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Short communication

The modified swirl sedimentation tanks for water purification

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ABSTRACT

This paper discusses design, evaluation, and application for the use of swirl/vortex technologies as liquid purification system. A study was performed using modified swirl sedimentation tanks. The vortex separators (OW, OWK, OWR and OWKR) have been studied under laboratory conditions at liquid flow rate from $2.8 \cdot 10^{-5}$ to $5.1 \cdot 10^{-4}$ [m^3/s]. The pressure drop and the efficiency of purification of liquid stream were analyzed. The suspended particles of different diameters were successfully removed from liquid with the application of swirl chambers of proposed constructions. It was found that damming of liquid in the tank increases alongside liquid stream at the inlet and depends on the tank construction. The efficiency of the sedimentation tanks increases alongside the diameters of solid particles and decrease in the liquid flow rate. The best construction proved to be the OWR sedimentation tank due to smallest liquid damming, even at high flow rates, and the highest efficiency of the purification liquid stream for solid particles of the smallest diameter. The proposed solution is an alternative to the classical constructions of sedimentation tanks.

1. Introduction

Technological advancements, economic and industrial growth as well as the related high level of industrialization, all favor the increase of quality of life, in particular of human civilization needs. The recurring emergence of new technologies gives rise to significant amounts of contaminants that mix with waste water and in turn lead to disruptions in water management and environmental sustainability (Simate, 2015). An important issue appears to be surface water purification, allowing for its further use to ensure adequate conditions for human life and also for industrial purposes. For this reason, numerous modernization works in sewage treatment plants and water purification stations are being now conducted in Poland and other countries (Cywiński et al., 1972; Kowal and Świderska-Bróż, 2000; Bień and Wystalska, 2011). Simpler water purification constructions, such as sedimentation tank systems, are also being developed with the aim of increasing their number in urban areas and improving their purification capabilities while saving space required for their installation (Field and O'Connor, 1996; Weib, 1997). Pre-treatment of suspensions, enabling their further processing and use, forms the basis for sewage waste management (Mołoniewicz et al., 1979). The sedimentation plays an important role in the removal of sediments (Simate, 2015; Chhetri et al., 2016). By implementing the technique of sedimentation it is possible, through the simple construction of the sedimentation tank, separate contaminated liquid from solid particles at a relatively low cost (conventional clarifiers, enhanced gravity separators and lamella gravity settlers) (Bandrowski et al., 1995; Field and O'Connor, 1996; Davidson and Summerfelt, 2005a; Patziger et al., 2012; Tarpagkou and Pantokratoras, 2014; Liu et al., 2015; Chhetri et al., 2016). Such technical solutions are currently all the more preferred since they do not require the application of complicated constructions, or the use of materials that are rare or difficult to access. The use of sedimentation tanks in such a wide environmental range is possible due to their simple construction and easy operation (Bandrowski et al., 1995; Liu et al., 2015). The tanks are widely used, among others, in ground water and surface water purification systems, for chemically enhanced primary treatment of sewage, highway runoff treatment (removing particles and metals) and wastewater treatment (Field and O'Connor, 1996; Davidson and Summerfelt, 2005a; Li et al., 2008; Hreiz et al., 2015). These devices can be operated in the periodic, semi-continuous or continuous mode (Anielak, 2000; O'Doherty et al., 2009). Detailed classification and description of the settlers

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are shown in articles (Heidrich and Witkowski, 2005; Królikowska, 2011).

The measure of effectiveness of sedimentation tanks is the content of solids in the water after the sedimentation process (Field and O'Connor, 1996; Luyckx and Berlamont, 2004; Weib, 1997). Sedimentation efficiency η depends on the type of sedimenting particles and duration of the process, and is referred to as (Kuropka, 1988; Weib, 1997):

$$\eta = \frac{m_z}{m_0} \cdot 100\% \quad (1)$$

where:

m_z – mass of the solid retained in the sedimentation tank, [kg],
m_0 – mass of the solid in the water at the inlet to the sedimentation tank, [kg].

Swirl sedimentation tanks offered by many of companies (EcoTech Sp. z o.o. Sp. k., 2016; Pur Aqua System Sp. z o.o., 2016) in the market are designed to collect solid contaminants, sludge, slurries resulting from rainwater and snowmelt, as well as technological wastewater flowing gravitationally through sewers. The tanks prove to be the appropriate solution for urban areas where devices with high efficiency and relatively small dimensions are required. Their construction results in highly efficient separation of suspensions at heavy hydraulic loads (Mołoniewicz et al., 1979; Egarr et al., 2009). Sometimes a small changes in separator design contribute to the improvement of the efficiency of purification of liquid stream, for example Davidson and Summerfelt (2005a, 2005b) showed that a radial-flow settler was found to provide approximately twice the solids removal efficiency of a swirl separator of identical size and surface-loading rate.

The swirl cylindrical separators with a conical base were studied by Veerapen et al. (2005). The authors showed that tank height and the position of the inlet have a minor influence on separation performance compared to outlet geometry, inlet diameter and tank diameter. It was also shown that solids separation is mainly due to gravity rather than centrifugal forces. The centrifugal forces was too small. Swirl dimension tanks are, in principle, highly efficient purificators, have smaller installation area as compared to other tanks, offer the possibility of placing the inlet at any angle (which facilitates connection to the sewage system) as well as easy operation (EcoTech Sp. z o.o. Sp. k., 2016; Pur Aqua System Sp. z o.o., 2016).

