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Post-coagulation sludge management for water and wastewater treatment with focus on limiting its impact on the environment

Ewelina ŁUKASIEWICZ
Opole University of Technology, Poland

Abstract: Water treatment process produces great amount of sludge. According to growing interest in sustainable development and environment protection, sludge management problem should be taken into consideration. Accordingly, its recovery, recycling and reuse are optimal solutions for Water Treatment Sludge(WTS) management. The conventional Water Treatment Plants (WTP) produce even up to 100 000 ton/year of sludge. The coagulation process produces a huge amount of sludge. This contamination may be recovered and reused. Some amount of coagulants may be recovered and reused during the wastewater treatment process. The Water Treatment Sludge with e.g. iron or alum content, may be also used as a coagulant at a wastewater treatment plant. In the course of this paper, few methods for post-coagulation sludge management are presented.

Keywords: post-coagulation sludge, sludge management, water treatment

JEL codes: Q25, Q55

1. Introduction

Water and wastewater treatment process results in the formation of various types of deposits, the utilization of which is a significant problem. The amount of sludge is variable and depends on the quantity of water or wastewater treated, the quality of its content, color intensity, doses of coagulants and many others (Szerzyna, 2013: 614).

Depending on the methods of water purification, waste products occur in the form of waste water and sewage sludge. The processes which are associated with periodical sludge formation

Correspondence Address: Ewelina Łukasiewicz, Department of Thermal Engineering and Industrial Facilities, Faculty of Mechanical Engineering , Opole University of Technology,5 Mikołajczyka Street, 45-271 Opole, Poland. Tel.: +48 774498876 E-mail: e.lukasiewicz@po.opole.pl

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include: filtration (rinsing the filter), membrane processes and ion exchange (regeneration of ion exchangers). Sludge will arise during unit operations as coagulation with aluminum or iron salts, softening the water by precipitation or removal of iron through oxidation of ferrous ions, Fe (II) to Fe (III). The greatest amount of sludge is produced during the coagulation process. The quantity, composition and properties of sludge depend on the quality and quantity of treated water, the type and dose of coagulant and process conditions (mainly mixing). Water content of post coagulation sludge depends on the type of settling tank and sludge removal frequency (Balcerzak and Luszczek, 2015: 59). It assumes values in the range between 98.5 - 99.9%. The characteristic feature of sludge and washings formed after the coagulation process with aluminum and iron salts, is that it may contain toxic metals, such as arsenic (As), barium (Ba), cadmium (Ca), chromium (Cr), nickel (Ni), lead (Pb) and zinc (Zn) (Bartoszewski, 1996). Hence, the microbiological verification of sludge composition is of great importance, as well as defining health hazards during its processing and management. When temperatures are high, post-coagulation sludge tends to putrefy, which involves the buildup of unpleasant odors (Kyncl et al., 2012: 16).

In Poland, the management of sludge produced during water purification is not clearly regulated by law. According to the classification of waste as set out in the Act of 14 December 2012 on waste, sludge generated during the treatment of water should be treated as hazardous waste. Whereas the Regulation of the Minister of Environment of 09 December 2014 on the catalog of waste, classifies sludge from water clarification (code 19 09 02) and deposits from water decarbonization (code 19 09 03) as a non-hazardous waste (Nowacka and Włodarczyk-Makuła, 2014: 36).

The main objective of this paper is to present a comprehensive review of sustainable approaches and prospective trends in sludge management.

