E3S Web of Conferences **480**, 02027 (2024) https://doi.org/10.1051/e3sconf/202448002027
EEA2023

Possibility of utilizing waste activated sludge as a renewable energy source

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Abstract. This paper gives results of a study of biofuel granules made from a waste activated sludge of wastewater treatment. A novel method to enhance waste activated sludge dewaterability with untreated and calcined water treatment sludge of thermal power plants is proposed, and the potential reuse of dewatered sludge as biofuel is evaluated. The water treatment sludge destroyed membrane, resulting in the release of intracellular water by converting bound water into free water, thus enhancing sludge dewaterability. Biofuel granules can be used for technological needs, electricity generation and in heating and hot water supply systems at industrial and domestic facilities. Biofuel granule is a renewable energy that can substituted low grade coal from biomass sources.

1 Introduction

Currently, most of the final energy consumption in the industries is covered by fossil fuels with energy generation at thermal power plants (TPP). However, the overall energy efficiency of the TPP is low, even less than 40%. Therefore, the 21st century is characterized by the problem of depletion and shortage of natural resources, especially organic fossil fuels.

The transition to a renewable energy source is currently a global issue. Renewable sources of energy can help the Russian Federation mitigate climate change, build resilience to volatile prices, and lower energy costs.

One of the directions of the "Energy Strategy of Russia for the period up to 2035" is the use of new types of fuel, including mixtures with waste from technological processes. The use of industrial waste previously stored in landfills and sludge reservoirs facilities significantly reduces the coal, crude oil and natural gas use and greenhouse gas emissions.

The industrial solid waste recycling is a promising direction. Waste to energy (WtE) technologies help to convert industrial wastes into useful energy and minimize the problems related to it. In these technologies, waste is a secondary energy and material resource. In the context of the fossil fuel depletion and the increasing of its consumption volume, the development of WtE technologies based on alternative renewable fuels is an important task.

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2 Relevance

The main research fields of Russian and foreign scientists focus onWtE technologies, environmental impact, and energy technology innovations.

The waste activated sludge (WAS) is the large-tonnage waste, that must be removed from the process to keep the biological system in balance at biological wastewater treatment plants. WAS is a biocenosis of microorganisms capable of degrading various pollutants, including organic substances, phosphorus- and nitrogen-containing compounds in wastewater from industrial enterprises and the public sector. The activated sludge process is common for the wastewater treatment. The process uses a mixed culture of microorganisms that degrade the wastewater aerobically producing carbon dioxide, water and new biomass [1-3]. Some of the produced biomass is recycled and the rest requires disposal. The average WAS production amount in the Russian Federationis estimated at 3.5 billion tons per year. The main part (about 90%) is stored in landfills [4] and dried due to natural convection and radiative heat transfer. This raises different important problems. Large landfills decrease the value of the land adjacent to it, bring hazards such as putrefactive odor, that spreads around the landfills, insect pests and surface waterpollution. Such gases as carbon dioxide, methane, water vapor, nitrogen, oxygen, ammonia, sulfides and other are also produced at landfills and can create smog if left uncontrolled.

Hense, there is a growing interest in low-cost and sustainable methods of energy production from wastes. There are various methods of WAS processing: deposition on sludge landfills, the use of WAS as fertilizers, gasification and pyrolysis, incineration, etc. [5-7].

In the study [8] activated sludge and algae biomass are used as substrates in microbial fuel cell (MFC) to produce electricity. Activated sludge is used at anode as inoculum and nutrient source. Various concentrations (1–5 g/L) of dry algae biomass are tested. Among tested concentrations, 5 g/L (5000 mg COD/L) produced the highest voltage of 0.89 V and power density of 1.78 W/m^2 under 1000 Ω electric resistance.

Influence of different pretreated sludge for electricity generation in MFCs was investigated in the study [9]. Pre-treatment has shown significant improvement in MFC electricity productivity especially from microwave treated sludge. Higher COD reduction in the MFC has been revealed from microwave treated sludge with 55% for total and 85% for soluble COD, respectively.

The authors [10] investigate the sludge index, dehydrogenase activity and elimination rate for glucose and ammonium ions in activated sludge obtained from urban sewage in treatment plants in the city of Irkutsk to determine the relationship between the factors and the ability to generate an electric current in MFC.

