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INFLUENCE OF THE GAS FLOW ON THE EFFICIENCY OF ELECTROSTATIC PRECIPITATORS

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WPŁYW PRZEPŁYWU SPALIN NA SKUTECZNOŚĆ ODPYLANIA W ELEKTROFILTRZE

Elektrofiltry należą do najczęściej stosowanych w energetyce urządzeń odpylających. Do niedawna sądzono, że wszelkie turbulencje w komorze odpylacza prowadzą do obniżenia skuteczności jego pracy, stąd dążono do osiągnięcia równomiernego przepływu spalin wewnątrz elektrofiltru. Zastosowanie komputerowego modelowania procesu odpylania w elektrofiltrze radykalnie zmieniło pogląd na rolę przepływu gazu w urządzeniu. Stwierdzono bowiem, że nierównomierne, odpowiednio ukształtowane przepływy spalin (tzw. przepływy skośne) prowadzą do poprawy skuteczności pracy odpylacza. W artykule dokonano przeglądu typów skośnych przepływów spalin stosowanych w elektrofiltrach oraz ich wpływu na skuteczność pracy urządzenia. Zaprezentowano wyniki własnych symulacji komputerowych, wykorzystujących prosty model obliczeniowy, obrazujące wpływ sposobu przepływu spalin na skuteczność odpylania w elektrofiltrze, ze szczególnym uwzględnieniem długości strefy. Wyniki badań wskazują, że zróżnicowanie prędkości spalin prowadzi do poprawy skuteczności odpylania szczególnie w przypadku krótkich stref w elektrofiltrze. W przypadku stref długich, maksymalna skuteczność odpylania jest osiągana, dla przyjętego dwuczęściowego modelu strefy odpylania, przy równomiernym przepływie spalin w urządzeniu.

Summary

Electrostatic precipitators (ESP) are the most commonly used devices for gas cleaning in the power industry. From the beginning of ESP usage on a commercial scale, it has been said that all swirls and turbulences should be eliminated from the gas flow, approaching uniform gas distribution in an ESP chamber. Application of CFD (Computer Fluid Dynamics) methods in electrostatic precipitation caused radical changes in views on the role of the gas flow. Series of non-uniform gas flows was then indicated, causing an increase in ESP efficiency. This paper is a review of the gas flow distributions used in ESP and their influence on ESP efficiency. The results of computer analysis presented in this paper show that diversification of gas velocity in the ESP chamber leads to efficiency improvement for shorter zones; however, for longer zones it causes an efficiency drop. The efficiency raise owing to diversification of gas flow profile is a consequence of exponential gas velocity – efficiency dependence.

INTRODUCTION

Electrostatic precipitators (ESP) are the most commonly used devices for gas cleaning in the power industry. From the beginning of ESP usage on a commercial scale, it has been said that all swirls and turbulences should be eliminated from the gas flow, approaching uniform gas distribution in an ESP chamber [17]. The mean value of gas flow velocity in cross-section of the ESP zone as an identification of gas flow was used in theoretical efficiency calculations.

Application of CFD methods in electrostatic precipitation caused radical changes in views on the role of the gas flow. In the 1980s series of non-uniform gas flows was indicated, producing an increase in ESP efficiency.

This paper is a review of the gas flow distributions used in ESP and their influence on ESP efficiency.

GAS FLOW THROUGH THE ESP

There are different ways of taking gas distribution (velocity field) into account in predicting the efficiency of the ESP. The basic equation enabling calculations of expected value of efficiency is Deutsch formula [1], which takes into consideration only mean value of gas velocity (v_s) in cross-section of the ESP zone:

$$\eta = 1 - \exp\left(\frac{-Lw}{s\upsilon_s}\right) \tag{1}$$

L – the length of an electric field,
w – dust particle migration velocity,
s – discharge electrode to collecting plate distance,
v_s – mean value of gas velocity in cross-section of the ESP chamber.

More detailed description of gas velocity field was given by White [17], incorporating into the equation (1) an inlet gas velocity function *f(v)*. The efficiency of ESP is given by an equation:

$$\eta = 1 - \int_0^{\upsilon_{max}} \exp\left(-\frac{Lw}{s\upsilon}\right) f(\upsilon)\, d\upsilon \tag{2}$$

According to Idelcik and Aleksandrow [7], diversified velocity field can be described using coefficient:

$$M_k = \frac{1}{A}\int_A \left[\frac{\upsilon(x,y)}{\upsilon_s}\right] dxdy \tag{3}$$

A –inlet area of ESP,
v(x,y) – gas velocity.
The efficiency of ESP is given by an equation:

$$\eta = 1 - \left[\frac{Lw}{s\upsilon_s}\frac{1}{M_k}\right] \tag{4}$$

Similar opinion is represented by Mc Donald and Dean [9], who introduced analogous coefficient of the gas flow uniformity and analogous as (4) efficiency equation.

