The Potential of Utilizing the Sewage Sludge Produced from Nablus West Wastewater Treatment Plant as an Energy Source and or a Fertilizer

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Abstract

In Palestine, there are five major wastewater treatment plants built to treat not more than 100million m^3 per year of domestic wastewater which is equivalent to 20% of total produced wastewater. Nablus West Wastewater treatment plant, NWWTP, is the most recent plant commissioned in 2013 with 70% of its full capacity of 15000m^3/day.
The 12ton/d produced semi sludge forms a severe ecological problem as it is still not fully accepted to be disposed in the sanitary landfill. Therefore, the current practice of improper disposal of the sludge is a threat to the groundwater as well as the agricultural lands due to the pathogenic and toxic content of the sludge. However, according to the Palestinian legislations on the sludge disposal, numerous biological and physicochemical parameters are fully analyzed in this study for further use of sludge.

Potential use of the sludge as a biomass, fertilizer and a biodiesel production feed stock was studied. A "TGA" analysis of dried sludge shows that the organics content is around 40wt%. The yield of lipids extracted from sludge was25wt% oil/dry sludge thus a 1.4 ton of biodiesel can be produced daily. The calorific value of residual sludge is 12.7MJ/kg. Mixing it with saw dust can raise the heating value up to 15MJ/kg. Heat integration concept shows that direct burning of sludge produced can generate 1.52 times the electricity consumption at NWWTP. Finally, the produced sludge can be used as a fertilizer that equivalent to 11% of total fertilizers used in Palestine.
Key words: sludge utilization, biodiesel, fertilizer, energy source.

I. Introduction

A huge increase in the energy demand in the world, the continuing rise in energy costs, limited resources of petroleum, as well as the pollution problems caused by the wide use of petroleum-based fuels have encouraged recent interests in seeking alternative energy resources. Biodiesel has proven itself to be the most promising alternative.

Many studies [1-5] confirm that biodiesel is one of the most promising alternatives with the attention of using used vegetable oil or wastewater sewage sludge instead of virgin vegetable oils. Utilization of wastewater sewage sludge was the concern of many researchers who conducted research on the production of lipids from activated sludge and optimize operating conditions for biodiesel production from lipids. Phosphor was also extracted from ash sludge to produce high –quality fertilizer [6-8].

On the other hand, many researchers [9-11] worked on thermal processing of sewage sludge, especially combustion. Researchers showed that the utilization can play an important role for sewage sludge disposal. Several technologies for both mono- and co-combustion of sewage sludge currently exist to achieve high combustion efficiencies with low emission of pollutants.

The possibility of using the sewage sludge as a fertilizer on calcareous soils was found to be an attractive option due to its high macro and micro nutrients content. Several researches was carried out to evaluate the effects of sludge on seed germination and growth performance of seedlings [12-13].

In this work, lab experiments were carried out for the possibility of utilizing the activated sludge from NWWTP in fertilizer production and energy source.

II. Methodology

2.1 Materials and equipment

Stabilized sludge was collected from the mesophilic anaerobic digester facility at NWWTP. It was immediately then stored at 4°C prior to use. Sodium hydroxide, potassium hydroxide, hexane and ethanol chemicals of high purity are used in the experimental work. All these materials were bought from Sigma-Aldrich. The physical and chemical characteristics of the sludge is determined using Inductively coupled plasma mass spectrometry (ICP-MS), thermogravimetric analysis (TGA) and American Society for Testing and Material (ASTM) standard tests.

2.2 Biodiesel Production

For the production of biodiesel from sludge, five stages were applied, these are: lipid extraction, titration, trans esterification, separation and purification.

2.3 Lipid Extraction

Lipid extraction from dewatered and digested sewage sludge is the first step in the biodiesel production from these wastes. In this research the lipids extraction was done using two solvents (hexane and ethanol) in different sludge-solvent ratios, hexane was either used alone in some experiments or blended with ethanol in others. This was followed by lipid treatment where a certain amount of extracted lipid was heated for 15 minutes to remove excess water, the heated lipids were filtered.

