Separation and Purification Technology 154 (2015) 89–95

Contents lists available at ScienceDirect

Separation and Purification Technology

journal homepage: www.elsevier.com/locate/seppur

Short Communication

# Effect of uniformity of the residual dust cake caused by patchy cleaning on the filtration process

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ARTICLE INFO

*Article history:*
Received 8 May 2015
Received in revised form 29 August 2015
Accepted 20 September 2015
Available online 25 September 2015

*Keywords:*
Residual dust cake
Uniformity
Patchy cleaning
Filtration model
Regeneration efficiency

ABSTRACT

Residual dust cakes have significantly influenced the filtration process, although its distribution uniformity has been rarely studied in previous references. In this research, we propose a definition of the dust cake uniformity for the first time, based on the assumption that the dust cake was rearranged into new location on the filter and the filtration area was divided into three regions. A simple but effective model was established with the main focus being the effect of the residual dust cake uniformity $R_U$ on the filtration process. Results show that the numerical model was validated by the experiment, with $R_U$ being a key factor within the filtration model. The pressure drop increased noticeably with increasing $R_U$, and the exponential correlation between the residual pressure drop and $R_U$ was obtained. The filtration cycle time decreased, with the increase of $R_U$, while the regional surface dust mass, regional filtration velocity and rebuilding dust cake uniformity increased. Additionally, evolutions of the pressure drop increasing rate and regional dust cake thickness were complex with $R_U$.



## 1. Introduction

Due to its high collection efficiency, fabric filters are widely used in various industry processes [1–3]. However, one key issue for this technology is that the pressure drops of filter magnifies with increasing collected dust. Consequently the filter needs to be cleaned regularly for its stable operation. Although the reverse pulse of cleaning air is an effective and widely used method for the filter regeneration [4,5], the insufficient of pulse intensity or the uneven of pulse flow brings patchy cleaning [3,6–8], a well known phenomenon, where parts of the filter are cleaned while other parts still contain residual dust. The patchy cleaning results in the increase of pressure drops, and reduces the filtration cycle time.

There have been a number of efforts made to model the filtration behavior after a patchy cleaning. Duo et al. [9] established a probabilistic model in order to characterize the filtration velocity, pressure drop evolution, area distribution and thickness of the dust cake. Dittler et al. [10,11] proposed a two-dimensional quasi-stationary flow model in order to predict the pressure drop using the parameters of regeneration efficiency and regeneration pattern of patchy cleaning. Mao et al. [12,13] developed a fabric filtration process prediction model to describe the change in pressure drop during filtration cycles using the parameters of surface cleaning fraction and residual dust mass. Calle et al. [14,15] also presented a model to determine the pressure drop pattern and the cleaned fraction, over a number of cycles, based on the experimental values of residual pressure drop after each cleaning. Although these models are successful in characterizing the actual filtration process after patchy cleaning, they are too complicated for practical use. There are no known studies that address the uniformity of the residual dust cake distributing on the filter after a patchy cleaning. A certain mass of residual dust distributes thickly on a small area of the filter, making a concentrated distribution, while thing distributions throughout a large area denotes a uniform distribution. When more severely uneven distribution of the filtration velocity over the filter appears under the more concentrated condition, the relatively higher partial velocity will be reached and higher filtration pressure drop will turn out. Patchy cleaning that leads to the residual dust on the concentrated condition is most likely caused by the uneven of the pulse flow, and on the uniform condition it is most likely caused by the insufficient of pulse intensity. This shows that the residual dust distribution has significant influence on the filtration process.

A simple but effective model was established to characterize the effect of the residual dust cake uniformity on the filtration

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http://dx.doi.org/10.1016/j.seppur.2015.09.038
1383-5866/

performance. An experiment was carried out for the validation of modeling results. Evolutions of the filtration pressure drop, pressure drop increasing rate, cycle time, regional surface dust mass, regional dust cake thickness and the rebuilding dust cake uniformity were studied in detail.

## 2. Modeling

It was determined that the influence of the regeneration pattern (the distribution of the uncleaned areas), from the experimental and modeling studies by Dittler et al. [10,11], on the pressure drop was slight at the very beginning of the filtration cycle and could be neglected at the later stage, while its influence on the filtration cycle time was not obvious. This demonstrates that the effect of distribution of the uncleaned area on the filtration performance can be negligible.

The unit dust cakes with different thicknesses and positions on the filter can be rearranged into new distribution with a rank of thicknesses decreasing from one side to another, without resulting in loss on generality. For the sake of simplicity, the filtration area is divided into three regions in the case of patchy cleaning: the completely uncleaned region $A_1$, with the dust cake unreduced in thickness, the partly cleaned region $A_2$, with the residual dust distributed equally in thickness, and the completely cleaned region $A_3$, with no residual dust. A schematic diagram that highlights how the residual dust cakes is rearranged, and the filtration areas are simplified to three regions is shown in Fig. 1. Since the cake thickness is usually ~1 mm, far less than the dimension of the filtration area, the transverse velocity can be neglected. Therefore, the regional boundary is regarded as the wall without thickness. It is reasonable to predict that the filtration velocities for three regions are different in the filtration cycle, which causes different regional dust mass loading rates.

