MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF ENVIRONMENTAL SAFETY,
ENGINEERING AND TECHNOLOGIES
DEPARTMENTOF ENVIRONMENTAL SCIENCE

APPROVED TO DEFENCE
Head of the Graduate Department
_____ Tamara DUDAR
«_____» _____ 2023

BACHELOR THESIS

(EXPLANATORY NOTE)

SPECIALTY 101 “ECOLOGY”,
EDUCATIONAL AND PROFESSIONAL PROGRAM:
“ECOLOGY AND ENVIRONMENT PROTECTION”

Theme: «Study of the parameters affecting the production of biodiesel from microalgae»

Done by: student of EK-402 group, Natalia S. Lialuk (student, group, surname, name, patronymic)

Supervisor: Ph. D. in Technological Sc., Associate Professor of the Environmental Science Department, Lesia I. Pavliukh
(academic degree, academic rank, surname, name, patronymic)

Standards Inspector: _____ Andrian IAVNIUK
(signature) (S.N.P)

KYIV2023

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
ФАКУЛЬТЕТ ЕКОЛОГІЧНОЇ БЕЗПЕКИ,
ІНЖЕНЕРІЇ ТА ТЕХНОЛОГІЙ
КАФЕДРА ЕКОЛОГІЇ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач випускової кафедри
_____Тамара ДУДАР
«_____» _____ 2023 р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯБАКАЛАВРА

ЗА СПЕЦІАЛЬНІСТЮ 101 «ЕКОЛОГІЯ»
ОПП «ЕКОЛОГІЯ ТА ОХОРОНА НАВКОЛИШНЬОГО СЕРЕДОВИЩА»

Тема: «Дослідження параметрів, що впливають на виробництво біодизеля з мікроводоростей»

Виконавець:студентка групи ЕК-402**,** Лялюк Наталія Сергіївна
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КИЇВ 2023

NATIONAL AVIATION UNIVERSITY
Faculty of Environmental Safety, Engineering and Technologies
Department of Environmental Science
Specialty, Educational and Professional Program: specialty 101 "Ecology",Educational and Professional Program: "Ecology and Environment Protection"
(code, name)

APPROVED
Head of the Department
_____Tamara DUDAR
«____» _____ 2023

BACHELOR THESIS ASSIGNMENT
Natalia S. Lialuk

1. Theme:«Study of the parameters affecting the production of biodiesel from microalgae» approved by the Rector on September 19th April, 2023, №529/ст.

2. Duration of work: from29.05.2023to18.06.2023.

3. Output work (project): raw material data for biofuel production.

4. Content of explanatory note: (list of issues): to analyze the current of the fuel and energy complex; to research biodiesel technologies in the context of sustainable development; to analyze the high energy properties of microalgae; to assess the prospects for the production of biodiesel from microalgae in Ukraine; to investigate parameters affecting the production of biodiesel from algae cultures; to calculate the total annual profit from the sale of biofuel from microalgae.

5. The list of mandatory graphic (illustrated materials): tables, figures.

6. Schedule of thesis fulfillment

№	Task	Term	Advisor's signature
1	Receive themes task, search the literature and legislation	29.05.2023	
2	Preparing the main part (Chapter I)	01.06.2023	
3	Preparing the main part (Chapter II)	03.06.2023	
4	Preparing the main part (Chapter III)	05.06.2023	
5	Formulating conclusions and recommendations of the thesis	06.06.2023	
6	Making an explanatory note to the previous presentation of the department, consultation with the norms controller	07.06.2023	
7	Presentation of the work at the department	10.06.2023	
8	Taking into account the comments and recommendations and training to protect	15.06.2023	
9	Thesis defense at the department	20.06.2023	

7. Date of task issue: «25»May2023

Diploma (project) advisor: _____ Lesia PAVLIUKH
(advisor's signature) (S.N.P.)

Task is taken to perform: _____ Natalia LIALUK
(graduate's signature) (S.N.P.)

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет екологічної безпеки, інженерії та технологій

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(шифр, найменування)

ЗАТВЕРДЖУЮ
Завідувач кафедри
_____Тамара ДУДАР
«____» _____ 2023 р.

ЗАВДАННЯ
на виконання кваліфікаційної роботи
Лялюк Наталія Сергіївна

1. Тема роботи «Дослідження параметрів, що впливають на виробництво біодизеля з мікроводоростей»
затверджена наказом ректора від «19» Квітня 2023р. №529/ст

2. Термін виконання роботи: з 29.05.2023 р. по 18.06.2023 р.

3. Вихідні дані роботи: дані про сировину для виробництва біопалива.

4. Зміст пояснювальної записки: проаналізувати стан паливно-енергетичного комплексу; досліджувати технології біодизеля в контексті сталого розвитку; аналізувати високоенергетичні властивості мікроводоростей; оцінити перспективи виробництва біодизелю з мікроводоростей в Україні; дослідити параметри, що впливають на виробництво біодизелю з культур водоростей; розрахувати загальний річний прибуток від продажу біопалива з мікроводоростей.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: таблиці, схеми.

6. Календарний план-графік

№	Завдання	Термін виконання	Підпис керівника
1	Отримання теми завдання,пошук літературних джерел та законодавчої бази	29.05.2023	
2	Підготовка основної частини (Розділ І)	01.06.2023	
3	Підготовка основної частини (Розділ ІІ)	03.06.2023	
4	Підготовка основної частини (Розділ ІІІ)	05.06.2023	
5	Формулювання висновків та рекомендацій дипломної роботи	06.06.2023	
6	Оформлення пояснювальної записки до попереднього представлення на кафедрі, консультація з нормоконтролером	07.06.2023	
7	Представлення роботи на кафедрі	10.06.2023	
8	Урахування зауважень. Рекомендацій та підготовка до захисту	15.06.2023	
9	Захист роботи на кафедрі	20.06.2023	

7. Дата видачі завдання: «25» травня 20 23 р.

Керівник кваліфікаційної роботи (проекту): _____ Леся ПАВЛЮХ
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Завдання прийняв до виконання: _____ Наталія ЛЯЛЮК
(підпис випускника) (П.І.Б.)

ABSTRACT

Explanatory note to the thesis "Study of parameters affecting the production of biodiesel from microalgae": 52 p., 8 tab., 3 fig., 37 references.

Research object: parameters that can affect the production of 3rd generation biodiesel.

The purpose of the work: to study the parameters which have impact on biodiesel production from microalgae.

Research methods: analysis, synthesis and generalization of data, classification of parameters affecting the production of biodiesel from microalgae, as well as assessment of biofuel production based on algae biomass.

The results of the thesis can be used not only for further research on the production of biofuel from microalgae, but also for solving Ukraine's energy problems in an ecological way.

MICROALGAE, BIODIESEL, SUSTAINABLE DEVELOPMENT.

CONTENT

INTRODUCTION

Relevance of the work. The rapid increase in the cost of traditional (fossil) types of fuels and the reduction of their natural reserves led to the need to find ways to produce fuels based on renewable energy sources.

Today, among the most studied alternative sources of energy are corn, soy, sunflower, rapeseed (in order words, vegetable raw materials). But microalgae can be another, no less valuable raw material for the production of biofuel. Biodiesel from microalgae is the third generation of biofuel, which is obtained by processing plant raw materials.

Advantage is that growing algae does not require preparation and fertilization, as they use carbon dioxide (CO_2) to grow. Also, growing algae can help solve greenhouse effect problems, because the higher the concentration of carbon dioxide, the faster the algae gain weight. However, any production opportunities and threats.

The use of biomass of microalgae biomass to produce biofuels for various purpose will allow to reduce the negative impact on the environment.

Aim and tasks of the diploma work

Aim of the work – to study the parameters which have impact on biodiesel production from microalgae.

Tasks of the work:

1. To analyze biodiesel technologies in the context of sustainable development;
2. To investigate the advantages of bioenergy from algae over biofuel from oil crops;
3. To study the parameters affecting the production of biodiesel from microalgae;
4. To estimate economic benefit from biodiesel production;
5. To provide practical recommendations to biodiesel production from microalgae.

Object of research - technology of obtained biodiesel from microalgae.

Subject of research – the parameters that affect the production of 3rd generation biodiesel.

