Improvement of separation processes in waste water treatment by controlling the sludge properties

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ABSTRACT
Separation processes in mechanical and biological waste water treatment are influenced substantially by the constituents of the waste water and the specific sludge properties. The electrical surface charge of the activated sludge, and, therefore, its natural flocculation, is particularly important in this connection. Knowledge of this is essential for improving the performance of biological waste water treatment plants. Using the example of an industrial and municipal plant, the increase in performance brought about by measuring the Zeta potential of the activated sludge is described. This method allows to investigate the influences on the sludge properties concerning solids/liquids separation. Furthermore, the treatment process as well as the use of chemical agents can be optimized.

KEYWORDS
Flotation; sedimentation; sludge properties; sludge separation; surface charge; Zeta potential

INTRODUCTION

In recent years the waste water administrative regulations have led to a constant rise in the purification performance demanded of waste water treatment plants. Because of this, the number of waste water treatment plants has been growing, and technical complexity has also been increasing. In order to keep the associated rising costs of capital expenditure and operation within bounds, intelligent process technology solutions have to be found. Besides having a deeper understanding of the individual processes, it is essential to consider the entire waste water treatment plant as a whole. Most treatment plants consist of a mechanical and biological waste water purification, sludge treatment and gas utilization. In three of these four stages, namely in the preliminary and secondary clarification of the waste water and in the thickening and dewatering of the sludge, the processes for solids/liquids separation are of crucial importance. The performance of the solids/liquids separation is mainly influenced by the properties of the sludge. In the first part of this paper, the parameters influencing these sludge properties are discussed.

To characterize the sludge properties in terms of solids/liquids separation, normally the sludge volume and the sludge index are used. The sludge volume means the volume of the sedimenting sludge measured in $ml \cdot l^{-1}$. The sludge index is determined by dividing the sludge volume by the MLSS, which means the concentration of the sludge. The two parameters describe the behavior of the sludge in solids/liqiud separation processes. However, it is difficult to determine the reasons for changes, or to investigate influences on the sludge properties. The authors found out that a suitable method is to determine the electrical surface charge of the sludge particles, which can be measured by the Zeta potential. This presented tool helps to build high performance solids/liquids separation plants, or it helps to upgrade existing plants.

In the first part of the paper, the measuring method and the parameters influencing the sludge properties are discussed. In the second part two examples are used to demonstrate the increase in performance of biological waste water treatment plants achieved by employing this measuring method.

PROPERTIES OF THE SLUDGE

Parameters influencing the sludge properties

The properties of sludge concerning the solids/liquids-separation are influenced by size, shape, density of the particles as well as its ability to deform, the solidity of its cell membrane and the properties of its boundary surface. In this context the physical-chemical and biological properties of activated sludge are of crucial importance for the separation processes in waste water treatment. The authors found out that these can be derived from the raw waste water, the biological process and the sludge treatment. In the case of waste water excessive hydraulic loads and fluctuating pollutant concentrations as well as a pH ≤ 6.5 and temperatures below 14 °C have a major effect on the sludge properties. High salt and surfactant contents also lead to adverse sludge properties. Besides the absolute concentration level of the waste water constituents, the carbon:nitrogen:phosphorus ratio (C:N:P ratio) in particular has a major influence. Thus, measurements by Schories and Vogelpohl (1996) have shown that the best separation of the activated sludge from treated waste water is achieved with a C:N:P ratio of 100 : 12.5 : 2.5.

The biological stage also has a major influence on the sludge properties. This is the result of the biological process chosen - anaerobic or aerobic – as well as of the F/M-ratio (concentration of waste water ingredients measured as chemical or biological oxygen demand, COD or BOD, in relation to the mixed liquor solids, MLSS) and the volume load (COD or BOD in relation to the volume of the reactor). The sludge properties are also influenced by the type of aeration, the oxygen concentration in the aeration and the use of metal salts, flocculants and defoamers in the biological stage. Negative influences of these parameters may result in a cloudy effluent from the secondary clarification stage owing to the removal of activated sludge. Associated with this, the increase is in the effluent concentrations of chemical or biological oxygen demand (COD or BOD) as well, as phosphorus and nitrogen contents above the permitted limits. The adverse effect on the sludge properties also frequently leads to a change in the electrical surface charge, and flocculation of the activated sludge.