Based on the divided three regions in two-dimensional model, the residual dust cake uniformity $R_U$ distributed on the filter is defined as the deviation degree of the cake barycenter from the filtration boundary of the side with thicker cake, as given in Eq. (1). During dust filtration, the surface dust mass $W_3$ in region $A_3$ is not 0, and the uniformity of the rebuilding dust cake $F_U$ (includes the residual dust) can be expressed in the same manner, as given in Eq. (2).

$$R_U = a\frac{0.5W_1A_1^2 + W_2A_2(A_1 + 0.5A_2)}{W_1A_1 + W_2A_2} \tag{1}$$

$$F_U = a\frac{0.5W_1A_1^2 + W_2A_2(A_1 + 0.5A_2) + W_3A_3(A_1 + A_2 + 0.5A_3)}{W_1A_1 + W_2A_2 + W_3A_3} \tag{2}$$

where the subscripts 1, 2 and 3 represent region $A_1$, $A_2$ and $A_3$, respectively. $W$ is the surface dust mass and $A$ is the area ratio. The value of the coefficient $a$ is defined as 2. Notably, the values of $R_U$ and $F_U$ can vary from 0 to 1. The larger $R_U$ or $F_U$ indicates a more uniform dust cake.

It is also assumed that the compression and rebound of the dust cake due to the variation of filtration velocity are reversible, and the filtration velocity within each region is uniform with the negligence of the unsteadiness in the boundary. The proposed model is applicable for the surface filtration and negligence the penetrating dust.

The total filtration pressure drop ($\Delta P_T$) can be considered as the sum of the pressure drop in the filter medium and the pressure drop across the dust cake [16]. Using these facts, the total pressure drop at the time $t$ can be given by:

$$\Delta P_{Ti}(t) = k_f v_{fi}(t) + S_i(t)v_{fi}(t) \tag{3}$$

where $i$ = 1, 2, 3 representing region $A_1$, $A_2$ and $A_3$, respectively. $k_f$ is the filter element resistance coefficient, $v_f$ the filtration velocity, $S_i(t) = k_{ci}(t)W_i(t)$ the dust cake resistance. $k_c$ is the specific resistance of the cake, $W$ the dust mass deposited per unit area.

After taking the fluxion of the dust cake compression and resistance with the filtration velocity, the relation between the specific dust cake resistance coefficient ($k_c$) and filtration velocity can be expressed as follows [16,17]:

$$k_{ci}(t) = m(v_{f_i}(t))^n \tag{4}$$

where $m$ and $n$ are constants which can be calculated from the data of pressure drop increasing rate. Constant $n$ indicates the dust cake compressibility in terms of the filtration velocity. Then, substituting Eq. (4) into Eq. (3) yields the following equation

$$\Delta P_{Ti}(t) = k_f v_{fi}(t) + m(v_{fi}(t))^{n+1}W_i(t) \tag{5}$$

Since these three regions are parallel, their pressure drops should be equal and can be expressed as follows:

$$\Delta P_{T1}(t) = \Delta P_{T2}(t) = \Delta P_{T3}(t) \tag{6}$$

The dust mass loaded on the filter increases with the filtration process, and the following relationship holds:

$$dW_i(t)/dt = c\,v_{fi}(t) \tag{7}$$

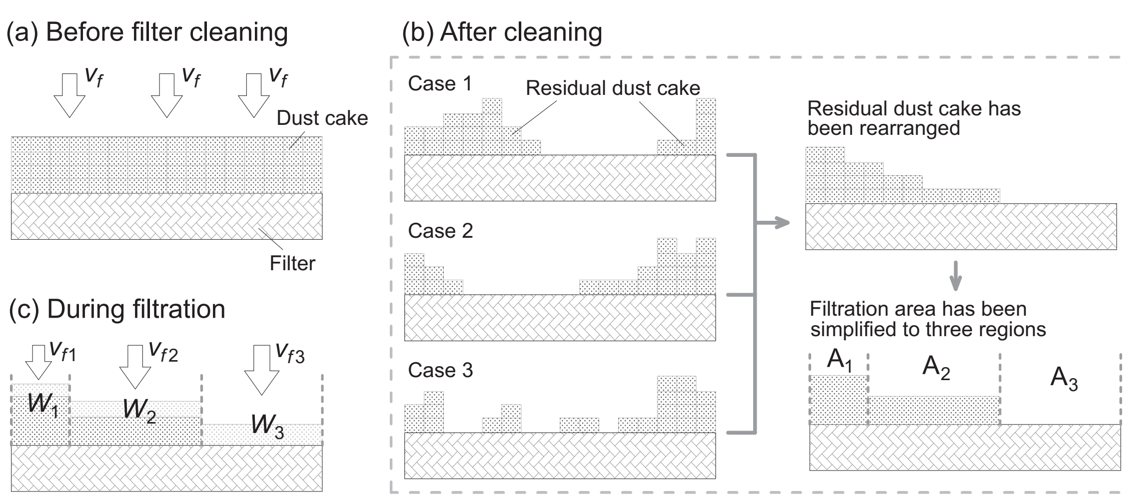


**Fig. 1.** Schematic diagram of the dust cake/filter cross-section showing that the residual dust cake is rearranged and the filtration area is simplified to three regions ($A_1$ completely uncleaned, $A_2$ partly cleaned, and $A_3$ completely cleaned).