International Letters of Natural Sciences
ISSN: 2300-9675, Vol. 9, pp 15-26
doi:10.56431/p-1fssg5

Online: 2014-02-07

Study of Venturi Scrubber Efficiency For Pesticide Industry

R. Desai, O. P. Sahu*

Department of Chemical Engineering, KIT, Jamnagar, Gujarat, India
Tel: +919752610958

E-mail address: ops0121@gmail.com

ABSTRACT

A venturi scrubber is designed to effectively use the energy from the inlet gas stream to atomize the liquid being used to scrub the gas stream. This type of technology is a part of the group of air pollution controls. The air pollution generated from the industry is now become serious problem for the environment, which affect the living and non living thing of the Earth. Among all the air pollution monitoring equipment venturi scrubber found to suitable for prevention of air pollution by pesticide. It was found that scrubber shows 99.1 % efficiency.

***Keywords*:** Air pollutant; Dissolved; Health; Suitable; Tox

1. INTRODUCTION

Air pollution is one of the most important agents that can affect human health as well as the environment, plants, and animals. Three million deaths from air pollution had been reported annually, making it one of the seven greatest hazards for the world [1]. Humans did not significantly affect the environment until relatively recent times. This is due to human population increasing for only a small part of recorded history, and the bulk of human-made produced air pollution is intimately related to industrialization [2]. With rapidly expanding industry, ever more urbanized lifestyles, and an increasing population, concern over the control of man-made air pollutants is now clearly a necessity [3]. In all the industry pesticides industry one of the toxic releaser industry and also responsible for environmental pollution.

In general, process emissions can be classified into channelised and fugitive emissions. The channelised emission is a point source emission from process operations and the fugitive emission is an uncontrolled emission from storage tanks/drums, spils, leaks, overflows etc. In order to identify the various sources of process emissions and their control systems in pesticide industries a questionnaire survey and in-depth study of some pesticide industries were conducted [5-7]. The manufacturing process for a product is a combination of various unit operations and unit process. The material balance of the reactants and products gives the characteristics and quantity of emissions. However, their quantity is constrained by the efficiency of conversion of the system. Chances of pure process emissions of only one gaseous pollutant are very less. The process emissions are contaminated by other vapours of raw materials, solvents and also sometimes product of the unit operations [8]. Theoretical emission of pollutants is difficult to compute. Very often during the unit operations

wastewater and solid waste are separated, where as waste gas is directly released from the reactions itself. It is observed that no process or production site is directly comparable to another. From the various pesticide manufacturing units, different identified pollutants associated with products are mention in Table 1.

Table 1. Pollutant generated with pesticide manufacturing.

S. No	Pesticide	Name of Pollutant
1	Acephate	HCl
2	Aluminium phosphide	P_2O_5 fumes
3	Captafol	Cl_2 and HCl
4	Captan	Cl_2 and
5	Cypermethrin	Cl_2, Cl and SO_2
6	Dimethoate	H_2
7	2,4-D-Acid	Cl_2 and HCl
8	Dichlorvos (D.D.V.P)	CH_3Cl
9	Ethion H_2S	C_2H_5SH
10	E phan	HCl
11	Fe	Cl_2 and SO_2
12	Isopr on	NH_3
13	Malathion	H_2S
	Monocrotophos	HCl and CH_3Cl
15	Phosalone	NH_3, HCl and H_2S

In l ture so many method are available for the pollution monitoring for the pesticide industry like, separation techniques, gas solid separation, liquid-liquid separation, gas liquid separation, conversation to harmless end product and thermal destruction. In case of gas solid separation technique cyclone separator, multiclone, electrostatic precipitator, wet dust scrubber and fabric filter including ceramic filter pollution monitoring equipment are used [9]. Among all techniques gas solid separator and the equipment venturi scrubber is the best one. The venturi scrubber is a device which uses liquid in the form of droplets to efficiently remove fine particulate matter from gaseous streams. In the scrubber the gas scrubber accelerates the scrubber liquid, together with the air or gas exhaust stream, to high velocities

and turbulence. This happens in the bottleneck of the venturi. Behind this bottleneck, the pressure drops, reducing flow velocity back to normal. At this point, contaminant particles are collected and removed [10].