Electrical surface charge of the activated sludge

Microorganisms behave like other solids in an electrolytic liquid, and therefore in waste water. Their natural flocculation is diverse from the agglomeration of other particles. The polymerstructure of the walls is changing and they own slime capsules with flocculent or dispersing properties. Further the shape of microorganisms changes. Owing to the structure of their cell walls, they have a greater or lesser electric charge, which has a direct effect on their natural flocculation properties. The electrical surface charge of the microorganisms is caused largely by amino, carboxyl and phosphorus diester groups (according to McKinney 1952 and Ho 1986). Furthermore, the slime capsules of bacteria from polysaccharides show the electrochemical reaction of a protein (according to Schlegel 1985). Since carbon, nitrogen and phosphorus compounds are required for the formation of these groups, the composition of the nutrients also has an effect on the electrical charge.

The physical principals during flocculation can be declared using the potential model according to McKinney (1952). The influence of the surface charge on the flocculation of solid particles and microorganisms should be noted in particular. To explain the electrokinetic processes in the immediate vicinity of the charged surface of the particles, the potential model will be explained. As can be seen from fig. 1, this model is based on a spherical solid particle with a certain base potential, also called the “Nernst potential”. Counter-ions are adsorbed directly at the phase boundary due to Coulomb or van der Waals forces. This mono- to bimolecular layer is called the “Stern layer”. This is the followed by the “diffuse double layer”, in the region of witch negative ions are also present. By addition of counter-ions into the surroundings of the negatively charged surface, the electrical potential is weakened continuously. The force of repulsion or attraction predominates, depending on the ionic strength. The situation of the resultant force is an important criterion for coagulation and/or agglomeration of the suspended solid particles in the waste water. It is possible to determine the potential relationships at the solids/liquids shear surface by electrokinetic measurements. The result of these measurements is the “Zeta potential”. In case of flocculation surface forces have to overcome these electrical forces. That means for inert particles, that the best flocculation can be achieved for a Zeta potential that is zero.

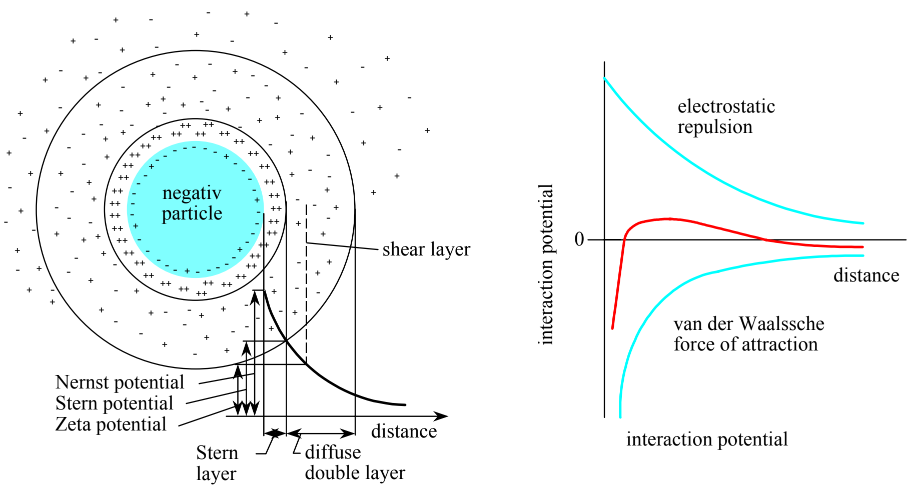

Figure 1: Potential model

In the investigations the equipment used was a PC-supported microelectrophoresis instrument, model Pen Kem 501, with which the Zeta potential can be read off directly. This measurement device consists of measurement chamber, laser, microscope, digital camera and personal computer. When a voltage is applied between electrodes at opposite ends of the measurement chamber, the resultant electric field causes a motion of charged particles relative to the fluid, called "electrophoresis". If a microscope is focused at the laser lighted measurement chamber, this electrophoretic motion can be observed. Since the electrophoretic velocity is proportional to the applied electric field, it is convenient to define a normalized parameter called the "Electrophoretic Mobility", equal to the electrophoretic velocity divided by the field strength. Then the Zeta potential can be calculated from the measured mobility, according to either Smoluchowski´s equation, or other appropriate model equations according to Hunter (1989). In this particular case the microscope is connected with a digital camera. The recorded picture is evaluated by a special PC-Program, that determines the distribution of the Zeta potential of the particles.

