PERFORMANCE IMPROVEMENT OF VENTURI WET SCRUBBER

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ABSTRACT

Environmental protection measures regarding industrial emissions and tightened regulations for air pollution led to the selection of wet scrubber to foundry units. Venturi scrubbers are compact and comparatively inexpensive to construct, but can be expensive to operate because they require high gas phase pressure drop to achieve high collection efficiency for small particles. Pressure drop is due to energy consumed as friction from gas flow, a loss that would occur even if no water were injected, and as energy to accelerate the droplets. Experiments were designed using Taguchi's L16 orthogonal array to determine the best possible combination of geometrical parameters of convergent, throat and divergent sections of venturi scrubber. It is found that a combination of larger diameters and minimum length contributed to minimum pressure drop. However, the limiting velocity to improve the performance of venturi scrubber is to be identified using a CFD simulation.

Keywords: Venturi scrubbers ; Pressure drop ;DOE Taguchi's L16orthogonal array;

Hypermesh; CFD.

1. INTRODUCTION

1.0 Environmental pollution

Increased public awareness posed by global warming has led to greater concern over the impact of anthropogenic emissions from industrial production. The concentration of pollutants emitted from industrial production are generally toxic and hazardous, which can be a serious health risk to humans not limited to respiratory ailments (asthma, bronchitis, tuberculosis, etc) but also to the photosynthesis in plants. Tall stacks have traditionally been used to reduce ground level concentrations of air pollutants at minimum cost. Their effectiveness depends on height, velocity and temperature of the stack gases, and atmospheric conditions such as wind speed and direction, atmospheric stability, local topography and air quality as such serious environmental effects such as acid deposition and forest decline can occur in a sensitive receiving environments or remote locations. Concern on the environmental and health effects of fine particles has lead to tightening of pollution control regulations word wide. Many applications that have provided adequate level of particle mass removal are now facing problems with fine and submicron particles.

2 LITERATURE REVIEW

- **Bashir Ahmed Danzomo *et.al* [1] "***Performance Evaluation of Wet Scrubber System for Industrial Air Pollution Control" -* In this study, an analytical method for design and prediction of spray tower scrubber performance based on cement dust particle removal efficiency has been described. The approach focused on the design of a scrubber system for the collection of dust particle sizes of 1µm, 5µm and 10µm (PM) that are emitted from cement production processes and predicting the performance of the system using Calvert et al. model for overall collection efficiency of counter current spray tower by considering droplet sizes of 500µm, 1000µm, 1500µm and 2000µm. The range of liquid to gas ratio of 0.7-2.7l/m3 recommended by the US Environmental Protection Agency (EPA) were used to investigate the appropriate ratio that will give the optimum result for the performance of the system. The result obtained was validated using the World Health Organization's air quality standards for particulate matter (PM).
- **Bashir Ahmed Danzomo1, et.al[2] "***CFD based parametric analysis of gas flow in a counter-flow wet scrubber system***"** ANSYS Fluent software was used to investigate the gas distribution within a counter-flow wet scrubber system based on airflow velocity and pressure fields. The velocity flow contours and vectors at the inlet, across the scrubbing chamber and the outlet (especially at 0.32m/s) shows a distributed flow and the velocity profiles have fully conformed to the recommended profile for turbulent flows in cylindrical pipes. The total pressure within the scrubber cross-section is constant which follows the Bernoulli's principle. The minimum pressure drop, *ΔPmin* for the scrubber system was obtained to be 0.30pa and the maximum, *ΔPmax* was 3.03pa which has conformed to the recommended pressure drop for wet scrubbers. From the par - ametric analysis conducted, it can be concluded that the numerical simulation using Ansys Fluent CFD is an effective method of studying the flow characteristics of a counter flow wet scrubber system.
- **Juntima chungsiriporn, et.al[5]"***Toluene removal by oxidation reaction in spray wet scrubber: experimental, modeling and optimization ",* Wet scrubber coupling with oxidation reaction using NaOCl as oxidizing agent performed effectively in removing toluene from waste air. The steps of design of experiment, surface plotting, model formation, and optimization problem formation and solving were used to study toluene removal in the wet scrubber. A mathematical model of the toluene removal was constructed based on the experimental results. Five operating parameters including toluene concentration, air flow rate, oxidant flow rate, NaOCl concentration, and size of spray nozzle were considered as the significant parameters in the model. Optimization problem was formed with an objective function of maximum removal efficiency and constraints of mathematical model and process limitation.
- **W. Peukert & C. Wadenpohl** , "*Industrial separation of fine particles with difficult dust properties*", There is a variety of solutions to separate solid and liquid particles with difficult dust properties. By looking at the

physical fundamentals of particle separation, new and innovative solutions can be found. Careful examination of the dust properties in the process is a precondition for the design of a gas cleaning process. The principal ways to reach this goal are: v enhance efficiency of transport mechanisms by introducing additional forces on the particles e.g. electro-cyclone., v change the particle properties so that they can be collected easier e.g. heterogeneous condensation in scrubbers., v avoid clogging of filter media by means of precoating e.g. tar collection., v investigate systematically the mechanism of separation; there may be still surprising results to be discovered e.g. ESP., v in case of sintering, changes in the process technology may be unavoidable.

