Some fundamental aspects of sludge dewatering

SOME FUNDAMENTAL ASPECTS OF SLUDGE DEWATERING

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1 Introduction

Because of the more severe legislation there is a need to find other solutions than disposal of dewatered sewage sludge on dumping sites and in agriculture. Smaller sludge volumes and smaller dewatering systems are needed. Other disposal options that are of interest now, are combustion and drying of dewatered sludges. Increasing the dry solids content of the dewatered sludge reduces the energy needed for combustion and drying. Volume reduction of the dewatered sludge can be reached in two ways:

1. Reduction of the production of sewage sludge by optimizing the existing waste water treatment plants.
2. Improving existing techniques or developing new techniques for dewatering sewage sludges. The basic aim is to achieve higher dry solids content of the sludge cake.

By getting more insight into the physical and physico-chemical processes involved in the sludge dewatering process can help us to improve the dewatering characteristics (high dry solids content and/or more rapid dewatering) of existing techniques.

In the beginning of 1990 we started a study of some fundamental aspects of sludge dewatering in our laboratory, within the larger Dutch research program entitled "Future treatment technique for municipal waste water (shortly RWZI 2000)". Participants in the study are Ir. A.J.M. Herwijn, Drs. E.J. La Heij and Ing. P.M.H. Janssen. The end responsibility is accepted by Dr.Ir. W.J. Coumans and Prof.Dr.Ir. P.J.A.M. Kerkhof. The study is financially supported by the "Institute of Inland Water Management and Waste Water Treatment (RIZA)" and the "Foundation for Applied Waste Water Research (STORA)".

One part of the study is aiming for the understanding of physical and physico-chemical phenomena occurring on microscale, and how these phenomena manifest themselves on the macroscopic scale. Important are the crosslinks between physical parameters, determined with various characterization methods. Another part of the study is the development of theoretical and simulation models predicting filtration and expression behaviour. These type of models could then be used in the optimization of dewatering processes and equipment parameters.

2 The presence of water.

In figure 1 we present schematically the way that water may be present in sludge and sludge cakes. In a suspension or in a filter cake we may distinguish a water phase and a floc phase. The flocs are formed from the basic sludge particles, in many cases with the addition of flocculants. Flocculants are used to promote the aggregation of basic particles and in this way improve the release of water of sludges. Flocculants that are usually applied in waste water treatment plants are $FeCl_3/Ca(OH)_2$ and polyelektrolytes.
The mechanical behaviour of flocs in a dewatering process depends on floc properties and conditions of dewatering as well. Floc properties of a given sludge depend on amount and nature of the flocculants. The flocs consist of a skeleton, in which interstitial liquid is present.
The properties of the basic sludge particles vary with place, season and conditions in the waste water treatment plant. Basic particles, like microbial cells, or pieces of wood, etc. contain water inside. Further we will have hydration layers at the particle surfaces.

