A Numerical Simulation for Predicting Influence of Flow Pattern in Electrostatic Precipitator on Exit Re-entrainment Loss

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Abstract: The electrostatic precipitator (ESP) numerical model developed by Author does a better job of qualitatively predicting influence of skew gas distribution in ESP upon performance. The results show that the higher efficiencies can be achieved by using some special non-uniform inlet & outlet gas distribution than that of uniform gas distribution and the re-entrainment of falling dust results in the dust load in the lower zone of a precipitator increasing compared to the upper zone as flow progresses through a precipitator. In this paper, the numerical model is applied to determine exit re-entrainment loss response to the variations in gas distributions across the full scale ESP entrance and exit. It examined how skew gas distribution affects re-entrainment loss and gives a physical explana-tion for the lower re-entrainment loss or higher efficiency with controlled using some special non-uniform inlet and outlet gas distributions.

Keywords: Electrostatic precipitator, Numerical simulation, Skew gas distribution, Re-entrainment loss, Collector efficiency

1 INTRODUCTION

The electrical operation of modern electrostatic precipitators can be so good that the losses govern the overall performance level. The losses contain surface re-entrainment, rapping re-entrainment and sneak-age. Particle loss caused by re-entrainment is one of the most severe and oft-recurring limitations in the electrostatic precipitation of dry particles. Further substantial improvement of performance can come from the attention to the re-entrainment losses. But there have been very few studies of the basic nature of the phenomenon and few systematic, quantitative studies of how re-entrainment is affected by different conditions. Because this problem is related to many fields which include electro-mechanics, aerodynamics, electricity, aerosols, and solid mechanics etc. It is difficult and impossible for us to solve re-entrainment losses systematically only by theory at present. In present paper, based on the flow field computation and the re-entrainment function described, a new two-dimensional computer model which is taken into account the particle re-entrainment is applied to study the exit re-entrainment loss response to the variation in gas distributions. The results show the higher efficiencies can be achieved by using some special non-uniform inlet & outlet gas velocity distributions than that of uniform gas velocity distributions because re-entrainment loss can be validly reduced.

2 NEW NUMERICAL MODEL REVIEW[1] [2]

2.1 Geometry Model

To compare the simulated values with the measured data, the ESP measured by Sproull in Lambton Generating Station [3] is used to set new numerical model. Its side view is shown in Fig. 1.The unit has three fields, each with collecting surface 9.15 meters high by 3.66 meters long. An overall efficiency of 99.0% is designed by Deutch formula with uniform gas velocity and without re-entrainment. The model applies the skew factor value by Hein defined in Fig. 2[4] to determine the gas velocity profile for the inlet face & the outlet face.

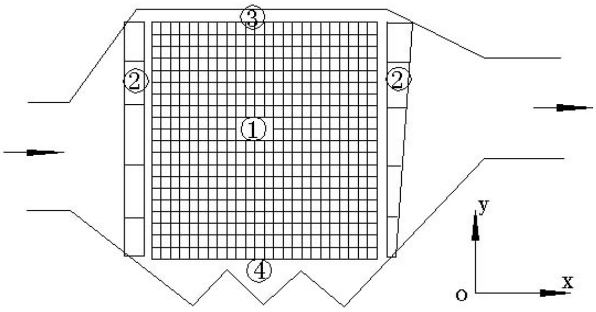


Fig. 1 Precipitator side view

① is the treatment zone grid.

② is the gas flow distributions.

③ is the busbar region of the ESP.

