Investigation of Some Qualitative Characteristics of Sludge Produced in Hamadan Wastewater Treatment Plant and Its Application in Agricultural Lands

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Abstract
In this study, qualitative characteristics of the sludge produced in Hamadan wastewater treatment plant and the feasibility of its application in agricultural lands were investigated. Samples were taken from the primary and secondary sludge and indices such as VS/TS, PH, TKN, COD, TKN, SOUR, Na, Ca, SAR, heavy metals and biological properties (the mean fecal coliform count and the number of parasitic eggs) were measured. The results were compared with the United States Environmental Protection Agency (US EPA) standards (40 FCR-503). The results showed that the VS/TS ratio of the raw sludge was 0.8, 0.55, and 0.55 and that of the secondary sludge was 0.65, 0.28, and 0.32 for fall, winter, and summer, respectively. The average concentration of COD, TKN, SOUR, Na, and Ca for the initial sludge was 51283, 107, 0.50, 609, and 952 and for secondary sludge, it was 35595, 81, 4.90, 306, and 493 mg/L, respectively. The MPN for primary and secondary sludge was determined to be $19.83 \times 10^6$ and $186 \times 10^6$, respectively and the average number of parasite eggs in primary and secondary sludge was 7.05 and 7.2 in 4 g of dry solids. Entamoeba coli had the highest number of parasite. The results of this study showed that the highest concentration of heavy metals in the sludge was $21.396$ mg/kg. The values obtained for the above-mentioned indices and heavy metals were in standards range. The results obtained for biological characteristics of sludge were not in the standard range. Therefore, it was revealed that the use of sludge for agriculture needed more stabilization.

Keywords: Sludge characteristics, Sludge discharge, Sludge management, Sludge application, Heavy metal

1. Introduction
In the treatment process of various types of wastewater, millions of tons of sludge are annually produced worldwide (1). Uncontrolled sludge contains various types of contaminants including bacteria, viruses, and parasites, as well as heavy metals and toxic organic compounds that can threaten the health of humans and other creatures through contaminating the agricultural products and the environment. Therefore, it is necessary to consider the rules and regulations for the disposal and reuse of sludge (2). The United States Environmental Protection Agency (US EPA) promulgated 40 CFR Part 503 which was published in 1993. It included the standards for sewage sludge applied to the land, placed on a surface disposal site, or fired in a sewage sludge incinerator (3). Sludge treatment and stabilization process account for about 40%-50% of total wastewater treatment costs. However, the reuse of treated sludge with the observance of the health aspects can offset some of the costs (4).

Sludge management includes pre-treatment, minimization, stabilization, burning, composting and sanitation. By taking a look at the history of the use and management of sludge in industrialized countries, it can be seen that the utilization and economic use of sludge for different purposes such as agricultural applications have developed in most of these countries. According to Table 1, in some European countries and the United States, more than 40% to 60% of sludge is used in agricultural
In Japan, due to lack of land, burning is used more than other disposal methods (5,6). In Iran, sludge of municipal wastewater treatment plants is often used for fertilization of agricultural fields and gardens (6). However, studies by Farzadkia (7) and Farzadkia and Taherkhani (8) in different cities of the country indicate that there are no standards for sludge disposal or desired costs in previous years.

Therefore, the aim of this study was to determine the physico-chemical and biological properties and the concentration of heavy metals in the sludge of municipal wastewater treatment plant in Hamadan, compare the results with global standards, and to assess the feasibility of its use for agricultural purposes.

2. Materials and Methods

2.1. Sampling

This descriptive-analytic study was carried out on sludge of urban wastewater treatment plant in Hamadan in 2014 during summer, fall, and winter. Currently, municipal wastewater treatment plant in Hamadan covers a population of 250,000 people, equivalent to 55,000 cubic meters per day. The treatment of the municipal wastewater is mainly carried out through aerobic/anoxic method. In this study, the parameters of TS, VS, pH, N, Na, Ca, COD, SOUR, MPN, *E. coli*, eggs of parasites, and heavy metals were evaluated in primary and secondary sludge. The sampling was carried out in fall, winter, and summer, according to the methods of analysis mentioned in Table 2, based on the *Standard Methods for the Examination of Water and Wastewater*.