3 Venturi wet scrubbers

A venturi scrubber is designed to effectively use the energy from the inlet gas stre g used to scr hnology is a p n controls col ers.

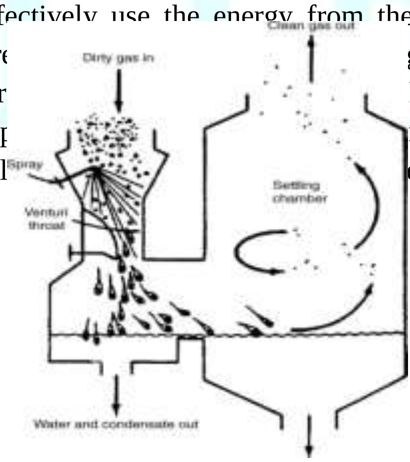


Fig.1. venturi wet scrubber

A venturi scrubber consists of three sections: a converging section, a throat section, and a diverging section. The inlet gas stream enters the converging section and, as the area decreases, gas velocity increases (in accordance with the Bernoulli equation). Liquid is introduced either at the throat or at the entrance to the converging section.

Venturis can be used to collect both particulate and gaseous pollutants, but they are more effective in removing particles than gaseous pollutants.

These types of scrubbers vary in complexity from simple spray chambers used to remove coarse particles to high-efficiency systems (Venturi types) that remove fine particles. Whichever system is used, operation employs the same basic principles of inertial impingement or impaction, and interception of dust particles by droplets of water. The larger, heavier water droplets are easily separated from the gas by gravity. The solid particles can then be independently separated from the water, or the water can be otherwise treated before reuse or discharge.

3.0 Design of experiments

In an engineering environment, experiments are often conducted to explore, estimate or confirm. Confirmation implies verifying the predicted results obtained from the experiment. In a designed experiment, the engineer often makes deliberate changes in the input variables and then determines how the output functional performance varies accordingly. It is important to note that all variables affect the performance in the same manner.

DoE is used to optimize the different parameter values which act as the control factors in an experiment. To conduct DoE taguchi approach have been used in this project. Taking various geometrical parameters in venturi scrubber the experiment have been calculated for minimum pressure drop.

DoE was performed using L16 orthogonal array.

3.1 Design of experiments using taguchi technique

Taguchi's approach complements these two areas. First, he clearly defines a set of orthogonal array, each of which can be used for many experimental situations. Second, he devised a standard method for analysis of the result. There are three stages in Taguchi methodology,

- System design
- Parameter design
- Tolerance design

3.2 Orthogonal Arrays

An orthogonal array is a fractional factorial matrix, which assures a balanced comparison of levels of a factor (or interaction of factors). Orthogonal array allow researchers to study many design parameters simultaneously and can be used to estimate the effect of each factor independently of the other factors. Thus the information about the design parameters can be obtained with minimum time and resources. L16 orthogonal array is chosen shown in table.

Number of Levels	Number of Parameters (P)										
	2	3	4	5	6	7	8	9	10	11	12
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27
4	L'1[illegible]	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32		
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50

3.3 Design calculations

Parameters	Convergent section	Divergent section	Throat section
Smaller diameter d1(mm)	369	369	369
Larger diameter d2(mm)	482	725	725
Length L(mm)	480	520	600
ϴ/2	2.388535032	2.388535	-
Beta β	0.952380952	0.952381	-
sin ϴ/2	0.683872798	0.683873	-
k geometric co efficient k-convergent	0.06182552	0.200933	-
A1(m^2)	0.755360978	0.755361	0.755361
A2 (m^2)	0.834327268	0.834327	-
Average area m^2	0.794844123	0.794844	-
volumetric Flow rate Q m^3/s	12.36	12.36	12.36
Velocity v m/s	15.55021878	15.55022	16.36304
density p, kg/m^3 @ 700 deg. C	0.363	0.363	0.363
Friction factor	-	-	0.011

Calculations

Formulas

Convergent section:

$$K = \frac{0.8\left(\sin\frac{\theta}{2}\right)(1-\beta^2)}{\beta^4} - - - - - - - - - - - - - (1)$$

$$\beta = \frac{d_1}{d_2} - (2)$$

Divergent section:

$$K = \frac{2.6\left(\sin\frac{\theta}{2}\right)(1-\beta^2)}{\beta^4} - - - - - - - - - - - - - (3)$$