2.4 Transesterification:

It is a conventional and the most common method for biodiesel production. In this process, fatty acid alkyl esters (biodiesel) are produced by the reaction of triglycerides with an alcohol, especially ethanol or methanol, in the presence of alkali, acid or enzyme catalyst etc. The sodium hydroxide or potassium hydroxide, which is dissolved in alcohol, is generally used as catalyst in transesterification reaction. Excess alcohol with adequate catalyst generally forces the reaction equilibrium toward the products of biodiesel esters and glycerol.

The first stage of transesterification determines the catalyst amount using titration. In this research two samples were titrated with 1 g/L NaOH solution, the first sample (control) consisted of 2 mL isopropyl alcohol with some phenolphthalein drops, the second sample consisted of 2 mL isopropyl alcohol and 0.2 mL lipids with some phenolphthalein drops. , V1 and V2 of sodium hydroxide solution where obtained respectively, then the acid value was calculated using the following equation [14]:

$$FFA\left(\frac{mg}{g}\right) = (V2 - V1) \times \frac{1.4}{doil} \quad (1)$$

The numeric value 1.4 is the mass coefficient to convert NaOH to KOH, d_{oil} is density of lipids. Based on this, then NaOH (lye) required for transesterification was calculated using the equation[14]:

$$Lye\left(\frac{g}{L}\right) = V2 - V1 + 5.0 \quad (2)$$

2.5 Separation and Purification

As contaminants (soaps, excess methanol, residual catalyst, and glycerol), dissolve better in hot water, a certain amount of boiled water were poured on biodiesel to wash it from contaminants.

III. Results and Discussion

3.1 Physical and chemical Properties of the activated sludge

By carrying out experiments, it was found that according to AMST D297, the total suspended solids (TS) was 78% of which the organic contents is 46%. Then the sludge sample was subjected to an increase in the temperature. The percent reduction of the weight of the sludge sample with temperature and its derivative was performed using TGA test. This is shown in Figure 1.

By looking at the heat flow curve in Fig.1 it is clear that there are many peaks; these peaks are either endothermic or exothermic peaks. The endothermic peaks are peaks at which the heat flow is reduced while the temperature increased. The presence of endothermic peaks at the heating flow curve means that an evaporation or crystallization processes take place during heating. Exothermic peaks where the heat flow increases with a temperature increase present when combustion process occurs. From the figure the first endothermic peak is at 120°C which corresponds mainly to the water evaporation from the sample; the second one is at 235°C which is due to the decomposition of the calcium compounds content of the sludge sample. This peak is followed by an exothermic peak at 305°C which may be explained by the presence of simple organic material. The largest mass change occurred at T= 390°C another exothermic peak appears. At this temperature the complex organic materials are probably combusted. After this point, many sequence endothermic peaks formed, this may due to the decomposition of clay or inorganic material. All conclusions above are still expectations depending on previous studies results and the common content of sludge samples in the literature. This data can also be used to determine the weight percent of these ingredients in the dry sludge sample. The sludge contents and their weight percentages are summarized in the Table 1.

Table 1: Thermogravimetric analysis of the dry sludge and its transition temperature

Ingredients	Transition temperature °C	wt.%
Water	120	0.77
Calcium compounds	235	7.2
Simple organic material	305	16.02
Complex organic material	390	35.28
Inorganic material	425-725	12.35
Residue (ash, soil, …)	850	28.38

