Design and Analysis of Venturi Scrubber

H.A.KhandeS.S.Dalvi,P.V.Agrawal, .P.Singh,A.Lokhande
Mechanical Department,SavtribaiPhule University

Abstract- Scrubbers are attached to the exhaust system of manufacturing units of various industries. Scrubbers separate the flue gases, particulate matter from exhaust system. Clean gas is sent to environment in order to avoid environmental pollution. There are many types of scrubbers used depending on the requirements. Wet scrubbers of venturi type are used when particulate matter is present in flue gas. This paper gives information about hazards of pollution and role of scrubber in controlling it. This paper also gives background of scrubbers, its design procedure and analysis.
Keywords-Venturi Scrubber, Particulate Matter (PM)

I. Introduction

In recent decades, the economic growth and the industrial development have been accompanied by an expansion of the urban area population and by the emergence of megacities. This rapid growth has resulted in a continuously increasing demand for shelter, resources, energy and utilities. At the same time urban emission of air pollutants has grown rapidly, leading to a worsening of the air quality both in the cities and in their surrounding areas. These latter, in particular, often concentrated in densely populated areas in the largest urban districts, may represent a significant source of emissions. According to the European Environment Agency, 90% of the urban population in Europe is exposed to pollutant levels above the threshold considered harmful by the World Health Organization (WHO), with a high cost in terms of health, safety and environmental damage. Moreover, in a recent study, long-term exposure to fine particulate matter air pollution has been associated with natural-cause mortality, even for concentrations well below the present European annual mean limit value. The need to achieve sustainability in urban environments has never been more acute.Wet scrubbers are particulate matter (PM) control devices that rely on direct and irreversible contact of a liquid (droplets, foam or bubbles) with PM. Scrubbers can be very specialized and designed in many different configurations. They can collect flammable and explosive dust safely, absorb gaseous pollutants and collect mists. Wet scrubbers are usually classified according to the method that is used to contact the gas and the liquid. The main feature of scrubber has no restrictions to temperature of incoming gases.

Venturi Scrubber :Venturi Scrubbers are designed to remove fine micron and submicron particulate from industrial and commercial effluent gases. These scrubbers are effective in the removal of dusts, fumes, vapours and mists as well as other air pollutants. Removal efficiency is related to the characteristics of the contaminant and the pressure drop induced across the throat section of the venturi. The performance of a venturi scrubber is dependent to some extent on the velocity of the gas through the throat. Venturi scrubber are efficient in removal of small particulate matter. Unfortunately, increasing the efficiency requires increase in pressure drop which in turns increases energy consumption.

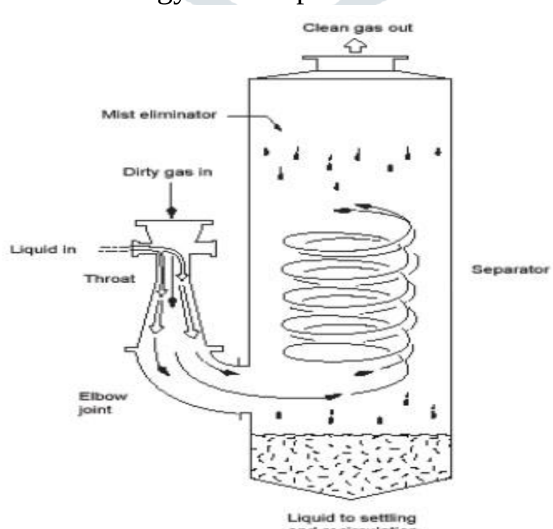


Fig No 1. Venturi Scrubber

The venturi accelerates the gas stream to atomize the scrubbing the flue gas with scrubbing liquid. As the gas flows through the throat the velocity and turbulence of flue gas increases. This scrubber is designed to eliminate the drawbacks of packed bed scrubber. This scrubber is easy to install and takes small space. Packed beds tend to "scale up" somewhat more rapidly, but have a much better operating range, than either the venturi or the flooded bed unless the venturi has been provided with a variable area throat to maintain high gas velocity under low loading conditions.

