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**MECHANISMS OF FLOW THROUGH COMPRESSIBLE POROUS BEDS
IN SEDIMENTATION, FILTRATION, CENTRIFUGATION, DELIQUORING,
AND CERAMIC PROCESSING**

Progress Report

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Dr. A.I. Yelshin spent an academic year in Houston under the auspices of IREX as a Visiting Research. Solid/liquid separation is his specialty at the Novopolotsk Technical Institute which is located in Byelorussia. His support cam from IREX.

Dr. A.M. Kirby of the Soils Division of the Commonwealth Scientific and Industrial Research Organization, Canberra, Australia spent one month in our Fluid/Particle Separation Laboratory. He analyzed data involving radial deposition of cakes. He was supported by funds arising from the M.D. Anderson Chair of the principal investigator.

Prof. Avner Adin of Hebrew University in Jerusalem, Israel spent an academic year as part if the team. He was partially supported by the DOE grant.

Mr. Y.L. Shen was vising scholar from the People's Republic of China. He was partially supported by the DOE grant and was principally involved in experimental aspects of the research.

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INTRODUCTION

The University of Houston research program is involved with the area 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 is the principle objective of the research. Exploring new aspects of basic separation mechanisms, verification of theory with experiment, and development of laboratory procedures are a part of the Houston program.

We should like to take special note of our activity in using the CATSCAN for studying some of the troublesome problems underlying the settling of flocculated particles and flow through compactible cakes. New insights into the relative movement of particles and liquids in sedimentation and filtration operations has resulted from our studies.

SUMMARY OF RESEARCH

1. **CENTRIFUGATION**
 - a. Centrifugal filtration theory
 - b. Centrifugal sedimentation theory
 - c. Comparison of cakes produced in filters and centrifuges
2. **CAKE FILTRATION**
 - a. Cake filtration combined with sedimentation
 - b. Improved cake filtration theory
3. **SEDIMENTATION AND THICKENING**
 - a. Theory of continuous thickening
 - b. Fluidization of compressible sediments
4. **OPTIMIZATION STUDIES**
 - a. Optimizing tubular arrangements in candle filters
 - b. Maximizing filtration rates with filter aids

1. CENTRIFUGATION

Centrifugal Filtration Theory. A series of studies have been carried out covering both sedimenting and filtering centrifuges. Centrifugation theory of concentrated suspensions (in the zone settling region) presently in the literature has been developed principally for incompressible beds. Inclusion of the effect of compressibility in our studies has led to improved understanding of the relative performance of filters and centrifuges (both sedimenting and filtering) with respect to average cake porosity.

Specifications based on experience indicate that commercially available filtering centrifuges generally are designed with larger diameters and lower angular speeds in comparison with sedimenting centrifuges. Inclusion of the effect of compaction in the theory leads to predictions which confirm rotational speeds and diameters which have evolved through experience. The formulas also point to the theoretical superiority of centrifugal filters. Practical problems of clogging of the perforated bowl have prevented the filtering centrifuge from replacing decanters. However, lower speeds and larger diameters typical of centrifugal filters points to the possibility of reducing maintenance (proportional to the cube of the speed) and increasing throughput (Tiller and Hsyung, "How Does Percent Solids Affect Centrifuge Cakes," Chem. Eng. Prog., 89, 20, August (1993).

Centrifugal Sedimentation Theory. A combined of theory developed for continuous gravity thickeners and centrifugal sedimentation is in the process of being combined to produce the theory of continuous decanting centrifuges.

Comparison of Cakes in Filters and Centrifuges. Pressure filters, centrifugal filters and sedimenting centrifuges (decanter) were compared with respect to the volume fraction of solids produced under equilibrium conditions. The behavior of three hypothetical materials were compared under a wide range of pressures and bowl speeds. Two highly flocculated examples with specific gravities of 1.1 and 4.0 were included along with a slightly compactible relatively easy to filter material. Compaction is effected by centrifugal forces in a decanter, frictionally generated drag due to liquid flow in vacuum and pressure which are sufficiently concentrated to ensure zone settling.

Filters are ineffective in reducing the liquid content of highly compactible flocs unless expression techniques (not covered in this paper) are employed. At low centrifuge speeds and with thin cakes, frictional drag dominates compaction; and compared with decanters, filtering centrifuges theoretically provide products with smaller liquid content, grow, decanters begin to approach perforated bowl centrifuges in performance provided there is sufficient density difference between the solid and liquid. With neutrally buoyant materials, decanters are inoperative; and filtering centrifuges and filters are equally ineffective with super compactible cakes (Tiller and Hsyung, "Relative Performance of Filters and Centrifuges with Respect to Average Porosity," *Advanced in Fil. and Sep. Tech.*, **3** (1990)).

