VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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RESEARCH OF SAPROPEL USE FOR HEAT PRODUCTION AND ENVIRONMENTAL ASSESSMENT

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
ENVIRONMENTAL ENGINEERING (04T)

VGTU
LEIDYKLA
Vilnius TECHNIKA 2012

Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2008–2012.

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The summary of the doctoral dissertation was distributed on 21 December 2012.

A copy of the doctoral dissertation is available for review at the Library of Vilnius Gediminas Technical University (Saulėtekio al. 14, LT-10223 Vilnius, Lithuania).

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

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SAPROPELIO PANAUDOJIMO ŠILUMOS GAMYBAI TYRIMAI IR APLINKOSAUGINIS VERTINIMAS

DAKTARO DISERTACIJOS SANTRAUKA

TECHNOLOGIJOS MOKSLAI,
APLINKOS INŽINERIJA (04T)

Vilnius LEIDYKLA TECHNIKA 2012

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Disertacija bus ginama viešame Aplinkos inžinerijos mokslo krypties tarybos posėdyje 2013 m. sausio 24 d. 14 val. Vilniaus Gedimino technikos universiteto senato posėdžių salėje.

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Disertacijos santrauka išsiuntinėta 2012 m. gruodžio 21 d.

Disertaciją galima peržiūrėti Vilniaus Gedimino technikos universiteto bibliotekoje (Saulėtekio al. 14, LT-10223 Vilnius, Lietuva).

VGTU leidyklos „Technika“ 2104-M mokslo literatūros knyga.

Introduction

Topicality of the problem

Lithuanian lakes are an important part of the landscape, and the processes taking place in them depend on a number of interacting processes: physical, chemical and biological. A large variety of sediment made scientists classify them, although sediments were and are examined in various aspects, but there have been no their general classification by now. The lakes are important for the preservation of fresh water, therefore they ought to be cleaned. During the cleaning process of lakes, large amounts of sapropel are extracted which is kept on the shore a long while until it becomes dry and later lack of being used further. Sapropel poured by the lake uglifies the landscape and needs large areas. Extracted non-dried lake sapropel can be used as a binder for production of different types of biofuel, especially since currently the development of production and use of domestic energy sources (biofuel from biomass) is one of the main aims of Lithuanian energenergetic strategy.

Reconstructed boilers producing heat and power seek that instead of non-shifting fossil fuel biofuel would be used. During the combustion process of biofuel briquettes with the sapropel binder, less gaseous pollutants are emitted into the atmosphere and composed ashes is non-hazardous waste and can be used as fertilizer in agriculture. Lithuania has a very little and limited resources of indigenous fossil fuel. Using energy sources, such as sapropel, not only less imported fossil fuel is necessary, but also a highly relevant environmental pollution problem is tackled. Thus both the economic and environment protection effect is reached.

The evaluation of pollution of environmental components, in particular geological environment (soil, sediments of water pools – sapropel) shows that the extent of anthropogenic influence can be quantifiable, often – the insecurity of this extent to biota, including humans.

Object of the work – sapropel and possibility to use it as a flammable binder for biofuel briquettes.

Aim and tasks of the work. The of the work aim is to determine the suitability of sapropel for the production of biofuel briquettes thermally and environmentally during comprehensive researches, and to evaluate the factors influencing its use possibilities as a biofuel type for the production of the thermal energy.

To reach the aim set in the thesis, it is necessary to tackle the following tasks:

1. To determine the composition of chemical elements of sapropel and content of organic carbon, affecting the quality of sapropel as a biofuel.

2. To examine mechanical properties of briquettes with the sapropel binder, affecting the suitability of its use for the production and use of alternative biofuel.
3. To determine thermal properties of briquettes with sapropel and its mixtures with other biofuels (straw, sawdust and peat) and to evaluate the release of gaseous emissions during the combustion process of these briquettes.
4. To simulate the combustion process and pollutant migration trends of sapropel briquettes.
5. To propose environmental solution, i.e. optimal option for biofuel briquette with sapropel mixture.

Methodology of research. Methods for the detection of chemical elements, physical parameters, heat transfer and combustion products of sapropel and briquettes with sapropel have been used in the work. In order to evaluate the pollutant concentrations generated during the combustion of briquettes with sapropel empirical formulas have been used. For the simulation of emissions of heat carries, nitrogen oxides, carbon monoxide, sulphur dioxide and particulate matter generated during the combustion of briquettes with sapropel *COMSOL Multiphysics* software package has been used.

Scientific novelty. Applied experimental and theoretical studies of sapropel, using sapropel as a binder for the production of biofuel briquettes, researches of pollutant emissions during the combustion process, simulation of thermal numerical values and pollutant emissions in combustion products.

Practical value. The use of biofuels in Lithuania is stimulated by international obligations related to the reduction of greenhouse gas emissions. Use of sapropel binder for the biofuel production allows the rational use of available fossil energy sources in Lithuania, reducing dependence on imported fuel.

The use of additives and binders – sapropel – for the production of briquettes and development of promising technologies will help to increase thermal value, mechanical stability of producible biofuel and to reduce air pollution as lower pollutant amounts in combustion products will be formed during the combustion process.

Defended propositions

1. A mixture most suitable for the use of production of biofuel briquettes consists of 30% sapropel and 70% sawdust.
2. Pollution amounts emitted into the ambient air during the combustion depend on the sapropel amount and nature in the content of briquettes.

3. The mechanical properties of the fuel briquette are best when 20–30% of sapropel as a binder is added.

The scope of the scientific work. The thesis consists of an introduction, six chapters revealing research material, general conclusions and recommendations, list of used literature and the author's publications on the dissertation topic.

Work scope – 169 pages, 45 numbered formulas used in the text, 47 figures and 17 tables. When writing the thesis, 220 literature sources have been used.