Owing to the genetic make-up of gram-negative bacteria, the Zeta potential of activated sludge is mostly in the range of -6 to -12 mV. The authors named this Zeta potential: "Natural Zeta potential". At this surface charge the activated sludge forms a compact floc with a fairly low sludge index. The specialists among the bacteria - Nitrosomonas and Nitrobacter – have a higher surface charge of -12 to -18 mV. They are normally incorporated in the activated sludge floc. This knowledge is based on many years of measurements by the authors at more than forty municipal and industrial waste water treatment plants. These investigations also showed that destruction of the activated sludge floc takes place at a Zeta potential of -14 to -20 mV, depending on the shear stress. An inherent collapse of the floc is observed at a Zeta potential greater than -20 mV. This seriously impairs the separation of the activated sludge by sedimentation or flotation.

The reason for the change in surface charge of the activated sludge may lie in the constituents of the waste water, or in the process technology of the waste water treatment plant. In practice, a highly loaded plant results in a Zeta potential of -14 to -60 mV. In the case in question the Zeta potential of the particles reached -32 mV with a F/M-ratio of 2 kg $BOD_5 \cdot kg\ TS^{-1} \cdot d^{-1}$. ($BOD_5$: five days biological oxygen demand). Moreover, the activated sludge flocs also act as adsorption surfaces to which dissolved waste water constituents can be attached. In the manufacture of E-PVC, for example, the waste water contains a low concentration of an anionic surfactant. As shown in fig. 2, this surfactant causes an extremely high negative charge of the activated sludge of 80 % of the particles with -45 mV. A further problem can arise in sludge treatment with cationic flocculants. The investigations showed that a Zeta potential of 95 % of the particles with +2 mV is achieved, with an auxiliary concentration as low as 5 $g \cdot m^{-3}$ sludge (fig. 2).

If the natural Zeta potential of the particles is modified by external or internal influences, the structure and strength of the activated sludge flocs are seriously impaired. In highly loaded waste water treatment plants, the flocs often form star-shaped outgrowths at the edge zones. As a result of these specific surfaces, some of these are large. Flow forces in pumps and pipelines exert a much greater destructive effect on the flocs. Generally speaking, it is only those microorganisms that form stable flocs, or are incorporated in these, that survive in the activated sludge. A Zeta potential outside the normal range produces an adverse form of activated sludge floc, which also has a great influence on the sludge index. The sludge index characterizes the separation and thickening properties of the activated sludge. To achieve an increase in performance of the separation processes in waste water treatment plants a knowledge of these facts is essential.

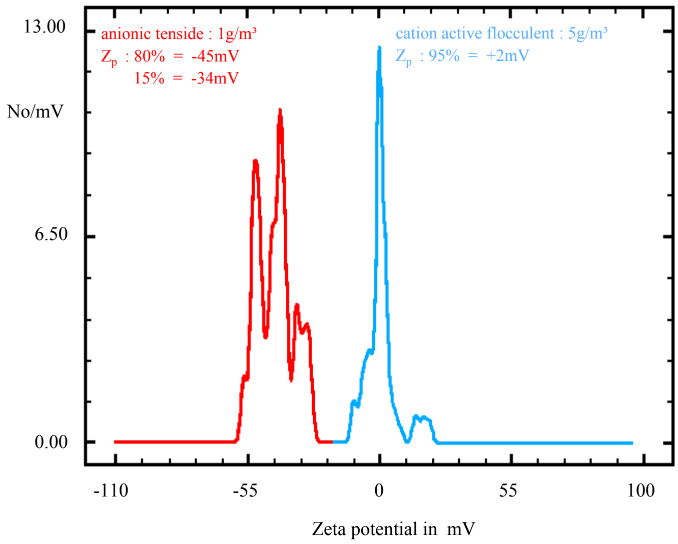

Figure 2: Influence of chemical agents on the Zeta potential of activated sludge

IMPROVEMENT OF SEPARATION PROCESSES IN WASTE WATER TREATMENT PLANTS

In the following, two examples are used to demonstrate the improvement of separation processes in waste water treatment plants achieved by employing this measuring method. Of an immense technical importance in this context is the sedimentation in the secondary clarification of waste water treatment plants. The main basis for separating the activated sludge is a perfect natural flocculation. In this case the activated sludge shows a Zeta potential between – 6 mV and – 12 mV. If another Zeta potential is measured, the flocculation does not work well and the parameters influencing the sludge properties have to be eliminated by the following methods:

- Destabilizing the particles in the waste water.
- Adsorption of solved ingredients by recycling the excess sludge into the precipitation.
- Realization of an fluidized floc filtration in the secondary clarification basin.

