Improving efficiency of transport fuels production by thermal hydrolysis of waste activated sludge

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Abstract. The article deals with issues of transport biofuels. Transport biofuels are an important element of a system of energy security. Moreover, as part of a system it is inextricably linked to the urban, rural or industrial infrastructure. The paper discusses methods of increasing the yield of biogas from anaerobic digesters at wastewater treatment plants. The thermal hydrolysis method was considered. The main advantages and drawbacks of this method were analyzed. The experimental biomass (from SNDOD-bioreactor) and high-organic substrate have been previously studied by respirometry methods. A biomethane potential of the investigated organic substrate has high rates because of substrate composition (the readily biodegradable substrate in the total composition takes about 85%). Waste activated sludge from SNDOD-bioreactor can be used for biofuel producing with high efficiency especially with pre-treatment like a thermal hydrolysis. Further studies have to consider the possibility of withdrawing inhibitors from waste activated sludge.

1. Introduction

The growth of energy consumption in transport sector has increased public interest in alternative non-fossil transport fuels. Especially critical problems are environmental pollution and climate change. This requires a search for alternatives to gasoline and diesel fuel. Alternatives may include biofuels, electricity, hydrogen fuel, synthetic fuel from natural gas. Currently, biofuels provide only a small part of total transport energy consumption (just about 2.5%). However, certain governments, public and private organizations have a policy to increase the use of biofuels. For example, in the European Union renewable energy in transport sector should reach 10% of the total energy use by 2020 [1].

A growing number of researches in different countries accompany development of biofuel technologies. The researches of the knowledge bases of Russian, German and Chinese biofuel technologies have been carried out in 2015 [2]. It is noted that the importance of researches of biofuels is clear in all three countries. There were total of 1797 Russian patents, 8302 Chinese patents and 21890 German patents in the European Patent Office database at the end of 2012. After analyzing the network of citations in patents, it is clear that Russia has poor fundamental basis for commercial biofuel production, in contrast to Germany and China. Because of the small number of stakeholders in Russia, the biofuel knowledge base is evolving rather slowly. However, the amount of research in this area is increasing for every year.

The stationary energy sector and the transport sector previously were considered as separate systems. However, in the case of using alternative energy, both of these sectors must be considered together, which is associated with a variety of factors.
Methodological approaches in which parts of the infrastructure energy systems and transport energy systems are studied separately will be the most widespread in the near future. However, consideration of connections between these systems becomes more and more important. Modelling of the total system will enable more energy efficient and environmentally friendly approach to transportation and infrastructure issues.

One of the most important elements of urban infrastructure is the wastewater discharge system. During wastewater treatment extra pollutions (primary sludge (PS) from primary settlers and waste activated sludge from bioreactors (WAS)) are generated. Disposal of PS and WAS a major operating cost for many of wastewater treatment plants [3-5]. This sludge has a great potential for recycling to biogas. After further treatment it can be used as biomethane and transport fuel.

PS and WAS contain large amounts of organic matter, thus becoming a good raw material to produce volatile fatty acids (VFAs). However, PS gives most of biogas. This is due to the fact that WAS is difficult to digest in anaerobic digesters.

Pretreatment technologies are effectively used to solve this problem. In general this preparation consists in dissolving an organic component of the activated sludge and hydrolysis of complex biopolymers. The most effective pretreatment is thermal hydrolysis process. Thermal hydrolysis at high pressure allows for increasing the degree of biodegradability of organic sludge components more than doubled. Energy balance of WWTP with TH and anaerobic digesters may become positive. The formation of volatile fatty acids significantly increased, which affects the output of biogas.

The most used technology nowadays is CAMBI™ (Figure 1) process (more than 30 operating facilities) [6], Previously dewatered sludge enters the pulper, where it is mixed and heated with recycle steam from the reactors and the flash tank. The gases which are released during the thermal process then are degraded in digesters. Then sludge passes thermal hydrolysis process in reactors at 160–170 °C (10–12 bar). The steam is fed back to the pulper. After thermal reactor sludge is fed to the flash tank by residual pressure in the reactor, which removes residual vapor which is recycled into the pulper after the precipitate temperature reduction in the heat exchangers. Then the sludge then is fed to the digester with mesophilic mode. There are systems, processing the mixture of PS and WAS, and systems processing exclusively WAS.

![Figure 1. Cambi™-reactors, Sarpsborg, Norway.](image)

Sewage sludge contains a large amount of water, and consequently, thermal hydrolysis may be used to produce chemical compounds therefrom [7]. High-temperature thermal hydrolysis positively affects the solubilization of organics and biopolymers in sludge [8]. The processes with high temperature and long duration are useful for the dissolution of proteins and carbohydrates, and promote the formation of biogas. Thermal hydrolysis leads to an increase of methane productions (up to 50%) and kinetics parameters [9].

Therefore, the main benefits of the technology are: exceeding the limit of productivity and efficiency, while maintaining conventional digesters volumes; increasing of fluid loss of waste activated sludge and
a significant (up to 25%) reduction of its further treatment costs; increasing the yield of biogas (up to 50%) [10].

The main drawbacks are: formation of the hardly soluble organic compounds at high temperatures; the reactor temperature should not exceed 180°.

For the study of effectiveness of biogas production it is necessary to correctly classify the substrate [11, 12]. To understand the potential of gas generation it is necessary to conduct the fractionation of the organic substrate [13, 14]. This characteristic can be used to build the balance equations [15].

