OPTIMIZED DESIGN FOR HEAVY MOUND VENTURI

by

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The venturi scrubber is one of the most efficient gas cleaning devices for removal of contaminating particles in industrial flue-gas purification processes. The velocity of the gas entering the scrubber is one of the key factors influencing its dust-removal efficiency. In this study, the shapes of the heavy mound and tube wall are optimized, allowing the girth area to become linearly adjustable. The resulting uniformity of velocity distribution is verified numerically.

Keywords: *venturi scrubber, linear control, dust removal efficiency, optimization*

Introduction

Numerous technologies are available for gas cleaning in different industries and power plants, including use of cyclones, settling chambers, fabric filters, electrostatic precipitators, and others, among which wet scrubbers are one of the most efficient devices for removing particles and gaseous contaminants from exhaust gases [1, 2]. These can be further categorized according to their configurations, which include spray-tower, mechanically aided, orifice, packed-bed, ionizing-wet, fiber-bed, moving-bed, tray, catenary-grid, condensation-growth, rod-deck, collision, ejector, and venturi scrubbers.

The venturi scrubber is a highly efficient gas cleaning device that uses liquid droplets to remove dust particles with diameters ranging between 0.1 and 300 μm and absorb gaseous contaminants, such as SO_2, I_2, and CH_3I, from gaseous streams. A venturi scrubber has the following advantages: the structure is relatively simple and compact, the footprint is small, there are no rotating parts, it is easy to install and maintain, it exhibits high temperature and corrosion resistance, and it is capable of synergistic removal of both particulate and gaseous pollutants [3].

A classical venturi scrubber consists of three main parts [4-8]: converging section, throat, and diffuser, as shown in fig. 1. The converging section is used to accelerate the gas to be cleaned to atomize the scrubbing liquid; the throat, located between the converging and diffuser sections, is where interaction of the liquid and gas takes place, and the diffuser permits deceleration of the gas to allow for some pressure recovery. The geometrical cross-section of a venturi scrubber can be either circular or rectangular.

Venturi scrubbers, which have a successful history, are still a popular choice among gas cleaning devices because they are potentially capable of meeting future emission standards with minimum modifications necessary to improve the collection of small particles.

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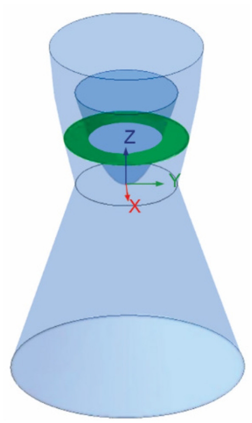

Figure 1. Schematic of heavy mound venturi tube

There are two main types of commercial venturi scrubbers. Namely, the constant-throat, Pease-Anthony [9], and variable-throat, McInnis-Bischoff [10] designs. To date, only a few studies have focused on the McInnis-Bischoff scrubber [11]. The main way in which current adjustable-throat venturi scrubbers can be modified is by adjusting the width of the throat.

The main factors affecting the dust-removal efficiency of venturi scrubbers are the liquid/gas ratio, particle size of the solid contaminants, gaseous and liquid flow rates, and pressure drop. The present study analyzes the influence of gas velocity on the dust-removal efficiency of the McInnis-Bischoff-type scrubber. In a conventional scrubber, the profile of the heavy mound is parabolic, but that of the tube is linear. Therefore, the girth area varies with height of the mound. At certain flow rates, the velocity distribution will be non-uniform, which will cause loss of pressure. In this study, we propose a new design to improve the uniformity of gas velocity in these scrubbers.

Optimized mound design

If the throat area is set as S, then when the mound advances by an increment dx, then the throat area should be covered by area dS of the mound. Considering linear control, the relationship can be given:

$$\mathrm{d}S = k\mathrm{d}x \tag{1}$$

The limiting conditions occur when the mound covers the throat entirely or not at all, which can be written as:

$$x = x_{\mathrm{min}} = 0, \qquad S_{\mathrm{max,mound}} = S_{\mathrm{throat}}, \qquad x = x_{\mathrm{max}}, \qquad S_{\mathrm{min,mound}} = 0 \tag{2}$$

Therefore, k could be calculated:

$$k = \frac{S_{\mathrm{throat}}}{x_{\mathrm{max}}} \tag{3}$$

Without loss of generality, the cross-section can be considered as a circle, *i. e.*:

$$S = \pi r_{\mathrm{mound}}^2 \tag{4}$$

then

$$x = \frac{\pi r_{\mathrm{mound}}^2}{k} = \frac{x_{\mathrm{max}} \pi r_{\mathrm{mound}}^2}{S_{\mathrm{throat}}} \tag{5}$$

The profile of the heavy mound is therefore parabolic.

