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Improvement of wastewater treatment by use of natural coagulants

Jelena Prodanović, Marina Šćiban, Mirjana Antov
Faculty of Technology, Novi Sad, Serbia

Abstract.
An activated sludge and other organic sludges from wastewater treatment processes are usually anaerobically digested prior to application on land. The purpose of digestion is to convert bulky, odorous sludges to relatively inert material that can be rapidly dewatering. The important benefit of this process is a biogas production, too. It is proper to enlarge primary sludge production in a primary settler by adding some coagulation aids, with aim to increase a biogas production, as much as possible. The most common coagulant is alum, but presence of large quantities of aluminum salts in sludge has a harmful impact on digestion and digested sludge application. Some natural coagulants, that have a numerous advantages, can be used instead of alum. Natural coagulants could be extracted from a different plant material, and considering the fact that they are of organic nature, the biogas yield can be enhanced by their presence. A plant material that remains after extraction can be used as a feed. The aim of this paper is a consideration of potential environmental benefits of substitution of alum by natural coagulant extracted from common bean seeds in sewage wastewater treatment process.

Keywords: alum, natural coagulants, sludge, wastewater

JEL Codes: Q25, Q53

1. Introduction

Coagulants can be applied in wastewater to reduce or remove suspended solids, nutrients, organic matter and different pollutants and also in sludge treatment processes. Commonly used coagulants are on the base of Al or Fe compounds. These coagulant aids occur in produced sludges and after their disposal get into the environment. On the other hand, a typically portion of the coagulant added in the wastewater is not removed completely during the treatment, remains as residual Al or Fe in the treated water, and released into the water in nature. Aluminum has no known function in living cells and presents some toxic effects in elevated concentrations. Aluminum toxicity is an important growth-limiting factor for plants in acid soils below pH 5.0, but can also occur at pH levels as high as 5.5 (Rout et al., 2001). Aluminum enters into the human body from the environment, from diet and medication, and its toxic effects on brain, liver, skeletal muscles, heart, and bone marrow are well established (Nayak, 2002). Although Fe is an essential element for all plant, high Fe content in acid soils could has a negative impact on nutrient and minerals uptake leads to yield losses (Becker and Asch, 2005).

Instead of chemical coagulants, the natural ones can also be successfully used. It was investigated water clarification and reduction of microorganisms (Pritchard et al., 2010), organic matter removal (Musikavong et al., 2005; Bhuptawat et al., 2007; Prodanović et al., 2011), sludge dewatering (Ghebremichael and Hultman, 2004), improvement of wastewater microfiltration performance (Katayon

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et al., 2007) etc. by natural coagulants which are usually obtained by extraction of different plant materials.

The application of natural coagulants is based on their traditional use in tropical, rural areas. Seed extracts from Moringa oleifera and Nirmali (Strihnos potatorum) are used for a century in Southern Asia, subSaharan Africa and Latin America. Recently, among these plant materials, the application of extracts of cacti (Opuntia ficus-indica and Cactus latifaria) (Yin, 2010), different Leguminose species as Cassia angustifolia and Phaseolus vulgaris (Sanghi, 2002; Šćiban et al., 2010) and so on, were investigated.

It is well known that the coagulants could enhance primary treatment in municipal wastewater treatment plants, thereby reducing the cost of the secondary treatment stage. Because of negative effects of conventional coagulants, the possibility of usage of natural coagulants, which are biodegradable and have no detrimental effect on health, on wastewater treatment, and their overall environmental impact will be considered in this manuscript.

2. Methods

2.1. Wastewater

Discussion was made to follow the example of wastewater. .Municipal wastewater from city having 40 000 PE (Population Equivalent) has average daily flow of 7200 m3/ day (180 L/resident • day). Wastewaters of two food factories, two metal industry factories and infiltration waters flow into the sewer system, too. Projected flow of total wastewater is 630 m3/h while the average concentration of particular components in mixture is given in Table 1.

Table 1 The average concentrations of pollution in influent (mg/L)

Biological oxigen demand **(BOD)**	Chemical oxigen demand **(COD)**	Suspended solids **(SS)**	Total Kjeldahl nitrogen **(TKN)**	Total phosphorus **(TP)**
265	**420**	**245**	**52**	**9**

Criterions for the purification of such wastewater are postulated on the base of EU Directive 91/271/EEC and they are shown in Table 2.

Table 2 Required percentage of wastewater treatment

Parameter **(mg/L)**	**Raw wastewater**	**Purified wastewater***	**Percentage of removal**
BOD	**265**	**25**	**90**
COD	**420**	**125**	**70**
SS	**245**	**35**	**86**
TKN	**52**	**15**	**71**
TP	**9**	**2**	**78**

***according to Eu Directive 91/271/EEC**

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2.2. Coagulants

As a coagulants alum ($KAl(SO4)2 \cdot 12\ H2O$) and natural coagulant from common bean seeds were considered. Natural coagulants from common bean seeds are extracted by the procedure described by Šćiban et al. (2010). An amount of a 10 g/L of grinded white bean seeds was suspended in distilled water. This suspension was stirred 10 minutes, and after that was filtered through a filter paper. Obtained filtrate should be kept in the refrigerator until use.