④ is the hopper region of the ESP

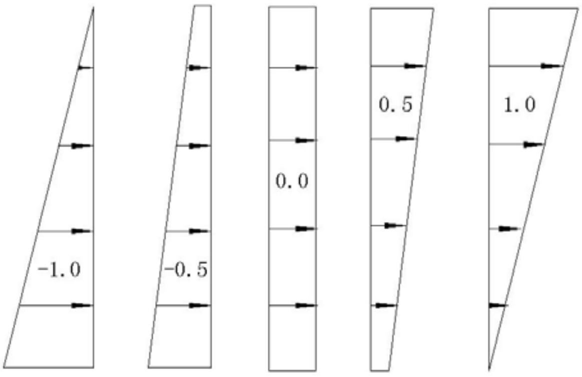


Fig. 2 Skew factor definition

2.2 The Governing Equations for Turbulent Flow

The turbulent flow governing equations contain the continuity equation, the momentum equation, the energy equation, the kinetic energy equation, and the dissipation equation. All these equations can be expressed in a single form:

$$\frac{\partial(\rho\varphi)}{\partial t}+\mathrm{div}(\rho\vec{V}\varphi-\Gamma_{\varphi,\mathrm{eff}}\,\mathrm{grad}\varphi)=S_\varphi \qquad (1)$$

where S_φ can be broken down into:

$$S_\varphi = S_{Normal} + S_{Buoyancy} \qquad (2)$$

And $C_1, C_2, C_3, C_D, \sigma_K, \sigma_\varepsilon, \sigma_H, \Phi, G_f, s_{\mathrm{Normal}}$ and s_{Buoyancy} are given in [5].

Where C_1, C_2, C_3, C_D is coefficients in k-ε turbulent model; σ_K, σ_ε, σ_H is Schmidt or Prandtl number; μ_{eff} is effective viscosity; V_j is flow velocity component in coordinate; K is kinetic energy of turbulence; ε is dissipation rate of turbulent energy; H is specific enthalpy; μ_t is turbulent viscosity coefficient; v_t is turbulent kinetic viscosity coefficient; g_i is gravity component; c_p is constant-pressure specific heat; ϕ is general fluid property; b is gas expended coefficient. $q = H - H_0$ is excess enthalpy, H_0 is a reference value.

The flow in duct precipitator can be simplified reasonably into two-dimensional velocity. The twenty-five velocity fields have been computed. Three type are showed in Figs. 3-5. ISF & OSF is respectively acronyms of the Inlet Skew Factor and the Outlet Skew Factor.

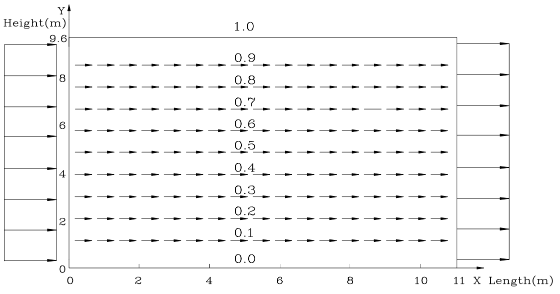


Fig. 3 Velocity profile of ISF=0.0 &OSF =0.0

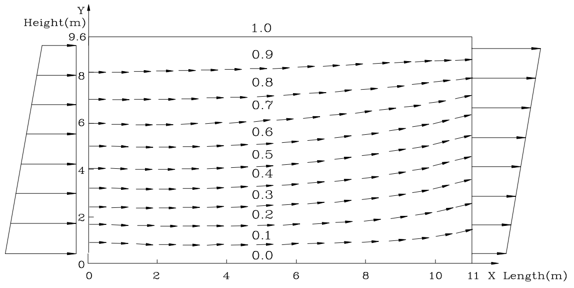
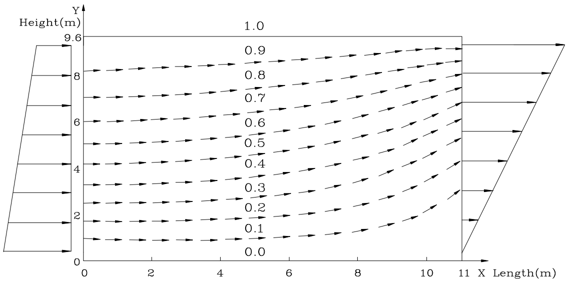


Fig. 4 Velocity profile of ISF= -0.5 & OSF=0.5

Fig. 5 Velocity profile of ISF= -0.5&OSF=1.0



2.3 Re-entrainment Function and Model

New re-entrainment function is obtained by fitting the curve which was given by Self et al in [6] and the data which was given by Sproull in [3] into empirical formula:

$$R=2.62\times10^{-2}\,U\,(1+CH^3) \qquad (3)$$

Where R is the fraction of re-entrainment, (%); U is local gas velocity, m/s; C is adjustable parameter; and H is the distance which dust has fallen, m. New model applies that C is equal to 47.32 to make its calculated values match data measured by Sproull in [3].