SKEWED GAS FLOWS

Application of CFD-methods in the electrostatic precipitation process analysis, especially in the case of gas flow distribution, led to surprising results. Non-uniform, suitable formed gas flows appear to be more effective and give higher de-dusting efficiencies than standard uniform flows. These new non-uniform flows were called "skewed". A number of applications of Skewed Gas Flow Technology confirmed former results achieved in computer testing.

Work led by Lind, Hein and Gibson [4–6, 8] gave a new view on the relationship between gas flow and de-dusting efficiency. Let us have a look at the types of gas flow in ESP.

Gas flow pattern, presented in Figure 1, according to Hein [5, 6], is characterized by high gas velocities at the bottom, decreasing to the top of ESP (in inlet profile) and low gas velocities at the bottom, increasing to the top – in outlet profile.

The profile of gas flow is described by skew coefficient $q = \frac{\upsilon_g - \upsilon_d}{1 \, m/s}$, as a quotient of difference between the value of gas velocity at the top of the profile and the value of gas velocity at the bottom to velocity 1 m/s.

For linear-skewed gas flow profile (as in Fig. 1) q < 0 in first zone of ESP, q = 0 in second zone and q > 0 in third zone. Uniform gas flow is presented in Figure 1 in second zone.

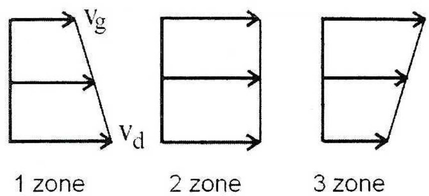

Fig. 1. Linear-skewed gas flow profile by Hein

Another type of gas flow profile was proposed by Frank [2] (Fig. 2).

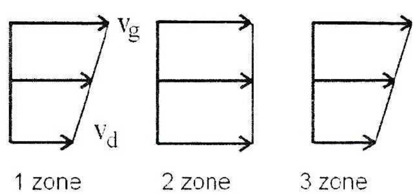

Fig. 2. Linear-skewed gas flow by Frank

As shown in Figure 2, both inlet and outlet gas flows are characterized by low gas velocity at the bottom, increasing to the top of ESP.

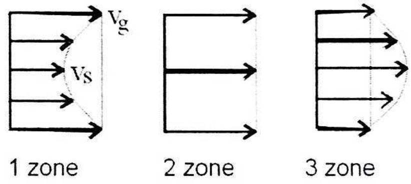

Fig. 3. Concave-convex flow by Sarna

A further gas profile was found as a result of investigations carried out by author of this paper [10]. The concave-convex flow is presented in Figure 3.

Inlet gas flow has lower gas velocity in the middle of the field, increasing to the border, while at the outlet the velocity profile is opposite. For this kind of flow skew coefficient can be calculated as a quotient of the difference between value of gas flow velocity in the middle of the field and on the edge, to velocity value 1 m/s.

EFFICIENCY OF DUST REMOVAL AND SKEWED GAS FLOW IN THE ESP

Investigations on Skewed Gas Flow Technology in ESP were not only computer analysis (CFD), but also numerous practical applications (carried out, among others, by TRI ESKOM in RSA) [3, 4, 16]. These works confirmed further expectations of ESP efficiency improvement – dust concentration on the outlet of precipitator was 24% to 80% lower compared to the dust concentration achieved using standard uniform gas flow.

