Wat. Sci. Tech. Vol. 28, No. 1, pp. 289-293, 1993.

0273-1223/93 $6.00 + 0.00

WASTEWATER SLUDGE RESEARCH: OVERVIEW AND PERSPECTIVES BY THE EDITORS

K. Keiding*, J. Aa. Hansen*, P. Aa. Vesilind** and G. L. Christensen***

** Environmental Engineering Laboratory, Aalborg University, Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark*
*** Department of Civil and Environmental Engineering, Duke University, Durham, NC 27706, USA*
**** Civil Engineering Department, Villanova University, Villanova, PA 190885, USA*

INTRODUCTION

This contribution represents the editors' overview regarding sludge research after the Wastewater Sludge Dewatering conference in Aalborg, Denmark, June 29-July 1, 1992. It is by no means an attempt to summarize the papers of the conference. Each author has for that purpose presented an abstract and a full text, and this material is available in its entirety in the proceedings.

It is the intention of the editors to add to the original work of the many authors, some projections and supplementary thoughts. These evolved as a result of reading the complete proceedings in context and observing some gaps in the existing scientific and technical information which should be addressed by future research.

SCALES IN SLUDGE RESEARCH

Research in sludge covers an impressive range of linear dimensions as illustrated in Table 1.

TABLE 1 Levels of Sludge Management and Research and their Associated Scales.

Levels	Scale (meters)	Unit
SLUDGE PROPERTIES	$1 \cdot 10^{-6}$	μm
SLUDGE CHARACTERISTICS	$1 \cdot 10^{-3}$	mm
SLUDGE TREATMENT	$1 \cdot 10^{0}$	m
SLUDGE DISPOSAL	$1 \cdot 10^{3}$	km

SLUDGE DISPOSAL involves research on the scale of kilometers, and relates to questions of policy and science relative to assimilation of sludge into the environment. Problems, such as the effect of emissions from sludge incinerators or the assimilative capacity of soil for cadmium, are considered on this scale.

The next smaller scale is in meters, and here research is on full scale equipment performance, or SLUDGE TREATMENT. Questions relate to the design and operation of new centrifuges, or the best methods of applying polymer conditioning to sludge dewatering on belt presses, or the design of sludge incinerators, or the effectiveness of various forms of disinfection, or the application of freeze/thaw mechanisms for dewatering in cold climates.

SLUDGE CHARACTERISTICS, on the other hand, are studied on the scale of millimeters, where questions address the proper expression for the specific resistance to filtration or what sizes of particles will clog filter media.

The very nature of the sludge particles and the flocs that form with these particles are in the range of micrometers. At this level, concerns center on the chemical constituents of water and particles, and their physico-chemical properties, such as, hydrophobicity, water binding potentials and free charges. These questions can collectively be thought of as research on SLUDGE PROPERTIES.

If effective sludge management is to be achieved, not only will all of these levels of research be important, but communication between the levels must be maintained. It is counterproductive to believe that one's own research agenda is the only point where progress can be achieved. Rather, all researchers should recognize the value of all levels along the sludge research scale, and appreciate that progress at any level may be useful and necessary.

Communication between adjacent levels of research is fairly straightforward and often very rewarding to researchers at any level. For example, a researcher working on full-scale dewatering can appreciate the need and value of laboratory scale-up equipment (mm to m) as well as the need for the production of sludge with high shear strength for disposal (m to km). Where communication breaks down, however, is where levels are jumped. A person concerned with the effectiveness of sludge injection on odor production (km level) will have little use for research on filtration theory (mm level), nor will the researcher on electrokinetic properties (m level) have much time for performances of full scale dewatering equipment (m level). It would be the unusual person who would be able to span such a gap and speak effectively and authoritatively on such a wide scale.

The Wastewater Sludge Dewatering conference, the proceedings of which are included in this volume, attempted to address questions of sludge management ranging from sludge properties to sludge treatment. It therefore spanned a spectrum of interests ranging from micrometers to meters. This range is considered productive for the much sought after interaction between practitioners and researchers. Both practitioners and researchers were present at the conference.

TREATMENT, CHARACTERIZATION AND MODELING

Results on improved full-scale performance of belt filter presses and centrifuges were reported by several authors, e.g. *van der Roest et al., Andreasen & Nielsen,* and *Senthilnathan & Sigler*. For full-scale performance *Andreasen & Nielsen* identified four essential evaluation parameters, i.e. capacity, dry solids of the dewatered cake, consumption of conditioning chemicals, and cost. *Denkert & Retter* added shear stress of cake (when disposing of sludge in landfills), and *Pöpel & Jardin* as well as *Grulois et al.* introduced return flows as an important performance parameter regarding both sludge dewatering and wastewater treatment. Adaptive technology, e.g. use of freeze/thaw mechanisms for dewatering in colder climates, was another example of useful information on full-scale developments.