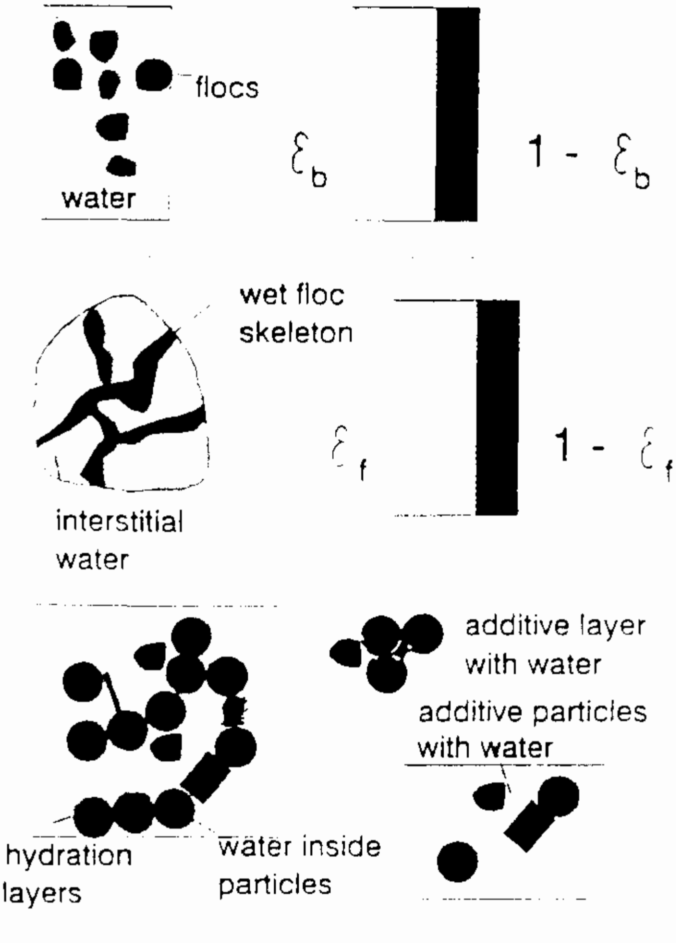

Fig. 1 Schematic representation of water in sludge

3 Mechanical dewatering.

After a sedimentation step further sludge dewatering is performed by means of filtration and expression. In filtration and expression the water phase moves relative to the solids and/or flocs under the influence of a gradient in liquid pressure. Dewatering techniques used in practice are the chamber filter press and the belt press and to a certain amount also the centrifuge.

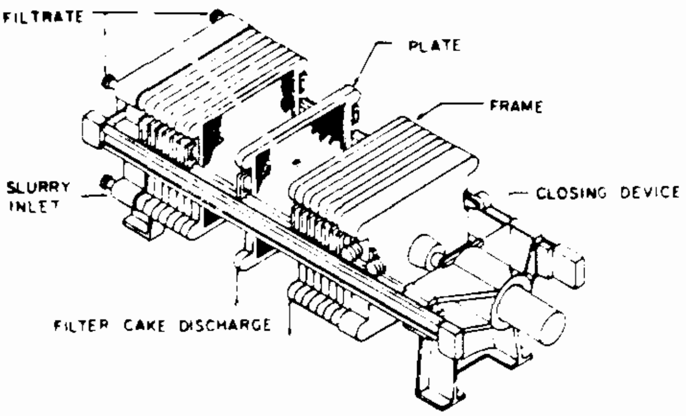

Fig. 2 The chamber filter press.

The conventional chamber filter press is a batch-operating pressure filter (fig. 2). Frames and corrugated plates are arranged alternately and supported on a pair of rails. The sludge is introduced through a port in each frame and the filtrate passes through the cloth on both sides of the frame. The liquid runs down the corrugated surface of the plates. Two cakes are formed simultaneously in each chamber. The process is stopped if the two cakes join, the chambers are opened and the cake is discharged. The types of flocculants that are used in this dewatering technique are $FeCl_3/Ca(OH)_2$

The belt filter press is a continuous pressure filter (fig. 3) which usually combines gravity drainage with mechanical squeezing of the cake between two running belts. Liberated water passes through the belts. Polyelektrolytes are the type of flocculants used in this technique.

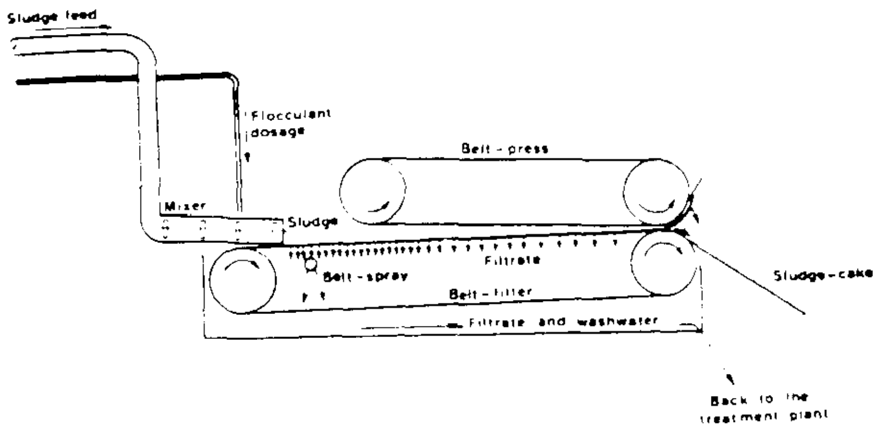

Fig. 3 Flow scheme of the belt filter press.