Methods of research **–** analysis, synthesis and generalization of data, classification of parameters affecting the production of biodiesel from microalgae, as well as assessment of biofuel production based on algae biomass.

Practical significance of the work lies in the fact that it can be used not only for further research on the production of biofuel from microalgae, but also for solving Ukraine's energy problems in an ecological way.

Personal contribution of the graduate: the practical part of this work aimed at studying the parameters that allow influencing, improving or correcting the situation with the production of biofuel based on microalgae. Characteristics, based on a SWOT analysis, which can be used as primary material for further scientific research or to influence the finding of the optimal method of obtaining biomass. Calculation of the total annual profit from the sale of biofuel from microalgae.

Publications*:*

1. Margaryta Radomska, Lesia Pavliukh, Natalia Lialuk, Veronika Petroschuk. Complex solutions for sustainable development of degraded lands of the Kherson region. Proceedings of the National Aviation University. 2021.Vol. 87(2). P. 48-56.

2. Lesia Pavliukh, Natalia Lialuk, Olena Horbachova. Assessment of biofuel production technologies from microalgae and organic waste. Science-based technologies. 2022.Vol. 54. No 5. P.155-162 . DOI: https://doi.org/10.18372/2310-5461.54.16753

CHAPTER 1
RESERCH OF BIOTECHNOLODICAL APPROACHES TO SUPPORT THE ENERGY COMPLEX OF UKRAINE

It has long been no secret that economic development and the standard of living of the population is determined by the energy potential of the country as a whole. Directly or indirectly, energy has an impact on the environment. This manifests itself in environmental pollution, climate change, depletion of natural resources, etc. Therefore, it is worth noting that the emergence of alternative energy sources can help solve certain environmental problems.

1.1. The current state of the fuel and energy complex

Energy is developing faster and faster every day, while the guarantors of energy security, as well as reducing the negative impact on the environment, are becoming priority development goals today.

Fossil fuels are still the main fuel for energy production. However, the rapid pace of economic development is accompanied by the depletion of deposits, and therefore the problem of finding and developing new deposits arises. And therefore, the unprofitability of most of the fuel resources and the increase in the price of energy carriers.

If you analyze all the stages of the energy industry, from the extraction of minerals to the direct burning of fuel, then all of them are accompanied by harmful emissions into the atmosphere. According to statistical data, the fuel and energy complex occupies one of the leading places in terms of emissions into the atmosphere. For example, sulfur dioxide and ozone oxides cause the appearance of acid rain, while burning organic fuel releases carbon monoxide into the atmosphere, where it accumulates, thereby increasing the greenhouse effect.

Having analyzed the above, we came to the opinion that the negative impact of the fuel-energy complex can be reduced in the following ways:

– to introduce technologies for the purification of exhaust gases, with the aim of minimizing harmful emissions to atmospheric air;

– rational use of energy;

– implementation of alternative energy sources.

We believe that one of the significant problems of the fuel and energy complex of Ukraine is the use of fossil energy sources, which are the cause of global environmental pollution. Whereas one of the most promising areas of alternative energy, in our opinion, is the use of biomass energy [1].

1.2. Biodiesel technologies in the context of sustainable development

At the modern stage, civilization cannot do without traditional types of fuel, but their reserves are exhausted, and the demand is growing and growing. Gradual transition to renewable energy sources (biodiesel) can be a great way out of this seemingly closed circle.

Ethanol, methanol and biodiesel are the three main types of biofuel. So what is "biofuel"? It is a fuel of organic origin that can be used as an energy source in an internal combustion engine. One of its main advantages is reproducibility, and it is made from raw materials of plant origin.

It may seem as if biodiesel appeared recently, but the first biodiesel was presented at the World Exhibition in Paris by Rudolph Diesel. It was the first diesel that ran on vegetable raw materials. Since then, technology has advanced significantly. So, what advantages will a motorist get if he starts using fuel that is unusual for many? Let's try to list them:

1) Biodiesel can be used not only in its pure form, but also combined with various types of traditional diesel fuel;

2) There is less carbon dioxin (by 80%) and sulfur dioxin (100%) among the exhaust gases;

3) Since the composition of biodiesel does not include sulfur, there is no soot, and therefore it significantly increases the service life of the engine;

4) Safely transported, as it is low-toxic and has a high ignition temperature;

5) There is a large selection of raw materials;

6) There is no unpleasant smell of exhaust gases [2].

One of the important components of the criteria of sustainable development is the gradual transition to renewable energy sources, the reasons for which were the constant increase in the price of energy resources and their exhaustive nature. It is obvious that the use of exhaustible resources leads to a harmful effect on the environment from the side of the economy and ecology, and at the same time cannot guarantee the sustainable development of world energy for a long period [3].

Humanity has always needed and will need the existence of energy resources for its own comfort. In the process of evolution of world society, the need for these resources has increased significantly. However, if at the beginning of scientific and technical progress, the main goal was to extract energy in any way, then now, when society felt the first bells from the side of the ecological situation, the ecological awareness of the need for changes in the field of energy began to progress. This is how the so-called "The Green Economy" appeared, with the aim of proving to people that everything on Earth is interconnected, that is, it is impossible to satisfy the ever-growing needs of humanity.

"The Green Economy" is aimed at economical use of gas and oil, as well as rational use of inexhaustible resources. The creation of the "Green Economy" was the first step towards the awakening of human consciousness. But the main goal of this program was to make people think about what we will leave to our descendants [4].

Over time, it became clear that the "Green Economy" has limited prospects. Therefore, in the last ten years, a program called "The Blue Economy" has been actively implemented. It is a program of economic thinking, according to which humanity can find sufficiently simple and cheap resources that do not harm the environment, for this it is necessary only to take a closer look at the way things are arranged on Earth.

Thus, one of the directions of the "Blue Economy" is deep industrial processing of algae in order to obtain valuable products. A separate area of their use is bioenergy [5].

1.3. Comparative analysis of biofuel production based on microalgae with other technologies based on plant raw material

Mineral and organic energy reserves in the near future will no longer meet the ever-increasing and greater energy needs of mankind. New technologies are already emerging around the world that allow the production of organic biofuels based on many plant species. However, the cultivation of crops, on the basis of which in the future will produce biofuels, leads to depletion of land resources. Simply put, the thin layer of fertile humus, as well as the top layer of humus is gradually depleted, which can lead to the decommissioning of millions and billions of hectares of arable land [11].

Another advantage is that algae, unlike the cultivation of other plant materials, do not need fertilizing. For their full growth, algae use only carbon dioxide (CO_2). Moreover, the higher the concentration of carbon dioxide, the faster the algae will gain weight [12].

Algae are universal because they do not have a true root system or leaves. They do not contain cellulose or lignin, which improves the conversion of raw materials into biofuels. For greater clarity, we can show quantitative comparative characteristics of the fat content in terrestrial plants and their aquatic relatives. From 0.4 hectares of occupied area you can take liquid fuel: corn – 68.4L; soya – 181.7L; sunflower – 408.8L; rape – 480.7L; algae (natural conditions) – 7003L; algae (laboratory indicators) – 18,927L – 56,781L [13].

Equally important is that in a closed system, algae require 99% less water than other land crops. Due to the fact that aquatic plants do not have a strong stem and roots and accumulate nutrients with their entire surface, they are able to gain biomass much faster than other economic plants.

In the last 5 years, oil from agricultural crops has become more and more expensive, which is connected with the increase in the prices of fertilizers, as well as their later transportation. Here again, algae are an alternative, as the production of oils from algae using inexpensive waste is a very attractive alternative for next-generation biofuels. Also, the use of oil from algae, instead of oil obtained from food crops, does not compete with

food products and does not affect food prices.

But, despite the great prospects of bioenergy from algae, their cultivation is also an expensive pleasure. For example, if we take into account the heterotrophic cultivation of algae. Heterotrophic cultivation is based on the use of sugar as a carbon source and leads to a significantly higher oil content compared to those grown under phototrophic conditions. But this technology is expensive and competes with the food market, which complicates the economically successful application of the method [14].

