Renewable Energy Investments for Sustainable Business Projects

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Chapter 1

Sustainable Investments in Biofuel Production Projects

Lyailya Maratovna Mutaliyeva and Ulf Henning Richter

Abstract

Bioenergy remains the largest branch of renewable energy, and microalgae are a promising object of research among other types of biomasses whose scale for energy purposes is increasing. On the other hand, the growth of global energy production and urbanization, which results in high rates of municipal waste and wastewater generation, requires the development of integrated technologies that allow waste to be disposed of as fully as possible. Sustainable investments in the production of energy by various technologies are one of the methods to solve this complex problem. In this chapter, we study the methods of microalgae utilization of nutrients from wastewater and by-product liquid waste of sustainable investments from microalgae by hydrothermal liquefaction (HTL) technology. Wastewater has a complex composition, and the treatment of nitrogen and phosphorus and other biogenic elements, as well as heavy metals, using biological objects is optimal and cost-effective. Also the water phase after HTL is a by-product that has limited energy value. Biofuel investments have higher growth rates and at the same time do not compete with the investments in fossil fuels. Biofuel investments' cost of seaweed fuel can be reduced through high-value-added related products, such as food and feed additives, and pharmaceutical and cosmetic products.

Keywords: Renewable energy sources; technological innovations; microalgae; biofuels; energy investments; clean energy; green energy; environmental considerations; wastewater; hydrothermal

1.1 Introduction

Microalgae (microalgae) as a raw material for the production of biofuel investments remain a relevant object of research among other types of biomass.

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Hydrothermal liquefaction (HTL) is one of the most promising technologies for the production of biofuel investments from biomass, since it makes it possible to process the wet biomass and convert all carbon-containing components (lipids, carbohydrates, proteins) into fuel. However, the HTL process leads to the formation of a secondary water phase, which has a limited energy value and needs to be disposed of. It is proposed to consider the possibility of using the water phase (as well as municipal wastewater for the cultivation in combination with the production of biofuel investments). This strategy is promising, as it reduces the cost of nutrients (fertilizers) and fresh water for cultivation, as well as emissions of CO_2 in the production of biofuel investments. HTL-water phase to improve the energy efficiency of biofuel production by HTL technologies.

Production of biomass on municipal wastewater, its conversion by the method of HTL. This study focuses on the conversion of bio-oil into biofuel investments with subsequent utilization of the by-product water phase to partially close the cycle of production of bio-oil for nutrients in order to reduce environmental burden.

1.2 Materials and Methods

Microalgae strains with a high growth rate and capable of responding to changing environmental conditions (decrease/increase in the concentration of basic biogenic elements, the presence of toxic substances in the culture fluid, etc.) (Baboshkin, Mikhaylov, & Shaikh, 2022; Baig et al., 2022; Barykin, Kapustina et al., 2022; Barykin, Mikheev et al., 2022; Bhuiyan, An, Mikhaylov, Moiseev, & Danish, 2021; Bhuiyan, Zhang et al., 2022; Candila et al., 2021; Danish et al., 2022; Dinçer et al., 2022; Dong, Ikonnikova, Rogulin, Sakulyeva, & Mikhaylov, 2021; Li, Yüksel, & Dinçer, 2022; Liu, Panfilova, Mikhaylov, & Kurilova, 2022a, 2022b; Mehta et al., 2022; Mikhaylov, 2015, 2021a, 2021b; Mikhaylov & Grilli, 2022; Mukhametov, Bekhorashvili, Avdeenko, & Mikhaylov, 2021; Saqib, Chan, Mikhaylov, & Lean, 2021; Yüksel, Khomyakova, & Mikhaylov, 2021; Yüksel, Mikhaylov, & Ubay, 2021; Yüksel, Mikhaylov, Ubay, & Uyeh, 2021).

