CRUD HOLDING AND BACKFLUSHING CHARACTERISTICS OF AN ETCHED DISC FILTER IN A GAS STREAM

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ABSTRACT

Experimental and analytical studies were conducted on an etched disc filter to determine the crud holding characteristics, the ability of the filter to be backflushed, and the initial filtration efficiency prior to crud barrier formation, for service in a gas stream. A.C. Fine Dust was used as the experimental contaminant, and nitrogen as the fluid medium.

Dust was added to the gas upstream of the filter, and differential pressure and filtration effectiveness data were accumulated. Backflushing operations were performed when suitable differential pressure levels were attained. Statistical analyses were performed on the dust, relating the particle number and mass probability densities to the filter element pore size, thereby yielding filtration efficiency.

Differential pressure increased with added dust loads, but leveled off significantly as large quantities of dust were added. Experimental filtration efficiency approached 100 percent. The filter backflushed satisfactorily. Analytical results indicate the initial filtration efficiency was 95.6 percent, based upon mass probability density.

NOMENCLATURE

Symbol	Definition	Units
a	Element Surface Area	Ft.^{2}
b	Element Pore Size	Microns
c	Crud Load (A.C. Fine Dust)	Lb.
$p_m(s)$	Mass Probability Density	
$p_n(s)$	Number Probability Density	
q	Flowrate	Ft.^{3}/sec.
s	Particle Size	Microns
v_f	Face Velocity (q/a)	Ft./sec.
ε	Filtration Efficiency	
Δp	Filter Differential Pressure	psi
σ_m	Mass Standard Deviation	Microns
σ_n	Number Standard Deviation	Microns

INTRODUCTION

The etched disc filter has seen extensive service in liquid streams of the nuclear power industry in facilities such as Millstone I, Rancho Seco and Barnwell, as well as in high temperature water streams in submarine reactor systems. [1,2] Results of this service experience left no doubt of the ability of the filter to remove crud from the fluid stream. Primary concerns for gas stream service were the differential pressure increase with increasing crud loads, and the backflushability of the filter with the purely gaseous medium.

Previous applications in water streams had the differential pressure increasing to 75 psi prior to the backflushing operation. Service in gas streams includes requirements for significantly lower maximum differential pressures, amplifying the necessity for determining crud holding - differential pressure characteristics. The backflush operation had incorporated a form of two-phase flow; that is, the water in the normally downstream side of the element was caused to flow in the reverse direction at relatively low velocity through the element pores; as the water exited the element pore, it was immediately followed by a high velocity gaseous nitrogen flow which effectively scoured the upstream surface of the element. This transition from water to gas flow fields at the pore exit is thought to be the overriding physical phenomenon in the backflushing of the liquid filter.

A nitrogen flow test system was constructed at Vacco Industries, and a six-micron etched disc filter was tested, using A.C. Fine Dust as the referee contaminant. This contaminant was selected because it has a particle size distribution comparable to that of the crud which occurs in the English advanced gas cooled reactors. Differential pressure and filtration effectiveness data were obtained at several dust load levels. The backflush operation was performed a number of times and the differential pressure was measured after each backflushing.

An analysis was conducted, based upon the statistical particle size distribution provided by the supplier, on the dust container. Probability density curves were generated, based on these data, for particle number and particle mass. The numerical and mass average particle sizes were calculated for the dust; the initial filtration efficiency was calculated, with both the particle number efficiency and the particle mass efficiency being predicted.

EXPERIMENT

Test Specimen and Apparatus

A six micron filter element was fabricated and assembled as shown in Fig. 1. The element was assembled in a filter vessel, and installed in the test system illustrated in Figs. 2 through 4.

