Polymer Nanofibers from Recycling of Waste Expanded Polystyrene

C. Shin, and G. G. Chase*,
Microscale Physiochemical Engineering Center
The University of Akron
Akron OH 44325-3906
330-972-7946, gchase@uakron.edu

Abstract

In this study polystyrene (PS) nanofibers are electrospun from recycled expanded polystyrene (EPS). These fibers are mixed with micro glass fibers to modify the glass fiber filter media. The filter media are tested in the separation of water droplets from an emulsion of water droplets in oil. Water-in-oil emulsion separations are important to the petrochemical industries for product quality, safety, ecological and economic reasons.

The experimental results in this work show that polystyrene nanofibers with diameters of around 600 nm were produced by the electrospinning method. The addition of the nanofibers to conventional micron sized fibrous filter media improves the separation efficiency of the filter media from 68 to 88 %.

Introduction

Expanded polystyrene (EPS) is commonly used for insulation and packing materials. EPS is manufactured in the form of very small beads of polystyrene with a molecular weight between 160,000 and 260,000 which contains 4 to 7% blowing agent, usually pentanes or butane. Many industries use EPS because of its versatility, dimensional stability, cleanliness, and low cost. After use, EPS usually ends up in land fills or is incinerated.[1] Various techniques are available for recycling the waste plastics such as chemical, thermal, and material recycles.[2-9] EPS is one of the least economical polymer products to recycle because it contains so much air, making the bulk volume uneconomical to transport to recycle facilities. If the EPS can be recycled into a useful nanofiber for which large lengths are produced per mass of polymer then the economics may be more favorable. In this paper the electrospinability of the recycled EPS is demonstrated and the electrospun fibers are tested in filter media. The economics of the process will be considered in future work.

Polymer nanofibers[10-12] are used in industrial applications such as filter materials[13,14], wound dressing materials, nano-composites, non-woven fabrics, and many others.[15] To our knowledge this is the first reported use of electrospinning to recycle a polymer. The objective of this work is to electrospin PS nanofibers from EPS and to compare the performance of glass fiber filter media with that of glass fiber media supplemented with nanofibers in the coalescence separation of water droplets from a water-in-oil mixture.

Experimental setup and procedures

Electrospinning

The electrospinning process forms nanofibers of long lengths and with diameters typically in the range of 10-500 nm.[15] Electrical forces on free charges on the surface or inside a polymeric liquid drive the process. When the free charges in the polymer solution, which are generally ions, move in response to the electric field, they quickly transfer a force to the polymer solution. When the electric field reaches a critical value at which the electric force overcomes the surface tension force, a charged jet of the solution is ejected from the tip of a cone protruding from a liquid drop of the polymer. As the jet stretches and elongates in the air, the solvent evaporates, leaving behind a continuous charged polymer fiber that lays itself almost randomly on a collecting metal screen. The fibers are produced to form a non-woven mat. Non-woven mats of electrospun fibers have large surface areas and small pore sizes compared to commercial textiles, making them excellent materials for use in filtration applications.

Figure 1 shows a schematic diagram of the apparatus used for electrospinning. The EPS solution, prepared by dissolving 20 wt% waste EPS (from chemical packing) by mass in 80 wt% N,N-dimethylacetamide (DMAc), is loaded into the syringe. The flow rate from the syringe is controlled with a syringe pump (WPI, Model Sp101i). A tube from the syringe connects to a needle with a 1 mm inside diameter and the needle is charged to 15,000 volts (Gamma High Voltage Research, Model D-ES30PN/M692) to produce the nanofibers. The grounded collecting surface is placed at a distance of about 20 cm from the tip of the needle of syringe pump.

Coalescence filtration

The recycled nanofibers are used here to modify the performance of coalescence filters. Coalescence filter performance depends on flow rate, bed depth, fiber surface properties, and drop size.[3-12] Filter media with large contact areas per unit mass generally

perform better than media with lesser surface areas. Fibrous filter media provide the advantage of high filtration efficiency at economical energy costs.

