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Larysa E. Piskunova[1], Oleksandr I. Yeremenko[2], Tetiana O. Zubok[3], Hanna A. Serbeniuk[4], Zoia V. Korzh[5]

Scientific and methodological aspects of solid biofuel production processes in compliance with labor protection and environmental safety measures

Abstract: This paper considers modern production technologies of solid biofuels from the point of view of compliance with labor protection and environmental safety measures. The relevance of the study lies in the fact that environmental safety, in our opinion, supported by the results of the analysis of literature sources and their research, covers almost all residential areas of the community. The purpose of this scientific research is to develop theoretical foundations and practical management solutions to ensure environmental safety when producing solid biofuels. Thematic works of dome-

✉ Corresponding Author: Larysa E. Piskunova; e-mail: piskunova7087@uoel.uk

[1] National University of Life and Environmental Sciences of Ukraine, Ukraine; ORCID iD: 0000-0003-0853-4050; e-mail: piskunova7087@uoel.uk

[2] National University of Life and Environmental Sciences of Ukraine, Ukraine; ORCID iD: 0000-0002-3377-0015; e-mail: yeremenko@lund-univer.eu

[3] National University of Life and Environmental Sciences of Ukraine, Ukraine; ORCID iD: 0000-0001-7559-0859; e-mail: zubok@nanyang-uni.com

[4] National University of Life and Environmental Sciences of Ukraine, Ukraine; ORCID iD: 0000-0001-9187-0623; e-mail: serbeniuk@u-tokio.eu

[5] National University of Life and Environmental Sciences of Ukraine, Ukraine; ORCID iD: 0000-0002-7676-132X; e-mail: korzh@singapore-uni.com

stic and foreign specialists form the theoretical and methodological basis of the research. The following methods of scientific research were used as objective methods: logical analysis of knowledge, scientific generalization, deduction and analogies. The practical significance of the obtained results lies in the application of established models and emergency situations as well as environmental safety in practice. An environmental safety system was developed that regulates the state in its natural conditions based on established production control models for solid biofuels. The article presents recommendations for students of higher educational institutions (technical areas) to study materials on labor protection and the environmental safety of our time.

Keywords: solid biofuels, processing technologies, environmental hazards, engineering and environmental criteria, technology

Introduction

Biofuels are alternative energy sources. However, these sources include those that do not come from conventional mineral hydrocarbons, namely natural gas and oil. Even wood, which has been used by mankind for centuries to generate thermal energy, is an alternative option according to this classification. Alternative energy sources are environmentally friendly and renewable, and in some cases, they are infinite, such as solar power or Aeolic (wind) energy. Biofuels are renewable and environmentally friendly energy sources. They are products of biological origin that can be solid, liquid or gaseous. The extraction and use of biofuels based on our economy allow us to achieve autonomy from purchased energy sources while solving the problem of recycling various organic waste from the contents of wells to weeds removed from beds (Ieremenko and Zubok 2019).

The use of biofuels has its drawbacks, one of which is the high cost of its production. When deciding to produce energy from biological materials, it is necessary to calculate how much money will be spent on the construction of a fuel plant, how much equipment will cost and how much the profit will be, as well as consumers' savings using biofuels. Practice shows that a plant that produces biofuels is very profitable if it is sold to consumers. In the modern world, natural hydrocarbon gases, liquid oils and solid fuels (coal and brown coal, shale, peat and wood) are the main sources of fuel and energy. The properties of fuel are largely determined by its chemical composition: carbon, hydrogen, oxygen, nitrogen and sulphur. Solid fuels are mainly used to generate heat and other types of energy. More than three-hundred different chemical compounds can be obtained from solid fuels by proper processing. The transfer is of particular importance to valuable types of liquid fuels – LPG and LNG (Tres et al. 2019).

The study of modern technologies of solid fuel processing systems allows us to assess the environmental risk of thermal methods of solid fuel processing, taking into account the technology used. For these purposes, it was previously proposed to use two sets of criteria – engineering and environmental. The engineering criterion covers the production of actual products, corrosion

safety and variability of the cooling-process efficiency. The environmental criterion addresses the requirements for raw materials, specifically – the possibility of processing oil shale of a certain fractional and chemical composition, the use of other types of hydrocarbon raw materials, the dependence of the technological process on the quality of raw materials, the formation of additional volumes of solid and gaseous waste, the possibility of short-circuiting gas technological cycles, the consumption of water resources, reliability and continuity in operation.

