Application of the Blaine Apparatus for direct assessment of different suspended mixture filterability

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Abstract. The article is devoted to research work, in which an attempt is made to apply the Blaine apparatus for direct assessment of filterability of different materials. In the theoretical part of the article the main laws linking the Blaine index of the powder material and the average specific cake resistance are described. A number of experiments with materials taken from actual operating plants are carried out. To determine the Blaine-index the laboratory Blaine apparatus is used and standard tests of filterability on the batch pressure filter is used to determine the average specific cake resistance. As a result of processing experimental data and the necessary calculations direct relations between the Blaine-index and average specific cake resistance are obtained.

1. Introduction

The standard method for calculating the filtration process, determining the conditions for its occurrence and the subsequent commissioning of an industrial filter at the beneficiation plants implies a preliminary test of the filterability of the suspension. Such tests are usually carried out on special laboratory pilot filters that differ from industrial installations only in size and operating pressure drop. In some cases, this is not an easy task, as it requires either transportation and subsequent adjustment of the laboratory pilot filter at the processing plant, or sending a sufficiently large amount of the suspension directly to the laboratory.

In this article, the filtering process is considered on the example of filtering process pulps for non-ferrous metallurgy enterprises. As a rule, when filtering after a multi-stage grinding process and flotation concentration, the concentrates of various metals contain a large amount of moisture, which must be eliminated. Often, before convective drying, which requires large amounts of energy, a filtration process is carried out to remove the bulk of the liquid phase. It is precisely the quality and quantity of the filter product that depends on the efficiency of the installed filters, but also the cost of the subsequent drying of the material, if it is still necessary. Therefore, one of the main tasks for today is to intensify the work of various filters.

One of the directions in solving the problem of intensifying testing is the use of new laboratory equipment that has not previously been used to determine the filterability of suspensions. It is this setup that is the Blaine apparatus, which measures the Blaine index, or in other words, the specific surface area of the particles of the powder material. This characteristic is one of the main indicators of the size of these particles of the powder material. On the other hand, the particle size, in fact, determines the resistivity of the precipitate formed during the filtration process on the filter septum. Thus, it is possible
to follow a definite connection between the Blaine index and the filterability of various suspensions.

2. Theoretical studies

2.1 Air Permeability Testing

The method of determining the Blaine Index is based on measuring the time required for a certain amount of air to pass through a known volume of the bulk material under investigation. This time is used in further calculations to determine the specific surface area of particles (expressed in cm\(^2\) \(\cdot \) g\(^{-1}\) or in m\(^2\) \(\cdot \) kg\(^{-1}\)). Similar tests are conducted on a cheap and easy-to-use Blaine apparatus.

The method of testing powders on a Blaine apparatus is described in detail in ASTM C 207-07 (the standard method for determining the specific surface area of hydraulic cements by air permeability) and consists of several stages [1].

Despite the obvious advantages of determining a specific surface area using a Blaine apparatus, this method has its drawbacks [2]. Based on numerous experiments, it was shown that the accuracy of the method is reduced when testing powders consist of very small particles. It was found that the method becomes practically inapplicable when testing materials with a specific surface area of particles greater than 500 m\(^2\)/kg due to the great unreliability.

2.2 Evaluation of the suspension filterability

The filterability of the suspension is entirely determined by the properties of its solid and liquid phases [3]. The most important characteristic of a filter cake, from a theoretical point of view, is its average specific resistance. The most widely used model for describing the movement of the liquid phase of a suspension through a layer of sediment, taking into account the influence of particle sizes, is the Kozeny-Karman equation [4]:

\[
Q = \frac{\varepsilon^3}{K \cdot (1 - \varepsilon)^2 \cdot \text{SSA}^2 \cdot \rho_S^2 \cdot \mu_L \cdot \Delta p \cdot A},
\]

where \(Q\) is the volume velocity of the liquid phase [m\(^3\) \(\cdot\) c\(^{-1}\)], \(\varepsilon\) is the local porosity of the sediment, \(\Delta p\) is the pressure difference [Pa], \(A\) is the area of the filter septum [m\(^2\)], \(K\) is the Kozeny constant, \(\text{SSA}\) is the specific surface area of the sediment particles [m\(^2\) \(\cdot\) kg\(^{-1}\)], \(\rho_S\) is the density of the solid phase of the suspension [kg \(\cdot\) m\(^{-3}\)], \(\mu_L\) is the viscosity the liquid phase of the suspension [Pa \(\cdot\) s], \(L\) is the thickness of the precipitate [m].

