DOE/PC/90756--T8

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QTR #6

DE93 003895

Research on Thermophoretic and Inertial Aspects of Ash Particle Deposition on Heat Exchanger Surfaces in Coal-Fired Equipment

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Quarterly Technical Report on: DE-FG22-86 PC 90756

Total Contract Period: 9/1/86 - 8/31/89

Quarterly Period Covered: 12/1/87- 2/28/88

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1. Introduction

DOE-PETC has initiated at the Yale HTCRE Laboratory a systematic three-year experimental and theoretical research program directed toward providing engineers with the data, methods, and rational correlations needed to significantly improve the generality and accuracy of prediction of inorganic particle **deposition rates** under typical coal combustion conditions (i.e., those leading to the importance of thermophoretically-enhanced diffusion (submicron mode) and the inertially-enhanced "impaction" (supermicron mode), often in the presence of simultaneous alkali salt vapor condensation. After a brief statement of objectives (Section 2) we outline our experimental and theoretical progress during this quarterly reporting period (Section 3), with our results summarized in the references documented in Section 5. Section 4 gives relevant administrative information (personnel, research plans).

2. Background Statement: Objectives

The goal of our research in the area of ash **transport** is to develop the capability of making reliable engineering predictions of the dynamics of net deposit growth for surfaces exposed to the products of coal combustion. To accomplish this for a wide variety of combustor types, coal types, and operating conditions, this capability must be based on a quantitative understanding of each of the important mechanisms of mineral matter transport, as well as the nature of the interactions between these substances and the prevailing "fireside" surface of the deposit. This level of understanding and predictive capability could be translated into very significant cost reductions for coal-fired equipment design, development and operation.

Our emphasis in the present program: "Research on Thermophoretic and Inertial Aspects of Ash Particle Deposition on Heat Exchanger Surfaces in Coal-Fired Equipment" is on experimentally validating* and developing rational, theoretical methods of predicting the role of **inertia** and ash particle **thermophoresis** in determining net deposition rates (see, e.g., Rosner, 1985; 1986). We also wish to quantify how simultaneous **vapor** deposition (eg., alkali sulfate) can influence the sticking and erosion associated with impacting particles. Specifically, as a result of this DOE-PETC supported program, we believe that it will be possible for us to develop:

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* Our previous DOE-METC supported experiments have been confined to vapor and submicron particle systems in the absence of inertial phenomena (see, e.g. Rosner, 1988b). For an overview of convective mass transfer, see the PI's recent textbook (Rosner, 1986), (especially Chapters 6, 8), nominated for the 1988 Meriam/Wiley Award of the American Society of Engineering Education.

a. An understanding of the factors governing impacting particle capture and deposit erosion probabilities, leading to rational correlations (see, e.g., Rosner and Nagarajan, 1987).

b. Clever applications of recent **mass** transfer theories and available **heat** and **momentum** transfer data to develop prediction methods for important practical situations - eg. deep tube bundles ('banks')(see, e.g., Rosner, 1986).

c. Necessary extensions of available particle deposition rate theory (see, e.g., Park and Rosner, 1987).

To be able to develop tractable but realistic/rational 'subroutines' for predicting the evolution of wall deposits, it will be necessary to intensify communication with more empirically oriented engineers/chemists who have the necessary boiler fouling/slagging experience. If successful, we will ultimately be able to recommend economical 'subroutines' (compatible with practical requirements of global computer codes, recent deposition research results and cumulative empirical observations) to predict the evolution of wall deposits for, say, design studies of coal-fired furnaces and boilers (see, e.g., Gokoglu and Rosner, 1984).

3. Research Program

During the present reporting period, we have initiated work on a) the interpretation of our recent data (see QTR5) on deposition rates under the simultaneous influence of **inertia** and **thermophoresis**, b) the possible rate of particle **photophoresis** in environments characterized by high **radiative** heat loads, and c) the influence of particle size **distributions** on total mass deposition rates. The fruits of these initiatives will be reported in subsequent quarterly technical reports. Here, we focus on our recent theoretical results in the important but previously uncharted area of the relations between particulate deposition **mechanisms**, deposit **microstructure** and deposit **properties**. Experimental verification of some of the most interesting predictions will be the subject of future HTCRE-Lab studies.