4 Characterization of sewage sludge.

Characterization of sewage sludge means determining chemical and physical properties, which are of importance in the dewatering process. I will give some results concerning a few characterization methods available in our laboratory.

a. Particle size distribution and particle morphology.
These two characteristics represent the initial conditions of the flocs as they enter the dewatering process. Besides laser-diffraction equipment also the optical image technique and electron microscopy are important to get impressions of irregularities in shape, and of structure.

b. Water binding and transport.
Since water may be present in various ways, it is of interest to quantify the several types of water.
Drying experiments on filter cakes may be analysed in terms of an effective water diffusion coefficient and its concentration dependence. The value of the effective diffusion coefficient is a measure for the bond strength between solids and water. From a drying experiment also information about the amount of free and bound water can be obtained. If in a drying experiment the rate of evaporation remains constant, free water is transported and mass transfer is limited by external drying conditions. A decreasing rate of evaporation indicates that mass transfer is limited by diffusion in the sludge cake.
In a drying experiment, which is carried out in thermal analysis equipment, weight loss and the energy required for evaporation are measured simultaneously. With these data the bond energy between sludge particle and water can be calculated as a function of the water content of a sludge cake sample. In figure 4 a result is given. Lowering the water content of a sludge cake sample from 5% increases

the bond energy enormously. So it is very difficult to release the last *remainders of water in* a sludge sample by mechanical means. This information is of importance for a better understanding of the drying process of sewage sludges.

Freezing curves of sludge cakes may also provide information on the amounts of free and bound water. Bound water is by definition not available for crystallization. The bond energy of the bound water is larger than 330 kJ/kg, being the crystallization energy of free water. From these experiments it can be concluded that the bound water content of a sludge cake is about 0.4 kg water/kg dry solids.

The water vapour isotherm, which is the equilibrium relation between the water content of a sludge cake sample and the relative humidity of the surrounding atmosphere, provides additional information on the bound water. This information can be obtained in two ways:

a. A decreasing relative humidity with decreasing water content of the sample indicates the presence of bound water in the sample.
b. By measuring sorption-isotherms at different temperatures the bond energy can be quantified as function of moisture content using the Clausius-Clapeyron equation.