The significant improvements already realized in practice represent a challenge to the "laboratory scientists" to become more involved in the development of new methodologies for characterizing sludges, conditioning chemicals, and conditioning processes in order to better predict full scale performance based on small scale testing. The "laboratory" and the "real" worlds should increase interaction and it may be time for some of the traditional laboratory procedures, e.g. CST and SRF, to be up-dated, modified or replaced. The success of *Novak et al.* in introducing the Wedge Zone Simulator to predict belt filter press performance is a good example of such new laboratory scale developments.

The continued and extensive use of the CST and SRF laboratory procedures to interpret or predict full-scale dewatering performance is questionable. On the one hand, the CST and SRF measurements are often found to correlate well with full-scale performance, cf. *Sarikaya & Al-Marshoud.* On the other hand, changes in sludge characteristics, such as solids compressibility, will require new laboratory procedures for developing empirical relationships that describe the unique characteristics of each sludge. Development of a much better solids compressibility characterization test should be high priority sludge research and the impact on CST or SRF or other laboratory testing methodologies should be documented to develop better links between sludge characterization, laboratory scale testing, and full-scale performance.

Mixing of sludge and conditioner is still a poorly studied and understood field of work. *Langer & Klute* addressed certain aspects of mixing during chemical conditioning. These investigators obtained good filterability of polymer conditioned, anaerobically digested sludge using only a very short period of rapid mixing. Further, their results indicated that sludge viscosity increased dramatically shortly after polymer addition. Sludge viscosity was shown to be a function of sludge flocculation during conditioning and varied with sludge type, polymer type as well as polymer dosage. Therefore, common mixing regime characteristics such as the mean velocity gradient and Reynolds number could not be determined. Chemical requirements for sludge conditioning were affected by mixing intensity as well as mixing time, cf. *Langer & Klute* and *Novak et al.* The effects depended, however, on sludge type and polymer dosage.

Modeling of dewatering mechanisms is going to be increasingly important. On the one hand, the number of parameters needed to characterize sludges, conditioners and dewatering machinery is going to increase. On the other hand, each parameter and the complexity by which it is expressed and experimentally determined may increase as well. Only through adequate mathematical modeling and numerical solution methodology will it be possible to handle this information and improve the predictability of full-scale performance based on new information on sludge characteristics and properties. Modeling will also be increasingly important because of the need for more automatic control in full-scale dewatering in order to improve performance, cf. e.g. *van der Roest.*

Mathematical modeling was addressed by *Tiller & Hsyung* in a unified theoretical approach relevant to thickening, filtration and centrifugation. Their basic work may prove very useful for more practically targeted modeling in the coming years. Through a combination of numerical modeling of filtration and expression and based on experimental evidence, *Sorensen & Hansen* identified a filter skin which formed during the dewatering of compressible solids, e.g. biological sludge solids. It seems necessary to reanalyze and modify the compressibility concepts currently in use in order to more realistically model reality. Such a revised conceptual framework might significantly improve sludge characterization and modeling of dewatering.

SLUDGE CHARACTERISTICS AND PROPERTIES

Improved understanding and use of sludge characteristics seem closely related to more work on sludge properties. Physical, chemical and microbial properties are all important in this respect.

The successful use by *Mustranta & Viikari* of Fenton's reagent to alter the chemical constituents of paper-mill sludges shows that addressing the question of chemical sludge properties does offer new possibilities for manipulating the sludges and achieving better dewaterability. The methodologies used by *Pere et al.* to characterize the effects of Fenton's reagent signals that use of techniques and concepts from colloidal science offers new and useful information. Concepts from colloidal chemistry are also found in the use of charge titration, zeta-potential, and the effects of pH and conductivity on dewaterability by *Friedrich et al.*, *Agerbæk & Keiding* and *Sarikaya & Al-Marshoud*; and in the discussions of particle size effects by *Lotito et al.*, *Friedrich et al.*, and *Olböter & Vogelpohl.* Indeed, the successful application of a streaming current detector in sludge conditioner selection and control by *Dentel & Abu-Orf*, the discussions of electroosmosis by *Laursen*, and the discussion of the streaming potential by *Agerbæk & Keiding* illustrate that the adaptation of principles and techniques of colloidal sciences to sludge processing may be a profitable path to pursue.