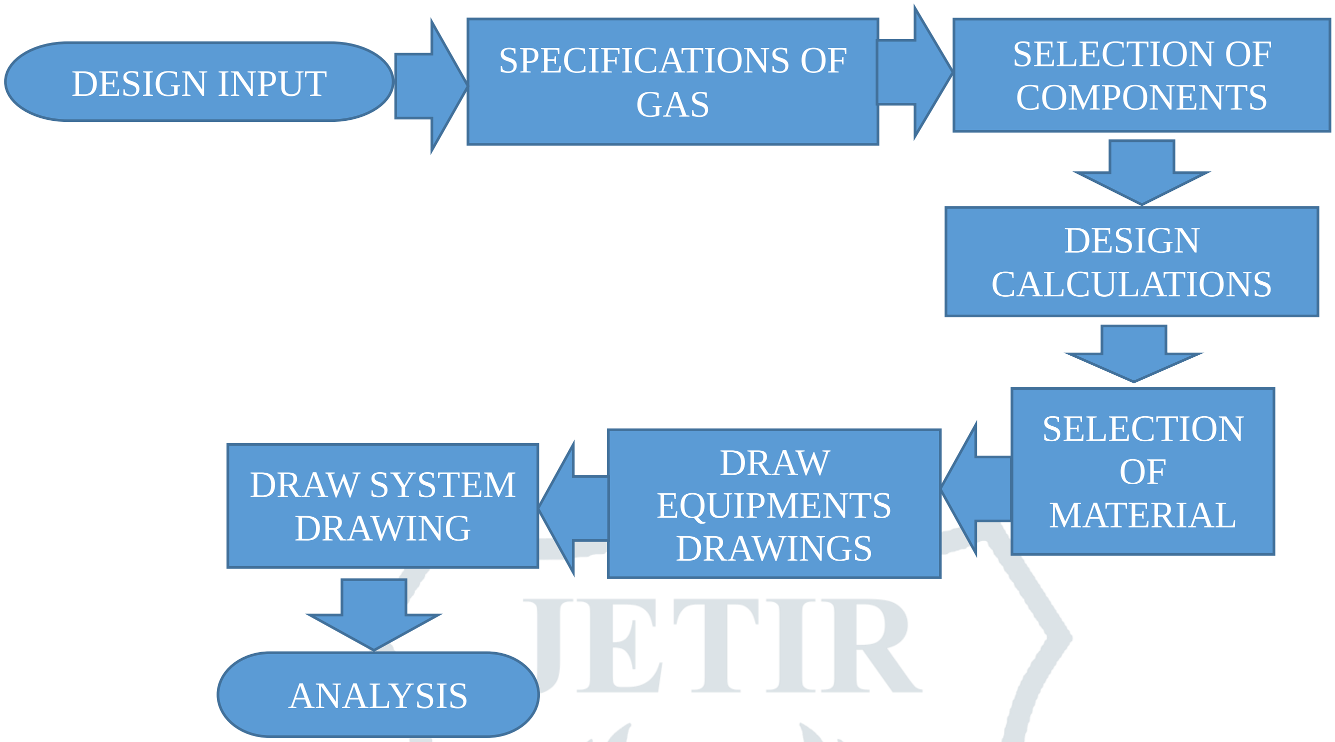
- Major accessories required for making of Wet Scrubber for plant will be filter, Pall rings and demister.

Filter: Many wet scrubbers are available with pre-filters and final filters to further reduced emissions.
Pall Rings:Pall rings are one kind of random packing named by inventor. Mostly it is made of alumina ceramic, has high crushing strength, resistance of acid and alkali. Pall ring has cylindrical dimensions but has two rows of punched out holes, with fingers or webs turned into the centre of the cylinder, with significantly increases the performance of the packing, in terms of temperature, efficiency and pressure drop.
Demister:A demister is a device often fitted to vapour liquid seperator vessels to enhance the removal of liquid droplets entrained in a vapour stream. Demister may be a mesh type coalescer, vane pack or other structure intended to aggregate the mist into droplets that are heavy enough to separate from the vapour stream.