With the aid of these methods, the sludge properties can be strengthened and, with this, the flocculation of the particles.

Industrial waste water treatment plant

In such a plant the flow rate of the incoming waste water is about 4,800 $m^3 \cdot d^{-1}$ with a BOD_5 of 1,800 $mg \cdot \ell^{-1}$ and a COD of 6,500 $mg \cdot \ell^{-1}$. For biological waste water cleaning in the first stage, a BIOHOCH®-reactor with an activated sludge tank of 6,000 m^3, and a secondary clarification unit with sedimentation with a clarification area of 300 m^2 are used (fig. 3).

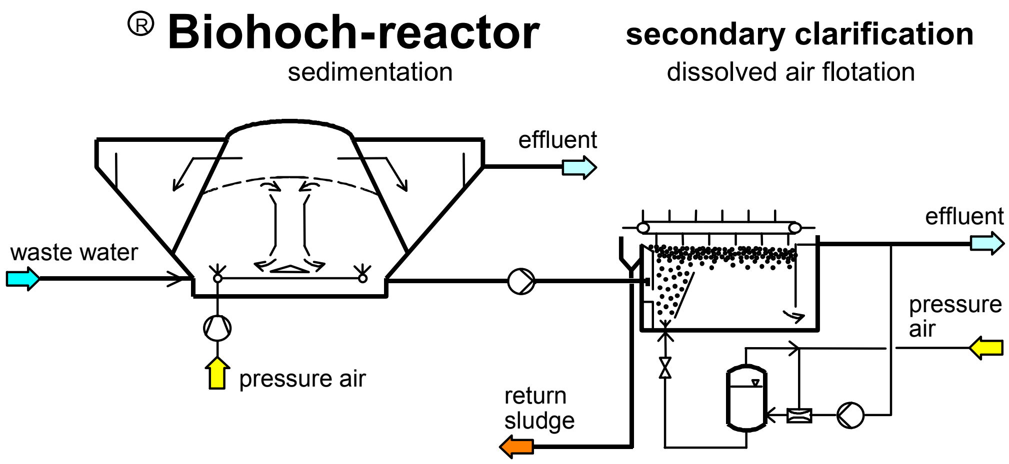

Figure 3: Industrial waste water treatment plant

The relatively low biomass concentration of 1 to 2 g·ℓ^{-1} and thus the high F/M-ratio in the plant is attributable to an extremely high sludge index of 400 to 1,000 mℓ·g^{-1}. The cause of this is to be found in the ingredients of the waste water and the very special type of biocenosis with its characteristics. All the bacteria have a distinctly characteristic slime capsule from polysaccharides which results to bad sedimentation properties of the sludge. In particular the low varieties of types of bacteria in the activated sludge as well as their surface load of -20 to -48 mV are to be emphasized (fig. 4).

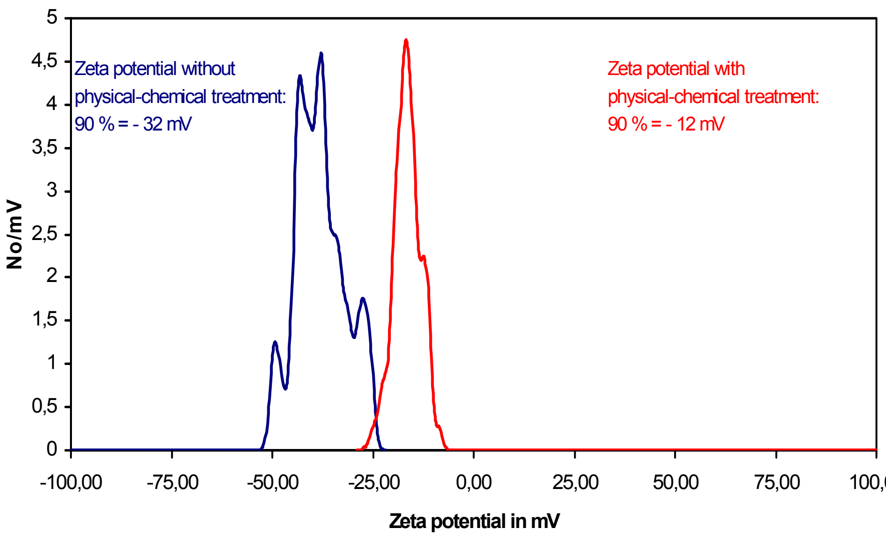

Figure 4: Zeta potential of activated sludge with and without physical-chemical treatment