2. Sludge management

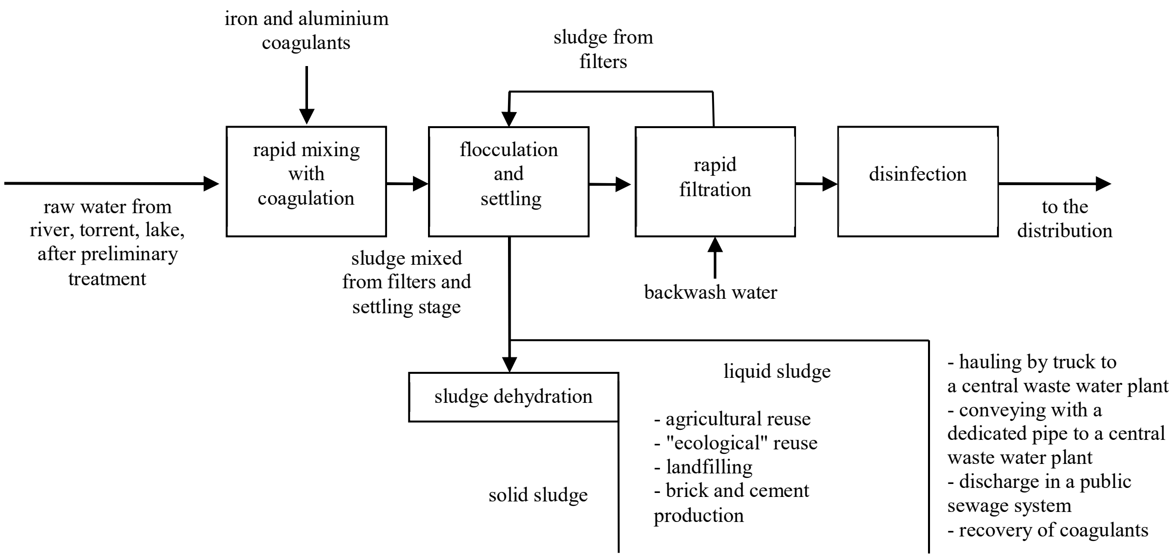
The conventional Water Treatment Plants (WTP) produce about 100 000 ton/year of sludge. On a global scale, a daily production of sludge exceeds 10 000 ton. The Water Treatment Sludge (WTS) is of environmental concern and requires careful consideration, when managed in an environmentally acceptable and sustainable manner. For example, in India the most of the WTS is disposed of on the open lands nearby to WTP. This method of final disposal is not a proper solution since the contamination of water bodies and soil from chemical products can be reused. Proper handling of residual sludge is an economic and environmentally friendly manner which remains a very important problem. The recovery, recycling and reuse is an optimal solution for WTS management (Ahmad et al., 2016: 7).

Coagulation process combined with filtration is most commonly used to remove dissolved organic carbon, iron (Fe), manganese (Mn), additives causing turbidity and color, and it can also remove heavy metals. During this process, the post-coagulation sludge and washings is formed. The reaction products may comprise from 20-92% of the solid phase of sludge. The most commonly used coagulants include salts of aluminum ($Al_2(SO_4)_3$, $AlCl(OH)_5$), iron ($Fe_2(SO_4)_3$, $FeCl_3$ and polyacrylamides $(C_3H_5NO)_n$. The polymerized aluminum coagulants, such as polyhydroxychloromethyl of aluminum or polyaluminumhydroxychloride ($Al_n(OH)_mCl_{3m-n}$) (Leszczyńska and Sozański, 2009: 578) become increasingly popular.

The possibilities of using technological waste from the WTP, mainly sludge after coagulation and washing of filters, have been studied in Poland and abroad. It has been stated that washings ferruginous as a source of large quantities of iron waste, can be used in the preparation of coagulants for wastewater treatment, but also in phthalate oxidation Fenton process and binding hydrogen sulfide formed in sewage systems, whether coming from the biogas generated during anaerobic digestion of sewage sludge or slurry. It is possible to recover coagulants from post-coagulation sludge. Specifically, iron and alum components may be utilized for wastewater treatment. Deposits could be used as a secondary raw material for the production of cement, bricks, tiles, ceramic tiles and pipes (Pasela et al., 2015: 1668). One of the methods of sludge management is the recovery ofalum salts and its reuse as a coagulant in WTP. Recovery method of alum compounds is possible with the use of sulphur acid. The aluminum hydroxide or hydrated aluminum oxide is back-transformed to aluminum sulphate in a chemical reaction. Researchers analyzed also the possibility to use WTS in other industrial sectors. Post-coagulation sludge may be employed in civil engineering, e.g. for bricks production. Iron and alum sludge may replace the clay; additionally, iron may give intensive red brick color. After being burnt, WTS forms ash with alum and silica minerals. Its addition to cement causes an increase of strength and its resistance to corrosion (Luo et al., 2008: 248).