Venturis are the most commonly used scrubber for particle collection and are capable of achieving the highest particle collection efficiency of any wet scrubbing system. As the inlet stream enters the throat, its velocity increases greatly, atomizing and turbulently mixing with any liquid present. The atomized liquid provides an enormous number of tiny droplets for the dust particles to impact on. These liquid droplets incorporating the particles must be removed from the scrubber outlet stream, generally by cyclonic separators [11-13]. Particle removal efficiency increases with increasing pressure drop because of increased turbulence due to high gas velocity in the throat. Venturis can be operated with pressure drops ranging from 12 to 250 cm (5 to 100 in) of water. Presently pesticide industry using mechanical aided scrubber, it shows very poor efficiency is low. By this study suggested using venturi scrubber instead of mechanically aided scrubber. The aim of study is to calculate the efficiency of venturi scrubber in the monitoring of pollutant generated by pesticide.

2. MATERIAL AND EXPERIMENTAL METHOD

2. 1. Material

The sample was collection from the pesticide industry. The plant for the manufacture of Agrochemicals is located in nearby Ahmedabad City. It manufacture TGP (Technical Grade Pesticides) which include synthetic pyrethroids such as Cypermethrin, Permethrin and Alpha Cypermethrin and organic phosphorous compounds such as Acephate as well as new Technical Grade Pesticides such as Imidacloprid and Triazophos, Formulations and Pesticides Intermediates such as MPB and CMAC.

2. 2. Experimental setup

A venturi scrubber is used for the process of reducing air pollution in pesticides industry is shown in Figure 1. Equipment was designed for 3000 Kg/h scrub the gas stream for effectively use of the energy from the inlet gas stream to atomize the liquid being used. Basically it was made of MS, SS304, SS316, Polypropylene, PVDF, FRB, and Graphite [14]. The Caustic Soda, Potash, water, lime is used as motive fluid used in scrubber [15]. 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.

The gas, forced to move at extremely high velocities in the small throat section, shears the liquid from its walls, producing an enormous number of very tiny droplets. Particle and gas removal occur in the throat section as the inlet gas stream mixes with the fog of tiny liquid droplets. The inlet stream then exits through the diverging section, where it is forced to slow down. Venturi can be used to collect both particulate and gaseous pollutants, but they are more effective in removing particles than gaseous pollutants [16].