1. Properties of sapropel and potential for its use

Sapropel is a compound Greek word ("sapros" – rotten, "pelos" – mud) – this is bed sludge present of ancient freshwater pools, substance formed during the biological processes from residues of dead plants and animals, having rested for centuries. Having avoided fermentation and putrefaction, this mass gained valuable properties during the long period, in other words, sapropel is sludge containing organic and mineral substances accumulated in lakes and marshes under the peat.

According to its composition of sediments, sapropel is usually divided into: organic, lime, mineral (silicate or siliceous) and the mixed (organic – carbon, organic – siliceous). Sediment considered typically organic sapropel is the one containing more than 50% of organic matter. A sapropel layer of about 1–3 mm is accumulated over the years; if water vegetation sprouts more, this accumulation of sapropel is increased tenfold. Sapropel layer thickness ranges from a few to 18 meters, depending on the amount of vegetative and animal organisms in the water. Physical properties of sapropel are distinctly reflected by its moisture, ash-content and content of mineral substances. Sapropel is divided into organic, or low ash–content, with up to 30% of ash, and with high ash–content (30–85% of ash). Sapropel with high ash–content, depending on the ash composition, is divided into the siliceous, which consists primarily of silicon, and calcareous sapropel, which consists primarily of calcium carbonates, and mixed which has the same amount of calcium and silicon oxides.

Mostly, natural sapropel is used as fertilizer which can be applied to animal, ornithic, piscine feed as an additive with mineral and biologically active substances. Sapropel is used in cosmetics and medicine, may be a raw material for the chemical industry, and production of building materials (drainage pipes, lightweight wall bricks, expanded clay). Sapropel is used in the production of biofuels as an integral binding part of briquettes or pellets, mixing it with other biofuels. Sapropel is used not only as sticky material or binder, but during its chemical processing, various chemical products are got: coke, methyl alcohol, various types of oils (light, medium and heavy), gasoline, engine oil, varnish, etc.

2. Researches of sapropel chemical composition and physical properties

Composition of chemical elements of lake bed sediment is an important indicator of environmental quality. Composition of sapropel depends not only on the processes of natural sedimentation, but also on anthropogenic pollution. Type and scope of application of sapropel depend on the content of chemical elements, heavy metals and organic matter. Sapropels in three different Lithuanian lakes have been studied: Poežerių (I sample), Medžialenkės (II sample) and Talkša (III sample) (Fig. 1).

Fig. 1. The place of investigated lakes in Lithuanian map

During the production of briquettes with sapropel binder, moisture content in sapropel is an important and integral factor. Recommended moisture content in the sample in briquette production is 78–82%, in pellet production – 52–60%. Sapropel moisture content in Poežerių lake makes 58.7%, Medžialenkės lake – 73%, Talkša lake – 80%. Samples taken from Medžialenkės and Talkša lakes are appropriate for the production of briquettes with sapropel binder. Sapropel chemical elements predominantly consist of carbon (38–58%) and oxygen (37%), nitrogen (1.1 to 4.2%) and sulphur (0.1 to 0.7%) make a small part of it. Also, silicon contents (3.2 to 11.5%) are found in the analyzed samples; mainly in sapropel sample from Poežerių lake – 11.5%, which is not suitable for the use in the production of briquettes or pellets due to the high content of silicon. Minimum amount of other chemical elements of 4% was measured in sapropel of Medžialenkės lake. Total composition of carbon, i.e. organic and inorganic carbon contents, were studied in all samples of sapropel. High content of organic carbon shows that sapropel can be used as a binder in the production of biofuels. Content of organic matter in the sample from Poežerių lake is about 44%, sapropel from Medžialenkės lake – 85%, sapropel from Talkša lake – 37%. According to the content of organic matter, examined sapropels are divided into: siliceous (sapropel in Talkša lake), silicon – organic (sapropel in Poežerių lake) and organic (sapropel in Medžialenkės lake).

Sapropel from Medžialenkės lake is used as a binder in the production of briquettes due to the high organic content (85%). pH rate describes these sapropels as neutral or slightly acidic. As the sapropel is not widely used as a binder in production of briquettes or pellets, therefore there is no regulation what concentration of heavy metals could be contained in it (Fig. 2). Contamination of sapropel is evaluated according to the requirements of LAND 20–2005 (Ni – 50 mg/kg, Zn – 300 mg/kg, Pb – 140 mg/kg, Cr – 140 mg/kg, Cu – 75 mg/kg) related to its use of sewage sludge for fertilization and recultivation. Sewage sludge is burned alone or mixed with other fuels, therefore concentrations of heavy metal in sapropel samples are compared with given concentrations permissible for sewage sludge. Sludge, which can be used for fertilization, recultivation of pits and combustion is assigned to sludge category I.

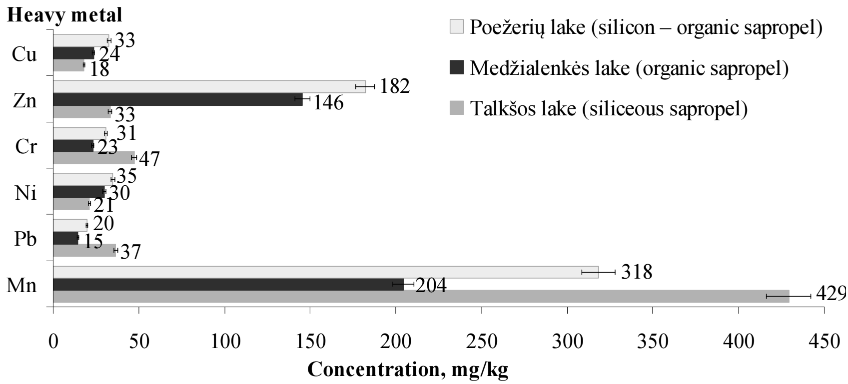


Fig. 2. Variations of heavy metal concentration in the sapropel of lakes

Defined contents of heavy metals in silicon-organic, organic and siliceous sapropel do not exceed those given in standard LAND 20–2005. All sapropel samples are assigned to the sludge category I and can be used without restrictions.