II. Case Study

Air pollution is a critical problem in urban and rural India, estimated to be responsible for 1.62 million premature deaths per year*(Smith et al., 2014; Smith and Sagar, 2014).* As India is on growing economy, the overall population grows, the pollution levels are expected to increase further *(Goenka et al., 2015; Guttikunda et al., 2014).* The other side of India's present energy and pollution dilemma is that almost 300 million people lack access to electricity, with many more facing crippling shortages *(Kale, 2014).* With 60% of the nation's existing electricity supply derived from coal, the country struggles to balance the need to alleviate energy poverty, reduce fossil fuel use, and control the high air pollution levels associated with the extraction, processing, and use of coal. While renewable energy efforts are on the rise in India, the 'coal nation' *(Lahiri-Dutt, 2014)* remains heavily dependent on fossil fuel energy [1]. The sugar industry in India is an important manufacturing industry with 1062 factories providing employment of 95.025 million man days, and the invested capital of Rs. 342,052.2 million as of the financial year 2000–2001. The value of output produced by the sugar industry in India during this year was 276,336.2 million with the net value added amounting to Rs. 44,790.6 million. It is one of the most water polluting industries with the recently observed pollution concentrations for some factories in India as high as 1154 mg/l for Bio Oxygen Demand (BOD), 5915 mg/l for Chemical Oxygen Demand (COD), and 5759 mg/l for Suspended solids (SS). An attempt is made in this paper to study this problem using data from the sugar industry in India.*[2]* .Packed wet scrubbers are very good devices for the economical removal of particulates down to a nominal size of 5 micron . Below 5 mm size the removal efficiency of these devices will either begin to fall off or it will be necessary to operate them at higher than normal pressure drops or something over 0.25 in. of water head per foot of packed depth. It is possible to maintain a high efficiency scrubbing action down to about 3 micro metre particle size, however by this time the pressure drop will be up to 0.75 to 1.0 in. water/ft and severe misting of the irrigation liquid will set in. Higher gas mass velocities are needed for the removal of smaller size particles which means much more energy will be needed to provide separations.*[4]* .Venturis are commonly used, however, they are only effective at very high pumping cost for either the gas or the liquid and usually both. Venturis are therefore high consumers of energy though, if properly designed, they should remove particulate matter efficiently down through the 1.0 Mm range or less and have been known to be effective on some particulates as small as 0.1Mm. Flooded bed scrubbers are reputed to be as efficient as the venturi with a much lower liquid requirement. They are not capable of handling wide gas loading variations and are subject to rather high maintenance costs. Flooded beds are usually operated as multistage devices to achieve good efficiencies*[4]*

III. Methodology



- Below is Design Process and calculations for a Sugar Plant [8]

Design InputsTable No.1

Sr.No	Description	Specification
1	Plant Capacity	5000 TCD
2	Sugar plant	400 TPD
3	Possible Dust particle Source	a. Fluidized Bed Conveyor b. Grader Outlet
4	Dust load	25 kg/hr
5	Inlet Dust Density	5 gm/m3
6	Level of Emission	50 mg/m3
7	Scrubber Media	Water
8	Gas Volume	5000 m3/hr
9	Gas Temperature	60 centigrade
10	Gas Composition	Fumes & Sugar Dust
11	Dust Size	0-0.3mm
12	Gas Pressure	300 mmWG
13	Relative Humidity	60%
14	Absolute Humidity	0.165 water in Kgs/Dry air in Kgs

Calculations-

A) Converting Gas volume from m^3 toacfm (actual cubic feet per minute)-

$$= \frac{5000}{\left[\frac{60}{(3.28)^3}\right]} = \frac{5000}{1.7} = 2941 \text{ cfm}$$

$$\boxed{a1 = 2941 \text{ cfm}}$$

B) Converting operating temperature from ^{0}C to ^{0}F-

Temperature = 60^0C = 140^0F

$a2 = 140^0F$

C) Rankine temperature constant = 460^0R

$$\boxed{a3 = 460^0R}$$

D) Calculating lb-moles/ min of inlet gas using 'a1'-

$a4 = a1 \times (70^0 F + \text{Rankine Temp}) / 386 \times (\text{Operating Temperature } ^0F + \text{Rankine Temp})$

(Gas Constant = 386 ft^3)

$$\boxed{a4 = 6.73 \text{lb-moles/min}}$$

E) Calculating lb-moles/min of water vapor-

$$a5 = \frac{29 \times \text{Humidity} \times \text{'a4'}}{18 + (29 \times \text{Humidity})}$$

$$\boxed{a5 = 1.37 \text{ lb-moles/min of water vapor}}$$

F) Calculating lb-moles/min of Dry Air-

a6 = (lb-moles/min of mixture) – (lb-moles/min of water vapor)

$$\boxed{a6 = 5.35 \text{ lb-moles/min of Dry Air}}$$

G) Calculating lb/min of Dry Air-

a7 = lb-moles of dry air x Molecular weight of Dry air

$\boxed{a7 = 155.17 \text{ lb/min of Dry Air}}$

H) Using Psychrometric chart for Very high Temperatures for following data-

a) Operating temperature = 140^0F
b) Humidity = 0.16 water in Kgs/Dry air in Kgs.

