1. Introduction

The EAF dust disposal and treatment is a demanded issue in order to attend environmental requirements and industrial economical needs. A large amount of dust is generated by EAF process; in 1999, it was estimated that only in Japan about 500,000 tones of dust is produced per year. It contains large amounts of metals as iron and zinc to be possibly recovered and returned to the materials cycle and a considerable presence of hazardous elements as lead, alkali-s and dioxins that need to be removed. EAF dust treatment by the conventional processes presents not only high treatment costs but also a large amount of residue to be processed and disposed as landfills.

A process of direct separation and recovery of iron and zinc is now under development, which adds environmental and economical perspectives to the EAF dust treatment process. In this process, a coke bed filter can be directly connected to an EAF, collecting metallic iron and slag components, whereas the gas containing zinc and lead vapors flows to a zinc condenser. It results in zero amount of dust liberated to the environment. A two dimensional, axisymmetric and steady state mathematical model describing a coke fixed-bed filter is developed. The model solves coupled equations for gas-powder flow and is specifically applied in the investigation of over-micron and nano-scale powders (similar to EAF dust particle size) collection behavior. The theoretical model results are compared with the cold model experimental results, in which both injection of glass (over-micron) and silica (nano-scale) powders are considered. Microscopic observations and analysis are performed in order to describe better the injected powder behavior through the filter. EAF dust samples morphology is characterized as agglomerates of small particles. Its particle size distribution is obtained by the combination of leaching treatment and image analysis. Calculated results show that the powders particle size distribution has a direct effect in the static hold up. The model has been validated by its enough agreement for static hold up and pressure drop with experimental data from cold model experiments.

KEY WORDS: mathematical model; Electric Arc Furnace; dust treatment; environment; packed bed; filter.
have advanced for more detailed investigations, e.g. including the effect of the temperature, the presence of an electrified field, or the effect of the aerosol deposition on the filtration. A model equation adapted from the theory for a fibrous filter, describing the dust load distribution in a coke bed filter, has also been recently developed and tested.

The aim of this research is to contribute to the development and improvement of the process of direct separation and recovery of iron and zinc, testing and analyzing its efficiency and effectiveness. The physical modeling of the packed bed filter had provided a series of experimental results about pressure drop and the powder collection. In this work a mathematical model of a cold coke fixed-bed filter has been developed. This model is used to investigate the powder accumulation behavior and pressure drop with the injection of over-micron and nano-scale powders in a packed bed. The mathematical model developed here is expected to be the framework for simulation of a high-temperature coke fixed-bed filter and further on to study different aspects of this process.

2. Microscopic Observations and Analysis

Due to lack of information about aerosol collection in packed bed filters, including the theoretical analysis of powders collection mechanisms, more detailed information about the coke-powder interaction characteristics is needed. Fundamental microscopic observations and analysis constitute an important part in the theoretical model development. They are expected to provide the necessary information about the powders and coke interaction characteristics in order to support the coke bed filter mathematical model elaboration. Furthermore, the analysis of the injected powder behavior, in the coke bed filter cold model, as well as in the high-temperature experiments, can also contribute to the study of coke bed filters in general.

2.1. Cold Model of Coke Bed Filter

The dust collection mathematical model experiments are based on a coke bed filter as cold model (Fig. 1), which has 100 mm in inner diameter and 350 mm in effective height. The powders are injected with N2 gas through the gas and powder inlet. The area below the inlet has been found to be highly turbulent and though the gas pressure is measured there it has not been considered in the experimental results. The gas is considered to flow uniformly through the transversal area just above the inlet. Total amount of powder in the filter, as static and dynamic hold ups, is called total hold up. The amount of powder trapped in the filter by the coke particles is called static hold up. The dynamic hold up corresponds to the amount of powder, which left the filter through the top and is collected by water recipients.

The experimental results using the physical model measured dynamic and static hold up, pressure drop, and total amount of collected powder by injecting different fine powders and using different packed beds. In the numerical experiments, two kinds of coke were used as packed particles. Glass and silica powders were used to simulate the EAF dust injection. The calculated results are compared with this experimental results in order to validate the mathematical model.