The re-entrainment model is illustrated in Figs. 5 and 6. The meaning of each component is explained in Table 1. (5) governed by local mean velocity is re-entrainment mass measured by Self et al. It involves the continuous surface re-entrainment with rapper off and on. Where H=0, new re-entrainment function gives this component. (10) is not only related to the local velocity , but also related to the distance the dust has fallen from collection element (A). The new re-entrainment function involves the element local velocity and dust fallen distance. For this reason, it can be used to simulate how reentrainment and changes in gas velocity distribution within a precipitator affect performance. It is applied to the dust collected in each element and the re-entrained dust becomes part of the inlet dust loading for the elements in the next column. Beginning with element at top of the inlet face, this procedure is applied to each successive column to arrive at the outlet face losses.

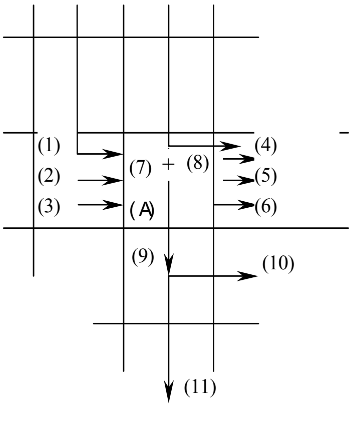


Fig. 6(a) Decomposition of component

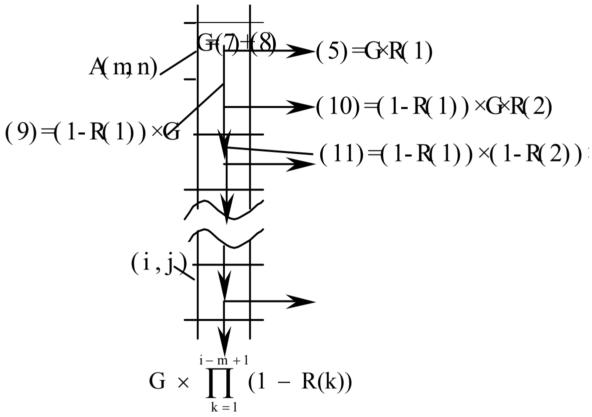


Fig. 6(b) Re-entrainment model

Table 1 Meaning of each component in Figs. 5 and 6

Inlet dust loading of the element (A)	(1) is loss on the reentrained dust from higher upstream elements (2) is Deutch loss on the reentrained dust from same row (3) is Deutch loss on the un-reentrained dust from same row
Outlet dust loading of the element (A)	(4) is Deutch loss of (1) and (2), (6) is Deutch loss of (3). (5) is surface re-entrainment loss of (A).
Depositing mass of the element (A)	(7)=(1)+(2)–(4), is deposition of inlet load (1) and (2). (8)=(3)–(6), is deposition of inlet load (3).
Dislodging mass	(9) =(7) + (8) – (5), is remainder downward from (A).
Reentrainment loss of the element (A)	(10) is the first reentrainment loss from (A). (11) is still downward from (A) by first reentrainment.

2.4 The Sneakage Model

we can obtain a quantitative prediction of the sneakage fraction from[7]. It gives values of sneakage within a factor of 2%. In according to this factor, the effects of sneakage are simulated by computing a fraction of the gas flow that passes through the hoppers and bus-bar region of the ESP (see Fig. 1). The dust mass carrying by the gas by-passage of electrified regions directly change into the outlet losses.

