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EXPERIMENTAL INVESTIGATION OF FILTRATION ON A ROTARY NUTSCHE

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The filtering ability of a pilot plant cylindrical rotary nutsche (RN filter) has been tested on the basis of vacuum and pressure filtration experiments with suspensions of diatomite, magnesian limestone, and cellulose. The rotary nutsche is constructed like a circular drum with the bottom half being used as the filter area. The drum is placed on four wheels and simple rope drive enables the drum to oscillate. It is declared that this arrangement should possess several merits in comparison with the classical nutsche. It was confirmed by results of filter tests that the filter can be used for anticipated applications with declared priorities following from principle of its construction. The results showed an evident dependence of filter performance and filter cake quality on the mode of filter drum rocking and the properties of solid.

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Introduction

Industrial separation of adequately coarse suspensions is often carried out on vacuum or pressure nutsches. In principle, these are open or closed vessels with a planar filter medium at the bottom. As an alternative of such a classic nutsche, a rotary nutsche (RN filter) was developed by Pierson [1]. The rotary nutsche is constructed like a circular drum with the bottom half being used as filter area. The drum is placed on four wheels and simple rope drive enables the drum to oscillate. It is declared that this arrangement should possess several merits in comparison with the classic nutsche.

The thick filter cakes created on the planar filter medium in a basic nutsche have a tendency to crack and hence can be washed and dewatered poorly. A semi-tubular filter bed, which is allowed to swing forwards and backwards, makes possible that the cake is formed uniformly and has an ability to fill in the cracks as long as the cake maintains a certain degree of fluidity. After a cake has been formed, washing can take place. The drum can be made to rock more vigorously (or inverted) causing the cake to reslurry. If hot air (or gas) is introduced, the RN filter can act like a tumble dryer. For the cake discharge, the drum is inverted and an airblast breaks the cake. The entire filter is totally enclosed, satisfying the most stringent safety regulations.

The anticipated merits of the RN filter have not been verified by filtration experiments yet. In this contribution, the results are presented of the testing the filtration abilities of a rotary nutsche following from the filtration tests performed with aqueous suspensions of diatomite, limestone, and cellulose on a prototype of pilot-plant RN filter.

Experimental

In our filtration tests, laboratory and pilot-plant filtration measurements were performed. The preliminary pilot-plant filtration experiments with suspensions of limestone were carried out in the vacuum mode, a set of systematic filtration tests were carried out in the pressure mode for the sake of easier measurement of filtrate mass.

Feeds

The suspensions of diatomite (kieselguhr), magnesian limestone, and cellulose were used in our filtration experiments. Concentration of solid in suspension varied from 25 to 50 kg m^{-3} of filtrate. Table I summarises the basic characteristics of the solids.

Diatomite represents a material with good filterability and can be used for both vacuum and pressure filtrations. On the other hand, aqueous suspension of the crushed magnesian limestone creates filter cakes with low permeability, thus exhibiting low filtration velocity, particularly in the very end of experiment. The suspensions of cellulose form filter cakes of stable fibrous aggregates with an open structure and with minimal adhesion to the filter medium. Preliminary laboratory experiments showed that all the materials used create filter cakes with a tendency to cracking, mainly at the vicinity of the equipment walls.

Table I Basic characteristic of feed solids and filter cakes created

Solid	Diatomite	Crushed magnesian limestone	Cellulose
Supplier	Calofrig Borovany, Czech Republic	KV Kunčice, Czech Republic	JRS Germany
Type	F-70	sort 7, class III	Arbocel BC-200
Particle size range (sieve diameter), μm	40 μm — 25% oversize 250 μm — 0% oversize	90 μm — 34% oversize 500 μm — 4.7% oversize	free-filtering fibres
Particle settling rate	slow	rapid	slow
Wet density, kg m^{-3}	300	1350	180
Solids concentration, $kg_{(solids)}/m^3_{(filtrate)}$	50	50	25
Cake formation rate, cm min^{-1}	0.1 – 1	0.01 – 0.1	0.5 – 3
Filtrate rate, m^3 m^{-2} h^{-1}	0.2 – 3	0.05 – 1.5	1 – 4
Cake compressibility	low	very low	high
Cake adhesivity	medium	high	very low

Filter Cloth

The filter cloth used in the filtration experiments was a polypropylene woven fabric of undefined pore size, which was firmly fitted to the filter draining section. For laboratory experiments an equivalent was chosen (PP 747 018, Technolen Lomnice nad Popelkou, the Czech Republic) which exhibited approximately equal permeability and retention for the feeds tested.

