CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

FACULTY OF TROPICAL AGRISCIENCES

Department of Sustainable Technologies

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Czech University of Life Sciences Prague
Faculty of Tropical AgriSciences

DIPLOMA THESIS

The Impact Analysis of Weight, Time Period and Storage Conditions of the Biomass Briquettes on their Abrasion Size

Author: Ing. Ivana Kukačková

Supervisor: doc. Ing. Josef Pecen, CSc.

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DIPLOMA THESIS ASSIGNMENT

Kukačková Ivana

Thesis title

The Impact Analysis of Weight, Time Period and Storage Conditions of the Biomass Briquettes on their Abrasion Size

Objectives of thesis

The aim of this diploma thesis is to find out whether there is dependence between the weight, time period and storage conditions in which are briquettes stored on the abrasion size of the biomass briquettes. There will be various concepts and recommendations to reduce abrasion of briquettes specified in the conclusion of this thesis.

Methodology

There will be following hypothesis determined in this diploma thesis: The weight, time period and storage conditions have not an impact against abrasion size of the biomass briquettes. This hypothesis will be tested by using statistical methods such as regression and correlation analysis is.

Schedule for processing

September 2012 – October 2012: studying relevant literature and searching for valid information
November 2012: measurement in the laboratory, analysing of data
December 2012: evaluation of obtained values, measurement in the laboratory
January 2013 – February 2013: writing and applying of data in the thesis, measurement in the laboratory, consulting with supervisor
March 2013: consulting with supervisor, making final statement and evaluation of thesis, final arranging of thesis, printing, binding and submission

The proposed extent of the thesis

approximately 50 pages

Keywords

energy crops, biomass briquettes, mechanical durability, analysis, hypothesis, abrasion of briquettes, dependent variable, independent variable

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Recommended information sources

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The Diploma Thesis Supervisor

Pecen Josef, doc. Ing., CSc.

doc. Ing. Jan Banout, Ph.D.
Head of the Department

doc. Ing. Jan Banout, Ph.D.
Director

Prague August 30. 2013

DECLARATION

I hereby declare that I have written presented diploma thesis “The Impact Analysis of Weight, Time Period and Storage Conditions of the Biomass Briquettes on their Abrasion Size” by myself with help of the literature listed in references.

Prague, 30 August 2013 ……..……………………..

Ivana Kukačková

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ABSTRACT

This diploma thesis reflects on issue associated with usefulness of a digestate as a by-product from biogas plant. One of the possibilities of its effective utilization is the briquetting technology. The paper presents the experimental results which deal with the mechanical resistance of digestate briquettes. There was used different composition of digestate briquettes to achieve the aim of this research. The separated and partially dehydrated digestate was compressed into the form of the briquettes with diameter 65 mm, various length and mass. These briquettes were subsequently tested in the rotary drum according to standard ČSN EN 15210-2. The resulting data were analysed by using statistical indicators, parametric and non-parametric test with significance level $\alpha = 0.05$. The abrasion of briquettes was analysed and the most important result of this thesis was ascertaining that the abrasion does not depend practically on the mass of produced briquettes (i.e. on the size groups of briquettes). It was also investigated the impact of long-term storage of briquettes on their quality. Also briquettes from other vegetable materials, such as *Miscanthus x giganteus* and *Miscanthus sinensis* were tested for better comparison of non-energetic properties of the briquettes made from digestate.

Key words: abrasion of briquettes, digestate briquettes, mechanical durability, *Miscanthus x giganteus*, *Miscanthus sinensis*, standards

ABSTRAKT

Diplomová práce reflektuje problematiku využití digestátu jako vedlejšího produktu z bioplynové stanice. Jednou z možností jeho efektivního zpracování je briketování. Studie prezentuje experimentální výsledky, které se zabývají mechanickou odolností briket z digestátu. Pro dosažení tohoto cíle byly použity brikety s různým složením. Oddělený a částečně dehydratovaný digestát byl lisován do formy briket o průměru 65 mm, různé délky a hmotnosti. Tyto brikety byly následně testovány v rotačním bubnu podle normy ČSN EN 15210–2. Výsledná data byla podrobena zkoumání pomocí statistických ukazatelů, parametrických a neparametrických testů na hladině významnosti $\alpha = 0,05$. Při analyzování opotřebení briket bylo zjištěno, jako nejdůležitější výsledek práce, že oděr prakticky nezávisí na hmotnosti vyrobených briket (tj. na velikostních skupinách briket). Vliv dlouhodobého hlediska skladování briket na jejich kvalitu byl rovněž zkoumán. Pro lepší porovnání neenergetických vlastností briket z digestátu byly testovány i brikety z jiných rostlinných materiálů, jako jsou *Miscanthus x giganteus* a *Miscanthus sinensis*.

Klíčová slova: odrol briket, brikety z digestátu, mechanická odolnost, *Miscanthus x giganteus*, *Miscanthus sinensis*, normy

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LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
ANOVA	Analysis of Variance
CEN	European Committee for Standardization
CL	Confidence Limit
CO_2	Carbon Dioxide
CULS	Czech University of Life Sciences
D	Diameter
DU	Mechanical Durability
g	Gramm
GHG	Greenhouse Gas
ha	Hectare
H_0	Null Hypothesis
H_1	Alternative Hypothesis
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
m	Mass
MG	*Miscanthus x giganteus*
mm	Millimetre
MS	*Miscanthus sinensis*
N	is used to represent the size of a population (the population size)
n	is used to represent the size of a sample (the sample size), the number of observation
L	Length
MJ	Megajoule
OECD	Organisation for Economic Co-operation and Development
RES	Renewable Energy Sources
t	Ton
THC	Tetrahydrocannabinol
α	Alpha, Significance Level
β	Beta, the Power of a Test
Δ	Delta, Standard Error
%	Per Cent

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1. FOREWORD

Briquettes made from biomass are environmentally friendly fuel because they are made of natural materials which do not contribute to the pollution in the world. Briquettes could be produced either from energy crops which are intentionally cultivated on the agricultural land or agro residues. One of the agricultural remains is digestate. It is a by-product of biogas plant and it is traditionally used as a mineral fertilizer. Recently, a new form how to process digestate has been discovered. At first, digestate is necessary to be dried and then its solid fraction must be separated. Then it should be compressed into the form of pellets or briquettes. Digestate can increase new possibilities of its utilization by using this way.

Applying the dehydrated digestate as solid biofuel seems to be a promising alternative, but it has not been investigated so far. The properties of briquettes made from separated and partially dehydrated digestate have not been closely described yet, because these methods are relatively new. Therefore, this thesis is focused on this issue, especially on mechanical resistance of briquettes made from digestate with different additives, like zeolite and dolomitic limestone.

The main objective of this diploma thesis is to find out if the size of briquettes has an impact on mechanical durability of briquettes. In other words, whether there is a correlation between mass and abrasion. If the dependence between mass of briquettes and their abrasion was proved, it would be possible to produce specific dimension of briquettes, because the abrasion would be reduced.

There were used basic statistical indicators and methods to describe these properties. Arithmetic mean, median, standard deviation, parametric and non-parametric tests, and regression and correlation analysis were conveniently applied. All the briquettes were produced in the same way and had the same shape. The experiment was done at the laboratory conditions by using special rotary drum, where the mechanical durability of briquettes was tested.

The durability of briquettes in the time period also belongs to very important qualities of briquettes and that is why this thesis is besides other things interested in storage time. Energy crops - *Miscanthus x giganteus* and *Miscanthus sinensis* were used instead of digestate briquettes. There will be verified if the storage time has an influence on abrasion of briquettes. Briquettes pressed from *Miscanthus x giganteus* and *Miscanthus sinensis* were mixed with sawdust and wood shavings.

According to the results of determination of mechanical durability should be suggested whether digestate from biogas station is suitable for briquettes production and whether the briquettes made from *Miscanthus* are advisable for long time storage. In this thesis, the emphasis is given on determination of mechanical durability of briquettes but not on their economy and profitability.

2. LITERATURE REVIEW

There is an exponential grow of population on earth. This fact depends on the growth of civilisation needs, among which belongs the consumption of energy. Reliable and accessible source of energy is considered to be an important part of modern society (White et al., 1981).

There were more than one per cent of world´s fossil fuels reserves consumed until the end of Twentieth Century. The greenhouse effect is natural part of earth and the living conditions on earth, as well (Ochodek et al., 2006).

Responsible behaviour in power supply means mainly rational and effective use of energy and moreover also meaningful usage of renewable sources of energy (RES) (White et al., 1981). These sources include the primary energy equivalent of solar, wind, tide, wave, hydro and geothermal. It also involves energy derived from solid and liquid biofuels, biogases and the renewable fraction of municipal waste (OECD, 2013). Renewables have local character and that is why they strengthen safety and reliability of energy supplies (White et al., 1981).

The means of hydropower were pumped out crucially in the Central Europe, potential of wind energy is dependent on local conditions and we have not been able to effectively transform solar energy, yet. Solar energy has very limited possibilities of transformation into heat. It is not easy to accumulate heating in remarkable scale. People use accumulation of heating in the winter and that belongs to the main advantages of biomass, which is one of the RES. It is advisable to use this advantage fully (Ochodek et al., 2006).

The potential of hydropower and wind energy is rather low in the Czech Republic. On the other hand, the potential of biomass is getting higher because its aliquot part is more than 80% of whole amount of RES in the Czech Republic. The usage of biomass includes consumption of wood waste, sawdust, wood shavings, motor bio fuels such as biodiesel, biooil, bioethanol and specifically grown energy crops, which are part of agricultural area that is not in use. In the Czech Republic, the most remarkable item of biomass is its kind that is produced from growing in the agriculture area, which is not suitable for growing foodstuff and from anthropogenic soils. This matter is characteristic approximately for 45% of unused land in our country (Ochodek et al., 2006). The supply of domestic energy and the export of biofuels to other European countries are two main purposes why is biomass in the Czech Republic produced (Lewandowski et al., 2006).

2.1 BIOMASS

There are many definitions of the word biomass, one of them is that this subject is derived from the organic matter and it can be used in various ways. It consists of plenty of elements such as carbon, hydrogen and oxygen (White et al., 1981). According to OECD (2004) "biomass is the quantity of living material of plant or animal origin, present at a given time within a given area". White et al. (1981) reported that biomass could be harvested from grown crops that are used for food and manufactured raw materials, and through kinds of waste (municipal and industrial).

Main advantage of biomass is that its primary source of energy, the sunlight, is free. Biomass energy can be used to lower greenhouse emissions. It saves environment much more than fossil fuels, because of its less emission (Malaťák et al., 2008). Global warming is a contemporary problem in the world and it is caused by CO_2. The global surface temperature is going to rise up at intervals 1.1 – 6.4 °C during the 21st century. By using biomass we can reduce the negative impact of global warming (IPCC, 2007).