2.5 New Model

The new numerical model has been established by using the geometry model, the two-dimensional k-ε turbulence model, re-entrainment model and sneakage model.

3 TEST NEW MODEL

With no re-entrainment and an inlet skew factor 0.0, new numerical model predicted efficiencies shown by Fig. 7. For uniform inlet and outlet gas distribution (or ISF & OSF=0.0, see Fig. 3), in the first of all, an overall efficiency of 99.0% is produced by new model. For holding uniform inlet and vary outlet gas distribution, the best efficiency is uniform flow, vice versa. These are one and same Deutch formula.

With re-entrainment and uniform inlet and outlet gas distribution, new numerical model simulated the dispersion of falling dust by the new re-entrainment function, also reproduced measured data which were reported by Sproull in [3], so new re-entrainment function is testified by reproducing the Sproull's data in uniform gas velocity. The higher concentration appears at the top and bottom is due to effect of sneakage and the hopper "boilup" (see Fig. 8).

The new model predicts re-entrainment losses[1] are qualitative consistent with some published information that is available from tests and model in [7] & [8].

The three tests demonstrate that new re-entrainment function with adjustable parameter 47.32 is of the right order and confirm that new model can be used to predict farther influence of the skew gas distribution on re-entrainment loss.

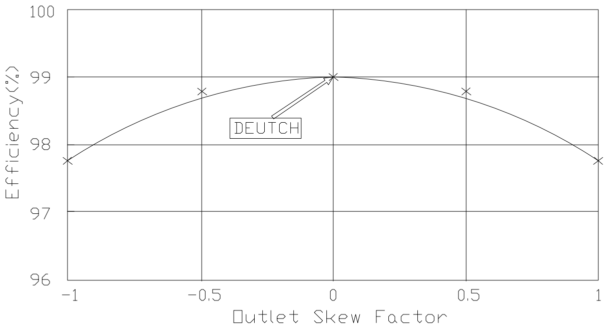


Fig. 7 Efficiencies with an inlet skew 0.0

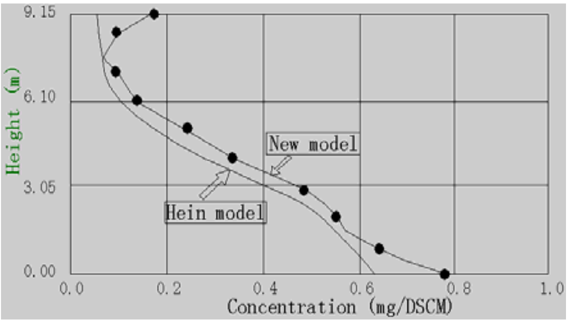


Fig. 8 Compare new model with sproull's data by Hein simulated

4 INFLUENCE OF THE SKEW GAS DISTRI-BUTION UPON EXIT RE-ENTRAINMENT LOSS

Based on the two-dimensional velocity field computation and the new numerical model described above, Performance efficiencies and exit re-entrainment loss corresponding to twenty-five velocity fields have been predicted. Efficiencies and exit re-entrainment losses are accordingly showed in Figs. 9 and 10. Exit re-entrainment loss is equal to the ratio of loss on re-entrained dust to inlet loading.

