United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

Research and Development

EPA-600/S7-81-125 Dec. 1981

EPA

Project Summary

Spray Charging and Trapping Scrubber for Fugitive Particle Emission Control

Shui-Chow Yung, Julie Curran, and Seymour Calvert

The control of fugitive particle emissions (FPEs) with a Spray Charging and Trapping (SCAT) scrubber was evaluated both theoretically and experimentally. The system uses an air curtain and/or jets to contain, convey, and divert the FPEs into a charged-spray scrubber.

Experiments were performed on a 225 m^3/min bench-scale spray scrubber to verify the theory and feasibility of collecting fugitive particles with charged water spray. The effects of charge levels on drops and particles, nozzle type, drop size, gas velocity, and liquid/gas ratio on collection efficiency were determined experimentally. The results of the experiments and the comparison between theory and data are presented.

An air curtain was developed for conveying the FPEs to the spray scrubber. The design and air flow field for the air curtain are presented.

A prototype SCAT scrubber was built to study the effects of crosswind and hot buoyant plume. Available data revealed that the air curtain was successful in deflecting crosswind up to 15 mph and containing a hot buoyant plume. Theories were developed for predicting the trajectories of the air curtain jet stream and the hot buoyant plume.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Spray Charging and Trapping (SCAT) scrubber system is a simple and inexpensive way to control fugitive particle emissions (FPEs). The SCAT system uses air curtains or air jets to contain, divert, and convey FPEs into a charged spray scrubber located near the source.

The SCAT system has two sections arranged in a push-pull configuration with the fugitive particle emission source located between them (Figure 1). The fugitive particles are contained by air curtains and are pushed from the source into the spray scrubber. The scrubber has a low-pressure-drop entrainment separator to remove the spray drops.

Water from the entrainment separator can be passed through a separation process, such as a filter, to remove the collected dust particles. The water may then be recycled and the dust may be disposed of to prevent its redispersion. Alternatively, a blowdown stream of dirty liquid may be directed to a disposal system.

The major SCAT system feature, suiting it to FPE control, is the use of air curtains and/or air push jets. The use of air curtains minimizes the requirement for solid boundaries and enables access to the source. Air curtains could also be used to deflect the wind or to deflect a buoyant plume from a hot source. The SCAT system is very compact and portable.

Preliminary Experiments

The SCAT system has three basic functions, to: (1) contain and convey the fugitive emissions to the scrubber, (2) remove the particles with charged water sprays, and (3) collect the particles and water drops. There is insufficient published information on the design and performance of an air curtain and a charged-water spray scrubber. To generate design data, the air curtain and the charged spray scrubber were studied individually in separate bench-scale experiments. A prototype SCAT system was built and used to study the effects of hot buoyant plumes and crosswinds.

Air Curtain

An air curtain is a sheet of moving air formed by round or rectangular jets. Air curtains have been widely used in industrial and commercial plants, mainly to provide constant access or to isolate a warm interior from the cold outdoors or vice versa.

Most published information on air curtain performance and design relates to air conditioning and ventilation. There is little published literature on dust containment even though it has been used for this purpose in industry. The design of the SCAT system requires information on the jet expansion angle, air entrainment ratio, mixing of particles in the curtain, and the effects of crosswind and hot sources. Jet expansion angle and particle mixing determine the overall cross-sectional dimensions of the spray scrubber. The air entrainment ratio determines the volumetric flow rate. Crosswinds and heat effects dictate the nature and placement of air curtains and sprays.

Ideally, the air curtain should have small expansion angle, small air entrainment ratio, and a uniform velocity distribution.

Experiment

The air jet nozzle of the air curtain used in this study was a continuous slot 2.1 m (7 ft) long. The slot was formed by two parallel plates which protruded 22.9 cm (9 in.) from one side of the duct. The distance between the plates, which is the slot width, could be adjusted. The slot was divided by thin cross-plates at 5.1 cm (2 in.) apart, so that the air would discharge perpendicularly to the longitudinal axis of the duct.

The discharge distribution for this manifold was uniform and the discharge angle close to 90°.

