Supplementary Material

Optimal Design of Multi-Layer Fog Collectors

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Tables and Figures

Table S1: The filtered fraction φ computed as a ratio of areas (l_∞^2/l^2).

Collector	l_∞	l	l_∞^2/l^2
4-layer harp	0.093	0.10	0.82
closed	0.047	0.10	0.21
open	0.096	0.10	0.88

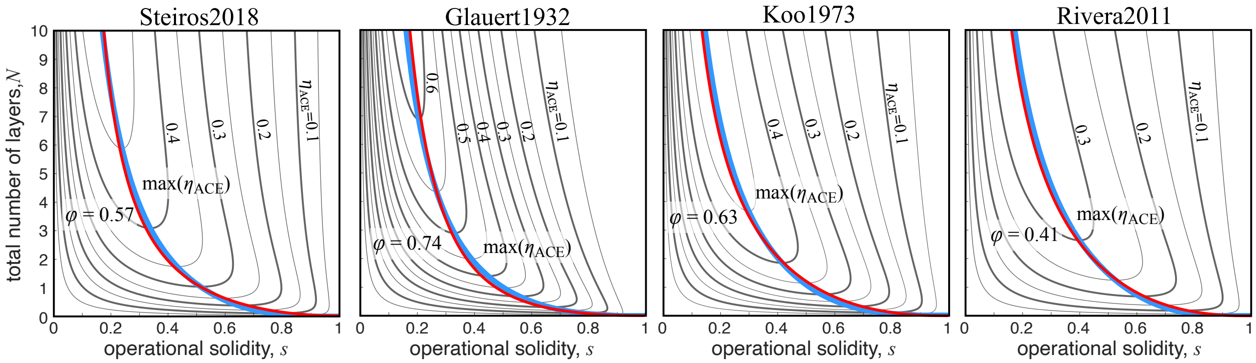

Figure S1: The max(η_{ACE}) subspace (blue curves) overlaps closely with level curves for the filtered fraction (red) in design space.

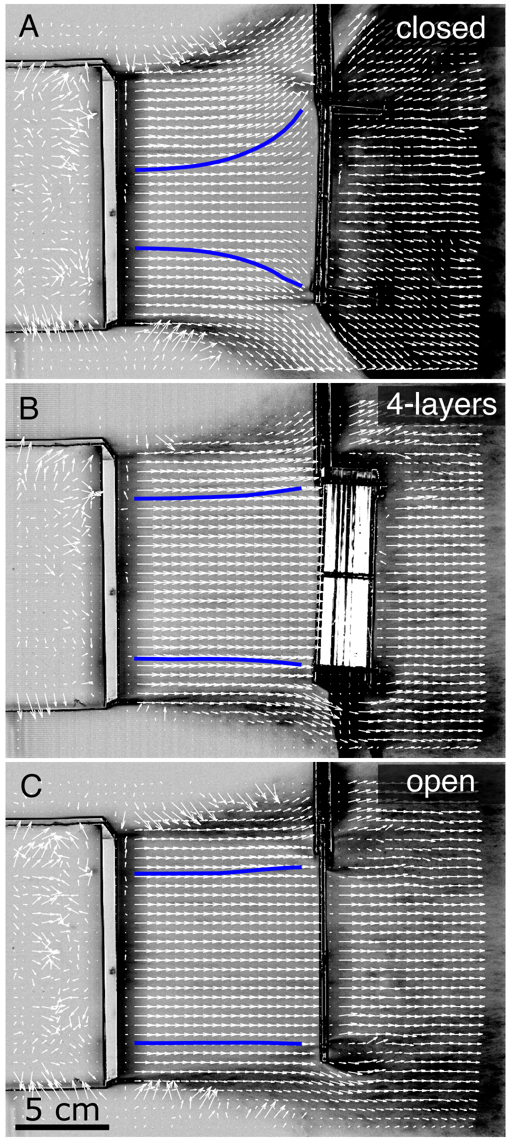

Figure S2: Fog flow for three test conditions: a closed collector (top), a 4-layer harp collector (middle), and an open collector (bottom). In all three cases, the "collector" was square with a central area of 100 mm × 100 mm and a frame of 7 mm on all four sides. The blue curves show the streamline dividing the filtered flow from the by-pass flow. The flow field downstream of the closed collector is not zero because the visualization protocol captures the flow that has by-passed the solid surface laterally. Also, the area ratio in (A) is not zero because our protocol to map the flow field does capture the flow within 10 mm of the collector surface. This effect leads to an artificially inflated filtered fraction.