According to Italian researchers (Verlicchi and Masotti, 2000: 69), about 15% of local population uses surface water. It can be estimated that a total annual production of wet sludge of roughly 15 000 000 m^3, after dewatering, is reduced to 750 000 ton/year. This residual is usually disposed in landfill, and the costs is approximately 50 million euro/year. It is astonishing that in the USA, France, Germany and in the Netherlands, the lime sludge from water softening and after coagulation processes is commonly used for agricultural purposes. Figure 1 depicts production and disposal of solid and liquid sludge of a surface Water Treatment Plant.

Figure 1. Production and disposal of solid and liquid sludge in a Water Treatment Plant



Source: Verlicchi and Masotti, 2000: 70.

Coagulation with a hydrolysing metal salts such as alum of ferric coagulant is an effective water treatment method, but also results in a waste of by-product, as the coagulant precipitates into particles that aggregate to form 'flocks'. Sedimentation of these flocks causes that the sludge can be thickened, centrifuged or filtered previous to the ultimate disposal. These dewatering processes decrease the volume of waste stream resulting in both environmental and financial benefits (Verrelli et al., 2009: 16).

3. The reuse of WTS for treating urban wastewater

The up flow anaerobic sludge blanket (UASB) reactor is essentially a tank with a sludge bed, where the dissolved organic matter in the wastewater is degraded. As a result of this digestion, biogas is produced. UASB are commonly used for wastewater treatment with high organic content or in the food industry. Wastewater flows from the bottom of the reactor, and at the top, biogas is collected and the effluent of treated water comes out. Above the sludge bed, a blanket zone with suspended biomass particles is being formed. This is a separation zone between the water flowing up and the suspended biomass (Gomez, 2011). Although this type of reactor produces low amount of sludge, it does not meet disposal standards, especially in relation to organic content, suspended solids, nutrients and pathogen content. Before being discharged into water bodies or reused in irrigation, UASB reactor effluent must be post-treated. Nair an Abhilash(2015: 274) carried out research on the potential of WTS as a coagulant for post-treatment of UASB reactor, treating urban wastewater. Very similar research was conducted by Jangkorn et al (2011: 591). The selected WTP used polyaluminium chloride (PACl) as a coagulant. In all of the tests the same batch of sludge has been used. The UASB reactor effluent came from the municipal wastewater treatment plant. The characteristic parameters for WTS and UASB reactor are shown in table 1 and 2, accordingly (Abhilash and Ahammed, 2015: 275).

The chemical composition of water treatment sludge depends on the coagulant composition, raw water quality and the dose of used coagulant. The effect of WTS dose on Chemical Oxygen Demand COD, turbidity, Total Suspended Solids SS and Volatile Matter VSS removal was investigated. Analytical methods were described in the work of Abhilash and Ahammed (2015: 275). The tests were conducted at an adjusted initial pH of 7,3. The doses of sludge were 0, 5, 10, 15, 20, 25 g/dm^3, respectively.

Table 1. Physico-chemical characteristics of WTS

Parameter	Unit	Value
pH		6,4
Solid content	%	5,4
VSS/SS		0,24
Al	mg/g dry sludge	112,47
Fe	mg/g dry sludge	48,33
Ca	mg/g dry sludge	20,51
Mg	mg/g dry sludge	10,89
Si	mg/g dry sludge	3,82

Source: Abhilash and Ahammed, 2015: 277.

Table 2. Physico-chemical properties of UASB effluent

Parameter	Value[1]
pH	7,2 - 7,8
SS (mg/dm^3)	138 - 161
VSS/SS	0,72 - 0,76
Turbidity (NTU)	192 - 218
COD (mg/dm^3)	220 - 248
BOD (mg/dm^3)	81 - 98
Phosphates (mg/dm^3)	4,4 - 4,9
[1] Based on analysis of 5 samples.	

Source: Abhilash and Ahammed, 2015: 277.