The air curtain flow field was measured for several slot widths and slot exit velocities with the slot vertical. Linear velocity was measured for three vertical levels at several locations downstream of the slot. The jet expansion angle and the air entrainment ratio were calculated from the measured velocity distribution. The results were compared with the equations derived from a two-dimensional jet exhausting into still surroundings and jets with two-sided expansion. Figures 2 and 3 show the measured centerline axial velocity decay and entrainment ratio, respectively. The measurements lie between the predictions by Abramovich and the present study and are equal t the average of the two predictions.

The measured jet expansion angl was 20-28°, depending on air exi velocity. The average of measured je expansion angles agrees with tha calculated for a pure momentum jet.

Charged-Spray Scrubber

For a spray system, collection b drops is the principal collection mechanism and the particle penetration for a given size particle depends on the drop diameter, the collection efficiency of a single drop, and the ratio of liquid-to-gas flow rates.

The instantaneous single-drop collection efficiency has been determined experimentally for uncharged drops collecting uncharged particles. There is no explicit expression for single-drop efficiency when electrostatic, inertial,

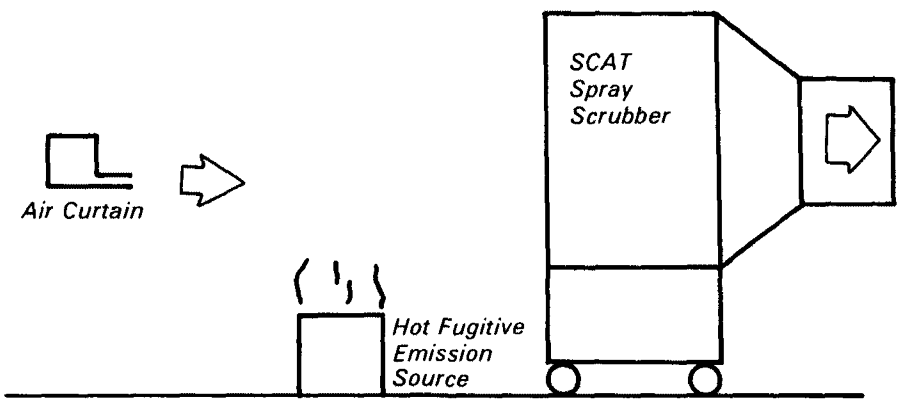

Figure 1. *SCAT system arrangment.*

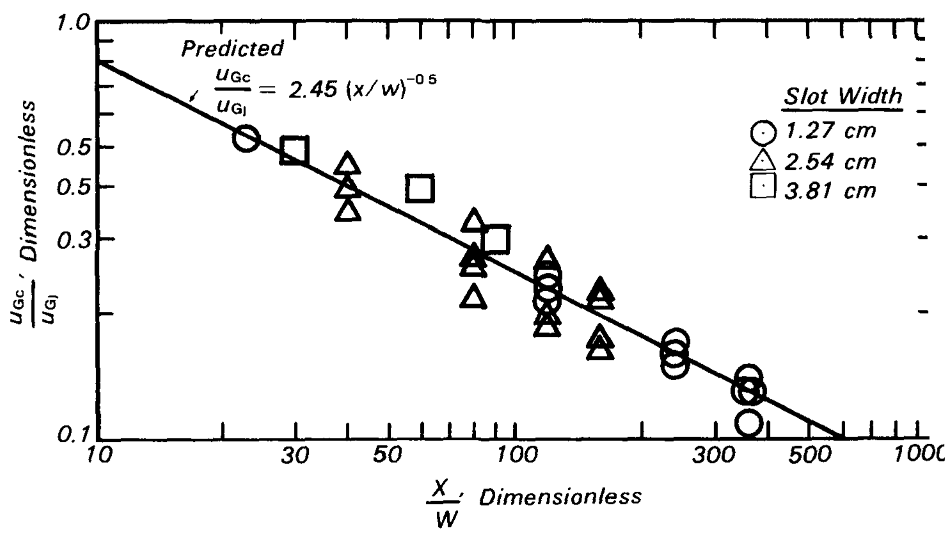

Figure 2. *Measured and predicted centerline axial velocity decays.*

and viscous forces are simultaneously present. The equations of motion have been solved numerically for the collection of fine particles by a single spherical collector with various combinations of charge: the results can be used for predicting particle penetration.