A schematic diagram of the experimental apparatus is shown in Figure 2. A mixture of water-in-oil was used in the experiments, in which deionized water was dispersed in oil (viscor 1487, diesel fluid) in a concentration of 0.1/99.9 (vol./vol.) water in oil. The viscor 1487 (specific gravity = 0.83) is pumped from tank 1 by a peristaltic pump, at a constant flow rate through a mixing pipe (where the water drops are mixed with the oil), through the filter sample and into a settling tank and reservoir. The water-in-oil mixture flow rate is controlled by selection of tube diameter size for the peristaltic pump (Masterflex, Model L/S EW-07543-60). The flow rates for each of the experiments here were held constant at 100 ml/min.[16]

Results and discussion

To electrospin the EPS, the solution is prepared by dissolving waste EPS in N,N-dimethylacetamide (DMAc). The concentration of EPS in the solution affects the electrospinning. If the concentration of polymer is too small the polymer jet may spray small drops instead of a continuous fiber jet, or it may spin out fibers that have beads of polymer. If the solution is too concentrated the electrical forces may not be strong enough to form the jet. At some intermediate concentration smooth continuous fibers are formed. The electrospun beaded fibers are related to the capillary instability of the jet of polymer solution, surface tension of the solution, and viscoelastic properties of the polymer solution.[17] In this case, a 10 wt% solution of EPS forms beaded fibers (Figure 3) whereas a 20 wt% solution forms smooth nanofibers (Figure 4). The polystyrene nanofiber diameter varies from 500 to 700 nm, with an average diameter of about 600 nm.

Filter media are constructed with and without the nanofibers as described previously. SEM images the mixed glass fiber and nanofiber media show that the many of EPS nanofibers do not cluster together or wrap around the glass fibers, but tend to cross over the pore spaces between the larger glass fibers (Figure 5).

Five different filter media are tested in this work. The filter media compositions are listed in Table 1. The plots of pressure drop measurements over time (Figure 6) show that time the pressure drop initially increases but eventually levels off to a steady state value. This corresponds to the increase with time in water held-up in the filter media. When the amount of hold up water is sufficient, the water droplets begin to migrate through the filter medium until a steady state condition is reached in which the rate of water

entering the filter is balanced by the rate of water exiting the filter. The exiting drops tend to be larger than the incoming drops. Figure 6 also shows that the pressure drop also increases with the amount of nanofiber in a filter medium.

The steady state separation efficiencies of the filter media are plotted in Figure 7 as a function of the ratio surface area the nanofibers and that of the glass fibers. The efficiency of the separation is determined by mass balance of water entering the filter and the mass of water passing through the settler. Separation efficiency, E, is defined on a mass basis by

$$E = 1 - \frac{\sum_d \rho N_d \frac{\pi}{6} d_d^3}{\sum_u \rho N_u \frac{\pi}{6} d_u^3} \tag{1}$$

and was measured experimentally by determining the oil content of upstream and downstream, where N_u is the number of water droplets upstream of size d_u, and N_d is the number of water droplets downstream of size d_d. The particles counted at the sampling port, after the settling tank in Figure 2, are those that were not separated from the stream. The particle size distribution of upstream and downstream emulsion as measured by the Hyac Royco BR8 particle counter are shown in Figure 8. The design of the settling tank may influence these results; hence these results are compared between the experiments for relative performance.

Since all of the filter samples have the same amount of glass fiber (0.5 g) then the surface area ratio corresponds directly with the amount of nanofiber added to the filter media. The area ratio of nanofiber is defined as

$$Area\ ratio\ of\ nanofiber = \frac{A_{nanofiber}}{A_{glassfiber}} \tag{2}$$

and the areas of the fibers are calculated by

$$A = \frac{4}{d_f} \frac{m_f}{\rho_f} \tag{3}$$

where d_f is the average fiber diameter, ρ_f is the fiber intrinsic density, and m_f is the mass of fiber in the sample.