The results of Abhilash and Ahammed (2015: 275) studies were most optimal for WTS dose of 15 g/dm^3, and were presented in their article. The COD removal efficiency was 38%, turbidity removal was 50 %, SS - 59 % and VSS removal reached about 60 %. Presented system of water treatment sludge for UASB reactor effluent shows the potential to raise treatment efficiency. The studies demonstrated that the discharge of pollutants to the environment and toxicity of the sludge is possible. Therefore, the land requirement for landfill may be reduced.

4. WTS reuse for phosphorus removal

Iron sludge may be used for phosphorus removal in municipal wastewater treatment plants. Authors proved that doses of WTS directly to the activation tank in wastewater treatment plant reduce the phosphorus content below 2 g/l. It has improved sedimentation properties of the activated sludge and sludge index has been reduced. Phosphates can also be removed by alum sludge. Dried alum sludge may be added to wastewater treatment sludge and during the sorption process it can remove phosphorus compounds. The adsorption capacity can achieve 4-15 mg PO_4^- g^{-1} for dried sludge with the size of grain about 0,0125 mm (Kyncl et al., 2012: 16, Luo et al., 2008: 245).

Yang et al., (2006: 197) conducted a research on alum sludge use as an absorbent for phosphorus removal from wastewaters. The authors showed that the dewatered alum sludge has a latent adsorption capacity and can be utilized as a "low-cost" phosphorus sorption medium in wastewater treatment. For the research they used dewatered alum sludge cake with moisture content of about 72-75 % from a WTP where aluminum sulphate as a coagulant. Then, the sludge cake was air-dried until the moisture content decreased to 10,2%. Subsequently the sludge was grounded and sieved to provide correct diameter of absorbent, namely<0,063 mm. Model wastewater was prepared by dissolving pre weighed potassium dihydrogen phosphate (KH_2PO_4) in distilled water. The mixture was then incubated in the laboratory at 20±2 °C and adjusted to different pH (4,3-9). The results have shown, that pH has a significant effect on the adsorption capacity. Growth of the pH value from 4,3 to 9 caused remarkable decrease of P-adsorption capacity, from 3,5 to 0,7 mg P/g sludge. It is considered that phosphate adsorption by alum sludge is highly dependent on solution pH and the surface characteristics of the alum sludge.

5. Sludge stabilization by aerobic digestion

One of the most common method of sewage sludge stabilization is aerobic digestion. During this process, organic contaminants of sediments are decomposed under aerobic conditions. This method is based on biological decomposition of organic pollutants contained in sewage sludge. Anaerobic decomposition of organic matter involves under the conditions of substrate starvation. Aerobic digestion is usually carried out either in separate, opened or closed tanks with aeration, or with activated sludge method with extended aeration. This process reduces weight of the organic matter of sludge. Almost 1/3 of organic compounds may be converted into final products - mainly CO_2, H_2O, and NH_3. Depletion of organic material causes endogenous respiration (self-oxidation) process. By reducing the amount of organic matter, sludge becomes odorless (Borowski, 2000: 23).

Płonka et al., (2010: 107), conducted a research on effective stabilization of post-coagulation sludge from Water Treatment Plant during aerobic conditions. The sludge was sampled from the accelerator in which process sewage is treated with aluminum sulphate. After water treatment, the sludge is disposed into a storage tank. Then, the sludge may be dewatered in the belt press installation. During tests, total solids (TS), volatile solids (VS) and capillary suction time (CST), for "raw" and digestion sludge were determined. Raw sludge contains carbon and backwash water of contact filter. The laboratory experiment of aerobic digestion was carried out in reactor with a capacity of 2 $dm^3$and the aeration system and dissolved oxygen concentration of above 2 mg O_2/dm^3. There were 4 series of research conducted, for every season of the year. The period named 0 refers to "raw" sludge parameters, 1 - first period of sludge stabilization (<11 days), 2 - second period of sludge stabilization (12 - 23 days), 3 - third period of sludge stabilization (>23 days). Below are found the results for second period of sludge stabilization. The results obtained for a series of studies conducted during the year are shown in Table 3.