K = Geometrical co efficient

d1 = Smaller diameter (mm)

d2 = Larger diameter (mm)

Using above parameters to calculate pressure drop:

Calculation:

Pressure drop Δp

$$\Delta p = \frac{(KV^2\rho)}{2g}$$

Using equation 1, 2, 3 pressure drop is calculated

L16 orthogonal pressure drop calculation:

Inlet diameter	**Outlet diameter**	**Throat diameter**	**Total pressure drop Δp**
482	725	294	43.53
482	750	319	30.84
482	775	344	22.429
482	800	369	16.676
507	725	319	30.087
507	750	294	44.621
507	775	369	16.279
507	800	344	22.985
532	725	344	21.354
532	750	369	15.891
532	775	294	45.724
532	800	319	32.393
557	725	369	15.514
557	750	344	21.884
557	775	319	31.609
557	800	294	46.838

CONVERGENT SECTION

Inlet Diameter D1(mm)	482
Outlet diameter D2(mm)	294
Length L(mm)	480
sin Θ/2	-0.195833333
Beta β	1.639455782
sin Θ/2	-0.195833333
geometric co efficient k-convergent	0.03660182
A1 (m^{2})	0.17786216
A2(m^{2})	0.06511104
Average area m^2	0.1214866
volumetric Flow rate Q m^3/s	3.333
Velocity v m/s	27.43512453
density ρ, kg/m^3 @ 700 deg. C	0.363
pressure drop Δp kg/m^2	**0.509711199**
pressure drop Δp mbar	**0.049985593**

DIVERGENT SECTION

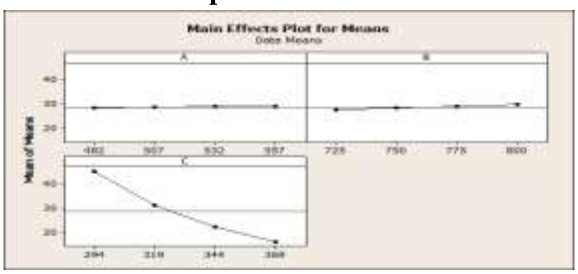
Inlet diameter D1 (mm)	294
Outlet diameter D2(mm)	725
Length L(mm)	520
sin Θ/2	0.414423077
Beta β	0.405517241
sin Θ/2	0.414423077
geometric co efficient k-divergent	33.29319117
A1 (m^{2})	0.06511104
A2 (m^{2})	0.405814385
Average area m^2	0.235462713
volumetric Flow rate Q m^3/s	3.333
Velocity v m/s	14.15510747
density ρ, kg/m^3	0.363
pressure drop Δp kg/m^2	**123.421093**
pressure drop Δp mbar	**12.1034746**

THROAT SECTION

friction co-efficient	0.011
Diameter (mm)	294
Length L(mm)	600
Area (m^{2})	0.065111

density ρ kg/m^3	0.363
Acceleration g	9.81
volumetric Flow rate Q m^3/s	3.333
velocity v m/s	51.18948
pressure drop Δp kg/m^2	**319.973**
pressure drop Δp mbar	**31.3786**

4 Main effects plot for means



5 Design of experiments using Minitab

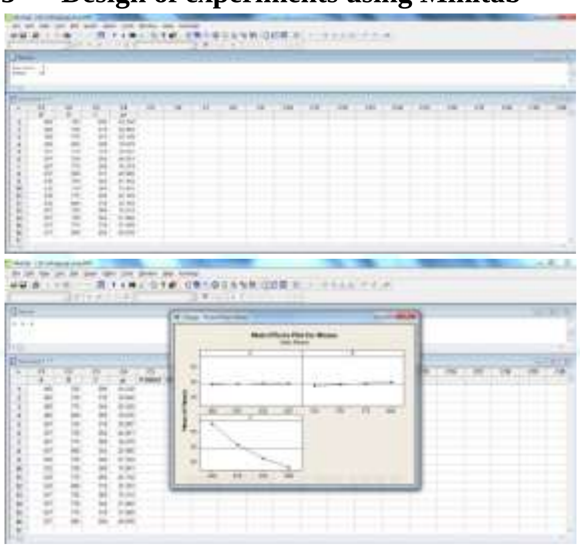


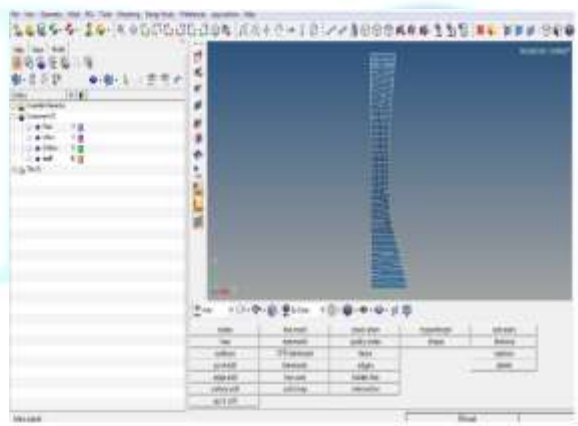
Fig.2. L16 orthogonal array taguchi techniques in Minitab

