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Performance of co-current horizontal liquid jet ejector scrubber for fly ash removal

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Abstract

Numerous conventional and novel technologies have been developed for the control of air contaminants, but the selection of suitable air control equipment is indeed an ever-important aspect. Among the several conventional control techniques, wet scrubbing is an efficient and versatile one. This technique can be applied to the cleaning of air streams containing a wide range of contaminants, whether solids or gases.

In the present investigation, an attempt has been made to evaluate the performance of a horizontal co-current type liquid jet ejector scrubber for the abatement of utility fly ash particles.

Experiments were conducted to determine the optimum operating conditions of the experimental set-up. Subsequently, employing the optimized conditions, the performance of the system for scrubbing of fly ash was evaluated. An overall removal efficiency of 99% could be attained at a scrubbing liquid flow rate of 900 lph, when the dust-laden gas flow rate was 1.21 m^3 /hr. However, a fractional removal efficiency of 98.4% was obtained for fly ash particles of size down to 2.72 mm under the same operating conditions.

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1 Introduction

Fly ash problem is essentially triggered off by burning of any fuel containing ash. Since day by day the global energy usage is progressively accelerated, more and more thermal power plants are in existence. As a consequence, fly ash problem also is intensifying. Though several conventional equipments such as ESP, Fabric Filter, etc are in use to combat the fly ash menace, wet scrubbing devices too are in competition owing to their advantages to remove gaseous emission also. As such, this device is nowadays envisaged as a control system for such industrial applications as thermal power sector among others. The ejector scrubber is a device which utilizes the velocity action of a contacting fluid to pump, scrub, and/or absorb the entrained gas. The extreme turbulence created by the high velocity of liquid jet provides an intimate contact between the two phases. The spray nozzle imparts a combination of axial and tangential velocities to the liquid jet stream. The angle of the spray and the size of the orifice are arranged in order to

i) impart sufficient tangential velocity to form a spray cone which fills in the ventury throat area,
ii) break up the motive fluid to proper drop sizes to permit efficient scrubbing or absorption of the liquid drop from the discharge gas, and
iii) impart sufficient axial and tangential velocities to obtain the desired pumping characteristics.

Harris and Haun[4] found that ejector scrubber was able to remove 98% of HCl from the air stream. Liquid jet ejectors (Biswas[2], Brady and Ligatsky[3]), where the energy of the liquid jet itself was utilized to aspirate and disperse the gas phase, are preferable from the standpoint of removal performance of gaseous emission, but may not be so attractive under the present circumstances aiming at particulate scrubbing due to high gas-side pressure drop.

Banerjee[1] has been able to achieve a very good removal of SO_2 gas from a wastegas stream using horizontal co-current flow of water or Sodium Hydroxide solution. In this study, more than 98% SO_2 scrubbing was obtained from lean gas mixture with water, whereas 99% SO_2 removal was achieved from a rich gas-SO_2 mixture using aqueous NaOH medium.

The present investigation was undertaken to examine the performance of a horizontal co-current liquid jet ejector scrubber for the removal of fly ash particles collected from a nearby (Kolaghat Thermal Power Plant, West Bengal, India) thermal power plant.

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2 Experimental programme

The schematic diagram of the experimental set-up is demonstrated in Fig.1. It consists of ejector assembly, extended parallel contactor, air-liquid separator, and other accessories (not shown in Fig.1) such as centrifugal pump, control valves, liquid storage tanks, etc. For making a visual observation of gas-liquid contact, the ejector assembly was made of perspex and the extended contactor of pyrex glass tubes.

A straight-hole nozzle was used in this investigation. This was machined as accurately as possible to avoid shock and other losses. The necessary motive fluid was tap water for both hydrodynamic study and scrubbing of fly ash particles. The secondary fluid was air for hydro-dynamic study, and fly ash-laden air for scrubbing.

