Utilizing Of Wastewater and Biomass Generated In Jordanian Sewage Treatment Plants

Aymen Awad

Abstract*: *This paper aims to produce and transfer data to a decision-maker so as to help within the creation of correct property sewer water biosolids management and utilization in Jordan. Jordan has around 31 wastewater treatment plants with annual total capacity of 350 Mm3. The deficiency of water demand in the country could be reduced by treating this quantity of wastewater. Treatment will produce a total amount of sludge waste around 20000 tons annually. Wastewater sludge could be utilized in different usages such as; biogas production (methane gas), organic fertilizers, additives in material construction and other applications. Considering these amounts of reclaimed water and biomass produced, they require an extremely high budget to operate different equipment to treat wastewater, utilize the sludge and finally to dispose of residual in landfills. This study will provide and help to adopt best practice technologies (BPT) and related techniques to generate energy from sludge in different wastewater treatment plants efficiently and economically while taking environmental impacts into consideration. It is concluded that the high percentage of the energy can be produced and reused, while the transportation cost and the disposal cost of the unwanted sludge will be reduced. A total amount of reclaimed water of 240-260 Mm^3 may be achieved by 2025, while daily electricity of 57128804 kWh will be generated from wastewater sludge. Wastewater utilization and management will reduce the environmental pollutions as well as providing economic value for the waste material as well. The results of suggested techniques and methodology for utilizing wastewater and sludge in this study will save about 10,683,086 JOD /Year (15 million $/Year).

Keywords: Wastewater, Sludge, Biogas, Utilization, Management, Jordan.

I. INTRODUCTION

Jordan is a country set within the Middle East region. Jordan falls inside the "absolute water scarcity" class [1]. Jordan is a poor country in water and its sources. It was essential to find another unusual source to reduce water demand deficit. In Jordan treated wastewater is considering as a source of water that can be used for various purposes. As a result, sludge is generated from wastewater treatments. In 2012 Jordan treated about 300000 m3/day which represented (115 million cubic meters/year), or about 98% of the collected wastewater from all wastewater treatment plants in the country (Wastewater Annual Reports., 2011).

Many wastewater treatment plants (WWTP) in different countries were built according to standards specifications to serve the communities with treated water, these plants include either the technology of extended aeration active sludge, trickling filers or stabilization ponds.

During the processes of treatment two products are generated, the safe and suitable quality of produced liquid effluent (treated water) and a byproduct called sludge (Biomass or bio-solids). Both the effluent and sludge are treated to quality levels suitable for disposal or recycling purposes [13]. There are many processes applied upon the sludge generated such as digestion, dewatering and granulation. The produced sludge depending on its composition and local standards can be used as a fertilizer, a soil conditioner disposal by landfill, use as a sealing material, incineration, co-incineration, wet oxidation, pyrolysis, gasification, verification, thickening, dewatering, digestion, drying. These applications upon the sludge are considered to be the highest ranked as Best Available Techniques (BAT) from an environmental point of view, on condition that the legal conditions related to sludge composition and treatment are fulfilled [3]. Anaerobic digestion is usually used for stabilizing sludge before any type of treatment [16]. Many countries used to generate electric power from recycling sludge produced from sewage treatment plants. For example, a Japanese technical team from Mitsubishi Heavy Industries, Ltd, company Led by Koga and others in 2007 success to produce electrical power from sewage sludge at that time. Treatment and utilizing sludge can reduce the pollutants emissions of global warming gases in sewage sludge treatment plants and reduce the consumption of further fossil fuel. The power generations from sewage treated sludge are affected by many factors such as temperature, residence time, mass rate loading. Optimization of those factors will cause a rise in biogas production of roughly twenty fifths. At present, Jordan has been pondering the exploitation of sludge from waste treatment plants. Nowadays, different applications of activated sludge management were utilized in Jordan. these applications are used for land fertility increasing, energy generation, fertilizer manufacturing and disposal for landfilling.

II. RESEARCH OBJECTIVES

Part (I) of this study aims to forward beneficial usage of reclaimed wastewater and municipal sewage sludge which generates from Jordanian's wastewater treatment plants.