2.2. Samples and Methods

Microscopic observations and analysis have been performed in order to describe better the injected powder behavior through the coke bed filter. Morphological and chemical analysis of coke samples, collected during experiments at a bench-scale experimental apparatus of a high temperature coke bed filter, have been done. Coke samples collected after cold model experiments, with glass or silica powders, have also been examined by scanning electron microscopy (SEM). The EAF dust samples have come from the baghouses of a Japanese steelmaking plant. Powder and coke samples have been collected at different positions of the coke bed filter bench-scale experimental apparatus.

An EAF dust sample has also been treated with a leaching solution prepared by reagent-grade HCl and distilled water at a concentration of 0.5 mol/l. The sample has been added to the solution in 1:10 solid/liquid mass ratio, and stirred for more than 2 h at around 200 rpm. Considering zinc ferrite as the main phase of EAF dust, and also that only those metals whose chlorides were more stable than their oxides could be leached, the leaching should occur according to the reaction:

\[
\text{ZnFe}_2\text{O}_4 + 2\text{HCl} \rightarrow \text{ZnCl}_2 + \text{Fe}_2\text{O}_3 + \text{H}_2\text{O}
\]

Also, the following reaction ensures that almost no iron should leach.

\[
3\text{ZnO} + 2\text{FeCl}_3 \rightarrow \text{Fe}_2\text{O}_3 + 3\text{ZnCl}_2
\]

SEM, energy dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and Auger electron spectroscopy (AES) are performed to analyze the samples described above. Image analysis technique is used to analyze the EAF dust samples before and after the leaching treatment. The morphological characteristics of the samples are obtained using a scanning electron microscope Hitachi S4100L. The quantitative EDS chemical analysis is performed using an electron probe X-ray microanalyser Hitachi X6505/KEVEX 7000Q. XPS/AES uses a Perkin Elmer PM15600, ESCA multiplex system.

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2.3. Morphological and Chemical Analyses

The EAF dust samples morphology is characterized by SEM (Fig. 2). Agglomerates of small particles and acicular structures are present in the samples (Fig. 2(a)). EDS analysis shows ZnO, FeO and MnO as the major components of the agglomerates and Zn, Fe and Cl as the major elements of the acicular structures. From the XRD results the peaks corresponding to ZnFe$_2$O$_4$ and ZnO are identified as the main phases. Though the peaks are very close to those of Fe$_3$O$_4$ and MgFe$_2$O$_4$, these results are further confirmed by the available literature. 3,5,6) XRD results also shows presence of PbO and Zn(ClO$_4$)$_2$. Zn, ZnO, Cl, Na, K, F, Fe, Si, O and C have been identified by XPS and AES analyses in the first nanometers of the sample surface.

After the leaching treatment the morphology by SEM of the EAF dust shows visible changes, the small particles become loosely aggregated and the acicular structures get disappeared (Fig. 2(b)). The XRD diffractograms shows ZnFe$_2$O$_4$ and $\alpha$-Fe$_2$O$_3$ as main phases. However, peaks corresponding to PbCl$_2$O$_4$, ZnCl$_2$, Zn(OH)$_2$ and Zn(ClO$_4$)$_2$ have been identified. Though XPS and AES analyses have not identified ZnO, they identify Fe peaks with higher intensity and the peaks corresponding to Zn, Cl, Na, F, Si, Ca and P, O and C. Powder samples, collected in the coke bed filter bench-scale apparatus, still keep some agglomeration of the particles, as observed by SEM.

The comparison of the above results suggests the presence of a layer containing oxides and precipitated chlorides covering the small particles of the EAF dust. This further, partially or fully disappears after the leaching treatment, revealing the atomic composition of the particles under this layer. Besides the physical forces that should keep together the small particles to form the agglomerates shown (Fig. 2(a)), some sort of chemical binding is also present, which disappeared after the leaching treatment (Fig. 2(b)). After the EAF, the dust passes through the gas cooler. The condensed ZnCl$_2$ reacts with ZnO and adhere to the small particles of ferrite in the dust. 6) In the case of a process where the coke bed filter is connected directly to the EAF, such layer will not exist because the dust does not pass through the EAF gas cooler.

As explained previously, the literature sets the EAF dust particle size in a range from 0.1 to 20 mm. 1,5,6) The morphological feature of the EAF dust after the leaching treatment (loosely aggregated) has provided further information in this regard. SEM pictures of the above samples are treated by image analysis, using Heywod approximation, to get the EAF dust particle size distribution (Fig. 3). The size of the individual EAF dust particles vary from 0.015 to 1.5 $\mu$m, with harmonic mean of 0.204 $\mu$m. The correlation with their estimated volume shows that particles between 0.38 and 1.2 $\mu$m represent about 81.9% of total particles volume. Using the same methodology to evaluate the EAF dust without the leaching treatment, mainly particles above 0.12 $\mu$m, as part of agglomerates ranging from 0.6 to 4.8 $\mu$m, have been identified. This is the same minimum particle size given by the literature.

