

Application of Motionless Mixers in Gas Purification – A Case Study

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Summary – The lecture gives a review on the application of motionless mixers in gas purification, where wet dust separation is carried out by water circulation trough vertical tubes filled with FixMixTM motionless mixer elements. Dusty gas and water are flowing downwards, co-currently. Solids phase is filtered continuously from the slurry.

Introduction and problem Specification

In this paper, a case study is reported, giving evidence and an example on a possible application of motionless mixers for gas purification.

This example for solving a really crucial industrial problem is as follows: Process gas arrives to a plant through a pipe of 1200 mm diameter, with 100 mbar overpressure, 25,000-30,000 m³/h volumetric flow rate and 20 °C average temperature. In summer, the temperature can be higher, rising up to 35 °C.

Before starting the work for this case study, the gas was not totally purified. Therefore, various organic and inorganic materials have deposited onto the tube wall, both in the main pipeline and in various tube sections after gas distribution, causing severe troubles in the pipeline operation and in the process gas utilizing plants, too. Periodic cleaning of these tube sections also caused considerable additional costs every year.

Figure 1 shows the contaminant material, after deposition from the process gas onto the pipe wall, found by dismantling a critical tube section of the pipeline. Figure 2 represents the particle size distribution of a sample taken from this deposited material.

To avoid these troubles, it was decided to clean the gas before its application. From a survey of the related literature, and from earlier experiences resulted by unsuccessful attempts, it was clear that the usual dry gas purification methods, e.g. electric dust

precipitation, gas cooling methods, etc. could not be used to solve this problem. The only possibility was to apply a wet method, namely scrubbing the gas by water. Our task was to establish such a gas washing method and equipment, which has the following advantages: simple, reliable, can be scaled-up easily, has small pressure drop against the gas flow, and where the removed solids is readily separable from the recycled liquid phase.

Laboratory tests

For model tests, laboratory-scale equipment was assembled for contacting of air and water in co-current streams, using motionless mixers. Another requirement was that the results of the laboratory tests had to be suitable for scaling-up of the process and equipment. On the basis of our earlier experiences obtained with dry and wet dust separation, a glass tube with 20 mm i.d. and 2000 mm length was applied, equipped with a long string of tightly fitted FixMis™ motionless mixer elements. This laboratory-scale equipment is shown in Figure 3.

During the experiments, the volumetric flow rate of air and the sprinkling intensity were varied systematically. Pressure drop was measured and flow regimes and other conditions were observed. On the basis of measurements and observations, the optimal parameters of the process were determined. These findings were also checked in the presence of fine solids, dispersed as dust into the introduced air. For this, fine lime hydrate and alumina powders with particle size distribution between 1-5 micron were used.

It is generally known that motionless mixers are passive process-intensification tools, which, in contrast with usual stirrers, do not move themselves. Utilizing the pressure, the potential and kinetic energy of the streaming phases, they create turbulence, relative displacements, attrition, multiple division and recombination, and can also be used for contacting of different phase elements. There are a number of different types of motionless mixers, used mainly in tubes, but also in other devices e.g. in vessels and columns. Figure 4 shows helical motionless mixers with regards of their working mechanisms. The FixMix™ elements, used by us for these experiments belong to helical type mixers, similarly to the well-known Kenics static mixers. But, FixMix™

mixers have certain specific features, namely: Each mixer elements succeeding each other are tapered, i.e. contracting along their lengths, are inclining relative to the tube axis, thus dividing the tube cross section asymmetrically.

On Figure 5, pressure drop of the experimental equipment is shown as a function of sprinkling intensity for various superficial gas flow rates.

It has to be noticed that above 210,000 kg/m²h sprinkling intensity, pulsation has arisen for all cases, which disturbed the normal operation of equipment. The curved arrows on the diagram show the starting values of sprinkling intensity, from where the introduced dust particles became well wetted making total separation of dust from the gas possible.

From the investigation on laboratory-scale equipment, it was found that 17.7 m/s superficial gas flow rate and 50,000-150,000 kg/m²h sprinkling intensity were optimal. For this, it was supposed that low water circulation is the main requirement, in order to decrease the necessary pumping performance or electric energy consumption.

First attempt to design industrial scale equipment

To design an equipment in commercial scale, whose performance is determined by the volumetric flow rate of the gas to be treated, the combined utilization of hydrodynamic similarity and the so-called additive scaling-up principles seemed to be appropriate. It means that tube diameter was increased from 20 mm to 49 mm i.d., and the length of tubes from 2 m to 3 m, keeping the sprinkling intensity and superficial gas velocity constant. According to our earlier experiments, it could be done without any risk of operational troubles or reduction of their separation performance. Additive scaling-up means the multiplication of the tubes working parallel to each other.

