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Short communication

Permeability distribution for filter media characterization in solid liquid filtration

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ABSTRACT

In solid liquid filtration, textiles represent a key element of the setup where it represents the barrier between disperse solid particles and the filtrate. Among other characteristic textile data, the specific flow at standard test conditions is relevant information of filter performance. Nevertheless filter media with comparable characteristic data may exhibit quite different filter performance in terms of filtration rate and filtrate clarity. For a better description of the interaction between filter media and suspension the determination of the permeability distribution (PD) is proposed. This characteristic function is derived from filtration tests where the filtrate is obtained cumulatively over time at constant pressure. Experimental data show that for the same suspension different filter media with different mean permeability show different permeability distributions but also result in different specific cake resistance.

1. Introduction

Porous media, most prominently textiles, have a wide range of applications. Particularly in technical separation, i.e., filtration they represent a key element of the setup. In solid fluid separation filter media represent the barrier where disperse solid particles are accumulated either inside the filter media through depth filtration or by cake filtration on top of the filter media [1].

As a standard, information about the filter media is provided such as mechanical, thermal, and chemical stability, geometric data at various scales, i.e., filter fibre characterization in terms of cross sectional area and fibre roughness, weaving or knotting technique, filter mat thickness, filter media pore size and shape distribution, respectively, and finishing procedure, e.g. calendaring [2]. In addition, information is sometimes provided such as the chemical composition, surface properties of the filter media and standardized flow resistance measurements, generally expressed as a specific flow of water or air at a standard pressure difference [3].

This information is all necessary and helpful in correctly guiding filter media selection for a certain separation task. But in essence it proves insufficient to correctly predict the actual performance of a filter media for a specific separation task [4]. Thus, tests are paramount where a representative filter media sample is used in the laboratory or pilot plant and the filter performance is established with the original slurry sample. Filter media with comparable characteristic data may exhibit quite different filter performance in terms of filtration rate and filtrate clarity without apparent reason. Even when the filter performance is similar with new filter media, filter performance can deteriorate quite differently over time resulting in significantly different life times.

To better account for the interaction between filter media and slurry/solid laden gas the determination of the so called permeability distribution (PD) is proposed [5]. This PD goes beyond a mean specific flow resistance value, since it accounts for the permeability of the actual filter media together with the formation of the first particle layer through surface filtration including its permanent contamination and aging situation. This characteristic function can be derived from filtration tests as well as during actual operation and it is based upon the transient profile that is characteristic for the type of operation and the result of an unequivocal permeability distribution of the filter media. Thus, the transient development of these permeability distributions allows a more substantiated extrapolation of filter performance including guidance for the optimal life span of a filter media until replacement. The consequences of different filter cleaning measures on subsequent filter performance can be evaluated and, to some extent predicted.

Although particle filtration from gas at constant volume flow is different from solid liquid filtration at constant pressure difference, the same approach, i.e., separation of variables is employed to again derive a permeability distribution of the filter media in conjunction with a specific suspension from experimental data.

2. Experimental

Experiments were performed with a vacuum filter test unit as schematically depicted in Fig. 1.

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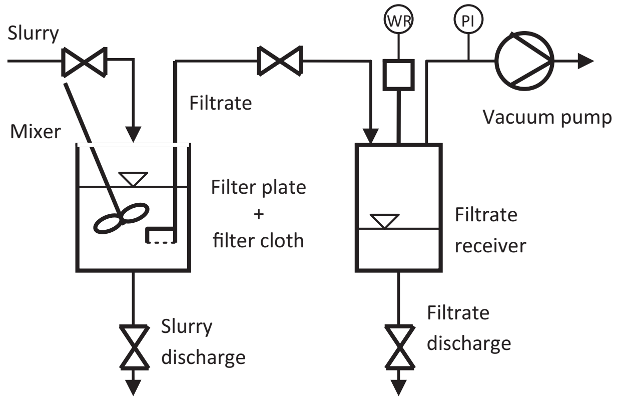

Fig. 1. Simplified flow sheet of experimental setup for discontinuous particle filtration from liquid slurry at variable filtrate flow and constant pressure difference.

Commercial grade calcium hydroxide was dispersed in water to obtain a suspension that was put in an open vessel (approximately 30 l) thoroughly mixed with a mixing device. A rectangular filter element was covered with a filter cloth that was tightly fixed with a rubber band in a suitable groove on the side walls. In order to avoid the cake to be washed off from the filter media when submerged in the agitated vessel, a frame from thin metal sheets was attached at the circumferential sides of the filter element allowing the cake to be formed basically undisturbed by shear forces induced from the mixing device. The distance from the metal sheet edge towards the filter cloth was approximately 20 mm which was always more than the final cake thickness.