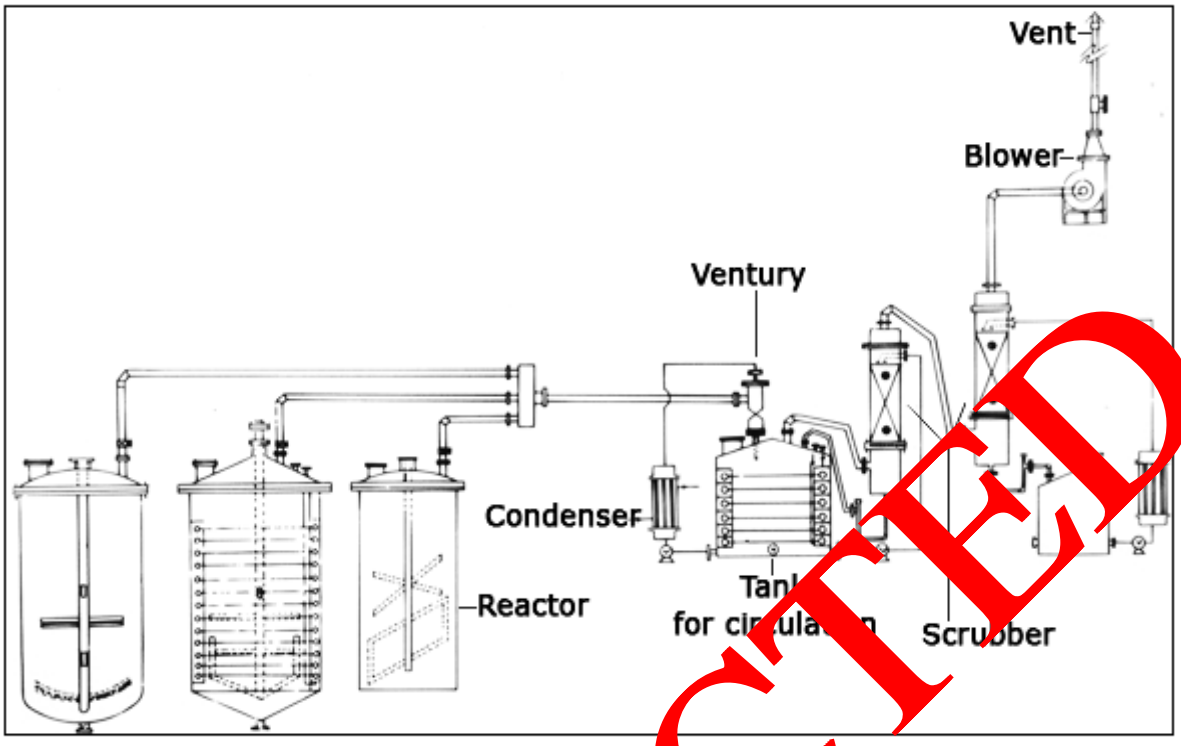

Figure 1. Complete setup of the venturi scrubber in the pesticide industry.

To accomplish this removal it is necessary to mix the "dirty" gas with fine droplets of the fluid used to remove them. A Venturi accomplishes this by passing the washing fluid through a tapered neck in the Venturi nozzle introducing the gas and liquid into the system. The high speed gas breaks the fluid into tiny droplets and mixes them with itself [17]. The fluid picks up the impurities and coalesces into larger droplets which either fall out of the gas or are collected on impingement plates or packing. The purified gas leaves the system; the dirty fluid is sent for disposal or purified for reuse.

2. 3. Emission Stream Characteristics

2. 3. 1. Air Flow

Typical gas flow rates for a single-throat venturi scrubber unit are 0.2 to 28 standard cubic meters per second (sm^3/sec) (500 to 60,000 standard cubic feet per minute (scfm)). Flows higher then this range use either multiple venturi scrubbers in parallel or a multiple throated venturi.

2. 3. 2. Temperature

Inlet gas temperatures are usually in the range of 4 to 370 °C (40 to 700 F) .

2. 3. 3. Pollutant Loading

Waste gas pollutant loadings can range from 1 to 115 grams per standard cubic meter (g/sm^3) (0.1 to 50 grains per standard cubic foot (gr/scf)).

2. 3. 4. Other Considerations

In situations where waste gas contains both particulates and gases to be controlled, venturi scrubbers are sometimes used as a pretreatment device, removing PM to prevent clogging of a downstream device, such as a packed bed scrubber, which is designed to collect primarily gaseous pollutants.

2. 4. Method

Generally different models are available for the calculation of Venturi particle collection efficiency. Johnstone equation, Infinite throat mode, Cut power method, Co[illegible]ct power theory, Pressure drop.

2. 4. 1. Johnstone' method

One of the more popular and widely used collection effici[illegible]y equations is that originally suggested by Johnstone et al (1954) [10].

$$\eta = 1 - e^{-kR(K_p)^{0.5}} \quad (1)$$

where η is the collection efficiency, K_p is the inertia[illegible]impaction parameter (dimensionless), R the liquid-to-gas ratio (gal/1000 acf or gpm/1000 ac[illegible]n) and k th[illegible] correlation coefficient, the value of which depends on the system geometry and [illegible]erating conditions (typically 0.1-0.2 acf/gal).