Experiment

Charged-spray scrubbers have been studied experimentally by several researchers. However, their data are not suitable for verifying a mathematical model because several important electrical parameters were not defined.

To obtain design data under well defined conditions, the charged-spray scrubber system shown in Figure 4 was built. The system consisted of a flow straightening section, an inlet particle sample section, a particle charging section, a spray section, an entrainment separator, and an outlet sampling section.

The particle charger section consisted of two rows of corona wires and ground electrode tubes. The spray section included two spray banks: the water was charged by induction.

Experiments were performed to determine the minimum water requirements, to evaluate spray nozzles, to study various drop charging methods, to determine the effect of drop and/or particle charging on particle collection efficiency, and to verify published theories. The particle collection efficiency, of the charged-spray scrubber was determined by injecting redispersed dust to the blower inlet and by simultaneously measuring the particle size distribution and mass concentration at the inlet and outlet of the scrubber.

Particle charge was measured with a Faraday cup which consisted of an isolated, shielded, glass-fiber filter connected to an electrometer. The filter collected the particles and their charges which were measured by leaking them to the ground through the electrometer. Charge/mass ratio was calculated from the measured charge and particle mass on the filter.

Drop charge was measured by placing a drop collector in the scrubber. The collector collected the drops and their charges which were measured by leaking the charge to the ground through an electrometer. Thus, by monitoring the current and sampling time, and measuring the amount of water collected, the charged level can be calculated.

Figure 5 shows the measured charge level on drops. Nozzles were hook-type hollow-cone nozzles. Curve A is for a water flow rate of 9.5 x $10^{-4} m^3/s$ (0.3 gpm) per nozzle and a pressure of 450 kPa (50 psig). Curve B is for a water flow rate of 7.2 x $10^{-4} m^3/s$ (0.25 gpm) per nozzle and a pressure of 380 kPa (40 psig). The drop diameter, measured and sized photographically, was about 0.24 mm for both conditions.

Results

The scrubber was operated for four conditions:

