Chapter 29
Experimental Research on Resistance Characteristics of Filtering Materials of Biofilter Process of Sludge Composting Plants

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Abstract A lot of hazardous gases will be produced during sludge composting, if treated improperly, pollution may be caused to the environment. Biofilter process is an effective deodorizing method. But the resistance of biofilter materials that in turn have critical effects on whether the ventilation system of the workshop can operate normally. The research group conducts researches on resistance characteristics of four commonly used filter materials in a view to helping similar sludge composting plants in designing ventilation system, choosing fans, and managing operation. The results of the researches show that biofilter material is of the law of high-speed non-Darcy flow, their resistance characteristics are related with the characters, superficial velocity, bed thickness, etc., of the filter material, about which the empirical computation formulas are given.

Keywords Biosolid sludge composting · Superficial velocity · Biofilter media · Resistance characteristics

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29.1 Introduction

According to statistics, there are 2,881 urban sewage treatment plants in China, which process 72.9 % of the urban sewage [1]. The sludge precipitated at sewage treating becomes another severe pollution source. Sludge composting is effective in decreasing urban sludge, administering biosafety treatment to the sludge, and making the sludge useful. As of now, sludge composting has become one universal technology in treating urban solid garbage over the world.

However, a lot of harmful gases may form during sludge composting, which include ammonia, hydrogen sulfide, sulfur alcohol, amine substances, etc. [2–4]. These gases are harmful to human body, even carcinogenic, if treated improperly, they might wreak severe potential hazards to workers who are exposed to these gases in the sludge composting plant and bring about occupational health problems [4]. Meanwhile, if discharged into the atmosphere without proper treatment, these gases might cause secondary pollution to the environment [3, 4]. Therefore, these gases must be sent to deodorizing equipments for treatment in an organized way before being discharged, during which the organized ventilation and deodorizing equipment will play important roles. The deodorizing methods commonly used in sludge composting plants include biofilter process, soil method, etc. [5, 6]. The biofilter process is used for most projects, which uses the microorganisms in the process to treat harmful gases [7, 8].

Biofilter process plays an important role in deodorizing. During his research, Song Gaoju [9] finds that the ventilation system of a sludge composting plant is an typical variable resistance system, wherein, the changes of resistance is mainly induced by resistance changes of biofilter materials that in turn have critical effects on whether the ventilation system of the workshop can operate normally. The research group conducts researches on resistance characteristics of four commonly used filter materials in a view to help similar sludge composting plants in designing ventilation system, choosing fans, and managing operation.

29.2 Research Situation at Home and Abroad

Because of its low cost and high efficiency, researchers both at home and abroad carry out researches on biofilter process from different perspectives. As early as in 1923, Bach [5] used soil to treat odorant gases like H_2S, etc., discharged by the sewage treatment plant. Biofilter materials in the biofilter process include screened compost, coke-compost mixture, root wood with bark, coconut fiber, bit of wood, ceramist, etc. Researchers both at home and abroad mainly focus on the filter efficiency while the filter resistance is rarely touched upon.

Biofilter material is a typical porous medium. And researches on the flowing characteristics of polluted air in the filter material are conducted on simulation model of the porous medium. Problems faced in researches and engineering in porous medium include petroleum exploitation and movement of underground

water, etc. Darcy's Law is a basic law about permeable flow. It is an important law in describing the resistance characteristics of porous media. It is widely acknowledged that Darcy's Law can only be used when Reynolds number of the laminar flow is between 1 and 10. However, there are more researches focusing on non-Darcy flow with Reynolds number above 10 and relevant empirical computation formulas are correspondingly worked out [10]. People like Li Qitao et al. [11] have conducted experiments to study the ventilation resistance of piles of three different kinds of grain and come up with the empirical formula after improving on Darcy's relationship expression. People like Li Zhenpeng et al. [12] studied the resistance characteristics of microspheric porous media and worked out empirical computation formulas with different Reynolds numbers. During the literature survey, it can be found that most of the researches focus on porous heat-conducting media; researches on biofilter materials are rare.

