Experimental Investigations of the Resistance Performance of Commercial Cylinder Filters and Effect Factors Under Humid Airflows

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Abstract

Experiments were performed to summarize the variations in the resistance of commercial cylinder filters applied in the air intake filtration systems of gas power plants under humid airflows. Seven clean cylinder filters composed of various materials (including synthetic, wood cellulose, nanofibers, and polyester fibers) are subjected to the airflow containing water mist. The results show that the resistance of polyester fiber filters and synthetic fiber filters was increased by the large droplets on the surface of the hydrophobic filter media when loaded with water droplets generated. Several factors including the water-holding capacity (WHC) of fibers, low filtration efficiency, and the unique composite structure of nanofiber filters media can limit the "P_{jump}" of cylinder filters, increasing the mass of water droplets loaded or avoiding the high resistance. By contrast, the resistance trends of nanofiber media increased significantly from the initial resistance when singly subjected to airflows with water mist at 5.96 g/m³ and 90% relative humidity, differing from the nanofiber filter whose resistance tends to stabilize. These differences were primarily caused by the pleat-free structures and the install directions of the nanofiber medium in the clamp, indicating differences in the filtration performance between the filter medium and its filters.

Keywords: Cylinder filter, Water mist, Water mist generation rate, Nanofiber filter medium, High relative humidity.

1 INTRODUCTION
Cylinder filters with low or medium filtration efficiency are frequently used in industrial ventilation systems to remove particles from the air. When a cylinder filter is used in a relatively dry environment, its filtration efficiency and resistance gradually change as particles are deposited in the filter (Thomas et al., 2001). The efficiency differences of filters in trapping dust or droplets were primarily attributable to their porosities and the specific surface areas of the medium fibers (Wang et al., 2008). Decreasing the filter porosity can increase the collection efficiency and pressure drop (Al-Otoom, 2005; Su and H. Fu, 2006). However, liquid aerosols in mist environments can significantly change the regular filtration performance of dust-loaded cylinder filters within a short time (Schwarz et al., 2020) under the mist environments.

In practice, the resistance of commercial cylinder filters in the air intake systems of gas power plants increases sharply in foggy or rainy weather, known as "$P_{jump}$", impairing the stability of the air intake systems and generation of electrical power (Sun et al., 2016). In some plants, intake air is heated to reduce the amount of water mist or humidity levels (Zhang et al., 2018). However, this introduces multiple consumables and leads to excessive energy consumption. Most air filters in air intake systems continue to increase their resistance growth rates rapidly by liquid aerosols. Many studies have investigated the resistance performance of filters and filter media subjected to highly humid airflows to understand the filtration mechanism associated with resistance growth.
Mist filters, such as coalescing filters, are typically used to filter liquid droplets in industrial applications, such as the filtration section of gas turbines (Raynor and Leith, 2000; Wilcox et al., 2010). The filtration mechanism, influencing factors, mathematical models and numerical simulations have gained the attention of researchers aiming to improve the understanding of the filtration process of capture liquid aerosols. The progress of mist filter loading with liquid droplets in an assumed constant gas flow was classified into four discrete stages, with resistance increasing during the first three stages (Charvet et al., 2010; Contal et al., 2004; Frising et al., 2005; Walsh et al., 1996). Various influencing factors could affect the dynamic resistance at each stage, including the fiber parameters fibrous media characteristics, operating conditions, droplets types and sizes, and viscosity and surface tension effects between aerosols and filter media. (Agranovski and Braddock, 1998; Agranovski et al., 2001; Andan et al., 2008; Contal et al., 2004; Gupta, 1992; Pei et al., 2019; Wang et al., 2020a). In addition to the mass concentration of liquid aerosols, the filtration velocity determining the average droplet size significantly influences filter clogging (Agranovski and Braddock, 1998a; Contal et al., 2004). The merits of wettable filters, effective in capturing fine liquid aerosols, and non-wettable filters, which discard liquid droplets down their front face, were demonstrated and applied in industrial design (Agranovski et al., 2001). The resistance and separation efficiencies of the hydrophilic and hydrophobic filters in a high relative humidity environment were compared. The results indicated a slighter increase in the hydrophilic
filter during airflow with high relative humidity (Wang et al., 2020), while the resistance surges of oleophilic and one oleophobic glass fiber filter media can be interpreted by the film-and-channel model (Kampa et al., 2015) during oil aerosols loading. The effects of operation conditions on the filtration efficiency have been concluded (Penner et al., 2019). The oil films formed can reduce in separation efficiency, independent of the loading rate but not the velocity (Kolb et al., 2017). However, the loading rate is related to the drop size. Large drops dominant at much lower rates, positively influencing the filtration efficiency. Furthermore, with respect to physical properties, the surface tension of aerosols determines the arrangement of droplets along the fibers, increasing the resistance (Briscoe et al., 1991; Mullins et al., 2004). This increase in resistance can be enforced owing to the continuous liquid columns until it reaches stability when the created hydrophilic fibers bring adjacent fibers closer (Labbe and Duprat, 2019; Wurster et al., 2015).