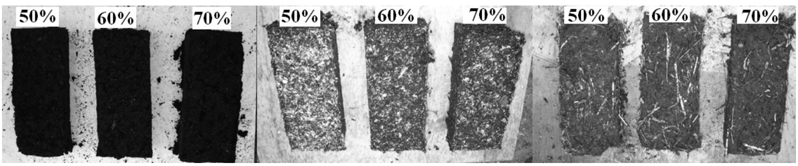
3. Research of mechanical properties of briquettes with sapropel

In order to get biofuel of higher calorific capacity, pressing is used. Pressed dry biofuel does not start to decompose under the impact of fungi and microorganisms, so it can be stored for a longer period of time. An important property of briquettes is their mechanical stability, i.e. resistance to compression and bend. This property is very important for storage, reloading or transport of briquettes. The aim of research is to identify the composition of formation mass for biofuel briquette binder with sapropel of mixed composition, influence of sapropel on mechanical stability of biofuel briquettes. A 10 litre capacity is used for researches, where there is a mixture of appropriate ratio: sapropel with peat, sapropel with sawdust; sapropel with straw (Table 1).

Table 1. The mixture of briquettes with sapropel binder

	Sapropel content, %	Peat content, %
Sapropel and peat briquettes	50	50
	60	40
	70	30
	Sapropel content, %	Sawdust content, %
Sapropel and sawdust briquettes	20	80
	30	70
	40	60
	50	50
	60	40
	70	30
	Sapropel content, %	Straw content, %
Sapropel and straw briquettes	50	50
	60	40
	70	30

For the production of briquettes with sapropel binder the following has been used: organic sapropel (Medžialenkės lake), peat, wood processing waste – sawdust, straw. Briquettes with sapropel binder consist of organic sapropel and organic additives (peat, sawdust and straw) (Fig. 3).



a) b) c)

Fig. 3. Briquettes with sapropel binder: a) sapropel and peat; b) sapropel and sawdust; c) sapropel and straw

Before the researches of resitance to compression and flexural strength, compression area of each briquette was measured. Each briquette was compressed until a compressive force increased on measuring device. When the force started to decrease, compression was stopped. Flexural strength of briquettes was measured analogously.

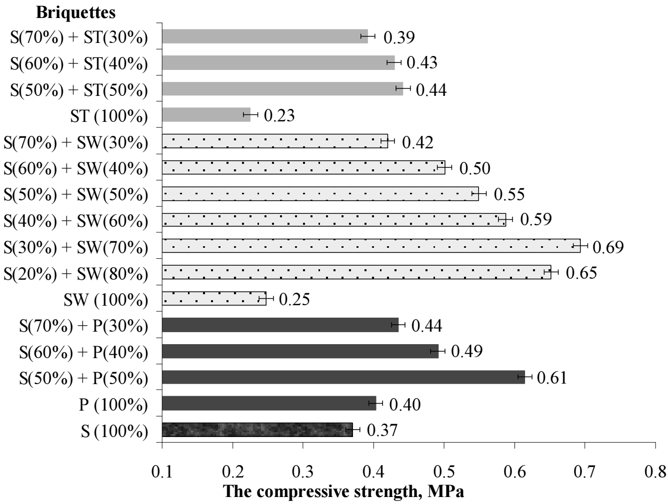


Fig. 4. The compressive strength in briquettes with the sapropel binder (S – sapropel; P – peat; SW – sawdust; ST – straw)

Briquettes with sapropel amounts up to 30%, and 70% of the sawdust are the strongest; their resistance to compression is up to 0.69 MPa. Minimum resistance to compression of 0.23 and 0.25 MPa has been determined in 100% straw and 100% sawdust briquettes, where sapropel has not been used in the composition. Use of sapropels in briquettes increases their resistance to compression from 1.1 to 2.8 times. Research of flexural strength shows that up to 30% of sapropel and 70% of additives in briquette biomass is the best to be used as these briquettes are stronger. The maximum flexural strength of 0.58 MPa has been determined in 20% sapropel and 80% sawdust briquettes, less value of 0.56 MPa has been determined in 30% sapropel and 70% sawdust briquettes. Theoretical and experimental results of the research showed that the lake sapropel can be used as a binder resulting in receipt of stronger and more qualitative fuel briquette.

4. Combustion of sapropel briquettes and assessment of environmental protection

The aim of this research is to identify calorific values of briquette components and mixtures with sapropel binder used in the production of briquettes, to measure the concentrations of gaseous pollutants emitted during the combustion of briquettes with sapropel. Made briquettes were burned in 25 kW capacity domestic boiler; concentration of emitted gaseous pollutants was measured during the combustion process.

Organic sapropel (of Medžialenkės lake) is suitable for the production of briquettes with sapropel binder because of its high calorific value (20.6 MJ/kg) and is similar to peat (22 MJ/kg). Calculations of thermal values of mixtures with sapropel have been carried out. Mixture of each briquette is of 100%. Thermal value mixtures have been calculated according to the ratio of components in different types of briquettes. The calculated calorific values knowing calorific value of each component were compared with the measured calorific values of mixtures prepared for the production of briquettes (Fig. 5).