1.4. Assessment of prospects for the production of biodiesel from microalgae in Ukraine

Ukraine has opportunities to grow microalgae for biodiesel production. According to IrynaLoginova for Infoindustry magazine, algae will help Ukraine in both energy and environmental aspects. "Cultivation of microalgae to obtain biodiesel will partially solve the environmental problems of carbon dioxide utilization and reduction of the greenhouse effect," the specialist thinks.

Under the leadership of Professor Yelizarov, in the laboratory of Kremenchug University, they created a plant that processes blue-green algae of the Dnipro into biogas.

"Algae are grown in phytobioreactors, which are closed, automated systems," says Iryna. She also emphasizes that due to the modern technologies of this reactor, the installation requires minimal consumption of materials and labor during operation.

According to Irina's expert, CO_2 should be supplied to the installation continuously during the daylight hours. She also claims that for the production of 100 tons of biomass from algae, it is necessary to have 180 tons of carbon dioxide. Personally, they supply gas from a CO_2 cylinder, but can also be supplied from diesel generator exhaust after pre-cleaning.

"Most algae develop in reservoirs at a temperature of 35-40°C, as the temperature rises, their number drops sharply. It should also be noted that the cultivation of algae in ordinary reservoirs is not effective, since the vertical placement of algae in special installations avoid problems with access to the sun and temperature," the expert notes [6].

Slobodian N.M., Shulgin S.V., Tsarenko P., Borysova O., Blum Y. are involved in the technology of producing biodiesel from algae in Ukraine. While the technology for growing algae is supplied by the Scientific and Production Company "Prombiotechnika" Mariupol, Donetsk region [7].

1.5. Impact of biofuel on environment safety and natural balance

As mentioned earlier, biofuel is an organic material, such as wood, waste, alcohol, or algae, which can be used for energy production and also has the ability to renew itself, unlike other natural resources (oil, coal or nuclear fuel). If we talk about the official definition of biofuel, then it is any fuel that contains at least 80% (by volume) of materials obtained from living organisms and which is more environmentally friendly than the usual sources of energy common to all. Let's move directly to the impact of biodiesel on environmental safety, as well as on the balance of the environment [8].

According to many experts, one of the main factors is that the cultivation of algae for the production of biodiesel will partially solve the environmental problems of CO_2 utilization and thus reduce the greenhouse effect [9].

Another advantage of algae biofuel is that the production of biofuel produces by-products that can be used to produce fertilizers with high nitrogen and phosphorus content. Algae fertilizers are much safer and more environmentally friendly than manure [10].

1.6. Conclusions to the chapter

So, whether it is due to the decrease in the subsoil of non-renewable energy resources or due to the rapid increase in interest in biofuels, but perhaps the usual ecological awareness, but more and more new and quite promising technologies for the production of biofuels are being created. Biofuel is one of the technologies of the "Blue Economy", the goal of which is to find simple and cheap solutions for natural resources, while not harming the environment. At this stage, "Blue Economy" is aimed at finding new solutions regarding biofuel from algae (and not only), which will be even safer for the

environment. Many articles and publications are devoted to this, research and production companies have been created in different countries of the world, which are engaged in the production of the most ecological biofuel.

In my opinion, Ukraine has a high potential for growing algae, which will be used as biofuel in the future.

In the conditions of our country, it is possible to produce biogas from algae. For development, you can take the green colonial algae Botryococcusbraunii, it contains more than 70% of carbohydrates by dry mass, and also has a wide geographical area of distribution in Ukraine.

CHAPTER 2
ANALYSIS OF HIGH ENERGY PROPERTIES OF MICROALGAE

2.1. Study of the characteristics of biofuels from vegetable raw materials: economic, ecological and social block.

In the table 2.1-2.3 economic, ecological and social characteristics of biofuel types are presented.

Table 2.1

Economic characteristics of biofuel types [15,16,17,18]

Plant	Cost of equipment	The duration of the growing cycle	Crop capacity (2017 -2020)	Fat content per 0.4ha
Sunflower	The price of equipment for sunflowers is higher than ordinary firewood.	6 – 8 weeks	10.1 – 14.2 million tons	408.8L
Corn	The cost of plant equipment - $200 million	6 – 25 days	35.8 – 40.2 million tons	68.4L
Rapeseed	450 thousands of dollars	45-55 days	1-1.2 million tons	480.7L
Soy	3 058 523.28 UAN	95-110 days	1.8 – 2 million tons	181.7L
Algae	4300 dollars	3 – 10 days	500 million tons	Natural conditions– 7003L Lab. conditions – 18 927 – 56 781L

Table 2.2

Ecological characteristics of biofuel types [19,20,21,22,23]

Plant	Production area (2018 – 2020)	Chemical reagents	Emissions into the atmosphere
Sunflower	4000 – 7000 thousand hectares	Synthetic additives and chemical compounds are not used in the production. However, fertilizers are used during germination.	No dangerous volatile substances or allergens are released during combustion. The volumes of carbon dioxide emitted are insignificant, so the atmosphere is not particularly damaged.
Corn	4000 – 5000 thousand hectares	Requires significant application of mineral fertilizers and plant protection products.	In general, the use of corn for energy purposes can reduce greenhouse gas emissions by 30%.
Rapeseed	61.6 thousand hectares	Rapeseed yields require more fertilizer than grain	Emissions of volatile organic compounds, in particular hexane, in interaction with nitrogen oxides cause the formation of photochemical smog, which adversely affects almost all components of ecosystems.
Soy	112.5 thousand hectares	When grown, it requires the application of fertilizers with micro- and microelements.	Because soy require fertilization, it has a fairly significant percentage of greenhouse gas emissions and other harmful substances into the atmosphere.
Algae	7500000 thousand hectares	Growing algae does not require preparation and fertilization.	Growing algae can help solve the problem of the greenhouse effect.

Table 2.3

Social characteristics of biofuel types

Plant	Competition in the market (+/-)	Production in Ukraine (+/-)	Traditional fuel replacement score (1-5)
Sunflowers	+	+	5
Corn	+	+	5
Rapeseed	+	+	5
Soy	+	+	5
Algae	-	+	5

2.2. Approaches to the bioenergy implementation

Third generation biodiesel, the source of which is algae, became a new stage in the development of biofuels. As you already know, there are certain varieties of algae that contain a significant amount of vegetable fats, from which the same biodiesel can be made in the future. It is not a surprise to anyone that in order to obtain biofuel from algae, they need to be grown, but for this it is not necessary to occupy the acreage of the land fund at all. Lower plants can grow in ponds, on the seabed or in specially arranged bays, that is, algae occupy those areas that are not involved in the production of food. It is because of this that it can be said that third-generation biofuel is still in the development stages, but it is already clear that this bioenergy has the greatest prospects.

The main problems that arise during the cultivation of algae in open water bodies are excessive sensitivity to temperature fluctuations. In order to overcome this problem, scientists began practicing the technology of growing algae in small bioreactors. Moreover, in bioreactors located near thermal or nuclear power plants. In this way, the waste heat of power plants will be able to cover up to 77% of algae's heat needs. Thus, this technology will not require a hot desert climate, but on the contrary, it allows to obtain biodiesel from algae in any part of the planet. Bioreactors can solve most of the problems faced by algae grown in open water bodies. But on the other hand, bioreactors require significant financial investments [24].

Algae are unpretentious and easy to grow and feel good in environments poor in mineral composition. They only need the presence of sunlight, carbon dioxide and nitrogen to grow, but much less nitrogen is needed than algae for agricultural plants [25].

Among the approaches to the implementation of this type of bioenergy, two types of conditions are known:

1. Phototrophic conditions (the presence of light and carbon dioxide as a carbon medium);

2. Heterotrophic conditions (absence of light, presence of glucose as a carbon source and presence of organic molecules as raw materials) [26].

At the same time, phototrophic conditions will not only be cheaper, but will help in solving greenhouse gas problems. Whereas heterotrophic conditions require significant capital investment, as sugar is a competitive product in the market.

2.3. SGT LipiTrigger technology, algae and oil production

There will not be enough oil for our age. And gas, and oil, and even ordinary fuel of organic origin, most likely, will not be enough even for our children. Looking into the distant future regarding the production of mineral fuels is absurd, but more and more often analysts claim that oil and gas resources will not be enough for more than 50 years. Therefore, at this stage, scientists turned their attention to the virtually inexhaustible biomass resource of the World Ocean.