Optimized venturi tube design

When the mound travels a distance of dx, the non-covered throat area decreases by dS', so:

$$\mathrm{d}S' = k'\mathrm{d}x \tag{6}$$

To maintain the same cross-sectional area, it must obey the limiting conditions:

$$x = x_{\min} = 0, \qquad S'_{\min} = S_{\text{throat}}, \qquad x = x_{\max}, \qquad S'_{\max} = S_{\max,\text{mound}} + S_{\text{throat}} \tag{7}$$

and it can be obtained:

$$k' = k = \frac{S_{\text{throat}}}{x_{\max}} \tag{8}$$

The relationship between area S' and x is given:

$$S' = kx + S_{\text{throat}} \tag{9}$$

Analogously, the profile of the tube is given:

$$x = \frac{x_{\max}\pi r_{\text{tube}}^2}{S_{\text{throat}}} - x_{\max} \tag{10}$$

The optimized profiles of the mound and tube are shown in fig. 2.

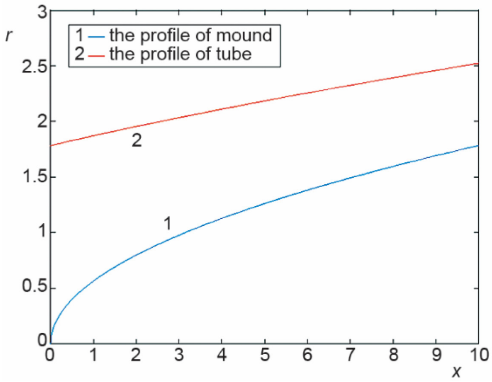

Figure 2. Optimized profiles of the heavy mound and tube

Linearly adjustable girth

When the mound advances a distance of m, the area covered by the mound is given:

$$S_{\text{mound}} = k(x + m) \tag{11}$$

and the girth area is given:

$$S_{\text{girth}} = S' - S_{\text{mound}} \tag{12}$$

From the profiles of the mound and tube, it can be found:

$$S_{\text{girth}} = S_{\text{throat}} - km \tag{13}$$

Therefore, the girth area is independent of x, which means that the girth area is the same for all values of x. The girth area at each cross-section is constant. Moreover, the girth area is linearly adjustable with parameter m.

Verification of optimized design

To verify that the optimized venturi scrubber did yield a uniform velocity distribution, the flow field was calculated using CFD. The parameters values are given in tab. 1, and the mesh information is listed in tab. 2.

Comparisons of the velocity distributions in the original and optimized designs are shown in fig. 3. As the heavy mound advanced, the girth area decreased and the velocity increased. However, the gradient of velocity distribution for the optimized venturi changed more smoothly. The gas passing through the heavy mound introduces a re-circulation zone. The zones for the optimized design are much smaller, which will reduce the pressure loss compared with that in the conventional design. Local velocities between the mound and tube wall are listed in tab. 3. Theoretically, the velocity in the optimized design should be constant. However, the numerical results show slight differences due to the effect of the boundary layer. The fluctuation is relatively small for the optimized design.

Table 1. Parameters used in CFD modeling

Parameter	Value	Parameter	Value
Inlet diameter of converging section [m]	3	Gas flowrate [kgs^{-1}]	350
Length of converging section [m]	3	Gas density [kgm^{-3}]	1.185
Throat diameter [m]	2	Relative pressure [Pa]	0
Outlet diameter of diffuser [m]	4.6	Turbulent mode	k-ε model
Length of diffuser [m]	4	Convergence criteria	1e−5
Height of heavy mound [m]	2		

Table 2. Meshes used in CFD modeling

	The minimum mesh size [mm]	The number of grid	The number of nodes
Before optimization	58	41536	38695
Heavy mound	31	9525	8720
After optimization	58	58159	54600

Table 3. Local velocities for heavy mound at different heights

Heavy mound distance [m]	Position from tube wall at throat [m]	Numerical velocity after optimization [ms^{-1}]	Theoretical velocity after optimization [ms^{-1}]	Numerical velocity before optimization [ms^{-1}]	Theoretical velocity after optimization [ms^{-1}]
	0	95.0292	99.0139	94.8096	99.0139
0.1	0.5	103.1540		109.257	107.6717
	1	100.3500		119.768	115.9684
	1.5	100.907		122.28	123.3617
	0	112.1630	117.5791	113.077	117.5791
0.4	0.4	119.1420		126.14	127.4593
	0.8	120.878		139.272	137.4301
	1.2	113.454		145.262	146.9739
0.7	0	138.6010	144.7127	132.225	144.7127
	0.4	142.791		157.139	160.032
	0.8	148.96		182.959	176.0019
	1.2	135.422		175.742	191.9658