From the graphs, it is easy to conclude that the filters supplemented with EPS polymer nanofibers have higher pressure drops and higher separation efficiencies than the glass fiber filter without nanofibers. The increase in pressure drop corresponds with the increase with the efficiency. The maximum efficiency is occurred for the medium with 0.122 g EPS nanofiber. Glass fiber filter media without EPS polymer nanofiber has the lowest pressure drop and 67.5% separation efficiency.

Summary

In this work, we converted waste expanded polystyrene into polystyrene nanofibers. We used the nanofibers to supplement glass fiber filter media. The filtration experiments show that the addition of small amounts of polystyrene nanofibers significantly improve the coalescence efficiency of the filter, but also significantly increase the pressure drop of the filters.

Acknowledgement

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Table 1. Filter media composition and their steady state efficiencies.

Filter	Glass fiber (g)	Binder (g)	Nanofiber (g)	Total weight (g)	Efficiency (%) ± 0.8%
Filter A	0.500	0.325	0.000	0.825	67.5
Filter B	0.500	0.352	0.020	0.872	72.3
Filter C	0.500	0.370	0.042	0.911	79.0
Filter D	0.500	0.369	0.060	0.929	85.4
Filter E	0.500	0.370	0.122	0.992	88.1

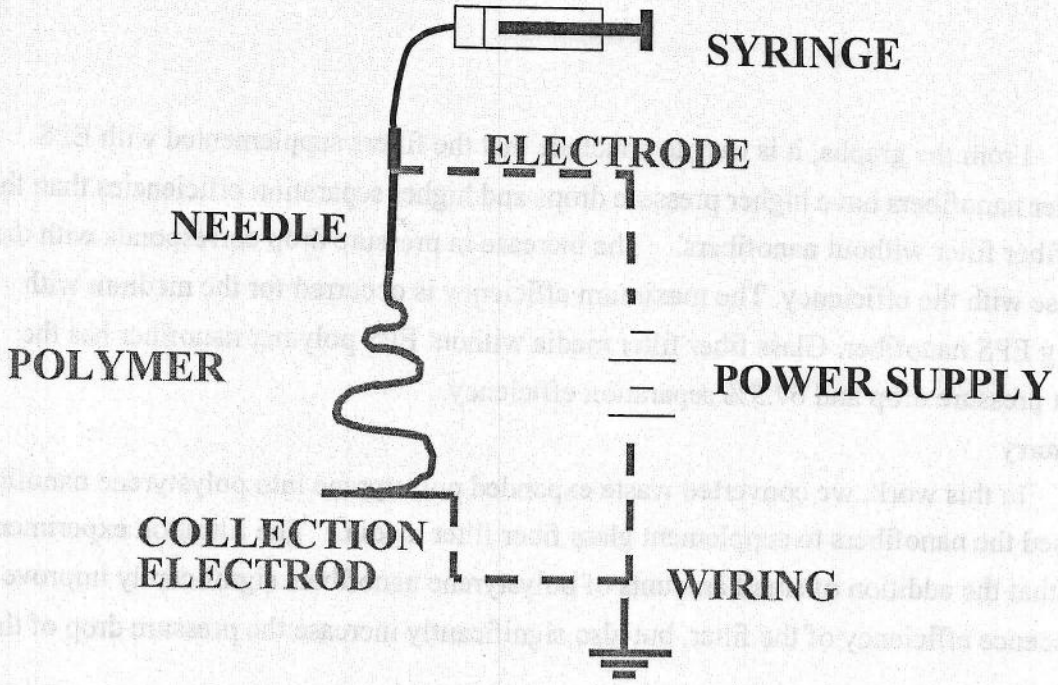

Figure 1. Electrospinning apparatus

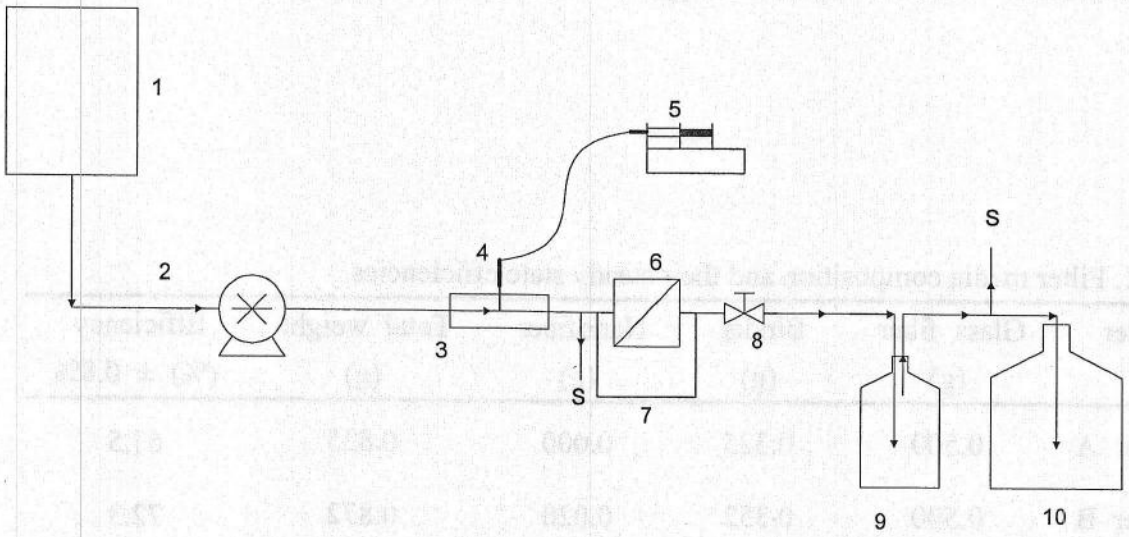

Figure 2. Experimental apparatus.

1. Oil Tank	2. Peristaltic pump	3. Mixing pipe	4. Hypodermic needle
5. Syringe pump	6. Filter Sample holder	7. Manometer	8. Valve
9. Settling tank	10. Reservoir tank	S. Sampling points	

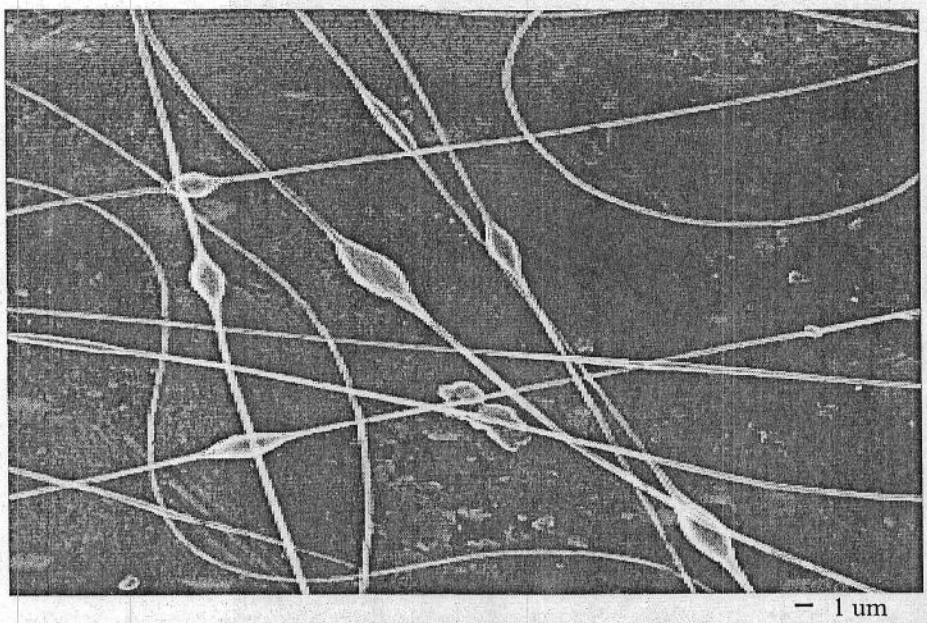

Figure 3. The morphology of beaded fibers (10 wt% EPS)