Revised Manuscript Received on November 06, 2019.
Aymen Awad. Civil Engineering Department – Faculty of Engineering - Middle East University. Amman, Jordan, aawad@meu.edu.jo

While part (II) aims to show the ultimate goal of this case study which aims how to lowering the electricity consumption by wastewater treatment plants in Jordan. This target could be done by utilizing the generated sludge of wastewater treatment plants the operation of WWTPs. In addition, this will help to use local expertise, creates jobs opportunities and improves operational security.

III. METHODOLOGY

A. Sludge Utilizations Technologies.

During the wastewater treatment processes to produce reclaimed water, some of the final products are generated by the treatment called sludge (Biomass solids). Sludge is defined as the unwanted by-product solids of the wastewater treatment process which may contain concentrated levels of contaminants that were originally contained in the wastewater. Sludge is officially classified as waste but in accordance with the hierarchy of waste management policy is accepted using them beneficially wherever feasible, either an organic fertilizer or as an energy source recovered from combustion or anaerobic digestion [7 and 19]. Sludge is usually generated in large quantities from conventional processes of wastewater treatment plants in different steps [7]. Figure. 1. represents the main step in activated sludge extended aeration process (secondary treatment) where the major sludge is produced. Sludge conjointly contains organic matter, nutrients, and energy which might be recovered. Sludge includes concentrated solids in water which is treated to reduce its volume and taking advantage of its characteristics to be stabilized. Sludge is used for certain uses, but for energy utilizing digestion are applied upon organic sludge to generate methane gas as clear in the following reaction:-

Organic matters + combined oxygen ====➔ New Cells + Energy for cells + CH_4 + CO_2 + Other end products …………………..........….. Eq. (1)

The methane gas production is estimated to be ranged 0.75-1.1 m^3 per kg of VSS destroyed [18]. Figure. 2 represents a simplified schematic of anaerobic degradation of organic matter. Gas generation is produced by an anaerobic digestion (AD) which is utilized from sewage sludge. During this technology (AD), microorganisms break down the organic matter (sludge) and convert it into biogas, a mixture of main methane and carbon dioxide, which can be used for electricity, heat and biofuel production [12].

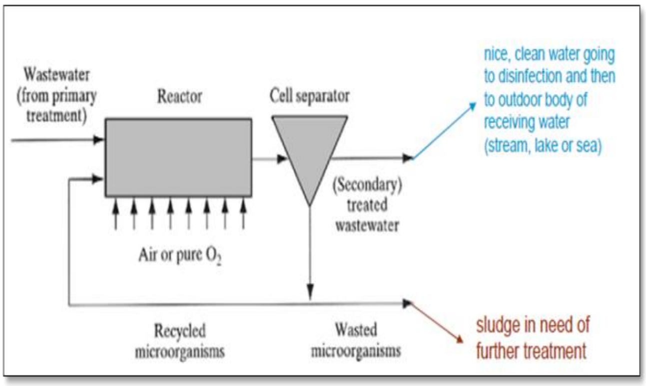

Fig. 1. Sludge production in secondary treatment step of the activated sludge extended aeration process [20].

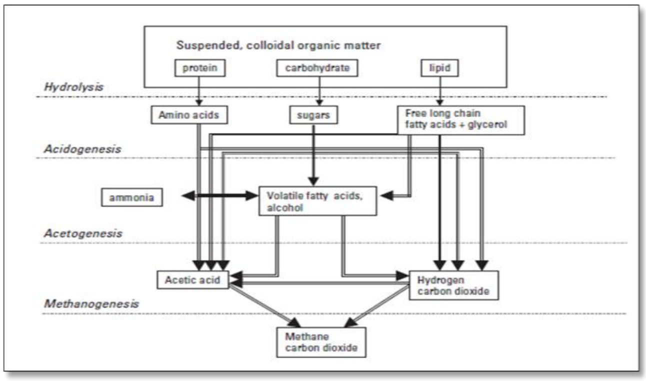

Fig. 2. Simplified schematic representation of the anaerobic degradation process [6].

B. Sludge Production Rate and Characterizations of Jordanian Wastewater.

Sludge is treated and stabilized to produce biogas from an anaerobic step in wastewater treatment plants which is a valuable energy source. In solids sludge digesters, the sludge undergoes mesophilic anaerobic digestion. The methane series generation could be a key advantage of the anaerobic method. After alkane series desulfurization, the treated biogas will be wont to generate heat and power in cogeneration units whereas reducing the carbon footprint and greenhouse emissions of the effluent treatment plant. Up to seventieth of the energy desires of a waste treatment plant are often provided by sludge digestion. There were about 30 wastewater treatment plants in different sites in the main cities in the kingdom. Table.1 summarizes the characteristic of these plants, including the treatment technology used, design flow capacity, design biological loading (BOD5). Those sewage treatment technologies gave removal efficiencies for BOD5, COD and toxic shock for final disposal in compliance with the Jordanian discharge properties [4].