The result of this was an insufficiently working sedimentation and, therefore, a low performance of the whole plant. With a view to increasing the hydraulic loading by 50 % and the oxygen-consuming organic compounds - measured as a five-day biological oxygen demand or BOD_5 - by 40 %, a biomass concentration of 4 to 6 $g \cdot \ell^{-1}$ was aimed for. In order to achieve this goal, at first a physical-chemical treatment was added to destabilize the biocenosis. The result can be observed in fig. 3. As shown in fig. 4, the Zeta potential for 90 % of the particles was moved from -32 mV to -12 mV. In a second step, the existing insufficiently working sedimentation unit was replaced by a flotation unit. Despite this higher load, a COD effluent value of about 2,000 $mg \cdot \ell^{-1}$ was able to be maintained. The associated BOD_5 was between 50 and 150 $mg \cdot \ell^{-1}$. This corresponds to an elimination of COD of about 80 % and of BOD_5 of more than 95 %. The flotation unit has a clarification area of 100 m^2 and is operated at a saturation pressure of 4 bar and a pressure water addition of 20 to 30 %. This results in a hydraulic load for the plant of 4 $m \cdot h^{-1}$ and a waste-water surface load of 3 $m \cdot h^{-1}$. The solids content in the return-sludge is 30 to 50 $g \cdot \ell^{-1}$.

Municipal waste water treatment plant

Fig. 5 shows a municipal waste water treatment plant consisting of mechanical and biological waste water purification and a sludge treatment. In such a plant the purification performance is mainly influenced by the separation of the sludge in the secondary clarification. In this field, problems are observed in many waste water treatment plants. The reasons for this are the properties of the activated sludge concerning solids/liquids separation. As shown in fig. 5, the influences on the sludge properties have to be divided into the ingredients from the waste water influent and the sludge treatment. In the first case, waste water from food producing companies contains a many tensides from cleaning processes. The influence of the sludge treatment results from high cationic flocculent demands.

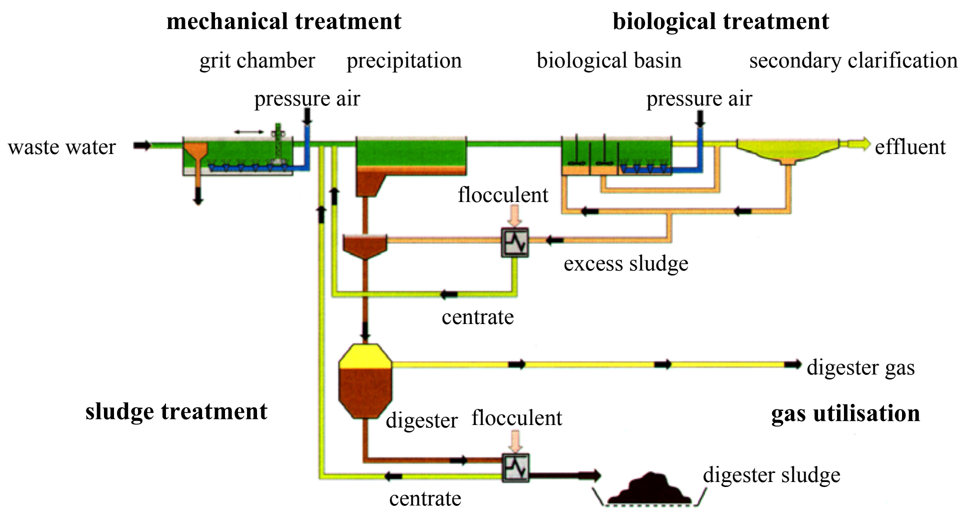

Figure 5: Municipal waste water treatment plant

To solve problems with the sludge treatment, a new concept was implemented. To reduce the flocculent demand, the excess sludge is thickened from 1 % up to 4 % MLSS by a flotation unit. Afterwards this sludge is thickened up to 8 % MLSS with a centrifuge. Instead of the normal flocculent agent demand of up to 3 kg per kg MLSS, only 0,5 kg are used in this process. Compared with a sludge thickening by using only centrifuges, this means a reduction of more than 50 %. In addition, the centrate from the sludge dewatering is lead through the flotation to use the remaining high concentration of flocculent agents. As a result of this, the whole centrate that is returned to waste water treatment contains only few flocculent agents. With the aid of this process, the negative influence of the flocculent agent in the centrate from the sludge treatment could be eliminated.

