Study on drainage layer strategy for improving performance of glass fibrous coalescing filter

Chengwei Xu [a,*], Chenglong Xiao [b], Yan Yu [c], Xiaodong Si [d]

[a] College of Electrical, Energy and Power Engineering, Yangzhou University, Yangzhou, 225127, China

[b] Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing, 210096, China

[c] College of Engineering, Hebei Normal University, Shijiazhuang, 050024, China

[d] School of Energy and Power, Jiangsu University of Science and Technology, Zhenjiang 212003, China

Abstract:

The drainage layer strategy is a common method for improving filtration performance of coalescing filter. In this study, using the commercial glass fibrous filters, the influence of sub-high efficiency drainage layers on high efficiency coalescing filters were investigated experimentally. The efficiency of coalescing filter slight increases, whereas the total wet pressure drop reduces 0.32 kPa after assembling drainage layer. In addition, the influence of pore size, thickness and wettability on performance were evaluated. While the pore size of drainage layer decrease, the wet pressure drop reduces and quality factor increase. Likewise, the thickness of drainage layer also has positive effect on filtration performance. By contrast, the wettability has a weak affect on the filtration performance. As different coalescing filter with the same drainage layer, the improvement in the filtration performance increase with the decrease of pore size difference between the coalescing and drainage layers.

Keyword: oil particle, drainage layer, property parameters, filtration performance, coalescing

filter

1 Introduction

Oil particle in gas stream is one of an important pollutant, which are generated from cooking activity and some industries processes, such as natural gas transport, large rotating crankcase ventilation and compressed air system [1-2]. In China, cooking fume containing large amount oil particles is directly or simply treated then released to atmosphere. The oil particles affect the air quality and harm human health [3]. In addition, oil particle existing in industries process also causes serious problems including indoor air contamination, machinery damage, corrosion and energy consumption [4-6].

Fibrous coalescence filtration is an effective and predominately used method for removing oil particles from gas stream. Based on "coalesce mechanism", oil particles are intercepted onto the fibers, then occur coalescence and migration process in the filter. Pressure drop and filtration efficiency are the key performance criteria of filters. Due to the mobility and redistribution of liquid, the coalescence filtration is a complex dynamic process and affected by several parameters, including structure of filter, properties of fibrous material, operating conditions and particle diameter and so on. Contal and Firsing et.al [7-8] divided the dynamic process into four stages according the change of pressure drop. They found that the accumulation of oil particles leads the exponentially increase of pressure drop and the coalescing filter was saturated by collected liquid finally. Then several researchers investigate the influence of fibrous materials, surface properties, filter structure on coalescence filtration process [9-11]. Those studies provide the valuable support for the performance optimization of filter.

Apart from above factors, the drainage layer is another important strategy on improving the filtration performance since it provide the drainage channels and increase liquid holding capacity. Patel et al. [12-13] reported the effect of woven drainage structure and surface energy of drainage channels in the filter media. The result shows that some filters with drainage layer show higher filtration quality factor. Chang et al. [14-15] used a series of different fibrous media as drainage layer to add to glass fiber filters and investigated the influence of drainage layer on saturation, pressure drop and efficiency of filters. They found that the drainage layer leads to increase of liquid amount on interface between coalescing layer and drainage layer, which causes increase of pressure drop and saturation of filter. However, according to "jump-and-channel" model [16-17], the jump pressure drop is the capillary phenomenon depended on pore diameter and contact angle of filter. Thus, the distinction of fibrous media between coalescing layer and drainage layer causes the extra break-through pressure, which bring the error of results as equipping drainage layer.

Herein, we used glass fiber filter with the different filtration grade as coalescing layer and drainage layer. Glass fiber media is one of the most common commercial material for coalescing filters owing to low cost, large surface face, high efficiency, ease of assembly and functionalization. The effect of drainage layer on performance of filter was investigated experimentally. In addition, we modified the glass fiber drainage layer to make the surface of drainage layer have superoleophobicity and superoleophilicity. The change profile of pressure drop was analyzed by "jump-and-channel" model and capillarity in coalescing filter. The results provide further understanding of influence of the drainage layer properties on coalescence filtration performance.

2 Experiments

2.1 Materials

The filters used in this paper were built as "sandwiches" consisting of 3 layers glass fiber media. All test filter sheets were cut into disks 2.5 cm in diameter and stacked to build the test sample. The glass fiber filters with four high efficiency grade (HEPA-H10, H11, H12 and H13) were used as coalescing layer. The coalescing layer was composed of 2-layer identical HEPA glass fiber filter. To reduce the flow resistance, drainage layer employed the glass fiber filter with large pore diameter and sub-high efficiency grade (ASHRAE-F6, F7, F8 and F9). The drainage layer was assembled at outlet side of test filter. In order to demonstrate the effect of drainage layer, another test filter consisting of 2-layer HEPA filters were used as the control filter. Table 1 lists the properties of the filter media.

Table 1. Properties of test filters

Filter	category	Fiber diameter (μm)	Grammage (g/m^2)	Thickness (mm)	Packing density	Pore size (μm)
HEPA-H13	Coalescing layer	1.35	85.6	0.33	0.094	7.29
HEPA-H12		1.47	81.5	0.33	0.089	10.96
HEPA-H11		1.70	75.4	0.33	0.082	12.7
HEPA-H10		1.94	71.3	0.33	0.078	15.9
ASHRAE-F9	Drainage layer	2.48	69.2	0.33	0.076	22.54
ASHRAE-F8		3.22	67.2	0.33	0.074	33.98
ASHRAE-F7		3.62	65.3	0.33	0.071	35.3
ASHRAE-F6		4.31	63.1	0.33	0.069	35.6

The fiber diameter was calculated by Davies' equation:

$$\Delta P = \frac{64\mu U z \alpha^{1.5}}{d_f^2}\left(1 + 56\alpha^3\right) \quad (1)$$

Where, ΔP is the pressure drop of clean filter, μ is the dynamic viscosity of air, U is the air velocity, z is the thickness of filter, α is the packing density of filter, d_f is the fiber diameter.