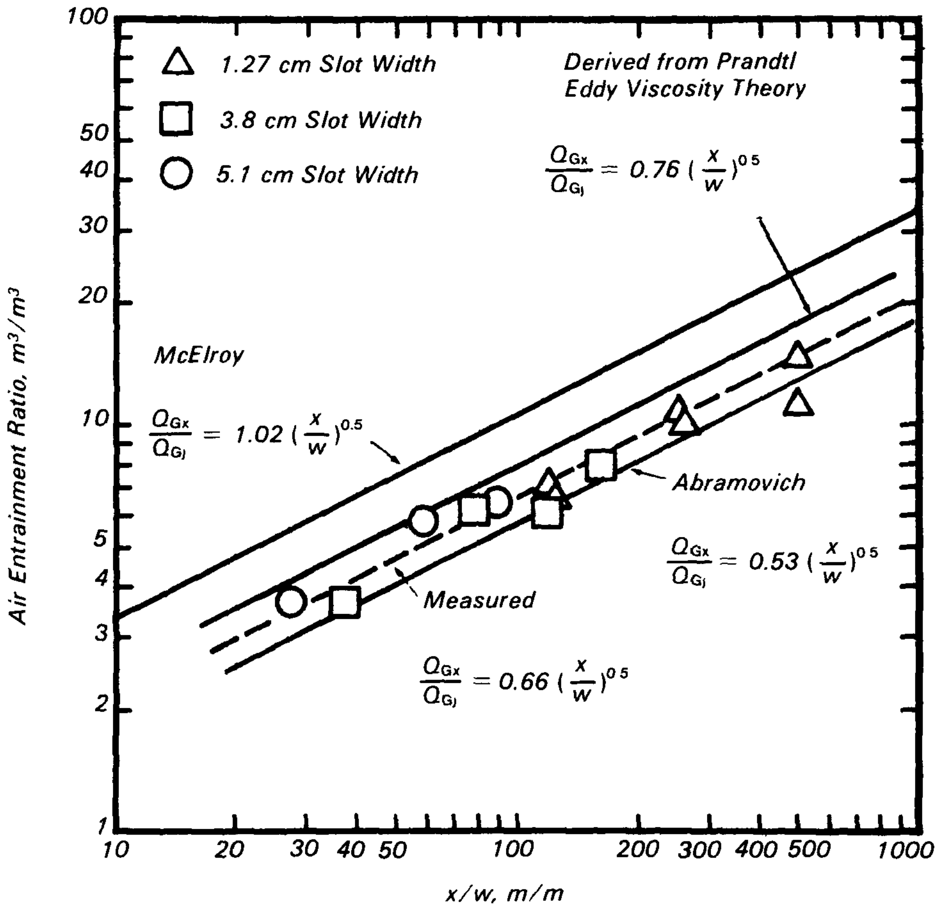

Figure 3. Measured and predicted air entrainment ratio.

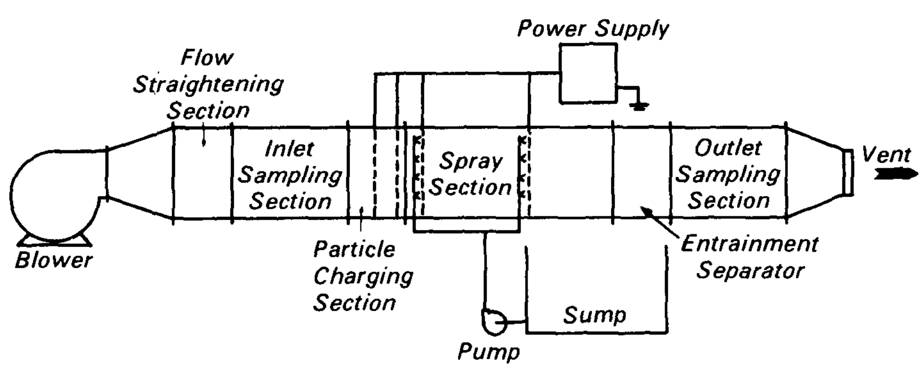

Figure 4. Experimental apparatus for studying charged-spray section of SCAT scrubber.

(1) Uncharged particles/neutral drops (UP/ND).
(2) Charged particles/neutral drops (CP/ND).
(3) Uncharged particles/charged drops (UP/CD).
(4) Charged particles/charged drops (CP/CD).

Figures 6 and 7 show data for nozzles A and B, respectively. The measured mass median drop diameter, spray angle, and discharge coefficient for nozzle A (hooktype) were 0.24 mm, 100°, and 0.63, respectively. They were 0.35 mm, 87°, and 0.69, respectively, for nozzle B (pigtail type). Only one spray bank was used in all experiments and nozzle pressure was maintained at 432 kPa (48 psig). One power supply was used to charge both the particles and the drops. The applied voltage was -10 kVDC. The measured charge/mass ratio was -1.5×10^{-5} C/g for particles with a mass median diameter of 3 μm aerodynamic diameter and a geometric standard deviation of 2.5.

The collection efficiency of the spray scrubber is improved by charging either the water or the particles. Further enhancement was measured when the water and particles were oppositely charged and it is greatest with submicron particles. For particles with diameters larger than 5 μm aerodynamic diameter, charging the water and/or particles has little effect on efficiency.

The scrubber with nozzle A has better collection efficiency at a lower liquid/gas ratio than that with nozzle B. A possible explanation is that nozzle A produced finer drops.

Comparison Between Theory and Experimental Results

The drops from a hollow-cone nozzle are localized at the edge of the spray cone and do not travel parallel to the gas stream, but at an angle which depends on the spray orientation with the gas stream. Therefore, in calculating the single-drop collection efficiency, the resultant relative velocity between the gas and the drop must be used for calculating the initial impaction parameter.