The results were compared with US EPA standards for the use or disposal of sewage sludge (40 CFR 503) and other valid standards.

In this study, the samples were also examined in terms of the presence of heavy metals (11 heavy metals). All chemicals used in this study including mercury sulfate, silver sulfate, potassium dichromate, sulfuric acid, potassium hydrogen phthalate, filter paper, potassium sulfate or selenium sulfate, boric acid, methylene blue dye, methylene red dye were provided from Merck Company, Germany.

3. Results and Discussion

The results are discussed in four aspects to evaluate the quality of sludge produced in the treatment plant and to compare it with standards for use in agriculture.

3.1. Investigation of Physical Quality of Wastewater Sludge

The average total and volatile solid concentrations of the samples in the three seasons of summer, fall, and winter are presented in Table 3. According to Table 3, the VS/TS
ratio for the primary sludge are 0.8, 0.55 and 0.55 and for secondary sludge, are 0.65, 0.28, and 0.32 for fall, winter, and summer, respectively. Based on these results, it was indicated that the sludge was not sufficiently stabilized in the treatment plant (the maximum allowable level is 0.6) (9) and if it is added to the soil, the desired results would not be achieved. In a study conducted on the physical and chemical properties of the sludge of Gaza treatment plant, El-Nahhal et al found that the application of sludge to the soil may alter its physical and chemical properties (10). In another study, Bahremand et al studied the effect of the sewage sludge on the physical properties of the soil after adding it to the soil at four levels of 0, 25, 50 and 100 tons/ha in Najafabad, Isfahan province. The results of this study showed that adding the sludge to soil has a favorable effect on the physical properties of the soil (11).

3.2. The Investigation of Chemical Quality of Wastewater Sludge

The values of the chemical properties of the sludge in different seasons are presented in Table 4. According to Table 4, the mean nitrogen concentration (in the form of TKN) in primary and secondary sludge was determined to be 107.28 and 81 mg/L, respectively, and the mean sodium concentration was determined to be 609.16 and 305.66 mg/L, respectively. The amount of potassium in sludge is usually low (between 0.22 and 2.64% of its dry weight). Therefore, the nutritional value of the sludge is due to its phosphorus and nitrogen content (12). In a study conducted on the sludge produced in the water treatment plant by Rosana et al. (2004), the nitrogen and phosphorus concentrations were found to be 19.9 and 54 mg/L (13). Moreover, Torabian et al reported that the mean nitrogen, phosphorus and potassium contents were 5403, 2625, 874 mg/kg dry sludge, respectively (14). Moreover, in another study, Bina et al reported the mean carbon content of the soil in the sludge produced in the water treatment plant (15), the mean nitrogen concentration (in the form of TKN) in primary and secondary sludge was determined to be 609.16 and 305.66 mg/L, respectively. The amount of potassium in sludge is usually low (between 0.22 and 2.64% of its dry weight). Therefore, the nutritional value of the sludge is due to its phosphorus and nitrogen content (12).

| Type of Sludge | Item | Summer | Fall | Winter | Average (mg/L) | Average (%) |
|---------------|------|--------|------|--------|---------------|------------|
| Primary sludge | TS   | 1115   | 1020 | 1660   | 1265          | 100        |
| Secondary sludge | VS | 620    | 820  | 920    | 786.7         | 62.2       |

Table 3. TS and VS Values of Primary and Secondary Sludge (mg/L)

In a study conducted on the sewage sludge of Gaza treatment plant, the pH values obtained in the study (the pH below 7) and the nature of the sludge indicate the absence of sludge stabilization (17). This pH range disturbs the growth and proliferation of microorganisms, as well as the treatment and stabilization of the sludge. The use of sewage sludge significantly reduces the pH of the soil which leads to an increase in the potential for the absorption of heavy metals and their movement in the soil profile. Therefore, measures should be taken in the long-term applications of this sludge to increase the soil buffering capacity. Scientists have proposed different sets of characteristics that affect soil quality and determined the soil quality index based on the total set of characteristics affecting soil quality.

