iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** V **Month of publication:** May 2017

DOI:

www.ijraset.com Volume 5 Issue V, May 2017
IC Value: 45.98 ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

A Review on Studies on Electrostatic Scrubbers for Sub-Micron Particle Removal

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***Abstract:** Presence of particulate and gaseous contaminants like, respirable dust, SO_x , NO_x , smoke gases etc. in the atmosphere is harmful to human beings, animals, plants and property. The current review summarizes the studies and research carried out to know the different types of air pollution control devices to control particulate matter or gaseous pollutant from environment.*
***Keywords:** Larger particulates (>5 microns) smaller particulates (<5 µ),. ELECTROSTATIC PRECIPATIOR (ESP), ELECTROSTATIC SCRUBBERS (ESS)*

I. INTRODUCTION

Many industrial processes result in emission of flue gases containing particulate matter. Usually particulate matters from these emissions are removed by the use of scrubbers, electrostatic precipitators, mechanical separators and bag Usually a pollution control device can remove either particulate matter or gaseous pollutant efficiently but not the both. Scrubbers on the other hand can be used to remove both gaseous and particulate pollutants equally efficiently.

A. Studies On Electrostatic Scrubbing George And Poehlein (1974) presented a mathematical model for the collection of aerosol particles smaller than 10µm. It considered inertial, viscous, gravity, and electrostatic forces and interception phenomena. The collection efficiency according to the author can be improved by the presence of electrostatic charges on the particles. The mathematical model was solved using Runge-Kutta type integration algorithm. But, the results were left for experimental verification.

B. *Pilat et al. (1974)* showed experimentally in a double chamber electrostatic droplet spray scrubber, the collection of small aerosol particles (0.05 to 5µ diameter range) by water droplets with higher efficiencies by electrostatic charging of the droplets and the particles to opposite polarity. The collection efficiency for 0.3µ particles was increased from 68.8% to 93.6%

C. *James et al. (1977)* provided overview of the relative merits of air pollution control devices.

D. *United States patent (1978)* Small highly charged droplets are produced without concurrent production of corona. If the droplets are to be electrically pulled away from the nozzle tip without corona, then the field must be substantially uniform over the tip surface, and the field must be large at the tip surface, there must be substantial field enhancement at the tip surface, but not so large so as to create corona discharge. Selected gas, solid particulates are removed by means of a unique electrostatic collector using the highly charged droplets. These droplets are caused to drift, by means of an electric field, through the gaseous effluent to a collecting electrode absorbing selected gases and aerosol particles and causing them to a collecting electrode.

E. *Sumiyoshitani et al. (1984)* showed experimentally the collection process for dust particles by charged water droplet using three kinds of particles with different wettability. The particles with good wettability were captured inside the water droplet, particles with poor wettability floated at regular intervals, whereas particles with medium wettiability were trapped on or inside the water droplet. The dust collection were observed using a stereo microscope and recorded using a still camera.

F. *Wang et al. (1986)* developed a theoretical model to predict collision efficiency of an accelerating droplet under the combined effect of inertial impaction and electrostatic attraction for an accelerating collector as a function of downstream distance. The calculated efficiencies were reported as a function of the distance traversed by the droplet. There was an increase in collection efficiency with increasing downstream distance. This model was verified by measuring the total particle mass collected by an accelerating droplet.

G. *Price et al. (1988)* presented briefly various electrostatic elements such as conductors, dielectrics, ferroelectrics, image forces, dielectrophoretic forces, etc. for better understanding and modeling of the electrostatic systems.

H. *Kraemer and John stone (1995)* gave a general theoretical solution and experimental verification for the deposition of aerosol particles from a moving stream onto stationary spherical surfaces and an introductory study of the deposition on

Volume 5 Issue V, May 2017
ISSN: 2321-9653

cylinders. On the basis of the study two new types of dust collection equipment (electrified filter mat and an electrified wet scrubber). It was experimentally shown that low relative velocities between the aerosol and collecting surfaces leads to an increased collection efficiency.

I. *Jaworek et al. (1996)* presented a paper using numerical model determined the trajectories of spherical submicron particles in the vicinity of a single charged spherical collector and there collection efficiency through simulation studies. The Results of the simulation showed that the process was controlled by a few parameters only: the Stokes, Coulomb, gravitational and inertial force. They also showed that electric forces significantly improve collection efficiency. For larger Stokes number the particle inertia became the most crucial factor.