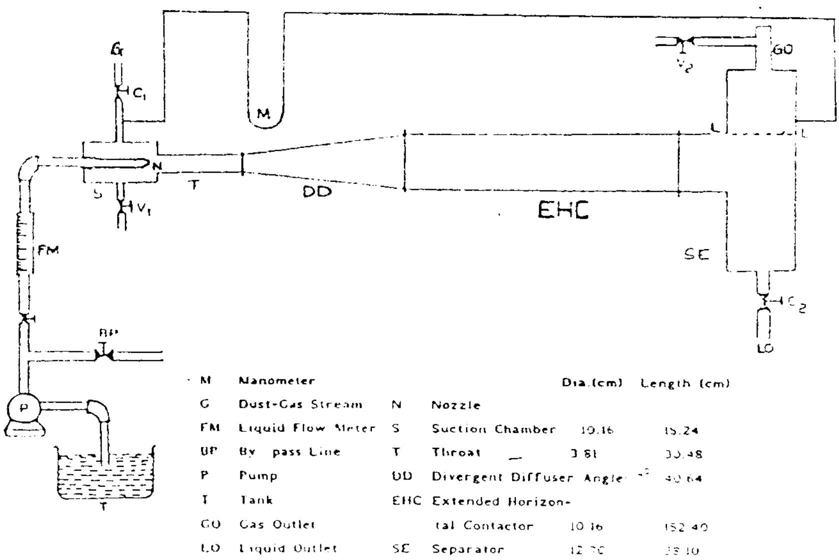

Figure 1: Experimental set-up for scrubbing of fly ash

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2.1 Dust generator

It has been found that the most important requirement in testing dedusting equipment is to ensure adequate disposal of test material in the air fed to the apparatus under test. The most satisfactory method of ensuring this is by the compressed air injector into which the fly ash was fed. The equipment worked under suction. The testing device is demonstrated in Fig.2 wherein the test material was poured into the feeder from the top and it was sealed with a cork firmly. The compressed air was then allowed to flow through the air line. Due to the suction developed at the bottom section, the compressed air sucked the fly ash particles and carried the same to the inlet of the ejector in uniform concentration.

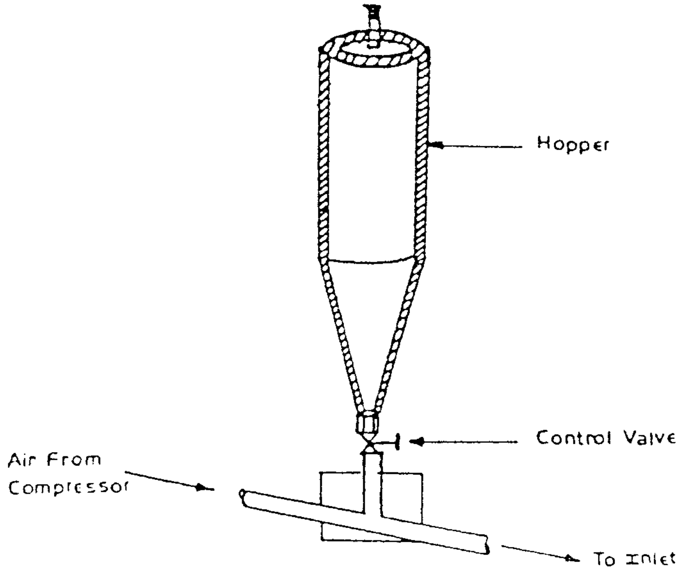

Figure 2: Dust generator

2.2 Particle sampling and analysis

In the collection device shown in Fig.3, Whatman filter paper (no.42) was placed, through which the fly ash particles were collected for a specified duration. Then, it was disconnected from the gas stream and the particles

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feeding line was refitted to the ejector. Again, the particle collection assembly was connected at the outlet end of the ejector with a fresh filter paper (Whatman no.42) through which the particle sample was deposited for the same period of time as was done for inlet collection. In both the collections, the weight differences were estimated which on division by the gas volume so collected gave the concentrations at the inlet and outlet as well. In order to calculate the overall collection efficiency at various gas and liquid flow rates, the respective available concentrations were used.

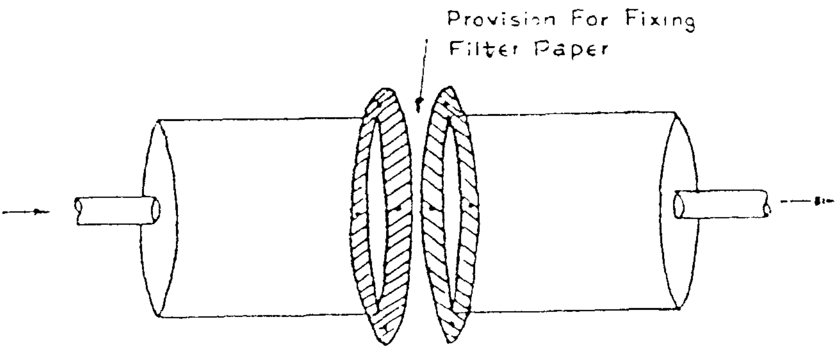

Figure 3: Particle collection device

The samples collected in the collection device were preserved and used for particle size distribution analysis. Amongst various methods for the analysis of particle size such as sedimentation, sieving, microscopy, photography, laser shadowgraphy, holography, and dust scattering, the laser shadowgraphy particle size analyzer was used for fly ash size distribution analysis. The fractional efficiencies were estimated based on the results provided by the analyzer for the samples collected in the inlet as well as the outlet regions. The particles were divided into five ranges as 188 - >49.8 μm, 49.8 - >20.5 μm, 20.5 - >9.81 μm, 9.81 - >5.4 μm, and <5.43 μm. The cumulative amount (in percentages) of particles in band was found for each range. To express the outlet amount as the percentage of the inlet, the outlet percentages are multiplied with (100-h)/100, where h is the overall efficiency for that particular run. Now the fractional efficiencies of removal for each size range under different liquid and gas flow rates are calculated as shown in a sample Table 1.

