# Thermal Recovery of Lemna Minor during the Process of Obtaining Hydrogen

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Received: 01 November 2022/ Revised: 09 November 2022/ Accepted: 16 November 2022/ Published: 30-11-2022


**Abstract—** *The aim of the article is a theoretical evaluation of the possibilities of using fast-growing aquatic plants, specifically Lemna minor, for the mass production of biomass suitable for the subsequent thermal treatment during the blue hydrogen production process. Much laboratory research has demonstrated the possibility of increasing the volume of biomass under controlled conditions, using water from wastewater treatment plants, or water contaminated with organic residues (faeces) from organic production. Hydroponic cultivation in controlled conditions has shown the possibilities of removing hazardous substances from wastewater, possibly reducing their contamination and at the same time, producing organic biomass with more favourable properties than in the case of dendromass.*

***Keywords*— Lemna minor, biomass, hydrogen, thermal treatment.**

## I. INTRODUCTION

The increasing effort of producing hydrogen, which is not tied to fossil sources, is the incentive to search for other methods of its mass production. In addition to methods that use water electrolysis for obtaining hydrogen, there is also a gradual expansion of methods that use organic substances to produce hydrogen, which subsequently undergo thermal recovery. In addition to synthesis gas, products of such thermal recovery are also various oils, tars and solid residue, which can subsequently be used in various industrial areas. The use of fast-growing biomass also enables the storage of solar energy by a method other than just in the form of batteries. Biomass stores solar energy transformed into lipids and other organic energy stores, while it´s considered a carbon-neutral source, since during its growth, an equivalent amount of CO2 is absorbed from atmosphere to the amount of CO2 released during its combustion process. Of particular importance is the potential of biomass-derived fuels to replace petroleum-based fuels, such as gasoline, jet fuel and diesel fuel, and thereby decreasing the dependence on imported oil. Hydrocarbon-based fuels offer several advantages over oxygenated biofuels (e.g. biodiesel, bioethanol), in that they have a higher volumetric energy content and are compatible with already existing infrastructure for the import and distribution of fuel [1].

## II. LEMNA MINOR

Lemna minor is one of the smallest and fastest-growing flowering plants on earth. It´s an extremely reduced floating freshwater plant, with one, two, three or four leaves, each of which has one root hanging in water. The root is 1-2 cm long. Leaves are oval, 1-8 mm long and 0,6-5 mm wide, light green colour, with three (rarely five) veins and small air spaces that allow the plant to float on the water surface. 1 As an aquatic plant, Lemna minor is commonly used to remove excess nutrients (e.g. nitrogen and phosphorus) and toxic metals from agricultural and municipal wastewater. For more than 30 years, researchers have been demonstrating the potential use of sewage grown Lemna minor as a possible food supplement for livestock. Due to considerable growth rate and high protein content, protein productivity can be ten times higher than that of soybeans, without encroaching on arable soil necessary for food growing [2].

The growth rate of Lemna minor in the wastewater is given in an open uncontrolled environment at the level of 29 $g \cdot m^{-2} \cdot day^{-1}$, which equals 104 $t \cdot ha^{-1} \cdot year^{-1}$. The rate of removal of excessive amount of nitrogen and phosphorus in wastewater was at the maximum of 3,36 $g \cdot m^{-2} \cdot day^{-1}$ for nitrogen and 0,59 $g \cdot m^{-2} \cdot day^{-1}$ for phosphorus [3]. By subsequent thermal processing it´s possible to regain phosphorus originally obtained from wastewater and use it for further technological purposes.

In addition to nutritional values, which are the main indicator for the use of biomass produced from Lemna minor for livestock fattening, the biomass also contains significant amounts of starch, which, unlike cellulose, can be easily converted into bioethanol that can serve as a potential source of biofuel produced in wastewater. Overall decrease in the contamination of wastewater from organic production with the most important components can be observed in Table 1.