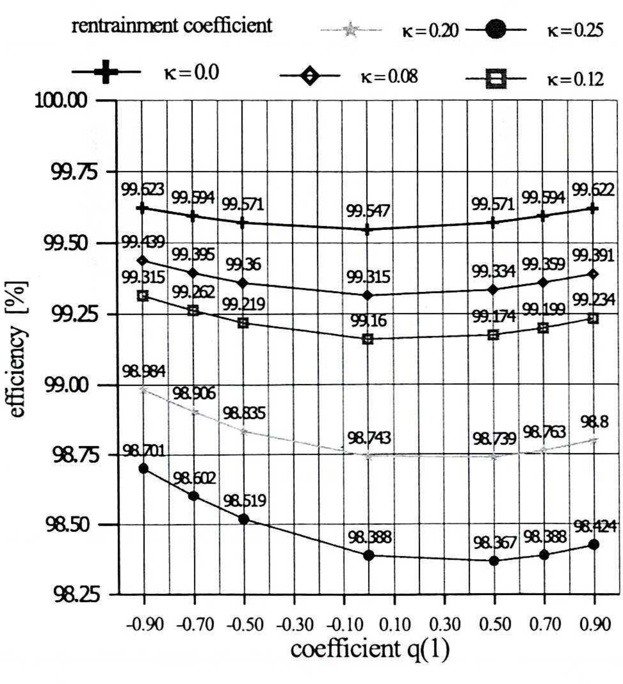

Fig. 4. Efficiency of ESP as a function of skew-coefficient

The main part of the investigation led by authors of this paper includes a computer analysis of the relationship between the gas flow profile and the efficiency of precipitation in the ESP. A discrete model of the ESP zone was established, implemented in the package of our own computer programs. The influence of the gas flow profile (Fig. 1–3) on the precipitator efficiency was tested, regarding dust re-entrainment and particle size-distribution. The results of that works show that gas flow according to Hein allows to achieve somewhat higher efficiency in the ESP than Frank-type flows, however, concave-convex flows give results close to Frank-type [10, 12]. The influence of re-entrainment and skewed flows on ESP performance is presented in the paper [15]. As shown, the application of non-uniform flow (adequately formed) is able to compensate the losses in efficiency caused by dust re-entrainment. The higher the re-entrainment level, the greater is the efficiency improvement effect (Fig. 4).

Research on the relation between dust particle size distribution and skewed gas flows proved that skewed gas profiles have an advantageous effect on fine dust collection. Fractional efficiency of the ESP for submicron dust particles increases more intensively owing to skewed gas flow (both linear and concave-convex), compared to coarse dust particles [11, 13, 14].

SKEWED GAS FLOW PROFILE AND ESP EFFICIENCY IMPROVEMENT

Explanations of ESP efficiency improvement by means of skewed gas flows are commonly unconvincing, as they are usually based on phenomenal description of the processes occurring in the ESP chamber. A lot of discussions and conferences are organized to discuss that problem (for example the ESP Round Table Conference in Charlotte, USA, in the year 2000, devoted to skewed gas flows).

The Air Flow Science Corporation made an attempt to elucidate skewed gas flow phenomenon. However, the results of that work are unknown to authors of this paper.

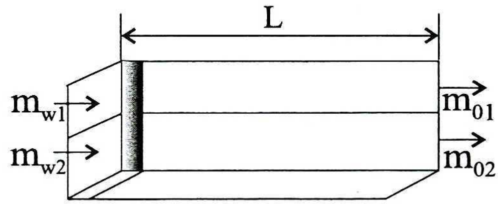

Fig. 5. Model of gas clearing in ESP

Probably all misunderstandings which occur while trying to understand the phenomenon of skewed flows (and sometimes even attempts to negate that occurrence) arise from the fact that nonlinear, exponential efficiency dependence on gas velocity is usually not taken into consideration. This dependence is showed in Deutsch formula (1). For good explanation of the ESP efficiency – gas flow dependence a simple model of ESP was established. Let us consider a division of cleaned gas into two parallel gas streams (Fig. 5). Each stream is characterized by different gas flow velocities v_1, v_2, such as $\frac{\upsilon_1+\upsilon_2}{2}=\upsilon_s$

An assumption is made that inlet dust masses in both fluxes are the same.

$$m_{w1}=m_{w2}=0.5\cdot A\cdot S_w\cdot \Delta L \qquad (5)$$

S_w – dust concentration.

On outlet the masses of dust are adequately m_{01} and m_{02}. The process of dust precipitation proceeds up to the Deutsch formula (1), therefore:

$$m_{01} = 0.5 \cdot S_w \cdot \exp(-k \frac{w}{\upsilon_1}) \tag{6}$$

$$m_{02} = 0.5 \cdot S_w \cdot \exp(-k \frac{w}{\upsilon_2}) \tag{7}$$

$k = \frac{L}{s}$,

L – the length of the electric field in ESP,

s – discharge electrode to collecting plate distance,

w – migration velocity of dust particle,

v_1, v_2 – gas flow velocities.