The existing standards and laws that directly apply for the use of sludge discharge with treated domestic wastewater is the Jordanian Standard # 1145/1996 [21] . It is estimated that the volume of sludge generated from Jordanian wastewater treatment plant in most cases as 2% of the total wastewater treated and [14]. This percent equivalent to about 450 x103 kg of sludge per year.

Because the cost of treatment and disposal of sludge is high, then the utilizing of sludge is very useful and can reduce the operating cost of the plant [17].

C. Methodology for Electricity Production from Wastewater Sludge.

The sludge generated from primary and secondary treatment steps is collected and heated for 10 to 20 days at around 35oC which increases the biological conversion. Digestion of the sludge mixture is continued. After that, the settled sludge is taken to dewatering and thickening. In the final step, a sludge stabilization is achived where the level of microorganism in the residual solids is reduced, eliminates odors, and reduces the potential for more decay. This process is shown below Fig 3.

Table 1. Characteristic of sewage treatment units and their operating design parameters @ 2014. [4].

UNIT	Treatment Technology	Hydraulic Loading (m^3 /day)	Design BOD_5 (mg/L)
As-Samra	AS	221510	650
Irbid	AS + TF	6696	800
Aqaba new + Aqaba	AS + SP	15000	750
Salt	EA	7700	1090
Jerash	EA	3598.3	1219
Mafraq	SP	3600	696
Baqa'a	TF	14900	800
Karak	TF	1679.3	708
Abu-Nusir	AS	4000	1100
Tafila	TF	1116	1000
Ramtha	AS	5400	1000
Ma'an	AS	2352	688
Madaba	AS	7600	950
Kufranja	TF	1900	850
Wadi Al Seer	AL	4000	780
Fuhis	AS	2400	995
Wadi Arab	AS	8316	836
Wadi Hassan	AS	1600	800
Wadi Mousa	AS	1820.4	701
Tal-Almantah	AS + TF	271.5	750
AL- Ekeder	SP	4000	1500
Alljoon	SP	634.8	750
AL-marad	AS	10000	800
Al-JIZA	AS	703.9	750

***Biological Filters, MP = Maturation Ponds, ASOD = Activated Sludge Oxidation Ditches, ASEA = Activated Sludge Extended Aeration, AS = Activated Sludge, AP = Aerated Ponds, SP = Stabilization Ponds, TF = Trickling Filters, value of waste material Treatment; lake systems from three.9 – one hundred files/m3; Activated sludge = nine 0-180 files/m^3 and Combined systems 180-700 files /m^3. (Sources: National Water Quality Monitoring Project Report for the year 2013, Ministry Of Environment and Royal Scientific Society, Amman Jordan, 2014; (Jordan Country Report, Arab Water Council, 2011; Safe Use of Treated waste material in Agriculture, Jordan Case Study, Arab Countries Water Utilities Association (ACWUA), December, 2001, national capital Jordan) [4].**

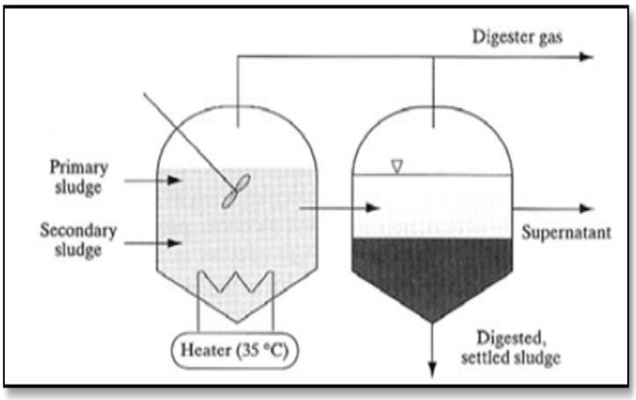

Fig. 3. Schematic of two-stage, high rate anaerobic sludge digester, [8].

