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DYNAMIC BEHAVIOR OF FIBROUS FILTERS DURING COLLECTION OF SUBMICROMETER AEROSOLS: A DISPERSION MODEL

Final Report

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13. ABSTRACT (Maximum 200 words)

A novel fundamental theory of the dynamic behavior of fibrous filters for aerosol collection is proposed. The theory is based upon an explicit and systematic procedure for calculating the filter efficiency η and for quantitatively describing the filter microstructure, both of which change continuously during filter operation as aerosol particles deposit on the fibers. This theory is free of any of the usual *ad hoc* assumptions, including the artificial concept of single-fiber efficiency η_c, explicit or implicit theories.

Upon viewing the filter bed as a continuum, the aerosol transport and deposition processes at this coarse-scale level of description are characterized by three fundamental 'global' phenomenological coefficients: (i) the mean aerosol velocity vector $\bar{U}^*$; (ii) dispersivity dyadic $\bar{D}^*$; and (iii) mean volumetric aerosol deposition-rate coefficient $\bar{K}^*$. Whereas for clean homogeneous filters these phenomenological coefficients are constants, continuous aerosol deposition on the fiber surfaces causes them to vary with both time t and position $\bar{R}$ within the filter bed.

The filtration efficiency may be rationally expressed explicitly in terms of these three physically realistic, experimentally accessible quantities. The scheme proposed herein will serve to calculate $\bar{U}^*$, $\bar{D}^*$ and $\bar{K}^*$, followed by subsequent use of these quantities to characterize the dynamic, i.e. temporal, filter behavior.

An outline of the importance of the proposed theoretical research is presented that addresses the following items: (i) rigorous and systematic study of the effects of the various filtration operating parameters and aerosol properties upon the dynamic behavior of fibrous filters; (ii) establishment of the limitations of existing filtration theory in the light of these new theoretical developments; (iii) interpretation of experimental data.

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This report* summarizes activities performed during the period 1 October 1987-31 December 1990.

STATEMENT OF THE PROBLEM STUDIED

Development of the dispersion/reaction model for collection of submicrometer aerosol particles in porous filters. Study of coarse-scale aerosol transport mechanics and particle deposition rates within the filter bed. Investigation of the dynamics of transport and deposition processes of fine particles within fibrous filters.

SUMMARY OF THE MOST IMPORTANT RESULTS

1. Development of a rigorous analytical theory of transport and deposition of aerosol particles in spatially periodic models of porous fibrous and granular filters. This theory constitutes a significant advancement in understanding and modelling of aerosol transport and collection processes in porous beds, as well as in the interpretation of available experimental data and planning of further experiments.
2. Development of a numerical finite-element model for computation of coarse-scale aerosol transport properties, namely the mean aerosol velocity vector, dispersivity dyadic, and effective volumetric aerosol deposition-rate coefficient. These data were used for direct calculation of the effective aerosol filtration length and filtration efficiency without utilizing the *ad hoc* concept of "single-element efficiency" employed in classical filtration theory.
3. Numerical study of the fluid velocity field within spatially periodic porous fibrous beds. Investigation of the effects of the microscale Reynolds number, filter void fraction, bed microstructure, and bed polydispersity upon the pressure drop across the filter.
4. Calculation of the coarse-scale aerosol transport and deposition properties and characteristic aerosol filtration lengths within spatially periodic lattice models of fibrous filters. Numerical study of the effects of characteristic microscale Peclet number and interception parameter, bed packing arrangement, and porosity upon the characteristic aerosol filtration length. Investigation of influences of diffusional and interceptional aerosol collection mechanisms upon aerosol collection rates. The results obtained were in accord with available experimental

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data, while the results of competitive models (derived from classical filtration theory) exhibited poor agreement.

5. Investigation of the roles of short-range dispersion forces in the deposition and accumulation of aerosol particles upon solid collector surfaces. Development of boundary conditions for the aerosol concentration field on the fiber surface, required for investigating the dynamics of aerosol collection and accumulation within the filter bed.
6. Numerical investigation of the transport and deposition of chemically reactive aerosol particles in fibrous filters. Study of the effect of the microscale aerosol reactivity upon the characteristic filtration length. Modelling of the influence of particle re-entrainment from the fiber collector surfaces (usually occurring during the process of filter contamination) upon the net aerosol collection rate.
7. Theoretical calculation of the coarse-scale aerosol transport coefficients for aerosol particles undergoing adsorption/reaction processes on the surfaces of fibrous collectors. Investigation of the effects of the aerosol surface-excess reactivity and fiber adsorptive properties upon the aerosol's coarse-scale transport mechanisms and collection rates.

ADDITIONAL ACHIEVEMENTS, WHICH WERE NOT ORIGINALLY PLANNED IN THE PROPOSED PROJECT

1. Investigation of electrostatically enhanced aerosol transport and deposition processes from turbulent flows in electrostatic precipitators.
2. Study of aerosol particle sedimentation in unbounded cellular flows.
3. Investigation of low Reynolds number motion of an aerosol particle in the vicinity of a curved collector surface, occurring within a spatially periodic filter bed.
4. Feasibility study of the control of aerosol particle motion in a closed environment by application of time-periodic external (e.g. electrostatic, magnetic, etc.) forces transverse to the air flow stream.
5. General theory of the convective-diffusive transport of aerosol particles in tube and channel flows, as well as in spatially periodic models of porous media.

LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES

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(4) David C. Guell, "The physical mechanism of osmosis and osmotic pressure: A hydrodynamic theory for calculating the osmotic reflection coefficient," Ph.D. Thesis in Chemical Engineering. Massachusetts Institute of Technology (November, 1990).

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REPORT OF INVENTIONS

None