29.3 Experiment on Resistance Characteristics of Filter Materials of Biofilter

According to the literature [5], the experimental superficial velocity should be between 0.02 and 0.04 m/s. Therefore, in some project of Song Yong-gang et al. [8, 13], the designed superficial velocities are, respectively, 0.03 and 0.06 m/s.

The following Eq. (29.1) can be used to identify the flowing regime when the fluid going through the biofilter materials and compute the Reynolds number:

$$\text{Re} = \frac{\rho v d}{\mu} = \frac{v d}{\upsilon} \tag{29.1}$$

In Eq. (29.1), "d" stands for the average diameter of solid particles in the porous medium. "v" stands for permeability velocity of the fluid whose unit is m/s, at this experiment it is actually the superficial velocity. "μ" stands for dynamic viscosity coefficient of the fluid. "υ" stands for kinematic viscosity coefficient of the fluid, whose unit is m^2/s.

The computed Reynolds number under experimental conditions of different biofilter materials are between 70 and 200. The fluid state is of non-Darcy flow [8]. The total energy loss in the porous media equals the viscous energy loss and dynamic energy loss. The dynamic energy loss dominates at high flowing speed while the viscous energy loss dominates at low flowing speed. When the inertia force dominates, Darcy's Law does not apply because inertia force is proportional to the square of speed. The high-speed non-Darcy flow can be described by the following nonlinear laminar law [13], namely,

$$v = KJ^m \left(\frac{1}{2} \leq m < 1 \right) \ \text{ or } \ \Delta P = Av^n \ \ (1 \leq n < 2) \tag{29.2}$$

In the above Eq. (29.2), "K", "A", "m", "n" are experimental constants.

29.3.1 Experimental Methods

The experiment workbench arrangement is as what is shown in Fig. 29.1. The superficial velocity can be computed with the tested systematic air quantity at the straight section of the air pipe. The static pressure measured in the plenum chamber is the resistance of the filter material. The filter materials are surveyed by group. Each filter material will be tested at 2 or 3 thickness values. At each thickness value, the air valve will be adjusted to see what will happen at five air quantities. The specific measuring methods can be found in *Code of acceptance for construction quality of ventilation and air conditioning works* [14] and *Industrial fans-performance testing* in situ [15].

29.3.2 Experimental Plan and Apparatus

Experimental plan: in accordance with the methods described in the literature [14, 15], the testing ports will be arranged and parameters will be measured. The Table 29.1 will be referred to for experimental apparatus and main parameters.

29.3.3 Experimental Apparatus

The experiment workbench will be set up as directed by literature [14, 15]. Different superficial velocity will be made by adjusting the valve installed at the discharge outlet of the ventilator to give different air quantity. The air quantity will be measured through the anemometer at ventilating pipe. The hot wire anemometer will be used to verify and adjust the precision of the air flow gauge. Resistance of the filter material will be measured by using the pilot tube and electronic differential pressure gauge. The difference between pressure in the plenum chamber and the atmospheric pressure is the resistance of the filter material.

Fig. 29.1 Sketch for installation of test-bed for biofilter: *1* fanner, *2* soft coupling, *3* air valve, *4* measuring port, *5* anemometer, *6* DN100 air hose, *7* DN300 air hose, *8* fender, *9* measuring port, *10* plenum chamber, *11* air distribution plate, *12* biofilter material
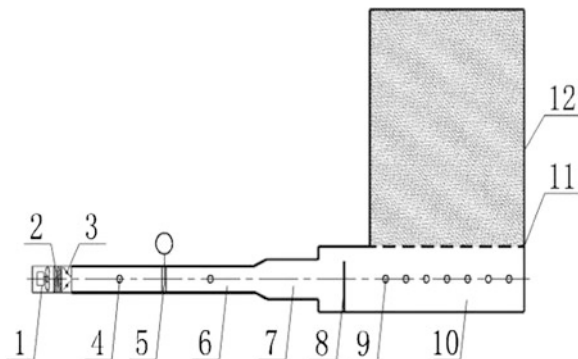
Table 29.1 Instruments of the testing and the parameters