**TABLE 1**
**COMPOSITIONS OF SWINE LAGOON WASTEWATER AND SH MEDIUM BEFORE AND AFTER CULTURE OF LEMNA MINOR. [4].**

| Elements | $NO_3^- - N$ $(mg \cdot l^{-1})$ | $PO_4^{3-} - P$ $(mg \cdot l^{-1})$ | $CO(NH_2)_2$ $(mg \cdot l^{-1})$ | $NH_4^+ - N$ $(mg \cdot l^{-1})$ | $total\ sugars$ $(mg \cdot l^{-1})$ | pH |
|---|---|---|---|---|---|---|
| SL wastewater | | | | | | |
| Day 0 | 0.8 ± 0.1 | 16.3 ± 0.6 | 16 ± 0.1 | 56.1 ± 0.9 | 36.3 ±0.2 | 7.4 |
| Day 18 | 0.2 ± 0.2 | 4.1 ± 0.3 | 0.2 ± 0.1 | 0 | 1.6 ± 0.1 | 6.8 |
| Removal (%) | 75.0 | 74.8 | 87.5 | 100 | 95.6 | - |
| SH medium | | | | | | |
| Day 0 | 495.3 | 85.1 | 0 | 35.5 | 10 000 | 5.6 |
| Day 27 | 24.2 ± 2.1 | 10.4 ± 1.2 | 0 | 0 | 250.6 ± 22.3 | 6.5 |
| Removal (%) | 95.1 | 87.8 | 0 | 100 | 97.5 | - |

As can be seen in Tab.1., according to the research by Jianfeng Xu et al., there´s a significant decrease in wastewater contaminants from agricultural production. A decrease in contamination in the case of wastewater in municipal wastewater treatment plants can be assumed at the same level.

## III. INCREASING THE YIELD OF LEMNA MINOR PER 1 M2 OF USEFUL AREA

Increasing the yield of biomass produced by Lemna minor is conditioned by maintaining an appropriate water surface population density. With the increasing population density of living biomass on the water surface, there is a significant slowdown in the production of new offshoots and thereby a slowdown in the biomass production. The growth rate is also significantly related to the ambient temperature and with rising temperature, the reproduction rate increases approximately linearly until the optimal population density is reached.

As stated by E. H. van Nes et al., the highest growth rate 0,30 $d^{-1}$ was observed at biomass population density of 10 $gDW \cdot m^{-2}$. During their experiments, in the measurement of growth rate they also reached a value of 26 $g \cdot m^{-2} \cdot day^{-1}$ [5], which does not significantly differ from the findings of team led by J. Cheng, although the difference could be caused by the different location during the experiment, when the J. Cheng´s team worked in Brazil during summer, while the team led by E. H. van Nes worked in the Netherlands during the spring.