This works have proved the concept of using algae biomass in MFC for high energy output. Then, the WAS sludge can be considered as a product (secondary raw material).

The paper [11] presents an assessment of the production of polyhydroxyalkanoates (PHA) in biomass sourced from full-scale wastewater treatment plants. A refined acetic and propionic acid feedstock was used to produce a polyhydroxy-butyrate-valerate copolymer in a single-stage from this biomass as-received. The mean overall storage yield was 0.25 ± 0.03 g COD of polymer per g COD feedstock consumed.

The removal of basic dyes from wastewater was studied using activated sludge biomass as an adsorbent [12]. The experimental results of COD removal (%) showed that for various basic dyes, adsorption by biomass was not only feasible but also effective. The kinetics of adsorption followed first-order processes, controlled by film diffusion.

The study [13] investigates biosorption of Oxytetracycline, a broad-spectrum antibiotic, using aerobic granular sludge as an adsorbent in aqueous solutions. It was shown that the aerobic granular sludge was a good alternative for biosorption of this pharmaceutical. The pharmaceutical was adsorbed better at pH values of 6–8. The adsorption can be well explained by Langmuir isotherm model. The waste activated sludge can be used as a sorption material for the oily wastewater treatment as well [14].

Activated sludge can be considered as an efficient renewable biofuel. The paper [15] proposes the usage of carbon-containing waste of industrial enterprises in producing the solid fuel for energy purposes. The WAS from the city sewage treatment facilities is applied as a binder. The paper determines the optimal composition of fuel to use in solid-fuel boilers and develops the technological scheme of the experimental setup. The proposed technology will contribute to resource - and energy saving.

In the work [16], dewatered WAS was subjected to hydrothermal carbonization to obtain hydrochars that can be used as renewable solid fuels. The hydrochars exhibited increased heating values (up to 22.3 MJ/kg).

The article [17] studied he method of thermal decomposition of silt deposits at the facility with the conduction of heat. It is established that with the pyrolysis of the slimy remainders of effluents the process is endothermic and proceeds in the range temperatures of 0-600°C, the output of liquid and gaseous products for the models of fresh silt is higher than for the deposited models, for which above output of solid products. The output of steam-gas products with an increase in the heating rate in 1,3 time increases on 10%.

Literature analysis showed that biofuels generated from WAS could be the most efficient and attractive process.

The purpose of the work is the production of solid biofuel granules based on waste for energy generation.

3 Materials and methods

In experimental studies the WAS from the biological treatment plant of OJSC «Kazan Synthetic Rubber Plant» is used for biofuel granules. The WAS characteristics are the moisture content of the WAS is 98%, after the sedimentation stage (physical process using gravity to remove suspended solids from water) - 95%, density - 1.13 g/cm3, ash content - 11%.

However, this raises the problem of its dewaterability. WAS is a difficult-to-filter suspension because of the large amount of bound water in the cellular mass [18]. Various materials including industrial wastes are used to increase the water-yielding capacity of the WAS.

In the work for dewaterability of WAS the water treatment sludge (WTS) is used. WTS of thermal power plants (TPPs) – a large-tonnage waste generated in the process of water treatment to replenish water and steam losses at TPPs, stored in sludge collectors [19]. In this study, the WTS from Kazan TPPs is used (Table 1).

Table 1. Chemical composition of the WTS (% wt).

Mineral part			
Cations		***Anions***	
Ca^{2+}	76.56 ± 11.30	CO_3^{2-}	71.7±10.6
Fe^{3+}	0.38 ± 0.15		
Mg^{2+}	9.7 ± 2.2	SO_4^{2-}	5.7±0.85
Cu^{2+}	0.040 ± 0.014		
Ni^{2+}	0.008 ± 0.003		
Zn^{2+}	0.033 ± 0.013	OH^-	10.03±3.61
Mn^{2+}	1.05 ± 0.41		
Cr^{3+}	0.0010 ± 0.0003	SiO_3^{2-}	0.52±0.11
Pb^{2+}	0.0020 ± 0.0003		
Cd^{2+}	0.22 ± 0.08		

The WTS also contains humic compounds – up to 11% wt., which were determined by the method of gas chromatograph-mass spectrometry [19]. Physical and chemical characteristics of the sludge are: the bulk density is 560 kg/m^3; the ash content of the dry sludge is 89%; the moisture capacity is 57% wt.; pH of the water extract is 8.53; the particle size distribution corresponds mainly to fraction from 0.09 to 0.5 mm [19].