Pore size of filters were measured by a pore size distribution analyzer (GaoQ, PSDA-20).Other parameters were provided by manufacturer. Before usage, all test filters were treated in ethanol by ultrasonic to remove grease, then were washed repeatedly using distilled water and dried at room temperature.

The superoleophilic and superoleophobic paints were obtained from school of materials science and engineering southeast university, the detailed preparation procedure was described in Ref [18]. Briefly, after washed and dried, the test drainage layer filters were separately dipped in superoleophilic and superoleophobic paints for 30 minutes to ensure all fibers were wetted completely. Then the wetted filters were taken out from the paints and dried at room temperature for 24 h. The superoleophilic and superoleophobic drainage layer sheets were obtained. The contact angle of oil on drainage layer filters were measured using a contact angle goniometer (Powereach® JC2000D).

2.2 Experiment setup

The filtration performance tests were conducted on a special apparatus as shown in fig.1. The edible oil was selected as pollutant to generate oil mist and dispersed into a polydisperse population by a Laskin Nozzle atomizer manufactured in-house. The size distribution of particles from liquid aerosol generator is in the range of 40 nm- 8 μm, and peak at 210 nm. The dried compressed air was applied as carrier gas and mixed gas. The test filters were placed into a filter holder. All coalescence test were carried out at face velocity of 18 cm/s and loading rate of 165.6 mg/h. An Electrical Low Pressure Impactor (ELPI, DEKATI) was used to measure the aerosol concentration and size distribution at upstream and downstream of test filters. The change of the pressure drop of test filters was continuously online recorded using a differential pressure transmitter (Asmik, MIK-9600D).

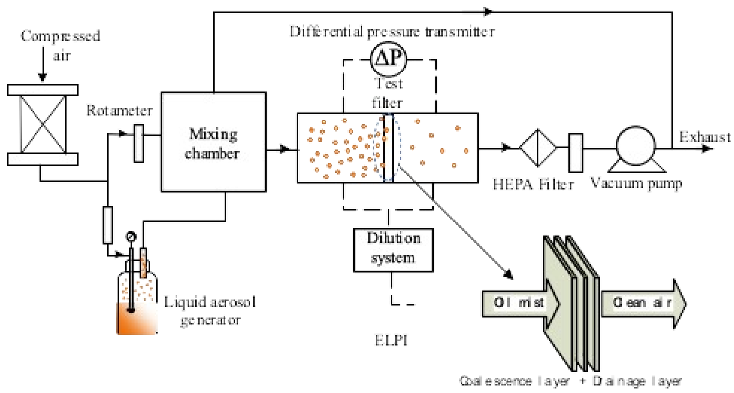

Fig.1. Experimental setup for filtration performance test.

After each experiment finished, the test filter was dismantled from the filter holder and disassembled to several sheets. The oil content of each sheet was weighed by an electronic balance. The saturation (S) of each sheet can be calculated as:

$$S = \frac{m_{oil}}{m_{oil,void}} = \frac{m_s - m_0}{V\rho_{oil}(1-\alpha)} \quad (2)$$

Where, m_{oil} is the mass of oil captured in the filter, $m_{oil,void}$ is the maximum oil content of the filter, V is the total volume of filter, ρ_{oil} is the density of edible oil, m_s is the mass of the saturated filter sheet and m_0 is the mass of the clean filter sheet.

3 Result and discussion

3.1 Effect of the drainage layer on coalescence performance

The filtration pressure drop can be generalized to three or four stages owing oil droplet migration and aggregation [7, 8]. However, as shown in Fig.2a, the pressure drop profiles of 2 layers glass filter can not be divided into three or four stages because the filters only are stacked without compaction and there are air gaps between filter layers. To illustrate the pressure drop evolution accurately, the jump-and-channel model is employed to analyze the wet pressure drop. According the model, the wet pressure drop consist of jump and channel pressure drop. For glass filter in this paper, the jump pressure drop is required to overcome the capillary force for exiting the filter, and the channel pressure drop reflects the liquid transport inside the filter. Fig.2a shows the pressure drop curve over the time. There are two channel and jump regions for two filter layers. The liquid transported through the first layer media and formed many liquid channels. This liquid channels took 11 min to reach stable state, as shown in Channel region in Fig.2a. The flow resistance from liquid channels is 2.13 kPa. Then, liquid gradually coalesced, redistributed and formed liquid film to cover the rear face of first layer media. Liquid on the rear face of first layer filter reached the front face of second layer filter cross the air gaps, which generated the jump pressure drop (5.55 kPa). Similarly, liquid transported in and drained out of second layer media to generate the channel and jump pressure drop.

Fig.2b shows that the pressure drop of each layer filter. It should be noted that the channel and jump pressure drop of second layer media is less than that of first layer, shown in Fig.2b. This is because that the first has efficient capture of liquid aerosols (>99.97%), which result in the liquid holding volume of first layer higher than second layer. In addition, the change of curve in Fig.2a indicated that the second layer is still almost dry before the first layer attains final saturation state. The result shows that the channel and jump pressure drop of each layer filter can be effected by not only media properties but also its liquid holding amount at different position.