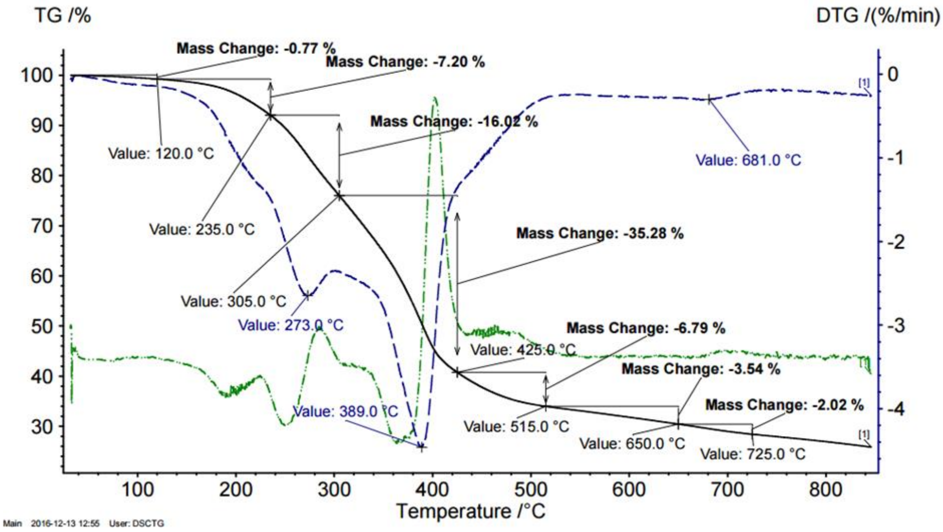

Figure 1: The percent reduction of the weight of the sludge sample with temperature and its derivative performed using TGA test.

3.2 Biodiesel Production

3.2.1 Lipid Extraction

Under the procedure describe in the above methodology to extract lipid, , sludge and the solvent were put in a separator funnel, manually shaken, and left overnight at room temperature to settle and separate properly, the upper layer consisting of lipids and solvent was collected and the yield was calculated. Six experiments were carried out and in each experiment a 100g of sludge was subjected to either pure Hexan of 100, 150 and 200 g or a mixture of Hexan /Ethanol of different ratio but with a total solvent weight of 200g.
Hexane shows higher extraction activity than ethanol, but the safety issues associated with hexane limited its use as a pure solvent, thus the best combination of both solvents was achieved at a ratio of 1:1.5:0.5 sludge-hexane-ethanol. Table 2 shows the percent of lipids extracted using the optimal ratio of solvents.

The results show that the yield of the lipid extracted from the digested sludge is higher than that extracted from the dewatered type since the dewatering step causes some reduction in the organic content by either further digestion or losses of some organics material with the removed water. By comparing the achieved yield with the that stated in the literature which is 21.9% for digested sludge it is clear that the achieved yield is higher.[8]

3.2.2 Biodiesel Production process

The following Figure (2) shows a schematic presentation of biodiesel production. After the mixture was separated into two layers, the lower layer was drained and the biodiesel layer formed was weighted was found to be 14%.

3.3 Energy Recovery from Sewage Sludge Incineration

3.3.1 Energy Recovery Process

Incineration is one of the most important methods for the disposal of sewage sludge. For the aim of evaluating expected amount of energy recovery from sludge sewage, the heating of combustion of sewage sludge was carried out in a constant volume bomb calorimeter. Electrical energy is used to ignite the sludge sample (fuel); as the fuel is burn, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter. When the air escapes through the copper tube it also heats up the water outside the tube. The change in temperature of the water allows for calculating calorie content of the fuel. Heating value measurement was also carried out for a mixture of dried sewage sludge and sesame peels in different ratios. This is shown in Table (3).

Mixing ratio of sawdust and sesame peels with the sludge were chosen based on the weight of 1 gram of sawdust and sesame peels with 1 gram of sludge. Since, the densities of sawdust and sesame were lower than sludge density, then the volume of sawdust and or sesame were in accordance to the mixing ratio shown in the table. Results show that the maximum average heating value was achieved at a ratio of 1:11 sludge-sawdust .

Table 2: The percent of lipids extracted using the optimal ratio of solvents.

Type of Sludge	Amount of Sludge used	Amount of Hexane /ethanol used	Lipids (g)	Lipids (%) as dry matter