Biomass production is very important part of sustainable development and solves a range of economic, social and environmental problems of society, especially:

- reduction of CO_2 emissions and mitigation the greenhouse effect;
- substitution of fossil fuels with renewable energy sources;
- the use of surplus soil generated overproduction of food crops;
- development of rural areas and reduction the level of unemployment;
- agricultural innovation and market expansion of agricultural commodities;
- increasing national energy self-sufficiency using indigenous energy resources (OECD, 2004).

2.1.1 Biomass Categorization

There are five main categories of biomass:

1.) **Virgin wood** consists not only of wood but also of other products such as bark, logs, wood chips and sawdust that are produced without applying chemicals. Virgin wood is suitable for a wide scale of energy. For instance, it can be burned for creating heat.

2.) **Energy crops** are kind of biomass which is used for fuel. One of the main advantages of this kind of biomass is high output per hectare with low inputs.

3.) **Agriculture residues** are waste from agriculture harvesting or processing such as straw, husks, animal manures, slurries, poultry litter and some kinds of organic material (i.e. grass silage).

4.) **Food waste** is obtained from manufactured food (i.e. cheese and other dairy products) and drinks (some kinds of alcoholic drinks), preparation and processing, and post-consumer waste. Kitchen waste is mostly characteristic for households and they usually produce more than million tonnes of it annually.

5.) **Industrial waste and co-products** can be eventually used or converted into biomass fuel. Two types of this kind of biomass are being recognised. Firstly, woody materials, that consists of damage wooden parts and wood composites and laminates. Secondly, non-woody materials included paper pulp and wastes, textiles and sewage sludge (Biomass Energy Centre, 2008).

2.1.2 Methods of Biomass Conversion into Energy

The way of obtaining energy is determined by physical and chemical properties of biomass (e.g. humidity). The amount of water and dry matter has impact on biomass processing and also on obtaining energy. Value of fifty per cent of dry matter is approximately a border line between wet and dry processes (Ochodek et al., 2006).

Biomass can be converted into energy in four ways:

- **Dry processes –** thermochemical conversion of biomass
    - combustion is the thermal process at which the material is heated under excess air (oxygen) condition; producing of heat with the consequent possibility of generating electricity; it is widespread use of biomass, nowadays;
    - gasification – only a small amount of oxygen is needed to decomposing the material; the result is a gas that is usually used in combustion engines either for propulsion of vehicles or for generating electricity and heating;
    - pyrolysis – there is no oxygen needed to decomposing the material; products are: gas, carbon-rich material and pyrolysis oil (Bechník, 2009; Ochodek et al., 2006).
- **Wet processes** - biochemical conversion of biomass
    - fermentation,

    - anaerobic digestion – producing of biogas with following possibility of it's modification to biomethane; it should be used in the same cases as natural gas (OECD, 2004; Bechník, 2009);
- **Mechanical processes**
    - cutting – the waste is sawdust, which is used for producing wood pellets and briquettes;
    - crushing,
    - chipping – wood chips are used for producing heat,
    - pressing pellets or briquettes (Bechník, 2009).
- **Chemical processes**
    - composting,
    - wastewater treatment,
    - producing of ethylalcohol – sugar beet, grain, potatoes, etc.,
    - producing of oils and methylester – rapeseed, sunflower, flax, etc. (Ochodek et al., 2006).

2.2 ENERGY CROPS

Energy crops are plants grown especially for use as a biofuel. According to the OECD (2004) the energy crops must meet these following criteria:

- "low cost, high yields;
- simple and low-input agricultural technologies;
- sowing is more preferable than planting;
- perennial crops are more preferable than annual;
- low input level of fertilising and plant protection;
- possibilities to use common agricultural machines;
- easy request conditions for harvesting;
- sufficient quality of biomass for fuel production;
- harmless to the environment" (OECD, 2004).

Specifically grown energy crops are generally categorized into two main groups:

a) fast growing trees - poplar, willow,
b) herbaceous - many of them are grasses (Petříková et al., 2006).

Herbaceous plants are often classified according to the vegetative period duration, namely in:

- annual – hemp (*Cannabis sativa* L.), mallow (*Malva verticillata*) etc.,

- biennial – evening primrose (*Oenothera biennis* L.) etc.,
- multi-annual and perennial – energy sorrel (*Rumex tianschanicus A.Los.*) etc. (Nováková, 2008).

Quantity of energy crops should be eventually grown on the land that is not suitable for food production to ensure feedstock for bioenergy, non-food products and biofuels. Briquettes or pellets are made of plants, which are intentionally grown on farmland. Mostly is a sorrel grown for this purpose. The other energy crops are some kinds of grass, hemp, fast growing trees, etc. There are also other sorts of energy crops but it is necessary to try them scientifically in use. For direct combustion are important crops that create high amount of mass above the ground (Petříková et al., 2006).

Most commonly grown energy crops in the Czech Republic are listed in this subchapter.

2.2.1 Miscanthus

Miscanthus x giganteus is a plant that is considered as an alternative source of renewable energy. By using favourable growing conditions *Miscanthus* can provide more than 30 tons of aboveground phytomass dry matter per hectare (Kahle et al, 2001). See Figure 1. This persistent grass makes good use of solar energy, water, nutrients and it is highly resistant to diseases and pests. However, its growing is limited by two disadvantages. The first one is that *Miscanthus* is in danger of freezing in the first year. Another disadvantage is its expensive seedlings (Petříková et al., 2006).

Figure 1: *Miscanthus* harvesting

Source: International Energy Crops, 2013

This bioenergy grass is native to eastern Asia and in the Czech Republic it was introduced for research purposes for the first time in 1990. Botanically it belongs to the family *Poaceae*. Enhanced expression of elephant grass is a myth. Such a plant exists, but it has nothing to do with *Miscanthus* (Strašil, 2009; Purdy et al., 2013).

As for kinds, there is neither variety nor form currently included in the list of them in the State variety book to June 15, 2012 (Ústřední kontrolní a zkušební ústav zemědělský, 2012). There are a number of varieties bred abroad, e.g. *giganteus, silberfeder, sirene, desert, spa* (Petříková, 2006). *Miscanthus* as a persistent plant should be based on at least 15 to 25 years (Purdy et al., 2013).

For energy use can be *Miscanthus* cut, baled, pelleted, briquetted, etc. In Western Europe, *Miscanthus* is mainly used for energy purposes mainly heat (Zeng, 2012). Currently, it is possible to incorporate this plant into a coal with which it could be burned together. Replacement of a part of coal leads to the reduction of CO_2, NO_x, SO_x, because biomass contains small amount of nitrogen and sulphur while compared to the coal. The net calorific value of the whole plant is about 19 MJ/kg, which is more than of our brown coal. Furthermore, it can be used in the building industry, as material for the production of woody boards, felts, mat, etc. Easily liquidated packaging materials can be made from this plant. It is excellent source of raw material for the production of pulp. It can even be used for feeding (Strašil, 2009).

2.2.2 Sorrel of Uteush

The hybrid sorrel of Uteush is a cross between English spinach (*Rumex patientia L.*) and Tien Shan sorrel (*Rumex tianschanicus A.Los.*). This robust, tall and persistent plant is bred in Ukraine and its height is from 1.5 meter to 2.5 meter. It can provides yields of 5–7 t/ha (dry matter), in optimal conditions it is over 10 t/ha (Havlíčková et al, 2010). It is a perennial energetic crop, which is characterised by very high adaptability in respect to the agricultural methods, sowing period and soil conditions for cultivation (OECD, 2004).

The sort of Sorrel of Uteush that is grown for energy purposes belongs to one of the most important intentionally grown energy crops in the Czech Republic. It could be cultivated only from legal seeds that are protected by international licence. This biomass has quite high net calorific value (17.89 MJ/kg) and also other parameters compared to wood are favourable (Petříková et al., 2006). Sorrel of Uteush could also be harvested in raw condition for feedstock purposes and in this condition it could be used for producing biogas and it is even possible to use it for briquettes and pellets production (Nováková, 2008; Havlíčková et al, 2010). See Figure 2.

Recently dry parts of biomass made of sorrel have started to be applied for producing building materials. Sorrel of Uteush is the best option for these products because in the process of producing it is stable and not getting plump as other kind of plants (Petříková, et al., 2006).

Figure 2: Sorrel of Uteush before harvesting on a dry matter

Source: Petříková, 2011

2.2.3 Hemp

Hemp (*Cannabis sativa* L.) is one of the oldest crops in the world grown mainly for fibre (Finnan et al., 2013). It is an ideal ecological crop that is suitable for both industry and agriculture, for alternative production of electricity and heat production from renewable sources, as well (Široká, 2009). It can also be used for medical and spiritual purposes (Finnan et al., 2013).

It is a thermophilic crop demanding on water, soil, nutrients and agrotechnology. It belongs to the family of *Cannabaceae* with height from 2 to 6 meters (Široká, 2009). It inhibits the growth of weeds and has reclamation and erosion control, draws from the soil contaminants, toxic substances and heavy metals. Hemp improves soil structure because it has extensive root system (Finnan et al., 2013). Male plants are taller and slimmer, they have green-gray top and ripen 4 or 6 weeks earlier than female plants. Hemp contains about 23% fiber and about 75% of the woody matter - so called the shives. The growing season lasts from 100 to 120 days and per one hectare of cultivated area during this period will grow at least two and half more woody material (mass), rather than one hectare of forest that grows several years (Široká, 2009).

According to Act No. 167/1998 Collection of Laws, about addictive substances, it is allowed to grow varieties of hemp with the amount of toxic substance THC up to 0.3%. The grower is bounded to announce growing of hemp at relevant customs office according to place of growing (Česko, 1998).

Hemp products consist of three parts: fiber that is used both in textil and automotive industry, seed that is rich in food and cosmetics oil and shives that is suitable for producing paper, building materials and green energy. Shives is waste product that remains when plant stem is manufactured to fiber. Plant stems are mechanically destroyed during this process and shives is from the fiber subsequently separated (Plíštil, 2004).

Hemp has good combustion properties and it could be used to produce either briquettes or pellets as a solid fuel for private households (Rice, 2008; Prade et al., 2011). Wood chips are pressed into briquettes and pellets with net calorific value from 16.5 to 18 MJ/kg. They are suitable especially for using in gasification wood boilers, stoves and fireplaces. These briquettes are pressed without any binding and other harmful substances. The pressure is high and briquettes shapes are cylindrical with diameter of 6.5 centimetres (see Figure 3). They are also very good usable in other kind of boilers. The amount of ash in them is very low and they are convenient for gardening as an ecological fertilizer (Rice 2008; Široká, 2009).