By this way, a square cross-sectional equipment was designed with vertical bundle of tubes filled with motionless mixers, ensuring the conditions and parameters, which proved to be optimal during the laboratory-scale investigations. Within this quadratic cross-section, altogether 218 tubes were necessary, spaced equidistantly in triangular network of a nearly square form tube-panel, along 15 rows. It means that there were 15

tubes in every second rows, and 14 tubes in the next rows, alternatively. Considering the 0,41 m² total free cross-section of the 218 tubes of 49 mm i.d., and the quantity of process gas used in the mentioned plant, the following operational conditions is to be ensured:

At the maximal 30,000 m³/h gas flow rate, the superficial velocity of the treated gas is 20.3 m/s, while for the 25,000 m³/h average gas flow rate, the mean gas velocity will be 16.9 m/s.

These values are close to the optimum condition determined during laboratory tests.

The planned sprinkling intensity corresponds to 30-70 m³/h water circulation. For this region, the pressure drop in the contacting tubes having 49 mm i.d. and 3 m length is between 200-500 mbar, generally about 350 mbar.

The calculated main dimensions of the rectangular contacting equipment are as follows: Vertical width and depth of the tube panel is 0,95 m x 0,95 m, the height of the tube bundle is 3 m.

After considering the relatively high gas velocity (maximum 20.3 m/s) and pressure drop (maximum 500 mbar), characterizing this equipment designed firstly, it was decided to increase the number of contacting tubes considerably. The high pressure drop requires to use sucking operation mode, with a depression that amounts even to 0,5 bar below the atmospheric pressure.

Increased demand for safety operation is also important aspect here because the quantity, particle size distribution, physical and chemical properties of solids contamination are frequently changing and not always known in the process gas to be treated. At high gas velocity in the cleaning unit, solid particles may have high kinetic energy, therefore collisions with the surface of the tube wall and motionless mixer elements can lead to deposition and plugging. This can disturb the safe and smooth operation, can cause additional maintenance costs, and may decrease the efficiency of the cleaning process. High gas velocity may cause entrainment of the small liquid droplets and mist formation can take place containing small particles. Increasing the

number of tubes working parallel in the wet cleaning unit can help to avoid these troubles, too.

Increasing the total cross-sections of tubes, the required performance and costs of the sucking pump or fan can also be reduced significantly. It is true that in this case higher water recycling is needed to maintain the same sprinkling intensity. The dimension and the investment costs of the purification units are also higher, especially in respect of the increased number of motionless mixers.

The main gas pipeline connecting to the planned gas purification unit has about 1.2 m diameter, which is larger than the horizontal dimension of the tube bundle determined above. Therefore, there was no obstacle to use somewhat larger equipment instead of our first design.

Final design and results

Considering all aspects outlined above, it was decided to increase the free cross-sectional area available for gas flow by using almost three times more contacting tube compared to the earlier design.

For this, in a rectangular tube panel with 1,7x1,6 m horizontal dimensions, a bundle of 637 tubes each filled with a string FixMix™ motionless mixer elements was applied. The diameter and length of the tubes remained the same, i.e. 49 mm and 3 m, respectively. The gas purification unit built up from these motionless mixer tubes operates with 6.9 m/s superficial gas velocity, 30,000 m³/h volumetric gas flow rate and 230-460 m³/h water circulation. Under these conditions, the pressure drop of the gas is about 110 mbar.

As regards the total quantity of the recycled water in the purification system, during contacting of the phases, some evaporation takes place. The inlet moisture concentration of the gas was measured, and it was found that its mean value is around 6 g/m³ (about 5 g/kg gas). Calculating with 30,000 m³/h gas flow rate and with the saturation concentration of the water which is 22 g/kg dry gas, the loss of water caused by evaporation is about 17 g per m³, which means 510 kg/h. Therefore, the fresh water

requirement to retrieve these losses is more than $0,5 \text{ m}^3/\text{h}$, not regarded the entrainment of the liquid phase from the cleaning unit, which is considered negligible.

Because the purified gas is used for heating of industrial furnaces, it has to be noticed that the water content in the purified gas causes caloric losses during its utilization.

From these considerations, it was thought that in spite of the high sprinkling intensity of $50,000\text{-}150,000 \text{ kg/m}^2\text{h}$, there is no need to have a great amount of water in the purification system. It is especially true, if it turns out that a sprinkling intensity close to the lower value will be suitable for the safe and continuous operation.