Vegetable raw materials are widely used all over the world as a renewable energy source (Hughes and Bailey 2019). According to experts, the demand for wood for energy production will increase in the future, and wood waste in the form of sawdust, wood chips and dust can be used for energy purposes (Aadi Moolam et al. 2016). Most of this waste is not used and is taken to landfills, and companies incur significant transportation and storage costs. In addition, this waste can be dangerous for the environment. Using the wood waste of sawmills and woodworking industries as raw materials or fuel is economically justified only when suppliers of wood waste and their consumers are nearby, otherwise the cost of wood waste transportation would be too high due to the low bulk mass. Large wood waste is usually used as fuel, often without pre-drying. For the effective functioning of the forest industry, it is currently advisable to process wood waste in the form of granular biofuels, which is most important for areas rich in forests (Piskunova et al. 2015).

Pellets and briquettes are the most technologically solid biofuels obtained from renewable biomass. Solid briquette fuels are easy to produce; this is mainly from woodworking and agricultural waste, but is also available from household waste. This is important because it provides a solution to the problems associated with waste disposal as well as providing a source of energy. A positive aspect of using solid biofuels is their minimal impact on the environment during combustion compared to conventional solid fuels with the same calorific value. Solid biofuels based on plant biomass (pellets and briquettes) are a real alternative to coal and oil (Dubrovin et al. 2014). Works of scientists who study and analyze modern issues of our topic form the theoretical basis of our research "Scientific and methodological aspects of solid biofuel production processes in compliance with labor protection and environmental safety measures". These scientists include Aadi Moolam et al. (2016), Yeremenko et al. (2019), Wang et al. (2021), Getman (2020) and Kuznietsova et al. (2020) to name but few. Within the framework of the topic under study, aspects of solid biofuel production processes are analyzed in compliance with labor protection measures that are still relevant today. Modern scientific research deals with various aspects of solid biofuel production processes.

This paper aims to collect and analyze scientific and technical information to identify new ways to improve methods for obtaining solid biofuels from wood waste with improved strength and water resistance indicators.

1. Materials and methods

This research was conducted in several stages. Based on the analysis of scientific and methodological sources of information, the paper describes the main concepts related to the subject of research, such as the concepts of "biofuels", "environmental safety", "solid fuel", "processing technologies", "environmental hazard" and "engineering and environmental criteria". The beginning of the analysis is the methodological basis of this study, namely the historical and geographical approach to understanding and analyzing the topic, which represents the production process of solid biofuels in compliance with labor protection measures. The need for a historical assessment of geographical phenomena in the context of advanced technologies in modern conditions is based on socio-economic integration and the principles that provide national orientation and universal values when analyzing historical and geographical facts. For an effective study of the international supervisory experience, the following research methods were defined: theoretical (analysis of scientific, historical, methodological and pedagogical literature concerning the topic); empirical (diagnostics, modelling, study of documentation).

In the first stage of the study, scientific, historical, technical, methodological and pedagogical literature on the research topic was analyzed. Data were collected on the topic of "production of solid biofuels". This concerns the probability of solving the research problem, the importance and purpose of the study, and the possibility of further studying workflow management in the modern world. The studied scientific literature was analyzed, which enabled the conditions of the subject under study to be determined; the main known monitoring methods were also analyzed and generalized. In the process of extracting solid biofuels, there are various options and models to develop labor protection processes. Therefore, specialists should carefully weigh up all different points of view and choose priority and do not follow certain dogma. At the second stage of the study, the justification of the conditions and mechanisms was analyzed to use the monitoring method when producing solid biofuels. This method enabled studying the individual aspects of a phenomenon and object, and making a number of scientific abstractions. Further combination leads to the study of the deep essence as the whole. This method is used when studying complex objects or phenomena. The third stage allowed us to clarify the theoretical theses of our research on the topic "Scientific and methodological aspects of solid biofuel production processes in compliance with labor protection and environmental safety measures" and summarize its conclusions. The research results were processed, theoretically generalized and classified, and the research materials were collected.