The inertial impaction parameter (K_p) is g[illegible] by Equation 2, where d_p the particle diameter (ft), ρ_p the particle density (lb/ft^3), [illegible] the thr[illegible]at velocity (ft/s), μ_G the gas viscosity (lb/ft-s), d_d the mean droplet d[illegible]eter (ft) and C the Cunningham correction factor (dimensionless).

The mean droplet diame[illegible]ter (d_d) [illegible]dard air and water in a venturi scrubber is given by the Nukiyama-Tanasawa relat[illegible]ship, shown in Equation 3. The overall collection efficiency of the syste[illegible]n be calcu[illegible]d using Equation 4, where M_d is the weight percent of the particles of a g[illegible]ven d[illegible]eter.

$$K_p = \frac{C d_p^2 \rho_p V_t}{9 \mu_G d_d} \quad (2)$$

$$d_d = \frac{16,400}{V_t} + 1.45 \times R^{1.5} \quad (3)$$

$$\eta_o = \sum (\eta_d \times M_d) \quad (4)$$

2. 4. 2. Pressure drop

The pressure drop in venturi scrubbers can be calculated by the model developed by Young et. al. (2007) [18] by the following Equation 5:

$$\Delta P = 2\rho_L V_G^2 \left(\frac{Q_L}{Q_G}\right)\left(1 - X^2 + \sqrt{X^4 - X^2}\right) \quad (5)$$

where ΔP the pressure drops (dyne/cm^2), and X the dimensionless throat length, which can be calculated by Equation 11 (where l_t the venturi throat length, in cm). The drag coefficient, C_D for droplets with Reynolds numbers, Re, from 10 to 500 can be obtained by Equation 9 [9]. The Reynolds number can be calculated using Equation 7 (where ρ_G the gas density, in g/cm^3).

$$C_D = \frac{24}{\mathrm{Re}} + \frac{4}{(\mathrm{Re})^{1/}} \quad (6)$$

$$X = \frac{3 l_t C_{} \rho_G}{16 d_d \rho_L} + 1 \quad (7)$$

2. 5. Operating Parameters

The venturi scrubber runs with two different pollutants existing on the plant. When gaseous or the particle the pressure drops, liquid to gas ratio, liquid inlet pressure and removal efficiency are mentioned in Table 2.

Table 2. Venturi scrubber operating condition.

S.No	Pollutant	Pressure drop (ΔP)	Liquid to gas ration (L/G)	Liquid inlet pressure (P_L)	Removal efficiency
1	Gaseous	13-250 cm of water (5-100 in of water)	2.7-5.3 l/m^3 (20-40 gal/1,000 ft3)	< 7-100 kPa (< 1-15 psig)	30-60 % per venturi, depending on pollutant solubility
2	Particles	50-250 cm of water (50-150 cm of water is common) 20-100 in of water (20-60 in. of water is common)	0.67-1.34 l/m^3 (5-10 gal/1,000 ft3)		90-99 % is typical

3. RESULT AND DISCUSSION

To determine the efficiency of venturi scrubber it was decided to calculate with Johnstone equation. This type of technology is a part of the group of air pollution controls collectively referred to as wet scrubbers. Venturi devices have also been used for over 100 years to measure fluid flow (Venturi tubes derived their name from Giovanni Battista Venturi, an Italian physicist). About 35 years ago, *Johnstone (1949)* [10] and other researchers found that they could effectively use the venturi configuration to remove particles from gas streams. The following operating characteristic of venturi scrubber was mention below.