It seems an open question to which extent sludge flocs can be regarded as particles in suspension and how such particles should be characterized in terms of compressibility, cf. the filter skin formation already mentioned above. *Tosun et al.* added evidence that the surface of the filter medium can influence dewatering, providing dewaterability characteristics that would normally be ascribed to the sludge cake. Having formed a filter skin over which the total pressure drop takes place means, therefore, that skin characteristics must be studied to improve dewatering in both theory and practice. Because the skin formed seems to have a thickness of only 15-25 m, it is evident that sludge properties must be better understood to improve the characterization necessary to model and predict dewatering of sludge. Suggested sludge properties to be investigated in this context could be hydrophobicity/water angle, streaming potential and sensitivity of these to changes in cation concentrations, pH and temperature. Additionally, in order to understand blinding phenomena and other more general aspects of dewatering, particle size distributions may be important. Reliable and reproducible measuring techniques are necessary, but based on the work presented, there is still much progress to be made.

RECOMMENDATIONS AND FUTURE RESEARCH

Some specific recommendations are presented above in the context of several broad topics addressed at the conference. Additional specific recommendations follow:

- Cake solids, e.g. as a full-scale performance parameter, should be expressed in terms of sludge solids proper. It is confusing to include conditioning chemicals with sludge solids when expressing increased cake solids as a result of conditioning and dewatering. When using lime, for example, it is important to make a correction for conditioner addition.

- Changes in floc structure seem, according to *Bruus et al.* and *Eriksson & Alm*, to change both sludge dewaterability and polymer consumption. Such changes in floc structure indicate a need for a much better understanding and description of the microbial population dynamics in activated sludge systems.

- It seems necessary to improve characterization of sludges to be dewatered by providing more systematic documentation on correlations between traditional laboratory experiments using SRF, CST, polymers, etc., and more fundamental sludge constituents and properties, such as, extracellular polymeric substances, pH, conductivity, contact angle/hydrophobicity, particle size distributions, etc..

- Novel experimental procedures and concepts may be extremely important in order to achieve new insight into sludge properties and characteristics. It may be time for an annual prize for the best experiment, or experimental design, or experimental result in sludge research at any level. The IAWQ Specialist Group on Sludge Management should consider how to organize and finance such competition.

Of a more general nature are the following recommendations regarding sludge to be seen in the context of the overall functioning of the entire sewer and wastewater treatment system, cf. Figure 1.

It is important to note that more than fifty percent of the organic load entering the wastewater treatment plant will be as solids. These solids are either original constituents of the wastewater or formed as a result of processes in the sewer. Solids may have extended residence times in sewers. In the processing tanks of the wastewater treatment plant, sludge flocs are formed and transformed. Final sludge properties and characteristics are the result of both hydraulic, chemical and microbiological conditions applied before floc separation and dewatering. Because sludge properties and characteristics are so important for dewaterability, it seems obvious that we should not passively accept sludge as a given by-product of wastewater treatment, but rather actively consider the design of flocs to produce those properties and characteristics required for efficient floc separation and dewatering.

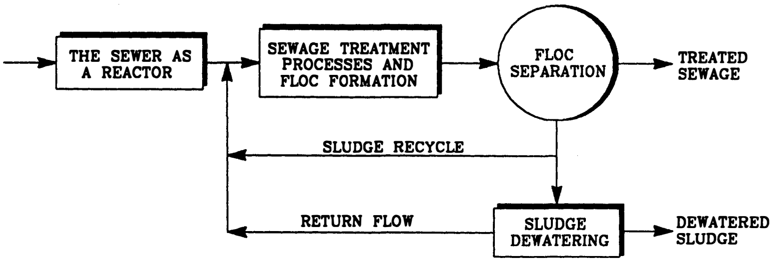

Fig. 1. Physical and conceptual framework for sludge floc formation, separation and dewatering.

A conceptual change to include floc formation, efficient separation and dewatering in the overall design of the wastewater treatment plant may lead to improved plant performance and overall economy. Such new thinking will properly direct attention to the processes that occur in sewers as well as treatment plants and emphasize that flocs in the wastewater treatment processes be engineered and "designed" to have properties and characteristics that facilitate good separation (clean effluents to receiving waters), efficient dewatering (high solids in sludge cakes for land use), and useful disposal properties (high phosphorus and low metal content).

The last issue of high cake solids and the disposability of sludges is a shift from the meter to the kilometer scale of sludge management. As noted in the introduction, although the disposal of sludges is as important as any other sludge management concern, it is beyond the scope of this conference and these proceedings.