Effect of Scrubbing Liquid height on the performance of Self Priming Venturi Scrubber

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Abstract. The Containment Filtered Venting System (CFVS) is used to scrub the Particle matter & gaseous pollutants that are liberated during the severe accidents in nuclear power plants (NPP). This research work aims to an experimental study of the fluid dynamics of gas-liquid interaction of the circular cross-sectional self- priming VS at different experimental inputs. The performance of self-priming VS is indicated by the Pressure drop, Liquid to gas ratio & Collection efficiency. The effect of Scrubbing liquid height on these performance indicators is studied at different gas flow rates. The experimental result shows that the scrubbing liquid height greatly influences the performance of self-priming VS. It improves the Liquid to Gas ratio which is helpful to improve the collection efficiency.

1 Introduction

Post-Fukushima-Daiichi accident updating of passive safety devices was suggested as an urgent need to avoid the release of radioactive pollutants to the environment. By considering this updation the Filtered Containment Venting System (FCVS) used to remove the radioactive gaseous pollutants & PM from the gas flow which coming out from the NPP containment. The venturi scrubber is the main important part of FCVS system. It consists of three main segments as shown in fig. 1: convergent part due to its decreasing cross-section gas stream with particles passing through it gets accelerated & the velocity of the gas increases and pressure gets reduced. After that inside the throat, part gas achieves high velocity where the scrubbing liquid is get entrained inside the throat through orifices and due high gas velocity at this section the entrained scrubbing liquid gets atomized into small droplets.

The particle or gaseous pollutants get interact with these smaller droplets and due to the inertial impaction mechanism, the particles get stick to these droplets and get scrubbed[1]. And the divergent part where the increasing cross-section recovers the pressure of gas stream and reduces the high gas velocities. Due to a small cross-sectional area at the throat gas velocity increases and the pressure gets reduced heavily. Thus the pressure drop in the throat and the scrubbing liquid head outside of the throat cause the self-priming action of liquid at the throat through the orifices.

The study of the self-priming operation of venturi scrubber done previously by M. Lehner[2], Ali, et al.[3], Naoki HORIGUCHI et.al.[4] & Paridhi Goel et.al [5]. The conclusions showed that the rise in gas flow rate reduces the entrainment of scrubbing liquid inside the throat at constant scrubbing liquid height inside the tank.

It was also reported that the increase in scrubbing liquid height increase the liquid entrainment at the throat at a constant gas flow rate.

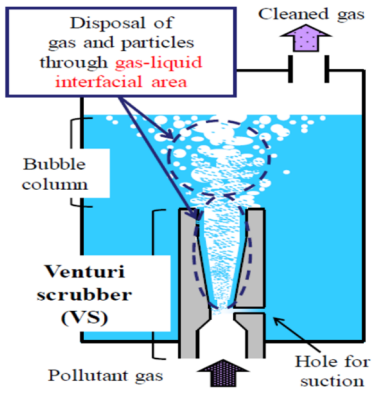

Fig. 1. Self Priming Venturi Scrubber[4]

The pressure drop across VS and collection efficiency are the important performance parameters of Self-priming venturi scrubber[6]. Also, the liquid to gas ratio (L/G ratio) is also reported as the factor which affects the collection efficiency[7]. Hence all these parameters get largely influenced by scrubbing liquid height. The present research work reports the analysis of the pressure drop across the self-priming venturi scrubber, L/G ratio & collection efficiency are the functions of the liquid height of scrubbing liquid inside the tank.

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2 Experimental Setup

All the experimental readings were taken on the circular venturi scrubber as shown in fig. 2 which was submerged inside the square cross-section scrubber tank of dimensions (300X300X1600mm). The scrubber tank was filled at three different liquid heights of 300mm, 550mm & 800mm. The compressed air at three different pressure i.e. 2 bar, 3bar, 4bar introduced at the inlet of the self-priming VS.