The world-famous company Sustainable Green Technologies is engaged in the development of fuel that does not lead to emissions of greenhouse gases into the atmosphere. She aims to invent ways to process algae to obtain oils that will be used to produce biofuel.

Algae are highly efficient converters of solar energy into renewable biomass, most algae known to company scientists stored solar energy in the form of sugars, such as starch or sucrose, but not in the form of oils (lipids or fats). In the presence of carbon dioxide, light and some trace elements, some algae are able to store only 15-20% of fat from their dry weight. And only under certain conditions, algae can switch to a process better known

as the "lime trigger" and store the products of photosynthesis inside their cells in the form of oils - which, for Suatainable Green Technology, were much more important than sugars.

LipiTrigger is a method developed by scientists at Sustainable Green Technologies. This method forces algae to synthesize more oils (from 15% to more than 50% of dry weight) without disrupting growth. The company's scientists concluded that if algae could synthesize more oils and achieve higher growth rates than other oil crops, this would lead to the production of not only environmentally friendly but also lower-cost biofuels [27].

Thus, the well-known company Sustainable Green Technologies has shown how algae can be used to meet our needs and to reduce the negative impact on the biosphere.

2.4. Alternative energy from algae: interest of different countries

Countries such as Japan, Israel, France, the USA and Germany first became interested in biofuel from algae in the 70s during the oil crisis. But as soon as the crisis receded, they forgot about alternative energy from algae. But the future disappearance of mineral types of energy reserves forced to restore the energy sector of the 70s.

At this stage, the Sustainable Green Technology is engaged in the development of new technologies related to the production of oils and algae. They focused on processes that would allow obtaining a high amount of biomass and on a steady increase in the percentage of oils from algae.

Sustainable Green Technology identified the main reasons for the development of technologies for extracting oils from algae:

- Diversification of alternative energy;
- Creation of new jobs on the green market;
- CO_2 processing and climate protection;
- Implementation of biofuel from non-food products.

So, as long as you do not have to pay for sunlight and it is more than enough for alternative energy, it compensates for about 80% of the total amount for this technology. Another part of the amount is for the conditions for growing algae.

In 1980, scientists at the Department of Energy focused on creating huge algae

farms in the sunniest regions of the United States.

The researchers set up algae farms in open but small water bodies in the United States and used carbon dioxide emissions as raw material. But scientific researchers of the Department of Energy encountered several shortcomings:

1. Since the ponds were small in size, in order for the algae to receive a sufficient amount of sunlight, as a result, they received limited biomass production due to the small depth of the pond;

2. The possibility of inhabiting ponds with other forms of life. An open pond is prone to colonization by other life forms, which as a result begin to compete with the algae for important nutrients, thus the desired yield of biomass products has been reduced;

3. A limited number of sources with large CO_2 emissions [28].

2.5. Conclusions to the chapter

In Ukraine, according to the statistical data of our table and information data from Internet sources, among the plants that can be used for the production of biofuels, rapeseed is the most common, since its sown areas are large, and the yield itself is quite high. Regarding its characteristics:

- it has a relatively short growing cycle;
- high fat content;
- available for biofuel production on the territory of Ukraine;
- can completely replace traditional fuel, but requires not cheap processing equipment.

We can say that rapeseed is an ideal substitute for traditional fuel, but not everything is so ideal from the side of the ecological block:

- occupies large areas of sowing, although it does not justify it with its productivity;
- cultivation requires a large content of chemical reagents;
- emits a large amount of volatile compounds into the atmosphere, forms smog, which negatively affects all components of the ecosystem.

Summarizing the above and comparing the data in the tables again, I am convinced

that algae biofuel is the most attractive of all the blocks of characteristics, because:

- algae have a very short growing cycle and, at the same time, the highest productivity and fat content;

- their cultivation does not require the introduction of chemical reagents, which prevents emissions into the atmosphere;

- algae is not only environmentally friendly for cultivation, but also helps in the fight against greenhouse gases;

- they have the prospect of production in Ukraine and can replace traditional fuel;

- do not compete on the market;

- even though the sown areas are large, they pay off with high productivity and ecological indicators.

The production of first-generation biofuels (corn, soy, sunflower, and others) requires significant raw materials. Their cultivation requires an appropriate land fund, which in turn will cause a reduction in the land fund of the food industry or the development of new lands.

The advantages of biofuel from algae over biofuel from vegetable oils are as follows:

1. Algae contain a large amount of polyunsaturated fatty acids, which help biodiesel not lose its fuel quality at low temperatures (cold operation);

2. The amount of fuel at the output from algae is 20-30 times greater than from vegetable oil crops, even if their growth will take place on the same land area.

Today, the production of biofuel from algae is the most effective technology for obtaining alternative fuels. It has advantages, in particular, over the same production of biofuel from vegetable oils. It should also be noted that algae saturate the atmosphere with oxygen, which is important for all mankind.

One of the main disadvantages of growing algae, or rather their further processing, is the rather high cost of equipment. However, the equipment itself does not need to be supplied from abroad, since the Scientific and Production Company "Prombiotechnika" is engaged in the production of equipment for processing algae on the territory of Ukraine.

CHAPTER 3
INVESTIGATION OF PARAMETERS AFFECTING BIODIESEL PRODUCTION FROM MICROALGAE

3.1. Parameters affecting the production of biofuel from algae cultures

Here we come to the main section, in which I collected the main aspects that should be paid attention to in the production of biofuel. For convenience, I decided to divide the research parameters into "general" and "direct".

In table 3.1 you can see 2 types of parameters that affect the production of biofuel from microalgae.

Table 3.1

Parameters affecting the production of biofuel based on microalgae

Parameters	
General	**Direct**
1)Lighting	**1)Type of algae**
2)pH level	**2)Features of cultivation** - in open systems; - in closed system.
3)Air temperature	**3)Collection of biomass**
4)CO_2 level	**4)Processing of biomass** - thermochemical conversion; - biochemical conversion; - chemical transformation.
5)Content of micro- and macromolecules	**5)Drying of biomass**
	6)Oilextraction - the method of mechanical failures; - supercritical fluid method extraction; - solvent extraction; - termochemical liquefaction with further cleaning; - ultrasonic extraction.

We called the parameters used and implied in most of the productions "general". Among them are: lighting, pH level, air temperature, carbon dioxide level in the air, as well as the content of micro- and macromolecules.

So, I suggest that we immediately proceed to the characteristics of each of the parameters.

Lighting: A sufficient amount of sunlight is necessary for the optimal development of algae. Their lack or excess can inhibit the growth of aquatic plants.

pH level: Some species can thrive in an environment with a pH value of 7.0 to 9.0, but a normal pH value should range from 8.2 to 8.7. Yes, as I already said, the plant will develop even at lower pH values, but in order to achieve a higher raw material base in a shorter period of time, you need to adhere to the norms that I indicated above.

Air temperature: Here everything is as simple as with the pH level, the temperature can fluctuate while the plant will grow and develop, but the best temperature should reach from 20°C to 24°C.

CO_2 concentration in the air: 0.03% is the level of CO_2 in the air that algae cells use for photosynthesis, however, in order to achieve a high amount of biomass, it is necessary to control that the air mixture contains at least 1% CO_2, because as I mentioned earlier, what the higher the concentration of carbon dioxide in the air, the faster the algae gain weight. Therefore, scientists note that the cultivation of algae is profitable near enterprises that produce a large amount of carbon dioxide. For example, one such enterprise can be a coal-fired power plant.

The content of micro- and macromolecules: This parameter is not mandatory, but its presence allows obtaining biomass containing up to 50% more lipids than without the use of mineral fertilizers. However, feeding algae is possible only when growing them in closed systems, or as a preventive measure for cleaning water from sewage pollution of a number of enterprises. Ammonia, mineral salts, and carbon dioxide are good nutrients for growing algae with a high lipid content.

It is also important to note that the quality of the initial product is greatly influenced by the fatty acid composition of hydrogen culture lipids. Among saturated acids, palmitic acid is typical for algae, while linolenic and palmitic acids are among unsaturated acids.