The spray nozzles in the spray scrubber were equally spaced in the duct so the drops travelled various distances before striking the wall. To simplify the calculation of particle penetration, the average range of all drops was used. Figure 8 shows the predicted and the measured grade penetration for the UP/NP condition. As can be seen, the agreement is good. For CP/ND and UP/CD conditions, the theory predicted no improvement in particle collection efficiency, which is contrary to experimental findings.

When drops and particles are oppositely charged, the theory predicted an increase in the collection efficiency. Figure 9 shows the predicted scrubber penetration along with that measured. The agreement is good for particles larger than 3 μm aerodynamic diameter, but not for those smaller than 3 μm.

These discrepancies could be due to the use of average drop range. Figure 10

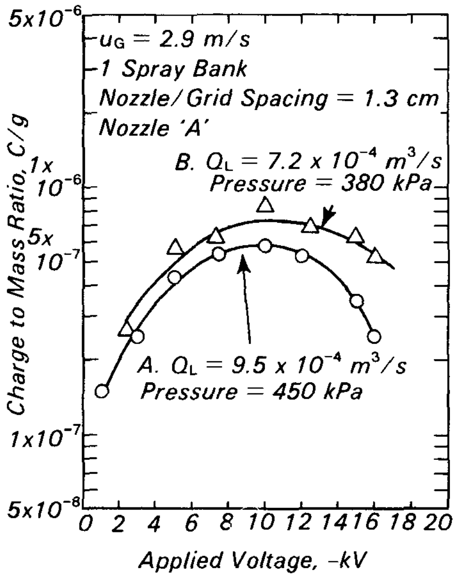

Figure 5. *Measured charge level on drops.*

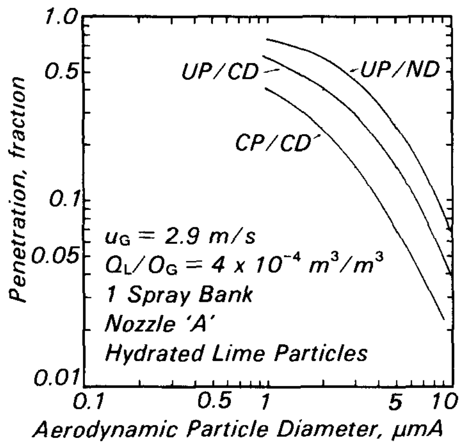

Figure 6. *Experimental spray scrubber penetration.*

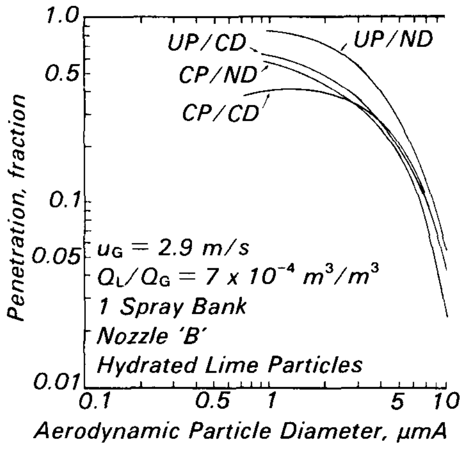

Figure 7. *Experimental spray scrubber penetration.*

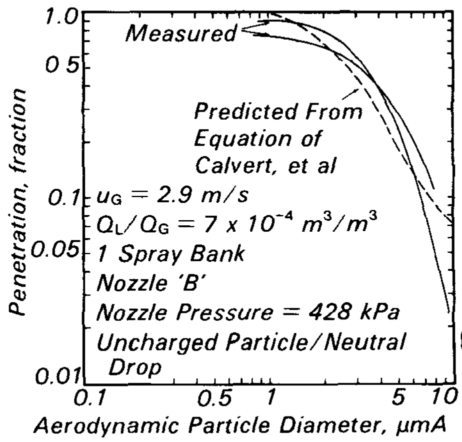

Figure 8. *Predicted and measured spray scrubber penetration.*

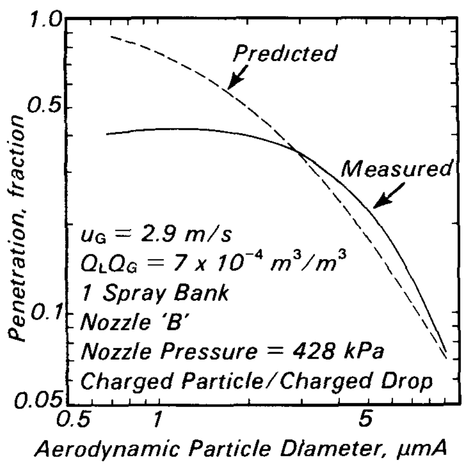

Figure 9. *Predicted and measured spray scrubber penetration.*

shows a plot of the predicted single-drop collection efficiency for 1 µm diameter particles vs drop range. Electrostatic augmentation does not have much effect until the drop has been slowed down; i.e., drop range is large. In performance predictions, drop range was limited to 70 cm, which was the average. In reality, drop range varied between 9 and 97 cm, depending on the location of the nozzle. Therefore, the use of average drop range could cause underestimation of electrostatic effects. Other possible explanations are that drops are not of uniform diameter and charge level.

Prototype SCAT System

A two-section SCAT scrubber system was designed and built for studying crosswind deflection and hot source control. One section housed the spray scrubber; the other section had three air curtains and one push jet. Both sections were on casters so the distance between the air curtains and the spray scrubber could be adjusted.

The spray scrubber had a cross section of 2.44 x 1.83 m (8 x 6 ft). The bottom 0.61 m (2 ft) was the scrubber sump. Therefore, the active scrubber cross section was 1.83 x 1.83 m (6 x 6 ft). There were 36 large pigtail nozzles set concurrent with the gas flow at the scrubber front surface. A zigzag baffle entrainment separator was used to remove the water drops.