Recent discussions with fouling engineers have convinced us that, despite recent advances in our ability to predict particle deposition **rates** in convective-diffusion environments, the important connection between resulting deposit properties (effective thermal conductivity, permeability, ...) and deposition **mechanism** remain poorly understood and only scarcely studied. Accordingly, as part of this DOE-PETC program, we have developed a discrete stochastic model to simulate particulate deposition processes resulting from a combination of deposition mechanisms. For the present, we have illustrated the model's implications through computer simulations of deposits grown on two-dimensional orthogonal lattices, with every particle following an asymmetrical random walk trajectory in the vicinity of the deposit. Particle motion is assumed to be determined by the superposition of a deterministic force that acts towards the collecting surface: e.g. sedimentation, thermophoresis, and a random force, which simulates Brownian diffusion. This comprehensive model generalizes two recent stochastic growth models, namely, the Ballistic Aggregation model and the Diffusion Limited Aggregation model, which now appear as limiting cases. In our results to date (Tassopoulos et al., 1988) we have characterized the resulting deposit microstructure via porosity, pore size/area distribution, surface area, transport properties, and have examined the evolution of these descriptors with time (equivalent to the number of particles deposited), for different deposition mechanisms. We have also examined the effect of **polydispersity** of the generating particle population and the **orientation** of nonspherical particles to the resulting deposit structure. A typical set of results is shown in Fig.1, which reveals the approach of the deposit toward an open, "tree-like" structure as the deposition mechanism becomes more 'Brownian' and less 'ballistic'. We will present a paper on this subject at the 1988 AIChE National Mtg., November 1988, Washington, D.C. (Appendix A), and we plan to submit the associated full length manuscript to AIChE J. shortly.

4. Administrative Information

During this reporting period, our research group has been joined by Dr. Daniel Mackowski, who will direct his attention to the problems of particle **photophoresis** in the presence of intense radiation heat loads, and the production/deposition of nonspherical (e.g., chain-like) particles.

We have submitted an Abstract of our deposit microstructure paper (Appendix A) for presentation at the AIChE National Mtg., November 27-December 2, 1988 (Tassopoulos et al., 1988)*, as well as a manuscript on chemical vapor transport (Rosner, 1988a) which exploits and develops further ideas on LTCE multicomponent transport developed in our earlier AFOSR, NASA and DOE-METC research programs. Moreover, our DOE-METC-supported paper on binary alkali-sulfate deposition (Liang and Rosner, 1987) has just appeared in AIChE J., and is being sent to interested deposition researchers elsewhere. In the present program, we will use some of the same ultrasonic nebulizer alkali sulfate seeding techniques to study the role of condensing vapors in determining the sticking probability, s, of impacting particles (Rosner and Nagarajan, 1987; and Konstandopoulos et al., 1987). Other aspects of our research on condensing alkali-containing

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* Professor James O'Brien of our Chemical Engineering Department is a co-advisor of this (dissertation-) research.

vapors will be put 'on hold' based on the termination (without renewal) of DOE-METC support at the end of March 1988. However, we have been invited to prepare a summary paper (Rosner, 1988b) on our integrated deposition-research program for the B. Levich memorial issue of the journal **Physicochemical Hydrodynamics** (Pergamon), scheduled to appear late Fall '88.

