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Influence of static magnetic field on sludge properties

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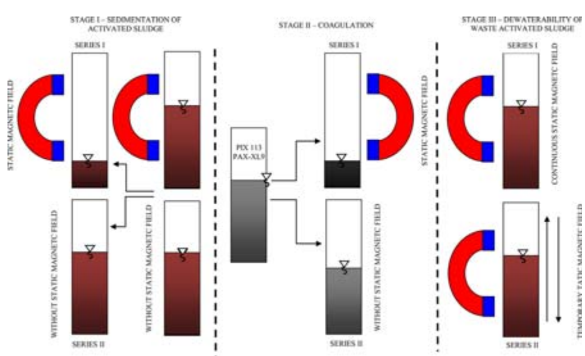
HIGHLIGHTS

- Static magnetic field enhanced sedimentation by limiting filamentous bacteria length
- Increased coagulation under static magnetic field with aluminum-based coagulant
- Static magnetic field did not increased coagulation with iron-based coagulant.
- Capillary suction time was significantly shorter under static magnetic field.

GRAPHICAL ABSTRACT



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ABSTRACT

The study investigated the influence of static magnetic field on sedimentation of activated sludge, coagulation efficiency in the bioreactors and dewaterability of the sludge. The sedimentation was improved when magnetizers were applied on the bioreactor and on the settling tank. The application of magnetizers only on the settling tank decreased the sedimentation properties of the sludge. The filamentous bacteria Type 0092 dominated in both bioreactors, but the significant differences were observed in its length. No effect of the static magnetic field on coagulation with the utilization of iron-based coagulant was observed. However, the static magnetic field enhanced coagulation with the utilization of aluminum-based coagulant. The results suggest that increased sedimentation of colloids and activated sludge, can in practice mean a reduction in the size of the necessary equipment for sedimentation with an unchanged efficiency of the process. Moreover, static magnetic field significantly reduced the COD concentration in filtrate and shorted capillary suction time during the dewaterability of waste activated sludge.

1. Introduction

Due to constantly increasing volume of produced wastewater, differences of its composition and properties, a steady evolution and development in the methods used for wastewater treatment can be observed, nevertheless effective and economically viable methods are still sought. An alternative assistive method for wastewater treatment can be technique based on the use of physical factor that is a static magnetic field (SMF) (Krzemieniewski et al., 2012; Zieliński et al., 2017).

Static magnetic field is generated typically by the use of the permanent magnets with magnetic stacks. The magnetic field causes modifications of the properties of solutions that result from changes in the molecular structure of liquids, polarization and arrangement of particles, and finally from changes of the electric potential (Krzemieniewski et al., 2004). The high induction of magnetic field has an effect on such properties of liquids as: surface tension, density, viscosity, light extinction and wettability of solid substances. The phenomenon of effective penetration of the atmospheric oxygen into the solutions pretreated with the

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magnetic field was also observed (Rusanowska et al., 2017). This might be advantageous due to most of microorganisms degrading organic compounds are aerobic. Thus, in the magnetized liquids, with increased oxygen concentration, bacteria growth rate and biodegradation of organic matter is higher (Zieliński et al., 2017).

Magnetizers are characterized by simple design. The greatest advantage of magnetizers' application is the lack of need to supply in any form of energy and that the intensity of the magnetic field induction is not weakened over time (Hattori et al., 2001). For these reasons such devices can be operated efficiently over many years. Moreover, magnetizers can be used in technological system without the need of adaptation period (Krzemieniewski et al., 2012).

The use of SMF in technology of wastewater treatment and sludge management has so far been widely described in the literature. In recent studies, it was proved that magnetic field exerts a positive effect on wastewater treatment. This effect depends on the intensity and frequency of the field, the static or oscillating character of the field, the wave form, the type of exposed cells and the condition of these cells (Dini and Abbro, 2005; Yadollahpour et al., 2014). Jung et al. (1993) reported that magnetic field with a strength of 9 mT did not have any effect on phenol biodegradation, magnetic field with a strength of 17.8 mT had a positive effect, while magnetic field of about 54 mT lowered the removal efficiency and growth of microorganisms. Magnetic fields with inductions of 150 mT and 350 mT improved phenol biodegradation by immobilized activated sludge (Jung and Sofer, 1997). Okuno et al. (1993) also proved that magnetic field is not lethal to microorganisms but might influence a growth rate of bacteria. SMF exerts also a positive effect on many properties of fluids, i.e. it changes the polarization and electric charge and set the particles. By these effects SMF also influence on sedimentation during the wastewater treatment. In other study authors observed enhanced separation of activated sludge from wastewater under SMF (Zieliński et al., 2014). The sedimentation of activated sludge strictly depends on the filamentous bacteria in the flocs. Although the presence of a certain number of filaments is important for proper floc formation, the occurrence of large filamentous bacterial populations is detrimental for wastewater treatment as it causes foam formation or settling problems of the activated sludge in the secondary settling tanks (bulking).