The comparison of the above results shows the EAF dust particle size distribution from a different perspective. Furthermore, these results are particularly important considering a process where the coke bed filter connected directly to an EAF. Considering the EAF dust as individual small particles, instead of particles agglomerates, has also a direct impact in the collection mechanisms considered in the theoretical model. As will be showed later (Sec. 3.1), particle size and gas velocity have a direct effect in the way the particles follow the gas streamlines and will be further collected by the coke. Thus the diffusional collection mechanism becomes more significant, whereas other mechanisms should have almost no influence.

Macroscopic observations of the silica powder collection in the coke bed filter cold model have shown how the injected powder accumulates among the coke particles. 29) In order to look at the relation between the size of the injected powders and the coke particles morphology, a series of samples are observed by SEM (Fig. 4). As Fig. 4(a) shows, the glass powder, which is sampled from the coke particles after cold model experiments with glass powder injection, gets trapped inside, in the coke pores. This collection char-
characteristic seems to be reasonable, considering the coke size
distribution. Two main regions of the size distribution in the
coke pores with high volume have been identified, one be-
tween 20 and 30 nm and the other from 50 to 100 nm.

Silica powder, collected in the coke particles after the ex-
periments with silica powder injection, shows the formation
of agglomerates (Fig. 4(b)). The nano-scale particles de-
posit on top of one another, in a process called thermal co-
agulation, forming the so-called ‘tree’ structures.20,21) SEM
observations of the EAF dust collected on the coke parti-
cles sampled from the bench-scale apparatus, shows the
combination of the collection behavior shown above. EAF
dust appears to be spread on the coke surface, and also
forming agglomerates of different sizes, which are collect-
ed inside the coke pores (Fig. 4(c)).

3. Mathematical Formulation of the Powder Collection
in a Coke Bed Filter

The proposed model is two-dimensional, axisymmetric
and steady state. It solves coupled equations for a gas-pow-
der two phases flow in a coke fixed-bed filter. The powders
are injected with the gas and can be deposited and removed
from the coke bed. The governing conservation equations
can be expressed by a common equation.

\[
\text{div}(\rho \vec{u} \phi_i) = \text{div}(\rho \Gamma_i \text{grad} \phi_i) + S_{\phi_i} \quad \cdots \cdots \cdots (1)
\]

The three terms in this common equation are the convection,
the diffusion, and the source terms. The dependent var-
iable, \( \phi_i \), to be solved, is set as velocity, representing the
respective momentum conservation equations. The sub-
script \( i \) refers to the phase being considered (\( i = \text{gas} \) and
powder). An appropriate expression is given for the transfer
coefficient \( \Gamma_i \), and for the source term \( S_{\phi_i} \) (Table 1).

3.1. Powder Collection Mechanisms

The collection mechanisms are responsible for the col-
lection efficiency of the filter and represent the physical
forces (mechanical or electrostatic) acting between the
powders and the collector. Diffusional (or Brownian), iner-
tial, gravitational and direct interception represent the me-
chanical forces between the powder and the collector.21–24)
The influence of the collection mechanisms in the particle
deposition behavior is summarized in Fig. 5.

The diffusional mechanism results from Brownian move-
ment of very small particles in a gas as a result of molecu-
lar collisions and becomes significant in the sub-micron
particle size range. Its influence on the powders collection
is generally proportional to \( \text{Pe}^{2/3} \).22–24) The diffusional col-
lection parameter (\( N_D \)) is expressed by the following equa-
tion.23,24)

\[
N_D = \exp \left[ -k_D \left( \frac{5.24 \text{Pe}^{-2/3}}{\epsilon \mu} \right)^2 \right] \quad \cdots \cdots \cdots \cdots \cdots (2)
\]