For testing the working ability of RN filter, the pilot-plant RN filter delivered by Chemquip LTD. England was used. Assembly of the filter and its main dimensions are shown in Fig. 1. The values of some quantities characterising the filter are given in Table II.

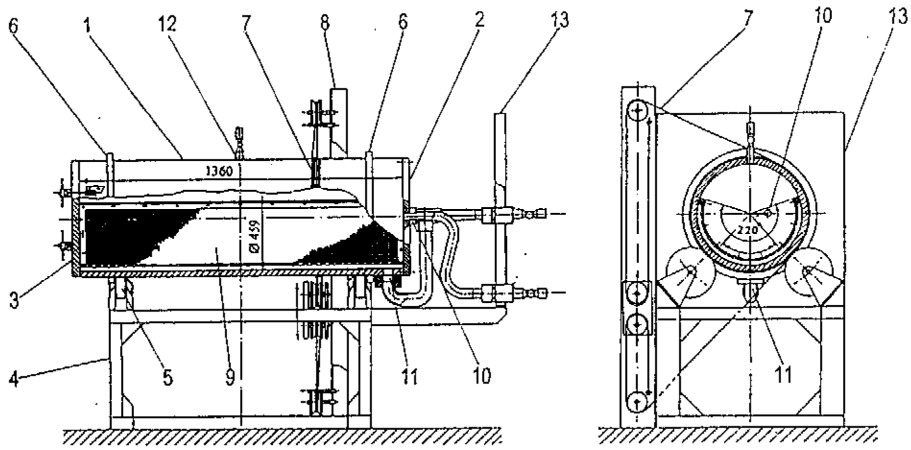

Fig. 1 Schematic diagram of the rotary nutsche (RN filter): 1 – cylindrical shell; 2,3 – circular covers; 4 – steel frame; 5 – wheels; 6 – circular strips; 7 – steel rope; 8 – pneumatic mechanism; 9 – plastic grid; 10,11,12 – pipe couplings; 13 – cover plate

Table II Values of quantities characterising the pilot-plant RN filter

Inner diameter of the drum	0.439 m
Length of the drum	1.36 m
Maximum filling	0.184 m^3
Minimum filling for immersion of the filter cloth	0.103 m^3
Height of spherical cup above immersed filter cloth	0.187 m
Dimension of the filter cloth	0.632×1.3 m
Filter face area	0.82 m^2
Thickness of the filter grid	0.02 m

The basic part of the filter is a cylindrical shell *1* made of polypropylene of 0.439 m in inner diameter and 1.36 m in length. The shell is closed by two circular covers *2* and *3* also made of polypropylene. The drum is placed in a steel frame *4* on four wheels *5*. On the outer perimeter of the drum shell, two circular strips *6* are attached preventing the longitudinal movement of the drum. On the front side of the drum shell, six coils of a driving steel rope *7* are wound up. The ends of the rope are fixed into a driving pneumatic mechanism *8* enabling the rocking or turning round the drum around to its longitudinal axis. In the inner part of the drum, a plastic grid *9* is mounted over more than one half of shell area. The grid is covered with the filter cloth (filtering area 0.82 m^2). In the cover *2*, there is a hole with pipe coupling *10* to which the suspension supply pipeline is affixed. In the front and middle parts of the drum shell, there are two other holes with couplings *11*, *12*. The first one is connected with a pipeline for filtrate output, the second one can be used for deaeration of the drum, discharge of suspension, or for supply of air. The supply and filtrate output pipelines lead into rotating seals installed in a cover plate *13*.

The arrangement of the pilot-plant filter apparatus is schematically shown in Fig. 2. Filtrate was collected in a filtrate receiver placed on an electronic balance (KERN UB150K50M, Germany). An oil vacuum pump (type VRO 05-21, Laboratorní přístroje Praha, the Czech Republic) was used to produce the required pressure difference for vacuum filtrations. A pressurised vessel (montejus), equipped with an agitator, was used for feeding the suspension or for creating the pressure difference during a pressure filtration. Alternatively, the filtration apparatus was pressurised with air making use of deaerating tube built in the shell of the filter drum.