For thickening the mixture of 380 $m^3 \cdot h^{-1}$ excess sludge and 200 $m^3 \cdot h^{-1}$centrate, a flotation unit is used with a clarification area of 140 m^2 and a volume of 420 m^3. Operating the pressure water supply with a differential pressure of 5 bar, the pressure water amount is only 30 % of the influent. The sludge from the flotation is thickened in the second step with a centrifuge with a capacity of 80 $m^3 \cdot h^{-1}$.

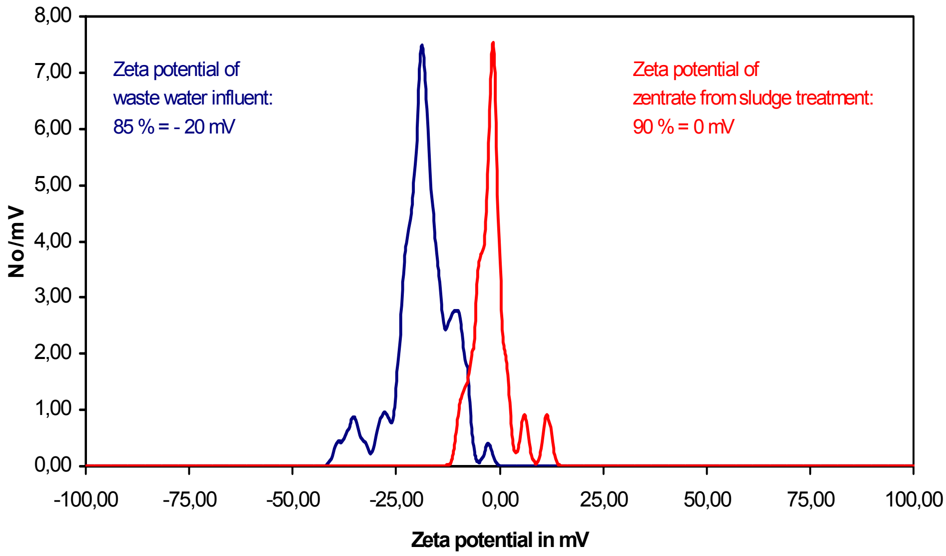

Figure 6: Zeta potential of solids and activated sludge in waste water and centrate from sludge treatment

CONCLUSIONS

It has to be pointed out that for a successful use of mechanical separation processes in waste water treatment plants; knowledge of the sludge properties is of decisive importance. The most important properties concerning separation processes are beside size, shape and density of the particles their ability to deform, the solidity of their cell membranes and the properties of their boundary surface. In this case, the electrical surface charges of the particles and microorganisms have to be considered specifically.

The authors found out that the determination of the electrical surface charge of the sludge particles, which can be measured by the Zeta Potential, is a suitable method. This presented tool helps to build high performance solids/liquids separation plants, or it helps to upgrade existing plants. On the one hand, this tool allows investigating the different influences on the sludge properties. And on the other, the performance of precipitation and flocculation agents can be optimized for each process.

Microorganisms behave like other solids in an electrolytic liquid and, therefore, in waste water. Owing to the structure of their cell walls, they dispose of a greater or lesser electric charge, which has a direct effect on their natural flocculation properties. The electrical surface charge of the microorganisms is caused largely by amino, carboxyl and phosphorus diester groups. Furthermore, the slime capsules of bacteria from polysaccharides show the electrochemical reaction of a protein. In the investigations, the equipment used was a PC-supported microelectrophoresis instrument, model Pen Kem 501, with which the Zeta Potential can be read off directly. This measurement device consists of a measurement chamber, laser, microscope, digital camera and personal computer.

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Finally, it can be pointed out that the measurement of the Zeta Potential helps to get a better understanding of the processes influencing the sludge properties and, as a result of this, the performance of waste water treatment plants can be increased.

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