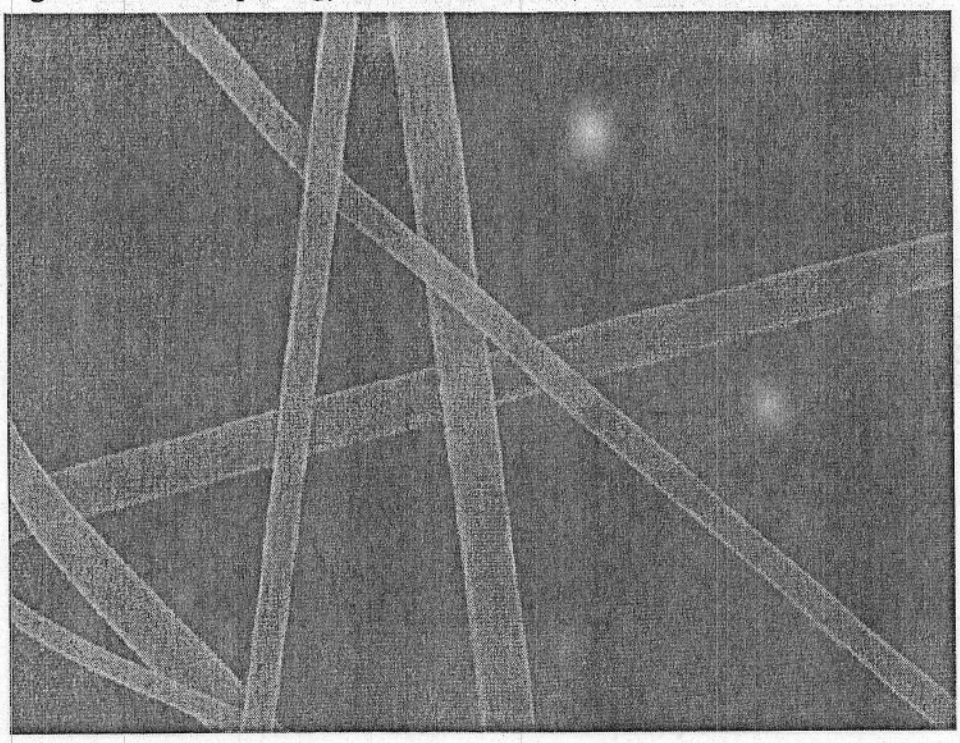

Figure 4. SEM image of EPS nanofibers.