Table 1: Fractional collection efficiency of fly-ash in different size ranges

Liquid flow rate = 900 litres/hr; Gas flow rate = 1210 litres/hr
Overall collection efficiency (η) = 99%

Particle size (μm) (1)	Avg. size (μm) (2)	Inlet (%) (3)	Outlet (%) (4)	Outlet as (%) of inlet (5)=(4) x η	Fractional Effy. (%) (6)
188- >49.8	118.90	10.9	---	------	100.00
49.8- >20.5	35.15	22.2	10.5	0.11	99.50
20.5- >9.81	15.15	25.3	30.4	0.30	98.81
9.81- >5.43	7.25	19.8	24.9	0.25	98.73
< 5.43	2.72	21.8	34.2	0.34	98.44
		100	100	1.00	

3 Results and Discussions

Two steps are involved in this part. In step one, the parametric optimization of the experimental set-up (Fig.1) was conducted and in step two, the scrubbing of fly ash was effected in the ejector under the optimized operating conditions attained in step one.

The calibration of the system was required to know the rate at which the dust-laden gas flowed through the ejector. The compressed air, without fly ash particles, was passed through the system by keeping the valve 'C_1' closed and the valve 'V_1' open. At this stage, there was no scrubbing liquid flow. The gas flow rates were obtained by a wet gas meter attached to the end of the ejector assembly at a particular pressure drop. The same procedure was repeated for different pressure drops to generate a calibration curve which was later used for estimating the flows at different experimental runs. In the parametric optimization step, the experiments were carried out to determine the total driving force obtainable for secondary flow or the total suction created at the expense of the jet energy. This was done with the liquid jet formed by forcing the liquid through the nozzle at desired flow rates, keeping the valves 'C_1' and 'V_1' closed and the valves 'C_2' and 'V_2' open. With a view to achieving the proper utilization of the jet energy for creating suction, the valve 'C_2' was gradually throttled and the liquid was allowed to build up in the separator. When the liquid level in the separator reached L-L position, the horizontal contactor was completely filled with the liquid and the jet was absolutely musked loosing its identity on emerging from the nozzle. Under this condition, the suction created was found to be maximum. Any further attempt to increase the suction by changing the liquid level in the separator from L-L, resulted in the flooding of the suction chamber or complete flow separation. The maximum suction obtained was found to be 2.0 cm of Hg. at the liquid flow rate of 900 lph.

The total suction (P_{st}) was utilized for achieving secondary flow rate to a varying degree. When the vacuum in the suction chamber was changed from P_{st} to P_s by partially opening the valve, 'V_1', the secondary flow rate changed from 0 to Q_s. The visible observation showed that the gas mixed with the liquid jet at the beginning of the parallel throat and dispersed into fine bubbles. The bubble flow moved forward through the parallel diffuser, divergent tail piece, horizontal contactor, and eventually got separated at the separator.

Five cases of inception of bubbling zones (IBZ) were considered, in which the first one was inception of bubbling at the suction chamber with no secondary flow (l_1), second one from the constant area throat to the separator (l_2), third one from `EHC' to the separator ($l_3$), fourth one was from 50 cm away from the start of the `EHC' to the separator (l_4), and the last one from 100 cm away from the start of the `EHC' to the separator (l_5). It was found that with the increase in utilization of the total suction there was a progressive increase in the secondary flow rate up to a point, beyond which any further attempt to increase resulted in the flow separation and conversion of bubble flow to axial flow. At this stage, the secondary flow was negligible. The results on the measurements of the total suction (P_{st}) at various `IBZ' are presented in Table - 2. The velocity of the liquid jet delivered off the nozzle is directly proportional to the flow rate through the nozzle and inversely proportional to the square of the nozzle diameter.

Table 2: Suction pressure drops (in cm of Hg) in various bubbling zones

Bubbling zone	Liquid flow rate (litres per hour)				
	200	400	600	800	900
l_1	0.7	1.0	1.5	1.7	2.0
l_2	0.5	0.8	1.1	1.3	1.6
l_3	---	---	---	0.3	0.8
l_4	---	---	---	0.2	0.4
l_5	---	---	---	0.1	0.2

It was found that in the bubbling zone l_2, the optimum suction pressure was obtained and at the same time the system produced very fine bubbles which offered turbulent mixing resulting in better air-to-liquid contact with no flow separation. Other bubbling zones, viz l_3, l_4 , and l_5 yielded very less pressure drops which means that the flow separation has taken place, ie the bubble flow has turned to co-axial flow. The optimized conditions, from the hydro-dynamic study using 0.45 cm diam. nozzle were:
a) motive fluid flow rate: 900 lph,
b) inception of bubbling zone at l_2 condition.