The Kozeny constant \(K\) depends on the structure of the precipitate. For randomly formed incompressible precipitation, the value of this constant is assumed to be 5 [5, 6]. Equation (1) can be transformed into a form expressing the dependence of the resistivity of the sediment on a number of factors:

\[
\alpha_{Av} = \frac{5 \cdot \rho_S \cdot \text{SSA}^2 \cdot (1 - \varepsilon_{Av})}{\varepsilon_{Av}^3},
\]

where \(\alpha_{Av}\) is the average resistivity of the sediment [m \(\cdot\) kg\(^{-1}\)], \(\varepsilon_{Av}\) is the average porosity of the sediment. Equation (2) clearly shows the quadratic dependence of the average specific resistance of the sediment on the specific surface area of its particles with a constant value of the average porosity. It should be noted that the last expression can be used to estimate the value of \(\alpha_{Av}\) only for incompressible or weakly compressible sediments. In the case of highly compressible sediments, which change their structure and porosity under the action of pressure drop, the formula becomes inapplicable [7].

3. Experimental equipment and methods

The purpose of the experiments was to investigate the possibility of the manifestation in practice of the relationship between the specific surface area, measured using a Blaine apparatus, and the average specific resistance of the sediment, as determined by conducting filterability tests.

A total of 11 different materials were tested, with different particle sizes, shapes, and their size distribution. Among them were wheat starch, coal powder, calcium carbonate, titanium dioxide, synthetic magnetite, apatite concentrate, industrial magnetite, iron concentrate, zinc concentrate, copper concentrate, and pyrite concentrate. All materials were taken from various processing plants.
Laboratory equipment consisted of a Blaine apparatus (Figure 1) for estimating the specific surface area of powder materials and a laboratory Nutsche filter (Figure 2) for determining the average specific resistance of precipitation [8].

**Figure 1.** Schematic representation of the Blaine apparatus: 1 - tinted liquid; 2 - U-shaped manometer; 3 - cell with packaged material; 4 - plunger; 5 - glass faucet; 6 - rubber-new pear; a, b, c, d are the markers on the manometer tube.

**Figure 2.** Schematic representation of the filtering system: 1 - laboratory analytical scales; 2 - capacity for filtrate; 3 - replaceable filter septum; 4 - laboratory suction filter; 5 - valve on the pipe to enter the suspension; 6 - pipe to enter the suspension; 7 - valve on the compressed gas supply pipe; 8 - tube for supplying compressed gas; 9 - valve for regulating the gas pressure inside the filter; 10 - gas cylinder (nitrogen); 11 - the computer.

4. **Results and discussion**
The graph of average specific sediment resistance versus specific surface area for all tested materials (1 - pyrite, 2 - iron, 3 - wheat starch, 4 - synthetic magnetite, 5 - apatite, 6 - copper, 7 - coal powder, 8 - titanium dioxide, 9 - zinc, 10 - industrial magnetite, 11 - calcium carbonate) is presented in Figure 3 and Figure 4.
Figure 3. Dependence of sediment resistivity on specific surface area for pressure drop across the filter 2.0 bar. Solid line - in view of all materials; Dash-dotted line - without titanium dioxide, synthetic magnetite and wheat starch

Figure 4. Zoom. Dependence of the resistivity of the sediment on the specific surface area for pressure drop across the filter is 2.0 bar. Solid line - in view of all materials; Dash-dotted line - without titanium dioxide, synthetic magnetite and wheat starch

Analyzing the experimental data obtained in Figure 3 and Figure 4, it is possible to conclude that for the majority of materials tested there is a direct relationship between the resistivity of the sediment and the specific surface area of the material [3, 8, 9]. Figure 3 shows an approximating straight line (dash-dotted line) constructed according to the quadratic dependence law. It clearly shows a completely expected result - the dependence of the resistivity of the sediment on the square of the specific surface area (equation 2). Moreover, the correlation coefficient is quite close to unity value - 0.969.

Also from the graphs, it is possible to see that some materials, such as titanium dioxide, synthetic magnetite and wheat starch do not obey the general dependence characteristic of all other materials. The first two materials consisted of very small particles (the specific surface area was much more than 500
m²/kg), which could have led to unreliable results when tested on a Blaine apparatus [2]. Wheat starch, also used in tests as an organic substance during filtration, could change its properties (for example, the size and shape of particles), making it more error in the final measurement result [10-12]. To clarify the dependencies obtained in the research work, it is further supposed to be tested with a much larger number of different materials, for example coals [13]. It would be interesting to test materials with a wider range of specific surface area (up to 1000 m²/kg).

5. Conclusion

Based on a literature search and conducting experiments with a fairly large number of different materials, it can be concluded that the method for measuring the specific surface area of materials on a Blaine apparatus may be suitable for estimating the specific resistance of precipitations of most materials used in research.

Despite some limitations of the definition of the Blaine-index, this technique is most appropriate for assessing the filterability of suspensions in cases where it is necessary to quickly obtain the final result, it is not intended to spend significant financial resources on experiments and in the presence of a very small amount of material for testing.

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