The fatty acid composition of microalgae can be changed by influencing the cultivation of algae or the physical and chemical conditions. If you increase the illumination or decrease the temperature, the content of unsaturated fatty acids will increase. At the same time, if you influence the mineral culture medium or change other physicochemical parameters, you can adjust the intensity and direction of lipid biosynthesis, the fatty acid composition, and the ratio of lipids. All these factors play a role in obtaining the final product [29].

In the table below, you can see the "general" indicators that are necessary for the normal development of microalgae summarized in the table 3.2.

Table 3.2

«General» indicators that are necessary for the normal development of microalgae

General parameters	Indicators for optimal development
Lighting	Optimal amount of sunlight
pH level	From 8.2 to 8.7
Air temperature	From 20°C to 24°C.
C02 concentration	At least 1%
Content of micro- and macromolecules	Ammonia, Carbon Dioxideandmineral salts

Thus, the "general" parameters that affect the production of algae are not only economically beneficial, but also ecologically promising. All parameters mentioned above can be controlled by phytobioreactors, which we will talk about in the analysis of "direct" impact parameters.

Now we propose to consider the parameters, which I decided to call "direct", since they derive directly from the technology of biodiesel production based on microalgae.

The process of obtaining biodiesel from algal cultures consists of cultural cultivation, selection and primary processing of biomass, destruction of cells and extraction of lipids, and later transesterification or hydrolysis to obtain biofuel or bioethanol [30].

It is worth noting that after cultivation of algae and several gradual processes, in the

final output we can get both biofuel and bioethanol. However, unlike the production of bioethanol from algae, the raw material for biofuel is lipids extracted from cells, which in a certain concentration and proportions with hydrocarbons of classical fuel can be immediately used as fuel.

So, researching each of the 4 main processes of biodiesel production, we identified the "direct" parameters that, in my opinion, affect the production of biofuels based on aquatic plants. You can see them in the form of a figure 3.3.

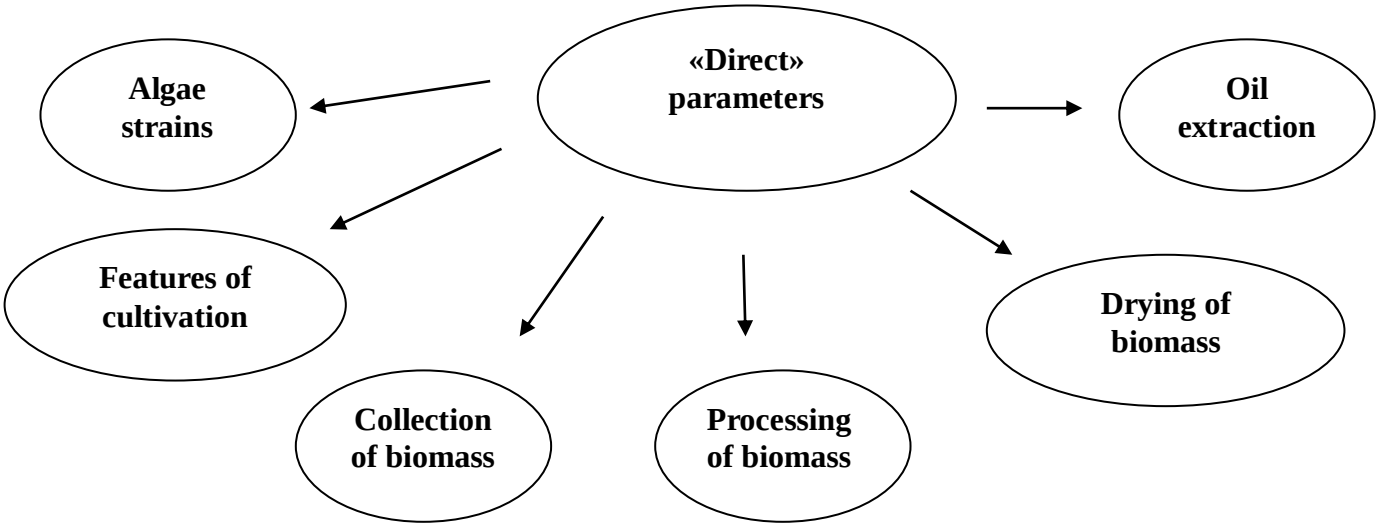

Fig. 3.3 "Direct" parameters affecting the production of biofuels based on aquatic plants

Now I propose to consider each of these parameters in more detail and at the end of the discussions to view the abbreviated version of the recorded studies in the table 3.3.

As I mentioned earlier, the peculiarities of cultivation, type of algae, processing technology, all this directly affects the result of biomass processing, since the final product can be both biofuel and other valuable substances: triglycerides, fatty acids, lipids, carbohydrates (sugar, starch), ethanol, cellulose, etc.

Microalgae have high productivity and the ability to build up significant volumes of biomass. It is important to note that they can accumulate up to 80% of lipids in their composition. For example, the genus Nannochloropsis may contain 70%, while blue-green algae are about 20%.

Valuable groups of algae for biofuel production are: Green algae; Diatom algae;

Golden algae; Cryptophytic algae; Haptophytic algae; Blue-green algae.

The table 3.4 presents the comparative characteristics of different groups of algae as raw materials for the production of biodiesel.

Table 3.4

Comparative characteristics of different strains of algae as raw materials for the production of biodiesel [31]

№	Groups of algae	Lipids	Carbohudrates	Proteins
1	Spirulinaplatansis	4-9	8-14	46-63
2	Chlorella vulgaris	14-22	12-17	51-58
3	Anabaena clylindricae	4-7	25-30	45-56
4	Euglena gracilis	14-20	14-18	39-61
5	Scenedesmusdimorphus	16-40	21-52	8-18
6	Dunaliellasalina	6	32	57
7	Tetraselmismaculata	3	15	52
8	Prymnesiumparvum	22-38	25-33	28-45

After analyzing this table, it can be noted that the content of lipids, proteins and carbohydrates in Shlorella vulgaris and Scenedesmusdimorphus exceeds the indicators of some other groups of algae.

3.2. Features of microalgae cultivation

If we return to the scheme of biofuel production from microalgae and characterize all production stages, cultivation is the most important, since it determines the qualitative and quantitative indicators of biomass.

The climatic zone of Ukraine causes seasonal fluctuations in air temperature, especially in the east and south. Such amplitudes make it impossible to cultivate algae in open water bodies, since in this case the cultivation process itself will not be profitable.

But, regardless of this, the cultivation of algae can take place in closed reservoirs, in other words phytobioreactors. This method of cultivation makes it possible to observe optimal conditions for the normal development of microalgae [32].

Cultivation in open systems. As I mentioned earlier, this method is used only in two cases. The first, if a large amount of biomass is needed, and the second - for the purpose of cleaning water bodies.

Cultivation in open systems should be used in areas with a warm dry climate, a small number of rainy days and minor temperature fluctuations.

Open systems for the cultivation of algae are usually represented by pools, trays, tanks or trenches with small depths.

Among the disadvantages of cultivation of algocultures in open systems should be noted:

- Dependence on the climate;
- Seasonal operation of systems;
- It is impossible to control the temperature regime and lighting;
- The need for constant control of the carbon dioxide content in the air and the pH level;
- Evaporation of water;
- The need to control the content of micro- and macromolecules.

Cultivation in closed systems. As you already understood, closed cultivation systems compared to open cultivation systems have many more advantages, in particular, the ability to control the cultivation conditions. Systems of closed types help to increase the volume of biomass by 1-2 times. Moreover, this is due to the fact that closed cultivation systems are able to independently supply CO_2 to the device and maintain its optimal amount in the air to increase the productivity of aquatic plants.

For the cultivation of large amounts of algae, it is advisable to use nutrient media that would help algal cultures obtain all the necessary micro and trace elements. As I have already mentioned, closed-type cultivation allows you to maintain the supply of necessary fertilizers to the apparatus, which is much more convenient and profitable than in open-type cultivation. Mineral fertilizers or mineral water with the addition of organic substances can be used as a nutrient medium.

An example of a closed cultivation system is a tubular reactor, the basis of such an institution is glass tubes, in which the reproduction of aquatic plants actually takes place.