Previous studies primarily examined the effects of wettability of fibers, liquid aerosols parameters, loading rate and wet environments on the filtration performance of typical glass filter media. However, no definitive and solid conclusion can be drawn regarding the effects of foggy and rainy environments on the resistance of commercial cylinder filters. Considering the differences in the physical properties of glass fibers and basic materials of cylinder filters, particularly wood cellulose with water absorption capacity (Gu and Liu, 1997), the filtration
performance of the typical materials used for cylinder filters needs substantial attention. Moreover, the liquid water content (LWC) in the atmosphere is positively related to the resistance growth rates of cylinder filters in gas power plants. Therefore, the filtration progress may be associated with the “loading rate” (Sun et al., 2016). In addition to the porosity of the cylinder filter, the pleat structures and installation directions of filters can also affect the volume of drops captured (Joubert et al., 2010). Thus, it is important to choose suitable filters for highly humid environments.

Accordingly, this study selected seven commercial cylinder filters to explore the sensitivity of their filtration performance to water mist airflows. Experiments were performed to investigate the effects of mist environments, medium materials, and filtration efficiency on the resistance of cylinder filters. The cylinder filter with optimum filtration performance would be recommended. In addition, the resistance of clean nanofiber media under high-humidity airflow and water mist environments were also compared to investigate the performance consistency between filters and corresponding media, and then the reasons for these differences would be analysed.

2 METHODS

2.1 Tested filters

This study tested the filtration performance of commercial cylinder filters composed of diverse materials. Table 1 lists the parameters of the nine experimental cylinder filters. These filters were
composed of different materials, including nanofibers (composited material) synthetic (multi-fibers blended), wood cellulose, and polyester fibers. M5, M6, F7, F8, and F9 are efficiency classes regulated based on the European Standard EN779:2012 on particulate air filters for general ventilation-determination of the filtration performance (EN, 2012). The rated airflow volume of each experimental filter was 1000 m³/h, according to the operating conditions of the power gas turbine. The test was halted when the final resistance reached 1000Pa.