2. Experimental

The aim of this paper was to construct and experimentally determine the efficiency of purifying water from solid contaminants in single-chamber swirl sedimentation tanks. The influence of tank construction and the volumetric flow rate of liquid on the efficiency of purification from model solid particles of different diameters was studied. Additionally, liquid damming in the studied constructions of swirl sedimentation tanks was also discussed.

The main items of experimental equipment (Fig. 1) were the studied swirl sedimentation tanks, VA-40 liquid flow meter delivered by Krohne Messtechnik GmbH&Co KG, a Center 309 multipoint electronic thermometer by Center, a Grundfos CHI 2–30 rotary pump, digital laboratory scale, Casio Exilim HS EX-F1 digital camera and PC computer. The camera was used for visualization of flow inside the sedimentation tanks.

The tested constructions of swirl sedimentation tanks are shown in Fig. 2. Experimental studies were conducted on four cylindrical, swirl sedimentation tanks with the internal diameter of 0.19 m and a total height of 0.65 m. Active height of the device was 0.4 m. The tanks differed in design of their inlet and outlet. The inlet and outlet had a diameter of 0.032 m. The following sedimentation

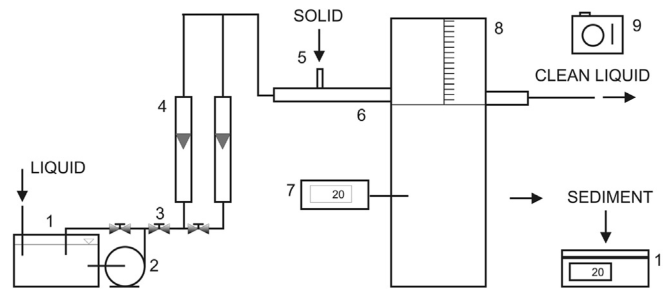

Fig. 1. Experimental set-up:
1–tank, 2–pump, 3–valves, 4–rotameters, 5–inlet port for solid, 6–entrance region, 7–thermometer, 8–swirl sedimentation tank, 9–camera, 10–scale.

tanks were studied: standard swirl sedimentation tank (OW), swirl sedimentation tank with a directional elbow (OWK), swirl sedimentation settler with a profiled pipe (OWR) and the swirl sedimentation tank with a directional elbow and reversed outlet (OWKR). The inlet was positioned at 0.4 m from the bottom of the device. All the tanks with a directional elbow had their inlet tube ended with the elbow bent at the horizontal angle of 45° and vertical angle of approx. 30°. In the OWR tank, the inlet pipe of the tank axis is directed vertically downward (length 0.1 m) and is ended with the above-mentioned elbow. The contaminated stream (containing the predetermined fraction of solids) was administered into the tank with the inlet marked grey in Fig. 1. The purified liquid stream left the tank through the outlet (marked white) located in the axis of the device. The values measured were: diameters of solid grains, mass of the solid entering the liquid stream and exiting the tank, volumetric liquid stream ($\dot{V}$), water damming (ΔH) and temperature of the process.

The research material consisted of sands from the area of Mielno, near Koszalin. The contaminants were coastal beach sands with well-rounded grains. Their characteristics was demonstrated in the earlier paper (Ochowiak et al., 2016). The sand dried in a laboratory drying oven at temperature 90 °C. The sand sieve analysis was performed using a set of sieves and the sieve shaker "Retsch AS 200". The precision scales "Radwag PS210/C/2" with the accuracy of +/−0,001 g was used to measure the suspension mass.

The choice of sedimentation tank is made primarily on the basis of the place of application of the device, as well as the type of suspensions and substances that are to be separated in the process of sedimentation (Bandrowski et al., 1995). Into account taken should be physical and chemical parameters, such as viscosity and density, disperse and dispersing phases along with their volume, hydration of the solid, impact of porosity and the rate of descent in terms of the volume of suspension storage and cardinality of removing suspensions from the sedimentation tank (Ciborowski, 1973; Mołoniewicz et al., 1979; Davidson and Summerfelt, 2005a; O'Doherty et al., 2009). In addition, determined should be the appropriate, mean size parameters for solid particles retained at the bottom of the tank, such as density and hydraulic diameters (Li et al., 2008; Egarr et al., 2009; O'Doherty et al., 2009; EcoTech Sp. z o.o. Sp. k., 2016; Pur Aqua System Sp. z o.o., 2016). It should be known that the sedimentation techniques will not remove the fine particles from the water. This is because fine particles (with diameters under 30 μm) have low settling velocities that make gravitational removal methods impractical. Assessment of the efficiency of the sedimentation tanks was conducted for the predetermined fractions of suspension with grain diameters of 125, 175, 250 i 400 μm. The tests were carried out within the range of the volumetric water stream from $2{,}8 \cdot 10^{-5}$ to $5{,}1 \cdot 10^{-4}$ [m^3/s]. The liquid temperature was 20 °C. The data obtained were processed and analyzed statistically using Statistica 12 software (StatSoft Inc.).