Biogas methane (CH4), hydrogen sulfite (H2S) and some siloxane (feedstock for personal care products) are generated from digester. It was founded that each 0.50 m3 of biogas generates one kilowatt (kWh). On the other hand, 1 kWh of electricity would be generated by 0.34 L diesel [15]. This power generated may be used to operate some of the wastewater treatment plants. Figure. 4. represents the process of generation of electric power and use it to power pumps and compressors.

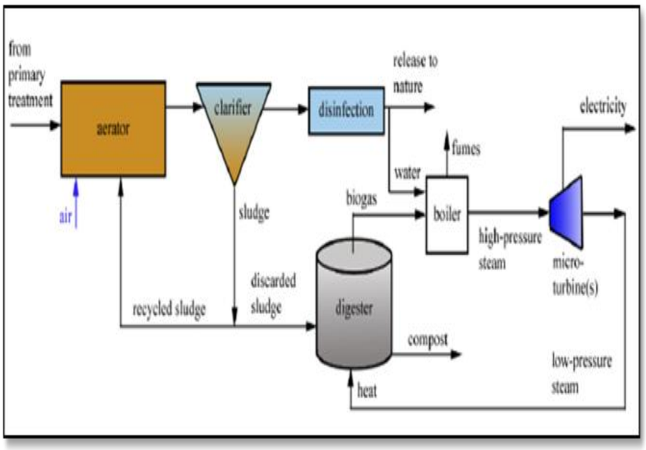

Fig. 4. Electricity generated from sewage sludge is used to power plant equipment.

IV. RESULTS AND DISCUSSIONS

A. Reclaimed water produced from Jordanian wastewater treatment plants.

One of the most important results achieved that the reclaimed is very important from different points of views. Reuse of treated water reduces the harmful problems to the environment, reduces the large quantities of wastewater generations and avoids the complexes of wastewater management plants needed, [5]. However, Jordan government considered that treated wastewater is one of important water resource and it can be reduce the water budget deficiency of the kingdom [2]. So, a high percentage of treated water about ninety percent is recycled and reused for irrigation [9]. Therefore, treated wastewater effluents from sewage treatment units are an important component of Jordan water budget. Table.2. below shows the amount of wastewater treated and production yearly.

Table. 2. Reclaimed water generated in Jordanian wastewater treatments yearly (Wastewater Annual Hashemite Kingdom of Jordan-Ministry of Water and Irrigation Reports, 2009, 2011 & 2016).

Year	Reclaimed (Million Cubic Meter)
2007	113.830
2008	111.527
2009	114.687
2010	117.83
2011	115.432
2020 -2025	240 - 262 (**Expected**)

Even though, the high cost of wastewater treatment and management, Jordan has efficient and effective procedures of wastewater treatment and collection Jordan. The treated wastewater will contribute to reducing the water deficit by 250 million cubic meters in the water budget in Jordan and by 12.5 % of the total demand for water on average.

B. Sludge production for Energy Production Application.

Biomass generated from wastewater sludge is considered as energy. The utilizing of the biomass will lower the greenhouse gases production and then realized the concept of recycling and reduction of solid waste produced from the treatment plant. In general, the produced power has to be kept and delivered efficiently to the consumers in a good economic way with adequate monitoring of fluctuating fuel properties during the processes of biomass collection, energy conversion, and the use of the biomass resources, [22]. For example, the disposal pathways for bio-solid sludge from municipal wastewater treatment plants in Germany in 2010 are divided into 53 % for incineration and then producing energy, 30 % for agricultural uses, 14 % for landscaping and 3 % for other uses, (BMU, www.bmu.de, 2010). The amount of sludge (biomass solids) generated from Jordanian wastewater treatment plants can be calculated by equation (2) and the results are tabulated in Table.3 below. While, Methane gas, energy equivalent and money saving are tabulated in Table.4. Results indicated that the equivalent liters of diesel fuel generated from all wastewater treatment plants are equaled to (19423793 liters per day), and the corresponding saved money for this amount yearly in JOD is estimated to be equaled (10683086 JOD/Year). The following formula is used to calculate the daily sludge production of wastewater treatment plants:-

$$P_{x,TSS} = \frac{QY(S_0 - S)}{1 + k_d\,(SRT)} \cdot \frac{1}{0.85} + \frac{f_d k_d YQ(S_0 - S)(SRT)}{1 + k_d(SRT)} \cdot \frac{1}{0.85} + QX_{0,f} + Q(TSS_0 - VSS_0) \qquad \text{.......(2)}$$