Table 1 The parameters of experimental cylinder filters

<table>
<thead>
<tr>
<th>Case</th>
<th>Filter materials</th>
<th>Dimensions (mm)</th>
<th>Efficiency class (based on EN779)</th>
<th>Water-holding capacity (kg)</th>
<th>Thickness of a filter medium (µm)</th>
<th>Pleat height/width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Synthetic fiber</td>
<td>210×325×660</td>
<td>M6</td>
<td>2.8</td>
<td>560</td>
<td>49/2.3</td>
</tr>
<tr>
<td>2</td>
<td>Nanofiber</td>
<td>210×325×660</td>
<td>F8</td>
<td>2.6</td>
<td>440</td>
<td>49/2.3</td>
</tr>
<tr>
<td>3</td>
<td>Wood cellulose</td>
<td>210×325×660</td>
<td>M6</td>
<td>3.2</td>
<td>350</td>
<td>49/2.3</td>
</tr>
<tr>
<td>4</td>
<td>Polyester fiber</td>
<td>213×323×660</td>
<td>M5</td>
<td>1.9</td>
<td>400</td>
<td>49/2.3</td>
</tr>
<tr>
<td>5</td>
<td>Polyester fiber</td>
<td>210×320×660</td>
<td>M6</td>
<td>1.0</td>
<td>400</td>
<td>49/2.3</td>
</tr>
<tr>
<td>6</td>
<td>Polyester fiber</td>
<td>210×320×660</td>
<td>F7</td>
<td>0.6</td>
<td>400</td>
<td>49/2.3</td>
</tr>
<tr>
<td>7</td>
<td>Polyester fiber</td>
<td>210×325×660</td>
<td>F9</td>
<td>0.2</td>
<td>400</td>
<td>49/2.3</td>
</tr>
</tbody>
</table>

2.2 Experimental setup

Fig. 1 shows a schematic of the experimental setup used to test the performance of the air filters. First, in the airflow rate control section, a nozzle airflow meter was used to monitor the changes in the airflow rate in real-time. A computer was used to adjust the variable frequency fan to maintain the airflow rate at its pre-set value. Second, a pressure difference meter was installed in front of
and behind tested cylinder filter to record the changes in pressure drop. An aerosol spectrometer (Palas Welas Promo 2000) was used to collect the number of solid particles upstream and downstream of the filter to calculate its filtration efficiency.

Fig. 1. Diagram of setup for testing performance of air filters

Fig. 2 shows a diagram of the water mist generator, placed in the plenum chamber shown in Fig. 1 and used to construct the mist environments for filter testing. The generator comprised an ultrasonic nebulizer, storage tank, solenoid valve, and liquid level sensor. The ultrasonic nebulizer was a high-power piezoelectric ceramic that could generate water droplets. A liquid level sensor was used to control the water level and maintain an optimal water mist generation rate.
The mass of water droplets contained in the airflows was set to be greater than the liquid water content (LWC) of the general convective rain in the Jianghuai region in China to test the water endurance of the cylinder filters. Fig. 3 shows the size distribution of the three generated water droplets measured using by a Malvern Spraytec laser scattering particle sizer.

Fig. 2. Diagram of a water mist generator
2.3 Experimental procedures

Each experiment began with a clean cylinder filter placed on the filter test apparatus, as shown in Fig. 1. Subsequently, the initial filtration efficiencies and resistance of the tested filters were measured at the rated flow rate. The water mist generator was then started, and the filter was subjected to the experimental airflows that contained water droplets. Finally, the experiment ended when the resistance of the experimental filter reached 1000 Pa or when the experiment lasted for 8 hours. During the experiment, the filter resistance data were recorded in real-time. The weights of filters were measured before and after the experiment to calculate the mass of trapped water. The interior structures of some experimental filters and their materials were also examined using
scanning electron microscopy (SEM). After the resistance curves of the cylinder filters under wet airflows were obtained, pleat-free filter media from the filters that maintained a minimum resistance increase would be retained. The filter media resistance experiments were performed on a filter media performance test rig built in previous studies (Wang et al., 2020b; Zhang et al., 2020). A small ultrasonic nebulizer and constant temperate water box were mounted on separate branches to form specific highly humid airflows before the filter media test section. Two clean nanofiber media were subjected to airflows with 90% relative humidity and water mist to investigate the influence of the high relative humidity and water mist airflows on the filtration performance of nanofiber media. The concentration of the water mist in the experimental airflow was maintained at approximately 5.96 g/m³. At an airflow of 32 L/min, a computer recorded the resistance until resistance reached twice the initial resistance or maintained stability.

