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Electrostatic Precipitator Gas Flow Model Studies

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The Institute of Clean Air Companies, the nonprofit national association of companies that supply stationary source air pollution monitoring and control systems, equipment, and services, was formed in 1960 to promote the industry and encourage improvement of engineering and technical standards.

The Institute's mission is to assure a strong and workable air quality policy that promotes public health, environmental quality, and industrial progress. As the representative of the air pollution control industry, the Institute seeks to evaluate and respond to regulatory initiatives and establish technical standards to the benefit of all.

Electrostatic Precipitator Gas Flow Model Studies

Summary: This publication provides information on and establishes design criteria for modeling gas flow using both physical flow modeling and computational fluid dynamic modeling in electrostatic precipitators.

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1. HISTORY

In August 1969, ICAC (as IGCI) first issued publication ICAC-EP-7 to alert purchasers and operators of electrostatic precipitators to the significant influence of gas distribution on collection efficiency. ICAC also established criteria that defined satisfactory gas distributions within precipitators.

ICAC revised ICAC-EP-7 in 1981, 1987 and 1997 to reflect increased operating experience, tighter collection requirements, an increasing awareness of the influence of gas distribution on collection efficiency, and changes in electrostatic precipitator technology, testing procedures, instrumentation, and modeling techniques since 1969.

The ICAC Electrostatic Precipitator Division produced this revision of ICAC-EP-7 to reflect current technology and operating experience, to clarify the text, and to allow users with lesser collection needs to perform appropriate model studies.

2. OBJECT AND SCOPE

The objectives of ICAC-EP-7 are: to establish precipitator gas velocity distribution criteria; to outline techniques and recommend procedures for model testing; and to establish guidelines for instrumentation, modeling parameters, and flow distribution responsibility.

ICAC does not intend this publication to relieve the electrostatic precipitator supplier of the responsibility for an effective and economical design to meet performance guarantees.

3. DECISION TO MODEL

3.1 During the pre-contract design stage, the layout of the gas inlet and outlet transport flues and the precipitator supplier should critically review the transition connectors to the precipitator to ensure that the proposed layout will provide proper gas flow distribution. The decision of whether or not a model study is required is based in part on this review, which should be performed even if the supplier will not do the detailed design and erection of the flues and transitions. While the precipitator supplier may have sufficient experience and technical expertise to be confident and willing to proceed without a model study in some cases, a model study normally will not be waived on large installations, as modeling costs represent a small portion of the contract value and the model ensures that proper gas flow will be achieved at optimum pressure loss through the system.

3.2 Other factors influencing this decision are:

3.2.1 *Guaranteed precipitator operating efficiency.* Gas flow uniformity becomes increasingly important as operating efficiencies approach 100% due to:

3.2.1.1 The tendency for the smaller particles to follow the gas flow streamlines more closely.

3.2.1.2 The increased need for almost total suppression of gas bypassing and hopper sweepage. Thus, the higher the guaranteed operating efficiency of a precipitator, the more important the optimization of the gas flow.

3.2.2 *Standardization of Design* - If an installation is a copy of another existing installation, which has satisfactory collection efficiency, the model study may be omitted. If an installation is not substantially the same as another, it should be recognized that apparent minor differences in geometry can result in considerable differences in flow distribution.

3.2.3 *Symmetry of Design* - Many large precipitator systems are subdivided into several identical symmetrical parts. In certain arrangements only one symmetrical division need be modeled.

3.2.4 *System Pressure Drop* - If the system pressure loss is guaranteed, the model study will assure minimizing dynamic losses and will locate areas of maximum loss. System losses should be reported as total pressure differences.

3.2.5 *Fan capacity* - Uniform flow conditions at the induced-draft fan inlet(s) will ensure that the design fan capacity is achieved. The ductwork between the precipitator and its associated fan thus should be included in the model study.

4. RESPONSIBILITY FOR FLOW DISTRIBUTION

4.1 The purchaser and the precipitator supplier should understand and agree on responsibility for gas distribution as it affects collection efficiency performance guarantees.