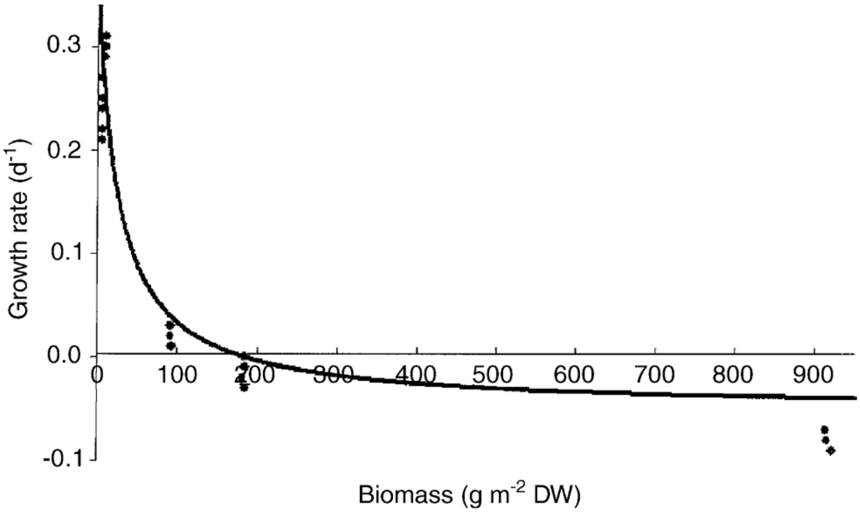
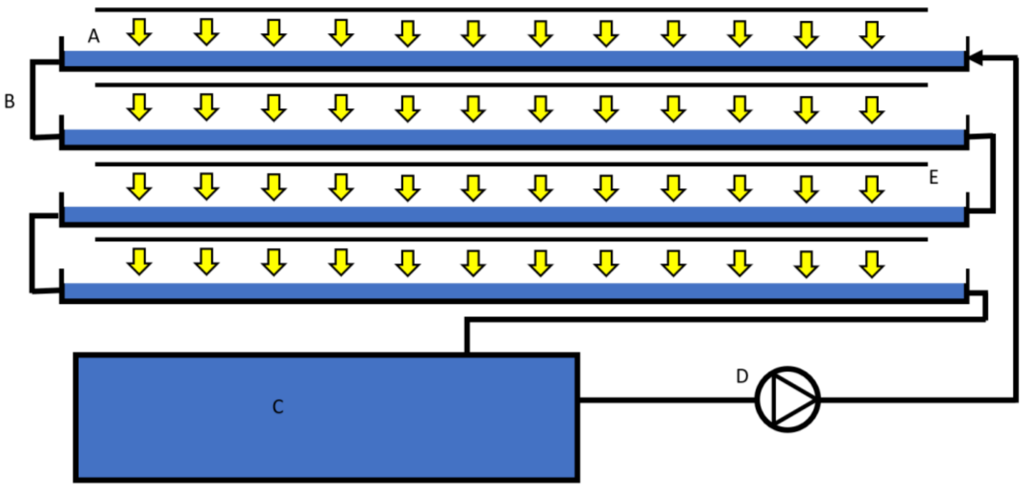



**FIGURE 1: Growth rate as a function of the initial biomass of Lamna minor (gDW m$^{-2}$). Dots indicate the measured growth rate. The solid line represents the curve described by the model at a constant temperature of 23 °C [5].**

The limitation of Lemna minor´s population density can by circumvented by the industrial method of hydroponic cultivation when it is possible to place tanks with wastewater on top of each other and ensure sufficient light with the use of electric lighting.




A – water reservoirs for biomass cultivation, B – connecting pipe, C – water tank with the water quality sensors, systems for adding and adjusting nutrients and systems for temperature controll, D – circulator pump, E – full-spectrum light

**FIGURE 2: Simplified scheme of Lemna minor multi-layer cultivation**

It is possible to implement the flow method of wastewater passage for the multilevel arrangement of tanks, when the wastewater enters the highest tank and subsequently, by the action of gravitational force, gradually passes through the lower tanks until it reaches the lowest tank, from where it flows farther for further cleaning, or closed circulation, when the large-volume container is filled with contaminated water, which then passes through the tank system using a circulator pump and a gravity, until the desired decrease in contamination, primarily by phosphorus and nitrates, is reached.

In hydroponic cultivation, it is possible to use technical spaces that have no practical use, because they are located underground without windows, have poor ventilation or other unfavourable properties, or buildings directly built for the purposes of hydroponic cultivation. During the theoretical analysis, it is possible to work with a closed room with dimensions 10x5x2,5 meters, where it would be possible to place wastewater tanks with a spacing of 25 cm. The given arrangement would allow the increase of useful area from 50 $m^2$ to 400 $m^2$. With the daily production of 29 $g \cdot m^{-2} \cdot day^{-1}$, which could be increased by lighting 24 $h \cdot day^{-1}$, a daily production of 11,6 kg DW·day-1 could be possible. If operated 360 days a year, the annual production of such a room would be cc 4175 kg DW·year [1].