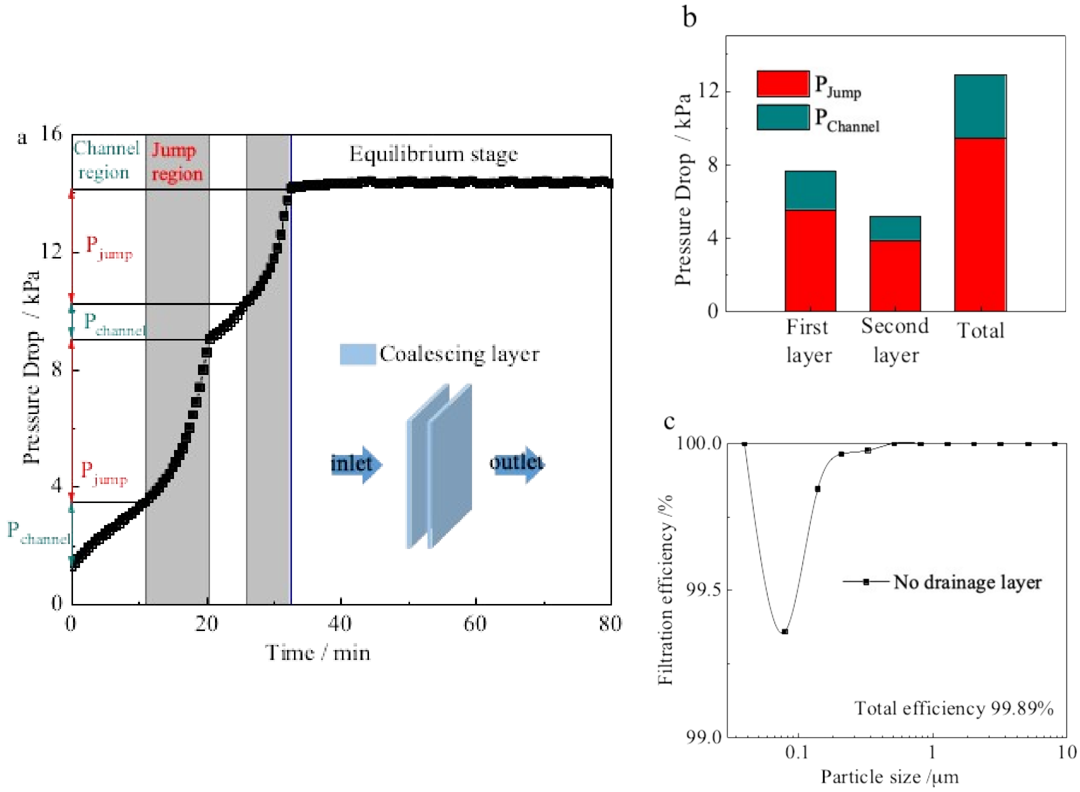

Fig.2. Pressure drop evolution and filtration efficiency of 2 layers HEPA-H13 filter without drainage layer, a) pressure drop profile versus time; b) channel and jump pressure drop of filter media; c) filtration efficiency of different size particles at equilibrium stage.

The filtration efficiency of different size particles is shown in Fig2c. The total number efficiency is 99.9%. It is attributed to the high filtration grade of each media (HEPA). The lower efficiency at most penetrating particle size (MPPS) represents that the filtration efficiency at MPPS can no be improved by increasing the thickness of filter.

When assembling the ASHRAE-F6 drainage layer outside of the coalescing layer, the pressure drop evolution in time changed, as shown in Fig.3a. Compared with the filter without drainage layer, the most signification difference is the wet pressure drop proportion of each layer filter. The time required to reach saturation state of first coalescing layer increase from 20 to 25 min when equipping the drainage layer. The second coalescing layer attain the saturation state only need 10 min and the jump pressure drop increase amplitude prominently reduce. In addition, the drainage layer only generate the channel pressure drop (0.53 kPa), which result the trifling increase of total wet pressure drop.