Figure 3: Kinds of ecological fuel from hemp

Source: Široká, 2009

2.3 DIGESTATE

Digestate is the material which remains after the anaerobic digestion (AD). It arises during a biogas production in biogas plant. Biogas plants usually process vegetable material, cattle manure, pig slurry or other remains of animal origin (Marada et al., 2008). Currently, there are approximately 400 biogas plants in the Czech Republic (Energetický regulační úřad, 2013).

Digestate consists of two main parts: separate and fugate. Separate is a solid fraction of digestate whereas fugate is a liquid part (Marada et al., 2008).

The way of using digestate could be different. Digestate could be either used as fertilizer or for compost production (Marada et al., 2008). The recycling of digestate in agricultural systems has positive effects on soil biological properties (Alburquerque et al., 2012). Another alternative is its separation and drying of solid part with following utilization for solid biofuel production (Marada et al., 2008). Černá (2013) published that compressed digestate in the form of briquettes can be used in agriculture, in particular for targeted treatment of soil mechanical properties and the water regime in soil. Rusín et al. (2011) concluded that energetic use of digestate is applicable only in its solid part (separate). Unnecessary water is removed during drying or pressuring. Net calorific value is mainly dependent on feedstock and moisture content. Water reduces net calorific value because feedstock must be dried beforehand. Subsequently, it starts to burn and releases needed amount of heat (Kužel, 2010).

Net calorific value of briquettes is from 12 to 18 MJ/kg thus they can be used as an alternative to coal and firewood (Panwar, 2011; Pelety biomasa, 2013). Physical properties and chemical composition of digestate fuel briquettes depend on the mixture of substrates used as feedstock for biogas production (Kratzeisen et al., 2010). Separate could be mixed with other kinds of biomass (for instance straw and sawdust) or it could be complemented with other substances, such as mineral fertilizer (Černá 2013; Pelety biomasa, 2013).

2.4 BIOMASS BRIQUETTES

Wood chips or straw are mainly used in large fabrics for heating instead of other biomass. On the other hand, in households it is necessary to modify biomass into suitable shape that allows manipulating with biomass briquettes during lighting a fire. Intentional cultivating of energy crops is an interesting and extraordinary material from which it is possible to create fuel for heating of various buildings (Petříková, 2007).

The briquette is a fuel that is artificially adapted by pressing of bulk material without binding (Česko, 2006). Petříková (2007) describes it as a solely natural material.

Briquettes must have suitable shape for burning. There are two major kinds of briquettes: long and small. The advantage of small ones is in their easier manipulation. It is allowed to use them in the same way as coal (Petříková, 2007).

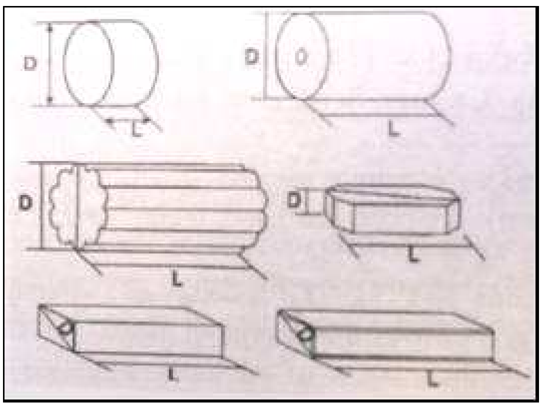
Briquettes have to fulfil demands of valid technical, safety, health, hygienic and trade standards. Environmental standards are also accepted by using briquettes (Malaťák et al., 2008).

During briquetting is a standard form of fuel for its following use in combustion chamber achieved. Due to manufacturing the volume of briquettes material is crucially reduced and its bulk density and potential of energy are increased. Bulk density and mechanical resistance (durability) are both very important. These properties depend on the material used and material structure, level of water and compacting pressure. We can apply Austrian norm ÖNORM M 7135 from the year 2000 and German norm DIN 51735 (Malaťák et al., 2008). Czech rule of law that is commonly used is standard No. 14 – 2009 MŽP ČR (Česko, 2009).

2.4.1 Characteristic of Briquettes

Briquettes have cylindrical, hexagonal, rectangular or other shapes. Furthermore, briquettes can be divided into the types without the bore hole and the other types with internal hole, which support better combustion (Plíštil, 2003). The forms of briquettes are shown in Figure 4 and 5.

Figure 4: Forms of briquettes



Source: Havrland et al., 2011

Briquettes typical length is from 30 to 300 mm and diameter is bigger than 25 mm (mostly about 50 - 75 mm). Following characteristics are typical for them:

- "low-sulphur content fuel – less than 0.07%
- typical range of net calorific value is 15 – 19 MJ/kg
- required moisture content up to 12%
- density 800 – 1000 kg/m^3
- ash content – less than 1.2%
- capable for economic storage with a relative humidity of up to 80% for virtually unlimited periods." (Havrland et al., 2011).

The content of moisture in briquette should be kept between 4 - 10%. Higher level of moisture may result bursting of briquette (Havrland et al., 2011). On the other hand, density is essential factor for briquettes. Furthermore, density has direct impact on their quality. According to Havrland et al. (2011): "The denser the briquette the higher is it quality. The lower the briquette density the lower is its net calorific value."

Figure 5: Briquettes and pellets

Source: International Energy Crops, 2013

There are listed most important properties of briquettes according to ČSN EN 14961-1 in Table 1.

Table 1: Properties of briquettes

Properties	**Value**
diameter	from 40 mm to 125 mm
length	from 50 mm to 400 mm
moisture	from 10% to 15%
ash	from 0.5% to 10%
particle density	from 0.8 g/cm^3 to 1.2 g/cm^3
mechanical durability	only if traded in bulk

Source: ČSN EN 14961-1, 2010

2.4.2 Use of Briquettes

Briquettes should be burned in all kinds of wood boilers. It is possible to use them in large scale of combustion equipment, for instance: stoves, tile stoves, hearthstones and central heating. They are ecological substitution of coal and an alternative for municipalities that struggle with smoke from combustion of coal. Wood gas boilers maximize the effect of briquettes combustion. All in all, biomass briquettes are pure and renewable source of energy (Stupavský et al., 2010).

Briquettes are most suitable for using in gasification boilers due to their low moisture. During full combustion are colourless carbon dioxide, water vapour and low harmful substances produced. Through burning, there is a little amount of ash generated. It fits approximately to one per cent of burning fuel that is ten kilograms per one ton of briquettes. This ash also consists of phosphorus - P, potassium - K, calcium - Ca, magnesium - Mg and other important elements. All of them are possible to use as a fertilizer for garden or lawn (Stupavský et al., 2010).

2.4.3 Production of Briquettes

Briquettes are produced from wood or plant residues by strong pressing that is named briquetting. New kind of solid biofuel come up from briquetting. Briquettes have almost the same net calorific value as brown and black coal, that is 12 - 18 MJ/kg. So as these both types of coal, briquettes should be manipulated, stored and transported (Stupavský et al., 2010).

Pressuring is factor that has an impact on production. Compacting at low pressures helps some materials (such as corn stover grind) to burn more efficiently. On the other hand, compacting at high pressures is required by other materials such as wheat and barley-straw are (Mani et al., 2004).

Briquettes are produced by pressing entering dried raw material in special briquetting presses without using any added mixtures, binding or glues (Stupavský et al., 2010).

Different press technologies can be applied. Grover et al. (1996) published: “A piston press is used to create solid briquettes for a wide array of purposes. Screw extrusion is used to compact biomass into loose, homogeneous briquettes that are substituted for coal in co firing. This technology creates a toroidal, or doughnut-like, briquette. The hole in the centre of the briquette allows for a larger surface area, creating a higher combustion rate.”

Through briquetting of waste is its volume reduced to eight times. The waste is also cheaper transported and stored. One of the great advantages of briquette machines is the valuation of waste (Briklis, 2011).

The distribution of briquettes is made either in sacks that weight mostly ten kilograms or in folded pallets weighing up to one thousand kilograms (Stupavský et al., 2010).

The prices of briquettes should crucially differ under the influence of season. They are the lowest in summer and it is advised to buy them for the whole heating season because the prices are rising up to approximately 40% in winter (Stupavský et al., 2010).

2.4.4 Advantages of Production Briquettes

Briquettes have many advantages. The most important of them are:

- they belong to renewable source of materials and they can be used as a fuel,
- briquettes can be easily insert into the combustion chamber and they differ from non-briquetted wastes,
- there is very low quantity of ashes from briquettes, it does not go over 0.5 - 1% of the used fuel overall quantity,
- net calorific value of briquettes according to a density is 4.5 – 5 $kWh.kg^{-1}$ which is 1.5 times more than wood and it is comparable to coal,
- briquettes do not consist of chemical additives and gluing substances and that is why they are environmentally friendly,
- they save environment, because CO_2 is released into the air through burning and it is fully absorbed by plants during photosynthesis,
- thanks to their size, that is compressed by 4-12 times in volume, they should be effectively transported and storaged,
- finally, the briquettes can well flare up, have a long burning without sparing and their warmth is allowed as more pleasant than the heat produced from coal, light fuel oil or natural gas (Havrland et al., 2011).

2.4.5 Equipment for the Briquettes Production

In the past, there have been developed two different directions in the biomass briquetting technology. The reciprocating ram/piston press was invented and perfected in Europe and the United States, while in Japan was explored and developed the screw press technology. Although both technologies have their advantages and disadvantages, it is well known that the screw pressed briquettes are miles better than ram pressed solid briquettes because of their excellent storability and combustibility (Grover et al., 1996).

Piston, matrix with the closed and open chambers, roller, ring, screw and mouthpiece, all of these types of presses are used for briquetting (Havrland et al., 2011).

Following equipment is used to make fuel briquettes:

- dryer machine,
- crusher,
- conveyor,
- biomass briquettes machine,
- packing machine (AGICO, 2012).

Inhabitants have started to generate briquettes at home. While the first machines in households able to create briquettes were made from compressed sawdust, modern machines that are used for producing briquettes can utilize any sort of dried biomass (AGICO, 2012).

Haverland et al. (2011) reported: "The briquette press BrickStar, or hydraulic pressing system (HPS) allows to produce briquettes of diameter 65 mm and length 30 -50 mm. The raw material for briquette production contains no binding agent and the effect of hardening is achieved only by means of pressure in a cylindrical matrix, thanks to counteracts their own material." See Figure 6.

Figure 6: Briquette press BrikStar CS 25, 50

Source: Briklis, 2011

2.5 QUALITY CONTROL OF BIOFUELS

There are different standards of producing wood pellets and other solid biofuels, recently. The absence of common (European) standards had negative impact on export and import and understanding among producers of boilers and fuels, as well. That is why the rise of promising industry of RES slowed down. Firstly, new European standards have positive effect on high and comparable quality of biofuels. Secondly, these standards help customers to better orientation in the market. Finally, the producers of combustion equipment should specify demands on suitable fuel by using previously mentioned standards (Kotlánová, 2012).