## IV. THERMAL TREATMENT OF DRY LEMNA MINOR

According to N. Muradov et al., the chemical analysis of dry Lemna minor is as follows (hm. %):

- humidity – 3,7.
- total volatile substances (120–950 °C) – 78,0 (including volatile substances released at 120–650 °C – 67).
- solid carbon – 8,8.
- ash – 9.5.

The final analysis of the dry sample of Lemna minor gave the following chemical composition of individual elements (%): C – 39,11; H – 6,13; O – 37,74; N – 5,52; S – 0,67

The high proportion of carbon and oxygen in the dry sample of Lemna minor indicates the formation of a significant amount of carbon dioxide and carbon monoxide, during the biomass heat treatment process. As shown by the results of N. Muradov et al., increasing the temperature of the process has a significant effect on the production of carbon monoxide in favor of the formation of carbon monoxide and hydrogen.

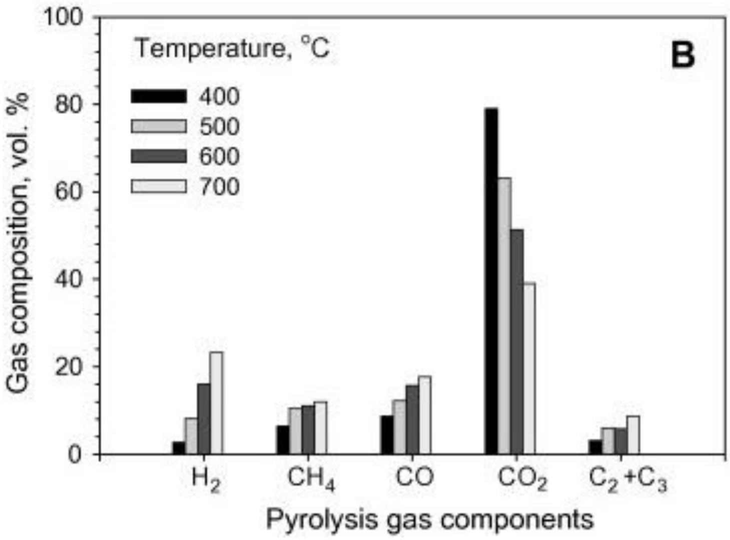



**FIGURE 3: Composition of pyrolysis gas produced by Lemna minor pyrolysis depending on the pyrolysis temperature at Air flow rate of 60 $ml \cdot min^{-1}$ [6]**

The amount of carbon dioxide produced as result of thermal conversion of Lemna minor to synthesis gas is too high for subsequent processing in obtaining hydrogen. By increasing the temperature of the Lemna minor thermal recovery process, or by using a plasma reactor system, an increase in the proportion of hydrogen and gases such as methane and carbon monoxide could occur, which can then be technologically processed using WGS reactors using a suitable catalyst and water vapor into carbon dioxide and hydrogen.

## V. CONCLUSION

As a result of the evaluation of the many projects in the field of cultivation, use and processing of Lemna minor, it is possible to come to conclusion that the production of biomass from the mentioned plant with the use of wastewater, represents one of the ways to reduce our society's dependence on fossil fuels and dendromass, which currently represents a short-term but slow renewable compensation. The suitability of direct thermal treatment of Lemna minor to synthesis gas suitable for hydrogen production is debatable. A more suitable procedure is to use methanogenic organisms to produce methane from Lemna minor biomass, which can then be technologically modified using WGS reactors for hydrogen and carbon dioxide.

## ACKNOWLEDGEMENTS

This paper was written with the financial support from the VEGA granting agency within the project solutions No. 1/0626/20 and No. 1/0532/22 from the KEGA granting agency within the project solutions No. 012TUKE-4/2022 and with financial support from the granting agency APVV within the Project Solution No. APVV-15-0202, APVV-21-0274 and APVV-20-0205.

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