2. Results

The term "biomass" covers a range of biological material with different chemical compositions. Examples of biomass include wood, bark, straw, reeds and crops (excess wheat); from a chemical point of view, biofuels consist of carbon, oxygen and hydrogen at a ratio of around 50, 6 and 44%, respectively. From a technological point of view, biofuels consist of water, combustible and non-combustible components, ash. Today, the following classification of solid biofuels is recognized around the world: firewood, wood chips, pellets, briquettes, wood dust, peat, waste, fuel based on crops (Senatore et al. 2016). Of the mentioned groups of biofuels, pellets, briquettes and wood dust are referred to as "improved" or "refined" by producers of biomass fuel (fuel from purified biomass). This means that they were obtained by processing and, therefore, have improved properties compared to any other biofuel. This is why pellets and briquettes have become so popular in Europe and around the world. Briquettes and pellets are most often produced from (soft) coniferous residues formed during activities such as sawing, carpentry and furniture manufacturing. The main advantages of refined biofuels over biomass include: their smaller volume per unit of energy than conventional biofuels, better moisture quality, weight per unit volume, structure, calories and ash; can be stored longer without any maintenance; there is no danger of fuel pieces sticking together.

Pellets are obtained by pressing wood waste to a very fine fraction (Harshita et al. 2019). To obtain such a fraction, raw materials require pre-treatment. The initial depth of processing depends on the properties of the raw material. The ideal raw material for pellet production is dry shavings, which are found in furniture factories; this raw material requires the smallest amount of processing equipment. Dry sawdust is the same good raw material (humidity up to 12%). From this raw material, pellets of excellent quality are obtained, which are in demand in all European markets. Initial drying of up to 12% is required if wetter (13–55%) sawdust, wood chips, shavings are the raw material to be processed into pellets/briquettes.

Briquetting technology is much less developed and less common than pelleting technology, but it is also simpler (Kumari et al. 2018). There are several small briquetting equipment manufacturers in Europe. In general, production lines are similar to those for pellets, but the production volumes usually do not exceed 500–800 kg/year, and dry raw materials are usually used to produce briquettes. These lines are usually used by furniture manufacturers, etc. In our opinion, briquette fuel will soon be very popular in the domestic market, while first-class pellets will remain mainly as an export product for a long time.

Bioenergy does not contribute to climate change by releasing carbon dioxide and other greenhouse gases into the atmosphere (Vicent and Font 2019). The number of substances released and consumed during plant growth and photosynthesis is roughly comparable to the amount of the same substances released and absorbed during the combustion or natural decomposition of these materials. Emissions of sulphur dioxide and nitric oxide are the main components of the oxidation process of air, water and soil. However, levels of these pollutants formed or released when burning biomass are practically zero since biofuels contain small amounts of sulphur. Even small amounts

of emissions are a natural link in the natural cycle because these substances are released in any case when the wood is devoid of such substances. The concentration of heavy metals is also insignificant in biomass, so burning biofuels does not lead to their release or concentration. If biofuel ash is processed on forest or agricultural land, the use of biofuels does not entail changes in the eternal cycle of substances in nature – processes that occur during natural growth and decay.

There are many applications of pellets and briquettes (Piskunova et al. 2017). High-quality pellets are mainly used in small and medium-sized boilers, furnaces and chimneys (up to 1 MW). In addition, specialized boilers and liquid fuel boilers equipped with a specialized pellet burner are suitable for using pellets (a pellet burner can be used instead of an expired liquid fuel nozzle/burner or installed in a new boiler, see paragraph 10). In Europe, pellet heating systems are increasingly popular in the private sector and the number of pellet heating systems is increasing exponentially. Industrial pellets are used in more powerful power plants (more than 1 MW), as well as in cogeneration systems. Most often, these facilities are built in small towns and villages to provide heat or energy to urban areas. Today, one of Europe's largest thermal power companies supplies heat and electricity to the Greater Copenhagen region of Denmark using natural gas, liquid fuel, straw and pellets at a power plant, with the latter being used in fields previously flooded with coal, which all of Western Europe refuses to use today. Briquettes are mainly used in the private sector in wood-burning fireplaces, clay stoves, etc.; however, they can also be burned in boilers designed to burn dry biofuels, mainly as an alternative to coal. Cylindrical briquettes are suitable to automatically feed combustion chambers using conveyors. Rectangular briquettes are intended for the manual feeding of small installations. It should be remembered that briquettes are not only more efficient than coal or wood but are also more eco-friendly and aesthetic, and in addition, are not difficult in storage and require much smaller areas for this. Purified solid biofuels are fuels specially prepared for combustion. As a result, they can be used in all the listed ways (Piskunova and Bondar 2020).