In addition, a limited number of soil properties, which provide a better representation of soil quality, have been suggested as a set of minimum properties that affect soil quality (18). Ions of Na+, Ca2+, and Mg2+ are the dominant exchange ions in the soils of arid regions. The sodium adsorption ratio (SAR) has been mentioned as an effective

| Type of Sludge | Solid part | Summer | Fall | Winter |
|---------------|------------|--------|------|--------|
| Primary sludge | pH         | 5.75   | 5.7  | 5.49   |
|              | COD        | 33150  | 41500| 79200  |
|              | TKN        | 79.35  | 155  | 87.5   |
|              | SOUR       | 0.48   | 0.56 | 0.48   |
|              | Na         | 415.5  | 762  | 650    |
|              | Ca         | 1031   | 1102 | 723    |
|              | pH         | 5.6    | 5.9  | 5.96   |
| Secondary sludge | COD       | 33150  | 35035| 38600  |
|                | TKN        | 50.5   | 140  | 52.5   |
|                | SOUR       | 5.3    | 5.2  | 4.21   |
|                | Na         | 201    | 396  | 320    |
|                | Ca         | 520.5  | 556  | 402    |

Table 4. Chemical Properties of Sewage Sludge in Hamadan (mg/L)

| Type of Sludge | Na+ | Ca2+ | Mg2+ |
|----------------|-----|------|------|
| Primary sludge | 18.7| 51.55| 621.25|
| Secondary sludge | 8.74| 51.5| 516.5|

Table 5. The Amount of Sodium, Calcium and Magnesium
indicator of the suitability of water for use in agricultural irrigation (19). In the study of the effect of sludge on agronomic soils, the final sodium absorption ratio of the soil solution was considered. Table 5 shows the amount of calcium, sodium, and magnesium in the sludge (mg/L).

The SAR in three seasons of summer, fall, and winter for primary sludge was 1.01, 1.96 and 1.44 mmol/L and for secondary sludge, it was 0.497, 0.869 and 1.26 mmol/L, respectively. The results show that the highest SAR calculated for the initial sludge was observed in the fall, and the lowest SAR for secondary sludge was reported in summer. The SAR reported for secondary sludge in the summer and fall was less than 1, but it reached more than 1 in winter. This is due to a 75% decrease in the magnesium content of this sludge in winter. However, this sodium absorption ratio is much lower than the standard for grouping of agricultural waters based on SAR. Therefore, the application of this sludge is allowed in agricultural soils considering the sodium adsorption ratio.

