Rheological properties of selected polyelectrolyte aqueous solutions for dewatering sewage sludge

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In many industrial processes it is necessary to separate the solid phase from the liquid phase. The separation process can be found in many fields, including those related to chemical engineering, environmental engineering, and the processing of minerals. Thickening and dewatering are among the basic processes that lead to a reduction in the volume of sludge, in turn changing its consistency, and thus creating the possibility of its transport, use, storage or processing. Sewage sludge is a substance from which it is difficult for water to be released. Without its pretreatment and conditioning, dehydration effects and the degree of phase separation are very low. An improvement of the efficiency of the process can be achieved through the use of chemicals that contribute to the aggregation of sludge particles (combining smaller particles into larger ones). Aggregation can be based on two distinct phenomena, which are called coagulation and flocculation. Flocculation is the process of combining single dispersed particles of the solid phase after the introduction of high-molecular organic compounds into the suspension, which then adsorb simultaneously on the surface of several particles (Hurt, 2018). Coagulation involves the introduction of counterions (usually trivalent metal ions, e.g. Fe^{3+}, Al^{3+}) into the suspension in order to neutralize the surface charge of the particles, and thus eliminate the electrostatic force that repels the particles from themselves. Polyelectrolytes are used in the process of treating drinking water, in the process of water recycling, in industrial wastewater treatment, and for the dewatering of flotation and biological sludge (Hyrycz et al., 2022).

In dewatering and thickening processes, appropriately selected types and doses of conditioning agents such as polyelectrolytes (flocculants) are used to improve the ability of sludge to release water [1]. Polymer compounds of natural or synthetic origin are used. The raw materials for the production of natural polyelectrolytes are, e.g. starch, cellulose, and gelatin. The following are used for the production of synthetic polyelectrolytes: polyethylene oxide, polyacrylic acids, and polyacrylamides. The rheological properties of the used polyelectrolyte solutions are very important in the sludge flocculation process. It is necessary to achieve an even distribution of polyelectrolyte chains throughout the sludge's volume in the shortest possible time with the use of intensive mixing. This prevents excessive local adsorption of chains, thanks to which it is possible to reduce the flocculant dose without decreasing the efficiency of the process. Polyelectrolytes in the form of a concentrate are characterized by having a very high viscosity, and their chains can be destroyed as a result of too intensive mixing. Due to the high viscosity, proper mixing of the concentrated flocculant with the sludge may be impossible, and therefore in practice high dilutions are used. Aggregates of solid particles, which are formed as a result of flocculation, may also be mechanically damaged during transport to drainage devices, or in the devices themselves. The strength of flocs depends on the properties of the sludge, and also on the used polyelectrolyte and its dose. The mechanical destruction of flocs causes a decrease in separation efficiency, and therefore a deterioration in the quality of the leachates and the sludge cake. Flocculant solutions that are too viscous cause an excessive exploitation of pumps, and an increased consumption of the electricity used for their pumping. In addition, the high viscosity of flocculant solutions adversely affects the mixing of polymer chains with sludge particles, and may also cause mechanical destruction of the flocs during transport (Fryzlewicz-Kozak et al., 2015; Maciejewska, 2022).

The aim of this work was to investigate the rheological properties of selected polyelectrolytes. Cationic polyacrylamide (Zetag 8187) from Solenis Company, and a water-soluble cationic polymer (polyelectrolyte F 7055) from SNF Company [4] were tested. The rheological properties of polyelectrolyte aqueous solutions were tested in the plate-cone system using the MCR-501 rheometer from Anton Paar GmbH Company (Germany). On the basis of the obtained results, curves of the dependency between the shear stresses and shear rate were plotted for the polyelectrolyte F 7055 (Figure 1a) and polyelectrolyte Zetag 8187 (Figure 1b). The tests were carried out for a concentration of polyelectrolyte in water ranging from 0.2 to 0.6%, and for shear rates from 10 to 1000 1/s.
It was noticed that with an increasing polyelectrolyte concentration in the solution, the features of non-Newtonian fluids appear. The values of the flow coefficients decrease, which at higher polyelectrolyte concentrations means that the Ostwald de Waele model of the following form should be applied:

$$\tau = k \cdot \dot{\gamma}^n \qquad (1)$$

where: k is the experimentally determined rheological parameter, and n is the flow coefficient. Table 1 presents the values of the k and n coefficients for various concentrations of polyelectrolytes.

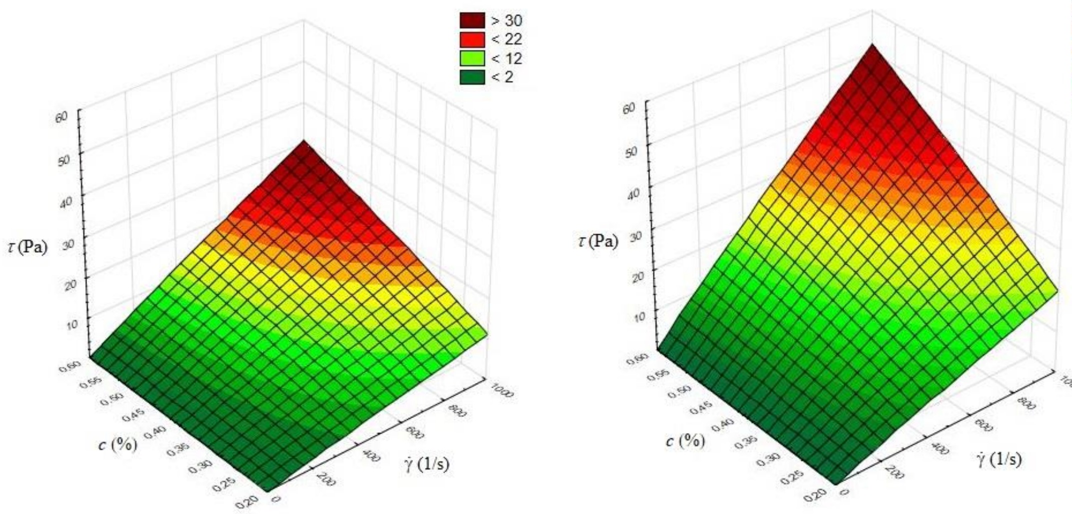

Figure 1. Relationship between the shear stresses, shear rate and polyelectrolyte concentration: a) F7055, b) Zetag 8187.

Table 1. Consistency and flow coefficients of polyelectrolytes.

Concentration (%)	F 7055		Zetag 8187	
	k (Pa · s^n)	n (-)	k (Pa · s^n)	n (-)
0.2	0.012345	0.98	0.025588	0.96
0.3	0.021019	0.97	0.042545	0.95
0.4	0.027218	0.97	0.050458	0.95
0.5	0.03234	0.96	0.062886	0.95
0.6	0.04094	0.96	0.073609	0.95

On the basis of the obtained data, it was found that the tested solutions of the polyelectrolyte F 7055 exhibit properties of Newtonian fluids (values of flow coefficients $n > 0.98$) at low concentrations, and non-Newtonian fluids at higher polyelectrolyte concentrations in the solution. Zetag 8187 solutions are closer to non-Newtonian fluids. An increasing concentration of the polyelectrolyte causes an increase in viscosity (Maciejewska, 2022). Aqueous solutions of the Zetag 8187 polyelectrolyte were characterized by higher viscosity values when compared to the F 7055 solutions at the same concentration, which may affect the efficiency of mixing with sewage sludge. In order to achieve a high mixing and flocculation efficiency, the concentration of Zetag 8187 solution should be lower when compared to the concentration of F 7055.

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