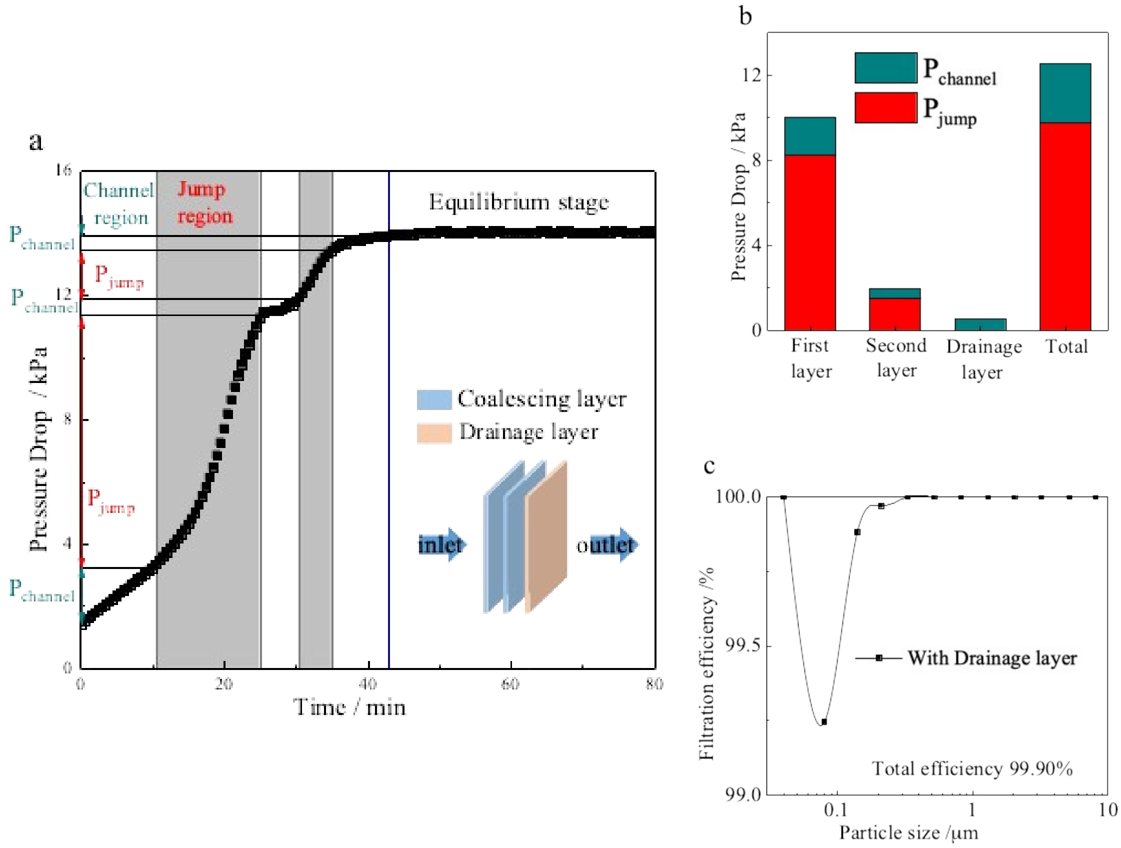

Fig.3. Pressure drop evolution and filtration efficiency of 2 layers HEPA-H13 filter with drainage layer (ASHRAE-F6), a) pressure drop profile versus time; b) channel and jump pressure drop of filter media; c) filtration efficiency of different size particles at equilibrium stage.

Fig.3b shows obvious higher jump pressure drop value of first layer than second layer, due to the increase of the saturation of first layer. The value of jump pressure drop represent the degree of liquid film. The high jump pressure drop of first layer suggested that the area and amount of liquid film increase between the coalescing layers. It is difficult to observe the distribution and change of liquid film on the rear face of first layer because capillarity cause redistribution of the liquid once the air flow is shut off. The change of pressure drop of first layer is derived from the saturation, as shown in Fig.4b. It can be seen that the saturation of first layer increase differently due to equipping different drainage layer. Furthermore, the lower jump pressure drop of second layer indicate that the drainage layer can reduce the accumulation of liquid on the rear face of the adjacent layer. The channel pressure drop of first layer is no obvious change in either cases. And the channel pressure drop of second layer decrease from 1.31 to 0.48 kPa as equipping the drainage layer. It can be caused by the decrease of liquid holding volume of second layer and the amount of liquid channel. Fig.3c show the filtration efficiency of different size particles of filter with drainage layer. It can be seen that the total efficiency mildly increase due to the enhancement of efficiency at 0.33 μm.

On the other hand, the total wet pressure drop of the filter with drainage layer reduces 0.32 kPa. It shows that wet pressure drop of filter can be improved slightly by equipped with drainage layer. To achieve an ideal improvement by drainage layer, the effect of properties and parameters of drainage layer is further investigated in the following sections.

3.2 Effect of the properties of the drainage layer on coalescence performance

Pore size of drainage layer is an important parameter which affects the performance of coalescing filter. To investigate the effect of pore size of drainage layer, four different grade filters (ASHRAE-F6, F7, F8 and F9) were employed as drainage layer. The pore size of drainage layer range from 35.6 to 22.54 μm, shown in Table.1. Fig.4a shows that the wet, channel and jump pressure drop of coalescing filter. The wet pressure drop of filter decrease with the decrease in pore size. The reason for reduction of wet pressure drop is that the decrease of pore size result in the increase of capillary force. The capillary pressure is inversely proportional to the capillary radius according to Laplace's equation. Mullins et al [19] analyzed the coalescence process of oleophilic fibrous filter media and developed the relationship between the capillary radius and the properties parameters of filter, where;

$$r_c = \left(-A\log_e\left(\frac{\alpha}{r_f}\right) - B\right)c_f \qquad (3)$$

Where, r_c is the capillary radius, r_f is the fiber radius, A and B are the media-specific constants, c_f is the correlation coefficient.

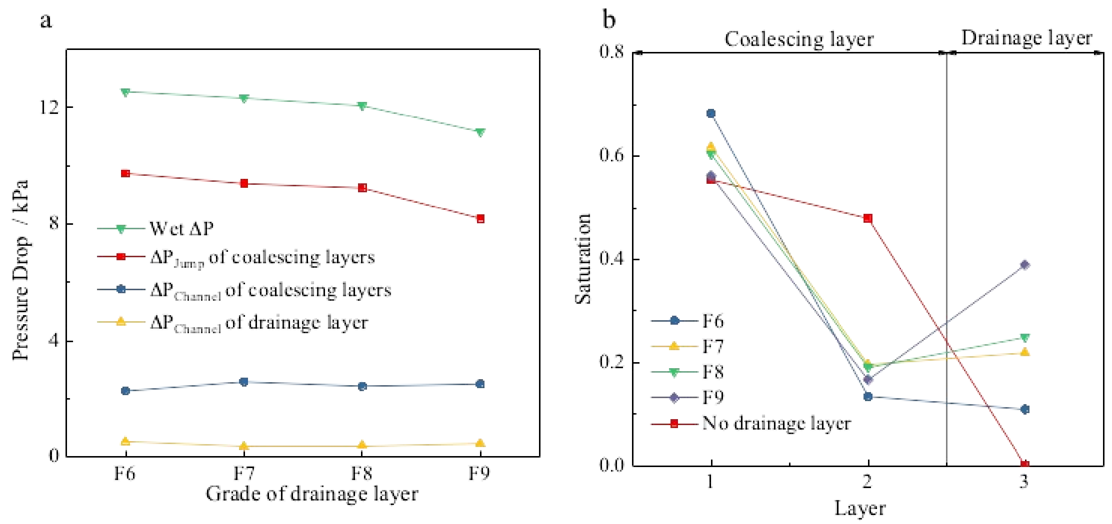

Fig.4. Pressure drop and saturation of filter with different drainage layers, a) pressure drop; b) saturation.