All types of biofuels initially have a fraction suitable for combustion in layered furnaces. Since all of them have good fluidity and minimal humidity, the best method of combustion is to burn such fuels on a stationary inclined grate. The second applicable method is combustion in a turbine furnace with a horizontal axis of rotation. In Europe, combustion in chamber furnaces with powder burners is the most popular and efficient method of burning this biofuel. However, it should be understood that pellets, briquettes, wood chips, pieces and shavings must be pre-crushed to a powdery state.

There is only one way to burn this type of fuel efficiently and safely. Therefore, it should be remembered that different types of biofuels have specific characteristics and therefore require special approaches when considering the choice of the necessary technology to burn sugar biofuels. These special types of purified biofuels include pellets and briquettes made from straw, peat, bark, sugar cane, and other materials. The high ash content and the ability to sinter ash is the main distinguishing feature of these materials, and this means that they require a special approach. For this reason, these complex refined biofuels combust at low temperatures (up to 850 degrees). Therefore, the most suitable combustion technologies will be combustion in a mobile inclined network or a pseudo-liquefied layer.

Untreated dry biofuel is a small-scale biofuel with a humidity of up to 30%. This category includes woodworking waste (dry sawdust and wood chips), grain-drying waste, crushed straw, sunflower straw, rice, etc. Most subtypes of this fuel have very high volatility, so combustion in turbine furnaces with horizontal and vertical rotation is the most effective combustion technology for such fuel. We should not forget about special types of fuels with high ash content and sintering, for which combustion is optimal in a pseudo-liquefied layer or in mobile networks (Rönnqvist and Ouhimmou 2019).

In the forest areas of the country, a significant amount of waste generated during wood processing has accumulated. The method of processing this waste into solid biofuels can be changed. The most technologically advanced type of solid fuel obtained from wood waste includes briquettes and pellets. This is an environmentally friendly fuel, the use of which increases environmental safety. An analytical review presents a detailed technological process used to produce fuel briquettes with sawdust which have the characteristics of different types of briquettes. Ecological use of safe plant polymer binders production enables increasing the strength, water resistance and calorific value of solid fuel. The analysis showed a high growth rate in the use of biomass to produce thermal energy. The production of briquettes and pellets is on the rise in Europe, the USA, and Canada.

In recent years, a lot of wood waste has accumulated in woodlands because they are not used in most cases. The problem of wood waste disposal is one of the most urgent problems in our country as currently about half of the tree biomass is lost under existing processing methods (Rogoskii et al. 2020). This indicates that there is a low technological level of carpentry processes. Countries with a highly developed sawmill and carpentry industry, which is the main supplier of waste, have achieved the most significant results in the use of wood waste (Strapchuk and Mykolenko 2021). These countries include the United States, Canada, Japan, and several countries of Northern and Central Europe. This was facilitated by the high concentration and integration of the woodworking industry.

At the site of formation, waste is divided into wood waste and woodworking waste (Kryvenko 2021). Lumber waste is created during wood harvesting, and most of this remains in forests. This group of residues includes felling residues (branches, twigs, tops), sawdust, stumps, roots, low-quality and commercially valueless wood. Woodworking waste is generated at industiral sites. In sawmills and mechanics, such processing waste is comprised of bark, sawdust, offcuts, wood chips, wood shavings, pine cones, cracked wood, lumpy residues. Wood waste is also classified according to such characteristics as its physical, mechanical and chemical properties, its potential uses, and technical and economic availability (Dubrovin et al. 2014). It should be noted that the presence of different classifications does not always make individual groups of data comparable, which complicates the financial and scientific analysis of wood waste. Currently, the main indicators for determining the directions of waste use are size and quality characteristics (large knots, small soft knots) and economic factors (availability and profitability).