J. *Adamaik et al. (1997)* developed a numerical model for determining the trajectories of spherical aerosol particles in the vicinity of a charged spherical collector. The Coulomb, image, Stokes and gravitational forces acting on the particle and the collector were considered in the equations of motion. The Flow field was determined by numerical simulation of the Navier-Stokes equations using stream function and vorticity. In study showed that image forces are only effective for short distances. For small Reynolds and Stokes numbers that is for low relative velocities only the electrostatic forces are dominant.

K. *Jaworek et al. (1998)* in paper presented numerical algorithm for simulation of the trajectories of changed dust particles moving horizontally in vicinity of a freely falling oppositely changed liquid space relative to the liquid droplet. Air drag, electrical and gravitational forces were considered. The trajectories were determined from the different air flow was determined using stream function. The solution for stream function was calculated using seen linearized equation.

L. *Hoferer and Schwab (2000)* showed experimentally correlation between the quality of dust layer and the occurrence of back corona at the collecting electrodes of electrostatic precipitators at a laboratory scale. The current intensity was formed increasing in the local areas of both low resistive and high resistive dust layers where back corona appeared. Due to low atmospheric temperature and low dew point, no back corona occurs in the low resistive dust layer**.** High resistive dust with high electric field was found responsible for the occurrence of back corona that decreases the collection efficiency of The ESP.

M. *Adamaik et al. (2001)* provided a numerical algorithm for simulating the deposition process in wet scrubbing. They implemented a mathematical model in which the trajectories of particles and droplet were simultaneously traced by solving Newton equation, taking into account inertial, air drag, gravitational and electrostatic forces. The Results of the simulation showed that the process was controlled by a few parameters only: the Stokes, Coulomb, and Reynolds numbers. They showed that for small Stokes number and zero Coulomb number air drag practically controls the particle movement and the deposition efficiency is minimal.

N. Jaworek *et al.* (2001) compared the experimental results of the aerosol particle trajectories approaching a spherical collector with the results of a numerical simulation model. Approximate equations of the flow field around the collector were described for a fixed collector. Image forces were found negligible when compared to the large Coulomb force. The trajectories determined numerically were in agreement with the experimental results.

O. *Jaworek et al. (2005)* showed experimentally that a multi nozzle electro spray system can be used as a developed as a charged droplets source for cleaning a gas contaminated with the particles. The droplets here are generated by electro hydrodynamic method, which is more effective than mechanical atomizer with induction electrodes in particle charging. Electro hydrodynamic spraying produces droplets in the size range of 50 to 100 um in diameter. In the experiment, the spray of droplets of size lower than 100 um, were charged either positively or negatively. Cigarette smoke was used as a source of sub-micrometer particles. Variations of smoke particles concentration within the chamber were determined at different time intervals of spraying water. It was demonstrated that the charging of droplets and smoke particles allowed an increase of particle removal efficiency. Water consumption was decreased to 1/3rd.

P. *Jaworek et al.(2006)* The principles of electrostatics were discovered by Coulomb (1785) and first successfully applied to the control of particulate air pollutant emissions by Cottrell (1908) whose research results gave rise to the large-scale utilization of dry electrostatic precipitators as industrial gas cleaning devices. Research in the mid 1950's led to the development of wet electrostatic precipitators which used water to wash the particle collection electrodes. The wet electrostatic precipitators still have the same general configuration as dry precipitators with an additional feature of water-cleaned plates. Electrostatic space charged scrubbers' involving water droplets and aerosol particles with some charge was suggested by Hanson and Wilkes (1969). In these the dust was collected onto the scrubber walls when the droplet and the dust were charged to the same polarity and onto the collector droplets when they were charged with opposite polarity.

Q. *Jaworek et al. (2007)* reviewed the current trends in the field of electrostatic devices and methods to remove sub-micron particles from gases. In this paper, the methods like gas conditioning and intermittent energization to improve the collection efficiency of conventional ESP were briefly explained. In the second part modifications to the collection electrodes in ESPs as well as methods for improving non electrostatic devices, such as, fibrous or granular filters by imposing an electric field were explained.