$\boxed{\text{Outlet temperature of Gas} = 142^0\text{F}}$

Using the outlet temperature of gas, the saturated humidity value is 0.165

Therefore,

$\boxed{\text{Saturated humidity} = 0.165 \text{ water in Kgs/Dry air in Kgs.}}$

I) Calculating lb/min of water vapor*-

a8 = lb/min of Dry Air x Saturated humidity.

$\boxed{a8 = 25.603 \text{ lb/min of water vapor.}}$

J) Calculating lb-moles/min of water vapor*-

$$a9 = \frac{\text{lb/min of water vapor}}{\text{Molecular weight of water}}$$

$\boxed{a9 = 1.42 \text{ lb-moles/min of water vapor}}$

K) Calculating lb-moles/min of Mixture*-

a10 = 5.35 + 1.42 ------------------------------- (Using a6 and a9)

$\boxed{a10 = 6.77 \text{ lb-moles/min of mixture}}$

L) Calculating mixture in cfm from mixture in lb-moles/min*-

$$a11 = \frac{\text{lb-moles/min of mixture x 386 x (Operating Temperature } ^0\text{F + Rankine Temp)}}{(70^0 \text{ F + Rankine Temperature})}$$

$\boxed{a11 = 2969.27 \text{ cfm of Mixture.}}$

***** Calculations are carried out with saturated humidity value.

M) Selection of scrubber-

Referring to Standard Scrubber Dimensional Chart,

a) The venturi inlet should be sized for Inlet gas.
b) The separator should be sized for Outlet gas volume.

Selected Scrubber is –SR-15/30

N) Calculating quantity of scrubbing liquid-

Assuming 10 GPM/1000 CFM of outlet gas as the scrubbing liquid quantity.

Hence,

$$= \frac{2969.27 \times 10}{1000}$$

$$= 29.6927 \text{ GPM}$$

$$\boxed{a12 = 6.74 \text{ m}^3/\text{hr.}}$$

O) Calculation of Bleed-off Liquid-

$$\text{Bleed of liquid (a13)} = \frac{(\text{m}^3/\text{hr}) \times \text{Dust load (kg/m}^3) \times \% \text{ Recycle}}{\% \text{ Bleed-off} \times \text{Density of water}}$$

Bleed-off = 10%. Recycle = 90%.

Dust Load = 0.0022gm/m^3

$$\boxed{a13 = 9.9 \times 10^{-5} \text{ m}^3/\text{hr.}}$$

P) Calculation of Make-up Liquid-

Amount of Dry Air = 5.35 lb-moles/min

$$= \frac{5.35 \times 28 \times 60}{2.2}$$

Amount of Dry Air = 4085.45 kg/hr ----------------------------- 1

Difference in Humidity = 0.165-0.16 = 0.005 ------------------- 2

Hence,

Amount of water = 0.02042 m^3/hr. (factor 0.001 is to convert kg to m^3). (from 1 and 2)

Therefore, Make-up Liquid = 0.000099 + 0.02042

$$\boxed{a14 = 20.52 \text{ liters/hr.}}$$

Q)Calculation of Recycle Tank Capacity-

a) Assuming retention time of 6 minutes.
b) Quantity of Scrubbing Liquid = 6.74 m^3/hr.

