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Comparison of nonwoven glass and stainless steel microfiber media in aerosol coalescence filtration

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ABSTRACT

Coalescing filters are used to remove fine drops from aerosols and emulsions. Fibrous nonwoven filter media are commonly used to coalesce small drops into larger drops for easier removal. The coalescing performance of a medium is dependent upon several parameters including permeability, porosity, and wettability. In many coalescing filters, glass fibers are used. In this work, we measure the properties of steel fiber media to see how these properties compare to glass fibers in coalescence performance.

Steel fiber media have several differences in material properties from glass fiber media that may prove advantageous in performance and filter design. Steel fiber media are more ductile than glass fibers making them more suitable for vibrating environments and easier to machine with reduction of fiber shedding. The steel fiber media are elastic and can be compressed to change media properties such as permeability and porosity. The steel fibers have different wetting properties than glass and may give better coalescing performance for some liquids and they can be applied at higher operating temperatures than glass fibers.

Nonwoven stainless steel and glass fiber media with fiber diameters of 2 and 6 μm were used. Permeabilities were measured using a Frazier Permeability Tester, porosities were measured using a custom made pycnometer, and wetting properties were measured with a modified Washburn test.

The media performances were evaluated in a coalescence test apparatus. The overall performances of the steel fiber and glass fiber media are compared using a filtration index. 2 μm glass and 6 μm stainless steel fiber media had separation efficiencies of about 85%. Due to the higher permeability of 6 μm stainless steel media, its filtration index was significantly higher.

1. Introduction

Coalescing filters are used to remove small liquid droplets from air streams. They have numerous industrial applications including dehumidification, cabin air filtration, compressed air filtration, metal working, and automotive engine crank case ventilation [1–4].

In the coalescence process an aerosol passes through a nonwoven microfiber filter medium to coalesce the droplets into larger drops. The inlet aerosol droplets are captured on the fibers of the medium, coalesce, and migrate through the fiber medium. The enlarged drops are dragged through the medium by the gas flow and drain from the exit surface of the filter medium [5,6]. The performances of coalescing filters are measured in terms of separation efficiencies and pressure drops. The separation efficiency is dependent on properties of the aerosol (e.g. composition, density, viscosity, drop size etc.). It also depends on the filter properties including the fiber surface wetting properties, fiber size, fiber orientation, porosity, binder content, and filter bed length [7–13]. The gas flow rate is important as it controls the mechanism of droplet capture on the fibers, the inertia force of drop–drop collision and coalescence, and the drag force on the coalesced drops to cause the drops to migrate through the filter [10–14]. Glass fiber media are commonly used as filter media. However, new non-woven polymer, carbon, metal, and ceramic fiber materials are being developed. Non-woven steel fiber media with comparable fiber diameters to glass fiber media have been produced and have unique properties that may improve coalescence performance [15,16].

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In some filter designs, the fibrous filter media can be compressed during filter fabrication. An example is when fiber sheets are wrapped onto a cylinder to form a spiral-wound filter cartridge. By adjusting the tension on the sheet during the wrapping different compressive forces can be applied to the media. The ductile steel fiber media can be compressed without breaking the fibers to change permeability and porosity properties of the media.

The steel fibers in the media evaluated in this work were sintered and did not have a glue or binder to hold the fibers in the media together. The glass fiber media often are fabricated with a binder to hold the fibers together and give the media its rigidity. Stainless steel and glass media also differed in their wettability toward the liquids in the experiments due to their different surface energies.

The objectives of this work are to (i) compare the properties of steel and glass fibrous media and (ii) compare coalescence filtration performance.

2. Experimental description

2.1. Materials and preparation

The 316 stainless steel (SS) fiber media (Bekaert, Belgium) with two different fiber sizes 2 and 6 μm were tested. Two sizes of glass fiber media (Hollingsworth and Vose (H&V), USA), 2 and 6 μm, were tested. Table 1 lists the basic information of the different media.

Both of the SS media samples and the 6 μm glass fiber media were supplied as sheets of commercial media having sheet thickness of about 0.2 cm. The SS and glass fiber sheets were cut into disks 6 cm in diameter and stacked as layers to construct the 1.0 cm thick test samples. The 2 μm glass fibers from were provided as bulk loose fibers and were vacuum formed into disk shaped filter media of thickness of 1 cm via a custom made vacuum molding apparatus [17].