The scrubber was designed for an air velocity of 4.5 m/s (10 mph), at which the pressure drop for the entrainment separator is approximately 1.3 cm W.C. (0.5 in. W.C.): an induced draft fan was needed to overcome the entrainment separator pressure drop. In some applications (e.g., spray scrubber located downwind from the FPE source), the fan may be unnecessary.

In the other section, two air curtains were vertical and about 1.83 m (6 ft) apart; the third was horizontal and 2.7 m (9 ft) above the ground. The air curtains could be swivelled as needed to deflect crosswinds and bouyant smoke plumes. A propeller fan was at the center.

Even though the air curtain section had three air curtains and one air-push jet, they need not be operated simultaneously. Under calm conditions only the air-push jet may be required to move the dust into the spray scrubber. When there is crosswind, one air curtain may be enough to deflect the wind and to convey the dust into the scrubber.

Crosswind Experiments

Under windy conditions, the SCAT system spray scrubber can be put downwind of the fugitive particle source and the wind will carry the particles to the spray scrubber. If the spray scrubber cannot be put downwind, the wind can be deflected from the FPE source with wind screens or air curtains. Sometimes one air curtain can be used to both deflect the wind and convey the particles.

Complete wind deflection, required to maintain dust containment, occurs when the resultant air flow of crosswind and SCAT air curtain jet flow bypasses the SCAT scrubber. At this point the blocking distance (range produced by the SCAT air curtain) is just larger than the distance between the air curtain and the spray scrubber.

For wind deflection, the momentum of the air curtain flow in the direction opposing the wind must be equal to or greater than the momentum of the wind. Wind deflection depends on several SCAT operating parameters: the incident angle at which the air curtain meets the wind is the most important. Several formulas for correlating the parameters mentioned above are available in the literature. Indoor experiments were intended for identifying the best correlation. Experiments were performed by fixing the range, wind speed, air curtain slot width, and slot exit velocity, and varying the incident angle for wind deflection. Actually, both the wind speed and direction fluctuate. For this reason, additional crosswind experiments were done outdoors.

One outdoor experiment was for determining the air curtain range. The scrubber and air curtain were so arranged that the wind direction was perpendicular to the spray scrubber and the air curtain jet discharged at 45° against the wind. Smoke or tracer particles were injected at various locations for flow pattern observations. The air curtain range was determined visually as the distance from the air curtain nozzle to the nearest location where the tracer plume is disturbed by the cross wind.