3 RESULTS AND DISCUSSION

3.1 Effects of different generation rates of water mist on the filter resistance

Specific generation rates of water mist were adjusted to construct experimental airflows containing water droplets to determine the influence of liquid water content in humid airflows on the resistance of cylinder filter. Fig. 4 shows the resistance curves of the four types of filters during loading with water droplets contained in the airflows and adjusted to specific generation rates of 3 kg/h, 6 kg/h, and 9 kg/h.
Fig. 4. Resistance curves of cylinder filters composed of (a) synthetic fibers, (b) nanofibers, (c) wood cellulose fibers and (d) polyester fibers under airflow with three water mist generation rates.

The resistance growth rate was increased significantly with an increase in the mass of water droplets. A special mass of water mist contained in the airflow for different cylinder filters can be used to estimate the resistance trends. First, the resistance trends of cylinder filters Cases 1, 3, and 4 were changed from flat to sharp as the water mist generation rate changed from 3 kg/h to 6 kg/h and 9 kg/h. The higher the water mist mass per unit of air volume, the larger the average particle
size of the droplets caused by collisions between droplets. Small liquid films or large droplets load on a filter can cause a more significant proportion of the pores to be blocked, leading to the "$P_{\text{jump}}$". Therefore, the filtration velocity was enhanced by the agminated liquids which were magnified by the increase in the water mist generation rate. However, it may take a longer time for filters under the humid airflow with a generation rate of 3 kg/h to achieve a sharp increase in resistance of these cylinder filters.

Second, the resistance growth trends of the wood cellulose cylinder filters (Case 3) varied under the three water mist generation rates. The resistance curve fluctuated below 6 kg/h and was smooth after 6 hours. The resistance shown a "$P_{\text{jump}}$" under 9 kg/h water mist airflow. Therefore, wood cellulose fiber materials can tolerate an environment with higher humidity; these materials can be custom-made according to the local high humid conditions. The resistance growth rate of the wood cellulose fiber cylinder filter (Case 3) was lower than that of the polyester fiber cylinder filter (Case 4) under the same humid airflows. This resistance growth rate can be explained by the minor expansions in the filter media porosity owing to the water absorption of wood cellulose fibers at the initial stage of the experiment. This water holding capacity differed from directly hung fibers (Agranovski and Braddock, 1998b) for non-wettable fibers. Therefore, the resistance of the M6 wood cellulose fiber cylinder filter (Case 3) increased more slowly than that of the M6 synthetic fiber cylinder filter (Case 1) in the same water mist environments.
Finally, the different water mist generation rates barely changed the resistance trends of the nanofiber cylinder filters, although the final resistance increased with LWC added. The only increments were attributed to the mass of water droplets per unit of time. The diameter of liquid droplets expands with the water mist generation rate increasing, which means that the nanofiber media can filter most liquid droplets owing to their high filtration efficiencies. However, accumulated liquid droplets were drained owing to the hydrophobicity of fibers and the gravity of the liquids. Subsequently, the resistance growth rate decreased gradually. The resistance tended to remain unchanged when the effects of drops trapped and drained on resistance were offset.

In conclusion, the size distribution of the water droplets and water holding capacity of the cylinder filters varied under different water mist generation rates. Their influences on the resistance tendency of the cylinder filters were also related to the hydrophobic properties and structures of the filter materials. Additionally, experiments were performed to explore the effects of high-humidity airflows on nanofiber media because of the excellent water mist endurance of the nanofiber filters.

3.2 Resistance performance of cylinder filters composed of different filter media

Fig. 5 shows the resistance curves of cylinder filters composed of different medium materials under the experimental airflows with the water mist generation rate of 9 kg/h for 8 hours.
Fig. 5. Resistance curves for cylinder filters composed of different medium materials under water mist generation rate of 9 kg/h

The resistance growth trends can be classified into three categories. In the first category, the resistance of the synthetic fiber filter (Case 1) and polyester fiber filter (Case 4) increased gradually before 4 hours and exhibited an exponentially increasing trend after 4 hours. In the second category, the resistance of nanofiber filters (Case 2) initially increased faster than that of the other types of filters. However, the rate of increase decreased gradually, and the resistance was steady during the loading of liquid droplets. In the last category, the resistance growth rate of the wood cellulose fiber filter (Case 3) was more extensive than that of the other cylinder filters before 4 hours.
However, variation trends of resistance tended to be constant after 6 hours rather than increasing exponentially.

lists the initial filtration efficiencies, the changes in filtration efficiencies, the response time of resistance and water-holding capacity. The 5% the initial resistance was defined as the reflex of the sensibility of a cylinder filter to water mists because of the system error, known as the resistance response time. Water-holding capacity (WHC) represented the mass of water held by the experimental filter when its resistance was unaltered or reached final resistance.