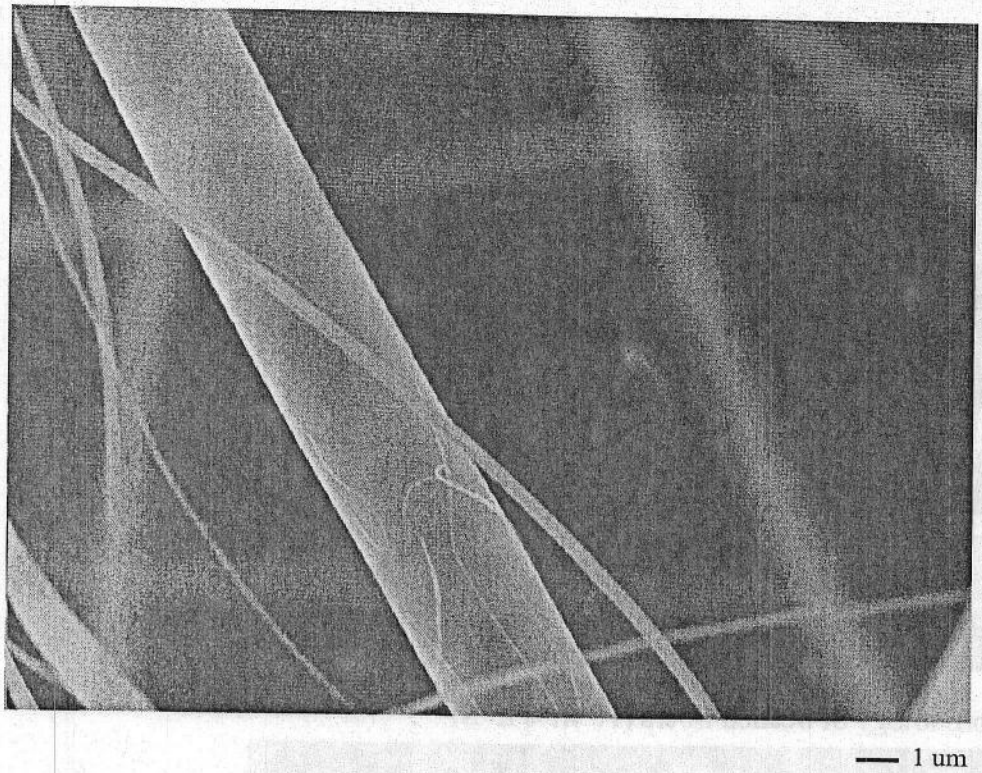

Figure 5. Commercial glass fiber and eletrospun EPS polymer nanofibers.

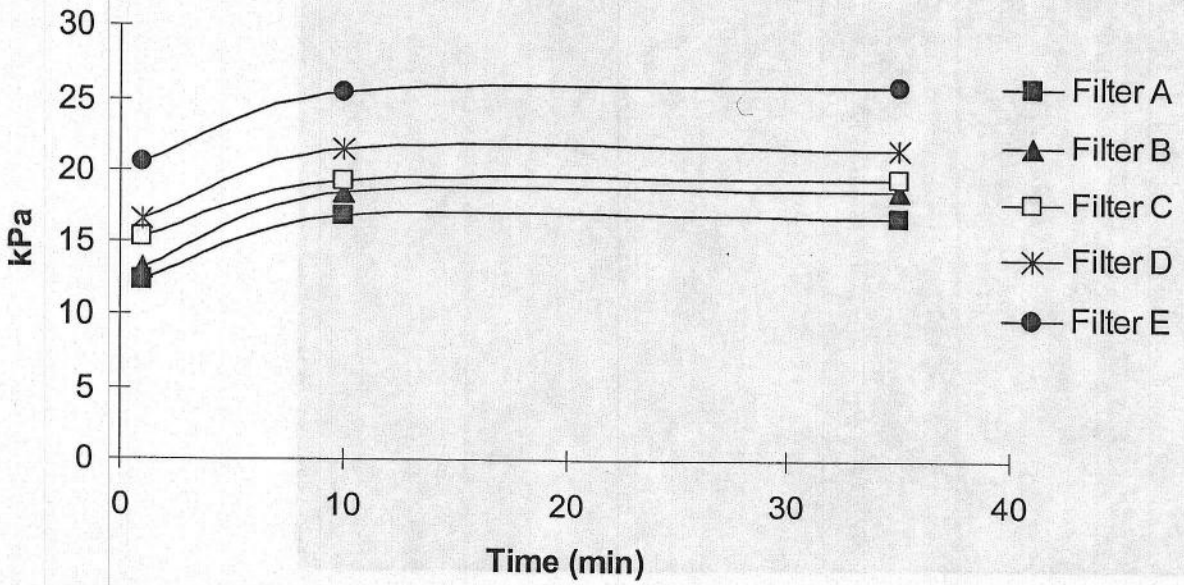

Figure 6. Pressure drop vs. time for different filter media listed in Table 2. All of these measurements are for the same size filter media and same flow rate (100 ml/min).