3. 1. Calculation

Initial Condition

1) Mass-media particle size (physical) *dps* = 9.0 µm
2) Geometric standard deviation σ*gm* = 2.5
3) Particle density pp = 1.9 g/cm^3
4) Gas viscosity µg = 2.0 × 10^{-4} g/cm-sec
5) Gas kinematic viscosity vg = 0.2 cm^2/sec
6) Gas density pg = 1.0 kg/m^3
7) Gas flow rate QG = 15 m^3/sec
8) Gas velocity in Venturi throat vgt = 90[illegible] cm/sec
9) Gas temperature (in Venturi) [illegible] = 80 °C
10) Water temperature Tl = [illegible] °C
11) Liquid density pl = 1000 kg/[illegible]
12) Liquid flow rate Ql = 0.014 m^3/sec
13) Liquid-to-gas ratio L/G = 0.0009 L/m^3

Step 1. *Calculate the Cunningham slip correction factor. The mass median particle size (physical) dps is [illegible] um. Because the particle aerodynamic geometric mean diameter dpg is not known, we must [illegible]*

Equation

dpg = dp[illegible](Cf × pp) to calculate *dpg*, and calculate the Cunningham slip correction factor *Cf*. From Equation:

Cf = 1 + [(6.21 × 10-4)T]/dps

Cf = 1 + [(6.21 × 10-4)T]/dps

= 1 + [(6.21 × 10-4)(273 +80]/9

= 1.024

From Equation:

dpg = dps (Cf × pp)0.5

= 9 µm (1.024 × 1.9 g/cm^3)0.5

= 12.6 µmA

= 12.6 × 10^{-4} cmA

where A[=](g/cm^3)0.5

Note: If the particle diameter is the aerodynamic geometric mean diameter *dpg* and expressed in units of µmA, this step is not required.

Step 2. *Calculate the droplet diameter dd from Equation:*

d_d = 50/V_{gt} + 91.8(L/G)1.5

(Nukiyama and Tanasawa equation):

d_d = 50/v_{gr} + 91.8(L/G)1.5

where

d_d = droplet diameter, centimeters

vgr = gas velocity in the throat, centimeters per second, *L/G* = liquid-to-gas ratio, dimensionless

d_d = 50/(9000 cm/sec) + 91.8(0.009)1.5 = 0.00980 cm

Step 3. *Calculate the initial parameter for the mass-media diameter Kpg,*
By equation

(K pg = (dpg)2vgt/(9µg dd

where

Kpg = initial parameter for mass-median diameter, dimensionless

dpg = particle aerodynamic geometric mean diameter, centimeters

vgt = gas velocity in the throat, centimeters per second

= gas velocity, grams per second centimeter

d_d = droplet diameter, centimeters

K pg = (12.6 × 104 cm)2(9000 cm/sec)/{[9(2.0 × 10^{-4} (g/cm-sec)(0.008 cm)]} =992

Step 4. *Calculate the Reynolds number N_{REO}, using Equation*:

$\mathbf{N_{REO} = v_{gt}\, d_d / v_g}$

Where

N_{REO} = Reynolds number for the liquid droplet at the throat inlet, dimensionless

v_{gt} = gas velocity in the throat, centimeters per second

d_d = droplet diameter, centimeters

v_g = gas kinematic viscosity, square centimeters per second

$N_{REO} = v_{gt}\, d_d / v_g$

= (9000 cm/sec)(0.008 cm)(0.2 cm^2/sec)

= 360

Step 5. *Calculate the drag coefficient for the liquid at throat entrance,*

CD, using

$\mathbf{CD = 0.22 + (24/N_{REO})[1 + 0.15(N_{REO})^{0.6}]}$

where

CD = drag coefficient for the liquid at the throat entrance, dimensionless

N_{REO} = Reynolds number for the liquid droplet at the throat inlet, dimensionless

$CD = 0.22 + (24/N_{REO})\,[1 + 0.15(N_{REO})^{0.6}]$

$= 0.22 + (24/360)[(1 + 0.15(360)^{0.6}] = 0.628$

Step 6. *Now, calculate the parameter characterizing the liquid-to-gas ratio B,*

By using :