The Peclet number (\( \text{Pe} \)) takes into account the aerosol par-
cle diffusivity (\( \delta = k_D \text{TC}_{D'/D} \)) due to Brownian mo-
tion, which can be estimated from the Stokes–Einstein
equation and takes into account the Cunningham slip correction ($C_c$) based on the Knudsen number.\textsuperscript{23,24} The inertial mechanism results from the particle inertia and depends upon the particle mass and velocity. It is predominant for high gas velocities and large particle size.\textsuperscript{22} In the present model, it is evaluated ($N_d$) by the effective Stokes number ($St_{eff} = 0.5S_t(A_d + 1.14Re^{0.5}\frac{\varepsilon_g}{\varepsilon_f})$), which considers the Stokes number ($St_t$), the Reynolds number ($Re = \frac{\rho_d u_t}{\mu_d}$) and the Happel parameter ($A_d$).\textsuperscript{24}

\[ N_d = (kSt_{eff}) \] (3)

In the gravitational mechanism the particle trajectory and its contact with the collector may be altered by the gravity. It becomes relevant only for low gas velocities and for heavy particles with high terminal velocities.\textsuperscript{14,22} It is evaluated by $N_{G}$, as follow.

\[ N_G = \exp \left[ -k_G \left( \frac{u_t}{u_{ef}} \right)^2 \right] \] (4)

The direct interception mechanism occurs when a particle passes from the collector surface at a distance shorter than its radius and is also relevant only for larger particle sizes. Generally its effect is evaluated together with other collection mechanisms because it is difficult to evaluate separately due to their simultaneous occurrence.\textsuperscript{21,22} The influence of the electrostatic collection mechanism should be taken into account when there is an electrostatic field across the filter or when the aerosol particles are electrostatically charged.\textsuperscript{24} The nano-scale powder samples utilized in this study were subjected to a treatment where the particles are neutralized thus its effect has not been considered here.

### 3.2. Deposition Rate of the Powder

The deposition rate of the powder ($R_t$) can be expressed by:

\[ R_t = k_s \varepsilon_t \rho_t \bar{u}_t A_s - k_d \rho_t \varepsilon_f \bar{u}_t \] (5)

The first term corresponds to the sticking rate (proportional to the mass flux of powder) and the second to the departing rate (proportional to the static hold up, quantity of deposited powder and gas velocity). Where $k_s$ and $k_d$ are coefficients of the sticking and departing rates. The collection parameters representing the effect of the collection mechanisms are taken into account in $k_s$ ($k_s = N_{D} + N_{I} + N_{G}$).

\[ k_s = \exp \left[ -k_G \left( \frac{u_t}{u_{ef}} \right)^2 \right] + k_sSt_{eff} + \exp \left[ k_D \left( \frac{5.24 \varepsilon_g^{-2/3}}{\varepsilon_f} \right)^2 \right] \] (6)

Gravitational settling and inertial deposition are the predominating collection mechanisms for the over-micron powder injection. They are represented by first and second terms in this equation, respectively. Diffusional deposition is predominating for the nano-scale powder. It is represented by the last term in the above equation.

The constants $k_D$, $k_s$ and $k_d$ have been determined experimentally by fitting as 4, $1.6 \times 10^{-3}$, and $3.6 \times 10^{-6}$, respectively.\textsuperscript{14} In this study the same values have been used except for $k_d$ that has been found to be higher, $3.6 \times 10^{-9}$. $k_D$ have been considered to be 1.

### 3.3. Static Powder Accumulation on the Coke Packed Bed Interstices

Coagulation of the aerosols\textsuperscript{21,22} and the process of adhesion or fusion of aerosol particles upon contact with one another, plays an important part in its collection. However, the influence of the collector-particle and particle-particle collection on the filter’s efficiency has been shown as a complicated task.\textsuperscript{26,35,36} Different kinds of approach have been studied, however the method below has been chosen because of its simplicity and the good simulation results for the case of silica powder injection.

Observations of the packed bed after the silica powder injection experiments showed a large amount of powder trapped among the coke particles.\textsuperscript{29} The proposed equation for the deposition rate of the powder does not take into account the high dust load situation that maybe happened in these experiments. An experimental correlation based on close up observations of glass beads injected in a coke packed bed physical model\textsuperscript{19} is suggested to be used in this case. Considering the powder trapped between two coke particles, the static powder volume fraction in a cube ($\varepsilon_{fs}^s$), which is the maximum possible static powder volume among the packed particles, is given as follow.

\[ \varepsilon_{fs} = \frac{n_{contact} \times n_{particles}}{V_{cube}} \left( \frac{d^3}{6} \right) \] (7)

The coke particles are considered to be spheres, which can be packed in a face centered cubic structure (FCC) or in a body centered cubic structure (BCC). $n_{contact}$ represents the contact points between the spheres per cube; 12 for FCC and 8 for the BCC coke packed structure. Total number of nano-scale particles collected around the coke particles is given by $n_{particles} (= 6\varepsilon_{filter}^{0.3}/d_{sphere}^{3}/(4d^4))$. It is estimated from the nano-scale particles projected area and the superficial area of the total number of coke particles present in the filter. $V_{cube}$ is $(2d)^3$ for the FCC, and $(2d^2/3)^3$ for the BCC coke packed structure.