European Committee for Standardization (CEN) designed technical specifications for testing and prompts. Consequently, there were six standards EN 14961 released. General standard from 2010 EN 14961-1 defines the classification of solid biofuels according to origin: woody, herbal and fruit biomass. There were other standards for non-industrial use published in 2011: wood pellets (-2), wood briquettes (-3), wood chips (-4), firewood (-5) and non-woody pellets (-6), see Table 2. While general standard has rather informative parameters, other parts of standard are stricter (ČSN EN 14961-1, 2010; Kotlánová, 2012).

Members of CEN are required to fulfil EN 14961. Members of CEN are National Standards Bodies of these countries: Belgium, Bulgaria, the Czech Republic, Denmark, Estonia, Finland, France, Croatia, Ireland, Island, Italy, Cyprus, Lithuania, Latvia, Luxembourg, Hungary, Malta, Germany, Nederland, Norway, Poland, Portugal, Austria, Romania, Greece, Slovakia, Slovenia, UK, Spain, Sweden and Switzerland (ČSN EN 14961-1, 2010).

Table 2: National standards of the Czech Republic - Solid biofuels - Fuel specifications and classes

Name of standard	Specification	Valid from (month/year)
Solid biofuels – Fuel specifications and classes – Part 1: General requirements	ČSN EN 14961-1	07/2010
Solid biofuels – Fuel specifications and classes – Part 2: Wood pellets for non-industrial use	ČSN EN 14961-2	12/2011
Solid biofuels – Fuel specifications and classes – Part 3: Wood briquettes for non-industrial use	ČSN EN 14961-3	12/2011
Solid biofuels – Fuel specification and classes – Part 4: Wood chips for non-industrial use	ČSN EN 14961-4	12/2011
Solid biofuels – Fuel specification and classes – Part 5: Firewood for non-industrial use	ČSN EN 14961-5	09/2011
Solid biofuels – Fuel specifications and classes – Part 6: Non-woody pellets for non-industrial use	ČSN EN 14961-6	09/2012

Source: Author

It is necessary to know the quality and composition of biomass and biomass products (wood pellets and briquettes) which are intended for combustion and define it in terms for long term preservations quality and based on these specifications is important to make quality controls. The control of quality could be made mainly on the basis of specifications, which give values of individual physical and chemical properties (Kotlánová, 2009).

Testing of biomass should be practised by experienced laboratory. Correct sampling procedure is the primary thing. This activity should be performed by specialists and also the storage and transport of samples may effect on the results of analysis. Samples must be kept so that the moisture do not change and they must be prevented from contamination. Sampling is made according to general standard for sampling of solid biofuels ČSN EN 14778 (Kotlánová, 2009).

Samples of solid biofuels such as woodchips, grain, flax, rape straw, pellets and briquettes are usually analyzed in terms of following parameters:

- determination of moisture content,
- determination of ash content,
- determination of major elements,
- determination of content of volatile matter,
- determination of calorific value,
- determination of bulk density,
- determination of total content of sulfur and chlorine,
- determination of total content of carbon, hydrogen and nitrogen,
- determination of particle density,
- determination of mechanical durability of pellets and briquettes (Kotlánová, 2009).

Each of previously mentioned parameters is important for the quality of solid biofuels either in terms of the quality of the fuel for combustion or from the perspective of environmental protection.

One of the most important parameters is determination of moisture content that affects fuel efficiency. It is also consequential parameter for producing pellets from biomass. It is almost impossible to produce quality pellets from material with high level of moisture content. Determination of moisture content is provided by standard ČSN EN 14774-1 to 3 (Kotlánová, 2009). National standards of the Czech Republic regarding solid biofuels are listed in Table 3. Determination of ash content is also essential. It is provided by standard ČSN 14775. Metals and other elements could penetrate into solid biofuels through preservative chemicals (contamination of As, B, Cl, Cr, Cu, F, P, Zn), colours (Cd, Pb, Ti), used mineral oils and greases, soil, transport, used tools and machines (Fe, Cr, Ni) or additives. Determination of major elements in biofuels is provided by ČSN EN 15290. The other parameter is determination of content of volatile matter. Its high portion could affect emissions. This parameter is specified by ČSN EN 15148. Determination of calorific value is necessary for finding the utilization of the fuel in the combustion process. It proceed according to ČSN EN 14918. It is carried out in calorimeter. Determination of bulk density allows the assessment of required storage or space requirements during transport. This is provided by ČSN EN 15103 and made by pouring biofuel into standard container and weighed. It is advisable to know concentration of sulfur and chlorine. They are parts of solid biofuels and during combustion could convert into dangerous sulfur oxides and chlorides. Determination of total content of sulfur and chlorine is implemented by ČSN EN 15289. Determination of total content of carbon, hydrogen and nitrogen is made by using instrumental methods according to ČSN EN 15104. For pellets and briquettes are typical tests of their size, volume, density and abrasion. They are provided by ČSN EN 15150 when the pellet or briquette is fixed to the test tripod and immersed in a container with water and the buoyancy is calculated density of pellets or briquettes. Determination of mechanical durability of pellets and briquettes is important mainly for pellets dosed into the combustion machine. It is provided by ČSN EN 15210-1 (pellets) and ČSN EN 15210-2 (briquettes). Samples rotate in drum where they collide with partition and the result is abrasion (Kotlánová, 2009).

Most usually used standards in the Czech Republic regarding the solid biofuels are shown in Table 3.

Table 3: National standards of the Czech Republic - Solid biofuels - Sampling

Name of standard	**Specification**	**Valid from** (month/year)
Solid biofuels – Sampling	ČSN EN 14778	01/2012
Solid biofuels - Determination of moisture content – Oven dry method – Part 1: Total moisture – Reference method	ČSN EN 14774-1	05/2010
Solid biofuels - Determination of moisture content – Oven dry method – Part 2: Total moisture – Simplified method	ČSN EN 14774-2	05/2010
Solid biofuels - Determination of moisture content – Oven dry method – Part 3: Moisture in general analysis sample	ČSN EN 14774-3	05/2010
Solid biofuels – Determination of ash content	ČSN EN 14775	06/2010
Solid biofuels - Determination of major elements - Al, Ca, Fe, Mg, P, K, Si, Na and Ti	ČSN EN 15290	08/2011
Solid biofuels – Determination of the content of volatile matter	ČSN EN 15148	06/2010
Solid biofuels – Determination of calorific value	ČSN EN 14918	07/2010
Solid biofuels – Determination of bulk density	ČSN EN 15103	06/2010
Solid biofuels – Determination of total content of sulfur and chlorine	ČSN EN 15289	07/2011
Solid biofuels – Determination of total content of carbon, hydrogen and nitrogen – Instrumental methods	ČSN EN 15104	09/2011
Solid biofuels – Determination of particle density	ČSN EN 15150	06/2012
Solid biofuels – Determination of mechanical durability of pellets and briquettes – Part 1: Pellets	ČSN EN 15210-1	06/2010
Solid biofuels – Determination of mechanical durability of pellets and briquettes – Part 2: Briquettes	ČSN EN 15210-2	06/2011

Source: Author

From the above list of tests implies that solid fuels from biomass must have specified properties, which can affect previously mentioned tests. From the perspective of producers and consumers is essential that the quality of solid biofuels must be monitored and also declared on the products (Kotlánová, 2009).

3. OBJECTIVES

One of the possible types of waste biomass, which could be used as solid fuel, is a digestate. The aim of this diploma thesis is to verify whether digestate from biogas plant is suitable for briquettes production. The emphasis is given on abrasion resistance of briquettes from the point of view of used materials. This property is important for evaluation suitability of digestate products. The diploma thesis deals with following sub-goals.

The first of the objective is to find out and to evaluate whether the abrasion depends on the composition of briquettes. Digestate briquettes are mixed with mineral fertilizer, especially zeolite and dolomitic limestone.

Another goal is to conclude if the size of briquettes has an impact on mechanical durability of briquettes. In other words, whether there is a correlation between mass and abrasion. If the dependence between mass of briquettes and their abrasion was proved, it would be possible to produce specific dimension of briquettes, because the abrasion would be reduced.

The durability of briquettes in the time period belongs to very important qualities of briquettes and that is the third aim of the thesis. This last research ascertains whether the storage time has an influence on the abrasion of briquettes. There are also used energy crops, like *Miscanthus x giganteus* and *Miscanthus sinensis*. These kinds of crops are mixed with sawdust and wood shavings.

If some previously mentioned dependence is proved, another aim is to determine regression function and the tightness of dependence.

The other objective is to express the abrasion of each briquette and to determine the mechanical durability of the research samples according to standard ČSN EN 15210-2.

4. MATERIALS AND METHODS

4.1 USED MATERIAL CHARACTERISTICS

The material used for research purposes - digestate was obtained from the biogas plant which is located in agriculture cooperative in Krásná Hora nad Vltavou. There was following composition of feedstock: 60% of beef manure from the farm, 20% corn silage and 20% grass silage. Nutrient values of digestate are shown in Table 4. This material was processed in the dryer in the CULS to the finally content of 85-90% of dry matter and then was solid part of digestate separated.

Table 4: Nutrient values of digestate, expressed in %

material	ash	nitrogen	fats	fibre	organic matter	nitrogen-free extract
6% dry matter	1.02	0.78	0.02	1.86	4.95	2.28
100% dry matter	17.12	13.08	0.38	31.18	82.88	38.23

Source: doc. Ing. Josef Pecen, CS.c

The briquettes were pressed on 3rd December 2012 and they had cylindrical shape with diameter 65 mm, length approximately from 30 to 100 mm and their mass was from 27.4 g to 257.1 g. All of the briquettes were produced on the briquetting press type BrikStar CS 50, which is available at Technical Faculty of CULS.

The briquettes were stored for four months in the laboratory with an average temperature 23 ºC and relative air humidity between 45 – 60%. Each of briquettes were weighed separately. Three different types of briquettes were used: first type contained the pure digestate only, the second one contained digestate with zeolite added in ratio 6:1 and the third one was digestate with dolomitic limestone added in ratio 6:1. See Figure 7, Table 5. The briquettes were made from the stated materials without other additives, like binding. Properties of digestate are listed in Appendix 24 and 25.

