Testing method of fabric filter performance and modeling of filtration process

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Abstract

Various types of fabric filters are now available on the market, but there is no standard method to test the performances of various filer media. The objectives of present work are to propose a standard testing method for fabric filters by comparing the filter performances measured by the existing standards of VDI and JIS, and to develop a fabric filtration model which can express the pressure drop evolution in the filtration-cleaning cycles. The filter performance tests with VDI type-1 and JIS rigs showed that the filter cleaning efficiency measured with VDI type-1 is higher than that with JIS but that the difference in the filter performance measured with two rigs can be minimized by altering the aging condition to give the same residual pressure drop after the filter aging. A new model is proposed by breaking down the fabric filtration process into three stages; depth filtration stage, transition filtration stage and surface filtration stage. The model successfully described the time evolution of filter pressure during filtration cycles and the filter cleaning performance can be expressed with two parameters of the surface cleaning fraction and the residual dust load on the un-cleaned surface after cleaning by the model .

1. Introduction

Bag filters have been widely used for controlling air pollution as well as collecting powder product prepared via gas-phase reaction. It is important to establish a standard testing method, which allows us to compare the performance of different filter media under well-defined conditions similar to those encountered in practice.

Since bag filters are operated in a cycle of dust accumulation and cleaning, it is necessary to accurately predict the filtration performance during the cycle. The present work seeks to propose a filtration model which can express pressure drop development during the repeated filtration cycles taking into account the patching cleaning. We will also apply the model to evaluate and compare the filter cleaning performance measured by VDI type-1 rig and JIS rig.

2. Comparison of Filtration Performance measured by VDI and JIS Testing Rigs for Cleanable Fabric Filter

The filter performance test is conducted with JIS and VDI type-1 rigs. The results showed that that the filter cleaning efficiency with JIS rig is lower than that with VDI type-1 rig.

Fig.1 shows the relationship between the residual pressure drop and the residual dust load for the VDI type-1 and JIS rigs. In Fig.1, the data measured by both VDI type-1 and JIS rigs fall on a single straight line, indicating that the residual dust load is uniquely determined by the residual dust load even when the aging is conducted with different rigs of VDI type-1 and JIS.

Since the dust cleaning efficiency for VDI type-1 rig is higher than that for JIS rig, the increasing rate of residual dust load for VDI type-1 rig is lower than that for JIS rig. In order to obtain the same residual dust load or residual pressure drop after the aging, the number of filtration cycles should be reduced for JIS rig or increased for VDI type-1 rig. The filter performance test with the JIS rig was conducted using a filter aged with the number of filtration cycles of 2700 and the filtration cycle time of 5 s. The results are compared in Fig.2 with the previous performance test results for the two rigs. Fig.2 shows that the same testing results for the VDI type-1 rig and the JIS rig are obtained not only in the first 30 cycles before the aging but also in the last 30 cycles after the aging by decreasing the number of filtration cycles from 5000 times to 2700 times for JIS rig.