Municipal wastewater from Moscow was used as the wastewater model. Cultivation in wastewater and aqueous phase solution after HTL biomass of *arthrospyra* was carried out in Erlenmeyer flasks with a volume of 250–500 ml, and the initial concentration was about 0.16 g/l by dry weight. Cultivation was carried out in undiluted samples of the water phase and wastewater, as well as in the specified samples diluted with tap water (dilution intervals of the water phase: 150–500 times, and juicy water: 3–10 times). The control was the growth of the biomass of the selected strains on the standard nutrient media indicated above. Each experiment was carried out in three replicates, and the growth of biomass was controlled colorimetrically. Control and experimental flasks were grown on rocking chairs (rotation of 120 rpm; T = 33°C; lighting 25–30). Control over the absorption of biogenic elements was carried out by chemical analysis of standard biogenic elements in the culture liquid at different stages of cultivation (Bhuiyan, Dinçer et al., 2022; Conteh et al., 2021; Daniali et al., 2021; Denisova, Mikhaylov, & Lopatin, 2019; Huang, Masrur et al., 2021; Huang, Yona et al., 2021; Kalinina et al., 2022; Khan et al., 2021, 2022; Liu, Kato, Mandal, Mikhaylov, Hemeida, & Senjyu, 2021; Liu, Kato, Mandal, Mikhaylov, Hemeida, Takahashi et al., 2021; Mikhaylov, 2018a, 2018b, 2022a, 2022b; Mikhaylov, Burakov, & Didenko, 2019; Nyangarika, Mikhaylov, & Richter, 2019a, 2019b; Sediqi et al., 2022).

HTL of biomass was carried out at the facility previously described. Experiments were conducted to obtain bio-oil products HTL from microalgae at T = 270°C, 300°C, and 330°C (Alwaelya, Yousif, & Mikhaylov, 2021; An & Mikhaylov, 2020, 2021; An, Mikhaylov, & Jung, 2020; An, Mikhaylov, & Kim, 2020; An, Mikhaylov, & Moiseev, 2019; An, Mikhaylov, & Richter, 2020; An, Mikhaylov, & Sokolinskaya, 2019; Dooyum, Mikhaylov, & Varyash, 2020; Grilli et al., 2021; Gura, Mikhaylov, Glushkov, Zaikov, & Shaikh, 2020; Mikhaylov, 2020a, 2020b, 2020c, 2021a; Mikhaylov & Sokolinskaya, 2019; Mikhaylov & Tarakanov, 2020; Mikhaylov, Yumashev, & Kolpak, 2022; Moiseev, Mikhaylov, Varyash, & Saqib, 2020; Moiseev et al., 2021; Morkovkin, Gibadullin, Kolosova, Semkina, & Fasehzoda, 2020; Morkovkin, Lopatkin et al., 2020; Mutalimov, Kovaleva, Mikhaylov, & Stepanova, 2021; Varyash, Mikhaylov, Moiseev, & Aleshin, 2020; Yumashev & Mikhaylov, 2020; Yumashev, Ślusarczyk, Kondrashev, & Mikhaylov, 2020; Zhao, Cherkasov, Avdeenko, Kondratenko, & Mikhaylov, 2021).

The yields of bio-oil, gaseous products, solid residue, and aqueous solution were 34–46%, 12–18%, 12–18%, and 10–24%, respectively. The molecular formulas of the substances in the final products were determined. It was found that biofuel investments are dominated by compounds containing one and two nitrogen atoms, and there are also classes of ON2 and N3. Bio-oil obtained from algae with a high content of lipids and carbohydrates is similar in composition to traditional oil. Water solution after HTL was used to cultivate microalgae and check the possibility of its recycling (Adalı, Dinçer, Eti, Mikhaylov, & Yüksel, 2022; An, Mikhaylov, & Jung, 2021; Danish et al., 2020, 2021; Dayong, Mikhaylov, Bratanovsky, Shaikh, & Stepanova, 2020; Mikhaylov, Sokolinskaya, & Nyangarika, 2018; Nyangarika, Mikhaylov, & Tang, 2018; Shaikh, Moiseev, Mikhaylov, & Yüksel, 2021; Tamashiro et al., 2021; Uyeh et al., 2021; Yüksel, Dinçer, Eti, & Adalı, 2022).

1.3 Characteristics of Municipal Wastewater Composition

Due to the autumn period with a high level of precipitation, municipal wastewater samples were significantly diluted. Concentration of biogenic elements used includes NH4+, NO3-, PO43- low – 110, 2.4, and 15 mg/l, respectively. COD indicators (bichromate oxidizability) 140 MgO/dm3 and BOD5 = 85 MgO2/dm3 indicate that the sample contains a small amount of dissolved organic matter. By the value of the hydrogen index (pH = 8.2), wastewater is classified as alkaline. Amount of petroleum products (2.7 mg/dm3) and total aromatics (0.668 mg/dm3) exceed the average values for this class of wastewater. Comparison of the composition of wastewater with the classical composition of culture media for the growth of microelements shows that wastewater contains all the microelements necessary for the growth and development of microelements. To analyze the typicality of the wastewater used, we compared the content of the main biogenic compounds in wastewater according to the literature data. At the same time, we took into account works that are similar in orientation, i.e., devoted to the study of the growth in wastewater. Comparison showed that the wastewater used in the study is typical, but with an underestimated index, and an overestimated content of ammonium nitrogen.