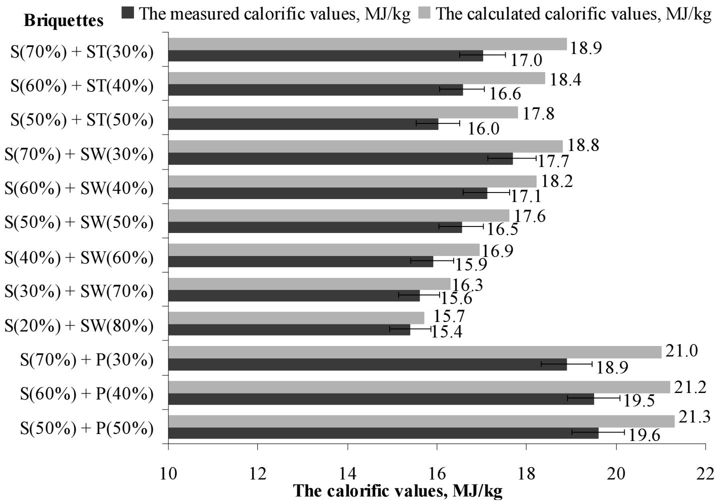


Fig. 5. The calorific values in briquette with sapropel

The calculated calorific values in case of all briquettes are greater than the measured values. Results of calculated values are based on absolute (idealized) primary data, while the measured values evaluate the amount of inorganic impurities in the sample. Measured values differ from the calculated ones between 1 and 10%, which demonstrates compliance with credible results. In point of calorific value, the best are 50% sapropel and 50% peat briquettes the measured calorific value of which is 19.6 MJ/kg. As the calorific value of peat is greater than the sapropel's, and therefore the calorific value of briquettes containing the greater amount of peat (50%) is the utmost compared to other briquettes. When increasing the amount of sapropel in the mixture of briquettes with sawdust, calorific value increases from 14.5 to 17.7 MJ/kg, with straw – from 15 to 17 MJ/kg. Comparison of the results of calorific value calculation and measurement shows that the minimum error of 6% is received in case of sapropel – sawdust briquettes.

Measured calorific values of sapropel and sawdust mixtures differ from the calculated ones by about 1 MJ/kg. To produce sapropel and sawdust briquettes or pellets, it is not necessary to measure calorific values of mixtures. It is enough to know calorific values of individual components, and calorific value of briquette or pellet can be calculated using their ratio in the mixture.

Good fuel combustion is stated when: fuel is fully used and burnt, and minimum level of CO and NO_x is left in smoke. Norms of concentrations during the combustion of biofuel are given in the Order of the Minister for Environment of the Republic of Lithuania "Related to the determination of LAND 43–2001 norms on emissions from large combustion plants and norms on emissions from fuel combustion plants". During the research, concentration of carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter (PM) in the smoke were periodically analyzed, as well as the smoke temperature at the concentration measurement point and the temperature in the combustion chamber.

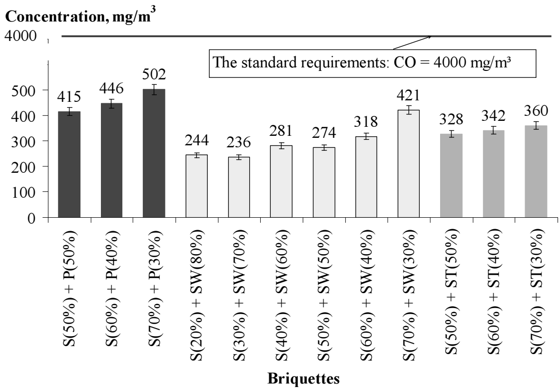


Fig. 6. CO concentration during burning briquettes (S – sapropel; P – peat; SW – sawdust; ST – straw)

A large amount of CO shows that carbon particles have been left unburned in the briquettes (Fig. 6). The largest CO concentration (502 mg/m^3) has been measured in 70% sapropel and 30% peat briquettes. The lowest CO concentration (236 mg/m^3) has been measured in 30% sapropel and 70% sawdust briquettes. CO concentration measured in sapropel – straw briquettes of different composition varies from 328 to 360 mg/m^3. During the combustion of sapropel briquettes and briquettes with additives, minimum and maximum measured CO concentration has the difference of 2-fold. NO_x is formed from air nitrogen and nitrogen in the briquettes (Fig. 7). The largest NO_x concentration (310 mg/m^3) has been measured in the 50% sapropel and 50% straw briquettes, the lowest NO_x

concentration (144 mg/m^3) has been measured in the 50% sapropel and 50% peat briquettes. During the combustion of sapropel – sawdust briquettes, NO_x concentration varies from 209 to 266 mg/m^3. It was found that the highest SO_2 emissions (67 mg/m^3) of were measured during the combustion of sapropel – peat briquettes, the largest concentrations of particulates (280 mg/m^3) were measured during the combustion of sapropel – sawdust briquettes, but the marginal values were not exceeded.

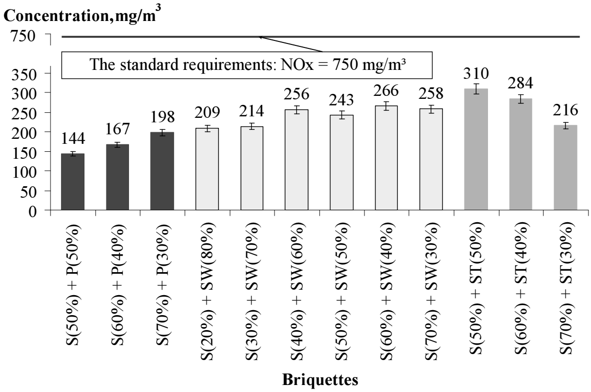


Fig. 7. NO_x concentration during burning briquettes (S – sapropel; P – peat; SW – sawdust; ST – straw)

CO and NO_x marginal values were not exceeded during the combustion of all briquettes, which are regulated by LAND 43–2001.