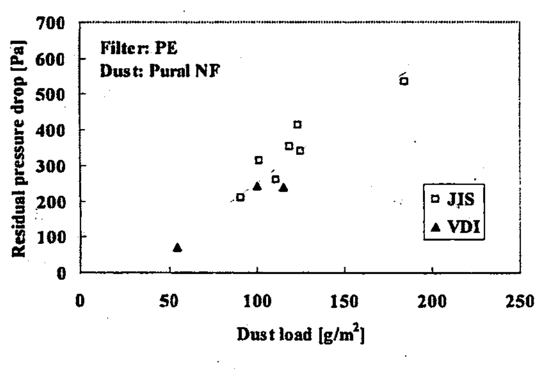

Figure 1 Relationship between residual dust load and residual pressure drop

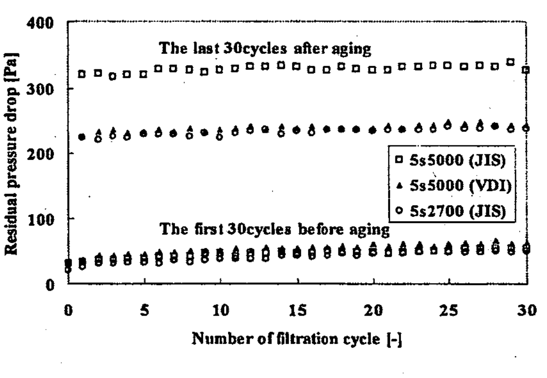

Figure 2 Effect of the number of aging cycles on filtration performance

3. Model for Filtration Performance Prediction of Flat-type Fabric Filter

3.1 Model description of the fabric filtration process

For a virgin filter, dust particles penetrate into filter and are collected inside the filter. When the pressure drop reaches a prescribed value, the filter is cleaned. After filter cleaning, a part of residual dust cake remains on filter surface. However, on a part of filter surface, not only the dust cake is completely removed but also a part of dust inside the filter is also cleaned. Therefore, the depth filtration takes place on the cleaned surface just after the filter cleaning until the dust load reaches the maximum retention in the filter. Once the dust begins to accumulate on the cleaned surface, the second stage of transition filtration stage begins. The local filtration velocity varies over the filter surface because of the non-uniformity in the dust cake distribution. This leads to non-linear pressure drop development of the filter. As time passes, the non-uniformity will gradually disappear because of self-equalizing mechanism for parallel path flows. The difference in local filtration velocity will then diminish and this will lead to uniform deposition of filter cake, which is the beginning of surface filtration stage.

3.2 Transition from depth filtration stage to transition filtration stage

In order to find the transition from depth filtration stage to transition filtration stage in each filter cycle, we introduce a new concept of interface dust layer on the filter surface. When the deposited dust fully occupy the voids of this layer or when the dust load reaches the maximum in this layer, the dust particles would not penetrate into the filter and therefore start accumulating on the filter surface.

3.3 Surface cleaning fraction and residual dust load after cleaning on the un-cleaned surface

In order to express the non-uniformity of residual dust cake distribution after filter cleaning in a simpler manner, the present model introduces two parameters, i.e. the surface cleaning fraction, f, which is the ratio of cleaned surface area to the total surface area of a filter, and the residual dust load on the un-cleaned surface after cleaning, m_{u0}. Both m_{u0} and f change with the number of filtration cycle.

f_i and m_{u0}^i are calculated and shown respectively in Figs.3 and 4.

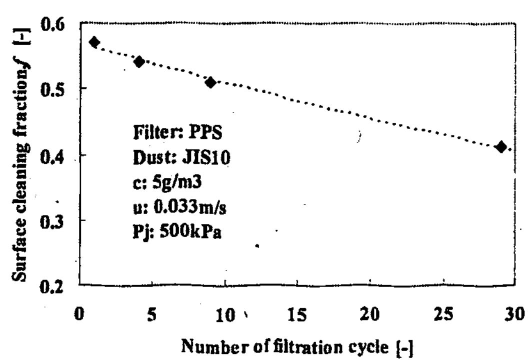

Fig. 3 Surface cleaning fraction

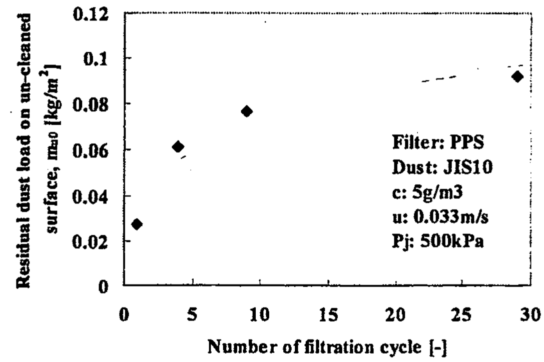

Fig. 4 Residual dust load on un-cleaned surface

4. Evaluation of filter cleaning performance by the proposed model

Utilizing the filter performance test results with VDI type-1 and JIS rigs, f and m_{u0} are calculated and plotted in Figs.5and 6. Fig.5 shows there is no significant difference in f by the rigs employed. However, in Fig.6, m_{u0} obtained with JIS rig is considerably higher than that with VDI type-1 rig for the last 30 cycles after the aging, indicating that the dust cleaning efficiency is higher for the VDI type-1 rig.