For the silica powder injection the relation between the particles size and the coke pore size distribution can also have influence in the observed high dust load of the filter. In this case, the effect of the maximum $\varepsilon_{fs}$, correspondent to the FCC structure, is added to $\varepsilon_{fs}$. The resulting $\varepsilon_{fs}^s$ ($\varepsilon_{fs}^s = \varepsilon_{fs} + \varepsilon_{fs}^s$) is taken into account in the equation for $R_t$, as follow.

\[ R_t = k_s \varepsilon_t \rho_t \bar{u}_t A_s - k_d \rho_t \varepsilon_f \bar{u}_t \] (8)

### 3.4. Interphase Drag Forces

The interaction forces between gas and solid phases are evaluated by the Ergun’s equation\textsuperscript{37} which has been further modified\textsuperscript{33} to take into account the static powder influence.

\[ \bar{F}_{gs} = 150 \mu_g \frac{(\varepsilon_{gas} + \varepsilon_{fs})^2}{(\varepsilon_{gas} + \varepsilon_{fs})^2 (1 - \varepsilon_{gas} - \varepsilon_{fs})} \bar{u}_g \]

\[ + 1.75 \mu_g \frac{(\varepsilon_{gas} + \varepsilon_{fs})}{\varepsilon_{gas} (1 - \varepsilon_{gas} - \varepsilon_{fs})} \bar{u}_s^2 \] (9)
The gas-powder interaction is represented by a single particle drag coefficient modified for particulates moving in a flow, with the Richardson and Zaki’s voidage function.

\[ F_{g} = C_{d} \left( \frac{ \varepsilon_{g}}{\varepsilon_{g} + \varepsilon_{i}} \right)^{4.65} \left( \frac{3 \varepsilon_{i} \rho_{g}}{4 d_{i} \rho_{i}} \right) \left[ \hat{u}_{g} - \hat{u}_{i} \right] \left[ (\hat{u}_{g} - \hat{u}_{i}) \right] \quad \text{(10)} \]

The interaction forces between the solid and the powder phases is based upon an experimental correlation from cold model experiments, where the interaction coefficient \( F_{ik} \) is related with the flow direction and dependent on Froude Number.

\[ F_{ik} = \frac{F_{ik}}{2D} \left[ \hat{u}_{i} - \hat{u}_{g} \right] \left[ (\hat{u}_{i} - \hat{u}_{g}) \right] \quad \text{(11)} \]

### 3.5. Calculation Conditions

The physical properties of coke particles and injected powders (glass and silica powders) used in the cold model experiments are shown in Table 2. The typical experimental conditions are shown in Table 3. The coke shape factor is calculated as a fitting parameter from preliminary results of the cold model experiments using the Ergun’s equation.

The fixed-bed calculation domain for the cold model apparatus considers that gas and powder inlet is located in the bottom of the filter and their outlet is in the top. Figure 6 shows the calculation domain and boundary conditions considered in the theoretical model.

### 4. Calculated Results and Discussion

The static hold up results for the case where glass powder is injected in the coke bed filter, using cokes A and B as packed particles, are shown in Fig. 7. Results, calculated by the present model, show that the static hold up decreases with the increase of the gas superficial velocity. These results are in good agreement with the experimental results. The exception was the static hold up measured at 0.42 m/s using coke B as packed particle. However, this can be related with a possible blockade of the packed bed due to a faster dust load that may happen at low gas velocities. This was previously observed by Shibata et al. in their packed bed under certain experimental conditions.