1.4 Characteristics of Microalgae Growth in Wastewater

Three clonal algologically pure cultures A. platensis Bios cells poorly grown on slightly diluted wastewater, and already on 5–7 days the crops died. On the contrary, the culture A. platensis Bios(P) cells with associated bacteria showed good growth in wastewater, diluting even two times. Therefore, experiments with culture A. platensis Bios(P) cells with associated bacteria were performed on 2–3-fold diluted wastewater. The growth of cultures in the experiment not only does not lag behind the control, but in the period of 7–12 days, the growth of cultures in wastewater with a dilution of 2× even outstrips the control.

On the 19th day of the experiment, the density of cultures in both variants reached the same values as in the previous stage of the experiment. In the future, the cultivation of the crop was continued for up to 47 days with the addition of the same portions of wastewater. Under these conditions, the growth and development of MCV occurred at an approximately constant rate.

1.5 Efficiency of Wastewater Treatment Using Microalgae

Inorganic nitrogen and phosphorus are particularly difficult to remove from wastewater. As shown by a comparative analysis of the main chemical parameters of wastewater before and after growing on it, A. platensis Bios (P) cells are capable of effective growth in slightly diluted wastewater, but under the mandatory condition of creating alkaline conditions for the growth and development of arthrospira cells in a nutrient medium by adding baking soda in an amount of at least 6 g/l. Cells A. platensis Bios (P) phosphorus in the form of orthophosphates, nitrogen in the form of ammonium and nitrates were completely consumed from wastewater, the concentration of which decreased by 430 times, 58–73 times, and 24 times, respectively.

In experiments with C.ellipsoidea due to the low rate of cell growth at the beginning of the experiment and the depletion of nutrients from wastewater, a fixed addition of Tamia nutrient medium with a potassium nitrate salt content of 5 g/l was made on the 27th day of the experiment, which increased the nitrate content in the nutrient medium to 807.7 mg/l. At the end of the experiment (47 days), nitrates were assimilated by chlorella cells by more than 70%, and phosphates and ammonium were completely assimilated.

G. pulchra adapted to the growth conditions by 25 days, resulting in 47 days of growing in diluted wastewater with the addition of an additional medium at intermediate stages BG-11 cells assimilated about 67% of the main biogenic elements from wastewater. *G. sulphuraria* not only adapted to cultivation in wastewater, but after the cultivation of MCV in wastewater, BOD indicators significantly decreased by 5, which indicates a reduction in the amount of easily soluble organic matter in wastewater.

1.6 Efficiency of Water Phase Utilization After HTL Using Microalgae

As mentioned above, in the production of biofuel investments from MCW by HTL, a significant amount of the water phase is formed as a by-product that has no energy value. Therefore, the study of the possibility of closing the process of biofuel production, namely the cultivation of microfuels with the maximum use of the by-product water phase, is relevant. We have studied the possibility of utilizing nutrients from the aqueous phase after HTL algae obtained during cultivation of A. platensis Bios. Nutrient content in the HTL-the water phase is orders of magnitude higher than in the standard nutrient media required for growing MCV. These include biogenic cations: ammonium (14,300 mg/dm3), potassium (4,500 mg/dm3), magnesium (up to 50 mg/dm3), sodium (3,800 mg/dm3), calcium (up to 50 mg/dm3), iron (up to 5 mg/dm3), silicon (20 mg/dm3) and biogenic anions: orthophosphates (5,200 mg/dm3), sulfates (530 mg/dm3), nitrates (up to 50 mg/dm3), bicarbonates (54,900 mg/dm3), carbonates (7,200 mg/dm3), and chlorides (600 mg/dm3). In addition, the aqueous solution contains a lot of trace elements vital for the growth and development of microalgae: manganese, copper, tungsten, cobalt, chromium, molybdenum, nickel, vanadium, zinc, boron, and titanium.