In a second experiment the jet stream trajectories for various wind speeds, incident angles, air curtain slot widths, and exit velocities were determined.

If the air curtain is also to convey the dust, then the spray scrubber needs to be rotated to intercept the curved jet stream. The third experiment involved measurement of the angle between the spray scrubber frontal face and wind direction for various crosswind and wind/air curtain incident angles.

Measured air curtain range and trajectory were compared with predictions in Figures 11 and 12. The agreement is good, so one can predict the location of the air curtain and spray scrubber relative to the crosswind and fugitive emission source.

Hot-Source Experiments

Some metallurgical processes, such as iron and steel manufacturing, emit

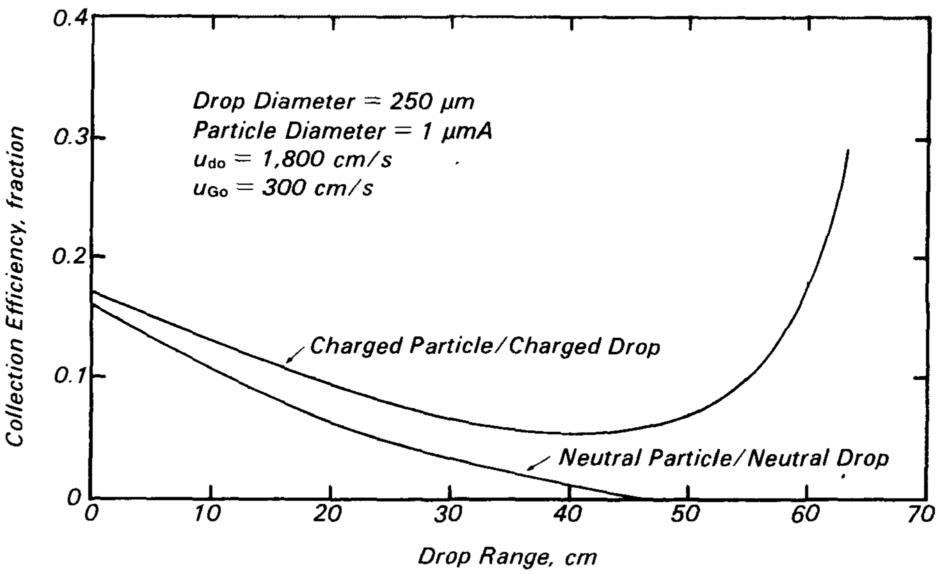

Figure 10. *Single-drop collection efficiency as a function of drop range.*

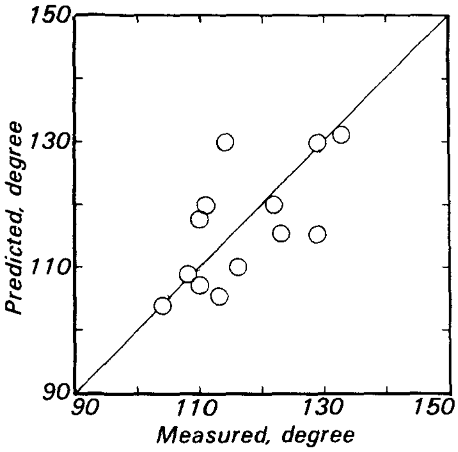

Figure 11. *Predicted and measured incident angle for wind deflection.*

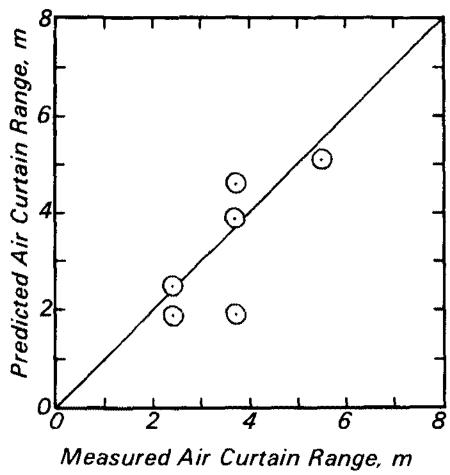

Figure 12. *Predicted and measured air curtain range (outdoor data).*

very hot plumes containing high concentrations of particles. The most efficient and economical way to clean these plumes is to capture them at the source where the concentration is highest and the gas volume smallest. In many cases, practical reasons (e.g., the presence of overhead cranes) make it impossible to capture the plume at the source or even vertically above the source with fume hoods. In these situations, an air curtain could be used as the "ceiling" to contain the fumes and dust and to horizontally displace the plume into a receiving hood or scrubber.