Dewaterd	115.3	173	5.6 (9 ml)	20
Digested	333.3	500 ml	7g (12ml)	25.9

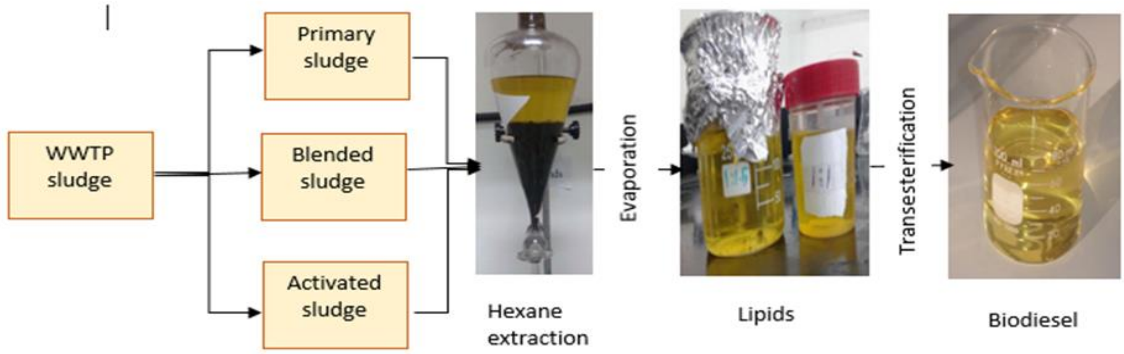

Figure 2: The whole process of Biodiesel production.

Table 3: Average Heating value (HV) of sewage sludge with sawdust and sesame peels at different ratios.

Raw sludge	Sawdust	Sesame peels	Sludge with sawdust		Sludge with sesame peels	
HV (MJ/Kg)	HV (MJ/Kg)	HV (MJ/Kg)	Mixing ratio (v/v)	HV (MJ/Kg)	Mixing Ratio(v/v)	HV (MJ/Kg)
12.7-13.4	18.3	12.76	1:7	14.9	2:7	12.65
--	--	--	1:11	15.2	2:11	12.97
			1:14	15	2:14	12.81

It is worthy to mention that the heating value of the sludge produced at NWWTP has a heating value around that measured by other researchers[15-16].

3.3.2 Energy Analysis

Based on measured heating value of sewage sludge and the amount of sludge that can be generated, an analysis of expected energy released from incinerating all sewage sludge produced from NWWTP are summarized in table 4.

Results show that using of dried sludge will have the capability of producing 1.5 times energy consumption by the NWWTP. Additionally, the heat lost from the electricity production process can be recovered by the thermal energy load.

3.4 Fertilizer Production from sewage sludge

The sewage sludge can be used to produce fertilizer. The produced fertilizer is a thickened biological sludge obtained by conventional aerobic activated sludge process followed by clariflocculation, digestion and drying as can be seen in Figure 3. If the sludge contains heavy metals then further processes such as: thermal conditioning, dehydration by filtration under a press filter should be done. The clariflocculation treatment combined physico-chemical addition of ferric chloride and a polymer to allow the phosphorus, present in dissolved form in water, to agglomerate.

Taking the amount of dried sludge produced daily from the NWWTP as 12 tons/day, 22% of this amount is water then it is expected to produce 3416 tons of fertilizer annually. The annual consumption of organic fertilizers in the West Bank is 30,000 ton, therefore the expected amount of produced organic fertilizer from sewage sludge accounts to 11% of the total consumption of fertilizers.

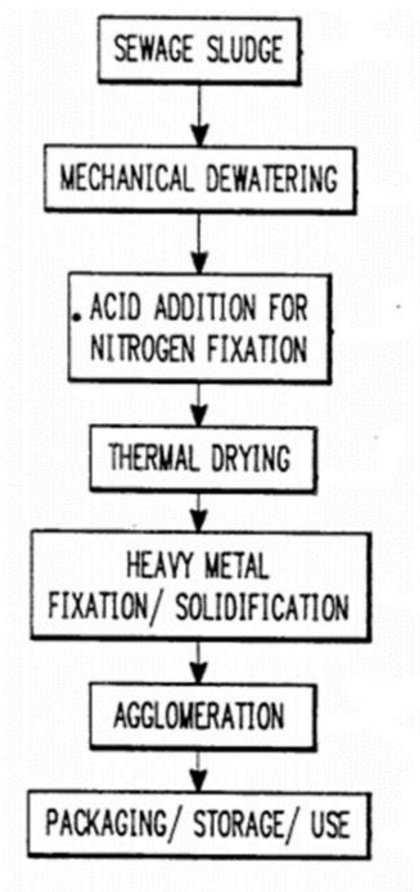

Figure 3: The fertilizer production process from Sewage sludge.