The tubes themselves are hidden in the body of the device, which accordingly protects the tubes from mechanical damage and the effects of environmental factors, and it also creates and allows maintaining the necessary parameters for better algae cultivation. Due to the fact that the tubes have a small diameter (about 1 cm), this allows you to solve the problem of insufficient lighting, because even the center of the tube will remain well lit, which will provide a larger area for photosynthesis.

Cultivation at the expense of such an apparatus and on a nutrient medium, which I mentioned earlier, allows you to obtain biomass that will contain up to 50% of lipids in its cells, and the reproduction process itself will take place at the expense of photosynthesis.

The process of cultivation of algal cultures in tubular reactor systems allows to increase the scale of production and increase the output volume of biomass. Moreover, the design will allow controlling environmental conditions that positively affect the quantitative and qualitative indicators of biomass output.

Among the disadvantages, it should be noted that when the tubes reach a certain height, the cultivation process begins to slow down.

3.3. Biomass collection, processing and drying

After the cultivation of algae, the next stage comes - the collection of biomass. As a rule, the quality of finished biofuel depends on the collection and separation of biomass from the substrate. Also, this stage is the longest and most expensive, since about 20% of costs go to the stage of biomass collection. Therefore, there is a need to establish a profitable technology for harvesting algal biomass for the production of biofuel in large volumes.

Factors such as cell density and size, biomass volume, biodiesel quality preferences all influence the choice of biomass collection method. In general, there are 4 popular methods. You can see them in the form of a figure 3.5.

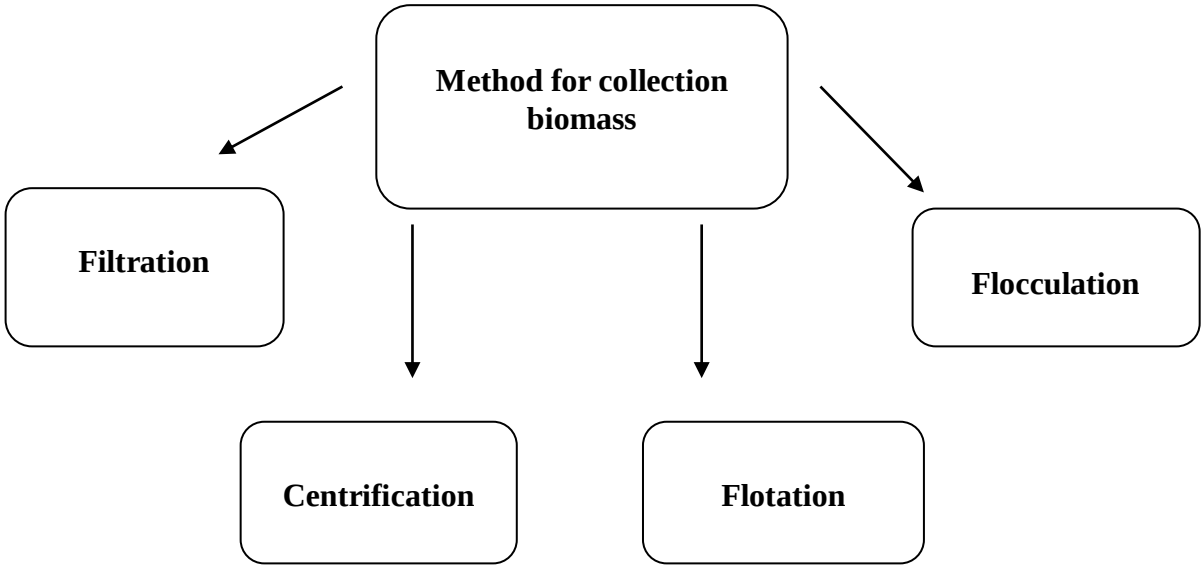

Fig. 3.5 Popular method for biomass collection

In the works of [33], it was investigated that an algae cell up to 20 μm has higher costs during biomass collection and requires more complex hardware. And it is precisely for such microalgae that the two-stage collection system is suitable.

The two-stage process of biomass collection includes: collection and thickening. First, the biomass is separated from the general suspension. Such a process is the collection of biomass. For this, you can use such methods as: flocculation, flotation or sedimentation. Whereas the process of thickening consists in achieving a concentrated form of suspension. For this, you can use such methods as: filtration or centrifugation.

In my opinion, flocculation and flotation methods are well suited for the large-scale production of biofuel based on algae cultures in Ukraine. Yes, these processes are expensive, but at the same time they will be profitable, as they give a high yield of oils.

No matter how trite it sounds, the quality of the final product, financial and hardware support affects the choice of technology that will be used for biofuel production.

Therefore, as the next parameter, we suggest considering method of processing algae raw materials. There are three of them in total and you can see them in the figure 3.6.

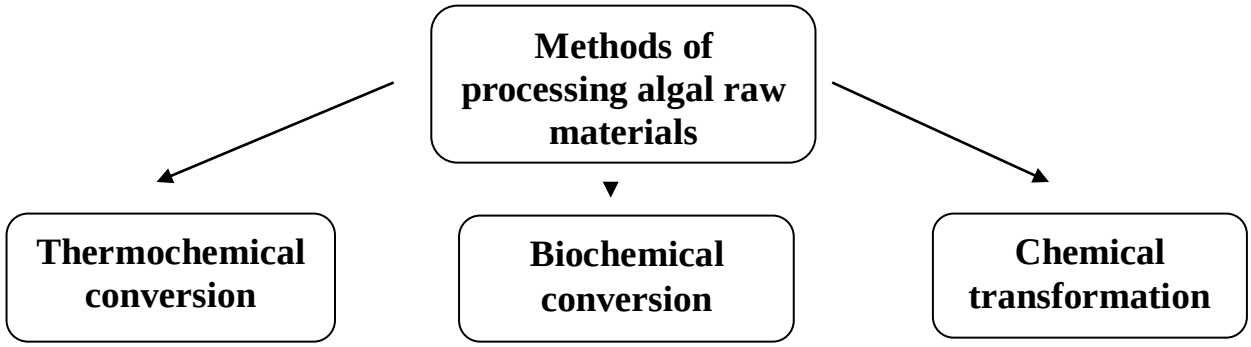

Fig. 3.6 Method of processing algal raw materials

Thermochemical conversion. This method includes: gasification, pyrolysis, hydrothermal liquefaction, used to convert algae biomass into full-fledged biofuel. Such processes, unlike biochemical ones, make it possible to transform not only carbohydrates and lipids, but the entire biomass of algae. It should also be noted that during the cultivation of algae it is not necessary to create special harsh conditions (for example, nitrogen minimization).

Biochemical conversion. This process is more difficult because it requires the use of microorganisms or enzymes to break down the algae into fuel. Also, biochemical conversion is a slower and less energy-intensive method compared to thermochemical conversion. The biochemical conversion method includes: anaerobic digestion, fermentation, and the final stage of direct production of a phytobiological hydrogen product.

Chemical transformations. It is accepted to divide them into ordinary or in situ (direct, in place). Conventional chemical processes require drying and extraction of lipids, while in situ bypasses the lipid extraction process. It is believed that in situ is a simpler and cheaper way to produce biofuel from algal cultures compared to conventional techniques[34].

Along with all the parameters that can affect the production of biofuel from microalgae, the drying of biomass is considered no less important. Algae are concentrated from water after passing through many stages. The concentration of microalgae in the reservoir starts with 0.01-0.15% (v/v), and then, after flocculation and settling, the same concentration is increased to 0.7% (v/v). Subsequently, the concentration is increased to 2% (v/v) through the use of the belt filter method. Then, from 2%-50% (v/v), the direct

drying of algae begins. Drying requires 60% of the energy content of the algae, so this process can be considered expensive and troublesome, since the energy content of algocultures needs to be controlled for the drying to be successful.

However, there are methods of obtaining oil without drying biomass, that is, according to their principles, wet biomass can be processed, and scientists pay increased attention to this method [35].

3.4. Methods of oils extraction

Traditionally, biomass requires drying before obtaining oils. However, since this process takes a lot of time and is generally expensive, an alternative method of further oil extraction is the processing of wet algae biomass.

