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The Influence of Temperature Conditions on The Yield of Biogas and Methane, which is Obtained from Aquaculture Waste

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***Abstract*. The research looks into the potential of generating biogas from waste generated by aquaculture. The EDF-5.4_2 bioreactor, produced by "Biotehniskais centrs" (Latvia), was utilized for the experimental study. Samples of sludge from a fish farm located in Nagļu parish, Rēzekne district were collected and analysed for their moisture and organic matter content before being mixed with crushed reeds to increase the organic matter available for fermentation and biogas extraction.**

In this study, biogas was produced by mixing different ratios of sludge and reed residue. The yield of biogas varied based on the temperature, with the best results being achieved at 40°C. During the experiment, 2.75 L of biogas containing 37.3% methane was produced from the mixture of 1,200 g of fish farming sludge and 100 g of crushed reeds. Although the highest methane content of 40.16% was recorded at 43°C, the total amount of biogas produced was lower by 15% at this temperature.

The least favourable results were recorded at 37°C, in terms of both the amount of biogas produced and the methane content. The experimental studies demonstrate that residues from aquaculture can be used for biogas production.

Keywords: Aquaculture, waste, biogas.

I. Introduction

Aquaculture waste, in both solid and water form, is one of the main challenges for any aquaculture production system (such as fish and shrimp crops) and often enters the ecosystem, causing environmental pollution. Feed wastage has been identified as a major cause of high pollution loads in aquaculture effluents. In semi-intensive and intensive aquaculture systems, moderate to high fish population densities depend mainly or exclusively on the supplemented feed [1]. Despite their higher costs (around 50% of total production costs), from 8.6% to 52.2% of fish feed is consumed, and the remain is discharged into farming waters. It is estimated that more than half of the nitrogen (N) and phosphorus (P) elements in culture ponds are derived from fish feed, for example, 57–71% N and 44– 58% P are found in water in the common carp farm of Cyprinus carp [2]. The amount of feed wasted depends to a large extent on feeding methods (such as conventional feeding or chamber monitoring during feeding to reduce feed wastage) and the feeding behaviour of the cultivated species. In addition, feed quality determines the concentration of nutrients released into water bodies and is thus a contributing factor to water quality in aquaculture. The intensity of aquaculture production systems (i.e., either extensive, semi-intensive or intensive aquaculture systems) is also directly related to the potential adverse effects on the environment [3]. In addition to feed, the release of fish is an important source of elements found in aquaculture effluents. As a result of excretion, macronutrients, including P and N, in particular in the form of ammonia resulting from the amino acid catabolism of cultured species, are introduced into the aquatic environment. In addition to feed and excretion, aquaculture effluents may contain chemicals used for a different purpose in fish farms, such as medicines, fertilizers, disinfectants and antifoulants [4]. For example, although the antibiotic chloramphenicol is banned in many countries because of its negative effects on human health, it is still used to control diseases in fish or shellfish in aquaculture. Chloramphenicol does not decompose easily at ambient temperature even after hydrolysis [5], and its residues can often be found in nearby aquatic environments and organisms.

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The "Sustainable Development Strategy of Latvia until 2030" discusses the utilization of biological waste as a potential resource for biogas production, which can be applied in various sectors such as public transport, agriculture, and heat production. According to paragraph 224, this can be achieved. In Latvia, the aquaculture industry produced 788 tons in 2018. "Nagļi" is currently the biggest aquaculture company in Latvia as well as the entire Baltics. It is a full-cycle aquaculture farm with its own carp and pike farming material, which incubates spawning fish, rears juveniles and then sends the fish products to the market. The aquaculture facilities cover an area of about 2000 ha, including ponds, dams, land under the incubator and workshops, as well as the Malta river reservoir, from which all fishing ponds are filled [7].