The WTS is used to increase the water-yielding capacity of the WAS. In the experiments untreated and calcined WTS is used as a mineral additive. The calcination process is carried out in a muffle furnaceat the temperature of 400°C for a period of 1 hour.

The centrifugation method uses centrifugal force to separate mixture into solids and liquid phase. Laboratory studies are carried out on a CM-6M centrifuge, in which the separation of the dispersed and liquid phases occurs by sedimentation of suspended particles under the action of centrifugal forces.

In the work the WAS, the mixture of WAS and untreated WTS and the mixture of WAS and calcined WTS in various proportions are centrifuged. Preliminarily, WAS is intensively mixed with untreated and calcined carbonate sludge in various proportions for 10 minutes. Then the mixture is placed into 10 ml centrifuge cylinders and is separated into wastewater solids and liquid under various conditions. The centrifugation time is 1, 2 and 3 minutes. The rotation speed of the centrifuge is from 500 to 1500 rpm.

The centrifugation index is used for calculating the water-yielding capacity of the solid. It shows the level of dewaterability of the medium in the field of centrifugal forces. Normal level of the centrifugation index is U≤6-8.

After centrifugation and detoxification, granules with a diameter of 3 to 5 mm are produced from the dewatered mixture of WAS and WTS particles by initially applying mild compaction force by hands using a binder. Granules consist of approximately 70% WAS, 8%WTS and 22% (wt.) binder.

By granulation of WAS and WTS are used binders such as: starch and technical lignosulfonate (LST). LST is a loose powdery material of light brown color and water content of 8% (wt.), which is a by-product at paper mills obtained from bisulfite pulping liquors.

After granulation, drying is carried out at 105ºC for 30 minutes. Elemental composition of carbon, hydrogen, nitrogen, sulfur of biofuel granules (CHNS - analysis) was carried out on the EA 3000 EuroVector analyzer.

4 Using the template

The results of the study are presented in Figures 1-3. It is experimentally established that the optimal conditions are (Figure 1): dose of injected calcined WTS is 1,2 g/dm^3, rotation speed is 500 rpm for 3 minutes. These conditions help to reach normal level of the centrifugation index (U=7.75).

According to Figure 2 the upper limit of the centrifugation index (U=7.95) is achieved with the introduction of untreated WTS with a minimum dose of 0.6g/dm^3 while centrifuging at a speed of 1000 rpm for 1 min and with the introduction of 0.3 g/dm^3 of calcined WTS under similar conditions.The centrifugation of WAS without WTS under the same conditions has a much higher index (U=10.05) and is inefficient.

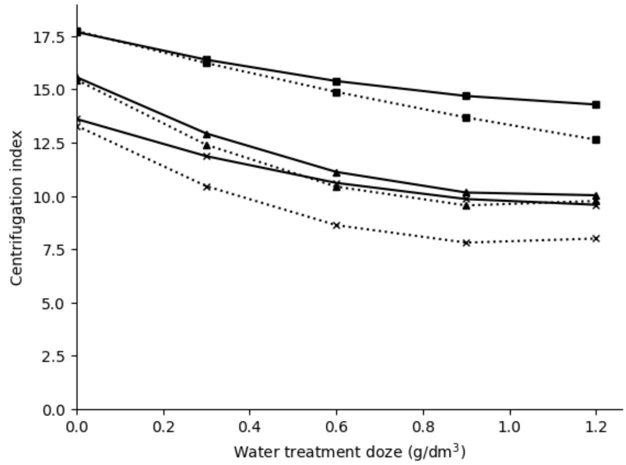


Fig. 1. Dependence of the centrifugation index value on the injected dose of WTS (500 rpm). (Centrifugation time: ■ - 1 min, ▲ - 2 min, × - 3 min; ─ untreated WTS; ⋯- calcined WTS).