According to equation .2, the daily sludge production needs to identify many variables and coefficients. Therefore, each wastewater treatment plants has the following parameters:- influent flow rate (Q in m^3/day) , soluble substrate concentration in the influent (BOD or bsCOD) (So in g/m^3 or mg/L) , the inert inorganics (total suspended solids) (iTSS) in (g/m^3) which is estimated to be 10 g/m^3 in this case, the non-biodegradable volatile suspended solids nbVSS Xo, i is equaled to 30 g/m^3. The mixed liquor volatile suspended solids concentration MLVSS (XT) is equal to 2500 g/m^3 where the recommended range value is (2000-3000) g/m^3. Sedimentation retention time (SRT) which is estimated to be 6 days. While the kinetic coefficients are as follows, the maximum rate of soluble substrate utilization k is taken to be 12.5 g COD/g.d, the biomass yield Y is equaled to 0.4 gVSS/g COD used, the half velocity constant Ks is 10 g COD /m^3, the endogenous decay constant Kd is 0.1 gVSS / gVSS.day and the amount of active biomass that remains as cell debris fd is equaled to 0.15 gVSS / gVSS. A sample calculation is done in the next example, if the wastewater treatment plant has been chosen to be As-Samra plant where the design hydraulic load is 276000 m^3/day and the design BOD_5 influent is 650 mg/l (g/m^3) then the daily rate of sludge production by using Equation (2) above is equaled to 57124.13 kg VSS/day and 68503.68 kg TSS/d. Other plants' sludge is calculated and tabulated in the same way as shown in Table. 3. It is clear that methane gas production is equivalent to be in the range of 0.75-1.1 m^3 per kg of VSS destroyed.

It is a fact that the biogas production varies according to the type and concentration of the biomass and process parameters. It was founded that the amount of biogas production was 80-200 m^3 / ton and 2- 45 m^3 / m^3 of sewage solid waste and animal manure of biogas, respectively [18]. Then, the daily methane gas production from As-Samra sewage treatment unit of methane is estimated to be 51411.717 m3/day (57124.13 kg VSS/d * 0.9 m^3/ kg). Salam in 1985 concluded that each one kilowatt is generated from one third liter of diesel oil 0.34 L diesel. On the other hand, this amount of electricity (one kilowatt) is generated by using gas engine generator by consumption of 0.50 m^3 of the methane biogas. Depending on this, As-Samra plant alone would generate a daily electricity amount of 102823.434 kWh per day, and the corresponding amount of diesel oil in liters per day needed to generate this amount of power which is equivalent to 34959.96 liters and the total cost of this equivalent diesel amount in Jordan's Dinar is equaled to 19228 JD/daily.

C. As - Samra Wastewater Treatment Plant.

It is obvious from (Table 3. and Figure. 5) that the major sludge production was from As Samra wastewater treatment plant. The plant is serving most of the population in three governess in Jordan (Amman, Zarqa, and Mafraq) about (2.27 million) and more with wastewater influent of 221510 m3/day which represents the hydraulic load of the plant in phase one of upgrading (2015).

Table. 3. Jordanian wastewater treatment yearly sludge generated and electrical energy production.

Treatment Unit	Treatment Method *	Hydraulic Loading (m^3/day)	Design BOD_5 (mg/L)	$P_{X,VSS}$ (kg/day)	$P_{X,TSS}$ (kg/day)
As-Samra	AS	221510	650	57124.13	68503.68
Irbid	AS + TF	6696	800	2158.74	2580.69
Aqaba new	AS + SP	15000	750	3513.32	4203.91
Salt	EA	7700	1090	2516.91	2997.31
Jerash	EA	3598.3	1219	1410.19	1677.38
Mafraq	SP	3600	696	429.79	514.85

