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EB3) Aerosol Filtration/Sampling Device Based on Irrigated Rotating Wires

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1. INTRODUCTION

The objective of this study is to analyze, design and evaluate a new gas cleanup or sampling system that will remove erosive, corrosive, and fouling contaminants present in an effluent stream as either solid or liquid particles providing a clean gas stream. The gas clean-up or sampling system considered in this study is an irrigated, rotating element device. The device consists of a central disk-like hub from which emanate radially wires or cylindrical elements. The hub and radial elements are rotated at high speed and collect solid or liquid particles on their surfaces, primarily by inertial impaction. To avoid buildup of material deposited on these elements, or to collect the deposited material during sampling, a liquid is introduced which flows radially outward along the surface of the element and is collected as it leaves the element tips in the form of droplets. The basic hub and wire concept is shown in Figures 1 and 2. The effluent gas stream passes perpendicularly through the plane of the rotating wires and solid or liquid particles suspended in the gas flow are impacted onto the thin film of liquid flowing along the wire surface. The liquid film keeps the wire collection surfaces clean and provides a more adhesive impaction surface. This liquid film can be generated by release of the liquid at the point of wire attachment at the hub with centrifugal force providing the driving force for the outward liquid flow along the wire surface. In this study, theoretical bases for design and operation of the rotating wires are presented and some technical issues are addressed experimentally.

2. THEORY

The volumetric cleaning flow rate, defined in terms of dimensions given in Figure 1, is

$$Q_S = 2\pi ND\int_{R_1}^{R_2} \omega x\, dx = \pi D\omega N(R_2^2 - R_1^2) \tag{1}$$

where x is the radial distance along the wires, N is the total number of wires, ω is the rotating speed, R_1 is the hub radius, R_2 is the total radius, and D is the wire diameter. The power required to operate the rotating wire device results primarily from the need to counter air drag as the wires are rotated. This power, P_2 is given by

$$P_2 = \rho_g C_D D\, 4\pi^3 \omega^3 N\int_{R_1}^{R_2} x^3\, dx = D\rho_g C_D \pi^3 \omega^3 N(R_2^4 - R_1^4) \tag{2}$$

where C_D is the drag coefficient for the wires and ρ_g is the gas density.

It can be seen from Eq. (2) that the power required increases quite rapidly with rotational speed. This indicates that lower speeds are preferable. However, to achieve adequate collection efficiency at the inner hub, it is necessary that the wire velocity at this point be above a minimum value. It becomes evident by examination of Eq. (2) and consideration of the collection efficiency requirements that the best configuration results when the inner hub is large and the wire length only sufficient to provide an adequate sampling rate. This will assure that the collection efficiency is more uniform but adequate along the wire length without the wire tips operating at a high velocity which uses unnecessarily large amounts of power while contributing little to the collection efficiency. However, this situation leads to another practical limitation in terms of the overall size (diameter) of the sampler. The size requirements therefore become the critical factor in detailed optimization and a trade-off in power for reduced size is made.

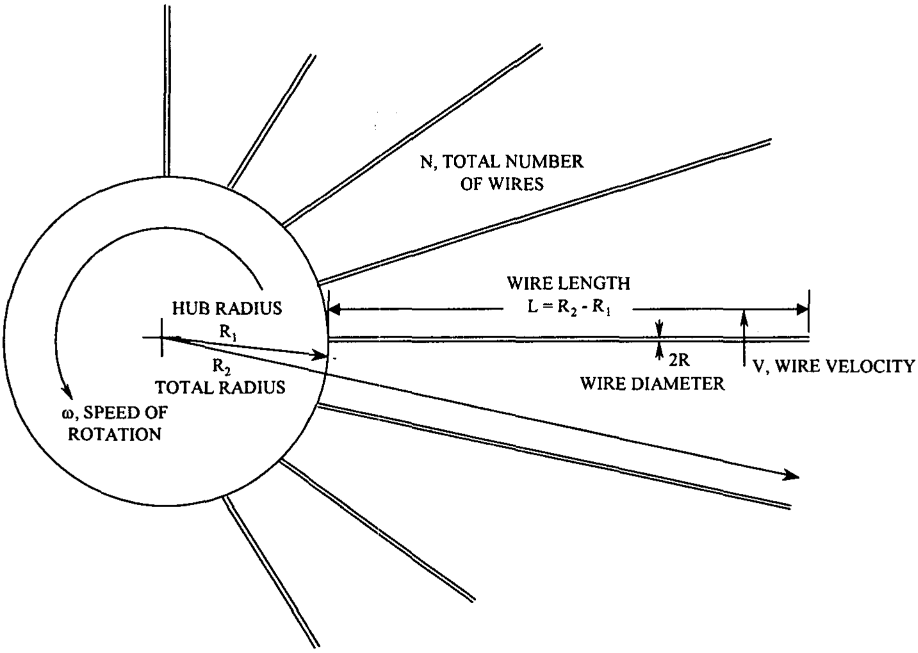

Fig. 1. Diagram of rotation wire configuration.