Table 4: summery for the energy analysis result

Electrical energy consumption (MWh)	200
Electrical energy consumption (GJ)	720
Heat to electricity efficiency assumption (%)	30
Heating value of dried sludge (MJ/kg)	12.7
Amount of dried sludge per month (ton)	280.8
Amount of heat from dried sludge per month (GJ)	3566
Amount of electrical energy produced per month (GJ)	1096.8
Percent of energy covered by sludge incineration (%)	152

To determine whether the sludge can be safely used and applied on agricultural lands or not, the concentration of some of the heavy metals, trace elements and macro-elements content were measured using the ICP-MS device. measured concentration in addition to the maximum allowable limits according to [17-18] are tabulated in the table (5)

The above table shows that the concentrations of the measured elements are below the maximum limits except for zinc which is 12% above the allowable limit. Thus according to the Palestinian standard document (PS/-989) [18], published by the Palestinian institution for standards and metrology, the sludge produced at NWWTP is suitable to be used as a fertilizer after reducing the concentration of the zinc which can be removed by using certain type of microalgae.

IV. Conclusion

The following conclusions can be drawn from this preliminary study about the utilization of NWWTP sludge.

In terms of biodiesl production it was found that around 1.4 tons/day of biodiesel can be produced. This amount is an equivalent to same amount of part of diesel currently consumed in NWWTP . More advantage of this is that it is more environmental friendly.
The energy analysis shows that energy production from incinerating the sludge can provide an equivalent energy of 1.5 the amount consumed in NWWTP
The potential use of sludge as fertilizer is promising as an equivalent of 11% of the whole fertilizers consumed in the Palestinian market can be provided from the conversion of sludge to fertilizer. Saying this, it is very important to make some treatment for the sludge specially for removal of zinc as the ICP-MS analysis shows a high concentration of zinc.

V. Recommendations

- This study is a preliminary and therefore, further works are needed to make sure that the biodiesel produced from sewage sludge meets the specification values of ASTM
- Based on satisfaction of biodiesel produced to the international standards, it is worth studying the specification of produced biodiesel once it si mixed with conventional diesel..
- The direct incineration of sludge may be seen as a potential source of pollution, and Environmental considerations during the combustion of sewage sludge must be taken, by using modern and effective flue gas cleaning technologies which are currently available.
- The sewage sludge combustion process can be promoted by mixing the sludge with charcoal to reduce the ignition temperature and make the combustion process more regular.
- The heavy metal content of the sludge should be periodically investigated by the inductively couple's plasma mass spectrometry (ICP-MS) .
- The long term effect of the dried sludge usage on soil should be investigated.

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Table 5: pollutant concentrations in the sewage sludge sample and their maximum allowable limits.

Pollutants	conc. (ppm)	Max. allowable limit (ppm) [17-18]
lithium	18.99±0.073	113
Beryllium	1.23±0.073	7
vanadium	150.31±0.7215	370
Iron	35959.68±415	218
Gallium	20.02±0.9729	27
Rubidium	32.06±0.2788	320
Strontium	638.57±.67	10
Indium	0.26±0.0185	-
Caesium	1.79±0.0239	7.9
Barium	186.31±2.59	100
Titanium	0.41±0.0337	0.25
Lead	74.48±0.9105	840
Bismuth	4.67±0.03415	-
Aluminium	32260.54±801	249
Chromium	149.91±2.3063	3000
Manganese	813.35±14.9558	208
Cobalt	14.17±0.179	150
Nickel	121.49±7.453	420
Copper	1443.1±25.797	4300
Zinc	93478.7±1421.6	7500
Molybdenum	24.43±0.248	40
Silver	45.18±1.23	5
Cadmium	5.77±0.195	85

Biographies

Mays Shadeed , the winner of King Abdullah bin Al-Husien Award for Innovation in 2016, is an instructor at the engineering colleague at An-Najah National University, Nablus, Palestine, she holds a master degree at the advanced chemical engineering from Jordan university of science and technology with excellent GPA. The B.sc was received from An-Najah National university as the top of class student with honor. In addition to teaching , Mays has research interests in polymer sciences , water treatment and renewable energy studies .

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Professor EL-Hamouz published more than 40 papers in refereed Journals and international conferences