4.2 Many different relationships between the purchaser and the precipitator supplier exist with respect to the design and construction of the flue system leading to and away from the precipitator. In general, the precipitator supplier takes responsibility for the gas flow uniformity when the following conditions are met:

4.2.1 The supplier either provides the flue design, or has review and veto power over the purchaser's general layout design.

4.2.2 The supplier either provides the final detailed erection drawing, or has review and veto power over the details of the internal flow control devices in the flue system. The review may be based on either previous experience, or on the results of a model study.

4.2.3 The supplier either erects the flue system, or has the opportunity to inspect the flues and require any necessary corrections before the installation becomes operational, to insure that the gas flow control devices have been properly fabricated and installed.

4.2.4 Velocity measurements are made in the completed precipitator to determine whether the gas flow distribution is acceptable.

4.3 Note that the usual primary guarantee offered by a precipitator supplier covers the collection efficiency, outlet emissions, pressure drop, and electric power consumption of the precipitator. A flow uniformity guarantee, if offered, is usually subordinate to this primary guarantee, and comes into play only when collection efficiency is deficient by virtue of unsatisfactory flow uniformity.

4.4 In this document, the term “flow modeling” refers to either physical flow modeling or computational fluid dynamic (CFD) modeling. Both forms of modeling have strengths and weaknesses that should be reviewed before a modeling study is undertaken.

5. GAS FLOW UNIFORMITY STANDARDS

5.1 Maximum theoretical precipitator collection efficiency results from perfectly uniform gas velocity. However, due to the inevitable formation of low speed, viscous, boundary-layer like regions in the collection chamber, and the fact that mechanical and re-entrainment considerations generally require shaped, non-planar, collecting surfaces, completely uniform flow throughout is neither achievable nor desired. Further, a sheltered low speed zone is usually deliberately established above the hoppers to minimize hopper sweepage.

Nevertheless, gas flow uniformity is desirable to maximize the operating efficiency of the precipitator. The following standards define today's practical limits of gas flow uniformity recommended in precipitator modeling. Depending upon site and design specific circumstances, full scale flow uniformity is likely to be different from that measured in the model.

5.1.1 Within the treatment zone near the inlet and outlet faces of the precipitator collection chamber, the velocity pattern shall have a minimum of 85% of the velocities not more than 1.15 times the average velocity, and 99% of the velocities not more than 1.40 times the average velocity. Average velocity refers to the mean of all velocity measurements made at a given face of the precipitator.

5.1.2 Consideration is often given to having a lower than average gas velocity at the upper and lower extremities of the collecting plate to minimize flow over and under the treatment zone. Lower velocity near the bottom of the collecting plate is particularly important to minimize re-entrainment and hopper losses.

5.1.3 For large precipitators subdivided into several chambers, but serving a single source, the uniformity criteria given in 5.1.1 above should be considered as a combination of all chambers and evaluated as a unit.

5.1.4 The individual chamber volumetric flow should be compared with total system volumetric flow to ensure that the flow in each chamber is within ± 10% of its theoretical share.

5.1.5 Baffles, large structural members and rapping mechanisms can cause dead zones immediately downstream of them. Including the velocity measurement made in these dead zones with the rest of the velocity data is not meaningful. Therefore, these test points may be excluded from the above determinations, provided that all the excluded velocities are less than the average velocity.

5.2 For electrostatic precipitators with target outlet emissions of greater than 100 mg/m^3 (0.044 gr/scf), less restrictive flow uniformity standards are appropriate, as follows.

5.2.1 Within the treatment zone near the inlet and outlet faces of the precipitator collection chamber, the velocity pattern shall have a minimum of 75% of the velocities not more than 1.15 times the average velocity, and 95% of the velocities not more than 1.40 times the average velocity.

5.2.2 The individual chamber volumetric flow should be compared with total system volumetric flow to ensure that the flow in each chamber is within ± 10% of its theoretical share.

5.2.3 Users of these less restrictive criteria should be careful to minimize hopper sweepage and bypass which might result from cross flows.