5. References

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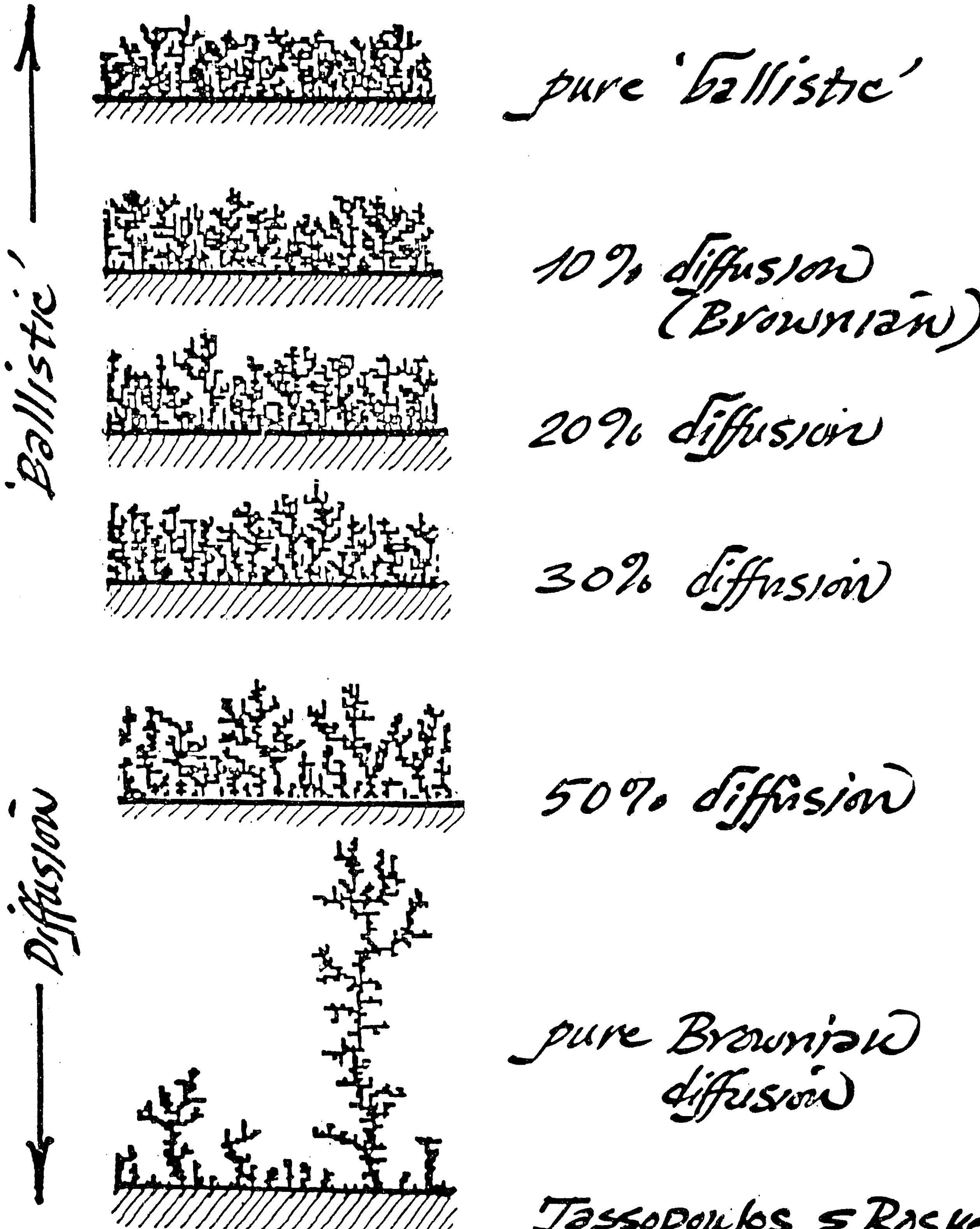
Figure 1

Dependence of Deposit Morphology on Particle Deposition Mechanism



Tassopoulos & Rosner O'Brien, (1988)

APPENDIX A

Rapid Estimation of Total Mass Deposition Rates by Convective-Diffusion from 'Polydispersed' Aerosols[1]

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Abstract: It is shown that for particle deposition from a coagulating 'polydispersed' aerosol by the mechanism of convective-diffusion, there is a simple relation between the actual total mass deposition rate and the 'reference' deposition rate one would calculate by imagining that all particles in the mainstream population had the average particle volume $\mathcal{V}(=\phi_p/N_p)$. Indeed, for laminar- or turbulent- boundary layers, free-molecule (Knudsen-) diffusion or continuum (Stokes-Einstein-) diffusion at high Peclet numbers, dense spherical particles or 'fractal' agglomerates, we find that the ratio of the actual deposition rate to the abovementioned reference rate (for a hypothetical 'monodispersed' aerosol), is, remarkably, about 0.90 ± 0.02, greatly facilitating engineering estimates of deposition rates from ubiquitous 'polydispersed' aerosols. Generalizations to include other important particle transport mechanisms, and departures from 'self-preserving' (asymptotic) aerosol particle size distributions, are outlined.

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1 Research supported, in part, by the US Department of Energy-Pittsburgh Energy Technology Laboratories, under Grant No. DE-FG22-86PC90756 and the US Air Force Office of Scientific Research, under Grant No. AFOSR-84-0034, Prepared for submission to AIChE J. (April, 1988); DER#168.

2 Professor of Chemical Engineering; Director, Yale HTCRE Laboratory

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DATE FILMED

12/28/92