Baqa'a	TF	14900	800	3692.91	4414.72
Karak	TF	1679.3	708	374.11	448.03
Abu-Nusir	AS	4000	1100	1318.39	1569.87
Tafila	TF	1116	1000	337.42	402.21
Ramtha	AS	5400	1000	1632.67	1946.20
Ma'an	AS	2352	688	511.15	612.42
Madaba	AS	7600	950	2194.28	2617.27
Kufranja	TF	1900	850	496.80	593.41
Wadi Al Seer	AL	4000	780	969.59	1159.51
Fuhis	AS	2400	995	722.36	861.13
Wadi Arab	AS	8316	836	2142.67	2559.92
Wadi Hassan	AS	1600	800	396.55	474.06
Wadi Mousa	AS	1820.4	701	402.07	481.59
Tal-Almantah	AS + TF	271.5	750	63.59	76.09
AL-Ekeder	SP	4000	1500	1754.39	2082.81
Alljoon	SP	634.8	750	148.68	177.91
AL-marad	AS	10000	800	2478.46	2962.90
Al-JIZA	AS	703.9	750	164.87	197.28
Total Per Day				86954	104115
Total Per Year				31738224	38002029

***Activated Sludge = AS , Trickling Filter = TF , Stabilization Ponds = SP , Extended AERATION = EA , Aerated Lagoon = AL.**

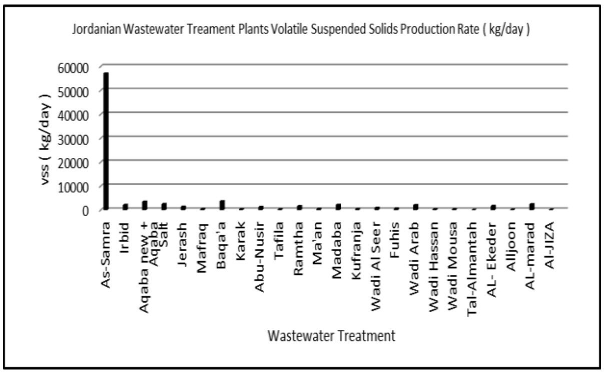

Fig. 5. Sludge production rate (kg/day) of wastewater treatment plants in Jordan.

Table. 4. Jordanian wastewater treatment yearly sludge generated and electrical energy production.

Plant	Methane gas (m^3 / day)	Daily Electricity (kWh)	Equivalent liters of diesel	JOD/ DAY
As-Samra	51411.717	102823.4	34959.9	19228
Irbid	1942.87	3885.73	1321.15	727
Aqaba new + Aqaba	3161.99	6323.98	2150.15	1183
Salt	2265.22	4530.44	1540.35	847
Jerash	1269.17	2538.34	863.04	475
Mafraq	386.81	773.62	263.03	144
Baqa'a	3323.62	6647.24	2260.06	1243
Karak	336.70	673.40	228.96	126
Abu-Nusir	1186.55	2373.10	806.85	444
Tafila	303.68	607.36	206.50	114
Ramtha	1469.40	2938.81	999.19	550
Ma'an	460.04	920.07	312.82	172
Madaba	1974.85	3949.70	1342.90	739
Kufranja	447.12	894.24	304.04	167
Wadi Al Seer	872.63	1745.26	593.39	326
Fuhis	650.12	1300.25	442.08	243
Wadi Arab	1928.40	3856.81	1311.31	721
Wadi Hassan	356.90	713.79	242.69	133
Wadi Mousa	361.86	723.73	246.07	135
Tal-Almantah	57.23	114.46	38.92	21
AL- Ekeder	1578.95	3157.90	1073.69	591
Alljoon	133.81	267.62	90.99	50
AL-marad	2230.61	4461.23	1516.82	834
Al-JIZA	148.38	296.77	100.90	56
Total Per Day	78258	156517	53215	29269
Total Per Year	28564402	57128804	19423793	10683086

D. Agricultural Uses of Sludge.

Crops are fertilized by different fertilizes; one method used is using that one produced by wastewater sludge. The sludge usually contains the most nutrients needed in the fields. The second application is when using sludge at golf courses, parks, etc…., and this may harm the environment by addition of phosphor to achieve eutrophication and this is complying with the conclusion by (Naturvårdsverket 5221, 2002). The biosolids have many bad and harmful effects for soil but have many advantages for improving soil quality [23]. In Jordan, many researchers were using biosolids and sludge producing from Jordanian wastewater treatment plants in the land application includes fodder and fruit tree farming [11]. Figure. 6, below shows sludge after the treatment and degradation processes and dewatering.

Fig. 6. Sludge after anaerobic digestion and drying.