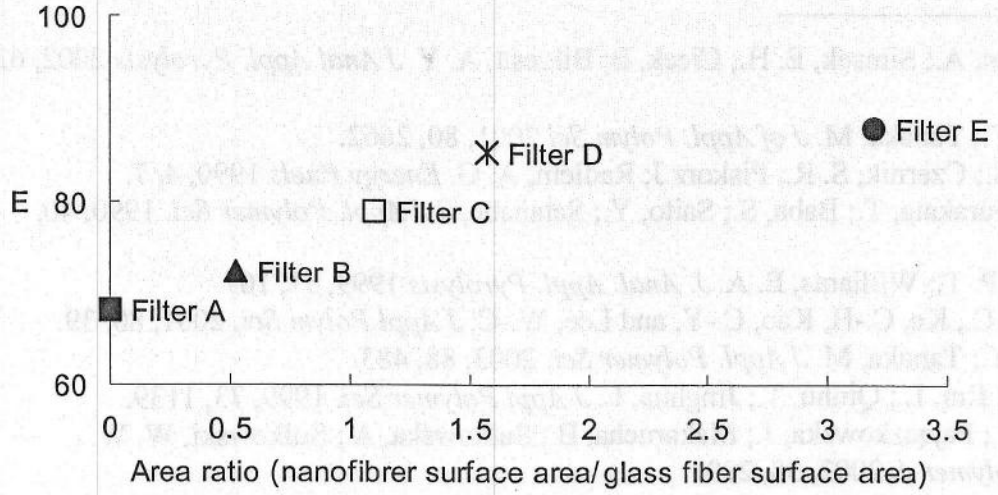

Figure 7. Effect of nanofibers on filter performance. The data are plotted as the efficiency versus surface area ratio of polymer nanofibers to that of glass fiber for four filters of the same thickness.

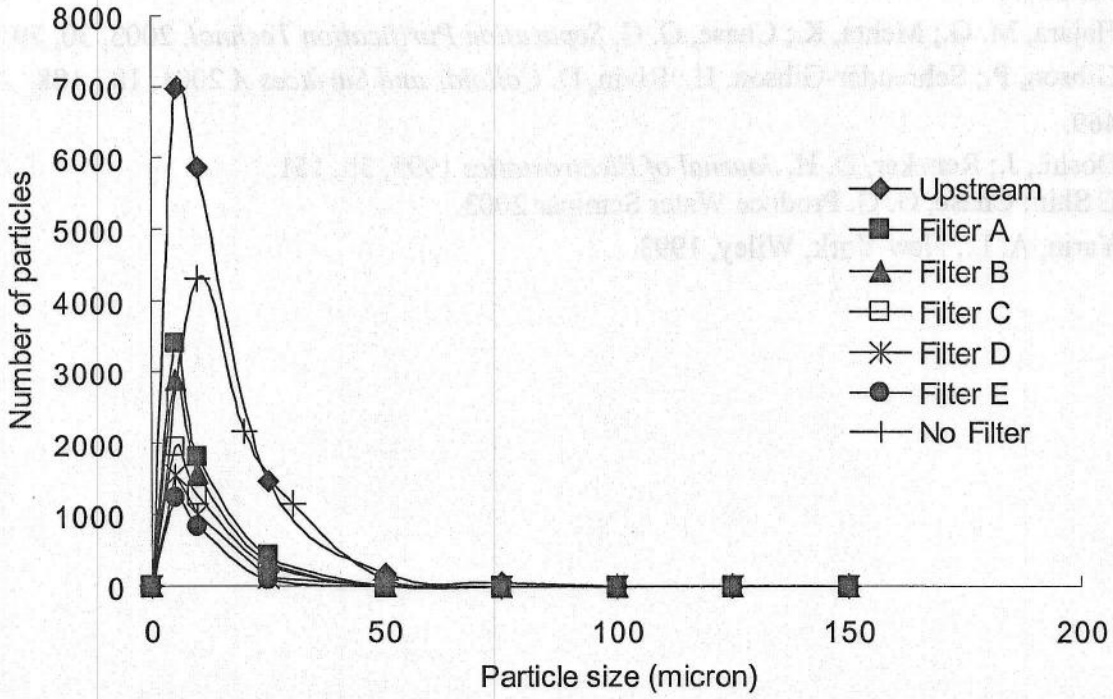

Figure 8. Particle size distribution of water droplets upstream and downstream of the five filters listed in Table 2.

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