Wood waste can be used after mechanical or chemical treatment as well as directly without repeated treatment The most valuable resources are those that can be used to manufacture various products (Yaremova 2021). This group includes lumpy remains such as bumps, plates,

and others. The range of their applications is wide, from dust products to chemical production (production of cellulose, alcohol, feed yeast, etc.). The least valuable waste is waste with limited potential for use since it can only produce certain types of products; this is comprised of soft waste such as sawdust, shavings and bark. Sawdust and wood chips are used directly for economic reasons for industrial purposes and as technological raw materials to produce slabs and forest chemicals (Senatore et al. 2016). Using sawdust, wood chips and bark as fuel and fertilizer is less time-consuming. This is used to form the most technologically advanced type of solid biofuels obtained from renewable biomass, including briquettes and pellets (Tres et al. 2019).

3. Discussion

Biomass of plant solid biofuels, namely pellets and briquettes, is a real alternative to coal, fuel oil, diesel fuel, and firewood (Hughes and Bailey 2019). Gas can be the main competitor of wood pellets and briquettes. Fuel briquettes are pressed under high pressure and this increases the temperature of the wood and plant material. High moisture resistance, density and strength are the main factors determining the quality of solid biofuels. This makes it possible to transport them over long distances without changing their caloric properties. The production of solid biofuels does not require large financial investment and can be organized on both large and small scales. As energy prices rise, obtaining solid fuels from secondary raw materials for energy production reduces company costs. The use of secondary raw materials enables the reduction of company costs, increases their profitability and improves the environmental situation.

To produce solid biofuels, the following types of renewable energy sources are used: wood waste of various origins; agricultural waste; household waste, sewage; specially grown fuelwood; pulp and paper production waste; peat and much more. For efficient incineration, the waste items must have approximately the same size and shape, allowing it to receive the greatest heat release when it comes into contact with air oxygen. The size and shape of the waste should also allow for mechanical processing and automatic feeding furnaces. For efficient use of wood waste as fuel, it is pressed into pellets and briquettes. Compressed biofuels have some advantages over conventional wood fuel:

- higher calorific value compared to bulk wood waste;
- low cost of boiler equipment;
- automated fuel supply capacity;
- biofuel storage capacity (50% less composition volume for less strict requirements for raw materials) (waste);
- no requirement for highly qualified personnel for equipment maintenance (Dubrovin et al. 2014).

Several types of biomass are used as raw materials for pellets and briquettes, they have significant energy values and physical properties, and allow the efficient grinding and pressing of the

material. The technology of production of pressed sawdust products is based on complex physical and chemical processes that occur in wood under the influence of physical and mechanical factors. Changes in some chemical and physical-mechanical properties of wood are determined during drying, steam treatment and thermal exposure. As a result of the influence of physical factors, the chemical composition of wood changes. It acquires new properties necessary to produce various pressed products. A briquette is a loose substance pressed into a dense product. The quality of briquettes always depends on many factors, the main ones being:

- the chemical composition of the compacted material;
- the mass of the compacted material;
- humidity;
- the particle size of the briquette;
- temperature and pressure;
- the duration of compaction (Harshita et al. 2019).

Fuel briquettes are a fully-recycled and environmentally friendly fuel that burns almost without smoke; it does not decrepitate or spark, so it is ideal for use in heating residential premises (Piskunova and Bondar 2020). Dry fuel is another name for fuel briquettes, as their humidity is reduced to 10%. A combustion temperature that is maintained for four hours (heat transfer from sawdust briquettes is 4,400 kcal or 18 MJ) is an important advantage of briquettes. The savings of briquettes consist in the fact that wood brick furnaces are three-times less common than those which use conventional firewood. To ensure the operation of a boiler with a power supply of 10 kW for 1 hour at 100% load, 2 kg of wood briquettes are sufficient (Senatore et al. 2016). Two types of fuel briquettes are available for this purpose: industrial and consumer briquettes. Industrial briquettes are used as fuel in industry, municipal boilers, and power plants. In terms of their calorific value, capacity and fractional composition, briquettes of this group are similar to brown coal, so they can replace coal in boiler houses without processing. Industrial briquettes are produced in small sizes or the form of washers. There is a huge domestic market for such briquettes, which is especially important for areas far from the western border.