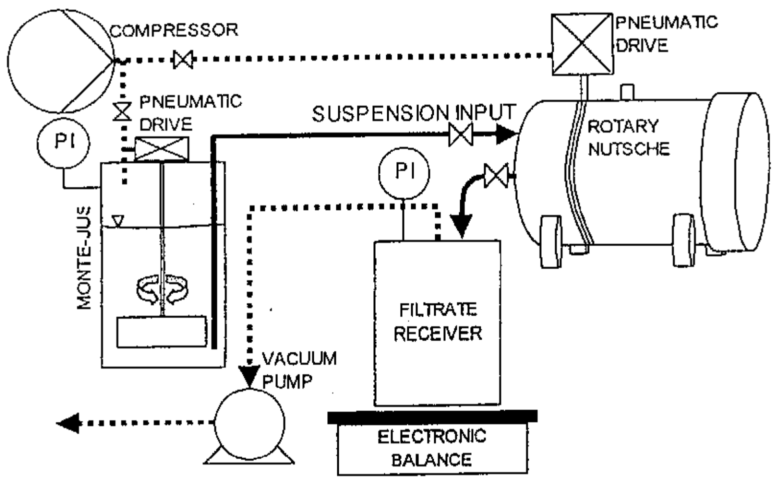

Fig. 2 Set up of experimental pilot-plant apparatus

Test measurements were performed using a laboratory planar filter. The laboratory filter cell was made from a perspex tube of 5 cm inner diameter and 50 cm length.

Procedure

A feed suspension, prepared from tap water and corresponding quantity of solid, was kept at room temperature (20 °C), introduced to the filtration unit, and the operating pressure difference (constant during the whole experiment) was adjusted either with the help of a vacuum pump or pressure air regulation system. The batch was mixed using rolling mode of the filter for several minutes. Then, the mode of the pneumatic drive was switched over into the rocking mode and the required rocking period was selected. After opening the filtrate outlet valve, the filtrate mass was measured by weighing the filtrate on the electronic balance and simultaneously the collection period was timing. Samples of the filter cake obtained were analysed for moisture, thickness, and homogeneity. To make the conclusions more objective, the digitised images of the filter cakes were also analysed using commercially available software Lucia — Screen Measurement supplied by Laboratory Imaging. The images were obtained by a high resolution video camera (Panasonic - NV-MS4E), which was interfaced to the Screen Machine II card installed in an IBM compatible computer.

Repeated experiments for selected filtration conditions showed a good reproducibility of the data measured. Between individual tests with the same solids, the cake was reslurried by gradually adding water and rocking the filter. At the end of tests with the same solid, the filter cake was discharged manually and the filter drum was washed.

The evaluation of filtration tests was based on the set of experiments performed with the above-mentioned water suspensions of diatomite, limestone, and cellulose on both laboratory and pilot-plant filters. The pilot filter tests were performed in the pressure filtration mode at different conditions of filter drum rocking. The conditions of filter test evaluated are summarised in Tables III and IV.

Results

Rotary Nutsche Performance

From filtration measurements, the dependencies of the cumulative filtrate volume on the time of filtration have been obtained. These dependencies can be exploited for the evaluation of filtration efficiency. Considering the changes of the filter cloth resistance between individual filtration tests, the measured data were corrected for this effect (using the mean value of filter cloth resistance) to make the comparison of the results of individual tests more perspicuous. The plots of corrected experimental dependencies of the ratio τ/V upon the cumulative filtrate volume V are shown in Figs 3 – 5.

Table III Laboratory filter measurement

Measurement	Solid	Concentration, kg m^{-3}	Pressure difference, kPa
L1	Diatomite	5	65
L2	Limestone	50	65
L3	Cellulose	25	65

Table IV Pilot-plant filter measurements

Measurement	Solid	Concentration, kg m^{-3}	Pressure difference, kPa	Oscillation time, s
P11	Diatomite	50	35	without rocking
P12		50	35	8 (manually)
P13		50	35	2
P14		50	35	1.5
P21	Limestone	50	35	without rocking
P22		50	35	8 (manually)
P23		50	35	2
P24		50	35	1.5
P31	Cellulose	25	34	without rocking
P32		25	35	8 (manually)
P33		25	35	2
P34		25	34	1.5

Filtration of a non-settling suspension on a nutsche with planar filter medium obeys the well-known filtration equation (e.g. Ref. [2])

$$V^2 + 2V_0V = C\tau \tag{1}$$

which was developed for a constant pressure difference filtration with the constant filter face area.