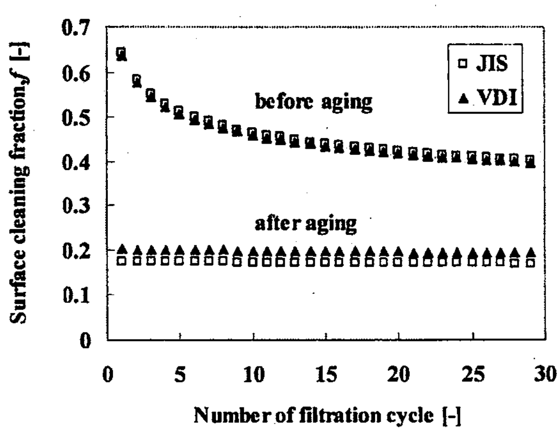

Fig. 5-3 Surface cleaning fraction

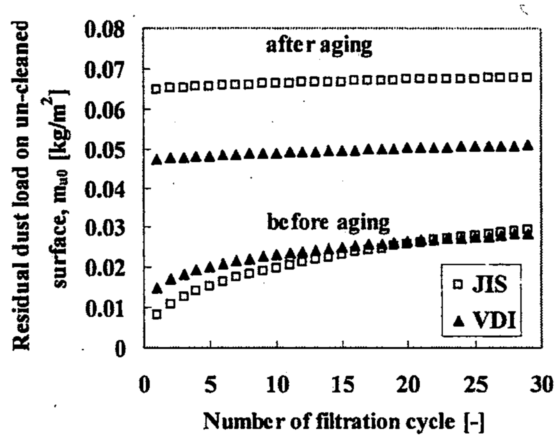

Fig. 5-4 Residual dust load on un-cleaned surface

5. Conclusions

The filtration performances measured by VDI type-1 rig and JIS rig was compared in order to find the testing conditions which give the same results by the two rigs. A model is proposed for the prediction of fabric filtration process, dividing a filtration cycle into three stages, i.e. the depth filtration stage, the transition filtration stage and the surface filtration stage. It is applied to evaluate and compare the filter cleaning performance between the two rigs.

学位論文審査結果の要旨

平成17年7月27日に第1回論文審査会、そして、8月2日に口頭発表と質疑応答を行い、引き続き開催した第2回論文審査会において以下のように決定した。

本論文は、主要な集塵装置であるバグフィルタ用ろ布の性能評価法を確立するため、代表的な試験装置の特徴を実験的に明らかにした。そして、ろ布への粒子の堆積と払い落としが繰り返されるろ過過程を、ろ材ろ過、遷移ろ過、ケーキろ過の3段階に分けて評価することが重要との判断から、ろ過過程をモデル化し、圧力損失の経時変化と払い落とし後の残留圧損を予測する方法を検討した。

その結果、ろ布の性能試験に関し、ろ布のエイジング処理において処理後のろ布の残留圧損を等しくすれば、異なった装置で同一の性能試験結果が得られること、また、バグフィルタのろ過過程のモデリングに関し、ろ布表面に仮想的な粉塵層を導入することにより、ろ材ろ過から表面ろ過に移行する時間を予測できること、遷移ろ過過程における圧力損失の増加を、ろ布表面の不均一な粉塵堆積量分布を考えることにより予測できることを示した。さらに、本モデルで導出された2つのパラメータ（払い落とし効率、残留粉塵量）を用いて試験装置の比較を行い、払い落とし効率は同じであっても、払い落とし後の残留粉塵層の厚さが異なることを示し、圧力損失の経時変化の予測を可能にした。

以上のように、本論文は、バグフィルタ用ろ布の性能試験法に関し重要な評価指針を与えるとともに、バグフィルタによるろ過に対し新たなモデルを構築しており、工学的な価値は高く、博士（工学）の学位を授与するに値すると判断する。