6 MODELING

Fig.3. 3D modeling of venturi wet scrubber

New Venturi wet scrubber is designed as per pressure drop calculation done in minimum pressure drop L16 orthogonal array using taguchi techniques.

7 HYPERMESH

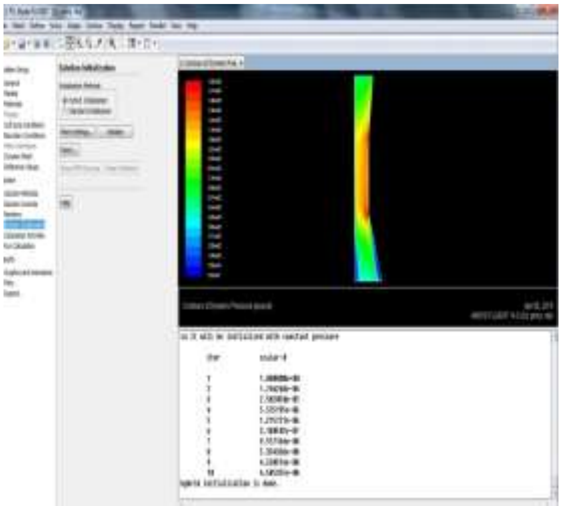


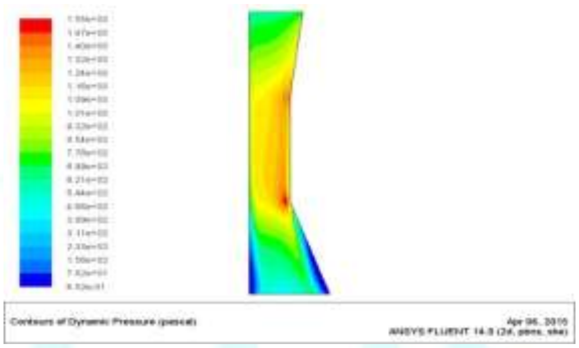
8 CF D analysis

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions.

For CFD analysis for the new dimension

PRESSURE DROP ANALYSIS





Maximum pressure (Pascal) = 1.55e+03
Minimum pressure (Pascal) =6.52e-01
Pressure drop (Pascal) = 1551.59
Pressure drop (mbar) =15.51

9. FINDINGS

From the literature survey, the following conclusions can be made about the minimum pressure drop to improve performance of venturi wet scrubber.

- Modifying geometrical dimensions can enhance the performance of the venturi wet scrubber.
- Using Design of experiments to minimize the pressure drop.
- While modifying geometrical parameters like inlet diameter, outlet diameter, throat diameter minimum pressure drop can be calculated
- The length of the venturi wet scrubber is maintained the same
- L16 orthogonal array is selected as per 4 levels and 3 parameters.
- So pressure drop is minimized by taguchi techniques.
- 3D modeling of venturi wet scrubber is convergent section, divergent section, throat section is calculated to minimize pressure drop.

10. CONFIRMATION EXPERIMENT

S.No	Inlet dia (mm)	Outlet dia (mm)	Throat dia (mm)	Pressure drop(mbar)
DoE L16 orthogonal array In Taguchi Techniques	532	750	369	15.691
Confirmation Experiment In CFD analysis	482	725	369	15.411

11. RESULTS

Experiments are designed using Taguchi's L16 orthogonal array considering three factors and three levels. The pressure drop at various different combinations was calculated. It was found that the pressure drop value is less at maximum diameters and minimum length. However, the limiting velocity for the optimum performance of the scrubber is to be identified, to improve the performance of venturi scrubber. The graphs below show the pattern of contribution by various levels of parameters to the pressure drop.

12. CONCLUSION

Pressure drop was calculated across various sections of the venturi wet scrubber. It was found that pressure drop is less with the combination of maximum diameter and minimum length.

However, the limiting velocity for optimum performance of the unit is to be calculated, which is considered as future scope of this project.

By limiting the pressure drop energy consumption can be reduced, but the performance is dependent on the limiting velocity so determining the same is also vital. It is proposed to conduct a CFD simulation to predict the limiting velocity.

Comparing the results, design of experiments with CFD analysis to improve performance of venturi scrubber for minimum pressure drop.

13. REFERENCES

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