Here,

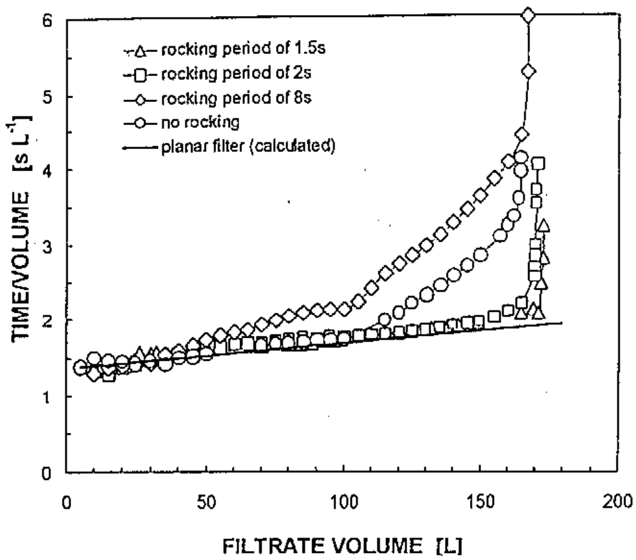

Fig. 3 Dependencies of τ/V upon V for filtration of suspension of diatomite

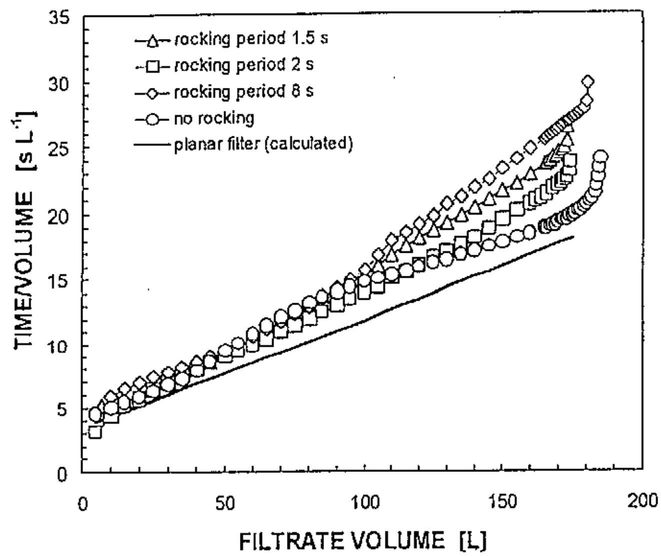

Fig. 4 Dependencies of τ/V upon V for filtration of suspension of limestone

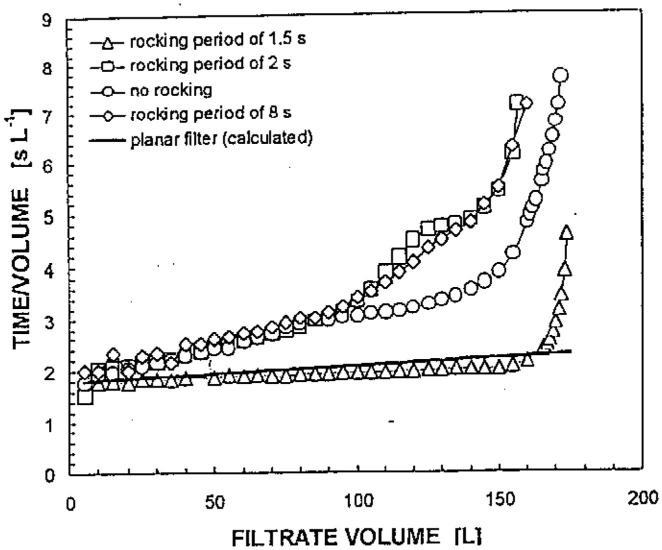

Fig. 5 Dependencies of τ/V upon V for filtration of suspension of cellulose

$$V_0 = \frac{RA}{\alpha x} \tag{2}$$

and

$$C = \frac{2\Delta p A^2}{\alpha \mu x} \tag{3}$$

are constants of filtration.

