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Research article

Water consumption management in polyethylene terephthalate (PET) bottles washing process via wastewater pretreatment and reuse

Beata Jabłońska

Czestochowa University of Technology, Faculty of Infrastructure and Environment, Institute of Environmental Engineering, Brzeźnicka St. 60a, 42-200 Częstochowa, Poland

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ABSTRACT

The increasing recycling of polyethylene terephthalate (PET) bottles requires more and more fresh water during washing the bottles. The post-washing wastewater is often treated as effluent, whereas it could be reused in the technological process after appropriate pretreatment. In this paper, coagulation together with flocculation is proposed for use in the pretreatment of the wastewater arising during PET bottles washing. Five flocculants and six coagulants were tested. The turbidity and total organic carbon (TOC) were reduced by up to 98% and 69%, respectively. Out of the tested flocculants, Praestol 611 BC at a dose of 2 mg/dm^3 had the best performances. The best coagulant in TOC reduction was PIX-123. As for turbidity reduction, ALS was the best, but PIX-123 was comparable, and therefore, PIX-123 was indicated as most suitable in simultaneous reduction of TOC and turbidity. The coagulation and flocculation together reduced the amount of pollutants and contaminants in the post-washing wastewater to the levels allowing the water to be reused in the washing process, which could bring both economical and ecological benefits.

1. Introduction

Washing PET bottles and other plastics during recycling requires extensive water demand. Currently, most of plants for plastics recycling use fresh water for this purpose, and generates significant amounts of wastewater. World literature scarcely mentions the amount of water consumed in the process of PET recycling. According to a study by Santos et al. (2005) on PET flakes washing, 3 kg flakes require about 80 dm^3 of water (5 min × 16 dm^3/min). Perugini et al. (2005) gives a value of 3.48 kg of water per 1 kg of recycled PET is used in mechanical recycling of plastic wastes. According to Kozanda (2012), one of plants recycling plastics used 3500 m^3 of fresh water per month during production of foils and plastic bags from plastic wastes in 2011. The required large amounts of fresh water for PET bottles/flakes washing are also caused by the growing PET bottles production and recycling. Based on the latest reports by EPRO (2016) and NAPCOR (2016), the amount of global PET bottles production in 2015 can be roughly estimated to 20 Mt, of which in average around 30% was recycled. According to Waste Framework Directive (2008), by 2020 the reuse and recycling percentage in EU should be at least 50%.

Sustainable management of water resources, as well as greater demand for drinking water have forced more and more frequent use of water recycling in many industrial installations (Hu et al., 2014; Woźniak, 2014; Vajnhandl and Volmajer Valh, 2014). In the world, a variety of systems are used for effluent and recycled water pretreatment, based on coagulation (e.g. Girczys and Caban-Pabian, 1999), ion exchange (e.g. Pidou et al., 2008; Haroon et al., 2013), membrane ultrafiltration (Loganathan et al., 2015), adsorption (e.g. Almukhtar and Ageena, 2012), flotation (e.g. Zaneti et al., 2012), reverse osmosis (e.g. Shannon et al., 2008; Haroon et al., 2013), membrane bioreactors (e.g. Boluarte et al., 2016), and photocatalytic treatment technology under artificial and solar illumination (Tsoumachidou et al., 2017). There are also attempts of multi-stage treatment of municipal wastewater, and the obtained secondary water is proposed to be reused, for example, to supply steam turbine boilers in power plants (Katsoyiannis et al., 2017). Water reuse in technological processes often requires introducing new technologies for wastewater treatment and using closed water circuits (Bixio et al., 2006; Güyer et al., 2016). Although it increases the initial costs, water recycling brings both ecological and economical benefits in the end. Consequently, this allows the plants to minimize the amount of wastewater generated, as well as reduce the amount of drinking water consumed by up to 50 ÷ 60% (e.g. Malarski, 2014; Ozturk et al., 2016). Hence, it seems reasonable to reuse water also in technological processes of PET bottles washing.

Abbreviations: AS, anionic surfactants; BOD, biological oxygen demand; BOD_5, 5 days BOD; COD, chemical oxygen demand; PEE, petroleum ether extractables; PET, polyethylene terephthalate; TOC, total organic carbon; TP, total phosphorus; TSS, total suspended solids

E-mail address: bjablonska@is.pcz.czest.pl.

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Apart from ecological and economical questions there are also legal ones. Industrial plants using fresh water in technological processes are subject to increasingly stringent regulations on environmental protection. Europe has not uniform legal requirements or guidelines for recycled water quality (Bożek et al., 2013). There are, however, many legislation acts supporting the idea of reuse of treated wastewater, e.g. Council Directive 91/271/EEC, which clearly indicates the necessity of reusing the wastewater where it is expedient. The criteria which should be taken into account when determining the permissible values for particular pollutants and contaminants are published by both US EPA and WHO – e.g. U.S. EPA (2012), WHO (2006). In 2003–2006 in Europe, AQUAREC project developed a model for estimating the reuse of water in the European Union. This model predicts that by 2025 the annual amount of reused wastewater in Europe will reach 3222 million m^3. This project was also an attempt to systematize the guidelines and standards for the renewed water (AQUAREC, 2006; Bożek et al., 2013). In most countries, the quality of the renewed water depends on the purpose of the water, and every branch of industry has specific quality requirements with regard to water to ensure suitable quality of the final product.