Actual cost for alum is about 25 dinars per kilogram, and for white bean is about 100 dinars per kilogram (wholesale price). Because of the probable price differences between geographical regions, manufacturers etc. the costs stated here should be treated as an indication rather than absolute values.

2.3. The plant design proposal

Municipal wastewater is possible to be treated on several different ways which certainly include aerobic biological treatment. Considering quantity and content of wastewater, conventional treatment is accomplished by a biological process called aerobic, suspended growth, activated sludge treatment. Both excess of active sludge from those processes and sludge originated from primary sedimentation unit are possible to be stabilized by anaerobic treatment which can be accompanied by production of certain amount of biogas.

According to presented assumptions, the proposal of procedure of spoken wastewater treatment is given (Fig. 1).

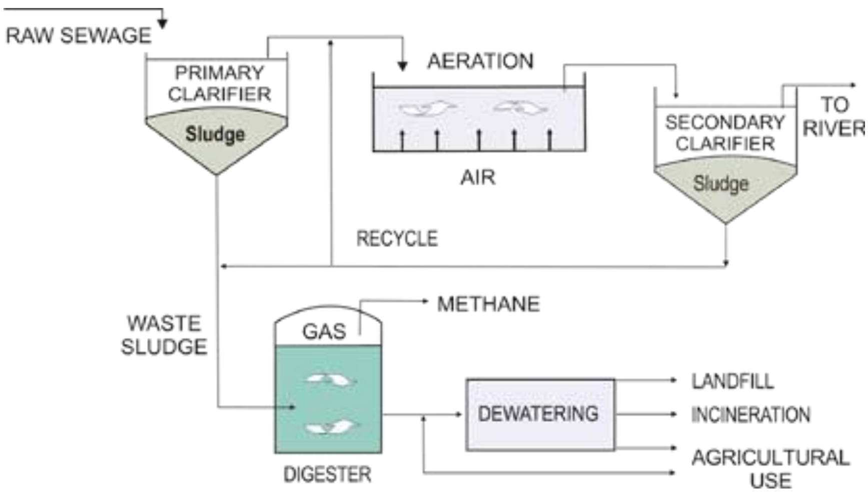

Fig. 1: Typical municipal wastewater plant
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The oil and grease, and sand are removed from raw wastewater prior the treatment. Primary settler allowing suspended solids with a higher specific gravity than water to settle as primary sludge. Secondary process removes either dissolved or colloidal in size organic material. Treated effluent from the aeration basins flows to secondary clarification. A portion of the secondary sludge from the clarifier is recycled to the aeration basins/reactors and the rest is withdrawn, or "wasted". The waste sludges are digested anaerobically and after that disposed by various methods. Anaerobic conditions promote the development of bacteria that biodegrade the sludge producing biogas - methane and carbon dioxide mixture. The biogas produced has an energetic value of about 6 kWh/ m3, and can be used for digester heating, producing steam or for generation of electricity. Anaerobic digestion of organic sludges reduces the need for subsequent addition of sludge dewatering chemicals. The costs associated with chemical conditioning exceed half of the sludge management and handling costs. Omissing this is another advantage of anaerobic digestion. The clarified effluent from secondary treatment is disinfected and discharged.

3. Results and discussion

All calculations were done on the base of common values characterizing such kind of wastewater treatment processes, presented in relevant literature (Gaćeša and Klašnja, 1994; Hicks, 2000; Hammer and Hammer, 2004). Efficiency of process with no coagulant in primary settler and with addition of alum or natural coagulant from common bean seed will be evaluated.

3.1. Efficiency of wastewater treatment with no coagulant

Well-designed and well-operated primary treatment should remove 50 to 70% of the suspended solids and 25 to 40% of the BOD. According to assumption that suspended solids removal is 60%, and BOD removal is 30%, than the water will go into the aeration basin with BOD of 185.5 mg/L and suspended solids of 98 mg/L. Secondary treatment typically removes 70 to 85% of the BOD entering with the primary effluent. For best removal, BOD in secondary effluent will be 27,8 mg/L, which is slightly higher than the value allowed by discharge regulation. It can be expected removal of total nitrogen and total phosphorus from 5 to 10% in primary settler, and in addition from 10 to 20% during secondary treatment. For the highest extent of removal, total nitrogen in secondary effluent will be 36.4 mg/L, and total phosphorus 6.3 mg/L. These values are too high in relation to the regulations (EU Directive 91/271/EEC). The solution is the introduction of additional steps of tertiary treatment for nitrification/denitrification and phosphorus removal. This requires significant investment and operational costs. Another, economically profitable solution is improvement of organics and nutrient removal in primary settler by addition of some coagulation aids.

It can be estimated that production will be around 3 m3/day of primary sludge with about 5% of total solids, and approximately 15 m3/day waste activated sludge with typically 1% of total solids. Influent in anaerobic digester is than 18 m3/ day of mixed sludges with 1.7% of total solids It can be expected that about 250 m3/ day of biogas can be obtained, which is equivalent with 1500 kWh/day. That quantity is probably enough to cover energy consumption needs of wastewater treatment plant.