Title	Model	Resolution ratio/range	Precision
Hot wire anemometer	KANOMAX A531	0.01 m s^{-1}	$\pm(\text{reading} \times 2\,\% + 0.01) \text{ m s}^{-1}$
Differential pressure gauge	Testo 512	0.01 hPa	reading $\times 0.5\,\%$
Pilot tube	L shaped		$K = 1$
Air flow gauge	TY-LUGB-2310	$125\text{–}1247 \text{ m}^3/\text{h}$	reading $\times 1.0\,\%$

29.3.4 Selection of Experiment Materials

After analysis of factors affecting the resistance of the filter material, it can be seen that there are mainly the following factors such as superficial velocity, thickness of the biofilter media, impurities, porosity and the kind of material, etc. In the experiment, we will choose four commonly used materials in China namely, mixture of peanut shell and bark, bits of wood, ceramsite, and mixture of ceramsite and bits of wood in different proportion. During the experiment, each filter material will be tested at two or three different thickness values and at each thickness value the filter resistance will be measured under five difference superficial velocities. Fresh air will be sent into the workbench through a ventilator. About the four filter materials used in the experiment, the mixture of peanut shell and bark has been used for 2 years before the experiment, bits of wood for 6 months; ceramsites are purely new ones; mixture of wood bits; and ceramsites are made in different proportion.

29.4 Experimental Data, Analysis, and Results
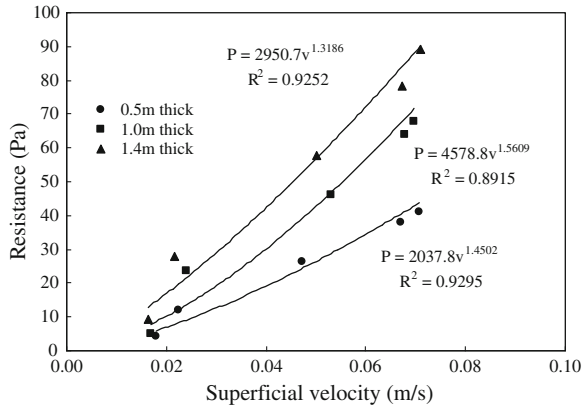
29.4.1 Experimental Results

The experimental results are shown as in Figs. 29.2, 29.3, 29.4, 29.5, 29.6, 29.7, and 29.8.

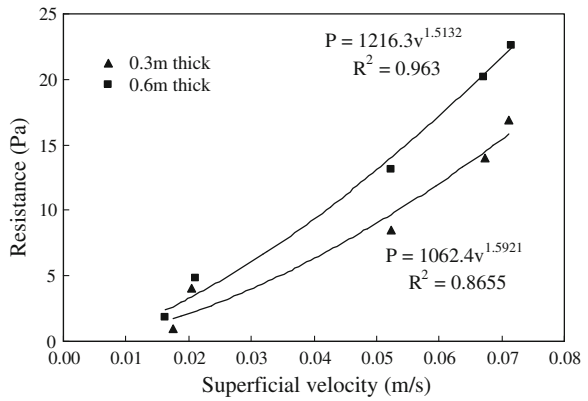### 29.4.2 Analysis of the Experimental Results

29.4.2.1 Analysis of Change Pattern of Superficial Velocity

As shown in Figs. 29.2, 29.3, 29.4, 29.5, and 29.6, filtering resistance and superficial velocity of the biofilter material have an exponential relationship and a better degree of fitting, which suits the description of Eq. (29.2). Because it is the
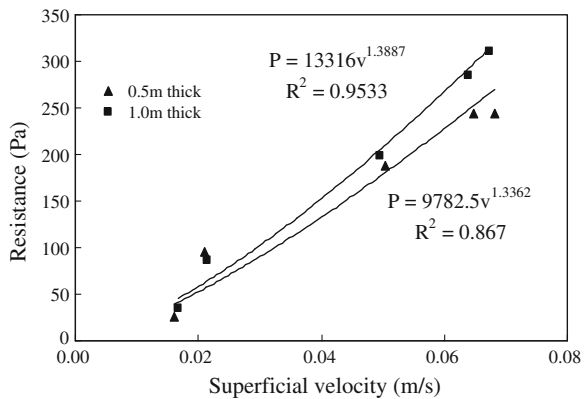
Fig. 29.2 Relationship between the filtration resistance and superficial velocity of wood bits
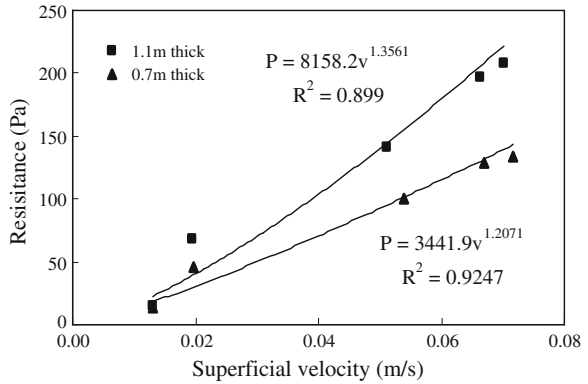
$P = 2950.7v^{1.3186}$
$R^2 = 0.9252$