Figure 7: Digestate briquettes and mineral fertilizers

Source: Author

Table 5: Types of produced briquettes

Type of briquette	Date of press	Date of abrasion			
		I.	**II.**	**III.**	**IV.**
8 kg digestate	03.12.2012	04.12.2012	09.01.2013	05.02.2013	05.03.2013
3 kg digestate + 0.5 kg zeolite	03.12.2012	12.12.2012	23.01.2013	05.02.2013	05.03.2013
3 kg digestate + 0.5 kg dolomitic limestone	03.12.2012	12.12.2012	23.01.2013	05.02.2013	05.03.2013

Source: Author

Briquettes made from *Miscanthus x giganteus* and *Miscanthus sinensis* were used for determination long time period of storage time. Both species were grown on land of CULS. The material was harvested in April 2011 and was dried under natural conditions in the sun. At first, dry stems of *Miscanthus x giganteus* and *Miscanthus sinensis* were crushed using hammer crusher with 8 mm diameter sieve and then the material was mixed with sawdust and wood shavings in ratio 1:1. Finally, it was processed by briquetting press. Totally, it was produced six types of briquettes. The first one were briquettes made from pure *Miscanthus x giganteus* (MG), next MG mixed with sawdust and the last was MG with addition of wood shavings. The same procedure was repeated with *Miscanthus sinensis*. The initial diameter of briquettes was 65 mm and length from 30 to 50 mm. These briquettes were stored for 16 months in the laboratory of CULS with an average temperature 23 ºC and relative air humidity from 45 to 60%. All the briquettes were produced in the same way and had the same shape.

I used partially results of laboratory measurements from Hojná (2012), which were supplemented by new finding. Briquettes were abraded seven times in the rotary drum. See Table 6. Compared to previous research, these briquettes were weighed as a sample of the total mass 2 ± 0.1 kg. See Appendix 23 and 24.

Table 6: Data of abrasion of briquettes made from *Miscanthus x giganteus* and *Miscanthus sinensis*

Date of abrasion						
I.	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**
15.11.2011	15.12.2011	17.01.2012	20.03.2012	19.09.2012	09.01.2013	27.02.2013

Source: Author

4.2 METHODS

Microsoft Office Excel was used to organize data obtained from laboratory measurements in this thesis. Software STATISTICA ver. 10 was used for processing of data.

The obtained data were firstly characterized by descriptive statistics and then tested for normality and homogeneity by using following tests with significance level $\alpha = 0.05$:

- Shapiro – Wilk's test,
- Bartlett's test,
- Levene's test.

Secondly, according to the results of normality, homogeneity and character of data, there was interaction of parameters tested with individual factors. These tests were applied to evaluate the dependency:

- ANOVA (analysis of variance),
- Kruskall-Wallis test,
- Scheffé's method,
- Friedman test.

With the help of regression and correlation analyses regression estimates were determined.

Furthermore, abrasion (i.e. mass, which is separated from the briquettes) and mechanical durability of briquettes (i.e. how large is the sample that remains after the test) were calculated.

4.2.1 Descriptive Statistics

Descriptive statistics identifies and summarizes information, processes it in the form of graphs and tables and calculates their numerical characteristics such as:

- arithmetic mean,
- median,
- lower quartile,
- upper quartile,
- variance,
- coefficient of variation,
- standard deviation.

Arithmetic Mean

$$\bar{x} = \frac{x_1 + x_2 + ... + x_n}{n},$$

n = number of observation

Confidence Limits for the Mean

$$P = (\bar{x} - \Delta < \mu < \bar{x} + \Delta) = 1 - \alpha,$$

$1 - \alpha$ = confidence coefficient

Δ = delta, standard error

Median or middle value also known as 50% quartile divides the statistical sample (population) into two equally numerous half. In the case, where the sample exist considerably outlier or extreme values, median better characterizes statistic sample than arithmetic mean (Diggle et al., 2011).

Quartiles are values that divide the statistic sample into four parts, each part contains about 25% units. There are three quartiles: lower quartile $\tilde{x}_{0.25}$ separates the lowest quarter of character values. The middle quartile - median $\tilde{x}$ divides the field of character values into two equal parts, each of them contains 50% of units. Upper quartile $\tilde{x}_{0.75}$ separates 75% of the lowest character values from remaining 25% of character values (Hawkins, 2009; Svatošová et al., 2009).

Variance is defined as the average squared divergence of each character values from their arithmetic mean (Hindls et al., 2006).

$$s_x^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}$$

Coefficient of Variation is defined as the ratio of the standard deviation and the mean. The coefficient of variation is a dimensionless quantity. Its centuple shows variability in per cent. According to very rough rule is coefficient of variation greater than 50% a sign of disparity of statistical sample (Svatošová et al., 2009, Kába et al., 2012).

$$v_x = \frac{s_x}{\bar{x}}$$

Standard Deviation is square root of the variance and it is expressed in the same units as the examined statistical character (Hindls et al., 2006).

$$s_x = \sqrt{s_x^2}$$

Box Plot (also known as a whiskers plot) shows considerably outlier and extreme value. It displays graphically depicting groups of numerical data through their five parameters: the smallest observation (sample minimum), lower quartile, median, upper quartile and largest observation (sample maximum). Box Plot may also marks the observations that are supposed to be outliers (Diggle et al., 2011; Kába et al., 2012).

Quantile - Quantile Plot (also known as a Q-Q plot) is a simple visualization tool for tentative assessment of normality. If the analyzed data are not in contradiction with hypothesis of normality of distribution, points in graph are approximately arranged in a straight line (Hindls et al., 2006; Svatošová et al., 2009; Kába et al., 2012).

4.2.2 Statistical Hypothesis Testing

Statistical induction methods play an important role in statistics. They are a set of processes that by researching a random sample and using the apparatus of probability theory allow to formulate conclusions about the population, from which was this random sample taken (Svatošová et al., 2007).

There are two important terms. One of them is a statistical hypothesis - a statement about the parameters describing a population (not a sample). The second one is a statistical test that is a procedure by which it is verified whether there is a relationship between the variables (dependence or difference). If, based on the test is determined that a survey result is statistically significant it is very unlikely that this result was due to a mere coincidence (Lehmann et al., 2005).

It is necessary to distinguish between parametric and non-parametric tests. Parametric tests require the fulfilment of many conditions (e.g. normal distribution of random variables tested) to justified their use. On the contrary, non-parametric tests are more versatile, but their smaller force (smaller ability to reject an incorrect null hypothesis) is their disadvantage (Jindrová et al., 2008; Diggle et al. 2011).

Statistical hypothesis that is tested is named the null hypothesis and is denoted H_0. Each task of testing hypotheses is formulated so that it confronts two hypotheses: the null hypothesis H_0 and alternative hypothesis H_1, that rejects the null hypothesis H_0 and we accept it when we refuse the null hypothesis H_0 (Hawkins, 2009; Kába et al., 2012).

Testing is done on a random basis. Every statistical decision that is based on this selection has the probabilistic character and therefore can lead into certain errors: The probability of type I error and the probability of type II error. The probability of type I error is named significance level and is denoted by the Greek symbol α (alpha). It indicates the amount of risk with which the H_0 is rejected, even if it is true. The rate of the type II error is denoted by the Greek letter β (beta) and related to the power of a test (which equals 1-β) (Hawkins, 2009; Kába et al., 2012).

ANOVA (Analysis of variance) represents a generalization of two-sided t-test to the case of more than two selections. This method is used when the influence of one or several factors on researched quantitave statistical character *X* is studied. In the first stage is by using this analysis the null hypothesis tested. If this H_0 is not rejected, our research ends. If this H_0 is rejected, in the second stage is tested which files are significantly different from each other (Hindls et al., 2006; Kába et al., 2012).

Friedman test is similar to the non-parametric analysis of variance for samples that are interdependent. It tests the null hypothesis H_0 that all selections originate from the same distribution. In case of the $p<0.05$ is the null hypothesis rejected and the alternative hypothesis H_1 accepted. The H_1 means that the observed values of at least two samples are significantly different from each other. For subsequent multiple comparison is used Neményi method for dependent samples. The procedure consists of comparing differences $|Ti – Tj|$ with critical value $N_{\alpha(k,N)}$. These values are tabulated for $N \leq 25$ and $k \leq 10$, where *k* is the number of classes being compared and *N* is the number of repetitions in each class. If $|T_i – T_j| \geq N_{\alpha(k,N)}$, is the hypothesis rejected, that *i-th* and *j-th* selection come from the same distribution (Jindrová et al., 2008).

4.2.3 Regression and Correlation Analysis

These analyses enable to solve two main tasks: firstly, to find a form of dependence and express it by mathematical (regression) function. This is called a regression task. Secondly, to determine the degree of force, it is so called correlation task (Svatošová et al., 2009).

Basic case of statistical dependence is a simple linear regression, which means the dependence only between two random variables *X* and *Y*. Observed values are shown by using scatter plot. Set of points in this scatter plot made correlation field and give tentative information on the study of dependence. If the points in scatter plot are arranged in such a way, that the course of the correlation field could be captured by a straight line, there is linear relationship indicating between variables *X* (grouping variable) and *Y* (dependent variable). In other cases, the process of correlation field should be captured by some non-linear function, in this case it is non-linear dependence. Linear regression function is in the following form:

$$y_i = \alpha + \beta_i + e_i,$$

where alpha and beta are parameters of the equation lines that represent the absolute term of alpha and beta the regression coefficient. The parameter *e* is the residue. The regression coefficient r^2 characterizes the average change of the dependent variable, which corresponds to a change of the independent variable on the one of its unit. If this coefficient is positive, the growth of values of the independent variable *X* is on average accompanied by the growth of the dependent variable *Y*. This dependence is called a positive correlation. If the regression coefficient is negative, growth occurs when the values of the independent variables are in a decrease in average values of the dependent variable. In this case, it is called negative dependence (Kába et al., 2012).

The second basic task of the statistical analysis of the relationships between random variables is to determinate the correlation (determine the degree of force or determine the tightness of dependence). While regression analysis focuses on the form between the observed variables, correlation analysis shows how strong this relationship is. Dependence between variables *X* and *Y* characterizes the correlation coefficient *r*. For rating of tightness of linear relationship between *X* and *Y* are following approximate scale used:

$0 < \lvert r \rvert \leq 0.3$	weak dependence
$0.3 < \lvert r \rvert \leq 0.8$	moderate (medium) dependence
$0.8 < \lvert r \rvert \leq 1$	strong dependence (Svatošová et al., 2009).

The coefficient of determination r^2 is another important measure of tightness of linear dependence. $r^2 * 100$ indicates how many per cent of changes of the dependent variable are explained by the selected linear regression functions (Kába et al., 2012).

4.2.4 Mechanical Durability

Mechanical durability of briquettes belongs to one of the most important tests of their mechanical resistance. It represents the ability of densified fuels to remain intact during handling and delivery (Carone et al., 2011). Mechanical durability is necessary for the evaluation of physical quality of solid biofuels, especially for briquettes and pellets. Both of them are inclinable to damage, especially during transport and storage. Test of mechanical durability was performed in special rotating drum with a partition (ČSN EN 15210-2, 2011).