Table 2. The response time of resistance, WHC, initial filtration efficiencies and reduction in efficiencies after being dried of different cylinder filters

<table>
<thead>
<tr>
<th>Case</th>
<th>Filter materials</th>
<th>Initial filtration efficiency for particles (&gt;0.5 μm) %</th>
<th>Reduction in efficiency after being dried (&gt;0.5 μm) %</th>
<th>The response time of resistance (h)</th>
<th>WHC (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Synthetic fiber</td>
<td>51.2</td>
<td>-8.5</td>
<td>1.1</td>
<td>120.7</td>
</tr>
<tr>
<td>2</td>
<td>Nanofiber</td>
<td>97.8</td>
<td>-8.8</td>
<td>0.5</td>
<td>116.4</td>
</tr>
<tr>
<td>3</td>
<td>Wood cellulose</td>
<td>52.8</td>
<td>-11.6</td>
<td>2.0</td>
<td>137.9</td>
</tr>
<tr>
<td>4</td>
<td>Polyester fiber</td>
<td>44.5</td>
<td>-3.2</td>
<td>1.0</td>
<td>81.9</td>
</tr>
</tbody>
</table>

The response time of the synthetic fiber cylinder filter (Case 1) and polyester fiber cylinder filter (Case 4) is similar, as shown in Fig. 4, attributed to the similarly low filtration efficiencies. A longer time is required to form steady liquid droplets that accumulate on the surface of the filter medium owing to the low initial filtration efficiency. The differences in reduction values for separating KCl
solid particles (more than 0.5 μm) were attributed to the fiber hydrophobicity. Furthermore, the structures of fiber media were affected by these liquid aerosols captured, leading to the deceases in filtration efficiency.

The shorter response time of the nanofiber filter (Case 2) than those of the other cylinder filters (Cases 1, 3, and 4) means that the airflow channels were clogged quickly by forming large droplets or some liquid films owing to high filtration efficiency, creating a “P_{jump}” (Kampa et al., 2014). In addition, the water-holding capacity (WHC) of this nanofiber filter illustrated that the composite filter media could reduce resistance surge owing to the water absorption of fibers and filtering droplets. The volume of droplets attached to the surface of the nanofiber layer with high separation efficiency per unit time was more adequate than the others, which led to a transient resistance surge in the initial stage. As the mass of water droplets collected on the surface gradually increases, gravity drains the accumulated droplets continuously. Meanwhile, the pores of the nanofiber layers were expanded irreversibly, as shown in a and b, leading to reduced filtration efficiency. Captured liquid droplets were easily deposited on the leeward wood cellulose layer, forming depth filtration. Consequently, the overall resistance growth rate decreased with the conversion between surface filtration and depth filtration. This transition was verified by the water absorption capacity of the wood cellulose cylinder filter. When the
surface of the windward nanofiber layer was broken, the water absorption of wood cellulose fiber was significant for holding the liquid to increase the WHC of the composite nanofiber medium.

Fig. 6. SEM photos of the nanofiber filter (Case 2), before and after being loaded with water droplets.

Similarly, the pores expanded owing to agglomerated fibers also occurred in the filtration process of the wood cellulose fiber filter medium, leading to decreases in filtration efficiency. The reductions in resistance growth rate after 6 hours were caused by the water absorption and deformations of wood cellulose fibers. It may be difficult for a wettable filter medium with large porosity to form an entire liquid film even though the fact that liquid droplets were accumulated on the surface medium before 4 hours. The resistance reached constant when the volume of liquid droplets captured was equal to the drained. This trend was also described in the historical literature (Raynor and Leith, 2000).
3.3 Resistance performance of nanofiber media under humid airflows

Although the excellent water endurance of a nanofiber cylinder filter has been proven, the uniformity of the resistance performance between the nanofiber filter and its filter medium requires further experiments because of pleat structures and install directions of the cylinder filters. The test results of an experimental nanofiber medium were shown in Table 3.