R. *Michael R. Beltran (2008)* Conventional scrubbing system (wet or dry) is generally not effective in controlling sub-micron emissions, consisting primarily of acid gas mists, condensed heavy metals and condensed organics. Wet tubular electrostatic precipitators, because of their ability to generate strong electric fields in a wet cooled atmosphere; have been shown effective in polishing the flue gas. Beltran technologies have developed a unique wet tubular precipitator. It is a vertical flow, hexagonal and rectangular tube type precipitator. The flue gases enter at the bottom and rise through the precipitator. There are generally two sets of spray headers the first set continually cools and saturate the flue gases. The spray header set at the top and directly below the collector washes down the collector and electrodes. Wet tubular electrostatic precipitators are ideally in applications involving high concentrations of fine particulates or for control of organic and acid mists. Further, they are suitable for difficult and corrosive applications

S. *Zhao and Zheng (2008)* described methods for enhancing the collection performance of fine particles with the help of electrostatic forces and dust removal techniques. Collection efficiency of submicron particles was only 5% in conventional wet scrubbers. It reached 25% in the particle charging wet scrubbers, 70% in the droplet charging wet scrubbers and 99% in the opposite charging wet scrubbers. Operational parameters like high liquid to gas ratio, smaller geometric mean, and slower droplet velocity were found beneficial to the high efficiency removal of fine particles.

T. *Bologa et al. (2009)* described CAROLA electrostatic precipitator of high velocity gas flow in the ionizing stage and a grounded field free collection stage. This electrostatic precipitator was used to increase the efficiency of particle charging, to generate strong space charge, and to transport the space charge into the collector. The tests with laboratory scale and pilot scale tests were carried out on these CAROLA ESP both with and without plenum chamber between the ionizing and the collection stages .Presence of plenum chamber decreased the mass collection efficiency of the ESP. Absence of the plenum chamber and the use of low operation voltage in the CAROLA precipitator improved stability of operation allowed.

U. *Carotenuto C et al. (2009)* Mathematical model was used to evaluate the particle removal efficiency in wet electrostatic scrubbers and find out optimal working conditions (maximization of particle collection efficiency as a function of different process parameters, like, contact time, specific water consumption, water/gas relative velocity, size and charge of sprayed droplets). The model was validated by comparison with different experimental data available in literature, both for charged and uncharged scrubbers. The study showed that the process optimization for micron and submicron size particles follows different criteria. For micron particles, the collection efficiency increases for higher water/gas relative velocity, with a small effect of droplet diameter and a moderate increase with the droplet charge. On the contrary, in case of sub-micron particles, the water/gas velocity plays a secondary role in the capture mechanisms, while a substantial increase of collection efficiency by improving the droplet charge level and reducing the droplet size has been observed. The model predicts collection efficiency as high as 99.5% with a water consumption of 100 ml/m^3 by adopting droplet diameters around 100 μm and charge to mass ratio from 1 to 3 mC/kg (corresponds to 10–30% of Rayleigh limit).

V. *Jong-Ho Kim et al. (2010)* showed experimentally using an electro spray with electrostatics precipitator to increase the collection efficiency of mono disperse nanometer-sized particles. Prior to the integration of the electro spray and the ESP, The particle collection of each process had been tested separately. The effect of electro spray on the particle collection shows that, collection efficiency increases with the decrease in particle size, but electro spray alone seems to be less efficient for particle removal. The effect of ESP on particle –collection shows that at close to corona onset voltage of -15 KV partial collection efficiency increased. The decrease in collection efficiency was also observed at -16.2 KV. High speed camera was used to observe the time resolved images of the electro spray. The droplets produced in the electro spray exhibited high velocity then those calculated by stokes’s law. The combination of ESP with electro spray increased the particle collection efficiency by 21-36% and reduced the energy consumption.

W. *Wen -Yinn Lin et al. (2011)* investigated the filtration characteristics .In this paper ESPs with AEF and DEF corona chargers were examined using potassium sodium tartar tetetrahydrate as the tested aerosol. Experimental result showed that the electric current of DEF is more than AEF. Ozone concentration was increased from 3 ppb to 48 ppb as the current of AEF increased from 1.9 µA to 1.09 µA .In case of DEF; ozone concentration was increased from 37 ppb to 658 ppb as a current increased from 18 µA to 206 µA.

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Moreover the particle penetration decreases as power consumption and applied voltage increase. When 0.2 um particle penetration was 4%, the power consumption of AEE and DEF were 16 watt and 18 watt respectively.

II. CONCLUSIONS

It is widely believed that a technology that combines both the scrubber and the electrostatic precipitator concepts can prove efficient enough for the removal of submicron particles from the emissions. Charging of either the particles of the gaseous stream or charging of the liquid droplets or both, in a wet scrubber can enhance the efficiency of the removal of submicron particles. Many simulation modeling studies (understanding the behaviour of both the particles and the liquid droplets in the charged conditions; tracing of trajectories/paths of the particles and particle collection efficiencies; etc.) carried out on electrostatic scrubber have shown this as possible.. This approach be used for charging the submicron particles in the electrostatic scrubber's needs investigation.

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