- ● 0.5m thick
- ■ 1.0m thick
- ▲ 1.4m thick

$P = 4578.8v^{1.5609}$
$R^2 = 0.8915$

$P = 2037.8v^{1.4502}$
$R^2 = 0.9295$

Resistance (Pa)

Superficial velocity (m/s)

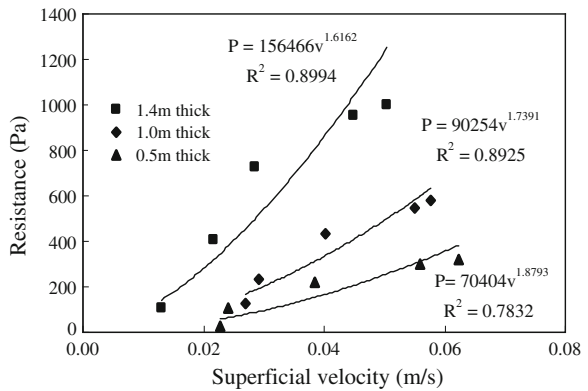**Fig. 29.3** Relationship between the filtration resistance of ceramsite and superficial velocity of ceramsite

$P = 1216.3v^{1.5132}$
$R^2 = 0.963$

- ▲ 0.3m thick
- ■ 0.6m thick

$P = 1062.4v^{1.5921}$
$R^2 = 0.8655$

Resistance (Pa)

Superficial velocity (m/s)

Fig. 29.4 Relationship between the filtration resistance and superficial velocity of ceramsites and wood bits mixed at 3:7

$P = 13316v^{1.3887}$
$R^2 = 0.9533$

- ▲ 0.5m thick
- ■ 1.0m thick

$P = 9782.5v^{1.3362}$
$R^2 = 0.867$

Resistance (Pa)

Superficial velocity (m/s)

Fig. 29.5 Relationship between the filtration resistance and superficial velocity of ceramsites and wood bits mixed at 1:1

P = 8158.2v$^{1.3561}$
R^2 = 0.899

P = 3441.9v$^{1.2071}$
R^2 = 0.9247

■ 1.1m thick
▲ 0.7m thick

Resistance (Pa)

Superficial velocity (m/s)

Fig. 29.6 Relationship between the filtration resistance and superficial velocity of mixture of peanut shell and bark

P = 156466v$^{1.6162}$
R^2 = 0.8994

P = 90254v$^{1.7391}$
R^2 = 0.8925

P= 70404v$^{1.8793}$
R^2 = 0.7832

■ 1.4m thick
♦ 1.0m thick
▲ 0.5m thick

Resistance (Pa)

Superficial velocity (m/s)

Fig. 29.7 Relationship between the filtration resistance and superficial velocity at the thickness of 1 m

▲ mixture of peanut shell and bark
■ ceramsites and wood bits mixed at 3:7
♦ bits of wood

Resistance (Pa)