$\mathbf{B = (L/G)\sqrt{(p_g C_D)}}$

where

B = parameter characterizing the liquid-to-gas ratio, dimensionless

L/G = liquid-to-gas ratio, dimensionless

pg = gas density, grams per cubic centimeter

pl = liquid density, grams per cubic centimeter

CD = drag coefficient for the liquid at the throat entrance, dimensionless

$B = (L/G)p_l /(p_g C_D)$

$= (0.0009)(1000 \text{ kg/m}^3)/(1.0 \text{ kg/m}^3)(0.628) = 1.43$

Step 7. *The geometric standard deviation σgm is 2.5.*

The overall penetration Pt x is 0.008.

Step 8. *The collection efficiency can be calculated using the equation:*

$\eta = 1 - Pt^*$ $= 1 - 0.008 = 0.992 = 99.2$ %

Step 9. *Determine whether the local regulations for particulate emissions are being met. The required collection efficiency is calculated by using the equation:*

$\eta_{required} = (dust_{in} - dust_{out})/dust_{in}$

$dust_{in}$ = dust concentration leading into the Venturi

$dust_{out}$ = dust concentration leaving the Venturi

$\eta_{required} = (1100 \text{ kg/h} - 10 \text{ kg/h})/1100 \text{ kg/hh} = 0.991$

$\eta_{required} = 99.1$ %

3. 2. Cost estimation

The following are cost ranges for venturi wet scrubbers of conventional design under typical operating conditions, developed using EPA cost estimating spread sheets and referenced to the volumetric flow rate of the waste stream treated. For purposes of calculating the example cost effectiveness, the pollutant is assumed to be PM at an inlet loading of approximately 7 g/sm^3 (3 gr/scf). The costs do not include costs for post-treatment or disposal of used solvent or waste [29]. Actual costs can be substantially higher than in the ranges shown for applications which require expensive materials, solvents, or treatment methods.

A) Capital Cost: $6,700 to $59,000 per sm^3/sec ($3.20 to $28 per scfm)
B) Operating & Maintain Cost: $8,700 to $250,000 per sm^3/sec ($4.10 to $119 per scfm), annually
C) Annualized Cost: $9,700 to $260,000 per sm^3/sec ($4.60 to $123 per scfm), annually
D) Cost Effectiveness: $84 to $2,300 per metric ton ($76 to $2,100 per short ton), annualized cost per ton per year of pollutant controlled.

4. CONCLUSIONS

Venturi scrubbers are primarily used to control particulate matter (PM), including PM less than or equal to 10 micrometers (μ m) in aerodynamic diameter (PM), and PM less than or equal 10 to 2.5 μ m in aerodynamic diameter (PM). Venturi scrubbers PM collection efficiencies range from 70 to greater than 99.9 percent, depending upon the application. Collection efficiencies are generally higher for PM with aerodynamic diameters of

approximately 0.5 to 5 μ m. Some venturi scrubbers are designed with an adjustable throat to control the velocity of the gas stream and the pressure drop. Increasing the venturi scrubber efficiency requires increasing the pressure drop which, in turn, increases the energy consumption. For PM applications, wet scrubbers generate waste in the form of a slurry or wet sludge. This creates the need for both wastewater treatment and solid waste disposal. Initially, the slurry is treated to separate the solid waste from the water. The treated water can then be reused o discharged. Once the water is removed, the remaining waste will be in the form of a solid or sludge. If the solid waste is inert and nontoxic, it can generally be landfilled. Hazardous wastes will have more stringent procedures for disposal. In some cases, the solid waste may have value and can be sold or recycled.

Reference

[1] Azzopardi B.J. and A.H. Govan (1984), 'The modeling of Venturi Scrubbers' Filtration and Separation, Vol. 23, pp. 196-200.

[2] Azzopardi B.J., S.F.C.F. Teixeira, A.H. Govan and T.R. Hunt (1991) 'An improved model for pressure drop in Venturi scrubbers', Transactions of the Institute of Chemical Engineers, B69, pp. 55–64.