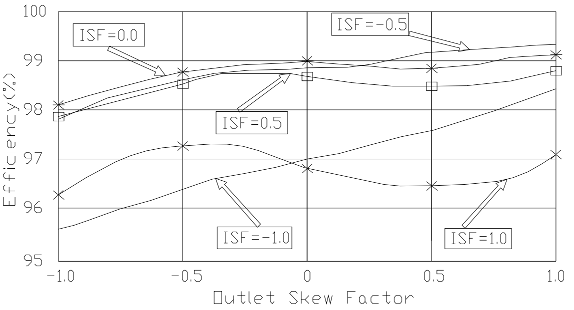


Fig. 9 Efficiencies with non-uniform gas flow

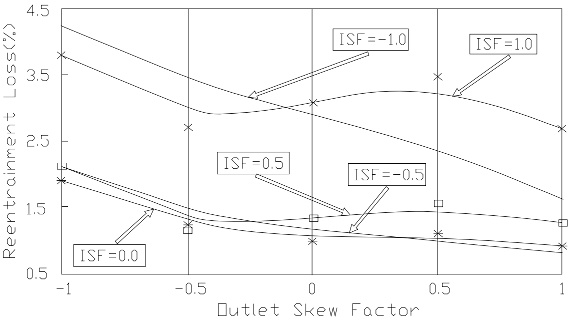


Fig.10 Exit re-entrainment losses with non-uniform gas flow

With the skew gas distribution, exit reentrain-ment losses vary enormously with different gas distribution. The relationships displayed by Figs. 8-9 show that a substantial performance improvement in electrostatic precipitator is available for some special non-uniform inlet & outlet gas velocity distributions, i.e. an inlet skew 0.0 response to outlet skew 1.0 and an inlet skew -0.5 response to outlet skew 0.5 or 1.0. Several analyses can be drawn as follows.

1) Total emission or loss includes loss on unreentrained dust which has not previously been collected and loss on reentrained dust (or exit re-entrainment loss) which was collected and then re-entrainment. Re-entrainment loss is defined by new model involves continuous surface re-entrainment with rappers off, some dust is reentrained at the level where it is deposited and is incapable of distinguishing from data measured by comparing rappers on and rappers off. The example of used to demonstrate the model results in 99.6 percent of loss due to re-entrainment. Re-entrainment loss controlled total emission. Further substantial improvement of performance can come from the attention to the re-entrainment losses.

2) When ISF and OSF is negative, more of dust is closer to the bottom, the average distance from the level where it is deposited to the hopper is less than that when ISF and OSF is positive & 0.0, the chance of re-entrainment is reduced, the gas velocity higher than mean velocity will appear in the higher dust loading zone, the penetration increases and the deterioration of re-entrainment at the higher gas speeds is undoubtedly due to re-entrainment caused by the scouring action of the gas-stream , e.g. OSF is -1.0. When the higher gas velocity results in less treatment time at the bottom in the more heavily dust loading zone and the higher penetration that cannot be compensated by re-entrainment reducing, re-entrainment losses are higher and efficiency is lower than uniform gas distribution. The opposite also holds true. So, when ISF=0.0 and OSF= +1.0, ISF= - 0.5 and OSF= +0.5 or OSF= +1.0, it will appear lower re-entrainment losses and higher operating efficiency than the uniform gas distribution.

5 CONCLUSIONS

The classical Deutch model assumes that turbulent mixing is strong enough to maintain a uniform dust concentration profile across the precipitator duct. This assumption yields that a uniform flow precipitator should ideally have the maximum collection efficiency. However, the perfect mixing is unlikely to exist, and re-entrainment, sneakage and the hopper “boilup” are also inevitable in industrial scale precipita-tors. These non-ideal conditions result in non-uniform dust concentration profile during whole operation. This has been confirmed by published information from Sproull in [3] and Southern Research Institute in [8], so it is doubted whether the optimum performance can be achieved by using uniform gas velocity distribution with non-uniform dust concentration profile in electro-static precipitator. Especially, the electro-static precipitator is of higher collecting surface. A series of runs produced the characteristic show that the best performance with some special non-uniform gas distribution is quite different from those determined by traditional Deutch formula and other model[4].

Re-entrainment loss controlled total emission. Improvement of performance can come from the attention to the re-entrainment losses. The maximum efficiency and the minimum re-entrainment loss can be achieved by using with ISF=-0.5 and OSF=1.0 gas distribution, because exit re-entrainment losses can be validly reduced. This can give a physical explanation for the performance may be improved by controlled non-uniform inlet and outlet gas distributions.

New numerical simulating supports Hein’s viewpoint [4], but it demonstrates different trends from Hein’s model predicted. Further research is required to develop and prove new model in electrostatic precipitator. Because there have been very few datum which are relate to re-entrainment studies can be collected, conclusion may be corrected after new data is obtained.

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