Figure 8 shown specific rotating abrasion drum according to ČSN EN 15210-2. It is a steel cylindrical drum with a volume of 160 litres with following dimensions:

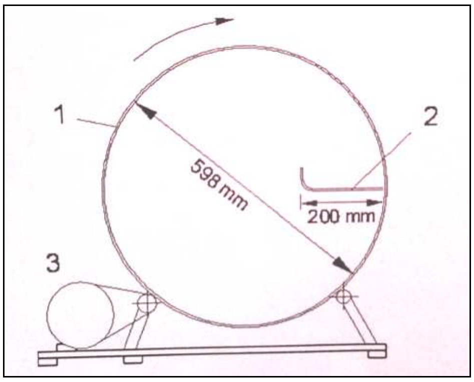
- inner length or depth: 598 ± 8 mm,
- inner diameter: 598 ± 8 mm.

The drum must be constructed of steel sheet with minimum thickness of 1 mm. The inner surface of drum must be smooth and free of any surfaces imperfections such as scratches or bumps are. Drum for mechanical resistance features a rectangular steel partition with following parameters:

- length: 598 ± 8 mm,
- height: 200 ± 2 mm,
- thickness: 1 mm (ČSN EN 15210-2, 2011).

Minimum test portion of the sample must be 2 kg. Prepared test portion of the sample with a minimum mass of (2 ± 0.1) kg is put into the drum and rotates approximately for 5 minutes or when 105 turns are made (ČSN EN 15210-2, 2011). See Figure 9.

Figure 8: Rotary drum according to ČSN EN 15210-2
Notes: 1 – Drum, 2 – Partition, 3 – Motor



Source: ČSN EN 15210-2, 2011

Figure 9: Rotary drum at Faculty of Engineering, CULS

Source: author

Mechanical durability of briquettes made from biomass is calculated by using the following formula:

$$DU = \frac{m_A}{m_E} * 100$$

where: DU= the mechanical durability in %,

m_E = the mass of pre-sieved briquettes before the drum treatment in grams (before abrasion),

m_A = the mass of sieved briquettes after the drum treatment in grams (after abrasion) (ČSN EN 15210-2, 2011).

There are no standard criteria for mechanical resistance of acceptance levels, but high durability means high quality briquettes (Kaliyan et al., 2009). Low mechanical durability leads to high dust emissions or it is responsible for an increased risk of fire and explosions during briquettes handling, transport and storage. Another problem can also appear during feeding boilers (Temmerman et al., 2006).

Minimum storage time for briquettes is 9 months. During this period, briquettes must not change their size, density and moisture content by more than 10% (Česko, 2009).

5. RESULTS

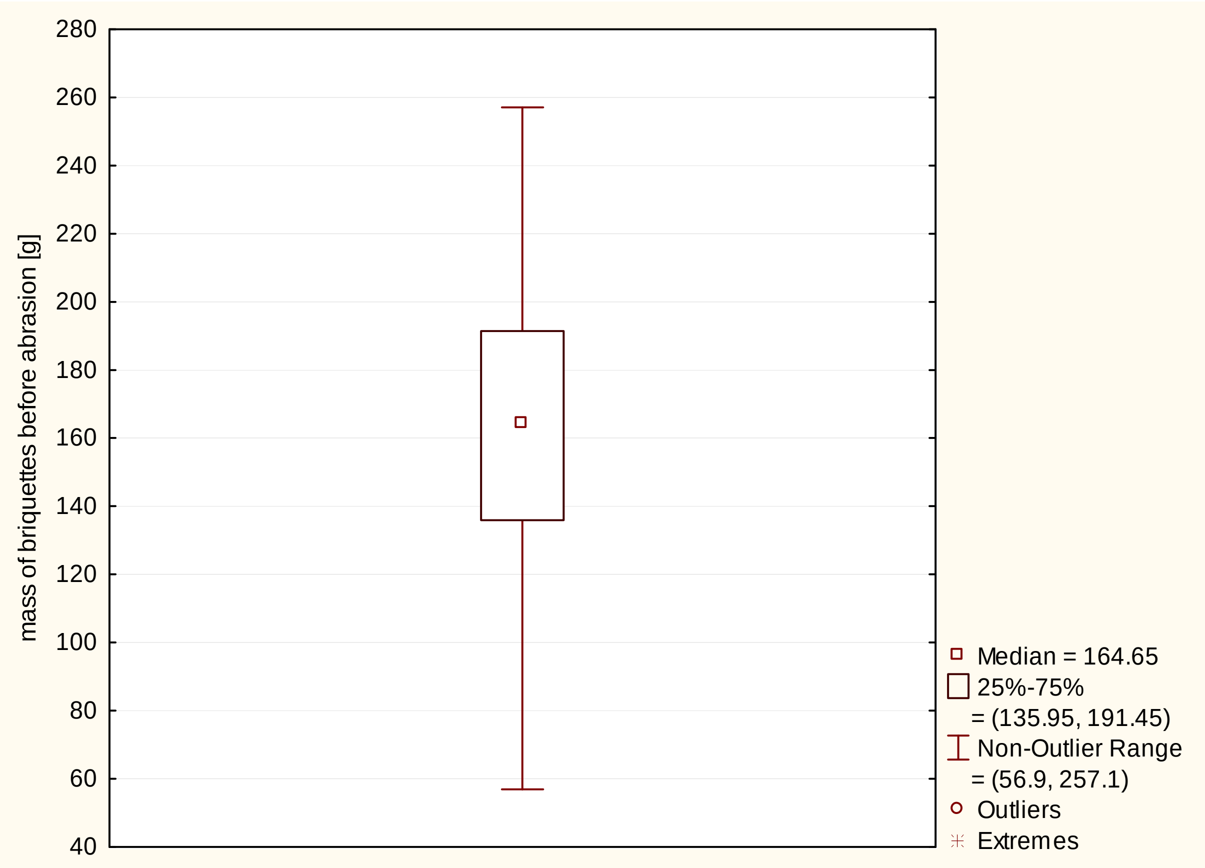
5.1 DESCRIPTIVE STATISTICS

5.1.1 Mass of Briquettes

There was a Box Plot constructed from 90 measured values. The graph in Appendix 1 shows that two outliers appear there (27.4 g and 35 g). These outliers were excluded from observation because their inclusion could distort the results.

The measures of central tendency and dispersion (variability) were calculated of the remaining 88 values. See Appendix 3. The average mass of briquette before abrasion was 162.2 g. Further, the confidence limit for the mean was calculated on the significance level $\alpha = 0.05$. It is possible to say with 95% confidence that the average briquettes mass before abrasion is between 153.1 g and 171.3 g. Standard Error $\Delta = 9.1$. Since the arithmetic mean can distort the results, there was also median calculated and Box Plot constructed. See Graph 1.

Graph 1: Box Plot of mass of briquettes before abrasion



Source: Author

Box Plot allows assessment of the robust estimate of median, then the symmetry of the data set and assessment of outlying or extreme values. Measured values (individual mass of briquettes before abrasion) are shown on Y- axis. From Graph 1 is evident that data does not make any outliers or extremes. From the shape of Box Plot is possible to determine the symmetry of the layout. Graph is represented by data from the normal distribution and not only because of its symmetry, but also due to the position of the median, that is situated almost in the total centre of a rectangle. For verification the value of arithmetic mean $\bar{x}$ = 162.2 g is very close to the median $\tilde{x}$ = 164.65 g. There are 25% of the samples (data) with a value that is less than or equal to 136 g and 75% of the values is smaller than or equal to 192 g. Non-outlier range is in the interval (56.9; 257.1 g).

In a Quantile-Quantile Plot of briquettes mass before abrasion (Appendix 2) there are compared structured values (by size) analyzed variables with theoretical quantile. Points in graph are arranged approximately in a straight line, and therefore it is possible to conclude that this could be a normal distribution. This result is necessary to be confirmed by using the statistical test, Shapiro-Wilk test.

H_0: Examined data come from a population with a normal distribution.

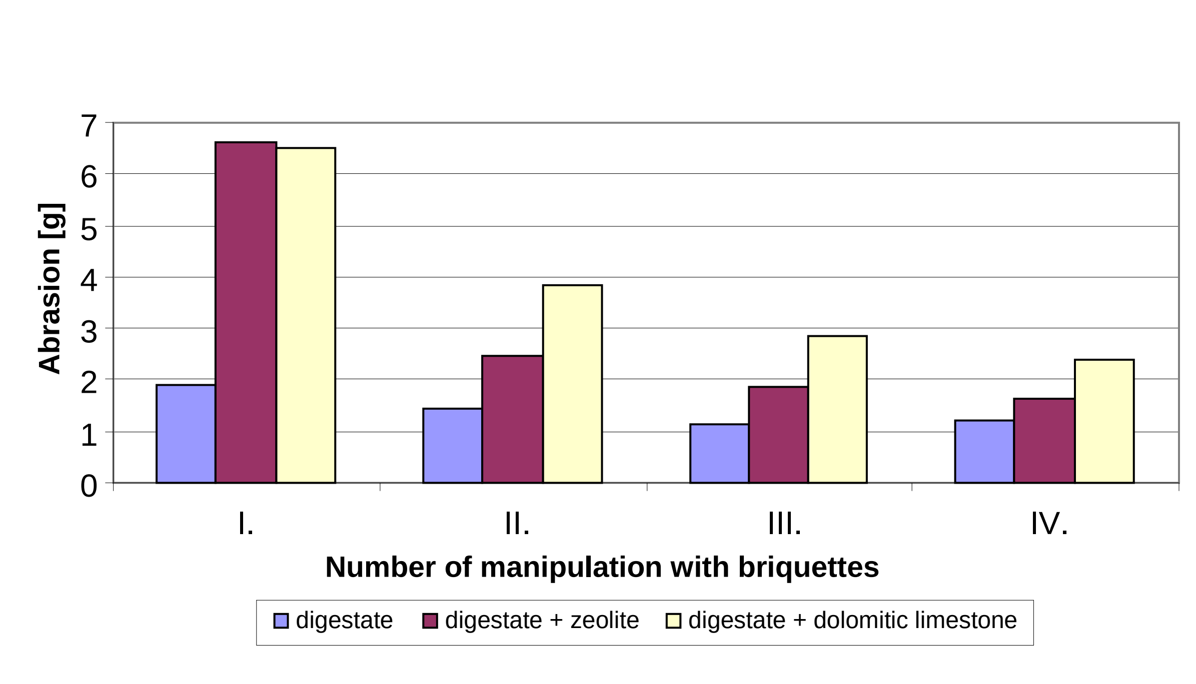
P-Value is in this case p = 0.6149 and this value is greater than significance level $\alpha = 0.05$. That means that the null hypothesis is accepted.

p-value > α; H_0 is accepted

5.1.2 Abrasion of Briquettes

From Graph 2 is apparent that the abrasion is dependent on the number of manipulations with briquettes, otherwise it is dependent on the number of abrasion in the rotating drum. The greater the number of manipulation with briquettes, the smaller is the abrasion of briquettes. Therefore, it is a downward trend. The worst (extreme) or the largest average abrasion of briquettes was observed in digestate mixed with zeolite followed by digestate mixed with dolomitic limestone in the first manipulation with briquettes. In the second, third and fourth manipulation was the worst (extreme) average of abrasion measured at the digestate with dolomitic limestone followed by digestate with zeolite. The best result, so the smallest average abrasion was achieved by pure digestate. There are calculated mean, minimum and maximum values and standard deviations in Appendix 4. The values of standard deviation are quite high, which means that the distribution around average is more dispersed.