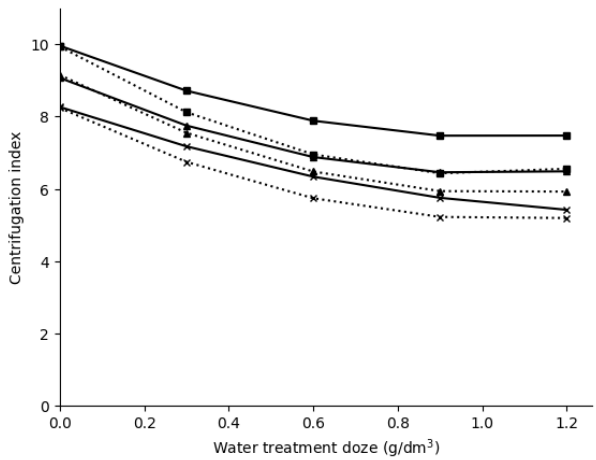


Fig. 2. Dependence of the centrifugation index value on the injected dose of WTS (1000 rpm). (Centrifugation time: ■ - 1 min, ▲ - 2 min, × - 3 min; ─ untreated WTS; ⋯- calcined WTS).

The centrifugation index has lower values with the introduction of raw and calcined WTS (Figure 3). The increasing of WTS dose reduces the level of the centrifugation index. A satisfactory level of the centrifugation index (U=7.91) during the processing of the WAS without the addition of WTS is covered at 1500 rpm for 3 minutes. Thus, it is the least profitable process.

Dosing the WTS leads to increasing the water-yielding capacity of WAS and to reducing energy costs for the process at the same experiment conditions.

Humidity of WAS after centrifugation is 84%, while the humidity of the mixture sediment (WAS and untreated WTS) ranges from 71 to 74% (depending on the dose of the injected WTS and the conditions of the experiment). The humidity of WAS with the injection of calcined WTS is up to 69%.

Then, the WTS acts as a mineral coagulant. The injection of WTS prevents agglomeration of WAS, destroys the hydration shell, enveloping activated sludge particles.

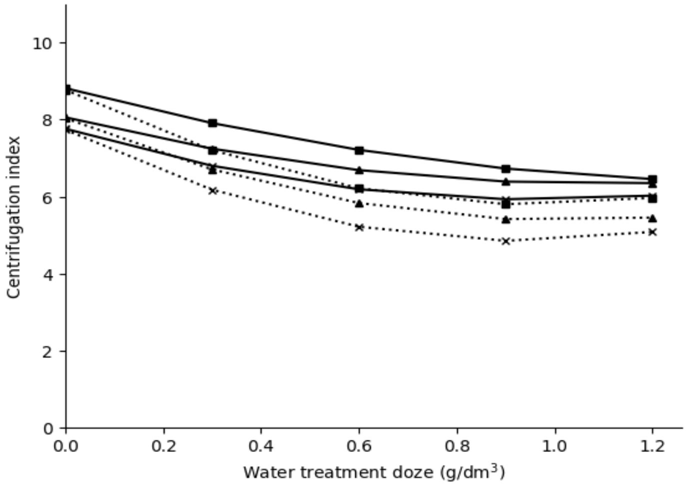


Fig. 3. Dependence of the centrifugation index value on the injected dose of WTS (1500 rpm). (Centrifugation time: ■ - 1 min, ▲ - 2 min, × - 3 min; ─ untreated WTS; ···- calcined WTS).

After the centrifugation of WAS with WTS strong structural bonds are broken, resulting the separation of bound water. Hence, there is a redistribution of the bound moisture of the WAS and the increasing of unbound water in the suspension. Increased Ca^{2+} concentration forms a hard mechanical sediment and electrostatic interaction with the WAS, which pH in the range from 4 to 9 is negatively charged [20].

Also, when WTS is introduced, WAS is neutralized due to its chemical detoxification. The dosing of WTS during dewaterability process of WAS produces the transition of heavy metal ions such as Fe^{2+}, Fe^{3+}, Zn^{2+}, Cr^{3+} into sparingly soluble and insoluble compounds. After this solid is removed from the system. Calcium carbonate, the main chemical compound of WTS, reduces the content of heavy metal ions in WAS (Table 2) [21].

Table 2. The content of hevy metals ions in the WAS and after treatment with calcium carbonate.