Superficial velocity (m/s)
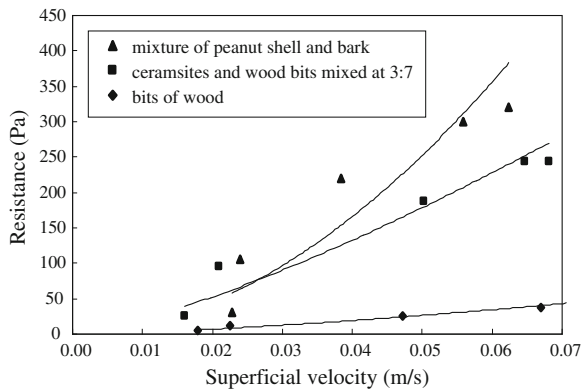
high-speed non-Darcy flow used in the experiment and there are different Reynolds numbers, viscous energy loss, and dynamic energy loss account for different part of it and different empirical coefficients are come up with. In actual

Fig. 29.8 Relationship
between the filtration
resistance and superficial
velocity at the thickness of
0.5 m
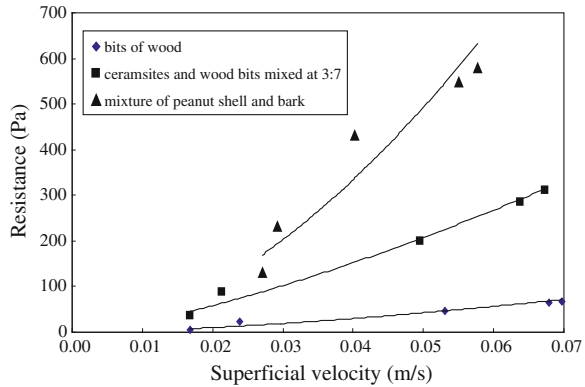
project conditions, thickness and superficial velocity of filter material are all set inside the required range. To facilitate its use in actual projects, the filtering resistance and superficial velocity are fitted into an empirical computation formula on the experimental basis and marked in Figs. 29.2, 29.3, 29.4, 29.5, and 29.6. On application in real projects, the resistance can be worked out by using the experimental empirical formula.

29.4.2.2 Analysis of Effects of Kinds and Thickness of Filter Materials

As shown in the experiment, the changes of filtering resistance with superficial velocity relates to the kind of filter material. Filter materials differ in change patterns of filtering resistance. Moreover, the experimental results (as shown in Figs. 29.2, 29.3, 29.4, 29.5, and 29.6) show that different thickness of the filter materials will bring about different empirical coefficient (coefficient and exponent) in their change pattern. With thickness of the filter material increasing, change rate of the resistance differs as the superficial velocity grows. As shown in Figs. 29.7 and 29.8, when at the same thickness, the filtering resistances of experimental filter materials change with the superficial velocity. When the superficial velocity does not change, the filtering resistance of wood bits is the smallest while that of peanut shell and bark mixture is the biggest.

29.4.2.3 Analysis of Added Earth and Sand's Effects on Filtering Resistance

As known from actual project experiences, earth and sand are often brought into the biofilter process at filling. To show the earth and sand's effects on filtering resistance, a comparative study has been conducted between a pure filter material and the same filter material with earth and sand blended into it, about which the experimental result are 125.2 and 250.9 Pa, respectively. From the results we

know that when earth and sand are blended into the filter material the filtering resistance increases. This is because that earth and sand have smaller particle size which will reduce porosity of the filter material. Therefore, earth and sand should be avoided when filling the biofilter material so as to prevent the filtering resistance from increasing.

29.5 Conclusion

1. Sludge composting is a major measure to reduce urban sludge, to administer biosafety treatment to the sludge and turn the sludge a useful resource. Biofilter is important in treating waste gases forming during sludge composting. To guarantee better performance of biosafety treatment of these waste gases will help sludge composting plants run better and exert greater environmental benefits.
2. The filtering resistance expresses an exponential relationship with the superficial velocity. The filtering flow fits the law of high-speed non-Darcy flow. Results of this experiment will help compute the filtering resistance of relevant filter materials.
3. Factors influencing the resistance characteristics include the biofilter material's character (like particle size, porosity, etc.), its bed thickness and service time, etc.
4. The blended impurities will have some bearing on resistance characteristics of the filter material, therefore, impurities like earth and sand etc., should be avoided when filling the filter material.
5. Resistance characteristics of the filter material change with its service time because the material may change in quality and undergo natural compaction; however, the change pattern requires further study.

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