ENVIRONMENTAL CONTROL

DEVELOPMENT OF SELF-REGENERATING FILTERING SYSTEMS WITH DECREASED HYDRAULIC RESISTANCE FOR ENERGY-SAVING DUST COLLECTION IN PRODUCTION OF REFRactories


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The kinetics of filtering dust-gas flows by rotating self-regenerating filter membranes with decreased hydraulic resistance for energy-saving highly efficient dust collection from process gases and aspiration emissions in the production of refractories is considered. A nomogram is proposed for choosing regeneration parameters for filter membranes, and the advantages and prospects of this dust-collecting method in the production of refractories are formulated.

Dust components emitted into the atmosphere in the course of production of refractories contain substantial amounts of materials that have to be recycled in the technological process. The cost of activities intended to protect the atmosphere from dust emissions at refractory works reaches 18% of the total capital investments [1, 2]. In this context, it is especially important to develop self-regenerating structures with decreased hydraulic resistance in order to achieve energy-saving highly efficient dust collection from process gases and aspiration emissions. The advantages of cylindrical granular filter layers with a small curvature radius makes them rather promising for dust removal from gases in a centrifugal field [3, 4].

Theoretical and experimental studies have been carried out to develop a steady hydrodynamic filtering regime, which involves the specifics of resistance of rotating porous bodies, as a dust-gas flow passes through them. We relied on extensive information on separating heterogeneous gaseous systems with a disperse solid phase in a centrifugal field [5 – 7].

There are known original designs of self-regenerating rotary filters for separating dust-gas flows [8, 9]. Therefore, it is interesting to estimate the effect of centrifugal force on pressure difference \( \Delta P \) in a centripetal motion of a dust-gas flow. To derive a dependence describing the filtering process, we assume here that the pressure difference observed as the flow passes through the filter cake \( \Delta P_{\text{c,dyn}} \) is lower than the pressure difference for a stationary element \( \Delta P_{\text{c,sta}} \) by a value \( \Delta P_{\text{c,cen}} \) determined by the effect of the centrifugal force on the cake:

\[
\Delta P_{\text{c,dyn}} = \Delta P_{\text{c,sta}} - \Delta P_{\text{c,cen}}. 
\]

The validity of equality (1) is obvious, considering that \( P_{\text{c,sta}} \) and \( P_{\text{c,cen}} \) are oppositely directed.

To determine \( P_{\text{c,cen}} \) the elementary pressure developed in the centrifugal field inside a coaxial cake element of a radius \( R \) and thickness \( dR \) is calculated from the following the formula [10]:

\[
d(\Delta P_{\text{c,dyn}}) = \rho_\text{c} \omega^2 R dR, 
\]

where \( \rho_\text{c} \) is the density of the filter cake (dust) on the surface of a rotating filter element; \( \omega \) is the rotational speed.

After integrating equality (2) in the corresponding limits, we obtain

\[
\Delta P_{\text{c,dyn}} = 1/2 \rho_\text{c} \omega^2 (R_{\text{o,c}}^2 - R_{\text{o,m}}^2),
\]

where \( R_{\text{o,c}} \) and \( R_{\text{o,m}} \) are the outer radii of the filter cake layer and the filter membrane.

1 Voronezh State Technological Academy, Russia; Semiluki Refractory Works, Russia; Voronezh Tel’man Railway Car Repair Works, Russia; Voronezh Ceramic Works, Russia.
We express the value \( \omega \) via \( n \) and use the obvious equality

\[
R_{o,c} = R_{o,m} + h_c,
\]

where \( h_c \) is the filter cake thickness.

Then

\[
\Delta R_{o,c} = \frac{\pi^2 n^2}{1800} \rho_c (R_{o,m} + h_c)^2 - R_{o,m}^2
\]

\[
= \frac{\pi^2 n^2}{1800} \rho_c h_c(2R_{o,m} + h_c).
\]

(5)

The volume of the cake on a cylindrical granular layer is expressed as a function of the transmitted gas volume \( V \):

\[
\pi L (R_{o,c}^2 - R_{o,m}^2) = x_n V.
\]

(6)

We substitute \( R_{o,c} \) from Eq. (4) into equality (6) and take into account that \( R_{o,m} = F/2\pi L \), where \( F \) is the outer surface; \( L \) is the height of the rotating filter element.