The efficiency of whole ESP is given by the formula:

$$\eta_a = 1 - 0.5\left[\exp\left(-k\frac{w}{\upsilon_1}\right) + \exp\left(-k\frac{w}{\upsilon_2}\right)\right] \tag{8}$$

Knowing that : $v_s = \frac{\upsilon_1 + \upsilon_2}{2}$

$$\eta_a(\upsilon_1) = 1 - 0.5\left[\exp\left(-k\frac{w}{\upsilon_1}\right) + \exp\left(-k\frac{w}{2\upsilon_s - \upsilon_1}\right)\right] \tag{9}$$

It is easy to notice that for $v_1 = v_2$ formula (9) becomes a classic Deutsch equation (1). Figure 6 shows the efficiency of the ESP (with two parallel gas streams), with the following parameters:

$v_s = 1.5$ m/s,

s = 0.4 m,

w = 0.12 m/s,

L = 4 m, L = 7 m, L = 9 m and L = 10 m.

As the Figure 6 shows:

- the gas flow – efficiency dependence is different for shorter ESP zones (4 m, 7 m) and for longer zones (9 m, 10 m);
- for shorter ESP zones, minimal efficiency is achieved for uniform gas flows ($v_1 = v_2 = 1.5$ m/s), however, maximal efficiency – in case of diversified values of gas velocity;
- for longer ESP zones (9 m, 10 m), diversification of gas velocities – lower than 1 m/s causes ESP efficiency drop, contrary to shorter zones.
- the longer the ESP zone is the higher the de-dusting efficiency becomes.

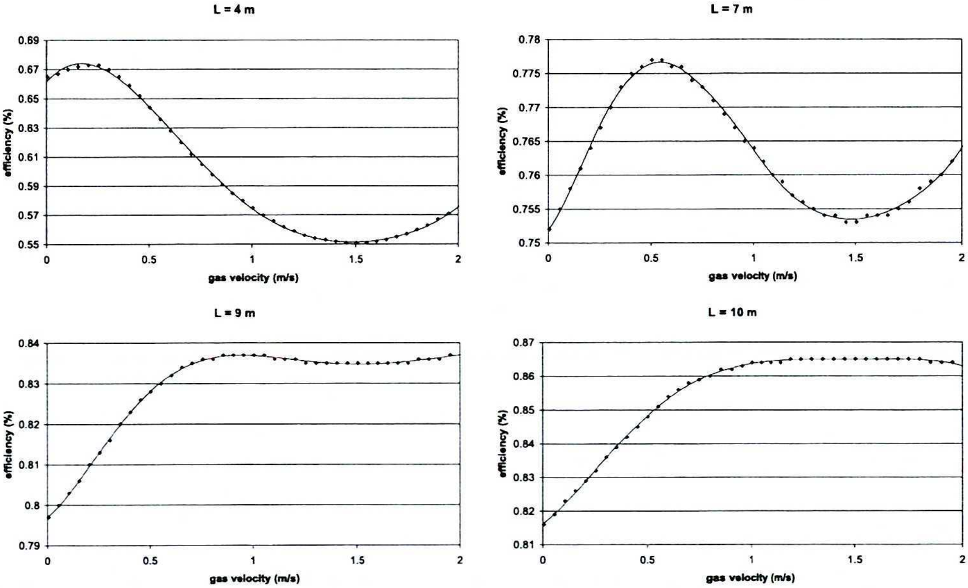

Fig. 6. The efficiency of the ESP in the middle of zone as a function of gas velocity (v_1) for L = 4 m, L = 7 m, L = 9 m and L = 10 m

CONCLUSIONS

As the obtained results show, longer ESP zones provide higher maximum efficiencies, what is comprehensible taking into consideration Deutsch formula (1). Diversification of gas velocity in the ESP chamber leads to efficiency improvement for shorter zones; however, for longer zones it causes an efficiency drop. For shorter ESP zones the lowest efficiency is obtained with uniform flow, diversification of gas velocities, even little, improves de-dusting process. However, for longer zones attained results show the higher efficiency for standard uniform flow. It can be advice for ESP constructors, that nonuniform, skewed flows can be considered mainly for shorter zones. The efficiency raise owing to diversification of gas flow profile in case of sorter zones is a consequence of exponential gas velocity – efficiency dependence.

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