5. Numerical simulation of sapropel combustion and pollutant emissions

Fuel combustion model always involves many different processes. Processing of simulation results is a complex part of researches. Results of direct research and modelling may vary significantly from each other. This chapter contains the presentation of method of numerical simulation for the combustion of briquettes with sapropel binder and obtained results of heat transfer and release of pollutants. *COMSOL Multiphysics* is a software programme that allows the modelling of processes and phenomena in various scientific and technical fields. It allows dealing with the most complex scientific and engineering tasks using the method of the finite element analysis (FEA) in the fields of energetics, alternative energitics and chemistry; from mechanics of fluid flow and heat transfer to electromagnetic analysis. The boiler model was created in calculating space. The boiler has been divided into three parts, the first part contained combustion process, the second part of the boiler has been for the stabilization of processes (further analysis of results is based on the parameters modelled within this area), and the third part has been designed for the removal of products of combustion resulting from the combustion process. 3 different types of briquettes have been chosen for the simulation (Table 2). Results received from the simulation of briquettes with siliceous sapropel have been compared with the results received during the calculation of thermal values. Results of thermal values of briquettes with organic sapropel and pollution emissions results have compared with values received during the researches. The model has a condition set that a complete combustion process is taking place. Boiler efficiency rate of 0.85 has been taken (based on the proposed methodology of *COMSOL Multiphysics*). Simulation data of briquettes with sapropel and research results received in the second boiler are given in Table 2.

Table 2. Calorific values results

Briquettes	Obtained value during the research, MJ/kg	Simulation value, MJ/kg
30% siliceous sapropel and 70 % sawdust	13.5	15.3
20% organic sapropel and 80% sawdust	15.4	16.8
30% organic sapropel and 70% sawdust	15.6	20.0

Experimental studies showed that the highest thermal value is in the briquettes containing 30% organic sapropel and 70% sawdust (Fig. 8b). Compared to the first version (Figure 8a), when the briquettes of 30% silicon sapropel and 70% sawdust composition are used, the thermal value is 1.3 times higher. The briquettes most suitable for the combustion shall be made using the 30% of sapropel and 70% of sawdust ratio. The briquettes of such composition emit 23 MJ/kg of calorific value during the combustion, and in the second boiler – 20 MJ/kg. Comparison with experimental studies showed a discrepancy of about 20%. Evaluation of other types of fuel – sawdust (14.5 MJ/kg) showed that obtainable calorific value is 1.4 times higher, and compared with straw (15.0 MJ/kg) – 1.3 times higher respectively. Obtained numerical simulation data proves once again that after quantitative choice (depending on the amount of materials used) of correct composition of briquettes, obtained calorific value is high enough – 20 MJ/kg, so the briquettes produced using the 30% of sapropel and 70% of sawdust ratio are promising for the use in small farm objects performing the combustion of organic fuel. When 30% organic sapropel and 70% sawdust briquettes are used in numerical simulation, received results show that the smallest amounts of carbon monoxide are released in the ambient air (250 mg/m^3). They are 3.6 times lower than in case of 30% siliceous sapropel and 70% sawdust briquettes. During the complete combustion, a lower amount of carbon monoxide is released into the ambient air when sapropel contains the most amount of organic matter.

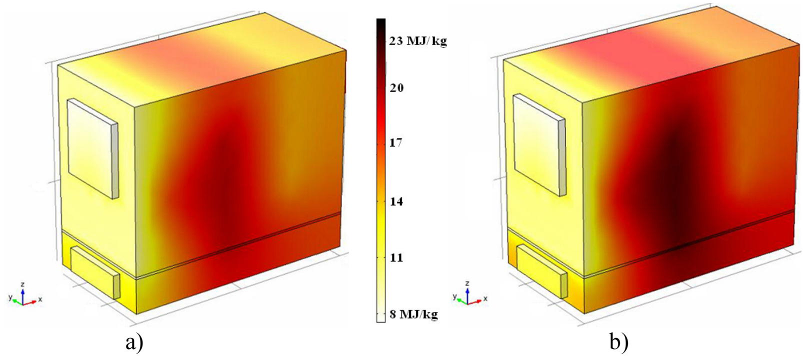


Fig. 8. The amount of energy distribution in model, when used: a) 30% siliceous sapropel and 70% sawdust; b) 30% organic sapropel and 70% sawdust briquettes

Using numerical modelling, error between the experimental studies and modelling makes 10%, which suggests that the data obtained is correlated. Numerical simulation revealed maximum concentration of nitrogen oxides of 260 mg/m^3 for 30% siliceous sapropel and 70% sawdust briquettes, the lower – of 240 mg/m^3 – for 30% organic sapropel and 70% sawdust briquettes. Simulation results were correlated with the data of experimental studies since an error makes only 13%. The highest concentration of nitrogen oxides have been determined in the fuel combustion area, then the intensity decreases by 5–10%, and remains almost unchanged in the second and third parts of the boiler. When briquettes of 30% organic sapropel and 70% sawdust composition are burnt in the kindler, the results show that emissions of nitrogen oxides varies little receding from the kindler, the highest concentrations have been found in the kindler itself and made 230 mg/m^3.

6. Environmental solution

This chapter provides the optimal amount of organic sapropel in the biomass mixture, which can be used for the production of briquettes (Fig. 9). It is important that a good biofuel briquette made using sapropel binder would be mechanically stable during the transportation or storage, would be of high calorific value energetically, and the smoke would have only a minimum amount of pollutants released into the ambient air left.

It is clear that the use of more than 50% of the sapropel in the biomass briquettes results in increase of pollutant levels emitted into the ambient air during the combustion of briquettes. Combustion of briquettes research showed that briquettes, which contain up to 30% of sapropel burn longest burn and emit the most heat. If the amount of sapropel briquettes is bigger, they combust badly, release a little energy, therefore such briquettes are not effective biofuels energetically. Although calorific value of sapropel is greater than sawdust, but if more than 30% of it is used, it loses its value as a biofuel.