According to Eq. (3), the smaller capillary radius of drainage layer caused by the smaller pore size. Thus, the capillary force of drainage layer increase with the decrease of pore size. More liquid collected by the coalescing layer were dragged into the drainage layer, which result in the reduction of wet drop of coalescing layer as shown in Fig.4a. Theoretically, the jump pressure drop is only affected by the fibrous media properties, rather than the other operating parameters [17]. Thus, the jump pressure drop of coalescing filter should remained constant after assembling the drainage layer. However, it can be seen that the evolution of jump pressure drop is in agreement with the wet pressure drop. It could be assumed that the jump pressure drop is the resistance of airflow essentially and directly related to the amount of oil film on the rear face of coalescing filter. This is visual evidence for the reduction of oil film on the coalescing layers caused by the decrease of pore size of drainage layer. Nevertheless, there is no direct correlation between channel pressure drop and pore size of drainage layer due to the small deviation of channel pressure drop in Fig.4a.

While equipping the drainage layer, the saturation of second coalescing layer decline sharply and the saturation of first layer increase in various degrees, as shown in Fig.4b. Although existing the capillary rearrangement phenomenon, this result suggests that the amount oil film on second layer is further less than first layer. Furthermore, the saturation of drainage layer increase with the decrease of pore size. To illustrate the correlation between the pore size and saturation, based on the modified Washburn equation, the equilibrium capillary rise height x_∞ is calculated by

$$x_\infty = \frac{CT\cos\theta}{A_c \rho g} \quad (4)$$

Where, C is the wetted perimeter of capillary, T is the surface tension of oil, θ is the contact angle, ρ is the density of oil, g is acceleration due to gravity.

According to Eqs. (3-4), the capillary height of liquid at saturation state raise with the decrease of pore size and more liquid was remained in the fibrous media. Thus, the saturation of the drainage layer increase with the decrease in pore size. In addition, the higher capillary height take longer time to reach the steady state.

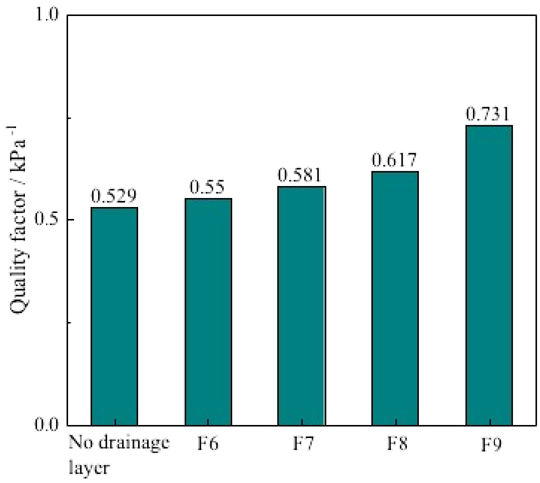

Fig.5. Quality factor of filters with different drainage layers at equilibrium state

The quality factor Q_f is defined as:

$$Q_f = \frac{-\ln(1-E)}{\Delta P}$$

Where, E is the filtration efficiency and ΔP is the wet pressure drop.Fig.5 shows that the quality factor of filters with different drainage layers. The coalescing layer with drainage layer (F9) shows the highest quality factor. It is reasonable to conclude that the drainage layer strategy could effectively improve the filtration performance of coalescing filter.

Thickness is another characteristic parameter of drainage layer. The initial dry pressure drop of drainage layer is only 0.067 kPa at face velocity 18 cm/s, which is further lower than the initial dry pressure drop of coalescing layer (1.33 kPa). Though the dry pressure drop is proportional to thickness, the effect of increasing thickness of drainage layer on dry pressure drop may be neglected. In this paper, the thickness of drainage can be varied by chancing the number of layers.

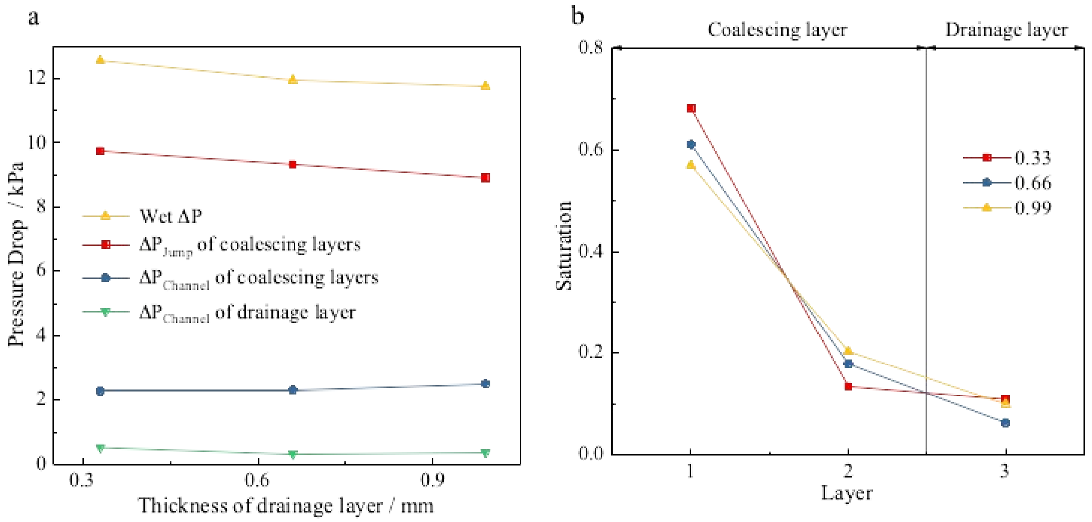

Fig.6. Evolution of pressure drop and saturation of filter at different thickness of drainage layers, a) pressure drop; b) saturation.