3.1 Scrubbing of fly ash

The optimization of the experimental set-up revealed that a maximum pressure drop of 2.0 cm of Hg occurred at a scrubbing liquid flow rate of 900 lph. But, the experiments were carried out with liquid flow rates varying from 200 lph to 900 lph. At a particular liquid flow rate, the dust-laden air was passed through the ejector at different flow rates such as 1.10, 1.14, 1.17, and 1.21 m^3/hr. The overall collection efficiencies were calculated at different gas flow rates for a specific liquid flow rate. These family of curves for different liquid flow rates. are shown in Fig. 4. It may be noted from Fig.4 that the overall collection efficiency improves with the increase in liquid flow rate at a given gas flow rate. The overall efficiency also increases with the increase in gas flow rate at a given liquid flow rate; but the amount of increase in the latter case is lesser than the same in the former case. The maximum overall collection efficiency of 99% was obtained at a gas flow rate of 1.21 m^3/hr and a liquid scrubbing flow rate of 900 lph.

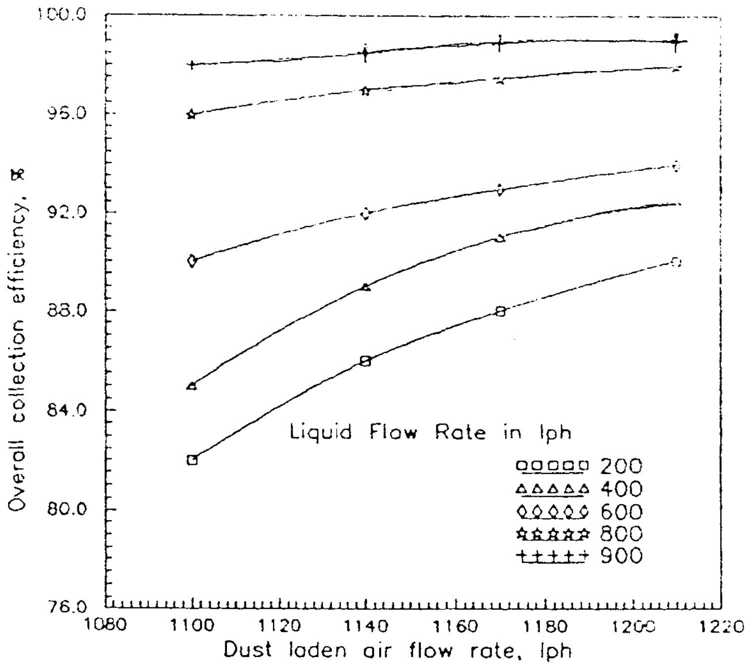

Figure 4: Overall collection efficiency curve W.R.T. dust laden gas flow rate

The fractional efficiencies were calculated as explained earlier. These fractional or grade efficiencies are useful to predict the percentage removal of particles in each size range. The grade efficiency values are shown in Table - 1 for liquid flow rates of 900 lph and for a specified gas flow rate of 1210 lph. Data are also available for the efficiency curves at different gas and liquid flow rates. The maximum removal of fine particles (2.72 μm diam. avg.) was found to be 98.44% when the gas flow rate was 1.21 m^3/hr and liquid flow scrubbing rate of 900 lph.

4 Conclusion

The results presented show that fly ash particles can be efficiently scrubbed in a horizontal co-current type liquid jet ejector scrubber. It is also found that for the same pressure drop, the ejector efficiency improves with the quantity of scrubbing liquid (water). It is noted that in a liquid jet ejector scrubbing assembly, the removal efficiency depends much more upon the scrubbing liquid flow rate rather than the gas flow rate.

5 References

1. Banerjee, G. Abatement of SO_2 from waste gas stream using horizontal co-current flow, *Journal IAEM*, **23(1)**, pp.38-44, 1996.
2. Biswas, M.N. *Studies on gas dispersion in liquid in horizontal co-current flow*. Ph.D Thesis, IIT, Kharagpur, India, 1975.
3. Brady, J. D. & Legatsky, L.K. Ventury scrubber, *Air Pollution Control and Design Handbook*, Part 2, P.W. Cheriminisoff and R.A. Young, Marcel Dekker, New York, 1977.
4. Harris, L.S. Haunman, G.R. The ejector ventury scrubber, *J. Chem. Engg. Prog.*, **60**, 1964.