3.3. The Investigation of Biological Properties of Wastewater Sludge

The study of the biological properties of sludge is important in assessing the sludge reuse in agriculture as a fertilizer (20). In the present study, the mean fecal coliforms count for the primary sludge was $19.83 \times 10^6$ and for the secondary sludge, it was $186 \times 10^6$ (Figs. 1 and 2). The results show that the raw and secondary sludge produced in this wastewater treatment plant during the three seasons (summer, fall, and winter) was dramatically different from the Class A regulations and it was also significantly different from the Class B of the US EPA regulations. Hence, the disposal or reuse of this sludge is totally inconsistent with the principles of environmental protection and has a high level of health risk. In addition, the average probable number of parasite in 4 g of dry solids of raw and secondary sludge was 7.7 and 2.7, respectively. Only total and fecal coliforms counts are sufficient to determine the biological quality of the sludge and there is no need for other microbiological assays. The importance of parasite has led to testing total parasite for all samples (21). The highest number of parasite was found for Entamoeba coli (cyst) (Table 6). Additionally, the highest number of parasite was recorded in summer for raw sludge. In the studies of Mesdaghinia et al (22), Takdastan et al (23), and Rahmani et al (2), which focused on the biological characteristics of the sludge produced in the treatment plant, it was indicated that the sludge produced in studied treatment plants did not meet the standards and should be used with limitations. Naji Rad et al conducted a study to measure the populations of coliforms in the sludge samples of three different sewage sludge treatment plants including Shoush, Ekbatan and Shahrek-e-Gharb and to compare the results with the standards. They concluded that these sludge samples were categorized as class B and there would be limitations in their applications (1). Based on all studies conducted in this field, none of the sludge of wastewater treatment plants in the country meets Class A standards (40 CFR Part 503). This goes against the fact that the present proposal also confirms this result. Shokouhi et al (24) reported that the sludge obtained from the stabilization process was appropriate for use in agriculture and met biological index of class A standards (40 CFR Part 503). Autothermal thermophilic aerobic digestion (ATAD) is an aerobic method for digestion of the sludge of treated wastewater. The ATAD does not require any external power source and its performance in removing organic compounds from the sludge is acceptable. Moreover, the output product is in accordance with the Class A standards of EPA (24).

3.4. The Concentration of Heavy Metals in Sludge

Concerns about heavy metal pollution are due to three important properties of these materials, including non-biodegradability, toxicity to soil organisms, and persistence in soil (1). In 2007, Banaras Hindu University (India) published an article on the global application of sludge in agriculture, which emphasized the limited use of sludge due to the accumulation of metals in soil and vegetables, and suggested that plant growth is limited in sludge-amended soils (25). As shown in Table 7, the average concentrations of these elements in the samples studied did not exceed the EPA standards (16) and the highest concentrations of heavy metals belonged to aluminum and magnesium. Therefore, the use of this sludge, in terms of these elements, is permissible for all sludge applications. The EPA standard for lead concentration is 300 mg/kg, and its mean concentration was 103 mg/kg for both types of sludge studied in the present study.

| Parasite type            | Unit     | Summer | The first week of fall | The second week of fall |
|-------------------------|----------|--------|------------------------|------------------------|
|                         |          | Primary| Secondary              | Primary | Secondary | Primary | Secondary |
| Entamoeba coli (cyst)   | N/10 cc  | 21     | 15                     | 10      | 4         | 10      | 8         |
| Giardia SP (cyst)       | N/10cc   | 5      | 0                      | 2       | 0         | 5       | 0         |
| Oxyuridae SP (ova)      | N/10 cc  | 1      | 0                      | 0       | 0         | 0       | 0         |
| Nematoda SP (larva)     | N/10cc   | 15     | 0                      | 8       | 3         | 14      | 0         |
| Nematoda SP (ova)       | N/10 cc  | 6      | 3                      | 0       | 0         | 0       | 3         |
| Blastocystis hominis (cyst) | N/10 cc | 10     | 5                      | 10      | 5         | 10      | 4         |

Table 6. Number of parasite in the Sludge of Wastewater Treatment Plant in Hamadan in Different Seasons
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The standard value for cadmium concentration is 39 mg/kg, and it was observed to be 4.5 mg/kg. The standards for nickel and chromium concentrations are 420 and 1200 mg/kg, respectively, and its value for chromium was observed to be 37.33 mg/kg. Aluminum, iron, and manganese contents are not specified in the standards of sludge for its use in agriculture or disposal. However, due to the high concentrations of these elements in comparison with other metals and their related problems, consideration should be given to eliminating the high concentrations of these toxic heavy metals from the environment and the waters or their use for various purposes.