Pressure drop results (Fig. 8) can be compared with the Ergun’s equation because this is used to evaluate the interaction forces between gas and solid. For a clean gas flow, the pressure drop calculated by the mathematical model for different gas superficial velocities show good agreement with the Ergun’s equation. The calculated results for the pressure drop, considering the glass powder injection, also agree with those obtained in the experiments using the cold model apparatus. The pressure increases with the gas superficial velocity, and decreases from the bottom to the top of the filter. In the case of powder injection, the gas–solid interaction force is given by the Ergun’s equation modified to take into account the effect of the static powder among the coke particles in the bed. Thus, the effect of the powder injection is expected to raise the pressure drop in comparison with the pressure drop for the clean gas flow. This tendency is also observed in the calculated results. Regarding the pressure drop at 0.42 m/s using coke B as packed particle, a rapid increase of pressure drop was expected due to the blockage. However, probably due to some leakage in the
apparatus during this experiment, the effect of the blockage in the pressure drop has not been observed in the experimental results.\textsuperscript{27)}

Calculated results for the static hold up and pressure drop for the case where silica powder is injected in the coke bed filter, using coke B as packed particles, are shown in Fig. 9. Both experimental and calculated results show that the static hold up is slightly higher at lower superficial gas velocities. However, the difference in the static hold up between the lower (0.21 m/s) and the higher (0.64 m/s) gas superficial velocities is about 1%. The agreement achieved between calculated and experimental results validates the proposed expressions to evaluate the static nano-scale powder accumulation in the packed bed.

Based on the Ergun’s equation, the pressure drop is expected to increase with the gas superficial velocity. The calculated results of pressure drop show a slightly increase and a good agreement with the experimental results.

For the case of nano-scale powder injection, in the predominant Brownian movement the trajectories of the particles do not coincide with the gas streamlines.\textsuperscript{21)} Further, the effect of the thermal coagulation due to Brownian motion contributes for the powder adhesion forces, accelerating its collection.\textsuperscript{20,21)} Both phenomena should increase the static hold up that affects the calculated pressure drop, which increases with the gas superficial velocity.

In the specific case of the coke bed filter cold model, visual observation of the packed bed after the experiments with silica powder injection showed that gas and dynamic powder have flowed by preferential channels.\textsuperscript{29)} In this case the measured pressure drop will be lower than the expected considering the same amount of static hold up. Channeling is not considered in the present mathematical model, and only the advancement of the model to simulate the high-temperature coke bed filter could bring data for further discussions.

A static hold up between 2 and 4.5% has been found for the glass powder injection. However, this is a lower amount compared with the static hold up for the silica powder injection, which is about 30%. This effect of the powders particle size in the static hold up is taken into account in the mathematical model by $k_s$, used to calculate the deposition rate of powder, which considers the effect of the collection mechanisms.

The particle size and gas velocity have a direct effect in the collection mechanisms, as discussed earlier. The calculated results clearly show the same effect. In the case of glass powder injection the inertial mechanism evaluated by the Stokes number predominates. For the silica powder injection the diffusional mechanism predominates, and this effect is evaluated by the Brownian diffusivity in the Peclet number.

As a consequence of the powder particle size effect in the static hold up, the pressure drop is also affected in the calculated results. The difference in pressure drop with the injection of glass and silica powders is more than one order of magnitude for the same packed bed (coke B). This effect has been taken into account in the mathematical model with the inclusion of the static hold up in the gas–solid interphase drag force by modifying the Ergun’s equation. The modified Ergun’s equation has been found to be applicable for packed particles, powders and experimental conditions used in the calculations, \textit{i.e.}, $h_s$ between 1.9 and 29%.

The good agreements for calculated results of the pressure drop and the static hold up with the experimental results further validate the present mathematical model.

5. Conclusions

A mathematical model of coke fixed-bed filter, which solves coupled equations for a gas-powder flow is present-
ed. The model has been further validated by its good agreement for static hold up and pressure drop with experimental data from cold model experiments. The comparison of results for glass and silica powders injection shows that the powders particle size distribution has a direct effect in the static hold up. It also affects indirectly the pressure drop, due to its effect in the static hold up.

Through microscopic observation and analysis, the overmicron and nano-scale powders, as well the EAF dust, collection behavior has been investigated. The EAF dust samples morphology is characterized as agglomerates of small particles and in the form of acicular structures. The chemical analysis results suggest the presence of a layer containing oxides and precipitated chlorides covering these particles. After the leaching the small particles became loosely aggregate, and the EAF dust particle size distribution (0.015 to 1.5 µm) is obtained by image analysis. Before the leaching, particles above 0.12 µm have been identified in agglomerates from 0.6 to 4.8 µm. From the Microscopic analysis, glass powder is collected mainly inside the coke pores, whereas silica powder deposits on top of one another; the same general collection behavior of EAF dust.