Another question is the selection of method used in wastewater pretreatment. The method must be inexpensive, easy to implement, and should take into account specific properties of the wastewater. Wastewater treatment methods can be divided into mechanical, physicochemical, chemical and biological. Mechanical methods would not fulfill their role well, as the wastewater is already partially mechanically purified due to gravity sedimentation, and filtration-based methods could be applied to sewage already pretreated with other methods. The composition of wastewater from the process of recycling waste plastics is very diverse and heterogeneous, because apart from detergents containing surfactants they also include soaps, natural oils, a large amount of suspended matter, salts, fats, and others. Such wastewaters are characterized by a high content of organic compounds and specific substances, which are hardly biodegradable or even toxic in many cases; therefore, the use of biological methods is limited. The commonly used methods in industrial wastewater treatment are coagulation and flocculation, which enable reduction in the number of indicators, mainly: turbidity, color, TSS, TOC, COD, TP and others (Domopoulou et al., 2015; Birjandi et al., 2016). They belong to primary processes in wastewater treatment and recycling because of their high effectiveness and simplicity (Parsons and Jefferson, 2006). They do not require as stable conditions as biological methods and allow for quick response to changes in process parameters. They also do not require complicated devices and high financial expenses, such as oxidation does, for example (Gupta et al., 2012). In the coagulation of wastewater, a coagulant is usually introduced, during hydrolysis of which insoluble colloidal particles charged oppositely to the colloids polluting the wastewater are produced. The effectiveness of hydrolyzing coagulants depends on the pH of the wastewater, temperature, contact time, gradient of wastewater movement velocity, and other factors. The coagulation of wastewater is frequently used with polyelectrolytes aiding the flocculation process. Therefore, coagulation together with flocculation can be expected to be effective in the pretreatment of PET bottles post-washing wastewater.

The aim of the study was to determine if coagulation together with flocculation can be used for pretreatment of wastewater from PET bottles/flakes post-washing in order to reuse the water in the next cycle of washing. Various coagulants and flocculants were tested to find out the most suitable values for operational parameters. The influence of pH of wastewater and various aluminum and iron coagulants on the quality of treated wastewater was tested and some economic aspects were considered.

2. Materials and methods

2.1. Materials

The research was carried out on real wastewater taken from one of the companies recycling PET bottles in the European Union. The company processes used PET bottles in full value granules (so called rPET), used later for the thermoplastic production of new bottles and many secondary textile products, like carpet bottoms, sleeping bags, pillows, insulation materials and textile fibers. It is worth mentioning that the use such fibers will increase in the coming years (Telli and Özdil, 2013; Telli and Özdil, 2015), generating the demand for rPET and increasing the water use. The company recycles about 2000 Mg of plastic waste per month, which indicates that it consumes about 7 thousand m^3 of water per month. The study used the wastewater after the process of PET bottles washing. Flakes produced during grinding the bottles in a mill are washed with detergents at 90 °C, which allows removing the dirt, glue, natural oils, paper and other impurities. After the washing process, the wastewater is directed to the tank with a reservoir of phosphoric acid in order to optimize pH. The wastewater for the research was taken from the pretreatment installation after changing pH from strongly alkaline to neutral. During the study period, the PET recycling plant used anionic detergents.

Five types of flocculants (Table 1) and six types of coagulants (Table 2) were used in the research. The flocculants were as follows: strongly cationic (Praestol 658 BC-S by Ashland), weakly cationic (Praestol 611 BC by Klimapol), weakly anionic (Praestol 2515 by Klimapol), medium anionic (Praestol 2440 by Klimapol) and non-ionic (Praestol 2500 by Klimapol). Two types of coagulants were aluminum-based – aluminum sulfate (ALS) and polyaluminum chloride (PAX 18) – and four types were iron-based – ferric sulfate (PIX 123, PIX 113), ferric chloride (PIX 111) and ferric chloride sulfate $FeClSO_4$ (PIX 110). The coagulants are produced by the Kemipol Ltd. chemical plant in the form of aqueous solutions.

2.2. Experiments and methods

In the first stage of the study, the type and volume of sediment during sedimentation – natural and aided with coagulation and flocculation – were determined. The measurements consisted in determining the sediment volume of easy falling settleable solids per 1 cm^3 of wastewater in Imhoff cone after 15, 30, 60, 90, 120, 180 and 240 min at natural pH and constant temperature of 20 °C. In addition, the natural and coagulation/flocculation aided sedimentation was also determined for pH ranging from 2 to 12. The pH adjustment was performed with use of H_2SO_4 and CaO prepared as milk of lime (5% aqueous calcium suspension). In these studies, the coagulant and flocculant used were PIX 123 at a dose of 3.5 g/dm^3 and Praestol 611 BC at a dose of 2 mg/dm^3, respectively. The reagents and their doses were established based on preliminary tests.

The next stage was to select the most appropriate flocculant. In order to determine the most favorable dose of these reagents, their solutions at a concentration of 0.1% were prepared and added to the

Table 1
Characterization of the tested flocculants (according to material safety data sheets).

Parameter	Praestol 611 BC	Praestol 658 BC-S	Praestol 2440	Praestol 2500	Praestol 2515
Ionic activity	Weakly cationic	Strongly cationic	Medium anionic	Non-ionic	Weakly anionic
Density, g/cm^3	0.65	0.65	0.7	0.65	0.7
pH activity range	1 ÷ 14	1 ÷ 10	6 ÷ 13	1 ÷ 7	3 ÷ 8