In the study, it was assumed that due to the possibility of acceleration of the coagulation by the influence of SMF, it would be possible to obtain better dewaterability of the sludge. Taking into account the fact that sludge consist mainly from water with suspended solids (organic and mineral components), it can be assumed that particles in SMF will behave like water. The influence of SMF on the sludge should therefore change its molecular structure and might lead to greater dispersion of the system. As a consequence, it should reduce the utilization of chemicals used to treat waste activated sludge, which entails a reduction in the cost of purchasing equipment for the disintegration and dispensing of these chemicals. Recently, the data about sludge dewaterability with chemicals and SMF can be found in the literature, but there is only few information about only pretreatment with SMF on the waste activated sludge.

The study investigated the influence of static magnetic field on sedimentation of activated sludge. Due to filamentous bacteria determine floc structure and sedimentation properties of sludge, the identification of filamentous bacteria was done during this process. The coagulation efficiency with the aluminum and iron-based coagulants in the bioreactors operated under SMF was examined. In last stage of the study, the investigation of the continuous and temporary magnetic field influence on waste activated sludge dewaterability was described. The study also summarized previous author's results about this processes.

2. Materials and methods

2.1. Organization of the study

The studies were carried out on a laboratory scale in three stages. In the stage 1, influence of SMF on the presence of filamentous microorganisms and sludge sedimentation in the secondary settling tank was investigated. In the stage 2, effect of SMF on coagulation was observed. In the stage 3, effect of SMF on the dewaterability of the waste activated sludge. The wastewater used in experiments was a model of dairy wastewater obtained by dissolving skimmed milk powder in tap water. The wastewater was characterized by chemical oxygen demand (COD) of 4181 ± 890 mg O_2/dm^3, pH of 4.8 ± 0.2 and temperature 20.2 ± 1.2 °C. The inoculum used in the study was activated sludge obtained from a municipal wastewater treatment plant in Olsztyn, Poland.

2.2. Experiments in stage 1

The experiments were carried out in two activated sludge bioreactors (volume 4.5 dm^3); one bioreactor was exposed to SMF (series 1) and second bioreactor was not exposed to SMF (series 2 - control). The magnetic field induction decreased along with the distance from the bioreactor walls. At a distance of about 4 cm from the bioreactor wall, the induction decreased by about 85%. In the center of the bioreactor magnetic field was about 1.6 mT. The hydraulic retention time was 22.5 d and the organic compounds loading was 0.15 g COD/(g TSS·d). The concentration of oxygen in the bioreactors was 3.5 mg O_2/dm^3. Raw wastewater was pumped to the bioreactors from the retention tank. In the both series, a mixture of the activated sludge and the effluent from the bioreactor was directed to the two secondary radial settling tanks (volume 0.04 dm^3, surface 0.02 dm^2, operating height 2 dm) - one with magnetizers placed on tank (variant 1) and second one without magnetizers placed on tank (variant 2). The hydraulic loading in secondary settling tanks was 10 $dm^3/(dm^2 \cdot h)$. The sedimentation time was 0.5 h. The biomass for filamentous bacteria determination from bioreactors was collected and the identification was done within 3 h.

The magnetizers were placed directly on the circumferences of the bioreactor and secondary settling tank. The magnetizers were built of two parts forming a ring. In order to increase the direct impact of SMF, a set consisting of two rings were placed on the bioreactors. The magnetizers had width of the ring of 65 mm, height of the individual ceramic magnet of 45 mm, weight of the individual ring of 1.25 kg, and nominal diameter range of 90–110 mm. The maximal induction of SMF was 6000 G (0.6 T).

2.3. Experiments in stage 2

Effect of SMF on coagulation was observed in the two reactors, one with magnetizers placed on the reactor (series 1) and one without magnetizers placed on the reactor (series 2 – control). The reactors had volume of 1 dm^3, surface of 0.7 dm^2 and height of 1.4 dm. Two inorganic coagulants were dosed to the reactors: an iron-based coagulant named PIX 113 (variant 1) and an aluminum-based coagulant named PAX - XL9 (variant 2) (Table 1). For both coagulants four doses were applied: 0.05 g/dm^3, 0.1 g/dm^3, 0.2 g/dm^3, 0.4 g/dm^3. After dosing of the coagulant to the reactor, 5 min of rapid stirring (200 rpm), 20 min of slow stirring (30 rpm) and 120 min of sedimentation took place.

In this stage of the study, SMF was provided by the use of permanent neodymium magnets (diameter of 0.7 dm, height of 0.02 dm). The energy density of magnetic field was 0.286–0.302 kJ/dm^3. The induction of

Table 1
Characteristic of the coagulants.

PIX 113	PAX - XL9
Total Fe 11.8 ± 0.4%	Al_2O_3 8.5 ± 0.4%
Fe^{2+} 0.4 ± 0.3%	Al_2 4.5 ± 0.2
pH < 1	Chlorides 10.0 ± 1.0%
	pH 3.0 ± 0.6%