Fig.6a shows that the wet pressure drop is plotted against the thickness of drainage layer. Similarly, the jump pressure drop decrease in the increase of thickness of drainage layer. As shown in Fig.6b, the saturation of first layer is close to second layer when the thickness increase. According to capillary pumping model of porous media [20], the thicker drainage layer pumped more liquid into the drainage layer. According to this theory, the actual holding volume of drainage layer enhance. However, owing to the void volume of drainage layers multiplied, the apparent saturation of drainage layer show the reduction tendency.

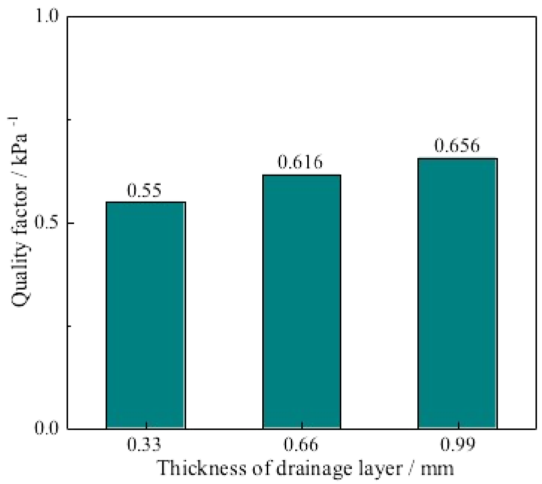

Fig.7. Quality factor of filter at different thickness of drainage layers

The quality factor can be calculated by the efficiency and wet pressure drop, as shown in Fig.7. The filter with the thickest drainage layer exhibited the best filtration performance. The results show that the coalescence performance can be improved by increasing the thickness of drainage layer.

The effect of wettability of drainage layer is studied by using three different surface property materials having untreated, superoleophilic and superoleophobic glass fiber media. The oil contact angle of original glass fiber filter is 55° and change to 6.5° after oleophilic treatment. The oil contact angle of superoleophobic filters is 155.4. Fig.8a-b show the photograph of oil droplet on treated glass fiber filter.

While the contact angle of drainage layer change from 55°to 6.5°, the jump pressure drop of coalescing layer reduce and the channel pressure drop increase, as shown in Fig.8c. According to the results in Fig.8d-e, the difference value of saturation between first layer and second coalescing layer decrease. Because the liquid in drainage layer is hard to drain due to the excellent lipophilicity. the increase of saturation of drainage layer indicates that more liquid is sucked into the drainage layer. In addition, the wet pressure drop and quality factor of superoleophilic drainage layer is close to that of untreated drainage layer. Thus, the effect of contact angle on filtration performance could be neglected as filter is oleophilic fibrous media.