Table 3. Further technical data of the nanofiber filter medium

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grammage</td>
<td>g/m²</td>
<td>130</td>
</tr>
<tr>
<td>Paper total thickness</td>
<td>µm</td>
<td>440</td>
</tr>
<tr>
<td>Corrugation depth</td>
<td>µm</td>
<td>280</td>
</tr>
<tr>
<td>Burst Strength</td>
<td>kPa</td>
<td>200</td>
</tr>
<tr>
<td>Air Permeability</td>
<td>L/m²/S</td>
<td>100</td>
</tr>
<tr>
<td>Max. Pore Size</td>
<td>µm</td>
<td>18</td>
</tr>
</tbody>
</table>

compares the resistance of nanofiber filter media exposed to significantly high-humidity airflows (with a humidity level of 90% and another containing the water mist with a concentration of 5.93 g/m³). The resistance growth rate of the nanofiber medium increased rather than decreased when loaded with liquid aerosols, different from the trend of the nanofiber filters shown in Fig. 5(b). These differences indicated that the pleat structures of the nanofiber filters were significant in highly humid environments. Furthermore, the installation direction of the nanofiber medium differed from its cylinder filter. For the filter medium, the
captured liquid droplets were not drained because the filter medium was placed horizontally on the test bench, different from the case of the nanofiber filters. Therefore, promoting the drainage of filter media by placing them can reflect the installation conditions of the filters and ensure system safety.

![Resistance curves of two nanofiber filter media under airflows with 90% relative humidity and 5.96 g/m³ water mist generation rate](image)

**Fig. 7.** Resistance curves of two nanofiber filter media under airflows with 90% relative humidity and 5.96 g/m³ water mist generation rate

Moreover, Fig. 7 shows that the variation trend of nanofiber media in 90% relative humidity airflows was initially stable and then increased by approximately 20Pa, and finally remained stable. These resistance results corroborate those presented by Joubert et al. (Joubert et al., 2010) obtained with pleated and flat filters in airflows with different humidity. Although the resistance of nanofiber
media was more sensitive to higher relative humidity (more than 80%RH), these slight increases were acceptable in actual projects (Xu et al., 2014).

Fig. 8 shows the weight of one nanofiber filter medium dried in a drying oven for 3 hours and subjected to airflows of stable relative humidity for at least 30 min. The relative humidity of the specific airflow increased from 10% to 90%. As shown in Fig. 9, the nanofiber filter media suffered from substantial water loss in extremely dry conditions (less than 10%RH) and water vapor absorption in excessively humid air-flows (more than 80%RH). This water loss occurred because water molecules can be absorbed around the polar groups in the amorphous regions of wood cellulose (Dammstrom et al., 2005). Therefore, the nanofiber filter medium composed of nanofibers and wood cellulose fibers can contain more water in a highly humid environment. However, the condensation of water vapor on the windward nanofiber medium can also be considered under specific temperature and pressure drop conditions (Ribeyre et al., 2014).
Fig. 8. Changes in weight of nanofiber media in airflows of different relative humidity levels

Fig. 9 shows the SEM images of nanofiber media before and after being exposed to 90% relative humidity airflow. Although the wood cellulose fiber can absorb water vapor, no observable morphological change affected the resistance of filter media. Therefore, the resistance tendency of the nanofiber medium under 90% relative humidity can be explained by the condensation of water vapor caused by the pressure difference before and after the windward nanofiber layer because the vapor condensation on the medium surface would reduce the transmission passage of the experimental airflow (Zhao et al., 2017).
Fig. 9. SEM images of (a) rear of a nanofiber medium treated by dry airflow and (b) rear of a medium treated by humid airflow