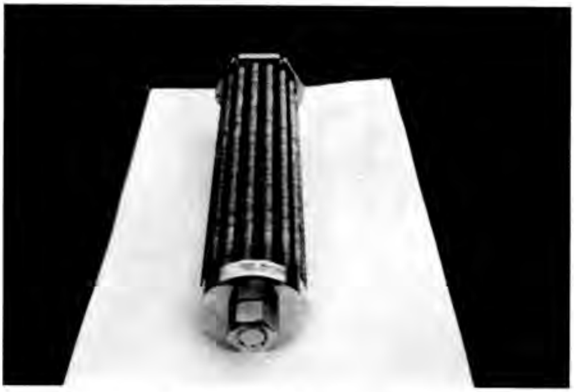

Fig. 1. filter element assembly

Fig. 2. test system viewed from downstream

The test system included an upstream pressure regulator for control of constant nitrogen inlet pressure, a flow control valve and a flow nozzle. A port was included for downstream effluent sampling with a millipore pad. A nitrogen pressure vessel was used as the backflush source; the backflush nitrogen exhausted to atmosphere from the normal inlet port of the filter vessel.

Fig. 3. filter and dust inlet port

Fig. 4. test system viewed from upstream

Experimental Methods

Nitrogen was caused to flow through the system at a pressure of 306 psig and flowrate of 10 scfm, yielding a face velocity of approximately 0.006 Ft./sec., and the differential pressure was measured and recorded. A dust load of 0.5 gram was added through the port upstream of the filter vessel and the differential pressure was again measured. Dust was added in larger increments, and the procedure was repeated for each dust load increment. Millipore samples of the effluent nitrogen were extracted after several of the dust loading operations.

At a differential pressure of approximately 30 psi, the filter was backflushed with 350 psig nitrogen from the backflush pressure vessel. The flow was re-established and the differential pressure was again measured and recorded.

This entire procedure was performed at several inlet pressures and flowrates, to determine the effect of face velocity and gas density.

Results

Dust loading data revealed that at very low levels of dust per unit area, that is, c/a between approximately 0.001 $lb/ft.^2$, and 0.010 $lb/ft.^2$, the differential pressure varied with c/a to the 0.4 power.

$$\Delta p \propto (c/a)^{0.4} \qquad (1)$$

Also, differential pressure varied directly with the face velocity, q/a.

$$\Delta p \propto v_f \, (c/a)^{0.4} \qquad (2)$$

These relationships are illustrated by the curve of Fig. 5.

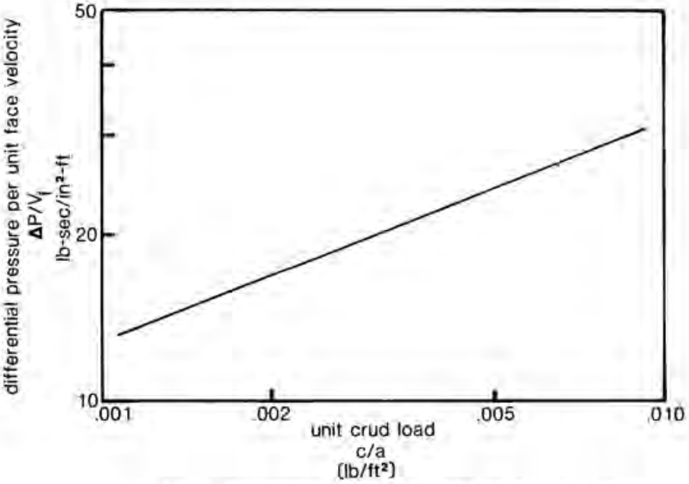

Fig. 5. differential pressure per unit face velocity vs. unit crud load,A.C. Fine Dust

At higher dust loading levels, the differential pressure increase was very low, so that the filter vessel was nearly filled with several pounds of dust as the differential pressure approached 30 psi. This indicates that the dust forms a very porous crud barrier, providing extremely fine filtration at low differential pressures.

Effluent millipore samples indicated that virtually no dust had passed through the filter. The filter efficiency was, therefore, greater than 99 percent with unit crud loads of 0.001 lb./ft.^{2}, and greater.

The filter backflushed successfully during each of twenty backflushing operations. The differential pressure after backflushing nearly always equaled the initial clean differential pressure.