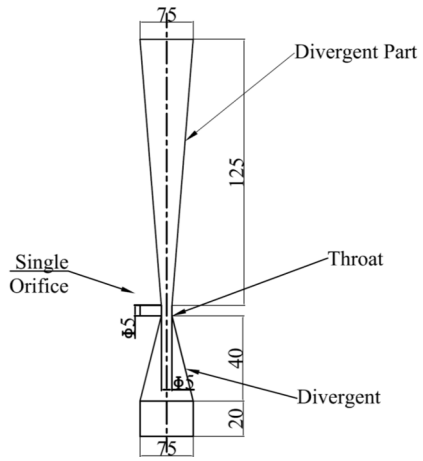

Fig. 2. Dimensions of Self-Priming VS

The fly ash of particle size (0.5 to 100 micron) as pollutants introduced in the compressed air stream before the inlet of venturi scrubber. For the measurement of pressure drop across venturi scrubber the use of pressure measuring devices has been done. To measure the airflow rate the Airflow rotameter was used to measure the airflow rate; also flow control valve provided for changing the flow rate of air. The measurement of the L/G ratio incorporated by using the secondary tank. Where the throat orifice hole was connected with the secondary tank and during measurement secondary and primary tank liquid heights kept at the same level. Other components of the setup are as shown in fig. 3

3 Results and Discussions

In this work, the effect of scrubbing liquid height above the throat on the pressure drop, L/G ratio & collection efficiency has been analyzed.

3.1 Effect of scrubbing liquid height on the pressure drop

The drop of pressure across the venturi scrubber has been calculated by differencing the pressure at the inlet of the convergent section and pressure at the outlet of the divergent section of venturi scrubber. The readings were taken at different liquid heights at 6 different pressure inlet conditions i.e. from 1 to 6 bar. Wherein pressure measurement at the outlet of VS calculated as follows: Pressure at the outlet of venturi = Atmospheric Pressure + Liquid Pressure head

Table 1. Pressure drop across venturi scrubber at different liquid heights

Pressure at Inlet	Pressure Drop in a bar at the different liquid height		
	300mm	**550mm**	**800mm**
2	0.75732	0.7328	0.70827
3	1.65732	1.6328	1.60827
4	2.65732	2.6328	2.60827
5	3.65732	3.6328	3.60827
6	4.55732	4.5328	4.50827

Table 1. Reveals that the increase in scrubbing liquid height decreases the Drop of pressure across the venturi scrubber.

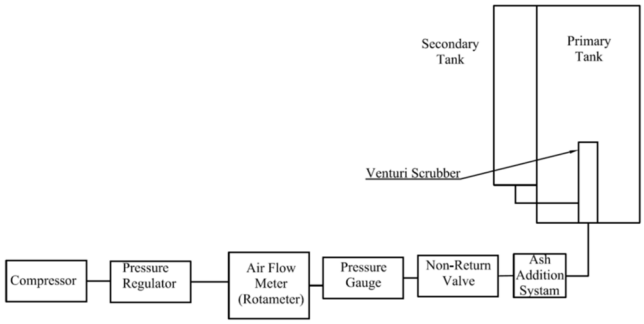

Fig. 3. Experimental Setup

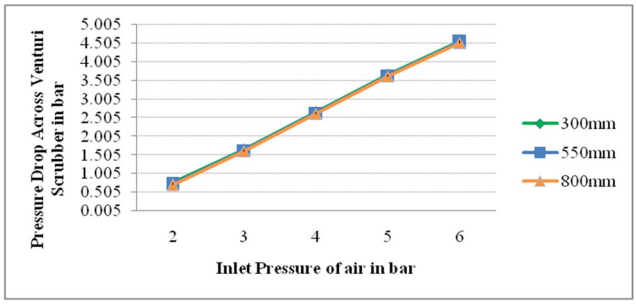

Fig. 4. Graph of Inlet Pressure vs Pressure drop at different scrubbing liquid heights

The fig. 4 shows that an increase in the inlet pressure to the venturi scrubber causes the increase in pressure drop across VS. This is caused due to the increase in throat velocity at the expense of pressure of air and the divergent section was unable to recover that loss of pressure at the end of venturi scrubber. Also, the pressure drop was slightly affected by the scrubbing liquid height it is found that pressure drop decreases with an increase in scrubbing liquid height.