5.3 Special circumstances such as aerodynamically inferior duct configurations required by limited space availability or the need to prevent dust dropout in horizontal or sloping ductwork when transporting large dust loadings may force the suppliers to deviate from the criteria given above. Alternative solutions such as increasing the size of the precipitator are often employed to address these problems.

6. VELOCITY MEASUREMENT INSTRUMENTATION AND PROCEDURES

The success of a gas flow modeling effort is dependent on the accuracy with which velocity data is obtained both in the field and in the laboratory or simulation.

6.1 Laboratory velocity measurement instrumentation should:

6.1.1 Be reasonably accurate and be reproducible to within 2% of the reading or 0.5% of full meter scale. In this service absolute accuracy is less important than relative accuracy and reproducibility.

6.1.2 Have, for electronic instrumentation, an overall system response time of less than one second.

6.1.3 The system (sensors, signal conditioners, readout/printout conditioners) should be recalibrated frequently as required.

6.2 Both laboratory and field velocity measurement procedures should:

6.2.1 Have a minimum number of test points equal to one-ninth the cross-sectional area of the actual precipitator face in square feet, i.e., one test point per nine square feet of cross-sectional area. To assure proper evaluation of the velocity pattern, a minimum of every third gas passage should be tested. Each passage can then be subdivided into equal points required to meet minimum requirements. However, the vertical test points should not be farther apart than 10% of the collecting plate height.

6.2.2 Have the data taken near the leading edges of the first bank of collecting plates and near the trailing edges of the last bank of collecting plates.

6.2.3 Have either continuous traverses recorded or discrete point measurements taken and recorded using an automated data acquisition scheme.

6.3 Common velocity measurement instruments are electronic ("hot wire") anemometers, pitot tubes, and velometers. A hot wire anemometer should have an output signal strength adequate to provide reliable results and must be frequently cleaned of dust contamination in field use.

Commonly used electronic anemometers only measure the magnitude of the principal velocity component, and not the direction, or magnitude, of the true velocity vector. Streamers, smoke and other qualitative devices are recommended for use in finding flow eddies and recirculating zones.

Draft gauge - pitot tube systems may be used instead of electronic anemometers to measure usual duct system velocities, but they are not well suited to measure the low velocities (normally less than 600 FPM) found within precipitator treatment zones.

Two types are commonly used: Prandtl or standard ("L-Head") pitot tubes are capable of higher accuracy (± 1% under ideal conditions), but are susceptible to clogging problems and their use may be precluded in locations with limited access. Stauscheibe ("S-Type") pitot tubes are less accurate than Prandtl pitot tubes, but are less susceptible to clogging and more versatile in locations with limited access. They also provide slightly higher pressure differences, which is helpful when measuring low velocities. It is recommended that the calibration of this type of pitot tube be checked regularly over the full range of velocities.

7. MODELING PARAMETERS AND TECHNIQUES

Users of models for velocity distribution studies must be thoroughly aware of the laws of fluid mechanics, and of the effects of these laws on model performance. Of particular importance is an understanding of the dimensionless Reynolds number, which defines the ratio of inertial to viscous forces acting on the fluid.

CFD models operate at full-scale, full-load, hot conditions, and therefore match the Reynolds number of the full-size counterpart. Because of the scale factor, the use of full-scale installation velocities results in the Reynolds number of the physical model being lower than that of its full-size counterpart.

However, as long as the Reynolds number is high enough to insure that the flow is fully turbulent throughout the model (above approximately 7000), a reliable gas flow model of the precipitator system can be made using 1/16 or larger scale construction.

In the flues and nozzles, the Reynolds numbers are sufficiently high (typically 1×10^5 to 1×10^6) so that the dynamic losses in the model and full scale are similar. The model flow is unquestionably fully developed turbulent flow.

However, between the precipitator collecting plates, the field Reynolds number can be less than 10,000. Therefore, since it is necessary to maintain turbulent flow (Reynolds number above approximately 7000) in the model, either the distance between parallel collecting plates can be increased, or the velocity through the collection chamber can be increased. It is important that the collecting plates be represented for each field in the geometric model since the plates act to preserve existing horizontal distributions. Therefore, the absence of one, or several groups of plates could make the modeled outlet velocity distribution different than it is in the actual unit.

