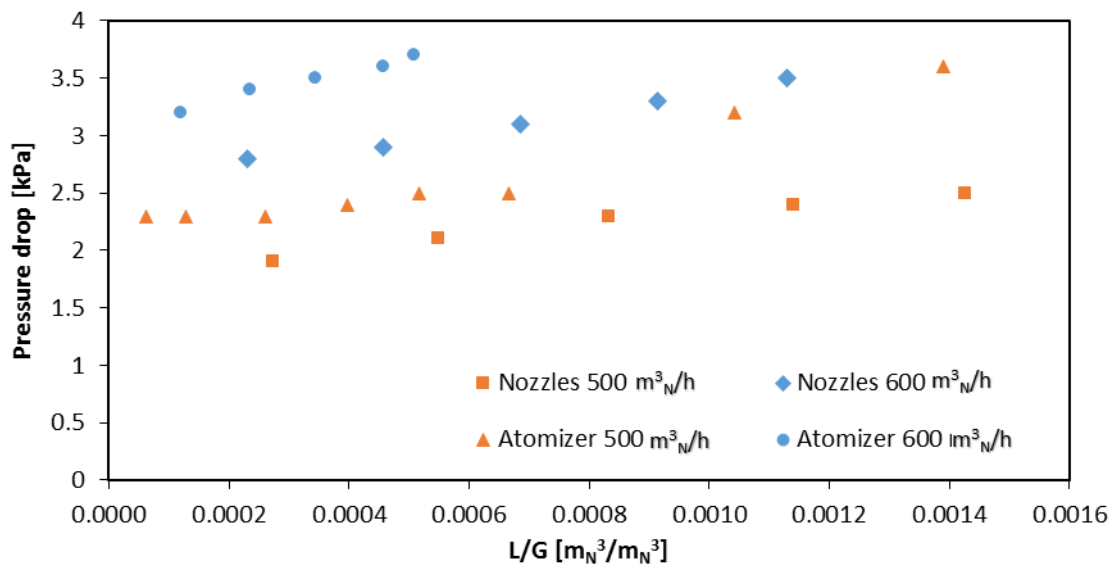


Figure 6: Dependence of the pressure loss on the L/G ratio (ratio of liquid to gas flow rate)

4. Conclusions

The issue of removing pollutants from flue gas generated during thermal disposal of wastes is quite broad. This research work deals mainly with the conditions under which the process of removing acidic components, especially SO₂, from flue gas cleaning processes by absorption process and construction of the equipment for the implementation of these operations in the laboratory and industrial scale. The work is based on interrelated activities carried out at two levels, namely at the level of experimental research and knowledge from actual operation and hazardous waste incinerators at the level of the theoretical research.

Experimental research of the fundamentally new device (i.e. O-element) usable for the first absorption stage, was based on a patented design solution. The detailed structural development of the O-element was conducted with several improvements over the previous solutions and the change from the planar embodiment of the main apparatus (2R) into a spatial arrangement was proposed to give rise of four-piped element (4R).

Experimental system commissioning and group of measurements and data acquisition was carried out at the first stage. Embodiment of the Venturi scrubber type, which is usually used for the flue gas purification at the first stage, served as the reference device in terms of the pressure loss in apparatus.

In the second phase, four-arm device O-element with injection by nozzles was designed and implemented. The experimental device was modified to use this new experimental element. Newly designed device was protected by a utility model CZ 28048 U1.

SO₂ removal efficiency increases linearly with an increasing L/G ratio (L/G was changed by increasing flow of absorption liquid). When using a water flow rate of about 1,000 times lower than the flue gas flow rate (L/G = 0.001), the SO₂ removal efficiency still exceeds 60 %. Pressure loss is increasing slightly with increase in liquid flow. The pressure drop of about 2.0 - 2.5 kPa equals the pressure drop at the venturi scrubber at similar conditions (L/G) for the flow of 500 m³/h. Output temperature for both models match very well the material balance and the liquid evaporation, where steady state after saturation of the flue gas with liquid is anticipated.

Acknowledgments

The results of this project NETME CENTRE PLUS (LO1202) were co-funded by the Ministry of Education, Youth and Sports within the support programme „National Sustainability Programme I“. The authors also gratefully acknowledge financial support of the project Waste-to-Energy (WtE) Competence Centre no. TE02000236.

References

- Bebar L., Lukas P., Filka J., 1975, Pipe fittings for the homogenisation of multiphase mixture flowing through the pipeline, Czechoslovak Patent, Author's certificate n. 181650, Czech Republic.
- Chandrasekara Pillai K., Chung S.J., Raju T., Moon I.-S., 2009, Experimental aspects of combined NO_x and SO₂ removal from flue-gas mixture in an integrated wet scrubber-electrochemical cell system, *Chemosphere* 76, 657–664.
- Chopey N.P., 2004, Handbook of chemical engineering calculation, Third edition, McGraw-Hill, New York, USA.
- Filip M., 2009, Application of efficient equipment for flue gas cleaning in real technological units, PhD Thesis, Brno University of Technology, Brno, Czech Republic.
- Gamisans X., Sarrà M., F. Lafuente J., 2002, Gas pollutants removal in a single- and two-stage ejector–venturi scrubber, *Journal of Hazardous Materials B90*, 251–266.
- Gao H., Li C., Zeng G., Zhang W., Shi L., Li S., Zeng Y., Fan X., Wen Q., Shu X., 2011, Flue gas desulphurization based on limestone-gypsum with a novel wet-type PCF device, *Separation and Purification Technology* 76, 253–260.
- Jecha D., 2010, Absorption cleaning of flue gases arising from the incineration of wastes, PhD Thesis, Brno University of Technology, Brno, Czech Republic.
- Lestinsky P., Jecha D., Brummer V., Stehlik P., 2015, Wet flue gas desulfurisation using a new O-Element design which replaces the venturi scrubber, *World Academy of Science, Engineering and Technology, International Science Index* 102, *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Eng.* 9 (6), 597–601.
- Li S., Li C., Zeng G., Li S., Wang F., Wang D., Lu P., 2008, Simulation and experimental validation studies on a new type umbrella plate scrubber, *Separation and Purification Technology*, 62, 323–329.