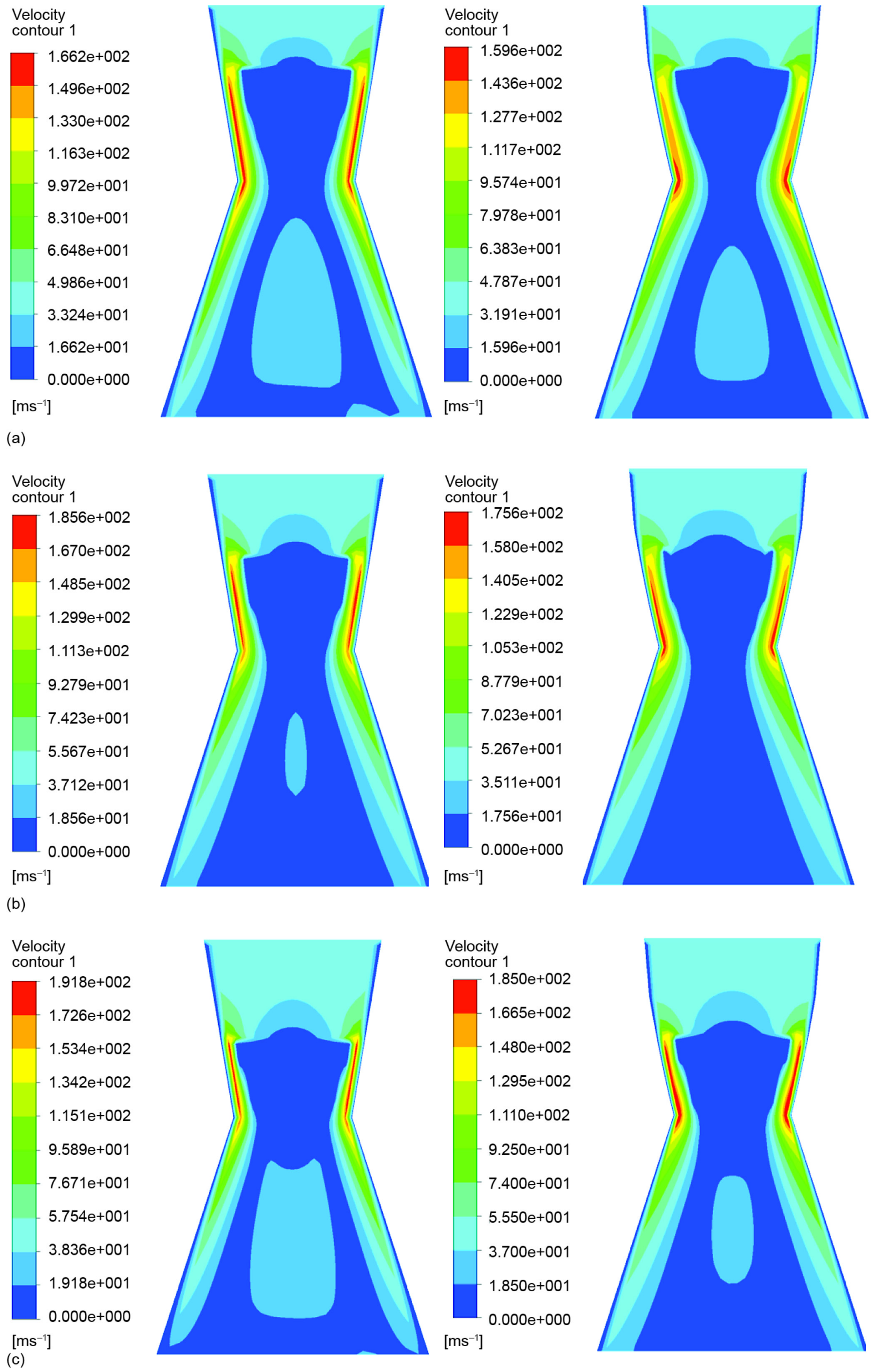

Figure 3. Comparison of velocity distributions of conventional (left) and optimized (right) venturi scrubber designs for mound distances of (a) 0.1 m, (b) 0.4 m, and (c) 0.7 m

Conclusion

An optimized design for a heavy mound venturi is proposed. The profiles of both the mound and tube are parabolic. Compared with the conventional structure, the girth area becomes linearly adjustable, which has benefits for improving the efficiency and reducing the noise of the venturi tube. The CFD simulation verified that the optimized design exhibited a more uniform gas velocity distribution.

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