Regardless of the modeling method, in constant cross sectional area flues, it is not normally critical to model the details of minor internal structural members (less than four inches) if they block less than 5 percent of the cross sectional area and their positioning will not result in their acting as a baffle. However, in the nozzle regions, accurate modeling of structural strut-work is important in obtaining close correspondence between the model and the field.

8. MODELING PROCEDURE

A geometric gas flow model study has many stages, the omission of any one of which detracts from the overall value of the study:

8.1 During the early design stage, the precipitator supplier should critically review the layout of the gas inlet and outlet transport flues and nozzles to ensure that the proposed design layout will not lead to unsolvable gas flow uniformity problems. This review procedure should be performed whether or not the supplier will do the detailed design and erection of the flues and nozzles, since for the great majority of precipitators the construction scheduling is such that major changes in the flue layout at the time of completion of the geometric model study would cause delays and added expense. The precipitator supplier's experience and gas flow technical expertise will help insure a good flue and nozzle design.

The supplier should again review any subsequent changes made in the flue design drawings.

8.2 After all parties approve a duct layout, model construction can begin. The model should include any devices, which significantly affect electrostatic precipitator performance in the selected layout, such as ductwork, air heaters, and induced draft fans. Should the arrangement of equipment and flues require verification or modification, the model construction should be delayed until the purchaser's approval is received.

8.3 A model should be checked for accurate construction. A physical model should be free of leaks. Model velocities should be reviewed to establish that the flow
exiting the inlet flue system and entering the precipitator nozzles is reasonably uniform. If not, alterations should be made to the vaning within the transport flue system until satisfactory uniformity is achieved. The inlet and outlet flue vaning may also be revised to minimize the system's dynamic pressure drop.

8.4 The model should be reviewed to find regions of separated or recirculating flow where particulate dropout could be troublesome. In a physical model, this should be accomplished with streamers, smoke dust, and other qualitative techniques. In a CFD model, flow velocities should be examined and patterns displayed using color contours and streamlines.

8.5 Inlet and outlet velocities in the precipitator collection chamber should be examined to determine if the uniformity standards laid out earlier in this publication are achieved.

Any modifications in the flow distribution devices should be examined with another velocity review (a CFD model must be run or a physical model traverse done). The sequence of velocity review - control device modifications - velocity review, etc., should be repeated until an acceptable flow uniformity is achieved.

8.6 If field-adjustable gas control devices are to be used (i.e., louver-type dampers), then the maximum, minimum, and optimal settings of the devices should be established during the model study, to establish over what range the device may be fine-tuned in the field without adversely affecting other gas flow factors.

8.7 Another test that should be performed during the model study is the simulation of gas flow in the collection chamber in order to check that significant amounts of gas are not exiting the precipitator without passing through the collecting plates ("sneakage"), and that there are no strong flows in the hopper regions (hopper sweepage), which could cause excessive reentrainment. In a physical model, neutral buoyancy smoke should be injected into the roof and hopper regions of the collection chamber for a qualitative test. In a CFD model, flow velocities should be examined and flow rates integrated in these regions. Color contours and streamlines may be used. If the tests indicate that extensive sneakage or hopper sweepage is occurring, then steps should be taken to minimize the effect, since this has a direct harmful impact upon the operating efficiency of the precipitator.

8.8 The results of the model study are then incorporated into the final precipitator design drawings.

8.9 After field erection of the system is completed, a thorough inspection of flues and nozzles should be made to ensure that the gas flow control and distribution devices have been properly located and installed in the full scale system.

8.10 Before the precipitator system is first brought on line, velocity traverses should be made at the inlet and outlet of the collecting chambers at the same locations that the laboratory tests were made. These measurements serve to establish the degree of agreement between the model and full scale flow pattern.

If field-adjustable gas flow devices were included in the precipitator, then velocity measurements should be made before and after each change in their setting.

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