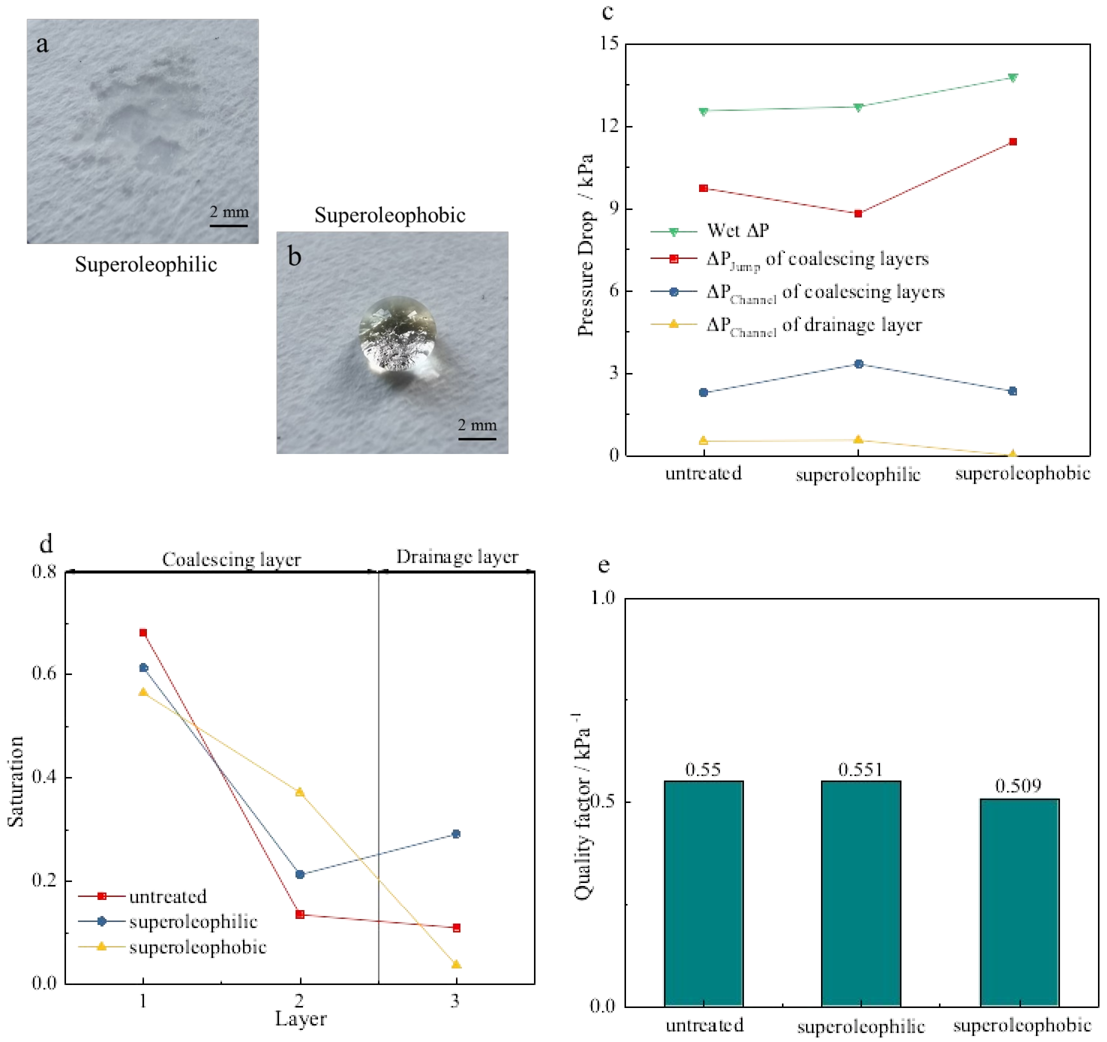

Fig.8. a-b) photograph of edible oil on superoleophilic and superoleophobic drainage layer; c) saturation profiles of filters at equilibrium state; d) pressure drop of filters; e) quality factor of filters at equilibrium state.

When the drainage layer is superoleophobic, the wet pressure drop and jump pressure drop of filter increase, as shown in Fig.8c. The increment of saturation of second coalescing layer is higher than decrement of first layer, which represents the increase of liquid amount on coalescing layer. The increase of jump pressure drop and saturation of second layer suggest that the liquid film on rear face of second layer increase. The reason for this result may be that the liquid on rear face of second layer aggregate largely because of the repellency of superoleophobic drainage layer and cannot be drained out in time. The quality factor of filter with superoleophobic drainage layer is 0.509 kPa^{-1} and lower than other filters. It is obvious that the wettability of drainage layer has slight influence on the filtration performance.

3.3 Effect of the drainage layer on different coalescing filter

In practice, the different coalescing filters are selected to fit the various filtration requirements. Thus, the experiments was conducted to investigate the effect of drainage layer on different coalescing filter HEPA-H13, H12, H11, H10. The variation of wet pressure drop and quality factor are shown in Fig.9.

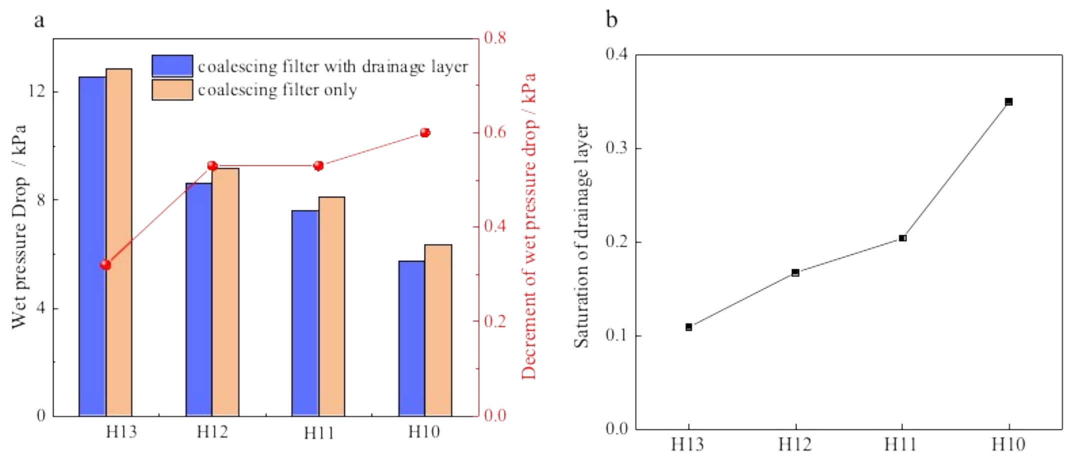

Fig.9. Variation of different coalescence filter with F6 drainage layer at steady state, a) wet pressure; b) saturation of drainage layer.

As equipping ASHRAE-F6 drainage layer, the wet pressure drop of all test filters has been reduced and the decrement of wet pressure drop increase with the decrease of filter classification at steady state. The gravitational force influence the drainage rate vertically and can not be discussed here. In this paper, the effect of drainage layer is mainly reflected in the liquid transport horizontally. A force balance of liquid film between the coalescing layer and drainage layer includes airflow force, drag force from coalescing layer, and suction force from drainage layer.

Due to the same drainage layer, the capillary suction force generated by drainage layer should be constant. However, the capillary drag force from coalescing layer decrease in the increase of the pore size of coalescing layer and the airflow force remains constant. Thus, more liquid transported into the drainage layer. It can be verified by the data shown in Fig.9b. The saturation of ASHRAE-F6 drainage layer increase with the reduction of pore size of coalescing layer. The result also indicates that the smaller deviation of pore size of adjacent layers is more favorable to liquid transport.

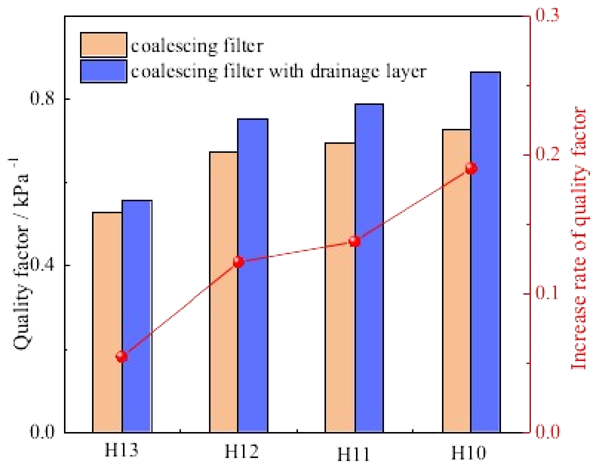

Fig.10. Quality factor of different coalescence filter with F6 drainage layer at steady state

Not unexpectedly, the HEPA-H10 coalescing filter with ASHRAE-F6 drainage layer shows the highest quality factor and best filtration performance, as shown in Fig.10. In addition, the increase rate of quality factor of HEPA-H10 reaches 19%, which is higher than other filters. The increase rate of quality factor gradually increases with the reduction of filter classification. This result shows that the impact of drainage layer method on diverse coalescing filter is different and this strategy can improve the filtration performance of coalescing filters.