E. Sludge in the production of construction materials.

Many researches approved that sludge could be reused in construction works as an alternative materials. These conclusions are investigated in different researches and sources [7]. These results are stated that sludge could be used with cement for producing paving tiles for external usage. Different types of sludge from wastewater or solid wastes were used in construction materials, for examples ; oily waste was used in manufacturing of ceramic [10] and other different uses such as cement manufacturing and additives in construction materials. In general, all investigations reviewed gave a good result indicated that sludge could be used with cement and aggregates in construction materials. This lead to reduce the cost of materials and solve part of the environmental problems countered with the generation of this solid waste.

V. CONCLUSION

It is concluded that treated water and bio-solids sludge generated from Jordanian wastewater treatment plants could be used for different usages. Reclaimed water could be used for restricted irrigations, cleaning, power plants and others usages. Sludge could be utilized for different beneficial uses. The sludge must have undergone a process to reduce its level of pathogens, odor and to inhibit decay.

Many applications were discussed, for examples, utilization of sludge in energy generation, in farmland usages as fertilizers and finally usage of sludge in construction materials. The most effective use of generated sludge is energy generation. This study approved that there is a valuable amount of energy could be generated from wastewater sludge as electricity. As Samra plant treatment plant is classified as the biggest one in the kingdom of Jordan which means that the production of energy based on sludge is maximum. It was concluded that daily electricity of 57128804 kWh could be generated from wastewater sludge in Jordan. The suggested techniques and methodologies for utilizing wastewater sludge in this case study will save about 10,683,086 JOD /Year (15 million $/Year) as a net value of electricity generated. The ultimate goal of this study is the protection of the environment from the side effects of sludge and its bad effects of spreading without treatment.

VI. ACKNOWLEDGMENT

The author of this article is grateful to the Middle East University (MEU), Amman, Jordan for the financial support granted to cover the publication fee of this research article.