**Nomenclature**

- \( A_p \): Happel parameter \( = \frac{[2(1-(1-\varepsilon_g)^{5/3})/\left(2-3(1-\varepsilon_g)^{1/3}+3(1-\varepsilon_g)^{5/3}-2(1-\varepsilon_g)^2\right)]}{\text{f}} \)
- \( A_s \): Surface area normal to flowing direction per unit volume \( [\text{m}^2/\text{m}^3] \)
- \( C_{\text{dr}} \): Drag coefficient for a single particle \( = \frac{24}{Re_p} \left( \frac{1}{Re_p^{0.67}} \right) \left( \frac{1}{Re_p} \right) \left( 1-\varepsilon_p < 1 \right) \)
- \( C_u \): Cunningham slip correction \( = e^{0.44} \left( 1.42 + 0.558 \exp(-0.999/k) \right) \)
- \( d_f \): Coke diameter \( [\text{m}] \)
- \( d_i \): Fines diameter \( [\text{m}] \)
- \( d_{\text{bed}} \): Coke bed filter diameter \( [\text{m}] \)
- \( D_1 \): Equivalent diameter of the packed bed for solids-powder interaction \( [\text{m}] \)
- \( F_1 \): Drag force between phases \( i \) and \( j \) \( [\text{N/m}^3 \text{bed}] \)
- \( R_s \): Interaction coefficient between solids and powder \([\text{m}] \)
- \( g \): Acceleration of gravity \( [\text{m/s}^2] \)
- \( k_B \): Boltzmann constant \([\text{J/K}] \)
- \( k_d \): Coefficient of departing rate \([\text{s}^{-1}] \)
- \( k_{\text{dr}} \): Constant for diffusional deposition \([\text{m}] \)
- \( k_i \): Constant for inertial deposition \([\text{m}] \)
- \( k_s \): Constant for gravitational settling \([\text{m}] \)
- \( h_{\text{filter}} \): Coke bed filter height \( [\text{m}] \)
- \( h_s \): Static hold up \( [\text{m}] \)
- \( n_{\text{contact}} \): Contact points between the spheres (coke particles) per cube \([\text{m}] \)
- \( n_{\text{particles}} \): Total number of nano-scale particles collected on the coke particles \([\text{m}] \)
- \( N_p \): Diffusional collection parameter \([\text{m}] \)
- \( N_i \): Inertial collection parameter \([\text{m}] \)
- \( N_s \): Gravitational collection parameter \([\text{m}] \)
- \( P_g \): Gas pressure \([\text{Pa}] \)
- \( P_e \): Peclet number \( = \frac{u_d d_p}{\delta} \)
- \( R_p \): Deposition rate of powder \([\text{kg/m}^3 \cdot \text{s}] \)
- \( R_s \): Stokes number \( = \frac{C_{\mu, d_p} \rho_p}{(9\mu_d \delta)} \)
- \( Su \): Effective Stokes number \([\text{m}] \)
- \( S_{\phi} \): Source term of \( \phi \) \([\text{N/m}^5] \)
- \( T \): Temperature \([\text{K}] \)
- \( u_f \): Superficial velocity for phase \( i \) \([\text{m/s}] \)
- \( u_t \): Fines terminal velocity \([\text{m/s}] \)
- \( V_{\text{cube}} \): volume of the cubic packed structure \([\text{m}^3] \)

**Greek letters**

- \( \delta \): Brownian diffusivity of the powders \([\text{m}^2/\text{s}] \)
- \( \epsilon_i \): Volume fraction of phase \( i \) \([\text{m}^3/\text{m}^3] \)
- \( \epsilon_{is} \): Static powder volume fraction \([\text{m}^3/\text{m}^3] \)
- \( \phi \): Dependent variable \([\text{m}] \)
- \( \Gamma_\phi \): Transfer coefficient of \( \phi \) \([\text{kg/m} \cdot \text{s}] \)
- \( \psi \): Shape factor of phase \( i \) \([\text{m}] \)
- \( \mu_g \): Gas viscosity \([\text{kg/m} \cdot \text{s}] \)
- \( \rho \): Density of phase \( i \) \([\text{kg/m}^3] \)

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