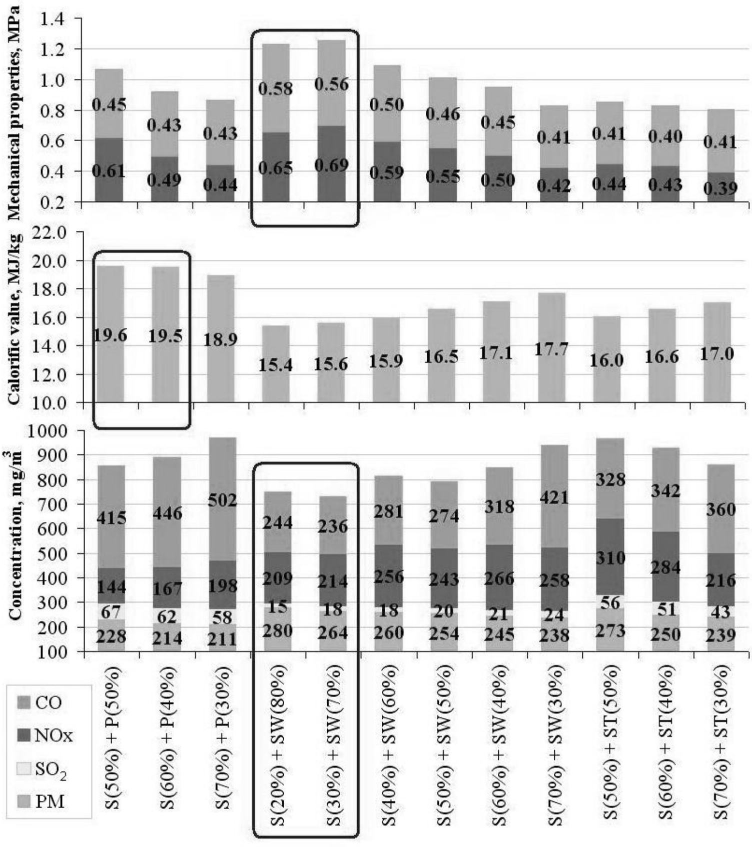


Fig. 9. Suitability of briquette with sapropel for burning

In terms of multi-criteria evaluation (environmentally, energetically and mechanically), and adopting environmental factor as crucial – the optimal engineering assertion is 30% sapropel and 70% sawdust of biofuel briquette. Organic sapropel increases mechanical properties and calorific value of briquettes. The most important factor is low amounts of pollutants released into the ambient air. CO, NO_x, SO_2 and emission limit values of particulate matter are not exceeded during the combustion of those briquettes, which are regulated by LAND 43–2001.

General conclusions

1. Physical and chemical properties of sapropel define its suitability for the use as a binder in construction industry and energetics. Organic sapropel is suitable for the use as a binder for the production for biofuel briquettes. During the production of briquettes, best binding properties of sapropel are revealed when its moisture is between 78–82%, and during the production of pellets – 52–60%.
2. Sapropel contains primarily 38–58% of coal, 37% of oxygen, a small part of nitrogen from 1.1 to 4.2% and sulphur from 0.1 to 0.7%, and content of other elements found is of very small amounts. Given the amount of organic matter, which is the most important factor in calorific capacity, sapropel samples are divided into different types: siliceous – organic sapropel, where the content of organic carbon is about 44.0%, siliceous – 26.0 to 48.0%, and organic where the content of organic matter is up to 85%; it has been used as a binder in the production of biofuel briquettes.
3. Mechanical stability researches of fuel briquettes with dimensions of 220 x 100 x 70 mm showed that the maximum resistance to compression of 0.69 MPa have 30% sapropel and 70% sawdust briquettes, resistance to compression of those briquettes observed is 2.8 times greater comparing to resistance of 100% sawdust briquettes. In briquette mixtures containing more than 30% of sapropel, sapropel loses binder properties during the formation of briquettes, thus when sapropel amount is increasing in the mixture, flexural strength is decreasing by 1.2 and more times.
4. The researches have shown that the use of organic sapropel for briquettes with sawdust increases the mechanical stability of briquettes and reduces their calorific value. When increasing the amount of sapropel in briquette with sawdust by up to 30%, the calorific value of the fuel briquette grows from 14.5 to 16.3 MJ/kg. During the combustion of the briquettes of different composition with sapropel binder, pollutants generated during the combustion do not exceed the allowable limits for biofuels.
5. Results of numerical simulation, which confirm the experimental results, show that 30% organic sapropel and 70% sawdust briquettes are suitable for the use in low-power boilers. They meet the requirements – high thermal value and low pollutant emission formed in the boiler.

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SAPROPELIO PANAUDOJIMO ŠILUMOS GAMYBAI TYRIMAI IR APLINKOSAUGINIS VERTINIMAS

Mokslo problemos aktualumas

Intensyvinant bei plėtojant gamybinius procesus didėja neigiama žmogaus veiklos įtaka gamtai bei visai supančiai aplinkai. Šiuo metu aplinkos taršai mažinti stengiamasi tobulinti bei taikyti įvairias aplinkosaugines technologijas, siekiant kuo geriau apsaugoti žmogų ir jį supančią aplinką. Vienas perspektyviausių atsinaujinančių energijos šaltinių yra įvairių rūšių bioenergija iš medienos, energetinių plantacijų, šiaudų, biodujų, sąvartynų dujų. Atitinkamai apdorota energetinė biomasė gali būti saugoma gana ilgą laiką. Įvairios biomasės rūšys gali būti naudojamos šilumai, elektrai, degalams ir dujų kurui gaminti. Energetiniai biomasės ištekliai apima ne tik žemės, miškų ūkio produkciją, jos apdorojimo ir perdirbimo atliekas, bet ir iki šiol visuomenei mažiau žinomus išteklius.