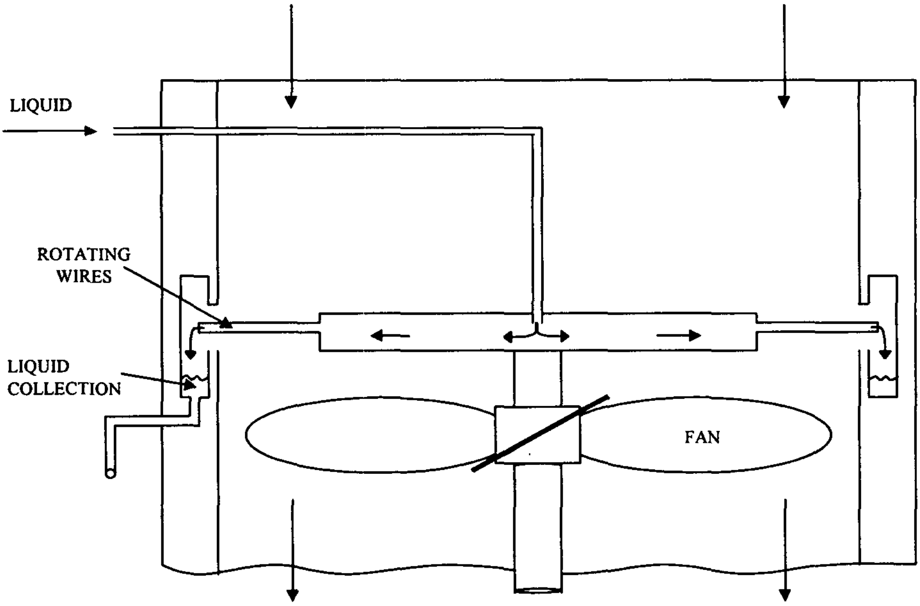

Fig. 2. Schematic of collector showing liquid flow.

3. EXPERIMENT AND RESULTS

The verification of design procedures and determination of operating characteristics were performed experimentally with the laboratory model and the prototype sampler. Particle collection efficiencies for particles in various size ranges were measured. The results are shown in Figure 3.

Based on the experiments performed, the extent of which the prototype sampler meets the expectations can be assessed as follows:

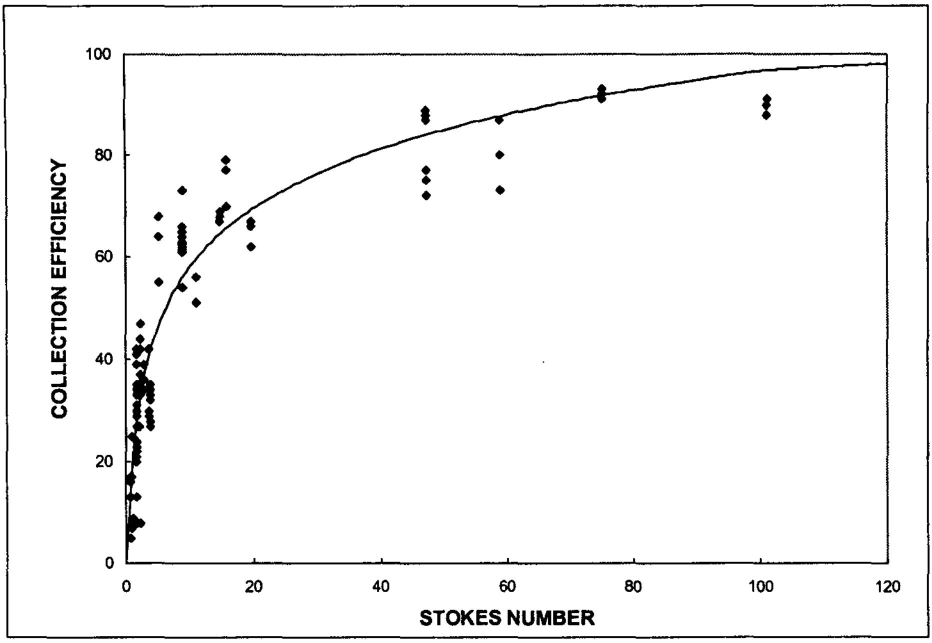

Fig. 3. Particle collection efficiency as a function of size.

(1) The sampling technique provides collection of unit density, 1 μm diameter particles with an efficiency of about 65 percent. For larger particles and particles of materials with greater densities, the collection efficiency is higher. Further, the overall recovery efficiency is such that almost 45 percent of ambient airborne particles are sampled and collected.

(2) The mass collection rate of particulate material will, of course, be directly proportional to the airborne particle concentration.

(3) The particles collected are concentrated into a small liquid volume of approximately 200 ml from a sampled air volume of 1.2 x 106 ft^3.

(4) The sampler will collect both organic and inorganic particles. There are some differences in collection efficiency to be expected. Organic materials will be collected with efficiencies approximately as given for the liquid droplets. Because of their greater densities, inorganic particles will be collected with higher efficiencies.

(5) The sampler is based on well-understood design principles and the general accuracy of these principles have been established experimentally. By using the design equations presented, the sampler can be designed to any scale. However, experimental verification of liquid behavior would be required.

4. CONCLUSIONS

A number of significant advantages exist for the concept suggested here. These include:

(1) required collection efficiencies can be achieved with low power consumption relative to the gas volume sampled,

(2) small collector size will lead to low equipment costs,

(3) solid, sticky, or liquid particles are handled equally well,

(4) particle collection principles are well understood giving confidence in design and scaling, and

(5) gas or vapor can also be removed.