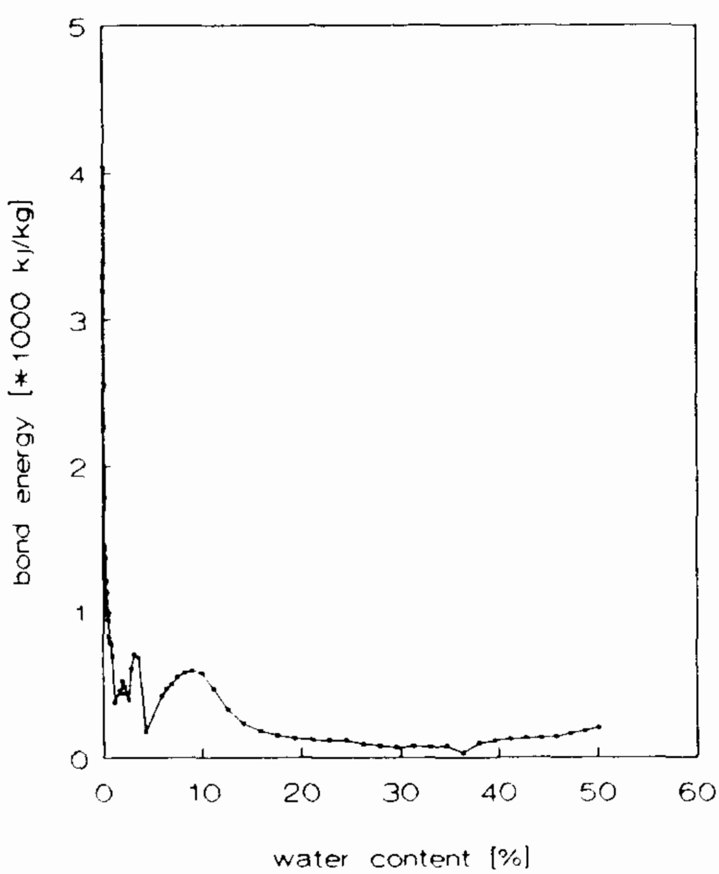

Fig. 4 Bond energy as a function of water content of a sludge sample.

c. Physico-chemical aspects.

For a better understanding of the dewatering process we study the colloid-chemical aspects. Interesting elements of study are floc formation, strength and structure and the consequences for the engineering aspects. Measurements of zeta-potentials for various additives are carried out to study floc formation processes. The zeta-potential of a sludge sample is determined with the Electrokinetic Sonic Analysis System. The floc formation process, which occurs when a certain amount of $FeCl_3$ is introduced in a sludge sample, is known as sweep flocculation. The metal ions form metal hydroxide complexes in the aqueous solution, which adsorb at the sludge particle surface. Sludge particles surrounded by layers of metal hydroxide complexes stick to each other and so flocs are formed.
By measuring the reological properties of a sludge sample with a Couette-rheometer, the strength of flocs can be determined.

5 Theoretical and experimental investigation into the solid-liquid separation process.

The conventional filtration theory has been derived for particles with a closed surface. It is known that flocs may have an open structure (see fig. 1). Therefore Kerkhof [1] developed the "DUAL FLOW MODEL", which takes into account that water flows both through the pores between the flocs and through the flocs themselves. Thus, compared with the conventional approach, now the liquid between the flocs is less decelerated at the floc surface for a given pressure gradient.
Further, the model allows the estimation of the effective permeability of a bed with permeable particles. The effective permeability of a bed depends on the porosity of the filter cake ϵ_b and the internal floc porosity ϵ_f (see fig. 1).
From simulations we may conclude that the flow through the flocs causes a large increase of the bed permeability especially for lower sludge cake porosities (ϵ_b <0.1). See fig. 5.
The "DUAL FLOW MODEL" is a good base for further refinement and experimental study. It will be especially of interest to investigate the separate deformations of flocs and filter beds in a filtration or expression process. Now deformation means that the porosities of both the floc and the filter bed change and so the effective permeability of the filter bed will be influenced.

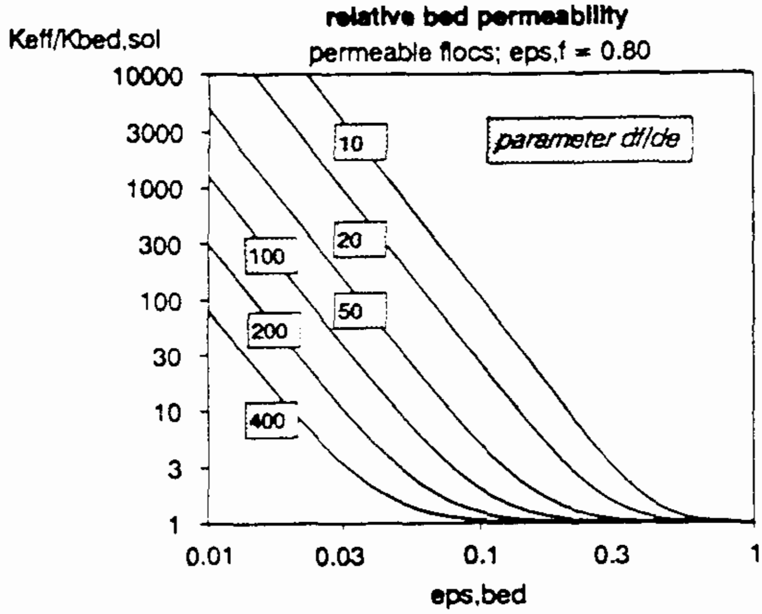

Fig. 5 Relative permeability of porous floc bed K_{df} compared to closed particles $K_{b,sol}$, as a function of bed porosity eps,bed with relative floc size df/de as parameter; df = floc diameter, de = diameter of elementary floc particles. Floc porosity eps,floc = 0.80.