It can be expected that Eq. (1) can be used for evaluation of filtration constants V_0 and C and filtration efficiency of a cylindrical rotary nutsche in the first period of filtration when the dependence $\tau/V = f(V)$ is linear. During this period, the decrease of filter face area, caused by progressive uncovering of filter media or by increase of filter cake thickness, does not manifest itself. The values of aforementioned filtration constants V_0 and C evaluated from beginning periods of pilot-plant filtration tests (Tab. IV) are summarised in Tab. V. For comparison, the corresponding values V_0 and C characterising the laboratory measurements (Tab. III), recalculated for the conditions of pilot-plant filtration tests using Eqs (2) and (3), are given in Table V as well.

Table V Filtration constants

Measurement	Solid	Oscillation time, s	Filtration constants	
			V_0, m^3	$C\times10^4$, m^6 s^{-1}
P11	Diatomite	no rocking	0.192	2.788
P12		8	0.131	0.552
P13		2	0.231	2.561
P14		1.5	0.153	2.571
L1		-	0.188*	2.836*
P21	Limestone	no rocking	0.022	0.083
P22		8	0.017	0.077
P23		2	0.021	0.094
P24		1.5	0.013	0.083
L2		-	0.021*	0.119*
P31	Cellulose	no rocking	0.056	0.802
P32		8	0.103	0.719
P33		2	0.104	0.731
P34		1.5	0.120	6.25
L3		-	0.102*	3.48*

* recalculated for conditions of pilot-plant filtration tests (Δp = 35 kPa, S = 0.82 m^2)

The application of Eq. (1) to the whole period of filtration gives a maximum estimation of filtration efficiency of the rotary nutsche. For the systems tested, this estimation, which was calculated from Eq. (1) using the values of V_0 and C determined from the measurements performed on the laboratory filter cell, is given in Figs 3 – 5 by solid lines.

Real reduction of the filtration efficiency of RN nutsche in comparison with that for planar nutsche will depend on the filter medium and suspension characteristics and on the rocking mode of RN nutsche. Inspecting the experimental dependencies given in Figs 3 – 5, we can draw the following conclusions:

For well filtering and slowly settling suspensions (suspensions of diatomite and cellulose), the optimum rate of drum oscillation can be found at which the filtration efficiency of RN filter is approximately the same as that for planar nutsche (see Figs 3, 5). In this case, the filter face area is sufficiently quickly overflowed with suspension and simultaneously the filter cake is not remarkably washed away from the filter cloth during filtration period. The filtration efficiency is lower for filtration of these suspensions without drum rocking and the effect of reducing filter face area becomes evident.

It was found that very slow drum rocking is unsuitable from point of view of filtration efficiency because the time of filter cloth uncovering is prolonged. This is documented by the graphs plotted in Figs 3 – 5 for filtration experiments with slow drum rocking achieved manually (oscillation period 8 s). For filtration of cellulose suspension with oscillation period 2 s, the similar situation also set in (Fig. 5) owing to separation of the non adhesive filter cake from the filter cloth during filtration period.

The course of a batch filtration of rapidly settling suspensions of limestone differs from that for suspensions of diatomite and cellulose, especially for the filtration mode without drum rocking (see Fig. 4). In this case, due to solid sedimentation during filtration, the height of the filter cake increases more rapidly in comparison with that predicted according to Eq. (1). After sedimentation of the main fraction of solids, the mechanism of filtration is similar to that of a deep bed filtration, and the filtrate flow rate decreases more slowly. Nevertheless, it can be expected that also for filtration of rapidly settling suspensions the optimum rocking mode can be found for which the filtration efficiency will not be much worse than that for planar nutsche.

Therefore, it can be said that a rough estimation of the filtration efficiency of RN nutsche can be based on calculations using Eq. (1). For a more precise prediction of filtering performance of RN filter, special equations of filtration should be proposed. These equations should take into account variability of the filter face area and, as the case may be, a kinetic coefficient characterising the washing away of filter cake during rocking. The solution of such a complex filtration model will not be simple and will necessitate the use of numerical procedures for solving the governing differential equations. Our first simple model of filtration on a cylindrical filter working without rocking [3], which has been solved analytically and took into account only the decrease of filter face area owing to its uncovering during the filtration period, did not yield good results. Namely, during filtration of suspensions of diatomite and cellulose, the effect of increasing filter cake height on filter face area cannot be neglected.