3.2 Effect of scrubbing liquid height on Liquid to Gas ratio (L/G Ratio)

As described by M. Lehner[2] the venturi scrubber having two different types based on the scrubbing liquid supplied at the throat through orifice: forced feed injection, and self-priming VS. In the case of the force-feed injection method, the scrubbing liquid is injected through the orifice external source i.e. pumps, so that the liquid flow rate is not dependent on the gas flow rate. Whereas, in the case of self-priming venturi scrubber, the rate of scrubbing liquid flow rate is totally dependent on the gas flow rate because the liquid entrainment at the throat is totally dependent on the pressure drop at the throat section.

The liquid flow rate at the throat part is measured at different gas flow rates by using those readings the Liquid to gas ratio in kg/kg found out at different inlet pressure 2bar, 3bar, 4bar. Figure 5, 6,&7 depicts that with the increase in the gas flow rate at constant liquid height decreases liquid flow rate and due to this L/G ratio also decreased. But the increase in the liquid height of the tank at constant gas flow rate causes an increase in liquid flow rate which is, in turn, increase the L/G ratio. At high gas flow rates at the throat, the dynamic pressure of gas increases and this reduces the entrainment of liquid inside the throat through the orifice. But as the scrubbing liquid height increases, it increases the hydrostatic head required for suction of liquid at the throat and more amount of liquid gets sucked inside the throat.

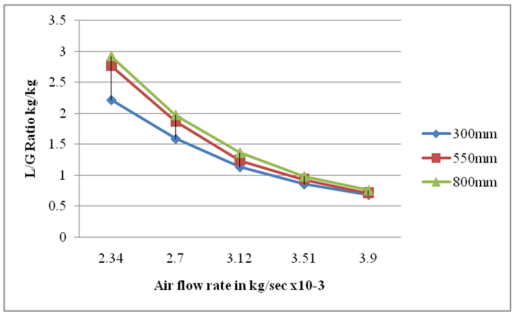

Fig. 5. Effect of airflow rate on the L/G ratio at different liquid heights at 2 bar

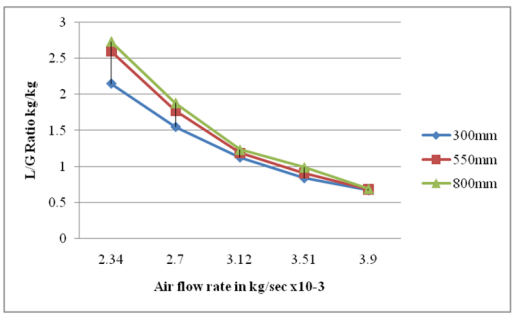

Fig. 6. Effect of airflow rate on the L/G ratio at different liquid heights at 3 bar

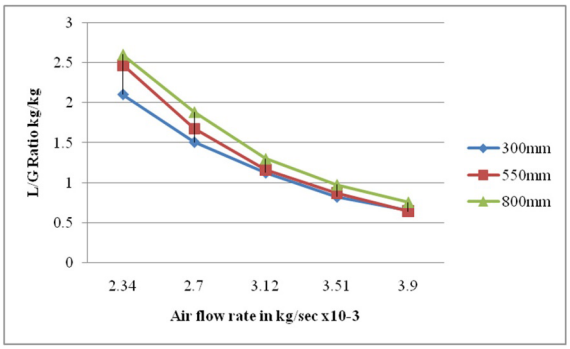

Fig. 7. Effect of airflow rate on the L/G ratio at different liquid heights at 4 bar

Table 2. Results of L/G ratio at different experimental conditions

Head of Water Level	Pressure in bar	Airflow rate in kg/sec X 10^{-3}				
		2.34	2.7	3.12	3.51	3.9
		L/G Ratio kg/kg				
30	2	2.218	1.59	1.133	0.855	0.684
	3	2.148	1.548	1.125	0.839	0.672
	4	2.103	1.507	1.125	0.824	0.654
55	2	2.772	1.87	1.242	0.933	0.712
	3	2.603	1.77	1.184	0.905	0.679
	4	2.475	1.675	1.161	0.867	0.641
80	2	2.925	1.973	1.364	0.983	0.758
	3	2.733	1.88	1.23	0.985	0.688
	4	2.602	1.883	1.299	0.974	0.755

Table No. 2 shows that the L/G ratio is gets affected by the inlet pressure of the gas. As the pressure at the inlet of venturi scrubber increases, it lowers the entrainment of liquid at the throat due to the increase in the throat pressure. Hence the decrease in entrainment reduces the L/G ratio.