The most common methods for obtaining oils from microalgae are:

- Method of mechanical failures;
- Supercritical fluid extraction method;
- Solvent extraction;
- Thermal liquefaction with subsequent cleaning;
- Ultrasonic extraction. In the following subsections,

I propose to consider each of these possible methods [36].

Obtaining oils due to the method of mechanical breakdowns. Mechanical disruption of algae culture cells involves destruction of the cell wall and direct extraction of intracellular material. This method includes: grinding, homogenization and mechanical pressing.

Biomass grinding is characterized by premixing small glass beads with microalgae biomass in a vessel that rotates at high speeds. As the biomass is rapidly mixed, the algal cell wall breaks down, causing cell damage.

Homogenization creates a rapid change in pressure and high shear stress, which causes ruptures in cell membranes.

Well, the last stage is mechanical pressing. During this, the oil is separated by crushing the cell walls with the help of a press. It should be noted that the size and shape

of the microalgae will affect the amount of damage caused to the cells. This method is practical for extracting and obtaining a small amount of oil.

Obtaining oils using the supercritical fluid method. Supercritical fluid extraction is a process that takes place with a liquid that simultaneously has the properties of a liquid and gaseous state and when the temperature and pressure rise above the critical point. This state of the solvent allows to increase the dissolving power and increases the diffusivity of the system, which leads to an increase in the extraction efficiency.

Given the pressure and moderately low critical temperature, carbon dioxide is most often used as a solvent. It is also important to note that CO_2 has low toxicity, low cost and availability.

In order to increase the extraction of lipids, co-solvents are used, for example, carbon dioxide in combination with ethanol. However, this method should be carried out only after the stage of drying the biomass. Because the presence of moisture in the biomass will reduce the efficiency of carbon dioxide diffusion.

The supercritical fluid extraction method has an advantage over mechanical and solvent extraction because it does not leave harmful solvent residues and is not long-lasting. Among the disadvantages of this method is the high cost of the equipment.

Solvent extraction. Solvent extraction refers to the use of various chemicals to extract lipids from raw biomass. There are many solvents, such as benzene, ethanol, hexane, or an ethanol-hexane mixture. However, hexane is most commonly used due to its availability, low toxicity, density, and boiling point.

During this process, crude lipids are transferred from a solid or liquid phase into a solvent. Further, these lipids are dissolved in a solvent and a solution is formed, separate from cellular remains. This is explained by the fact that the oil dissolves very well in the solvent.

Solvent extraction at high temperatures is considered quite effective for extracting lipids from algae. At the same time, the final yield of lipids is about 90% of the total amount of lipids. It is important to note that this method at high temperatures can be used not only for dry biomass but also for wet biomass. At the same time, costs for biomass pretreatment and biofuel preparation time are reduced. However, when using wet biomass,

higher pressure is required, and this can lead to the formation of polyunsaturated fatty acids, which will negatively affect the quality of biodiesel. This problem can be solved by stabilizing the operating temperature and moisture level in the biomass.

Method of thermal liquefaction with subsequent cleaning. Compared to pressing or chemical extraction, the thermal liquefaction method can be used for biomass with high moisture content, i.e. the drying process of the biomass can be omitted. After harvesting the moisture, the biomass will under certain conditions turn into bio-crude oil.

As I have already said, the advantage of this method is its application to wet biomass, while among the disadvantages it is worth noting the high energy cost, however, the development of technologies with obtaining by-products will improve the economy of the process.

The method of obtaining oils due to ultrasound. The process of using sound energy to destroy the cell membranes of microalgae, resulting in the release of cell contents, i.e. lipids, is called ultrasound extraction.

When using this method, the remains of the algae biomass are separated from the extracted lipid at the end of the process due to the ultrasound of the centrifuge.

Among the advantages of ultrasound extraction is an increase in the yield of microalgae oil in a short period of time with a low amount of residual biomass. Another advantage is that the method can be applied using wet biomass.

3.5. SWOT analysis of «direct» parameters of biofuel production from microalgae.

After a long description of the "direct" parameters, I created a table in which I offered the following analysis:

- Strengths;
- Weak sides;
- Opportunities;
- Threats.

Such an analysis helps to visually assess the strengths and weaknesses of biodiesel

production and predict all threats and opportunities that may be encountered in the production process.

The SWOT table 3.7 can be evaluated as an initial analysis for further or scientific research or for successful biofuel production. But it is necessary to understand that some strengths may be weak according to the country of manufacture, because the natural conditions will be completely different in different parts of the world.

Table 3.7

SWOT table of «direct» parameters of biofuel production from microalgae

Parameters	**Strengths**	**Weak sides**	**Opportunities**	**Threats**
1	**2**	**3**	**4**	**5**
1)A strain of algae	Some strains of algae can accumulate up to 70% of lipids	Some strains can accumulate up to 20% of lipids	Fuel efficiency	Low yield of oils
2)Features of cultivation				
in open system	Allows you to clean water bodies	Dependence on climate; the need for constant monitoring of «general» parameters	Cost-effective for obtaining a large amount of biomass	Affects the quality and quantity of the final bioful product
in close system	No need to control cuitivation condition	Tubular bioreactors have disadvantages with lighting	Increased output volume of biomass; obtaining biomass that will contain up to 50% of lipids	The process of cultivation in tubular bioreactors slow down over time
3)Collection biomass				
-filtration -centrifugation	Are popular and relatively inexpensive methods	Dependence on cell size, cell density, and biomass volume	High-quality, maximum and fast separation of biomass from the total mass	About 20-30% of the total cost of production is the collection of biomass for further processing

1	2	3	4	5
Two-stage process:				
-flotation -flocculation	Methods are suitable for collecting cells with a diameter of 2-20μm and do not depend on cell density	The process is long	They give a high yield of oils, which is important for the profitability and cost of finished products; suitable for mass production (including for Ukraine)	About 20-30% of the total cost of production is the collection of biomass for further processing
4)Processing of biomass				
-thermo-chemical conversion	Fast and uniform heating and simple hardware management	Includes many stages to convert biomass into a complete fuel; energy-intensive process	Allows converting the entire algal biomass, not just lipids	Affects the quality and quantity of the final bioful product
-biochemical conversion	Although the method is slower, it is less energy-intensive due to this (compared to thermochemical conversion)	Requires use-production of microorganisms or enzymes for splitting algae; requires pretreatment of biomass	-	
chemical transfor-mation:				
1)ordinary chemical transformation	Requires drying and extraction of lipids before the process itself and subsequent purification	Involves significant financial investments and complex transfor-mation technology	-	Affects the quality and quantity of the final bioful product

1	2	3	4	5
2)transfor-mation«in situ»	A simple and cheaper form of obtaining biodiesel	-	The method can be used without the biomass drying step	Affects the quality and quantity of the final bioful product
5)Drying biomass		The process is costly and troublesome	There are methods for processing wet biomass, so it is possible to simply avoid this stages	Drying requires 60% of the energy content of algae
6)Oil extraction				
-the method of mechanical failures	Is not long-lasting	Not all algae strains are suitable for this technology	Used to obtain a small amount of oil	The form of microalgae will affect the yield of oils
-supercritical fluid method extraction	The method does not leave harmful solvent residues and is not long-lasting	Cannot be used for wet biomass; high cost of hardware	It is possible to increase the yield of oils due to the use of a co-solvent	-
-solvent extraction	The yield of oils under the action of a solvent and hight temperature can reach 90%	The use of different chemicals is required to extract lipids from the crude mass	A fairly effective method of lipid extraction is extraction with solvents at high temperatures; can be used for both wet and dry biomass	When using wet biomass, higher pressure is required, which can lead to an increase in polyunsaturated fatty acids, which will affect the quality of biodiesel (but this can be solved by stabilizing the temperature and moisture of the biomass)

-termo-chemical liquefaction with further cleaning	-	High energy cost	Can be used for biomass with a high moisture level	-
-ultrasonic extraction	Technology occurs in a short period of time	-	Increasing the oil yield with a low amount of residual biomass; can be used for wet biomass	-

3.6. Conclusions to the chapter

So, the main idea of this section was to analyze the parameters that affect the production of biofuels based on algocultures, for ease of understanding I divided them into two groups: "general parameters" and "direct parameters". "General parameters" I called the parameters that are important in almost all enterprises and without which the production of any product is impossible. I included the following parameters: Lighting; pH level; Air temperature; Level of carbon dioxide; Content of micro- and macromolecules.