Filter Cake Quality

The experiments were also aimed at the elucidation of the effects of rocking period on the quality of the filter cake for the feeds tested. The resulting characteristics of the filter cakes evaluated are summarised in Table VI.

Generally, it was found that the rocking mode, as well as the suspension properties, had considerable influence not only on the RN filter performance but

Table VI Characteristics of the filter cakes obtained

Feed	Rocking period, s	Filter cake		
		Total solids, % wt	Structure	Thickness
Diatomite	no rocking	38.3 (31.2 at bottom)	cracks at the whole area	nearly uniform
	8	41.2	cracks at the edge	nearly uniform
	2	43.4	no cracks, at the top layer	nearly uniform
	1.5	43.5	no cracks, at the top layer	nearly uniform
Limestone	no rocking	75.6 (62.3 at bottom)	no cracks	nearly uniform
	8	91.3	no cracks	non uniform
	2	86.9	no cracks	non uniform
	1.5	83.2	no cracks	non uniform
Cellulose	no rocking	19.9	cracks	nearly uniform
	8	18.1	cracks and aggregates	non uniform
	2	13.8	aggregates, cakeless filter cloth	non uniform
	1.5	18.6	aggregates, cakeless filter cloth	non uniform

also on the cake formation, its structure, and quality. Analysing the filter cakes video records and the content of their moisture, we can draw the following conclusions:

In static (no rocking) mode an incidental filter cake cracking was observed, particularly for diatomite and cellulose feeds. At the same time, the highest content of moisture was determined for filter cakes of diatomite and limestone.

A higher rocking frequency led to more compact and uniform filter cakes of diatomite. In this case, the filter face area was sufficiently quickly overflowed with suspension. The optimum rocking period was found to be in the range from 1.5 to 2 s. At this conditions, high quality filter cake was obtained and simultaneously high RN filtration efficiency was reached.

The structure of cellulose filter cakes differed from that formed from diatomite suspensions. The higher rocking frequency, the less uniform filter cake was formed. This is probably caused by the considerably low adhesion of cellulose cakes, which have a tendency to create stable fibrous aggregates, to the filter cloth. Particularly at the medium rocking period of 2 s, the whole filter cake slipped down to the bottom of the drum. Nevertheless, it can be expected that also for the filtration of cellulose suspensions an optimum rocking frequency can be found for which the filter cake quality will be better than that for the static mode.

Rapidly settling suspensions of magnesian limestone create — in all cases of filtration modes — filter cakes whose thickness varies along the filter cloth perimeter. The thickness of a filter cake decreases in the direction of the longitudinal edge of the filter cloth. This fact is apparently due to a combined influence of the solid sedimentation and filter cake washing away from the filter cloth during high frequency rocking. Nevertheless, more compact filter cakes were obtained for the filtration performed in a rocking mode in comparison with those obtained from the filtration performed in the static mode.

Conclusion

The filtration efficiency of the pilot-plant cylindrical rotary nutsche (RN filter) has been tested on the basis of vacuum and pressure filtration experiments with suspensions of diatomite, magnesian limestone, and cellulose. It was confirmed that from technological point of view the filter can be used for anticipated applications with the declared priorities such as limited filter cake cracking, possibility of filter cake reslurring, and better efficiency of cake washing.

The results showed an evident dependence of filter performance and filter cake quality on the mode of filter drum rocking and properties of the solid. For determination of the optimum rocking mode, at which the filtration efficiency will be nearly the same as that reached on a planar nutsche for filtration of a given suspension, filtration tests on a model RN filter are needed.

It was found that the rough estimation of the maximum filtration efficiency of RN nutsche can be based on calculations using the simple equation valid for filtration on a planar filter at constant pressure difference. For the more precise prediction of filtration efficiency of the RN filter, special equations of filtration should be proposed taking into account the variability of filter face area during the filtration period.

Symbols

A filter face area, m^2
C constant of filtration, Eq. (3), $m^6\ s^{-1}$

Δp pressure difference, Pa
R filter medium resistance, m^{-1}
V volume of filtrate, m^{-3}
V_0 constant of filtration characterising filter medium resistance, Eq. (2), m^3
x concentration of suspension, $kg\,m^{-3}$
α specific cake resistance, $m\,kg^{-1}$
μ filtrate viscosity, Pa s
τ filtration time, s

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