Graph 2: Average abrasion of briquettes according to composition



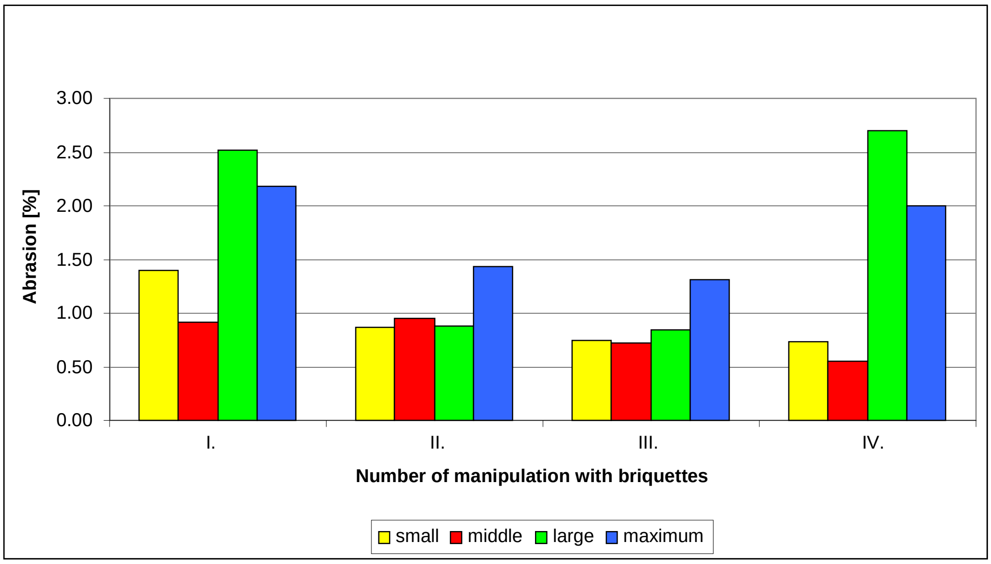
Source: Author

Briquettes made from digestate, digestate mixed with zeolite and digestate mixed with dolomitic limestone were divided into these four size groups according to their mass:

- small (S) < 130 g
- middle (M) from 130 g to174.5 g
- large (L) from 174.6 to 190 g
- maximal (MAX) > 190 g.

Appendix 5 shows description of these groups. Further, there was calculated an average abrasion of briquettes, which is expressed in per cent. For briquettes made from pure digestate is evident, that abrasion slightly increases with the mass of briquettes. See Graph 3. There are maximum values of abrasion expressed in per cent in the Appendix 6. It is obvious from the maximum values that in the briquettes belonging to the mass group above 190 grams also occur the largest abrasion.

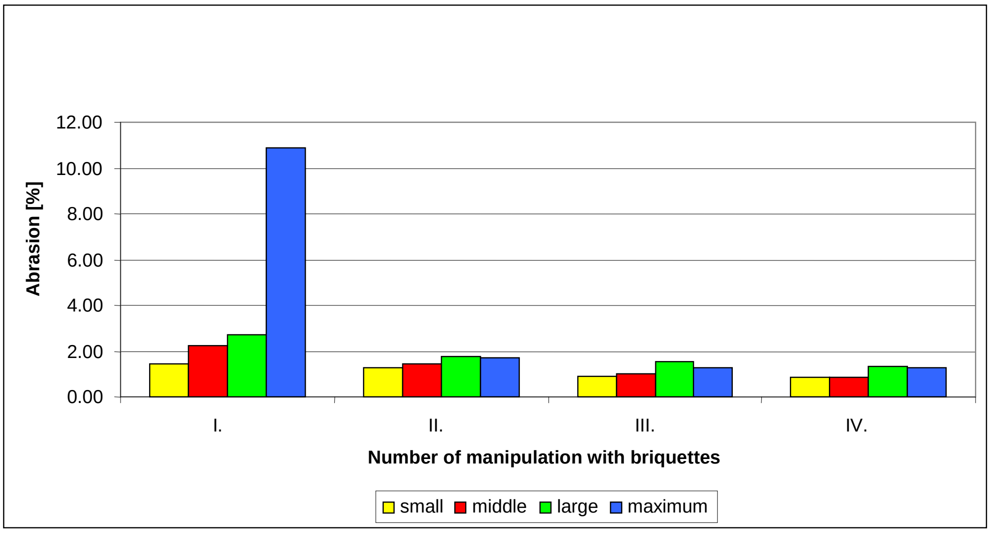
Graph 3: Average abrasion of briquettes made from digestate according to size groups



Source: Author

In the briquettes that are produced from digestate with the addition of zeolite is evident a similar trend as in previous briquettes. See Graph 4. The abrasion increases with a mass of briquettes. The maximum value was observed in the largest size group. The most noticeable difference is at the first manipulation with briquettes. The difference in the second, third and fourth manipulation in a rotary drum is almost insignificant. See Appendix 7.

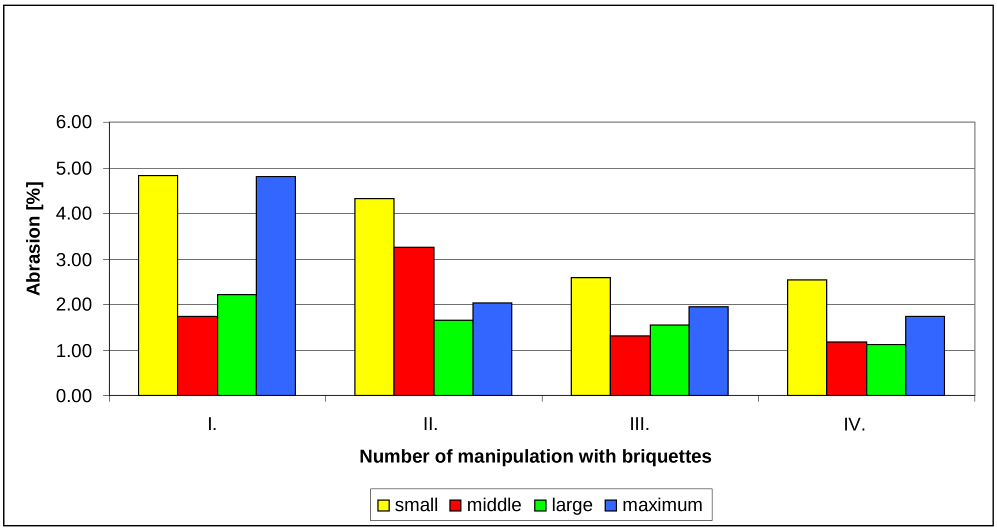
Graph 4: Average abrasion of briquettes made from digestate mixed with zeolite according to size groups



Source: Author

The briquettes made from digestate with addition of dolomitic limestone had the largest abrasion in small groups, followed by the maximum, large and medium size groups (in the first manipulation). See Graph 5 and Appendix 8.

Graph 5: Average abrasion of briquettes made from digestate mixed with dolomitic limestone according to size groups



Source: Author

In the next part of this diploma thesis, there will be statistically verified the hypothesis that the abrasion depends on mass (size) of briquettes and researched whether is this difference statistically significant.

5.2 STATISTICAL HYPOTHESIS TESTING

5.2.1 Comparing Composition of Briquettes

The aim of this part of the thesis is to determine whether there is dependence between the abrasion and composition of briquettes. From the graph ANOVA results for effect "briquettes made from" (Appendix 9) is evident that there will be differences between briquettes with different composition and their abrasion. It is also true that at first, second, third and fourth manipulation with briquettes is $p < \alpha$, H_0 is rejected and the alternative hypothesis is accepted: at least by one pair of the composition of the briquettes is significant difference in the abrasion.

- H_0: in the composition of briquettes is not significant difference in the abrasion;
- H_1: at least in one pair of the compared composition of briquettes is significant difference in the abrasion.

$p < \alpha$; H_0 is rejected

Test continues with the detailed evaluation but at first it is necessary to find out the normality and homogeneity of data by using Bartlett's test and Levene's test. It is obvious from Appendix 10, that I., II. and III. manipulation with briquettes must be solved by using nonparametric tests (Kruskall-Wallis test), because $p < \alpha$. The result was $p > \alpha$ in IV. manipulation, i.e. null hypothesis is accepted and will be solved by using the Scheffe's method. See Appendix 11. There are shown detailed assessments, among which variables are statistically significant differences in Appendix 12 and 13. In the first and second manipulation was proved statistically significant difference in the abrasion of briquettes with the composition 1 and 2, 1 and 3. There was statistically significant difference proven in the abrasion of the third and fourth manipulation but only in briquettes with structure 1 and 3.

1 = digestate; 2 = digestate + zeolite; 3 = digestate + dolomitic limestone

From the results of analysis it could be with 95% probability concluded that the factor of structure of briquettes has an important effect on the abrasion.

5.2.2 Comparing Size Groups

The aim is to find out if there are any dependencies between the mass of briquette and its total abrasion (the sum of four manipulations). There are graphs of effective hypothesis decomposition including *p-value* displayed in the Appendix 14. *P-value* was tested by the use of analysis of variance. There were null and alternative hypothesis for briquettes that are made from digestate worded:

- H_0: between size groups of briquettes made from digestate is not statistically significant difference in the abrasion;
- H_1: at least in one pair of the size groups exists statistically significant difference in the abrasion.

$p > \alpha$; H_0 is accepted

Further, there were also null and alternative hypotheses for briquettes made from digestate mixed with zeolite determined:

- H_0: between size groups of briquettes made from digestate mixed with zeolite is not significant difference in the abrasion;
- H_1: at least in one pair of the size groups exists significant difference in the abrasion.

$p < \alpha$; H_0 is rejected

Continues with more detailed evaluation, but at first it is necessary to find out homogeneity of data by using Bartlett's test. After the testing of homogeneity of variances is the result

$p < \alpha$, that means, that the task is consequently solved by using non-parametric tests. There is statistically significant difference in the small and maximal size group determined by application of Kruskal-Wallis test. Statistically significant difference is evident in the abrasion of briquettes with the mass up to 130 grams and over 190 grams. See Appendix 15.