2. Methods
The test for biomethane potential and COD fractions obtaining was carried out as part of the study of simultaneous nitrification and denitrification. Complex investigations of simultaneous nitrification and denitrification, which include both mathematical modelling and laboratory experiments, take place at the Moscow State University of Civil Engineering (NRU MSUCE). The experiments are conducted using the lab-scale models of oxidation ditches (SNDOD) [16]. Activated sludge at simultaneous nitrification and denitrification has certain properties so it is interesting to test its biomethane potential and obtain wastewater-biomass mixture COD fractions.

Fractionation COD is carried by respyrometric method. The total respiration rate is affected by the concentrations of all the biodegradable components [17].

3. Results
Major part of organic substrate for further high biogas yields is readily biodegradable substrate (Sb). It is composed of low molecular soluble compounds (VFAs, alcohols etc.). These compounds are degraded fully and rapidly.

For the experimental wastewater-biomass mixture from the SNDOD-reactor several respiration rate curves have been obtained (Figure 2). Nitrification for this process was inhibited. Respiration rate was monitored in the bioreactor with a daily cyclic feed by Ekama method.
Readily biodegradable substrate ($S_B$)(1):

$$S_B = \frac{V_{react} \cdot \Delta r_{O2,tot}}{Q_{WW} \cdot 1 - Y_{OHO}}$$  \hspace{1cm} (1)

where $V_{react}$ – volume of the reactor, $Q_{WW}$ – wastewater flowrate that enters into a reactor, total oxygen uptake rate of biomass, $Y_{OHO}$ – growth yield of heterotrophic microorganisms under aerobic conditions.

$S_B = 326$ mgCOD/L.

Slowly biodegradable substrate ($X_C B$) is composed of (high-molecular) compounds ranging from soluble to colloidal and particulate. These compounds cannot get into the cells (pass the cell membranes). Therefore $X_C B$ must undergo to $S_B$. $X_C B$ is considered to be a right part of a curve of respiration rate (Figure 3).

![Figure 3](image.png)

**Figure 3.** Respiration rates for estimation of $X_C B$ for the first experiment (blue markers) and the second experiment (red markers).

Slowly biodegradable substrate ($X_C B$)(2):

$$X_C B = \frac{2.86}{1 - Y_{OHO, ax}} \left( \int_0^{t_{W}} \frac{X_C B}{Y_{OHO, ax}} \right)$$  \hspace{1cm} (2)

$Y_{OHO, ax}$ – growth yield of heterotrophic microorganisms under anoxic conditions. It is lower than $Y_{OHO}$. $Y_{OHO, ax}$ is suggested to be taken as 0.54 gCOD biomass/gCOD substrate. $X_C B = 141$ mgCOD/L.

The results show high biodegradability of the experimental activated sludge. The substrate is saturated with low-molecular organic compounds. It may also affect the extracellular polymers of biomass.
4. Conclusion
Transport biofuels production can be combined with the use of new technologies of wastewater treatment (for example, with simultaneous nitrification and denitrification). Features of organic substrate and biomass in these technologies may increase the biogas yield. A separate study should be carried out for each of technologies. Simultaneous nitrification and denitrification previously has shown good results for COD-fractionation of biomass. This biomass will be used in further studies to estimate the biome thane potential.

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References
[1] Ahlgren E O, Hagberg M B and Grahn M 2017 Transport biofuels in global energy-economy modelling – a review of comprehensive energy systems assessment approaches (GCB Bioenergy)
[2] Kang J S, Kholod T and Downing S 2015 Energy Policy 85 pp 182–193
[3] Morgan-Sagastume F, Pratt S, Karlsson A, Cirne D, Lant P and Werker A 2011 Bioresource technology 1023 pp 3089–3097
[4] Allen E, Wall D M, Herrmann C and Murphy J D 2016 Renewable Energy 87 pp 656–665
[5] Carrere H, Antonopoulou G, Affes R, Passos F, Battimelli A, Lyberatos G and Ferrer I 2016 Bioresource technology 199 pp 386–397
[6] Pickworth B, Adams J, Panter K and Solheim O E 2006 Water science and technology 545 pp 101–108
[7] Suárez-Iglesias O, Urrea J L, Oulego P, Collado S and Diaz M 2017 Valuable compounds from sewage sludge by thermal hydrolysis and wet oxidation (Science of the Total Environment)
[8] Xue Y, Liu H, Chen S, Dichtl N, Dai X and Li N 2015 Chemical Engineering Journal 264 pp 174–180
[9] Cano R, Nielfa A and Fdz-Polanco M Bioresource technology 168 pp 14-22
[10] Phothilangka P, Schoen M A and Wett B 2008 Water science and technology 588 pp 1547–1553
[11] Skeer J and Nakada S 2016 Natural Resources 701 p 23
[12] Xia A, Cheng J and Murphy J D 2016 Biotechnology advances 345 pp 451–472
[13] Molino A, Nanna F, Ding Y, Bikson B and Braccio G 2013 Fuel 103 pp 1003–1009
[14] Patterson T, Esteves S, Dinsdale R, Guwy A and Maddy J 2013 Bioresource technology 131 pp 235–245
[15] Gogina E and Gulshin I 2016 Procedia Engineering 153 pp 189–194
[16] Gogina E and Gulshin I 2015 Procedia Engineering 117 pp 107–113
[17] Loosdrecht M C, Nielsen P H, Lopez-Vazquez C M and Brdjanovic D 2016 Experimental Methods in Wastewater Treatment (IWA Publishing)