Lietuvos ežeruose sapropelis sudaro didžiausią organinių nuosėdų dalį. Šios vertingos organinės ir kalkinės medžiagos panaudojama labai nedaug – tik pavieniais atvejais kaip ežero valymo produktą. Daugiau dėmesio skiriama sapropelio panaudojimui tręšti dirvas, gerinti dirvožemio derlingumą ir tik nedaugelis mokslininkų tyrinėja galimybes panaudoti jį kaip rišamąją medžiagą biokurui. Plačiau sapropelio deginimo galimybes savo darbuose nagrinėja Rusijos mokslininkai V. I. Kosovas (2004; 2007) ir L. A. Petrova (2007). Deginimo tyrimai bei aplinkosauginės šio proceso problemos, deginant biokurą su sapropeliu, aprašyti V. I. Kosovo ir A. S. Beliakovo (2004), L. A. Petrovos (2007) bei L. A. Nikolajevos (2009) darbuose, bet reikia atkreipti dėmesį, kad visuose darbuose sapropelis buvo vertinamas kaip homogeninis kuras arba kaip mažoji kito biokuro sudedamoji dalis.

Nuo 1965 metų, kai sapropelis, kaip rišiklis, nedideliais kiekiais buvo pradėtas naudoti gaminant briketus ir granules su iškastiniu kuru, atlikta nedidelis kiekis tyrimų. Buvo siūlomi įvairūs briketų mišinių ruošimo būdai (sapropelio kiekis iki 10 % nuo bendros masės), sudėtis, briketų gamybos metodai ir dydžiai, pagrindinį dėmesį skiriant arba šilumingumui, arba mechaninėms savybėms, bet ne jų sinergetiniam poveikiui. Trūksta daugiakriterių (aplinkosauginių, energetinių bei mechaninių) tyrimų, kuriuose rišamoji degi medžiaga – sapropelis – būtų naudojamas su medžio pjuvenomis, šiaudais arba durpėmis ir sudarytų briketų mišinyje daugiau kaip 10 % masės. Taip pat iki šiol nėra nustatytas optimalus sapropelio kiekis biokuro brikete, kuris būtų didelės energetinės vertės, pasižymėtų mažu teršalų išskyrimu ir būtų mechaniškai patvarus.

Tyrimų objektas – sapropelis ir galimybė panaudoti jį biokuro briketams kaip rišamąją degią medžiagą.

Darbo tikslas ir uždaviniai. Darbo tikslas – kompleksinių tyrimų metu šiluminiu bei aplinkosauginiu požiūriais nustatyti sapropelio tinkamumą biokuro briketų gamybai ir įvertinti veiksnius, lemiančius jo, kaip biokuro rūšies, panaudojimo galimybes šilumos energijos gamybai.

Darbo tikslui pasiekti darbe reikia spręsti šiuos uždavinius:

1. Nustatyti cheminę sapropelio sudėtį ir organinės anglies kiekį, galinčius turėti įtakos sapropelio, kaip biokuro, kokybei.
2. Ištirti mechanines briketų su sapropelio rišikliu savybes, galinčias lemti jų tinkamumą panaudoti alternatyviojo biokuro gamybai.
3. Nustatyti šilumines sapropelio ir jo mišinių su kitu biokuru (šiaudais, medžio pjuvenomis ir durpėmis) briketų charakteristikas bei įvertinti šių briketų deginimo proceso metu išsiskiriančių dujinių teršalų emisijas.
4. Taikant skaitinį modeliavimą išanalizuoti sapropelio briketų degimo procesą ir teršalų išsiskyrimo tendencijas.
5. Pasiūlyti aplinkosauginį sprendinį – optimalų biokuro briketo su sapropeliu mišinio variantą.

Tyrimų metodika. Darbe taikyti sapropelio ir briketų su sapropeliu cheminės sudėties, fizinių parametrų, šilumos pernašos ir deginimo produktų nustatymo metodai. Siekiant įvertinti briketų su sapropeliu degimo metu susidarančių teršalų koncentracijas, naudotos empirinės formulės. Šilumos pernašoms, azoto oksidų, anglies monoksidų, sieros dioksidų ir kietųjų dalelių emisijoms briketų su sapropeliu deginimo metu modeliuoti naudotas *COMSOL Multiphysics* programinės įrangos paketas.

Mokslinis darbo naujumas

Atlikti taikomieji teoriniai ir eksperimentiniai sapropelio tyrimai apima analizuotų biokuro briketų gamybos, panaudojant kaip rišiklį sapropelį, galimybes, deginimo proceso metu išsiskiriančių teršalų tyrimus, skaitinį šiluminių verčių ir teršalų emisijų degimo produktuose modeliavimą.

Praktinė reikšmė. Biokuro naudojimą Lietuvoje skatina tarptautiniai įsipareigojimai, susiję su šiltnamio dujų emisijų mažinimu. Rišiklio sapropelio panaudojimas biokuro gamybai leidžia racionaliai panaudoti Lietuvoje turimus iškastinius energijos išteklius, mažinant priklausomybę nuo importuojamo kuro.

Atitinkamų priedų bei rišamosios medžiagos – sapropelio panaudojimas briketų gamybai ir perspektyvios technologijos sukūrimas padidins šiluminę gaminamojo biokuro vertę, užtikrins briketų mechaninį patvarumą ir sumažins oro taršą, nes degimo proceso metu degimo produktuose susidarys mažesni teršalų kiekiai.