ANALYSIS

Particle number probability for A.C. Fine Dust was plotted versus particle size in microns, from information on the dust container label. The slope of this curve is the number probability density, $p_n(s)$. The number probability density is closely approximated by

$$p_n(s) = \frac{s}{\sigma_n^2} \exp(-s/\sigma_n) \tag{3}$$

This function is plotted versus the particle size(s) in Fig. 6.

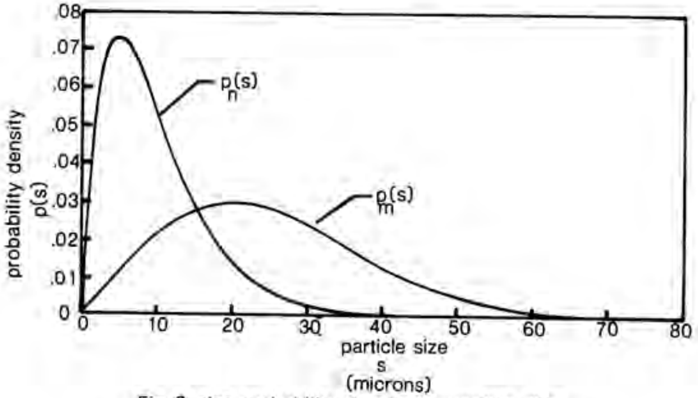

Fig. 6. size probability density vs. particle size of A.C. Fine Dust

The peak of this curve occurs at $\sigma_n = 5$ microns. The numerical mean particle size for this dust is

$$\bar{s}_n = \frac{\int_0^\infty s\, p_n\ (s)\ ds}{\int_0^\infty p_n\ (s)\ ds} \tag{4}$$

and

$$\int_0^\infty p_n\ (s)\ ds = 1 \tag{5}$$

in general. The mean particle size based on particle number is found to be 2σ or 10 microns.

If we assume the particles are of approximately spherical shape, the number probability density curve is cubed in $p_n(s)$ yielding the mass probability density, $p_m(s)$. This is closely approximated by the Raleigh probability density.[3,4]

$$p_m\ (s) = \frac{s}{\sigma_m^2} \exp\ (-s^2/2\sigma^2_m\ ) \tag{6}$$

This function is also shown on Fig. 6; the peak of the curve occurs at $\sigma_m = 20$ microns. The mass mean particle size is

$$\bar{s}_n = \frac{\int_0^\infty s\ p_n\ (s)\ ds}{\int_0^\infty p_n\ (s)\ ds} = 25 \text{ microns} \tag{7}$$

Filtration efficiency is typically based upon contaminant mass. If the element pore size is b=6 microns,

$$\varepsilon = 100 \times \frac{\int_b^\infty p_n\ (s)\ ds}{\int_0^\infty p_n\ (s)\ ds} \tag{8}$$

This is the initial mass filtration efficiency for the element with completely open pores. As particles are trapped at the pore entrance, they form a porous crud barrier, having a constantly decreasing pore size. When the outer perimeters of all the discs in the element are covered with dust, the effective filtration pore size is reduced, an order of magnitude, to below one micron, for the original 6 micron element. Filtration efficiency then approaches 100 percent.

$$\varepsilon = 100 \exp\ (-b^2/2\ \sigma_m^2\ ) \tag{9}$$

$$\varepsilon = 95.6\% \tag{10}$$

CONCLUSIONS

It was determined that for initial dust loading, corresponding to crud barrier formation, the differential pressure per unit face velocity increases with dust per unit area, with an empirical exponent of 0.4. At higher levels of dust loading, the differential pressure increase was very slight, allowing the filter vessel to be practically filled with dust prior to backflushing. This is an indication for the relatively high porosity of the A.C. Fine Dust. Experimental filtration efficiency was near 100 percent.

Backflushing was successfully accomplished during each operation.

Initial mass filtration efficiency is 95.6%, indicating that a 6 micron pore size will adequately filter A.C. Fine Dust, even during the early stages of crud barrier formation.

REFERENCES

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