Tank Capacity (m^3) = quantity of scrubbing liquid (m^3/hr) x Retention Time(minutes)

$$\boxed{a15 = 0.674 \text{ m}^3 \text{ (approx)}}$$

R) Calculation of Motor HP of recirculation pump-

a) Head= 25m
b) Quantity of Scrubbing Liquid = 6.74 m^3/hr.=1.87 lit/sec
c) Efficiency of the Pump = 75%

$$\text{Motor H.P} = \frac{\text{quantity of scrubbing liquid (liters/sec) x Head (m)}}{\text{75 x efficiency.}}$$

= 0.833 HP

Assuming, Transmission/coupling losses = 25%

Hence,
Motor B.H.P =0.833 x 1.25 = 1.03

$$\boxed{a16 = 2 \text{ HP (approx.)}}$$

S)Calculation of Motor HP for I. D. Fan-

a) Q = 2969.27 cfm = 5047.759 m^3/hr
b) Outlet area of packed bed scrubber = $(\pi/4) \times 0.5^2 = 0.1963 m^2$
c) Outlet velocity (v)= Q/ area = $\frac{(5047.759/3600)}{0.1963}$ = 7.14 m/s

v = 7.14 x 3.28 x 60 = 1405.72 foot/min

d) Velocity Pressure (VP) = $\left[\frac{\text{Velocity in foot/min}}{4005}\right]^2 = \left[\frac{1405.72}{4005}\right]^2 = 0.123$ psi
e) Static Pressure = 325 mm of water column = 0.46 psi
f) Total static pressure (TP) = VP + SP = 0.123 + 0.46 = 0.583 psi

TP = $\frac{0.583}{0.036}$ = 16.19 inches of water ….(density of water = 0.036 lb/in^3)

g) Air Horsepower,

$$\text{AHP} = \frac{\text{Q (cfm) x TP}}{6346} = \frac{2969.27 \times 16.19}{6346} = 7.57 \text{ HP}$$

h) $$\text{Shaft power} = \frac{\text{AHP}}{\text{efficiency}} = \frac{7.57}{0.65} = 11.65 \text{ HP}$$

$$\boxed{\text{Shaft power} = 12 \text{ BHP}}$$

IV. Conclusion

1) For the Gas Volume of 5000m^3 and at 60^0C operating temperature, the selected scrubber is SR-15/30
2) Recycle Tank capacity is 0.674m^3, but actual used is 1m^3
3) Motor BHP for recirculation pump =2 HP
4) i) Shaft Power for I.D Fan(calculated) = 11.65 HP
   ii) Motor Power for I.D Fan (actual used) = 15 HP

V. References

1. PatrikOskarssona(a) , Heather P. Bedi(b) a Swedish University of Agricultural Sciences, Sweden b Dickinson College, United States,2006

2. M.N. Murtya, SurenderKumarb, Mahua Paulc,1 a Institute of Economic Growth, Delhi University Enclave, Delhi 110007, India b TERI School of Advanced Studies, New Delhi 110003, India c Institute of Economic Growth, Delhi University Enclave, Delhi 110007, India Received 7 August 2003; revised 6 January 2005; accepted 5 April 2005 Available online 21 September 2005

3. Peter Rafaja, GregorKiesewettera , TimurGülb, Wolfgang Schöppa, JanuszCofalaa, ZbigniewKlimonta, PallavPurohita, Chris Heyesa, Markus Amanna, Jens Borken-Kleefelda, Laura Cozziba International Institute for Applied Systems Analysis (IIASA), Air Quality and Greenhouse Gases Program, Schlossplatz 1, 2361 Laxenburg, Austria b International Energy Agency IEA/OECD, World Energy Outlook: Energy Demand Division, 31-35, rue de la Fédération, 75739 Paris Cedex 15, France

4. John S. Eckert & Ralph F. Strigle Jr. To cite this article: John S. Eckert & Ralph F. Strigle Jr. (1974) Performance of Wet Scrubbers on Liquid and Solid Particulate Matter, Journal of the Air Pollution Control Association 5. Akshey Bhargava* 2016 Department of Civil Engineering, Global Institute of Engineering and Technology, Hyderabad, India;Wet- Scrubbers of Spray Tower to Control Air Pollutant.

6. LI Shan-hong, LI Cai-ting, ZENG Guang-ming, LI Si-min, WANG Fei, WANG Da-yong College of Environmental Science and Engineering, Hunan University, Changsha 410082, China Received 25 April 2007; accepted 26 June 2007;CFD Simulation on performance of new type umbrella plate scrubber

7. Manisha Bal a, BhimCharanMeikap ;2017 a Indian Institute of Technology (IIT) Kharagpur, Department of Chemical Engineering, West Bengal 721302, India b School of Engineering, Howard College, King George V Avenue, University of Kwazulu-NataDepartment of Chemical Engineering, Durban 4000, South Africa

8. Louis Weidley , reference book on design for air pollution equipments.