In addition to the abovementioned mineral elements, a large amount of total nitrogen is contained, mainly represented by ammonium cations in very large quantities (from 14.3 g/l in HTL-water phase at 270°C). The nitrogen content largely depends on the protein content, and more than half of the nitrogen is transferred to the aqueous phase during HTL (it is known that *Arthrospira* microalgae contain protein in record amounts – up to 65%). High value pH is found in the HTL-water phase, due to the high content of ammonia formed during protein hydrolysis and deamination. Organic carbon is mainly represented in the form of short-chain organic acids (acetic, propionic, etc.). Moreover, acetates are contained in large quantities (37.0 g/l). Acetate can act as a substrate for mixotrophic and heterotrophic growth of microarrays, contributing to an increase in the productivity of some strains.

The water phase without dilution inhibits the growth, which is associated with the presence of a large number of toxic compounds (phenols, cyclic nitrogen compounds, heavy metals, and ammonium ions). To prevent toxic effects, intensive dilution is necessary in the HTL-water phase of the diluted nutrient medium. Consortia *A. platensis Bios* with associated bacteria showed stable growth with less dilution of the aqueous phase after HTL, namely, 300–400 times. However, the cultivation of this consortium requires the addition of bicarbonate ions to create more favorable conditions for the growth and development of arthrospira. Thus, as a result of these studies, the possibility of utilization of candidate strains of nutrients from the soil was proved. HTL-water phase for partial closure of the bio-oil production cycle by nutrients.

1.7 Conclusions

Methods of cultivation in municipal wastewater and in the water phase after HTL of biomass were experimentally selected. The efficiency of wastewater treatment was analyzed during the HTL-water phase.

Addition of $NaHCO_3$ in wastewater in the amount of 6 g/l created favorable conditions for the growth and development of microarthrospyra ($pH > 8.5$; providing the culture with the anions necessary for the growth of HCO3-). When diluting wastewater by 1.2–1.5 times with the addition of $NaHCO_3$ the effective growth of this consortium with associated bacteria was observed for 47 days, as a result of which the concentration of nitrogen and phosphorus ions in wastewater decreased to trace values.

C. ellipsoidea in the first 12 days of treatment with wastewater without the addition of nutrients showed a significant increase in biomass (an increase in the density of biomass by 3.5 times). Adding on day 12 of the experiment a portion of wastewater, 1/4 of the Tanium medium, as in the case of *arthrospira*, led to a significant growth of chlorella cells to reach their maximum density of 0.8 g/l in dry matter.

It is established that for more efficient wastewater treatment by growing microbeads, it is necessary to select specific key factors for productive growth of biomass. The duration of the experiments (47 days) allowed us to identify the adaptive abilities of some microbes to wastewater as a growing medium and to obtain an algobacterial culture capable of "excessive" absorption of biogenic elements.

We experimentally selected MCV strains that can grow for a long period of time in a dilute state. HTL-water phase – *G. sulphuraria*, *C. vulgaris*, and *A. platensis Bios (P)*. The most active growth was also demonstrated by the consortium *A. platensis Bios (P)* with heterotrophic-associated bacteria that grew well on a less dilute surface. In HTL-water phase (300×–400×). *G. Sulphuraria* also grew well for more than a month in an aqueous solution, but diluted 500 times due to the transition of cells to mixotrophic nutrition.

The results obtained confirm that the microalgae-based technology of wastewater treatment and water phase utilization after the use of microalgae can be used in the following areas: HTL. It is technically feasible and promising and contributes to the partial closure of the bio-oil production cycle for nutrients and reduces environmental burden. For the future research directions, many different evaluations can be performed to increase clean energy investments. For instance, technological developments play a crucial role with respect to the cost minimization for green energy investments (Dinçer, Yüksel, Çağlayan, Yavuz, & Kararoğlu, 2023; Eti, Dinçer, Gökalp, Yüksel, & Kararoğlu, 2023; Yüksel & Mikhaylov, 2022). Hence, the competitive advantage can be provided to these projects (Li, Dinçer, Yüksel, Mikhaylov, & Barykin, 2022; Sun, Peng, Dinçer, & Yüksel, 2022; Wu, Dinçer, & Yüksel, 2022). Owing to this issue, biofuel investments can be preferred to fossil fuels (Kostis, Dinçer, & Yüksel, 2022; Yüksel et al., 2022). With the help of this condition, environmental pollution can be decreased (Kou, Yüksel, & Dinçer, 2022; Zhang, Zhang, Gong, Dinçer, & Yüksel, 2022).

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