The design of the final wet cleaning equipment is shown schematically in Figure 6. This rectangular equipment for gas purification consists of a gas-liquid contactor in the left upper part of the scheme, a droplet separator in the right upper part, and an inner basin for the recycled liquid. The contactor part of the equipment has two rectangular tube panels with $1.8 \times 1.6 \text{ m}$ dimensions, in order to fix 637 vertical tubes, each of them filled with a motionless mixer strings. Gas is introduced into the tube bundle from above, streaming co-currently together with the recycled water through the tubes. Stepping out from the bundle of tubes at their bottom, the gas and liquid phases are separated from each other. Gas is flowing up through a droplet separator with slanted plates, leaving the equipment at the top of the equipment. The liquid phase containing the removed dust particles and other contamination is pouring into the rectangular basin at the bottom of the equipment. The horizontal dimension of this basin, equal to that of the whole gas purification unit is $1.8 \times 3.2 \text{ m}$, and the liquid level is 3 m . Therefore, the total volume of liquid being in the equipment is about 16 m^3 . During its circulation, all this liquid is almost totally changed in the basin within 2-4 minutes, which means that the liquid being in this basin can be considered well mixed.

Because of the intensive mixing, the removed solids do not settle to the bottom of basin. Therefore, this method does not require periodic removal of the settled solid material from the equipment and any extra maintenance of the purification unit. Solids phase is filtered continuously from the recycled liquid after the circulation pump.

Because the realization of this method and equipment in commercial scale at the mentioned plant is in progress now, real operation data can not be accounted yet. But, as soon as such data and experiences will be available, more detailed account will be reported.

Summary and conclusions

In this lecture, a case study on wet purification of a process gas, available in great quantity and containing considerable amount of contamination was reported. Dust, solid particles, organic and inorganic contamination caused severe depositions of solids in the main pipeline and distributing tubes, also leading to operational troubles in the utilizing plants.

At first, laboratory tests were carried out using relatively small equipment, applying a string of FixMixTM motionless mixer elements in a vertical contactor tube. By this, the optimum conditions and parameters were determined. It proved to be that application of motionless mixers for co-current contacting of contaminated gas and scrubbing liquid is very advantageous. The solid particles introduced into the gas stream as dust could be totally removed, where the solids were separated from the recycled liquid by filtration.

On the sound bases of these laboratory experiments, industrial scale equipment was designed. During the first attempt, an equipment with a bundle of 218 tubes of 49 mm i.d. and 3 m length was envisaged. All the important operational parameters and conditions were determined by calculation, using the results and experiences obtained in laboratory tests. After considering the possible risks of the rather high superficial gas velocity in the motionless mixer tubes, it was decided to increase the free cross-section of the contactor tubes. For this, another equipment was designed having a tube bundle consisting of 637 contactor tubes of same diameters and lengths as the former design. This equipment involves the droplet separation unit and water recycling system, too.

The concept of the method and latter equipment were accepted by the plant, and its realization is under way now. When real operation data and experiences will be available, more detailed account will be reported.



Figure 1. Photo of the contaminant material deposited from the process gas onto the wall of a pipeline.

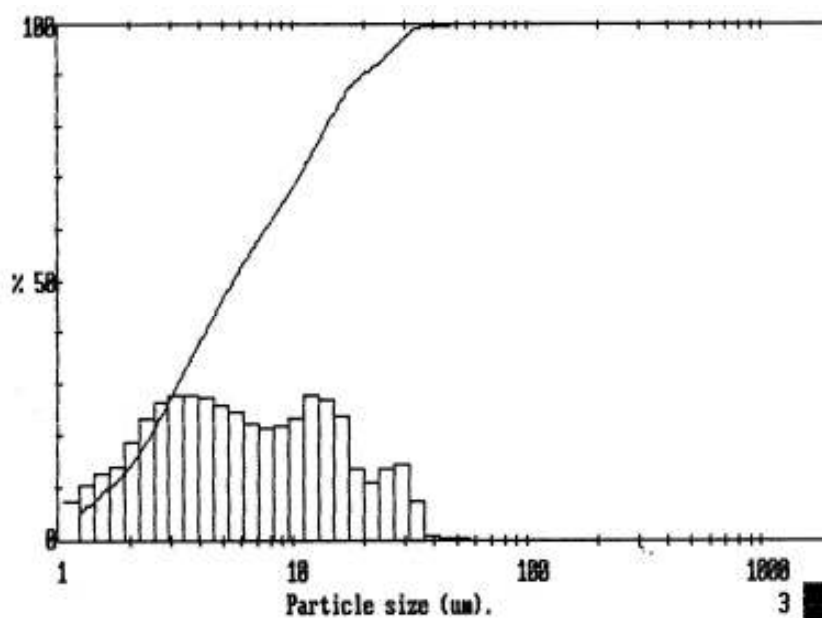


Figure 2. Particle size distribution of the deposited solid material determined from a sample taken a pipeline.