The model description of filtration and expression requires a more detailed analysis. However, interesting observations for practice can be obtained from laboratory tests, such as filtration of a sludge sample under constant gas pressure. By fitting the experimental relation of filtrate volume over time, we find an average value of the specific cake resistance. In fig. 6 we see the influence of the addition of $FeCl_3$ on the specific cake resistance. It is clear that the resistance decreases upon addition to a limiting value. The decrease is quite strong.

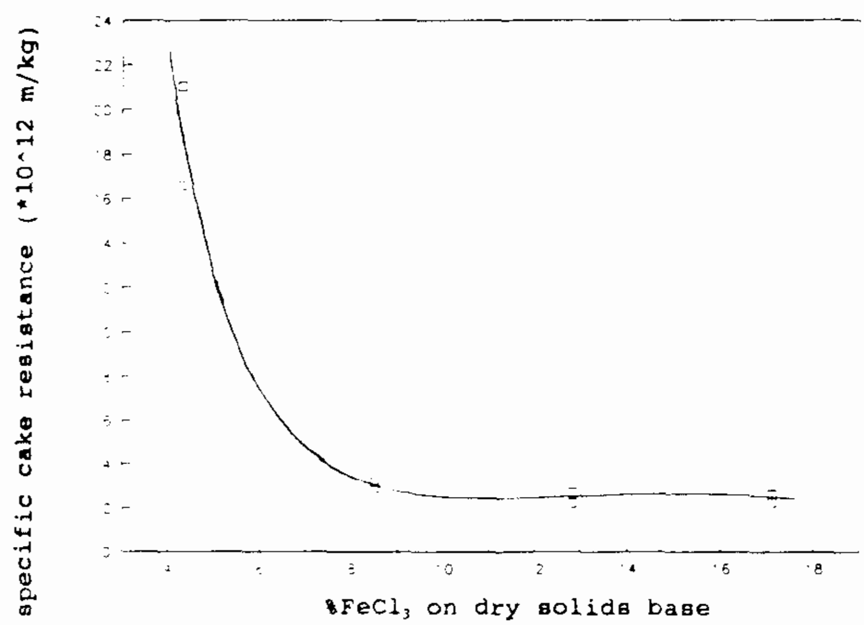

Fig. 6 Specific cake resistance as a function of the amount of added FeCl3.

Another laboratory test is the compression-permeability cell. In this cell the compression behaviour of a sludge cake can be studied. With this device the empirical relationship between cake porosity and cake permeability can be determined. Also the relation between cake porosity and compression pressure can be measured. These empirical relations provide basic data for the "DUAL FLOW MODEL".
Increasing pressure during a filtration cycle usually decreases the liquid content of filter cakes. However, highly compressible cakes, like sewage sludges, do not respond directly to an increase of filtration pressure. During filtration of sewage sludge a skin with a low porosity and a high flow resistance is developed next to the filter medium (porous sheet or cloth). To improve deliquoring of such cakes, the direction of the liquid flow can be reversed at the end of the filtration process. When reverse flow takes place, the skin serves as a piston which compresses the unconsolidated portion of the cake. In this way lower final moisture contents in filter cakes can be achieved. An experimental device will be developed to study this phenomenon.

6 Final remarks.

In the study of some fundamental aspects of sludge dewatering we try to get a better understanding of the sludge dewatering process. Therefore, sludge is characterized in several ways. It is important to find crosslinks between physical parameters determined with the characterization tests. Another important element of study is the theoretical description of the dewatering process. Hopefully, new insights can be used for optimization of process conditions and design of new dewatering equipment in the future.

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