Houdaji et al (26) conducted a study on the cress, lettuce, and spinach cultivated in soils fertilized by sewage sludge and reported that the amount of leads in leaves of cress significantly increased compared to control plants. The results of a study conducted by Ghamari and Danesh (12) indicated that the application of sewage sludge to the soil has led to a significant increase in the concentration of lead and cadmium in the plant. Rahmani et al (2) concluded that all heavy metal elements studied in the sludge were in acceptable level, except for arsenic, and the use of sludge is permissible. Wong et al (27) conducted a study on Chinese cabbage cultivated in the soils modified with sludge showed very low amounts of heavy metals (except for Arsenic), which were less than the acceptable standards. Naji Rad et al (1) concluded that due to the presence of the high amounts of heavy metals, especially zinc and copper, none of the sludge samples have the quality to be applied to agricultural land without restriction.

4. Conclusion

In this study, some physical, biological and chemical properties of sludge produced in Hamadan wastewater treatment plant were investigated. The results showed that if this sludge is used for agricultural purposes and surface disposal, more measures should be taken to stabilize and improve its quality. The results of this study showed that the VS/TS ratio for raw sludge was 0.8, 0.55, and 0.55 and for secondary sludge, it was determined to be 0.65, 0.28 and 0.32 in autumn, winter and summer, respectively, which indicated that neither type of sludge was stabilized in the treatment plant. Moreover, the investigation of pH values (mean pH of 5.64 for primary sludge and 5.82 for secondary sludge) showed that neither type of sludge was sufficiently stabilized in this treatment plant. The mean concentration measured for COD, TKN, SOUR for primary sludge was reported to be 51283, 107, 0.50, while it was determined to be 35595, 81, and 4.90 mg/L for secondary sludge, respectively, which illustrate that neither type of sludge was stabilized. Based on the results, the values obtained for Na, Ca and SAR were 952 mg/L, 609 mg/L and 1.5 for primary sludge and

| Table 7. Average Concentrations of Heavy Metals in Sludge in Different Seasons (mg/kg) |
|---------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Al                                          | 16418       | 26896       | 22154       | 15340       | 18609       | 28956       | 21396       |
| Ba                                          | 193         | 206         | 178         | 161         | 156         | 198         | 182         |
| Ca                                          | 29987       | 45856       | 38156       | 28871       | 39874       | 51425       | 39028       |
| Cr                                          | 31          | 44          | 36          | 28          | 39          | 46          | 37          |
| Cu                                          | 155         | 147         | 120         | 131         | 140         | 105         | 133         |
| Fe                                          | 17790       | 25823       | 22167       | 16096       | 8508        | 26717       | 19516       |
| Mg                                          | 7479        | 7111        | 6198        | 9075        | 8743        | 2678        | 6880        |
| Pb                                          | 60          | 80          | 102         | 48          | 81          | 49          | 70          |
| Sr                                          | 954         | 1336        | 1135        | 815         | 967         | 1329        | 2179        |
| Zn                                          | 574         | 615         | 520         | 557         | 858         | 534         | 610         |
| Cd                                          | 5           | 5           | 5           | 4           | 4           | 4           | 4.5         |

Fig. 1. Average Fecal Coliform Count in Different Seasons.  
Fig. 2. Average Total Coliform Count of Sludge in Different Seasons.
were 306 mg/L, 493 mg/L and 0.87 for secondary sludge, respectively. Since these values did not exceed the standard levels, the application of this sludge is permissible. On the other hand, the results of biological characteristics of primary and secondary sludge of Hamadan wastewater treatment plant determined by the average fecal coliforms count and the mean most probable number of parasitic eggs in each sludge revealed that the MPN for primary and secondary sludge was determined to be 19.83 $\times 10^4$ and 186 $\times 10^6$, respectively and the average number of parasite eggs in raw and secondary sludge was 7.05 and 2.7 in 4 g of dry solids, respectively. Furthermore, the highest number of parasitic eggs belonged to Entamoeba histolytica (cyst), indicating that these characteristics were significantly different from Class A regulations and were also significantly different from Class B regulations (US EPA). The use and reuse of studied sludge are inconsistent with the principles of environmental protection and has many health hazards. Therefore, it is recommended that appropriate sludge stabilization system should be provided to improve the quality of both primary and secondary sludge produced. The evaluation of the results of this study showed that the highest concentration of heavy metals in the sludge belonged to aluminum (21396 mg/kg) and the lowest concentration was observed for cadmium (4.5 mg/kg). According to the results obtained from investigation of the heavy metals, the average concentration of these elements in primary and secondary sludge produced in this treatment plant did not exceed EPA standards, therefore, the application of this type of sludge for all purposes discussed is permissible in terms of these elements.