Potentially, the "Nagļi" fishery can produce up to 1,500 tonnes of aquaculture production per year. At the same time, the amount of waste generated during the life cycle of fish also will be 1,500 tonnes per year. On the one hand, it is a very big problem to dispose and treat such amount of waste, but on the other hand, waste from fish farming processes is a good raw material for biogas plants. For example, a biogas plant with an electrical capacity of 100 kW_{el} requires about 6 tonnes of raw materials per day. Although biogas production from aquaculture waste is generally less effective than from other raw materials (e.g., from fish processing waste it is possible to produce 20 mL g^{-1} of biogas per day, but from corn stover – 40 mL g^{-1} of biogas per day), nevertheless, the aquaculture farm called "Nagļi" has the ability to supply enough raw materials to power a 100 kW electric biogas plant, which would address the issue of waste disposal while also generating electricity and heat for the farm's use. [8]-[10].

Likewise, waste management and energy scarcity are challenges encountered by companies involved in fish processing. As of 2018, Latvia had over 100 fish processing companies that generated almost 100 tons of fish products. The waste produced by these plants can serve as valuable input material for biogas facilities [11].

Biogas production can utilize various types of organic matter as feedstock, including readily available biomass such as manure, by-products of food production, forest and wood processing waste, sewage sludge, household organic waste, straw, and more. However, the quantity of biogas generated from each source can differ and is not constant [12].

The materials utilized for producing biogas can be categorized based on their source, dry matter percentage, methane production potential, and other characteristics [13].

The wet fermentation method involves using substrates that contain less than 20% dry matter, which encompasses materials such as animal slurry, sewage sludge, manure, and wet organic waste from the food industry (such as whey from dairy processing). On the other hand, dry fermentation is employed for substrates with a dry matter content of at least 35%, which is typically found in energy crops and silage [14]. Energy crops consist of grasses like grass, maize, and oilseed rape, as well as trees like willow, poplar, and oak, although the latter requires special pre-treatment to remove lignin [15].

The strict separation of wet and dry fermentation technologies is biologically misleading, as the microorganisms involved in the fermentation process need a liquid medium to grow and multiply [16]. The classification of technologies does not depend on the dry matter content of the individual substrates used, but on the dry matter content of the bioreactor. In wet fermentation technology, the dry matter content of the reactor is about 12%, and the reactor content can usually be pumped because it is liquid. If the dry matter content of the reactor is increased to 15-16%, the reactor content can no longer be pumped and this technology is called dry fermentation [17].

Obtaining biogas from organic fractions of municipal solid waste, various manure, fish waste, and agricultural waste has been described by different researchers. However, fewer studies have been reported on the use of aquaculture waste. McDermott et al. [18] reported the production of biogas while investigating the effect of sonication as a pre-treatment of aquaculture waste for anaerobic digestion. Lanari and Franci [19] produced biogas from rainbow trout faecal sludge biomass using an anaerobic recirculating upflow digester. Marheim et al. [20] described the treatment of solid waste from the fish processing plant by a combined digestion method with thermophilic anaerobic bacteria and blowflies to produce biogas. Batch fermentation of fish waste and sisal pulp was studied by Mshandete et al. [21] in bioreactors constructed using conical glass flasks. Gebaur [22] reported that anaerobic treatment is the preferred method for stabilizing and hygienizing sludge from saline sewage from fish farms due to its biogas production.

The initial attempts to obtain biogas from aquaculture waste under local conditions, as well as the influence of certain physical factors on biogas yield, were investigated in the authors' previous articles [23]- [24].

The scope of this present work was to conduct research work on laboratory scale in order to estimate the biogas producing from anaerobic digestion of aquaculture waste and crushed reeds.

II. Materials and methods

A. Biomass

Aquaculture residues (sludge) from a fish farm located in the Rēzekne district, Nagļu parish were selected as raw material for biogas production and research. The reeds from Daugavpils Esplanāde pond were used for increasing organic matter content. The reeds were dried 24 h in the drying oven Binder FD 23 at 70°C and 0% air recirculation and then crushed manually.

Digestate from the biogas plant "Skaista" located in Skrudaliena parish of Daugavpils district was utilized to effectively carry out anaerobic fermentation processes.

B. Laboratory scale bioreactor

The bioreactor *EDF-5.4_2* produced by “Biotehniskais centrs” in Latvia was utilized to conduct experimental research. This bioreactor is specifically designed for studying biomethane production, with a sturdy, ergonomic and compact build. Its design includes a glass cylinder vessel positioned between the metallic jacketed bottom and the upper lid. The bioreactor is easy to maintain and carry out basic operations, such as washing and autoclaving.