While all ball vales were closed, a vacuum pump was started to evacuate the system to a set differential pressure. Once this differential pressure was reached the ball valve connecting the filter plate with the filtrate receiver was opened and the filtration started, i.e., the filtrate started flowing and filling the filtrate receiver and the filter cake was forming and continuously growing. The weight increase due to filtrate accumulation was continuously recorded. Occasionally the filtrate was discharged from the vacuum receiver but not during an experimental run. The pressure difference was monitored during the experiment and was found to remain almost constant at the pre-set value. After a certain time the experiment was terminated by closing the ball valve in the line after the filter plate. At the same time the filter plate was lifted out carefully from the slurry tank to avoid the filter cake from falling off the filter cloth. Afterwards the filter cake thickness was measured at saturation one, i.e., the cake completely filled with liquid. The cake was scraped off the filter plate and heated in a heating oven to determine the characteristic data of the filter cake, i.e., solid content and cake porosity.

The conditions of the slurry were kept constant in terms of temperature (ambient), pressure (ambient), concentration, and water conditions. In the mixing vessel the suspension level decreased slightly during the course of an experiment since no slurry was added during an experiment but only after. The parameters of the mixing device remained unchanged during the set of tests. Moreover also the position of the filter element was kept the same, i.e. the submersion level of the filter element was kept at 200 mm. The constant operating and geometry as well as property data are listed in Table 1.

Three experiments were performed with the same pressure difference, solid concentration of the slurry but different filter media A, B and C though all of woven multifilament type.

Table 1
Constant operating, geometric and property data of laboratory scale liquid filter test.

A_{tot} (m^2)	Δp (Pa)	η (Pa s)	ρ_{liquid} (kg/m^3)	c_{sol} (kg/m^3)	ρ_{solid} (kg/m^3)
0.01	4×10^4	1.14×10^{-3}	1000	166.7	2240

3. Experimental results

In Fig. 2 the results are displayed obtained with three different filter media A, B and C, respectively. The cumulative filtrate volume is depicted over filtration time. Clearly filter media A allows much faster filtration rates compared with filter media B and C. The concave shape of the cumulative transient filtrate curve is quite typical since with increasing cake thickness the overall flow resistance increases having a lower filtrate rate as a consequence. The filled symbols indicate the termination of the respective experiment. The lines are the results of model simulations performed with mean values and described below. Please note that model prediction is already very good for media C whereas some discrepancies appear for media A and B.

In Table 2 the final mean cake height and the calculated cake porosity at saturation one are listed. The cake porosity is slightly different which can easily be attributed to e.g. measurement imprecisions of the cake height or a slightly uneven cake thickness. Moreover also the determination of the cake mass is associated with some errors.

Given that the cake porosity, the slurry and the operating conditions are the same one would expect very similar specific cake resistance parameters. When the experimental filter test data are evaluated based on Darcy's law for constant pressure filtration, the ratio of filtration time and filtrate volume is plotted versus the filtrate volume (Fig. 3). A linear fit of the experimental data allows deriving the filter media resistance (intersection with the ordinate) and the filter cake resistance (slope). (The solid black lines are the result of a non-linear fit whereas the dashed lines are the result of the linear fit based on the models described in chapter 4.) Clearly the slopes are quite different indicating that the filter media resistance is quite different as well. If the data do not strictly follow a linear trend, non-ideal phenomena could be a reason for it besides some experimental shortcomings particularly at the start of the experiment, where experimental operating parameters cannot be set instantaneously. A convex shape is an indication that cake compression effects may play a role [7]. A concave shaped curve particularly at the beginning of filtration can be due to particles that at least partly block the filter media right after start of the filter test [8] during the surface filtration phase. This initial filter cake formation is reported to be of statistical nature even on perfectly homogeneous filters resulting in a rather inhomogeneous apparent filter situation for subsequent cake filtration [9]. This phenomenon is often also termed filter blinding [10] which results in a possibly quite inhomogeneous filter permeability for the subsequent filtration.

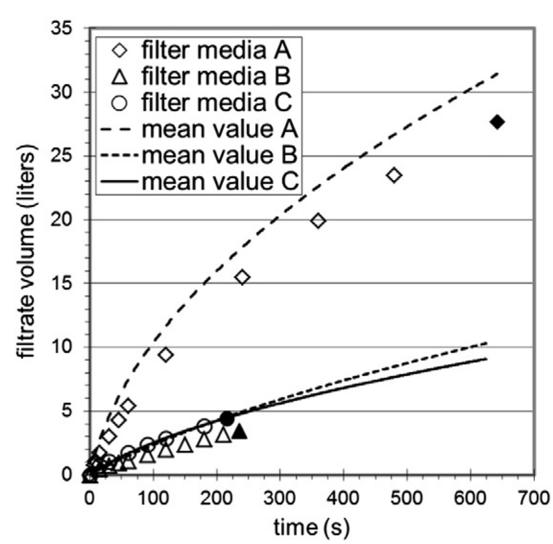

Fig. 2. Cumulative filtrate volume over time as a function of different filter media difference. (Symbols: experimental data, lines: model simulations.)