Then

\[
h_c = \frac{2x_n V}{\sqrt{4x_n V L + F^2 + F}}.
\]

(7)

The numerator and the denominator on the right-hand side of Eq. (7) are divided by \( F \), and we obtain

\[
h_c = \frac{2x_n w}{\sqrt{2x_n V/R_{o,m} + 1/\tau^2 + 1/\tau}}.
\]

(8)

We substitute \( h_c \) from relation (8) into Eq. (5) and after simple algebraic transformations obtain

\[
\Delta R_{o,c} = \frac{\pi^2 n^2}{900} \rho_c R_{o,m} g \left[ \frac{x_n w}{\sqrt{2x_n V/R_{o,m} + 1/\tau^2 + 1/\tau}} \right] R_{o,m} \times
\]

\[
\left[ 2R_{o,m} + \frac{x_n w}{\sqrt{2x_n V/(R_{o,m} + 1/\tau^2 + 1/\tau)} R_{o,m}} \right],
\]

(9)

where \( g \) is the free fall acceleration; \( \tau \) is the filtration time.

Equation (9) is rather complicated for practical use. However, analysis and application of this equation can be considerably facilitated if we use its dimensionless form, having divided both sides of Eq. (1) by \( \rho_g w^2 \), where \( \rho_g \) is the gas density and \( w \) is the linear filtration velocity. Then

\[
Eu_{c,dyn} = Eu_{c,st} - Eu_{c,cen},
\]

(10)

where

\[
Eu_{c,dyn} = \frac{\Delta P_{c,dyn}/\rho_g w^2}{},
\]

\[
Eu_{c,st} = \frac{\Delta P_{c,st}/\rho_g w^2}{},
\]

\[
Eu_{c,cen} = \frac{\Delta P_{c,cen}/\rho_g w^2}{},
\]

(11, 12, 13)

To determine the value \( Eu_{c,st} \) we can use the data from [2], whence

\[
Eu_{c,st} = \pi_2'//(Re_m G[ln(2Ho_m + 1)]^{1/(1-s)}),
\]

(14)

where

\[
\pi_2' = [1/2r_g(1-s)\mu^* w^2 h_m^{1-s} R_{o,m}]^{1/(1-s)},
\]

(15)

\[
Ho_m = \omega_n \tau/ R_{o,m},
\]

(16)

\[
G = h_m/d,
\]

(17)

where \( d \) is the equivalent channel diameter.

The dimensionless complexes \( Eu_{c,dyn}, Eu_{c,st}, Eu_{c,cen}, Re_m, Ho_m \), and \( G \) characterize the hydrodynamic similitude of the considered filtration process; \( s \) and \( h_m \) are the cake compressibility and the filtration membrane thickness, respectively.

Equation (9) is used to determine \( Eu_{c,cen} \). After algebraic transformations we obtain

\[
Eu_{c,cen} = \frac{C \Phi_{cen} Ho_m}{2Ho_m + 1} \frac{1 + 2Ho_m}{\sqrt{2Ho_m + 1}} = \frac{1}{2} C \Phi_{cen} Ho_m,
\]

(18)

where

\[
C = 2R_{o,m} g \rho_g w^2,
\]

(19)

\[
\Phi_{cen} = R_{o,m} \tau^2/900,
\]

(20)

where \( \Phi_{cen} \) is the separation factor.

We substitute \( Eu_{c,st} \) and \( Eu_{c,cen} \) from Eqs. (14) and (18), respectively, into Eq. (10) and obtain

\[
Eu_{c,dyn} = \frac{\pi_2'}{Re_m G[ln(2Ho_m + 1)]^{1/(1-s)}} - \frac{1}{2} C \Phi_{cen} Ho_m,
\]

(21)

It is obvious that regeneration occurs subject to the condition

\[
Eu_{c,dyn} = Eu_{c,st} - Eu_{c,cen} = 0.
\]

(22)

Using Eq. (21), the regeneration condition takes the form

\[
D[ln(2Ho_m + 1)]^{1/(1-s)} = Ho_m,
\]

(23)