Mass flow controllers from Hamilton ARC and pH and dissolved oxygen sensors were used for gas mixing. These sensors send signals directly to the process control system (PCS) and also facilitate data management via Bluetooth through a program that can be accessed through a smartphone or PC. The program generates a report detailing calibration procedures, sterilization numbers, and predicted service life. The sensors are also connected to the PCS for off-gas analysis to identify and estimate the volume of O_2, CO_2, and CH_4.

The PC implemented program algorithms, such as Matlab and Python, were utilized to perform on-line/off-line data analysis and advanced process control. These algorithms communicate with the PCS and the Supervisory Control and Data Acquisition (SCADA) system.

C. Determination of slugde and reed moisture

To determine the organic matter content of the sample, the crucibles were first heated to 800±10°C for at least 60 minutes in a muffle furnace *Nabertherm LE 6/11*. After being removed from the furnace, the crucibles were allowed to cool for 5-10 minutes on a heat-resistant surface before being placed in a desiccator to cool completely. Each cooled crucible was then weighed to the nearest 0.1 mg using an analytical balance, and 1 to 2 g of the test sample was added to the crucible. The test sample was then heated for two hours at 800±10°C in a muffle furnace, and placed back in the desiccator to cool. This heating and weighing process was repeated until a constant weight was achieved. The organic matter content was calculated as a percentage of the dry residue. This same procedure was carried out for the reed sample. Both procedures were performed according to the ISO 18122:2015 – Solid biofuels – Determination of ash content.

D. Preparation of the mixture for biogas production

The experiment was conducted three times. First, 100 grams of crushed reed powder was added to 1,200 grams of aquaculture sludge, and the mixture was thoroughly mixed. The prepared mixture was then immersed in the reactor vessel, and 300 mL of bog water was added and mixed thoroughly using a metal spatula. Finally, 1,000 grams of digestate was added, and the bioreactor lid was firmly sealed. The appropriate temperature mode and agitator rotation speed were selected and connected to the bioprocess controller.

E. Selected parametrs of the bioprocess controller

The following parameters were used in the bioprocess controller to perform the research:

- 37°C, 40°C, and 43°C temperature mode;
- Agitator rotation speed interval 50 RPM;
- Foam level sensors.

A computer equipped with SCADA software was connected to the bioreactor in order to monitor and record the volume and composition analysis of the biogas that was released.

III. RESULTS AND DISCUSSION

A. Determination of slugde and reed moisture and organic matter content

The moisture results acquired from the sludge samples are appropriate for generating biogas because the substrate samples contain roughly 15% dry matter (as seen in Table 1). These outcomes are consistent with the wet fermentation process used, which resembles other feasible biogas technologies [13].

TABLE 1 MOISTURE LEVELS AND ORGANIC MATERIAL COMPOSITION OF BOTH SLUDGE AND REED. AVERAGE VALUES AND RELATIVE STANDARD DEVIATIONS ARE GIVEN FOR THREE REPLICATE RUNS

Biomass	**Moisture [%]**	**Organic matter content (from dry matter) [%]**
Sludge	83.47±0.55	26.91±0.68
Reed	1.18±0.19	96.14±0093

The sludge samples contain roughly 27% organic matter, indicating a substantial amount of inorganic substances in the substrate. To increase biogas production in the study, a larger quantity of aquaculture sludge needs to be added to the bioreactor, along with another type of substrate that consists of 95% or more organic matter.

The reed samples contain roughly 96% organic matter, signifying a substantial amount of organic material. Thus, it would be beneficial to incorporate the reed samples with the fish-farming pool sludge in a specific proportion.

B. Biogas production

During the experiment, the amount of released biogas and its gas composition were studied with the software SCADA. The biogas release trend over 60 days at 40°C is shown in Figure 1.