The SS media were fabricated of sintered steel wires of uniform intrinsic density and contained no chemical binders. The 6 μm glass fiber media sheets contained an unspecified small amount of binder for mechanical strength. The vacuum molded 2 μm glass fiber media were formed with a small amount of binder added to the slurry with the recipe of 5 ml of binder (Megasol® S50 and starch, Wesbond Corporation), 5 g of glass fibers, mixed for 1 h in 6 l of water at pH of 4.0 and at room temperature.

2.2. Media characterization

2.2.1. Porosity

A mass method and a pycnometer method were used to determine the media porosities. The mass method is applicable for a medium of one material (ie, no binder) with known intrinsic fiber density. The pycnometer method, based on gas displacement and the ideal gas law, is applicable to media with multiple materials or materials of unknown relative mass quantities. Both methods were applied to the SS media and only the pycnometer method was applied to the glass fiber media.

For the mass method the porosities were calculated from the mass of the medium and its bulk volume using the formula

$$\varepsilon = 1 - \frac{M_{SS}}{\rho_{SS} V_{Filter}} \tag{1}$$

where ε is the porosity (void volume), M_{SS} is the mass of a medium, ρ_{SS} is the intrinsic density of the SS fibers and V_{Filter} is the macroscopic volume of the filter medium. The intrinsic density of SS fibers were estimated by measuring the weight of a similar material SS rod of known physical dimensions (density was calculated to be 7.72 ± 0.06 g/cm^3) and by a water displacement test of the same rod (density was calculated to be 7.72 ± 0.41 g/cm^3). These values are close to the value of 8 g/cm^3 reported in literature [18].

A custom made pycnometer was used to measure the changes in pressures during the gas displacements. The changes in pressure corresponded to changes in chamber volumes calculated using the Ideal Gas Law and from which the porosity was calculated [19,20].

2.2.2. Permeability

The permeabilities of the media were measured using a Frazier Permeability Tester and calculated using Darcy's Law

$$\frac{Q}{A} = \frac{k\Delta P}{\mu L} \tag{2}$$

The Frazier Permeability Tester passed a measurable flowrate of air, Q, through the porous medium and the pressure drop across the medium, ΔP, was measured. The cross-sectional area, A, and the thickness of the medium, L, were measured directly. The viscosity of air, μ, was obtained from literature. The permeability was calculated by rearranging Eq. (2)

$$k = \frac{Q\mu L}{A\Delta P} \tag{3}$$

2.2.3. Wettability

The wettabilities of the surfaces of the fibers to the liquid phase controls the coalescence of the droplets in the coalescing filter, and hence controls the overall performance of a medium. It was not possible to measure directly the contact angle of Sullube 32 on the fibrous surface of the media due to the irregular morphology of the fiber mat structure.

The individual fibers were too small in diameter and length to be practical for measuring contact angles. Hence, flat smooth surfaces of representative materials similar to the fibers, were used to measure the contact angles. The liquid was the same as that used in the coalescence experiments, Sullube 32 (Diversified Air Systems, Ohio, USA). The contact angles were optically measured using a drop shape analyzer (DSA20 Easy Drop, Krüss, Hamburg, Germany).

The contact angles on representative materials at best give an approximation of the contact angles of the fiber materials in the media. The crystal structures in SS metal grains in the flat sheet may differ from that of the fibers due to differences in manufacturing. Melting the SS fibers to create a flat surface would alter the crystal structures and affect the measurement. The glass fibers are amorphous and can be melted. But measuring the contact

Table 1
Test filter properties.

Supplier	Fiber material	Fiber diameter (μm)	Mass/area (g/m^2)	Filter diameter (cm)	Sheet thickness (cm)	Filter thickness (cm)
Bekaert	SS	2 ± 0.1	152	6	0.2	1.0
Bekaert	SS	6.5 ± 0.1	150	6	0.2	1.0
H&V	Glass	2 ± 1	150	6	na	1.0
H&V	Glass	6 ± 2	150	6	0.2	1.0