REFERENCES

1. Abdel-Khaleq, R., (2007). "Key challenges to ensure environmental security and sustainable development in the OSCE area". Land degradation, soil contamination, and water management. Prague, 21–23 May 2007.
2. Ahmed Ali Ulimat., (2012) "Wastewater Production, Treatment, and Use in Jordan". Ministry of Water & Irrigation Water Authority of Jordan". Second Regional Workshop 'Safe Use of Wastewater in Agriculture', 16-18 May 2012, New Delhi, India.
3. Diane Huybrechts., (2016). "Best Available Techniques For The Treatment, Use, And Disposal Of Waste Water Treatment Sludge". diane.huybrechts@vito.be.
4. Fayez A. Abdulla, Amani Alfarra, Hani Abu Qdais, and Ben Sonneveld., (2016). "Evaluation of Wastewater Treatment Plants in Jordan and Suitability for Reuse". Academia Journal of Environmental Science 4(7): 111-117, July 2016, DOI: 10.15413/ajes.2016.0305, ISSN: 2315-778X, ©2016 Academia Publishing.
5. Gabriela Neata, Razvan Teodorescu, Liviu Dinca, Adrian Basaraba., (2015). "Physico-chemical and microbiological composition of composts from Bucharest municipal waste ". International Conference, Agriculture for Life, Life for Agriculture, Elsevier Applied Science-Agriculture and Agricultural Science Procedia 6 (2015) 486 – 491.
6. Lettinga, G., L.W. Hulshoff-Pol, and G. Zeeman., (1999). "Biological Wastewater Treatment; Part I Anaerobic Wastewater Treatment". (Lecture Notes). Wageningen University and Research: Wageningen, The Netherlands.
7. Maha Alqam, Ahmad Jamrah, and Haya Daghlas., (2011). "Utilization of Cement Incorporated with Water Treatment Sludge". Jordan Journal of Civil Engineering, Volume 5, No. 2, 2011© 2011 JUST. All Rights Reserved.
8. Metcalf Eddy (1991). Wastewater treatment disposal and reuse 3rd. Ed., McGraw Hill.
9. Ministry of Water and Irrigation, (2016). "National Water Strategy in Jordan 2016-2025". Ministry of Water and Irrigation, United Kingdom of Jordan, 2016.
10. Monteiro, S., Vieira, C., Ribeiro, M. and Silva, F., (2006). "Red Ceramic Industrial Products Incorporated with Oily Wastes". Construction and Building Materials, 21: 2007-2011.
11. Mufeed I. Batarseh., (2011). "Polynuclear Aromatic Hydrocarbons (PAH) and Heavy Metals in Dry andWet Sludge from As-Samra Wastewater Treatment Plant, Jordan". Prince Faisal Center for the Dead Sea, Environmental and Energy Research, Department of Chemistry, Faculty of Science, Mutah University, Karak, Jordan. Soil and Sediment Contamination, 20:535–549, 2011, Taylor & Francis Group, LLC.
12. Nathalie Bachmann., (2015)" Sustainable biogas production in municipal wastewater treatment plants". Technical Brochure, Copyright © 2015 IEA Bioenergy. First electronic edition 2015 - British Library. ISBN 978-1-910154-22-9.
13. Parul Kumar., (2014). "Sludge and Solid Wastes: Treatment and Disposal". http://www.biologydiscussion.com/waste-management/solid-wastes treatment. 11021.
14. Qasim, S., Motley, E. and Zhu, G., (2000). Water Works Engineering, Prentice Hall, India.
15. Salam B.A., (1985). "The contribution of the oil palm by-products towards the national energy policy – an economist point of view". In: Proceedings of the National Symposium on Oil Palm by- Products for Agro-based Industries, Kuala Lumpur, Malaysia. Bangi: Palm Oil Research Institute of Malaysia. pp 133-145.
16. Schomaker, A., (2001). "Extra vergistingsstap van zuiveringsslib veelbelovend voor grotere rioolwaterzuiveringen". 2001, Royal Haskoning.
17. Townsend, T., Jang, Y., Jain, P. and Tolaymat, T., (2001). "Characterization of Drinking Water Sludge for Beneficial Reuse and Disposal". Report Published by State University System of Florida and Florida Center for Solid and Hazardous Waste.
18. T.Z.D. de Mes, A.J.M. Stams, J.H. Reith and G. Zeeman., (2003). " Methane production by anaerobic digestion of wastewater and solid wastes ". MES–Chapter 4–pages58-102.
19. Valentin Feodorov., (2016). "Modern technologies of treatment and stabilization for sewage sludge from water treatment plants ". 5th international conference "Agriculture for Life, Life for Agriculture ". Elsevier Applied Science - Agriculture and Agricultural Science Procedia 10 (2016) 417 – 430.
20. William W. Nazaroff and Lisa Alvarez-Cohen, (2001). "Environmental engineering science". New York: John Wiley & Sons, Inc., [2001].
21. Yasser K. Nazzal, Mohammed Mansour, Mohammad Al Najjar, and Peter McCormick., (2000). "Wastewater Reuse Law and Standards in the Kingdom Of Jordan". The Ministry Of Water and Irrigation, Amman, Jordan, March 2000.
22. Youichi Koga, Hiroshi Oonuki, Takeshi Amari, Yuuki Endo, Kazuaki Kakurata and Kimitoshi Ose. (2007). "Biomass Solid Fuel Production from Sewage Sludge with Pyrolysis and Co-Firing in Coal Power Plant". Mitsubishi Heavy Industries, Ltd. Technical Review Vol. 44 No. 2 (Jul. 2007).
23. Yucel, D., Yucel, C., Aksakal, E., Barik, K., Khosa, M., Aziz, I., and Islam, K., (2015) "Impacts of Biosolids Application on Soil Quality under Alternate Year No-Till Corn-Soybean Rotation". Water, Air & Soil Pollut., 226, 1-11.

AUTHORS PROFILE

Dr. Aymen Awad, has a bachelor Degree in Chemical Engineering 1990 Jordan University – Faculty of Engineering and Technology, Master in Water and Environmental Engineering Civil Engineering Department 2008 - Jordan University – Faculty of Engineering and Technology and PhD in Environmental Engineering from UNESCO Chair for Water Resources – Sudan 2014. He is the head of Civil Engineering Department in Middle East University. He was the manager of UL-Bashaier Jordanian Company in Sudan. He was member of Board of Directors of UL-Bashaier Jordanian Company. He is consultant in CAP program with Environmental Ministry. Dr Awad Area of Specialty and Experiences: Twenty two years of engineering experiences in (Water Treatment, Industrial Wastewater Treatment, Sanitary Treatment Plants, Environmental works and Chemical engineering works, Water and irrigation works). Countries visited or living: Germany, Italy, Belgium, Luxembourg, Netherlands, France, Saudi Arabia, Sudan and Austria.