2. CAKE FILTRATION

Cake Filtration Combined with Sedimentation. Filtration is carried out industrially with cake deposited (1) horizontally on a surface facing upward (horizontal leaf filter), (2) horizontally on a surface facing downward (drum filter rotating with a portion of the filter surface immersed in the slurry), or (3) vertically (vertical leaf plate-and-frame, or disc filter). Laboratory filters are most frequently of the type in which cake is deposited on the top side of a horizontal medium as exemplified by a Buchner funnel filter. In all of these filters, gravitational sedimentation is of importance. The gravitational deposition of solids on cakes has been omitted from most theoretical developments.

CATSCAN studies enabled us to ascertain the precise effect of sedimentation and to demonstrate how it could be identified in an ordinary laboratory constant pressure filtration on a horizontal surface facing upward. After all of the solids had been deposited, the remaining liquid flowed at constant pressure through the cake which had a constant resistance. Consequently, the flow rate was constant; and the filtrate volume was linear in time. The linear portion of the filtrate curve is wash to identify and permits accurate calculation of average values of the permeability and specific resistance (Tiller et al., "CATSCAN Analysis of Sedimentation and Constant Pressure Filtration," *Pro. Fifth World Congress on Filtration, Nice, France, Vol. 2*, 80 (1990)). Theory which has been recently developed is being incorporated into a new manuscript.

New Laboratory Filter. Prof. Cong with support from Dow Chemical Co. constructed a new rotating filter consists of slowly rotating (variable speed) cylinder with a vertical filter surface at one end. The vertical surface avoids gravitational sedimentation inherent to horizontal filter surfaces, and the rotation maintains a uniform suspension concentration. This remarkable but simple device could easily become the standard for laboratory work. (Tiller, Cong, and Hsyung, "New Revolving Laboratory Filter," *Advanced in Fil. and Sep. Tech.*, **45**, 6, (1992)).

3. SEDIMENTATION AND THICKENING

Theory of Continuous Thickening. A generalized graphical procedure was developed for determining the sediment height L of a continuous, flat-bottom thickener required to produce an under flow concentration ϵ_s at a given solid flux q_s . The method is based on an observation that plots of $\log L$ vs. $\log q_s$ at constant ϵ_{su} are approximately hyperbolic with asymptotes given by the minimum height L_{min} and the maximum flux q_{max} . An analytical equation for L_{min} as a function of q_{smax} provides an operating line on which a generalized relation of L/L_{min} vs. q_s/q_{max} is superimposed. The resulting curve permits calculation of L as a function of q_s for any system. (Tiller and Tarnig, "Generalized Method for Thickener Design," *Advanced in Fil. and Sep. Tech.*, 59, 6, (1992).

Fluidization of Compressible Sediments. The theory of fluidization of large particles forming incompressible beds does not apply to compressible sediments and must be modified. The usual theory predicts the simultaneous fluidization of all particles and the maintenance of uniform concentration dependent upon the velocity of the fluid relative to the solid. A compressible bed fluidizes at the bottom, and the entire bed then rises as a rigid solid. However, when the bed begins to rise, an unstable density condition exists; and the cake begins to disintegrate. (Tiller, Hsyung, and Tarnig, "Fluidization of Compactible Beds," *Fifth Ins. Sym. on Liquid-Solid Flows*, ASME (1994).

4. OPTIMIZATION STUDIES

Optimizing Tubular Arrangements in Candle Filters. Three problems were addressed in this research. The first related to determination of the best spacing of the cylindrical filter elements for a specific slurry given the slurry concentration and the permeability and porosity of the cake. The second problem involved finding the best operating procedure for an existing filter and a particular slurry. Given the tank diameter, pump characteristics, dead time when the filter is out of operation at the end of a batch, and the requirements for washing, the operator can only manipulate the pump rate and the cake formation time. Methodology for determining the best operating conditions were developed.

The third problem concerned the use of an existing filter to accommodate a wide range of slurries and cakes. Although seldom mentioned in the literature, compromise design of filters aimed at providing neatly optimal results for materials having a wide range of permeabilities and compressibilities is of industrial significance and can be addressed by techniques developed in this investigation. (Tiller and Yelshin, "Optimizing Candle Filter," *Filtration and Separation*, 26, 436 (1990).

Maximizing Filtration Rates with Filter Aids. Procedures for optimizing the quantity of filter aid used to clarify dilute suspensions in candle filters were developed. In contrast to the usual assumption that there is a fixed fraction of filter aid admix which yields the best results, we demonstrate that the optimum amount of filter aid varies with cake thickness, tube spacing, permeability, and dead time.

Filter aid decreases the permeability of the cake but at the same time adds to its bulk. After a sufficient quantity of filter aid has been added, the additional bulk offsets the decreased unit resistance; the total resistance rises; and the flow rate decreases after having passed through a maximum. In filters with fixed cake space, filter aid occupies part of the space originally allocated to the product solids. Additional cycles are required in order to process the original quantity of the product. Substantial improvement in cycle rates is

necessary to offset the increased bulk due to the filter aid. (Zhou, Fang, MS Thesis, University of Houston (1993).

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