Each of them has its optimal values for the production of biofuel from microalgae, at which the quality and quantity of fuel will be the maximum yield depending on the initial amount of biomass. Therefore, I created a table in which I entered indicators for the optimal development and cultivation of microalgae depending on the corresponding indicator.

By "direct parameters" I mean the parameters that are important in the process of producing biodiesel from microalgae. These parameters include:

- Microalgae strain;
- Peculiarities of cultivation of algae cultures;
- Collection of biomass;
- Processing of biomass;
- Drying of biomass;
- Oil extraction.

The process of obtaining biodiesel from microalgae consists of many stages, and each of them has a certain parameter that will affect the next stages of production, that is, production is a process that depends on the correctness of each step, so in order to start production, you need to understand each stage in detail and understand where it is possible to create an error and how to avoid it so that the final product is successful. It was for this purpose that I chose my practical part of the thesis. Therefore, my main task was to create a SWOT analysis, which will help in assessing the strengths and weaknesses of biofuel production from microalgae and predicting all the threats and opportunities that can be faced.

CHAPTER 4
EVALUATION OF BIOFUEL PRODUCTION FROM MICROALGAE

4.1. Annual productivity of biomass and lipids of microalgae in different regions of Ukraine

Growing microalgae requires a significant amount of energy. Taking into account that the weather conditions of Ukraine are not one of the most favorable in comparison with other regions of the world, the cost of cultivation in Ukraine is expected to be high, but the combination of wastewater treatment processes from biogenic elements with simultaneous cultivation for the production of biodiesel significantly lowers the cost of this process and makes it promising.

In the table 4.1 presents the annual productivity of biomass and lipids of microalgae in different regions of Ukraine, it is obvious that it will be higher in the southern and central regions.

Table 4.1

Annual productivity of biomass and lipids of microalgae in the region of Ukraine, kg/m^2

Region of Ukraine	Biomass productivity	Lipids productivity
Odesa region	14,4	5,5
Dnipropetrovsk region	13,9	5,2
Poltava region	13,7	5,1
Kyiv region	13,3	5,0
Lviv region	12,8	4,8

4.2. Calculation of the total annual profit from the sale of biofuel from microalgae

The average annual growth productivity of microalgae in biomass during cultivation in a photobioreactor in the weather conditions of Ukraine can be assumed to be 11.5 kg/m^2 of the surface of the working area of the phytobioreactor. The average lipid productivity will be 4.1 kg/m^2[37].

If wastewater is present in the working area of the photobioreactor as a culture medium for an average of 3 days, the total volume of the working areas of photobioreactors for wastewater treatment of the urban population of Ukraine will be:

$$5.8\times109 \times 3 = 17.4\times109 \text{ (l), or } 17.4\times106 \text{ (m}^3\text{)} \quad (4.2)$$

If the thickness of the effluent layer as a nutrient medium in the working area of the phytobioreactor does not exceed 0.2m, the total area of all photobioreactors should be:

$$\sum S_{photobioreactor} = \frac{17.7\times10^6}{0.2} = 87\times10^6 \text{ (m}^3\text{)} \quad (4.3)$$

Thus, the annual growth of microalgae biomass can be:

$$M_{biomass} = 87\times10^6 \times 11.5 = 1000.5\times10^6 \text{ (kg)} \quad (4.4)$$

The annual increase in lipids will be:

$$M_{lipid} = 87\times10^6 \times 4.1 = 356.7\times10^6 \text{ (kg)} \quad (4.5)$$

In real conditions, the efficiency of removal of microalgae biomass from wastewater is 90% (centrifugation data), the efficiency of lipid extraction from microalgae biomass is

90%, and the energy efficiency of processing lipids into biofuel is 90% of the annual mass of biofuel.

$$M_{biofuel} = 356.7 \times 10^6 \times 0.9 \times 0.9 \times 0.9 = 260.0 \times 10^6 \text{ (kg)} \quad (4.6)$$

Considering that the density of biodiesel is 0,86 kg/l, the volume of the obtained biodiesel will be:

$$W_{biofuel} = \frac{260.0 \times 10^6}{0.86} = 302.4 \times 10^6 \text{ (l)} \quad (4.7)$$

Assuming the price of one liter of biodiesel at the level of 60 UAH, the total annual profit from the sale of biofules will be:

$$\Pi_{biofuel} = 302.4 \times 10^6 \times 60 = 18144 \times 10^6 \text{ (UAH)} \quad (4.8)$$

The given calculations make it possible to assert the expediency of using microalgae biomass for biodiesel production in conditions of an energy crisis. But it should be noted that the application of a two-stage process is more effective, that is, the removal of biogenic compounds from wastewater based on the metabolism of microalgae with their simultaneous cultivation for the production of biodiesel.

4.3. Practical recommendations to biodiesel production from microalgae.

Recommendation for the production of biofuels based on microalgae:

- Choose a strain of algae that contains a large amount of proteins, carbohydrates, and most importantly lipids (for example, Chlorella vulgaris and Scenedesmus dimorphus);

- Cultivation of algae cultures is proposed to be carried out under the condition that wastewater is present in the working area of the bioreactor as a culture medium, this will

make the process cheaper and more promising;

- The method of flocculation or flotation for collection biomass, although it is not cheap, will give a high yield of oils;

- Processing of microalgae biomass should be carried out by the «in situ» method, as it will make production cheaper (as biomass can be used without prior drying) and obtain the final product in a shorter period of time;

- The extraction of oils shoud be carried out at the expense of ultrasound, this will allow to increase the yield of oils, since the yield of residual biomass will be significantly lower.

4.4. Conclusions to the chapter

Therefore, since the weather conditions of Ukraine are not favorable for the cultivation of microalgae compared to other countries with better conditions, their cultivation will be much more expensive. But if you combine the process of cleaning wastewater from biogenic elements with the simultaneous cultivation of algae, then this process can be made much cheaper and profitable even for Ukraine.

According to the data in Table 4.1, the annual productivity of biomass and lipids of microalgae in the southern and central regions of Ukraine will be higher, which is obvious.

Based on our calculations, we can say that in the conditions of the energy crisis, the production of biofuel from microalgae is expedient. But it should be noted that the use of a two-stage process (cultivation of algae and simultaneous removal of biogenic substances from wastewater) is more effective.

CONCLUSIONS

As a result of the qualification work development, an actual scientific and applied task was solved, which lies in both the environmental and economic planes.We completed the following tasks that were set by us.

1. The biodiesel technologies in the context of Sustainable Development have been analyzed. The advantages of biofuel from algae were established. The algae is an excellent representative of the "Blue Economy", it's not only simple and cheap substitute for natural resources, but also safe for the environment, because: algae are a source of oils, as well as a good raw material for the production of energy substitutes and natural gas; this is a technology with low capital investments and high productivity output of raw materials; the production of biofuel from microalgae allows to protect society from CO_2 emissions.

2. The energy potential of algae is 50-100 times greater than the potential of agricultural crops have been researched. In addition, algae grow 20-30 times faster than land plants and need only sunlight, temperature and carbon content for their growth. It is because of this that the costs of growing algal crops are much lower than the costs of growing oil crops, especially if you take into account that oil crops require significant acreage of the land fund, while algae can be grown directly in water bodies. Of course, the production of biofuel based on algae biomass has disadvantages, but it should be noted that they are much smaller than those of land plants.

3. The parameters affecting the production of biodiesel from microalgae, like lighting; pH level; air temperature; level of carbon dioxide; content of micro- and macromolecules, were studied.

4. We have made calculations of economic profit. Assuming the price of one liter of biodiesel at the level of 60 UAH, the total annual profit from the sale of biofuels will be 18144×10^6 UAH. For efficient and cost-effective production, we suggest

combining the cultivation of microalgae with the simultaneous purification of wastewater from biogenic substances, this will make this process not only promising, economically profitable, but also much cheaper.

5. Due to deep analysis biodiesel production from microalgae the practical recommendations were provided by us.

The prospects of using microalgae as a high-energy feedstock for biodiesel production in the context of energy collapse and from an environmental point of view are beyond doubt.

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