Experiments were done to study the feasibility of containing hot plumes with air curtains. The hot source was simulated with an open-top furnace with an open-flame burner. The furnace was at the center of the SCAT system with 3.1 m (10 ft) between the air curtain and the spray scrubber. Since the operation of the burner was fixed, the ceiling air curtain location was adjustable so that the jet stream could meet the hot plume at different temperatures.

Most of the experiments were performed with the ceiling air curtain exit axis 61 cm (2 ft) above the top of the furnace, where the peak plume rising velocity and temperature were about 190 cm/s (4.3 mph) and 471°C (800°F), respectively.

Experiments were done for three air-curtain slot widths and four slot exit velocities. Except for small slot width (2.5 cm or less) coupled with low exit velocity (20 m/s or less), the air curtain contained the hot plume. Experimental observation could be described by a correlation for predicting the hot plume trajectory which accounted for the buoyancy and momentum of the plume.

Conclusions

FPEs can be controlled by using air jets to contain and convey the emissions into a nearby spray scrubber. The collection efficiency of a spray scrubber can be improved by charging the water and/or the particles. Measured particle penetration can be predicted for the unaugmented scrubber but not very well for the electrostatically augmented scrubber.

The air curtain developed in this study can achieve a smaller expansion angle and a lower entrainment ratio than those reported in the literature. Small expansion angles and entrainment ratios are beneficial to the control of FPEs with the SCAT system.

A prototype SCAT system has been built to study the effects of crosswind and containment of hot buoyant plume. Reasonable predictions of experimental data on air curtain range and trajectory in the presence of crosswind can be made. The air curtain was successful in containing a hot buoyant plume and the trajectory of the plume can be predicted.

Recommendations

The theories and experimental data presented in this research permit the design of a SCAT system. However, additional studies are required to optimize the SCAT design. Future research and development work is needed in the following areas:

(1) The effect of obstacles on air-curtain flow field. One of many SCAT features which suit it for fugitive emission control is unobstructiveness. Workmen and equipment (e.g., cranes) can pass freely and work on the source during SCAT system operation. The presence of workmen and equipment may create turbulence and change the air-curtain flow field.

(2) The optimal design of the receiving hood to intercept the air-curtain jet stream.

A pilot study on an actual fugitive emission source is recommended to demonstrate the feasibility of using the SCAT system for controlling the emissions. Since electric arc furnaces, coke ovens, copper converters, etc. are the major fugitive emission sources and the plumes from these sources are hot, an ideal demonstration would be on one of these.

Nomenclature

Q_G = volumetric gas flow rate, m^3/s
Q_{Gi} = volumetric gas flow rate at nozzle exit, m^3/s
Q_{Gx} = average gas flow rate at "x" meters downstream from nozzle, m^3/s
Q_L = liquid volumetric flow rate, m^3/s
u_G = gas velocity, m/s
u_{GC} = centerline gas velocity, m/s
u_{Gi} = gas velocity at nozzle exit, m/s
u_{Gx} = average jet velocity at "x" meters downstream from nozzle, m/s
w = slot width, m
x = distance downstream from slot, m

S. Yung, J. Curran, and S. Calvert are with Air Pollution Technology, Inc., 4901 Morena Blvd., Suite 402, San Diego, CA 92117.
***Dennis C. Drehmel** is the EPA Project Officer (see below).*
The complete report, entitled "Spray Charging and Trapping Scrubber for Fugitive Particle Emission Control," (Order No. PB 82-115 304; Cost: $21.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

☆ U.S. GOVERNMENT PRINTING OFFICE:1981--559-092/3360

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA 335

Official Business
Penalty for Private Use $300

PS 0000329
U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604