[3] Boll R.H. (1973) 'Particle collection and pressure drop in Venturi scrubbers' Industrial & Engineering Chemistry Fundamentals, Vol. 12(1), 40-50.

[4] Calvert S., (1970) 'Venturi and other atomizing scrubbers efficiency and pressure drop', AIChE Journal, Vol. 16, pp. 392-396.

[5] Calvert S., D. Lundgren and D.S. Mehta (1972) 'Venturi scrubber performance' Journal of Air Pollution Control Association, Vol. 22, pp. 529-532.

[6] Charisiou N.D., G. Dsevi[illegible]is, [illegible]Boula (2011) 'Software development for the design of control equipment for particulate pollutants', Proc. Int. Conf. on Environmental Science and Technology VII, pp. A295-A302.

[7] Goncalves J.A.S., D. Fernandez Alonso, M.A. Martins Costa, B.J. Azzopardi and J.R. Coury (2001) 'Evaluation of the models available for the prediction of pressure drop in Venturi scrubbers' Journal of Hazardous Materials, Vol. B81, pp. 123-140.

[8] Goncalves J.A.S., M.A.M. Costa, M.L. Aguiar and J.R. Coury (2004) 'Atomizatin of liquids in a Pease–Anthony Venturi scrubber. Part II. Droplet dispersion' Journal of Hazardous Materials, Vol. 116, pp. 147-157.

[9] Cooper C.D. and F.C. Alley (2004) 'Air pollution control: A design approach' Waveland Press, Inc.

[10] Johnstone H.F., R.B. Feild and M.C. Tassler (1954) 'Gas absorption and aerosol collection in a Venturi atomizer', Industrial and Engineering Chemistry, Vol. 46, pp. 1601-1608.

[11] Miller R.L., D.M. Jain and M.P. Sharma (1990) 'Modeling Venturi scrubber performance for particulate collection and pressure drop' Chemical Engineering Communications, Vol. 89, pp. 101-112.

[12] Nasseh S., A. Mohebbi, Z. Jeirani and A. Sarrafi (2006) 'Predicting pressure drop in Venturi scrubbers with artificial neural networks' Journal of Hazardous Materials, Vol. 143, pp. 144-149.

[13] Pulley R.A. (1997) 'Modeling the performance of Venturi scrubbers' Chemical Engineering Journal, Vol. 67, pp. 9-18.

[14] Rudnick S.N., J.L.M. Koehler, K.P. Martin, D. Leith and Cooper D.W. (2006) 'Particle collection efficiency in a Venturi scrubber: comparison of experiments with theory' Environmental Science and Technology, Vol. 20(3), pp. 237-242.

[15] Silva A.M., J.C.F. Teixeira and S.F.C.F Teixeira (2009) 'Experiments in large s e Venturi scrubber: Part II. Droplet size' Chemical Engineering and Proc ing: Proce Intensification, Vol 48(1), 424-431.

[16] Theodore L. (2008) 'Air pollution control equipment', John Wile & So s Inc.

[17] Wang L.K., W. Lin and Y.T. Hung (2004) 'Catalytic o dati in: Ha book of Environmental Engineering, Volume 1: Air Pollution C ntrol Eng ering, ed. L.K. Wang, N.C. Pereira and Y.T. Hung, Humana Press Inc To a, NJ, US , pp. 369-394.

[18] Yung S.C., H.F. Barbarika and S. Calvert (2007) ressure l in Venturi scrubbers' Journal of the Air Pollution Control Association, Vol. 27, pp. 348 51.

[19] Yung S.C., S. Calvert and H.F. Barbarika 2008) 'Ven uri Scrubber Performance Model' Environmental Science and Technolog Vol. 12(4), pp. 456-459.

(Received 15 Ja ry 2014; cepted 21 January 2014)