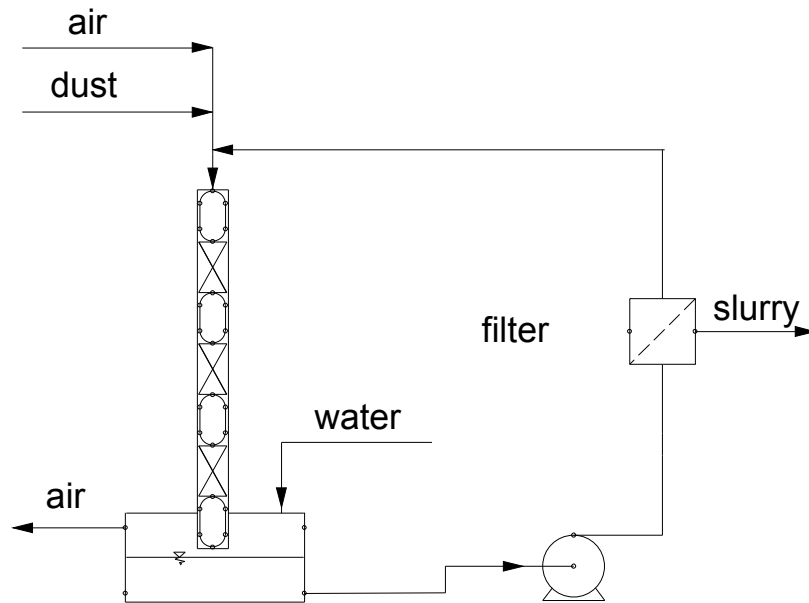


Figure 3. Schematic diagram of the laboratory-scale equipment with FixMix™ statix mixer elements used for wet dust separation

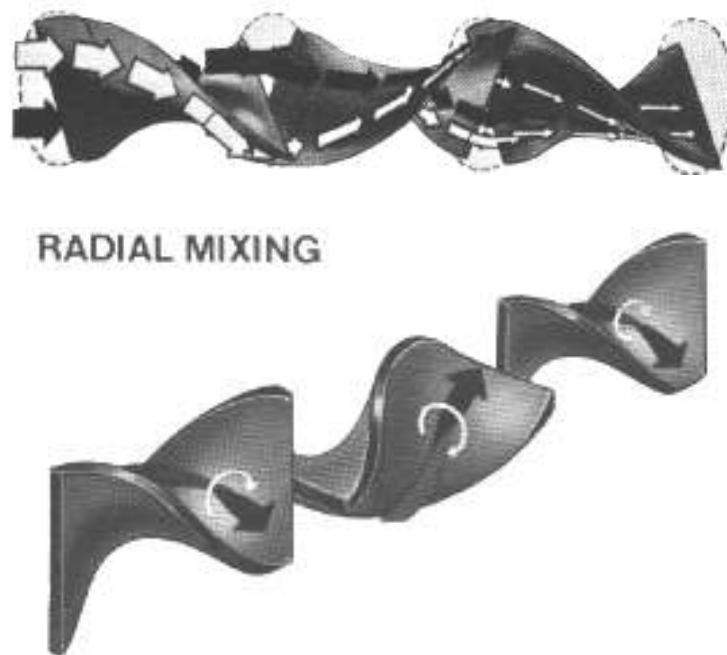


Figure 4. Helical motionless mixer elements, showing the main mechanisms of their operation

