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Office of Basic Energy Sciences
Department of Energy
ER-142, MS G-226, GTN
Germantown Building
Washington, DC 20545

Gentlemen:

We are pleased to submit a report covering our research program entitled *MECHANISMS OF FLOW THROUGH COMPRESSIBLE POROUS BEDS IN SEDIMENTATION, CENTRIFUGATION, DELIQUORING, AND CERAMIC PROCESSING.* The major topics covered in the investigation include:

1. Centrifugation
2. Cake Filtration
3. Sedimentation and Thickening
4. Capillary Suction Operations
5. Ceramics, Slip Casting
6. Optimization Studies
7. Wastewater

Support of the program by the Division of Basic Chemical Sciences, Office of Basic Energy Science, Office of Energy Research has led to substantial progress in a number of fields as indicted by the attached list of publications.

The principal investigator's activities in the research program were recognized by the American Filtration and Separations Society which established the Frank Tiller Award for theoretical contributions (Prof. S.H. Chiang of the University of Pittsburgh and Dr. B.J. Scheiner of the Bureau of Mines have received the Award) and named the Frank Tiller Educational Meeting in his honor. He also served as the founding editor of the *Fluid/Particle Separation Journal.*

With the termination of the program, the remaining funds were used to initiate a project at improving separation and recycling of biosolids in the Greater Houston Wastewater Plants. The knowledge gained in the DOE program has provided a sound foundation for attacking the formidable problems related to separation and densification of the supercompactible biosolids processed in thickeners, filters, and centrifuges.

The University of Houston research program was aimed at the specific areas of solid/liquid separation including sedimentation, thickening, cake filtration, centrifugation, expression, washing ,deep-bed filtration, screening, and membrane separation. Unification of the theoretical approaches to the various solid/liquid separation operations was the principle objective of the research. Exploring new aspects of basic separation mechanisms, verification of theory with experiment, development of laboratory procedures for obtaining data for design, optimizing operational methods, and transferring the results to industry were part of the Houston program.

Among the more important results, new methodology developed in our program now permits an engineer or scientist to handle thickening, cake filtration, centrifugation, washing, and expression in a unified manner. The same fundamental equations are simply adapted to the differing parameters and conditions related to the various modes of separation. As the system is flexible and adaptable to computational software, new developments can continually be added.

A number of significant activities were undertaken to disseminate basic fundamentals arising from the research. The Solid/Liquid Separation group of the University of Houston organized an informal consortium of universities (Penn State, Houston, Pittsburgh, Minnesota) and industrial companies (DuPont, Dow Chemical, Westinghouse, 3M, Donaldson) in a program to give four one-week short courses for engineering faculty in fluid/particle processing and separation, interfacial engineering, and particle science. The program was supported under the Faculty Enhancement Program of the National Science Foundation. Many short courses were supported by the American Institute of Chemical Engineering. The senior investigator gave special short courses for Dow Chemical, Alcoa, and CSIRO of Australia and gave invited lectures on research involving our DOE supported program in Japan, People's Republic of China, England, South Africa, France, Australia, Denmark, and Germany

PARTIAL LIST OF ACCOMPLISHMENTS

1. Development of a unified theoretical approach to operations (thickening, filtration, centrifugation, washing, expression, slip casting) involving flow through compactible porous media.

2. Theory of radial flow through compressible cakes in candle filters and centrifuges. Previously theory was only a available for incompressible beds.

3. Development of new theory demonstrating remarkable differences in behavior of moderately and supercompactible (highly flocculated) cakes. Theoretical and experimental proof that increasing pressure in filters beyond a value around one atmosphere has no effect on flow rate or the average volume fraction of solids in the cake for highly compactible materials like biosolids encountered in wastewater sludge.

4. Derivation of analytical equations for the maximum underflow solid flux and minimum sediment thickness for thickeners operating with a given underflow concentration.

5. Presentation of generalized design charts for thickeners operating in the compression mode.

6. Formulas giving the rate of cake buildup in slip casting.

7. Derivation of new theoretical equations for the fluidization of compactible cakes and sediments.

8. Methodology for choosing centrifugal pumps to match cake characteristics.

9. Development of the theory of capillary suction.
10. Revision of classical filtration theory to account for sedimentation on horizontal surfaces.

11. Optimization studies

    a. Determination of the quantity of filter aid (used as an admix) required to maximize either cyclical filtrate or solid rates.

    b. Determining the spacing of tubular elements in candle filters to give maximum cycle rates.

    c. Choosing mold characteristics in slip casting to maximize rate of cake buildup.

The principal and co-principal investigators and graduate students have been active in presenting papers at technical meetings of the American Filtration Society,. Amer. Institute of Chemical Engineers, American Ceramic Society, World Filtration Congresses (Belgium, France, Japan), Water Environment Assoc. of Texas, Int. Assoc. for Water Quality, Water Environment Federation, and the International Kenaf Association.

COLLABORATORS

A substantial number of visiting scholars, graduate students, and undergraduate students have been involved in the program.

Scholars Visiting for One Year

Associate Prof. J.B. Lee, Kyungsung University, Korea
Dr. Peter Sorensen, Aalborg University, Denmark
Prof. D.Z. Cong, East China Institute of Chemical Technology, Shanghai, PRC
Dr. A.I. Yelshin, Novopolotsk Technical Institute, USSR
Dr. A.M. Kirby*, CSIRO, Canberra, Australia
Prof. Avner Adin, Hebrew University, Israel
Mr. Y.L. Shen, East China Institute of Chemical Technology, Shanghai, PRC
President M.H. Sambuichi, Yamaguchi University, Japan
* 2 months

Graduate Students

S.L. Tarng, Ph.D.
F. Zhou, MS
V. Thopay, MS
W. Chen, Ph.D. and post-doctoral co-investigator
C.D. Tsai, Ph.D.
C.S. Yeh, Ph.D. and post-doctoral co-investigator
W.F. Leu, Ph.D and post-doctoral co-investigator

A number of undergraduates and high school students also participated.

The senior investigator particularly wishes to commend Dr. N.B. Hsyung who was co-investigator for six years. Other co-investigators include Dr. W. Chen, Dr. C.S. Yeh, and Dr. W.F. Leu. Success for the program has depended heavily on their contributions.

Sincerely yours,

Frank M. Tiller
M.D. Anderson Professor
Chemical Engineering
Civil and Environmental Engineering

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