**Conflict of Interest Disclosures**

The authors declare that there is no conflict of interests.

**References**

1. Naji Rad S, Ghavideli A, Alikhani HA, Ashrafi Soltnai Toolooood A. The Investigation of Heavy Metal Content and Their Chemical Forms in Tehran Sewage Sludge for Agricultural Application. Journal of Environmental Science and Technology. 2018;20(1):1-13. doi: 10.22034/jest.2018.12454. (Persian).

2. Rahmani HR, Moayyeri M, Mazaheri Kouhanestani Z, Khodabakhsh N, Sharifi H. Studying some of the qualitative properties and concentration of heavy metals in dried sewage sludge from Shahin-Shahr WWTP in Isfahan. Journal of Environmental Science and Technology. 2014;16(2):55-66. (Persian).

3. Najafi N, Abbaszadeh A, Aliasgharzad N, Oustan S. Effects of rice cultivation, submergence, sewage sludge compost and chemical fertilizers on soil solution pH, EC, potassium and sodium. Water and Soil Science. 2012;23(3):105-21. (Persian).

4. Shahteeipour S, Ayati B, Ganjidoust H. Reuse of Sewage Sludge for Agricultural Soil Improvement (Case Study: Kish Island), Water and Wastewater. 2011;22(2):85-93. (Persian).

5. Kelesissis A, Stasinakis AS. Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries. Waste Manag. 2012;32(6):1186-95. doi: 10.1016/j.wasman.2012.01.012.

6. Chang MW, Chung CC, Chern JM, Chen TS. Dye decomposition kinetics by UV/H2O2: Initial rate analysis by effective kinetic modelling methodology. Chem Eng Sci. 2010;65(1):135-40. doi: 10.1016/j.ces.2009.01.056.

7. Farzadkia M. Investigation of Sludge Stabilization and Reuse in Four Small Sewage Treatment Plants of Tehran City. Avicenna Journal of Clinical Medicine. 2002;9(2):55-62. (Persian).

8. Farzadkia M, TaherKhani H. Evaluation of sludge wastewater treatment sludge quality and comparison with environmental standards for reuse in 2001. Journal of Mazandaran University of Medical Sciences.2001;15(47):19-29. (Persian).

9. Catallo WJ, Comeaux JL. Reductive hydrothermal treatment of sewage sludge. Waste Manag. 2008;28(11):2213-9. doi: 10.1016/j.wasman.2007.10.005.

10. El-Nahhal Y, Al-Najjar H, El-Nahhal Y. Physicochemical Properties of Sewage Sludge from Gaza. International Journal of Geosciences. 2014;5(6):586-94. doi: 10.4236/ijg.2014.56053.

11. Bahremand MR, Afyuni M, Hajabassi MA, Rezaeinejad Y. Effect of sewage sludge on soil physical properties. Journal of Water and Soil Science. 2003;6(4):1-8. (Persian).

12. Ghamari N, Danesh S. Effects of sewage sludge application and leaching on soil properties, quality and yield of barley. Journal of Agricultural Engineering Research. 2007;8(3):65-80. (Persian).