3.4 Effects of the filtration efficiency on the filter resistance

Fig. 10 shows the resistance curves of four polyester fiber filters (Cases 4, 5, 6, and 7) when loaded with water droplets. The variation trends of the resistance for all filters were similar: they initially had low resistance growth rates, and then the growth rate rapidly increased at a specific time. Moreover, the polyester fiber filter of a higher efficiency class reached the final resistance of 1000 Pa in little time.
Table 4 displays the filtration efficiency, response time of resistance, and WHC of the four polyester fiber cylinder filters. A higher filtration efficiency reduced the WHC and shortened the resistance response time. An F9 polyester cylinder filter with less porosity can trap most water droplets at generation rate of 9 kg/h water mist. The large droplet size caused an earlier sharp increase in the resistance and less time to reach 1000Pa.

Table 4. Filtration efficiencies, response time of resistance and WHC of four polyester fiber cylinder filters
<table>
<thead>
<tr>
<th>Case</th>
<th>Initial filtration efficiency for particles (&gt;0.5 μm) %</th>
<th>The response time of resistance (h)</th>
<th>WHC (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>44.5</td>
<td>1.0</td>
<td>81.9</td>
</tr>
<tr>
<td>7</td>
<td>63.8</td>
<td>0.8</td>
<td>57.9</td>
</tr>
<tr>
<td>8</td>
<td>72.6</td>
<td>0.6</td>
<td>31.6</td>
</tr>
<tr>
<td>9</td>
<td>98.7</td>
<td>0.2</td>
<td>10.5</td>
</tr>
</tbody>
</table>

Combined with the data from Table 4, it is observed that the polyester fiber filter with a relatively higher filtration efficiency had a steeper resistance curve, and the response time of resistance was shorter than that of the other filters. The captured droplets aggregated into larger droplets and formed liquid films under the influence of capillary forces, leading to a few droplets penetrating the surface. When the adhesion forces between the droplets and fibers were less than the gravitational forces acting on the droplets, the large liquid droplets drained from the fibers (Mead-Hunter et al., 2011), and the resistance gradually leveled off. Captured liquid droplets tended to deposited on the surface of the filter media with higher filtration efficiencies, reducing the contact area between the liquid droplets and fibers and reducing the adhesion forces. Consequently, the resistance of the polyester fiber filter with higher filtration efficiency reaching 1000 Pa in less time, resulting in less water absorption capacity.

Filters with high filtration efficiencies may be replaced frequently in the air handling systems of gas power plants during perennial rain and fog. Therefore, the impact of droplets on the resistance should also be considered when choosing filters for gas power plants.
4 CONCLUSIONS

In summary, the influence of high-humidity airflows on the resistance of commercial cylinder filters should be considered when selecting suitable filters for existing air intake systems. Nanofiber cylinder filters without resistance surges are recommended for filtration in gas power plants, particularly those built on the seafront. The resistance tends of nanofiber filters under wetted airflows cannot be evaluated by their materials because of the pleated structures and installation directions of the cylinder filters. By contrast, the resistance of polyester and synthetic fiber cylinder filters, which have a weak water-holding capacity (WHC), are prone to jumping owing to the easily blocked airflow channels. In addition, cylinder filters composed of wood cellulose fibers could maintain resistance stability at no more than the generation rate of 6kg/h of water mist owing to the water absorption of wood cellulose fibers and large pores in filter media produced by drainage.

However, the effects of several factors, such as separation efficiencies of filters and liquid water content (LWC) in environments, on the resistance of these conventional cylinder filters must be considered. The "$P_{jump}$" can be achieved in advance as the filtration efficiency of filters and LWC contained in airflows increase. Thus, using a high-efficiency particulate air filter without considering the wet environment is not recommended.

The experiments performed in this study investigated only the resistance of clean cylinder filters and corresponding media in highly humid airflows. The performances of cylinder filters preloaded
with dust in mist environments have not been determined. Therefore, a detailed investigation on this subject should be part of further research.

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