Ginamieji teiginiai

1. Mišinys sudarytas iš 30 % sapropelio ir 70 % medžio pjuvenų yra tinkamiausias biokuro briketų gamybai.
2. Degimo metu išsiskiriančių į aplinkos orą teršalų kiekiai priklauso nuo briketų sudėtyje esančio sapropelio kiekio ir prigimties.
3. Mechaninės biokuro briketų savybės yra geriausios, kai į briketą kaip rišiklio įterpiama 20–30 % sapropelio.

Darbo apimtis. Disertaciją sudaro įvadas, šeši tiriamąją medžiagą atskleidžiantys skyriai, bendrosios išvados ir rekomendacijos, naudotos literatūros ir autoriaus publikacijų disertacijos tema sąrašai. Darbo apimtis – 169 puslapiai, tekste panaudotos 45 numeruotos formulės, 47 paveikslai ir 17 lentelių. Rašant disertaciją buvo panaudota 220 literatūros šaltinių.

Disertacijoje nagrinėjamos rišamosios degiosios medžiagos – sapropelio – susidarymo priežastys, analizuojamos pagrindinės jo savybės ir sudėtis, taip pat panaudojimo galimybės biokuro briketams gaminti. Pagrindinis disertacijos darbo tikslas – kompleksinių tyrimų metu šiluminiu bei aplinkosauginiu požiūriu nustatyti sapropelio tinkamumą biokuro briketų gamybai, įvertinti veiksnius, darančius įtaką jam, kaip biokuro rūšiai, ir panaudojimo šilumos energijos gamybai galimybes.

Įvadiniame skyriuje aptariama tiriamoji problema ir darbo aktualumas, pristatomas tyrimų objektas, formuluojamas darbo tikslas bei uždaviniai, aprašoma tyrimų metodika, mokslinis darbo naujumas ir praktinė darbo rezultatų reikšmė, pateikiami ginamieji teiginiai. Įvado pabaigoje pristatomos disertacijos tema autorės paskelbtos publikacijos ir pranešimai konferencijose bei apibūdinama disertacijos struktūra.

Pirmasis skyrius skirtas literatūros analizei, jame nagrinėjami sapropelio susidarymo ir išgavimo būdai, aprašomos pagrindinės sapropelio savybės, aptariama cheminė sudėtis ir panaudojimo galimybės. Analizuojamas sapropelio panaudojimas biokurui: briketavimas ir šiluminė vertė, teršalų išsiskyrimas, deginimo technologijos ir skaitinio modeliavimo galimybės. Skyriaus pabaigoje formuluojamos išvados ir tikslinami disertacijos uždaviniai. Antrajame skyriuje pateikta tyrimų metodika ir rezultatų analizė, nustatomas sapropelio tinkamumas naudoti jį energetikoje. Trečiajame ir ketvirtajame skyriuose pateikiami mechaninių briketų su sapropelio rišikliu savybių, šiluminių verčių ir deginimo tyrimai, pristatomas atliktas aplinkosauginis įvertinimas. Penktajame skyriuje pateiktas skaitinis briketų su sapropeliu degimo proceso modeliavimas. Šeštajame skyriuje aprašomas inžinerinis-aplinkosauginis sprendinys.

Bendrosios išvados

1. Sapropelio fizinės ir cheminės savybės nusako jo tinkamumą naudoti kaip rišamąją medžiagą statybos pramonėje ir energetikoje. Organinį sapropelį, galima panaudoti kaip rišamąją medžiagą biokuro briketams gaminti. Gaminant briketus geriausias sapropelio rišamosios savybės išryškėja tada, kai jo drėgnis siekia 78–82 %, o gaminant granules – 52–60 %.
2. Sapropelio mėginiuose vyrauja anglis – 38–58 %, deguonis – 37 %, nedidelę dalį sudaro azotas – 1,1–4,2 % ir siera – 0,1–0,7 %, kitų elementų randami labai maži kiekiai. Atsižvelgiant į organinių medžiagų kiekį, kuris yra svarbiausias šilumingumo faktorius, sapropelio mėginiai priskiriami skirtingiems tipams: silicio – organinis sapropelis, kuriame organinės anglies kiekis siekia apie 44,0 %, silicinis – 26,0–48,0 % ir organinis, kuriame organinių medžiagų kiekis siekia 85 %, jis buvo naudotas kaip rišamoji degi medžiaga biokuro briketų gamyboje.
3. Atlikti kuro briketų, kurių matmenys 220 x 100 x 70 mm, mechaninio patvarumo tyrimai parodė, jog didžiausiu atsparumu gniuždant 0,69 MPa pasižymi 30 % sapropelio ir 70 % medžio pjuvenų briketai. Šių briketų atsparumas gniuždant yra 2,8 karto didesnis nei 100 % medžio pjuvenų briketų. Briketų mišiniuose, kurių sudėtyje yra daugiau kaip 30 % sapropelio, briketų formavimo metu sapropelis praranda rišamosios medžiagos savybes, todėl didėjant sapropelio kiekiui mišinyje stipris lenkiant mažėja 1,2 ir daugiau karto.
4. Tyrimais nustatyta, kad organinio sapropelio panaudojimas briketams su medžio pjuvenomis padidina mechaninį briketų patvarumą ir padidina jų šiluminę vertę. Brikete su medžio pjuvenomis didinant sapropelio kiekį iki 30 % kuro briketo šiluminė vertė padidėja nuo 14,5 iki 16,3 MJ/kg. Deginant skirtingos sudėties briketus su sapropelio rišikliu, degimo metu susidarę teršalai neviršija biokurui nustatytų leistinų normų.
5. Pagal gautus skaitinio modeliavimo rezultatus, kurie patvirtina eksperimentinių tyrimų rezultatus, briketai sudaryti iš 30 % organinio sapropelio ir 70 % medžio pjuvenų yra tinkamiausi naudoti mažos galios katiluose, kadangi jų šiluminė vertė didžiausia, o teršalų išsiskyrimas mažiausias.

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