13. Sotero-Santos RB, Rocha O, Povinelli J. Evaluation of water treatment sludges toxicity using the Daphnia bioassay. Water Res. 2005;39(16):3909-17. doi: 10.1016/j.watres.2005.06.030.

14. Torabian A, Momenni Farahani I, Urban Wastewater Sludge Management Plan (Case Study of Qods Settlement), Journal of Environmental Studies. 2002;28(30):65-78. (Persian).

15. Bina B, Movahedian H, Amini A. Evaluation of Potentially Harmful Substances in Dried Sludge of Isfahan Wastewater Treatment Plants. Water and Wastewater. 2004;15(1):34-42. (Persian).

16. Taheri M, Alizadeh A, Farid Hosseini A, Ansari H. Study of Nitrate Transfer in Corn Fodder Cultivation using Treated Urban Wastewater as Reuse water (Case Study: Neyshabur Sewage Treatment Plant Effluent). Water and Wastewater. 2019;29(6):114-23. doi: 10.22093/wwwj.2017.86351.2411. (Persian).

17. Burton FL, Tchobanoglous G, Tsuschihashi R, Stensel HD. Wastewater Engineering; Treatment and Resource Recovery. McGraw-Hill Education; 2013.

18. Rasooli Sedaghami M, Ghodrat K, Ashrafi Saidlou S, Jafari M, Khodaverdiloo H. Evaluation of Soil Quality Indices in Changed Areas of North Zagros Forests (Case Study: Ashnavieh - West Azarbaijan Province). Journal of Soil Management and Sustainable Production. 2016; 6(3):83-99. (Persian).

19. Moghbal M, Farahbakhsh M, Boromand N. Boron adsorption isotherms in soil: Effects of sodium sorption ratio, solution pH, and ionic strength. Journal of Water and Soil. 2016; 30(6):1954-1963. (Persian).

20. Khalid U, Khan S, Umar Khan M, Ghulam S, Khan N, Anwar Khan M, Khalil SH. Sewage Sludge: An Important Biological Resource for Sustainable Agriculture and Its Environmental Implications. American Journal of Plant Sciences. 2012; 3:1708-1721.

21. Mirhosseini G, Alavi Moghaddam SMR, Maknoon R. Investigation of Application of Tehran Municipal WWTPs’ Dried Sludge in Agriculture. Environmental Sciences. 2007;4(4):47-56. (Persian).

22. Mesdaghinia AR, Panaahi Akhavan M, Vaezi F, Naddafi K, Moosavi GH. Waste sludge characteristics of a wastewater treatment plant compared with environmental standards. Iran J Public Health. 2004;33(1):5-9.

23. Takdastan A, Mehrdadi N, Torabian A, Azimi A, Nabi Bidhendi
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G. An Investigation on the Efficiency of SBR In Different Operation Conditions. Journal of Environmental Science and Technology. 2011;13(2):1-12. (Persian).

24. Shokoohi R, Rahmani A, Asgari G, Dargahi A, Vaziri Y, Abbasi MA. Evaluation of Autothermal Thermophilic Aerobic Digester Performance for the Stabilization of Municipal Wastewater Sludge. Pak J Biol Sci. 2017;20(5):260-6. doi: 10.3923/pjbs.2017.260.266.

25. Singh RP, Agrawal M. Potential benefits and risks of land application of sewage sludge. Waste Manag, 2008;28(2):347-58. doi: 10.1016/j.wasman.2006.12.010.

26. Houdaji M, Alyuni M, Abedi MJ, Mousavi SF. Effect of sewage sludge and cadmium application on cadmium concentrations in cress, lettuce and spinach. Journal of Agricultural Sciences. 2003;9(2):57-72. (Persian).

27. Wong JWC, Xiang L, Gu XY, Zhou LX. Bioleaching of heavy metals from anaerobically digested sewage sludge using FeS2 as an energy source. Chemosphere. 2004;55(1):101-7. doi: 10.1016/j.chemosphere.2003.11.022.