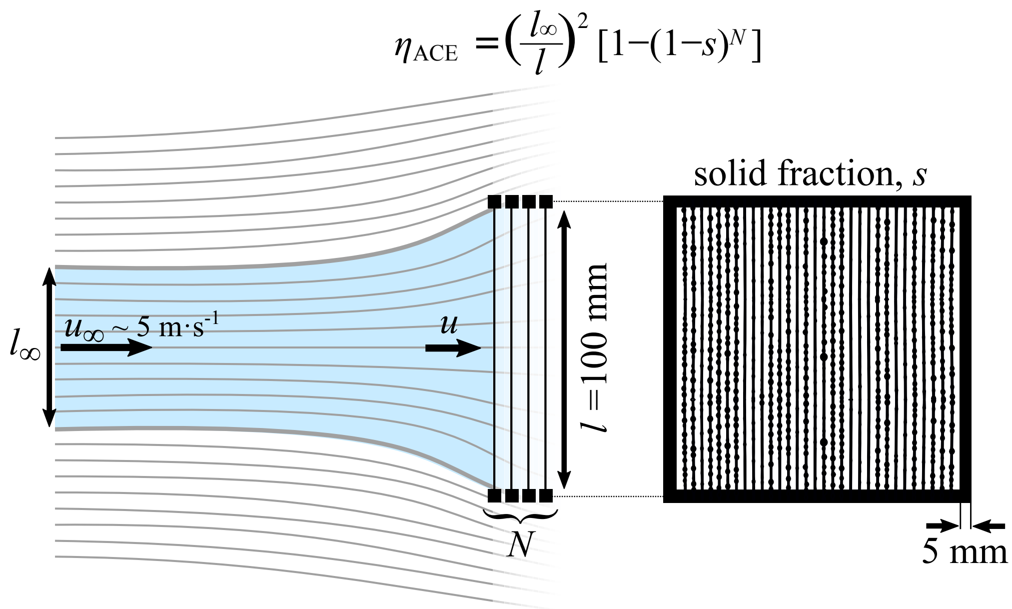

Figure S3: Proposed standard for the measurement of ACE. Prototypes should be square with 100 mm × 100 mm of open area and a frame of 5 mm on all sides. The operational solid fraction s and the number of layers N are free parameters to be adjusted. The ACE should be measured at a free stream velocity close to 5 m·s^{-1} and in the presence of fog.

1 Models for the filtered fraction

We consider below three alternative models for predicting the filtered fraction φ for a fog collector constituted of N layers, each with operational solidity s. As stated in the main text, the approach taken by most models is based on the following relation for the filtered fraction:

$$\varphi = \frac{A_\infty}{A} = \frac{u}{u_\infty} = \sqrt{\frac{C_D}{k}} \tag{1}$$

Therefore, we seek to express the drag coefficient C_D and pressure drop coefficient k in terms of N and s.

1.1 Glauert1932 Model

Glauert and coworkers[1] presented one of the first detailed analysis of the flow through and around a porous structure. Treating the flow in the porous medium as a series of sources, they arrived at the following relations:

$$C_D = \frac{k}{(1 + \frac{1}{4}k)^2} \tag{2}$$

and

$$k = s\left(\frac{1}{(1-s)^2} - \frac{2}{3}\right) \tag{3}$$

although the equation for C_D never appears in this form in their paper. The first relation was re-affirmed by Taylor[2] using two different approaches. However, as was clear at the time, the relation does not admit drag coefficients greater than 1 even in the limit of k approaching infinity (a solid plate) while it is known that the drag coefficient for a square plate is in fact 1.18 in the range of Re numbers of interest. Luckily, the equation is most robust for small k (small solid fraction), which is the regime of interest for fog collectors. Taylor and Davies[3] state that the equation could be valid for $k \leq 4$.

1.2 Rivera2011 Model

Rivera[4] took a slightly different approach by considering the flow through and around the collectors as the superposition of two distinct flow fields with the condition $u_\infty = u + \hat{u}$, where u_∞ is the velocity of the unperturbed upstream flow, u is the velocity of the uniform flow that filters through the porous collector and $\hat{u}$ is the velocity of the flow associated with a solid collector. Rivera then equates the pressure drop for the two components of the flow field based on Bernoulli's principle:

$$\Delta p = \frac{\rho \hat{u}^2}{2} \hat{C}_D = \frac{\rho u^2}{2} k \tag{4}$$

and since $\hat{u} = u_\infty - u$, we have:

$$\frac{\rho (u_\infty - u)^2}{2} \hat{C}_D = \frac{\rho u^2}{2} k \tag{5}$$

rearanging gives:

$$\left(\frac{k}{\hat{C}_D} \right)^{1/2} = \frac{u_\infty - u}{u} \tag{6}$$

and finally,

$$\varphi = \frac{1}{1 + (k/\hat{C}_D)^{1/2}} \tag{7}$$

where $\hat{C}_D = 1.18$ is the drag coefficient corresponding to a solid ($s = 1$) collector with square aspect ratio. For the pressure drop coefficient, the empirical relation given by Idel'Cik[5] was selected:

$$k = 1.3s + \left(\frac{s}{1 - s} \right)^2 \tag{8}$$

1.3 Koo1973 Model

Koo and James[6] revisited the model of Taylor and Davies[3] by considering the flow through a porous medium as equivalent to distributed sources. The problem was solved so as to ensure conservation of mass and momentum across the mesh, leading to the implicit relations:

$$k = \frac{2Dk + (Dk)^2}{(1+Dk)^2}\left(1 + \frac{Dk}{2}\right)^2 \tag{9}$$

$$C_D = \frac{k}{(1+\frac{1}{2}Dk)^2} \tag{10}$$

where D is the source strength. Because, Koo and James[6] were mostly concerned about the relation between k and C_D, they did not try to express k in terms of the solidity. We can however use Idel'Cik's[5] empirical relation (Eq. 8) to close the problem.

References

(1) Glauert, H.; Hirst, D.; Hartshorn, A. *The induced flow through a partially choked pipe with axis along the wind stream*; HM Stationery Office, 1932.

(2) Taylor, G. Air resistance of a flat plate of very porous material. *Aeronautical Research Council, Reports and Memoranda* **1944**, *2236*, 159–162.

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(5) Idel'Cik, I. E. *Memento des pertes de charge*; Collection de la Direction des Etudes et Recherches d'Electricité de France, Eyrolles: Paris, France, 1969.

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