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According to Municipal wastewater treatment plant energy baseline study (2003) energy consumption of wastewater treatment plant with air activated sludge process (without anaerobic treatment) vary from 0.45 to 1.13 kWh per m3 of treated wastewater. For a such wastewater flow of 630 m3/h, that is 285 to 710 kWh/day. Thus, the biogas produced would probably cover the energy needs of the whole plant.

3.2. Efficiency of wastewater treatment with alum

By addition of 80 mg/L of alum in influent (municipal wastewater) to primary settler, it can be enhance COD removal to about 80% and suspended solids removal up to 95% (Younis et al., 1998). In that case, effluent from primary settler has BOD of about 50 mg/L and suspended solids of 13 mg/L. This method also can reduce phosphorus to 1 mg/L and nitrogen in colloidal form, in some extent. After secondary treatment, BOD in the effluent can be reduced below 10 mg/L. Thus treated wastewater quality meets the requirements of regulation for main calculated parameters.

Activated sludge secondary treatment typically accounts for 30 to 60% of total plant energy consumption. There are significant differences in energy consumption even from similar secondary plants depending on their size, age, method of aeration etc. In any case, the reduced organic load of aerobic reactors by over 70% will lead to nearly as much reduction of aeration costs. This is very important because, after labor, electricity is the largest operating cost at wastewater treatment plants.

The volume of primary sludge will be enlarged, but volume of waste secondary sludge is likely to be reduced. Therefore, the volume of the obtained biogas will be probably the same. All the facts are in favor of alum addition in primary settler, except of quantity of alum used. For a given size treatment plant it is needed (7200 m3/day ・80 g of alum per m3) 576 kg of alum per day and, additionally, certain quantity of soda ash for pH adjustment. That amount of alum (converted to aluminum 33 kg/day) will be after treatment, as well as purified wastewater and treated sludge, occur in nature. Concentration of aluminum in digested sludge will be about 1.8 g/L. In addition, this amount of aluminum will adversely affect anaerobic digestion, although is usually not mentioned as a limiting factor.

3.3. Efficiency of wastewater treatment with natural coagulant

In certain conditions, the natural coagulants are showed good coagulation ability. However, natural coagulants are not as good as conventional ones, and mostly required a higher dose level (Pritchard et al., 2010). Besides, they have many advantages which are especially augmented if the plant from which the coagulant is extracted is indigenous and widespread in some region. The most investigated plants for these purposes are from tropical areas. An example of application of natural coagulants obtained from common bean which is easily grown in continental area as large number of varieties is considered below.

Optimal dose of natural coagulant is depended on its origin, extraction procedure, water composition, pH etc. For example, by natural coagulants from common bean removal efficiency for COD of 60% by dose of 5 mL per liter of molasses stilage at pH 5.4 (Prodanović et al., 2011), 68% from sugar beet extraction juice stilage by the same dose at pH 8.5 (Krstić, 2009) and 50% turbidity from model turbid water with Karoline by dose of 2 mL/L at pH 9 (Šćiban et al., 2010) can be achieved. For following calculations it is presumed that 5 mL of natural coagulants per litre of wastewater will be optimal for around 60% COD (and BOD) removal. This 5 mL is originated from 0.05 g of common bean and consequently, for a given size treatment plant is needed (7200 m3/day ・ 50 g/m3) 360 kg of bean seeds per day. This quantity of beans costs 36000 dinars in contrary to alum cost which is 14400 dinars.

Therefore, the solid residue after common bean extraction can be used as a feed or can be anaerobically treated with other sludges. In both cases that is added value. Additionally, it will be no discharge aluminum in nature.

According to assumption that BOD removal by natural coagulant is 60%, than the wastewater after primary settler has BOD of 106 mg/L and after secondary treatment 16 mg/L. The removal of nutrients by natural coagulants is not investigated enough. Organic load of aerobic reactors is reduced by over 40% in comparison to treatment with no coagulant, and that significantly reduced aeration costs. Added natural coagulant, incorporated in primary sludge, occurs in anaerobic digester and enlarged biogas production.

Effectiveness of chemical coagulants is well-recognized. Implementation of alternative coagulants would require a detailed optimization thorough bench-scale and pilot-scale tests at different conditions, as well as detailed economic analysis of all costs and benefits.

4. Conclusions

On the base of conducted calculation and literature dates it is evident that application of natural coagulants has a favorable environmental impact.

Conventional treatment of municipal wastewater usually does not decrease organic matter and nutrient contents below maximum allowed concentration related to wastewater discharge regulation.

Addition of alum in primary settler could improve purification of wastewater to satisfactory level. As a result, a large quantity of aluminum will be discharged in nature, both as purified wastewater and treated sludge.

Application of natural coagulants has a numerous advantages. Wastewater purification is good, production of biogas is enhanced and anaerobic sludge has not contained aluminum salts. Although the cost for common bean is higher than for alum, overall cost of wastewater treatment spokes in favor of application of natural coagulants. Its application represents important progress in sustainable environment technology.

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