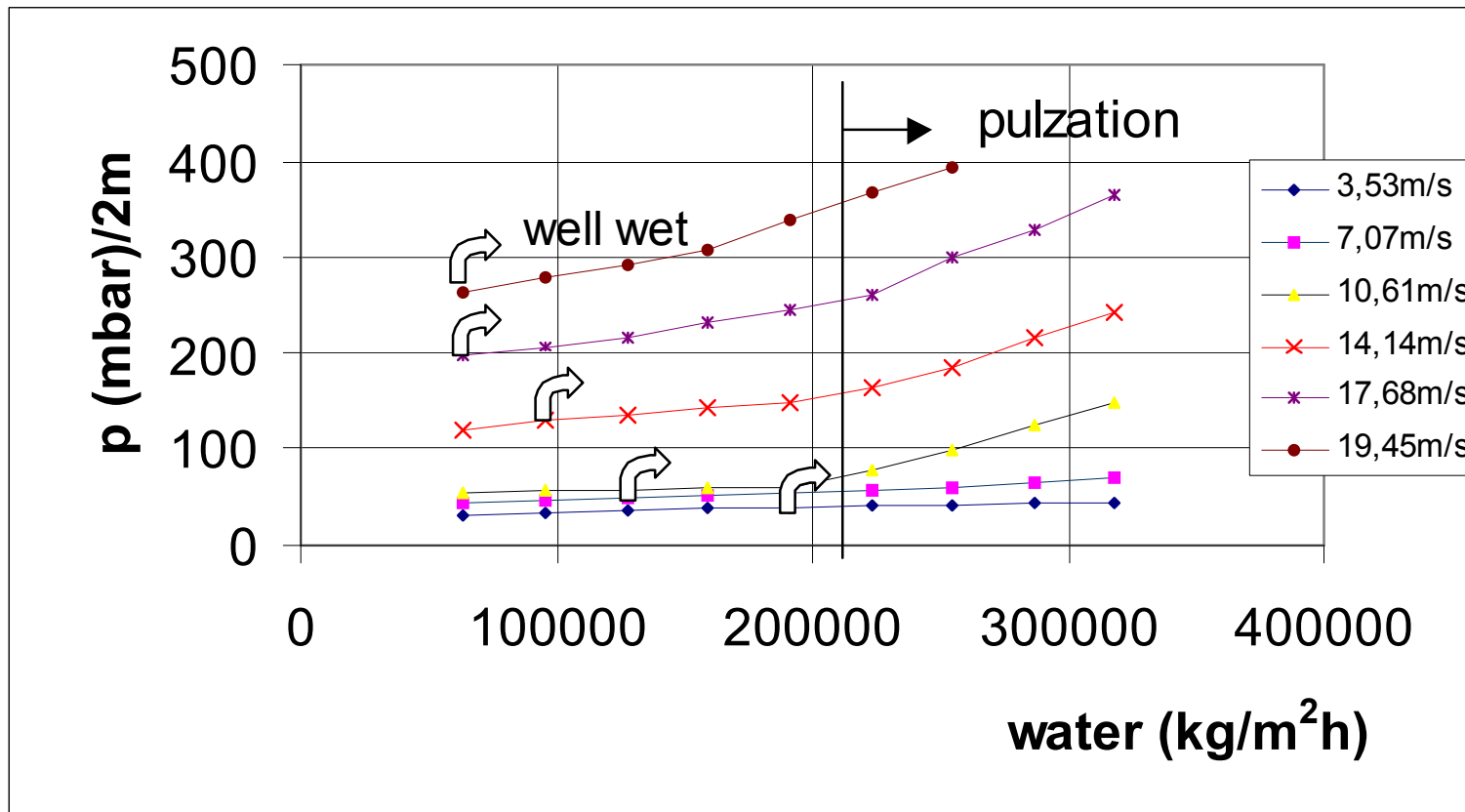


Figure 5. Pressure drop of the experimental equipment as a function of sprinkling intensity for various superficial gas flow rates.

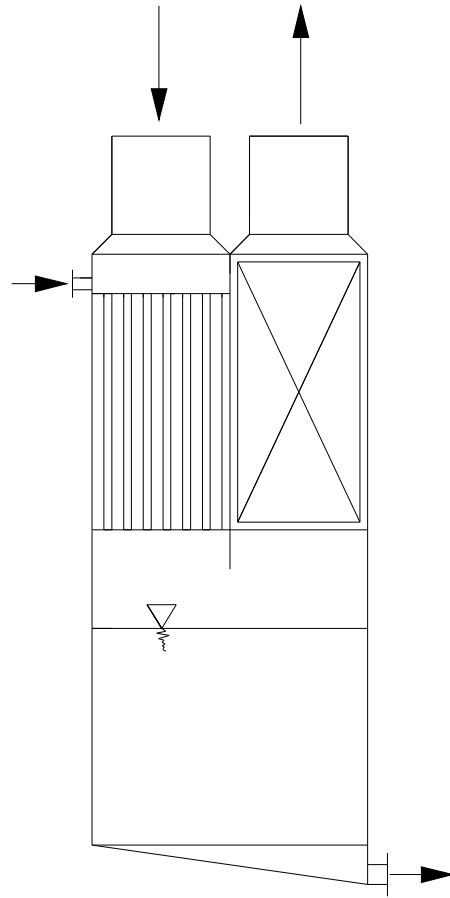


Figure 6. Schematic diagram of the final design of wet gas purification equipment, applying FixMix™ motionless mixer elements in the contacting tube units.