Table 3. Results for a 2 - second series of studies for one year.

Month	Total solids (TS), g/kg	Volatile solids (VS), %TS	Reduction of TS, %	Reduction of VS, %	CST s
January	6,04	37,6	6,1	19,2	61
February	8,42	32,2	3,9	14,0	79
March	10,68	31,9	3,8	14,8	75
April	5,57	45,3	4,0	10,0	43
May	20,2	39,4	7,8	19,0	83
June	25,7	35,6	4,1	14,0	95
July	14,20	33,8	6,0	18,6	50
August	17,30	36,2	2,8	8,6	67
September	14,10	31,8	6,6	18,7	101
October	19,90	36,4	2,5	7,3	155
November	11,13	37,1	3,2	8,8	81
December	7,28	43,8	6,7	16,1	58

Source: Płonka et al., 2010: 109.

Post-coagulation within water treatment plant was characterized with stable volatile solids (VS) throughout the year. The highest volatile solids content was obtained in April and reached 45,3% of TS, and the lowest, obtained in September was about 31,8%. During the stabilization process carried out under aerobic conditions in the test sludge we obtained a reduction of organic solids (TS) in the range from 2,5 in October to 7,8 % in May. Reduction of volatile solids decreased in October to 7,3 %, while it was on 19,2% in January. Capillary suction time was in the range between 43 s in April to155 s in October.

According to the Environmental Protection Agency of the United States, sludge stabilization requires a degree of organic material reduction that depends on the content of organic matter in the stabilization process. Therefore, the loss of volatile solids should be at least

38%(Płonka et al., 2010: 110). Other authors claim that during the aerobic digestion rate of 30% it is sufficient to fully stabilize sewage sludge. According to the Polish law criteria, the sludge is considered to be stabilized if it has undergone treatment processes that reduce tendency to putrefy, do not emit nuisance odors to the environment nor endanger your health. The process of aerobic digestion of post-coagulation sludge from water treatment plant may be considered as inefficient. The organic matter reduction was not sufficiently reduced, yet the emission of odors obtained in the process has decreased.

6. Conclusion

Post-coagulation sludge is generated by the surface or ground water treatment. It has an amorphous and formless structure. Depending on the treatment technology, types and doses of coagulant and the composition of intake water, the properties of post-coagulation sludge are different. According to environmentally-friendly policies, the appropriate management of sludge is required. It stands for recovery, recycle and reuse. After being dewatered, the sludge may be reused for agricultural and ecological purposes, for landfilling, or for brick and cement production process. The content of alum, iron or other coagulants allows the recovery of coagulants, which may be used again at water and wastewater treatment plants. For instance, sludge may be used as a coagulant due to its own composition. Sludge stabilization by aerobic digestion allows the reduction of organic matter content and limited odors' emissions.

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Zagospodarowanie osadów po procesie koagulacji wody, celem ograniczenia ich wpływu na środowisko

Streszczenie

Proces oczyszczania wody skutkuje powstaniem dużej ilości osadów. Polityka zrównoważonego rozwoju, wymaga bezpiecznych dla środowiska działań proekologicznych, związanych z gospodarką wodno-ściekową. Zgodnie z tym stosuje się metody odzysku, recyklingu oraz ponownego użycia w stosunku do osadów powstających podczas uzdatniania wody.Proces koagulacji wód powierzchniowych i podziemnych powoduje powstanie dużej ilości osadów. Konwencjonalna stacja uzdatniania wody może produkować nawet do 100000 ton osadu rocznie. W niniejszej pracy przedstawiono metody stosowane w gospodarce osadowej, takie jak między innymi odzysk koagulantów z osadów, użycie osadu jako koagulantu na stacjach uzdatniania oraz oczyszczalniach ścieków, zastosowanie osadów jako kompozytu w budownictwie, stabilizację tlenową osadu celem zmniejszenia jego ilości, poprzez redukcję materiału organicznego.

***Słowa kluczowe**:* osad pokoagulacyjny, gospodarka osadowa, oczyszczanie wody.