Reagent	**Concentration of metals, mg/kg**				
	$Fe^{2+,3+}$	Cr^{3+}	Cu^{2+}	Zn^{2+}	Ni^{2+}
Raw WAS	27.80	0.14	1.04	1.01	0.14
Calcium carbonate	19.53	0.09	0.83	0.93	0.09

The introduction of WTS solves not only the problem of increasing the WAS dewaterability efficiency, but also reduces the content of heavy metal ions in the sewage sludge.

At the same time, the introduction of calcined WTS has a higher efficiency of WAS dewaterability due to the pore space increasing, while the total volume of the compacted mass of WAS decreases.

The main technical characteristics of the obtained granules using starch and LST as a binder : moisture, bulk density, ash content, abrasion resistances are shown in Table.3 A calorimetric bomb C 2000 basic V. 1 is used in determination of the calorific value of biofuel granules.

Thus, the result show that biofuel granules using LST as a binder is more efficient. The biofuel granules are composed of 30.1% carbon, 2.9% hydrogen, 1.1% sulfur, 1.24% nitrogen.

Table 3. Chemical composition of the wts (% wt).

Granules	Binder	
	Starch	***LST***
Moisture,%	4.7±0.2	3.1±0.1
Bulk density, kg/m^3	828	788
Ash content, %	29.2	27.9
Ash colour	Light grey	Light brown
Abrasion resistances, %	0.5	0.1
Gross calorific value in bomb calorimeter, MJ/kg	9672.6	10345.5

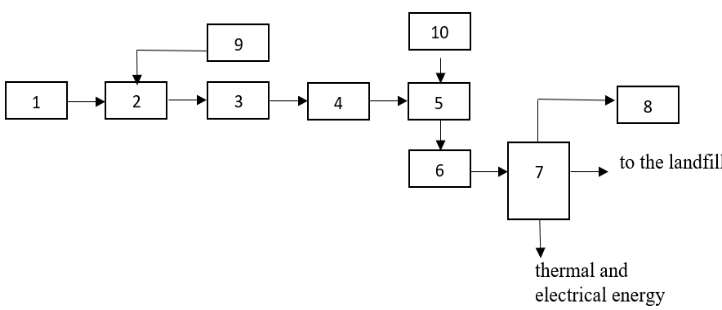
The net calorific value was calculated using the Mendeleev's equation:

$$Q_{ncv}=339.3C+1256H-109(O-S)-25.2(9H+W) \quad (1)$$

Where: Q_{ncv} - net calorific value, kJ /kg; C - carbon in the sample, %; H - hydrogen in the sample, %; O - oxygen in the sample, %; S - sulfur in the sample, %; W- moisture in the sample, %.

The net calorific value of biofuel granules with LST as a binder is 9582.8 MJ/kg.

The biofuel granules production and incineration technology are developed based on the results of the research (Figure 4).



1 - WAS storage bunker; 2 - mixing bunker; 3 - centrifuge; 4 - belt dryer; 5 - granules former; 6 - storage bunker for biofuel granules; 7 - furnace with a fluidized bed; 8-ash catcher; 9 - WTS storage bunker; 10 - binder storage bunker

Fig. 4. Technological scheme for the production and incineration of WAS.

From the WAS storage bunker 1 and WTS storage bunker 9, respectively, WAS and WTS are supplied using a ratio 6:1 by volume and mixed in mixing bunker 2. Then the mixture is centrifuged in a centrifuge 3. After the dehydrated mixture enters a belt dryer 4 for drying and is formed into granules 5 with binding agent from the binder storage bunker 10. The biofuel granules enter the storage bunker 6, then they are sent to the fluidized bed furnace 7 for incineration. In this case, thermal or electrical energy can be obtained, depending on the type of equipment. Flue gases are cleaned in the ash catcher 8.

5 Conclusions

Thus, biofuel granules can be used for technological needs, electricity generation and in heating and hot water supply systems to produce hot water at industrial and domestic facilities, in stationary boiler houses, as well as for autonomous heating systems.

The use of waste activated sludge as a biofuel resource makes it possible to reduce the environmental impact on the environment through waste disposal, to realize the transition from fossil fuel, which is non-renewable, to renewable fuel of biological origin.

Acknowledgement

The research was funded by the Russian Science Foundation, grant number 21-79-10406, https://rscf.ru/en/project/21-79-10406

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