4 Conclusions

In this paper, the experiments were conducted to investigate the effect of pore size, thickness and wettability of a series of sub-high efficiency drainage layers (ASHRAE-F6, F7, F8, F9) on high efficiency coalescing filters (HEPA-H10, H11, H12, H13). While assembling drainage layer, the jump pressure drop of second coalescing layer significantly decrease and that of first layer increase. The total wet pressure drop reduces 0.32 kPa. The results indicate that the drainage layer causes the redistribution of oil in coalescence layers and promote the drainage of the adjacent coalescence layer. In addition, the smaller pore size of drainage layer results in the lower wet pressure drop and higher quality factor. The thickness of drainage layer also affect the filtration performance. As increasing the thickness of drainage layer, the wet pressure drop of filter decrease and the quality factor increase. Furthermore, the superoleophilic and superoleophobic drainage layer were prepared as the control filters to explore the effect of wettability. It can be found that the wettability can impact the oil distribution and transport on coalescence layer but weakly affect the filtration performance. Moreover, four high efficiency coalescing filters with the same drainage layer shows diverse influence on wet pressure drop and quality factor. In particular, when the difference of pore size between the coalescing and drainage layers decrease, the improvement in the filtration performance is obvious.

Reference

1. Zhao X, Hu Q, Wang X, et al. Composition profiles of organic aerosols from Chinese residential cooking: case study in urban Guangzhou, south China. Journal of Atmospheric Chemistry, 2015, 72(1): 1-18.
2. Mead-Hunter R, King A J C, Mullins B J. Aerosol-mist coalescing filters–a review. Separation and Purification Technology, 2014, 133: 484-506.
3. Metayer C, Wang Z, Kleinerman R A, et al. Cooking oil fumes and risk of lung cancer in women in rural Gansu, China. Lung Cancer, 2002, 35(2): 111-117.
4. Lee J.H., Kim I., Seok H., Park I., Hwang J., Park J.O., Won J.U. Roh J. Case report of renal cell carcinoma in automobile manufacturing factory worker due to trichloroethylene exposure in Korea. Annals of occupational and environmental medicine, (2015), 27(1), 19-19.
5. Gonfa G, Bustam M A, Sharif A M, et al. Tuning ionic liquids for natural gas dehydration using COSMO-RS methodology. Journal of Natural Gas Science and Engineering, 2015, 27: 1141-1148.
6. Stahley J.S., Dry Gas Seals Handbook, PennWell Corporation, Tulsa, 2005
7. Contal P, Simao J, Thomas D, et al. Clogging of fibre filters by submicron droplets. Phenomena and influence of operating conditions. Journal of Aerosol Science, 2004, 35(2): 263-278.
8. Frising T, Thomas D, Bémer D, et al. Clogging of fibrous filters by liquid aerosol particles: Experimental and phenomenological modelling study. Chemical Engineering Science, 2005, 60(10): 2751-2762.
9. Manzo G M, Wu Y, Chase G G, et al. Comparison of nonwoven glass and stainless steel

microfiber media in aerosol coalescence filtration. Separation and Purification Technology, 2016, 162: 14-19.

10. Mullins B J, Mead−Hunter R, Pitta R N, et al. Comparative performance of philic and phobic oil−mist filters. AIChE Journal, 2014, 60(8): 2976-2984.
11. Bredin A., Mullins B. J. Influence of flow-interruption on filter performance during the filtration of liquid aerosols by fibrous filters. Separation and Purification Technology.2012, 90: 53-63.
12. Patel S U, Chase G G. Gravity orientation and woven drainage structures in coalescing filters. Separation and Purification Technology, 2010, 75(3): 392-401.
13. Patel S U, Kulkarni P S, Patel S U, et al. The effect of surface energy of woven drainage channels in coalescing filters. Separation and purification technology, 2012, 87: 54-61.
14. Chang C, Ji Z, Liu J. The effect of a drainage layer on the saturation of coalescing filters in the filtration process. Chemical Engineering Science, 2017, 160: 354-361.
15. Chang C., Ji Z., Zeng F. The effect of a drainage layer on filtration performance of coalescing filters. Separation and Purification Technology. 2016, 170: 370-376.
16. Kampa D, Wurster S, Buzengeiger J, et al. Pressure drop and liquid transport through coalescence filter media used for oil mist filtration. International Journal of Multiphase Flow, 2014, 58: 313-324.
17. Kampa D, Wurster S, Meyer J, et al. Validation of a new phenomenological “jump-and-channel” model for the wet pressure drop of oil mist filters. Chemical Engineering Science, 2015, 122: 150-160.
18. Xiao Z., Zhu H., Wang S., Dai W., Luo W., Yu X., Zhang Y. Multifunctional Superwetting Composite Coatings for Long-Term Anti-Icing, Air Purification, and Oily

Water Separation. Advanced Materials Interfaces, 2020, 7(8):

19. Mead-Hunter R, Braddock R D, Kampa D, Merkel N, Kasper G, Mullins B J. The relationship between pressure drop and liquid saturation in oil-mist filters–Predicting filter saturation using a capillary based model. Separation and Purification Technology, 2013, 104: 121-129.

20. Li J, Zou Y, Cheng L. Experimental Study on Capillary Pumping Performance and Permeability Measurement of Porous Structure. Proceedings of the CSEE, 2012, 11:95-99.