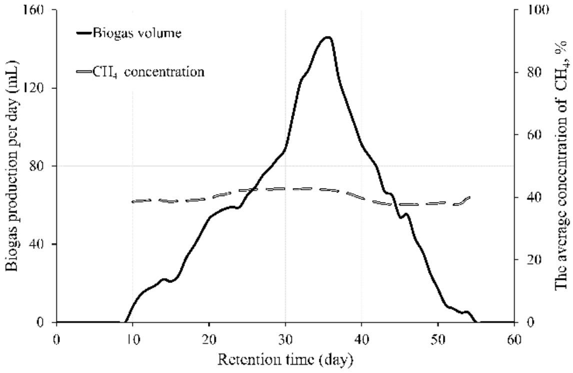

Fig. 1. Trend in biogas volume and proportion of methane in biogas release over 60 days at 40°C.

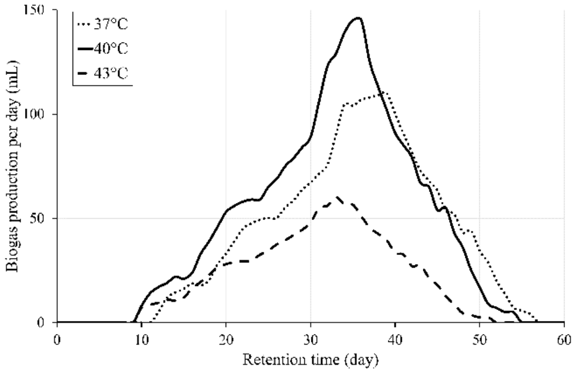

Fig. 2. Trend in biogas volume release over 60 days at different temperatures.

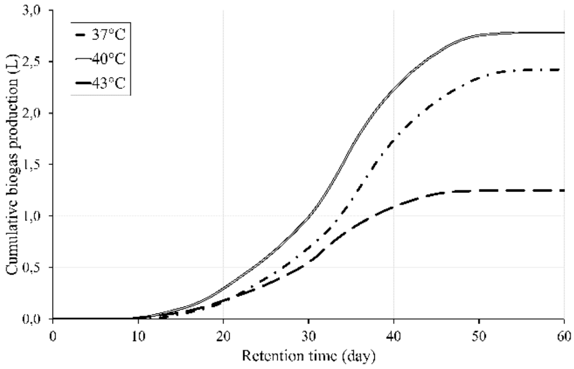

Fig. 3. Trend in cumulative biogas production over 60 days at different temperatures.

95% of the total biogas produced during the fermentation period (60 days) was produced between days 10 and 55. The optimal retention times are approximately 36 days. The total volume of biogas produced during the fermentation period is approximately 2.75 liters – it corresponds to 2,155 mL kg^{-1} waste. Similar results were obtained by Salam and Sarker [25], who investigated the anaerobic digestion of fish waste and co-digestion of fish waste and cow dung. The maximum ultimate gas yield was obtained from 1:1.2 fish waste and cow dung ratio and amounted to 1,955 mL kg^{-1} waste.

The average methane concentration in the biogas is 37.3%, the carbon dioxide is 61.8%, and the other gases are 0.9% of the sample.

Figure 2 shows the evolution of biogas volume over 60 days at 37°C, 40°C and 43°C. The optimal storage time is approximately 35 days at 40°C, 38 days at 37°C and 33 days at 43°C. The feed mixing mode during the experiment prevents the formation of dry and inactive flotation layers and can affect the optimal retention time. In this study, more than 95% of biogas can be produced in less than two months.

For three temperatures, the average cumulative biogas production in litres was measured and recorded daily, as shown in Figure 3. As can be seen from Figure 3, the influence of the temperature on cumulative biogas production is substantial. The temperature affects bacterial and archaeal community structure, diversity of microbiota and the high complexity of their interactions that mediate biogas production. Hence a detailed understanding of the temperature impact on microbiota is essential for the overall stability and performance of the anaerobic digestion process.

IV. CONCLUSIONS

The amount of biogas produced during the bioprocess is influenced by temperature, and our research found that the optimal temperature was 40°C. In our experiment, a combination of bog sludge and crushed reeds yielded 2.75 liters of biogas with an average methane content of 37.3% at 40°C. Although the highest proportion of methane (40.16%) was obtained at 43°C, the total amount of biogas produced at this temperature was approximately 15% lower. The worst results were obtained at 37°C – both in terms of biogas volume and methane content.

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