3.3 Effect of Scrubbing liquid height on Collection efficiency

Paridhi et.al [5] studied the effect of scrubbing liquid height on the collection efficiency of the self-priming VS and found that as the scrubbing liquid height increases the collection efficiency also increases.

In the present work, the measured quantity of 100mg fly ash particles is introduced at the start of the venturi scrubber in the air stream. During the scrubbing process, this fly ash particle flows with airstream at the throat part of the venturi scrubber. Due to the low pressure at the throat part scrubbing liquid gets entrained inside the throat through an orifice. This entrained liquid gets atomized into tiny droplets due to the high velocity of the gas stream which breaks the liquid. These droplets

provide the area for capturing the fly ash particles by the inertial impaction mechanism and scrub the pollutants from the air stream. After leaving the end of the venturi scrubber the air stream passes through the scrubbing liquid column in the form of bubbles and gets interacted with the scrubbing liquid in it. If the height of the liquid in the tank is maximum the interaction time for fly ash particle and scrubbing liquid increases and retention of fly ash in the scrubbing liquid increase. Then this retained fly ash gets settled at the bottom of the tank and the mass of it is measured for calculation of collection efficiency, hence higher collection efficiency is expected when higher scrubbing liquid height is used.

Table 3. Results of collection efficiency at different scrubbing liquid heights at the gas flow rate of 0.00234kg/sec

Water Head (mm) H	Fly ash Particles introduced (gm) M1	Fly ash Particles Collected (gm) M2	% Efficiency (M2/M1)*100
300	100	95.02	95.02
550	100	96.89	96.89
800	100	97.71	97.71

Table No. 3 shows that the increase in the height of scrubbing liquid inside the tank increases the collection efficiency at a constant gas flow rate of 0.00234kg/sec.

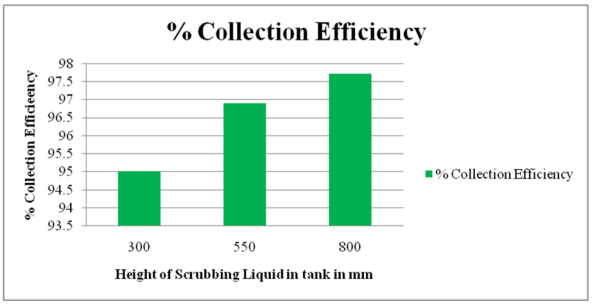

Fig. 8. Effect of Scrubbing liquid heights on the collection efficiency at 0.00243kg/sec gas flow rate

4 Conclusion

In this research experimental study of the effect of scrubbing liquid height in the tank on the pressure drop, L/G ratio and collection efficiency in self-priming venturi scrubber studied. The following conclusions are made from the present work;

1. The pressure drop across VS is slightly affected by the scrubbing liquid height, as it increases the pressure drop across venturi gets slightly reduced.
2. The liquid to gas ratio gets increased with increasing liquid height but gets reduced with increasing gas flow rate.
3. The collection efficiency of self-priming venturi scrubber is getting improved with increasing scrubbing liquid height in the tank.
4. It is also observed that the liquid entrainment at the throat is get reduced with increasing gas flow rate, thus it proves that the self-priming venturi scrubber works in a self-regulating way.

References

1. R. H. Boll, Ind. Eng. Chem. Fundam., **12**, 40, (1973)
2. M. Lehner, Aerosol Sci. Technol., **28**, 389, (1998)
3. M. Ali, Y. A. N. Changqi, S. U. N. Zhongning, G. U. Haifeng, and W. Junlong, Nucl. Eng. Technol., **45**, 203–210, (2013)
4. N. HORIGUCHI, H. YOSHIDA, A. KANEKO, and Y. ABE, Mech. Eng. J., **1**, TEP0026, (2014)
5. P. Goel, A. Moharana, and A. K. Nayak, Nucl. Eng. Des., **327**, 92, (2018)
6. Guerra, J. R. Coury, R. Be, and J. A. S. Gonc, Ind. Eng. Chem. Res., **51**, 8049, (2012)
7. V. Sekar, A. W. Gnyp, and C. C. S. Pierre, Ind. Eng. Chem. Fundam., **23**, 303, (1984)