Over the past 100 years, the average air temperature has increased by 0.6°C. For daily temperature fluctuations, this value is insignificant, but it is a lot in the context of the global climate. Burning traditional fuels releases large amounts of harmful substances, mainly carbon dioxide and methane, which many scientists and politicians believe leads to changes in the biosphere. Replacing traditional fuels with alternative fuels reduces this effect (Aadi Moolam et al. 2016). When burning plant biomass, carbon dioxide is released in the same way as when burning traditional fuels. However, plants emit as much harmful substances during combustion as they absorb during growth, thereby fulfilling a closed carbon cycle. All plants, including energy crops, stabilize the soil, reducing its erosion. Energy plantations can be located on land unsuitable for agriculture, places separating acreage, and flooded areas (Yeremenko et al. 2019). Like all plants, energy crops reduce the loss of nutrition or soil solids. Biomass is a very common source of heat and energy, especially in rural areas. However, their collection is often not very well organized, and the deforestation of natural forests harms the ecosystem. The creation of special energy plantations can solve this problem (Vicent and Font 2019).

To study the efficiency and reliability of biofuel supplies from energy plantations, it is necessary to develop a set of models. Model services should include a model for studying the efficiency of fuel supply to power plants under deterministic conditions and models for analyzing and synthesizing the reliability of fuel supply to power plants, taking into account random factors. When analyzing and generalizing about the reliability of fuel supply to energy plantations, it is necessary to take into account three random factors: possible deviations from the expected average value of fuel production volumes (efficiency), possible deviations in the volumes of annual fuel demand, and the fact that the ambiguity of this volume requires the development and application of special methods to describe the action of these factors. The method of the third random factor is particularly complex, since the cost of listed fuel reserves depends on random sales of products and consumption per year and other parameters, including the availability of transitional reserves from previous periods (Piskunova et al. 2017).

Conclusions

Currently, it is necessary to process resource-rich forests and wood waste into solid biofuels for the high efficiency of the regional forest industry. The most technologically advanced type of solid biofuel produced from wood waste includes briquettes and pellets. These are environmentally friendly fuels, the use of which increases environmental safety.

The detailed review covered the stages of the technological process of producing fuel briquettes from sawdust. Various types of briquettes were specified. Using environmentally friendly plant binders and polymer components to produce solid biofuels improves characteristics for the consumerby increasing stability, water resistance and calorific value. Data analysis of global solid biofuel production showed huge increases in the use of biomass to produce thermal energy, in private sector usage and in its use in central heating systems'Materials from raw vegetation are widely used in the world as renewable energy sources and thus the recycling soft sawmill waste, and production of fuel briquettes refers to environmentally friendly waste disposal methods, which allows for the recycling of substances and energy.

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Larysa E. Piskunova, Oleksandr I. Yeremenko, Tetiana O. Zubok, Hanna A. Serbeniuk, Zoia V. Korzh

Naukowo-metodologiczne aspekty procesów produkcji biopaliw stałych z zachowaniem zasad ochrony pracy i bezpieczeństwa środowiskowego

Streszczenie

W artykule rozważono nowoczesne technologie produkcji biopaliw stałych z punktu widzenia przestrzegania zasad ochrony pracy i bezpieczeństwa środowiska. Istotność badania polega na tym, że bezpieczeństwo ekologiczne, zdaniem autorów, poparte wynikami analizy źródeł literaturowych i ich badań, obejmuje prawie wszystkie obszary mieszkalne gminy. Celem tych badań naukowych jest opracowanie podstaw teoretycznych i praktycznych rozwiązań w zakresie zarządzania, zapewniających bezpieczeństwo środowiskowe przy produkcji biopaliw stałych. Podstawą teoretyczną i metodologiczną badań są prace tematyczne specjalistów krajowych i zagranicznych. Jako metody badawcze zastosowano następujące metody poznania naukowego: logiczna analiza wiedzy, uogólnienie naukowe, dedukcja i analogie. Praktyczne znaczenie uzyskanych wyników polega na zastosowaniu w praktyce ustalonych modeli i sytuacji awaryjnych oraz bezpieczeństwa środowiskowego. Opracowano system bezpieczeństwa środowiskowego, który reguluje stan w warunkach naturalnych w oparciu o ustalone modele kontroli produkcji biopaliw stałych. W artykule przedstawiono rekomendacje dla studentów wyższych uczelni (kierunków technicznych) do studiowania materiałów dotyczących ochrony pracy i bezpieczeństwa środowiska naszych czasów.

Słowa kluczowe: biopaliwa stałe, technologie przetwórstwa, zagrożenia dla środowiska, inżynieria i kryteria środowiskowe, technologia