The last null and alternative hypotheses were formulated for briquettes made from digestate mixed with dolomitic limestone:

- H_0: between size groups of briquettes made from digestate mixed with dolomitic limestone is not significant difference in the abrasion;
- H_1: at least in one pair of the size groups exists significant difference in the abrasion.

$p > \alpha$; H_0 is accepted

Only in briquettes pressed of digestate with addition of zeolite was proved statistically significant difference between the size groups and the abrasion, as well.

5.2.3 Comparing Time Period

There was in sample of 88 briquettes examined whether storage time affects the abrasion. Briquettes were stored for four months in laboratory conditions and were abraded in rotary drum. See Appendix 16. Null and alternative hypothesis is as follows:

- H_0: all selections come from the same distribution, i.e. storage time is independent on the abrasion;
- H_1: storage time is dependent on the abrasion.

As it is observation of the multiple dependent samples, the Friedman test was used. The results of this test can be seen in Table 7.

$p < \alpha$; H_0 is rejected

Alternative hypothesis is accepted and therefore more detailed assessment by using Neményi method for dependent samples will be made. There is a difference in totals of serial numbers $|Ti - Tj|$ calculated in Table 7. In the tables of critical values of Neményi method for depended choices can be found for $\alpha = 0.05$, $N_{0.05\ (4;88)}=23.5$. In the Table 8 where are differences between sums of serial numbers are with red colour marked differences that outweigh or coincide number 23.5 at the level of significance $\alpha = 0.05$. It is apparent with the 95% confidence that each month of storage affects the abrasion.

Table 7: Friedman test

Variable	Friedman ANOVA and Kendall Coeff. of Concordance (Time Period) ANOVA Chi Sqr. (N = 88, df = 3) = 120.9255 **p =0.00000** Coeff. of Concordance = 0.45805 Aver. rank r = 0.45182			
	Average Rank	Sum of Ranks	Mean	Std.Dev.
December	3.460227	304.5000	4.080682	7.070822
January	2.931818	258.0000	2.285000	1.945518
February	2.085227	183.5000	1.743182	1.323770
March	1.522727	134.0000	1.619318	1.685834

Source: Author

Table 8: Neményi method

i/j	*2*	*3*	*4*
1	304.5 – 258.0 = 46.5	304.5 – 183.5 = 121.0	304.5 – 134.0 = 170.5
2		258.0 – 183.5 = 74.5	258.0 – 134.0 = 124.0
3	134.0 – 258.0 = 124.0		183.5 – 134.0 = 49.5

Source: Author

5.3 REGRESSION AND CORRELATION ANALYSIS

Statistically significant difference was observed in briquettes made from digestate, digestate mixed with zeolite and digestate mixed with dolomitic limestone. Regression function was calculated for three kinds of briquettes (not for size groups). There are observed values of these briquettes illustrated by using Scatter Plots in Appendix 17, 18 and 19. The mass of briquettes before abrasion expressed in grams is displayed on the *X* axis and the abrasion in grams is shown on the *Y* axis.

There are results of regression analysis for briquettes made from digestate listed in Table 9. The regression coefficient – 0.0121 determines the slope of the line and its sign (minus) shows a negative dependence of the mass on the abrasion. The abrasion is explained by the linear function of 66%. The correlation coefficient is lower than 0.3, i.e. this implies weak dependence. Regression function has the form y = 3.0587 – 0.0121x. If the size of independent variable changes by one unit, the value of the dependent variable would be changed on average by regression coefficient. That means, if the mass of briquette increases to 100 grams, the abrasion would reduce on average of 1.2 grams.

Table 9: Regression summary for briquettes made from digestate

n=47	Regression Summary for Dependent Variable: abrasion, March (digestate) R= 0.25691070 R2= 0.06600311 Adjusted R2= 0.04524762 F(1.45)=3.1800 p<0.08129 Std.Error of estimate: 1.7966					
	b*	Std.Err. of b*	b	Std.Err. of b	t(45)	p-value
Intercept			3.058695	1.057393	2.89268	0.005867
mass before abrasion, March	-0.256911	0.144068	-0.012067	0.006767	-1.78326	0.081289

Source: Author

The briquettes pressed from digestate mixed with zeolite have regression coefficient r = 0.0325 this implies positive dependence. See Table 10. Regression function is in the form y = - 3.2110 + 0.0325x. The correlation coefficient is 0.75 and therefore it is a medium dependence. The abrasion is explained by the linear function of 57%. If the mass of briquette increases of 100 grams, the abrasion would increase on average of 3.3 grams.

Table 10: Regression summary for briquettes made from digestate mixed with zeolite

n=18	Regression Summary for Dependent Variable: abrasion, March (digestate+zeolite) R= 0.75198024 R2= 0.56547429 Adjusted R2= 0.53831643 F(1.16)=20.822 p<0.00032 Std.Error of estimate: 0.80536					
	b*	Std.Err. of b*	b	Std.Err. of b	t(16)	p-value
Intercept			-3.21102	1.079676	-2.97406	0.008951
mass before abrasion, March	0.751980	0.164796	0.03250	0.007122	4.56309	0.000319

Source: Author

The briquettes made from digestate with the addition of dolomitic limestone have the regression coefficient of 0.0131, i.e. this implies positive dependence. Regression function has the form y = 0.4651 + 0.0131x. See Table 11. The correlation coefficient is 0.46 and that is a medium dependence. The abrasion is explained by the linear function only of 22%. If the mass of briquette increases of 100 grams, the abrasion would increase on average of 1.3 grams.

Table 11: Regression summary for briquettes made from digestate mixed with dolomitic limestone

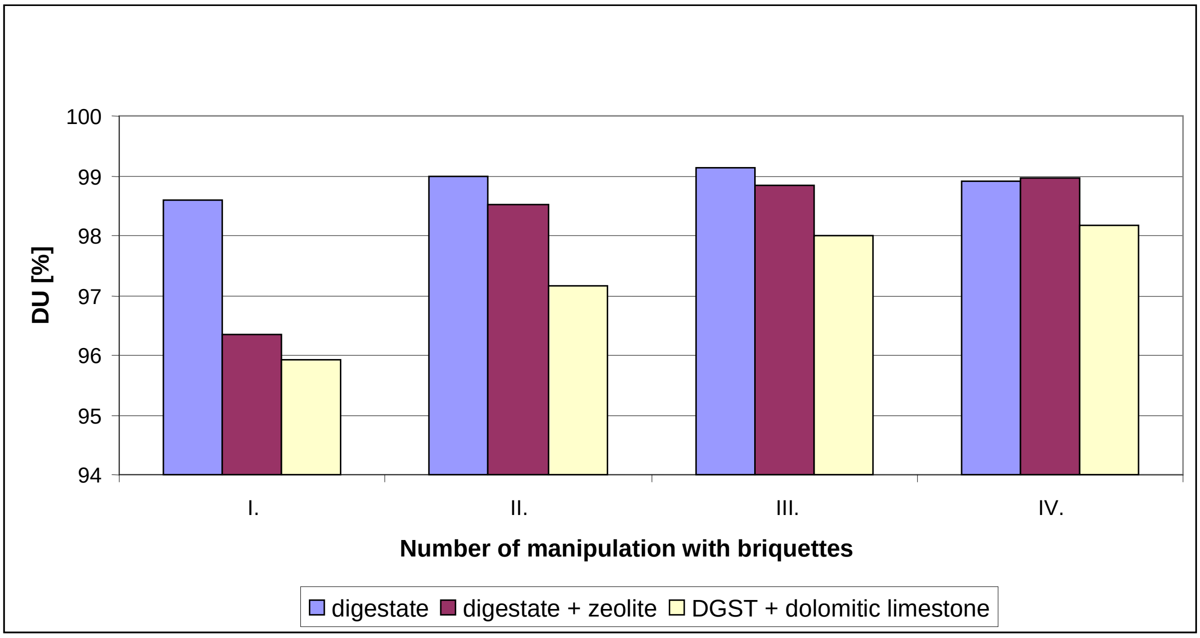
n=23	Regression Summary for Dependent Variable: abrasion, March (digestate+dol.limestone) R= 0.46393758 R2= 0.21523808 Adjusted R2= 0.17786846 F(1.21)=5.7597 p<0.02575 Std.Error of estimate: 1.3243					
	b*	Std.Err. of b*	b	Std.Err. of b	t(21)	p-value
Intercept			0.465052	0.850511	0.546792	0.590285
mass before abrasion, March	0.463938	0.193312	0.013089	0.005454	2.399939	0.025752

Source: Author

5.4 MECHANICAL DURABILITY

The best result in terms of mechanical durability (DU) was achieved for briquettes pressed from pure digestate and its DU was close to one hundred per cent. The worst DU was reflected on briquettes made from digestate mixed with dolomitic limestone. Briquettes prepared from digestate with zeolite had DU over 96% in the first manipulation with briquettes. Abrasion resistance was around 99% in other manipulations. See Graph 6 or Appendix 20, 21 and 22. It is evident from the point of view of DU that briquettes pressed from pure digestate are the best ones.

Graph 6: Mechanical durability of briquettes



Source: Author

5.5 LONG-TERM ASPECT STORAGE OF BRIQUETTES

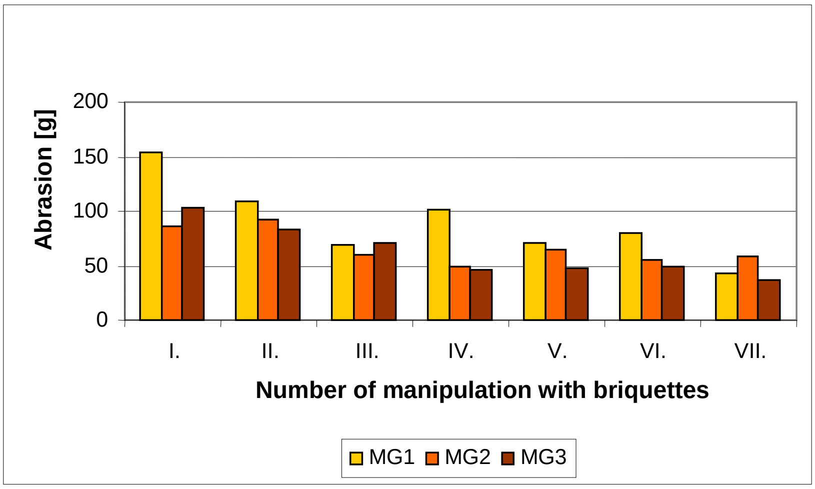
In this part of the thesis the partially results of laboratory measurements from Hojná (2012) were used and they were additionally supplemented by new finding. Briquettes made from *Miscanthus x giganteus* and *Miscanthus sinensis* were stored for 16 months in the laboratory of CULS. They were abraded for seven times in a rotary drum.

Average abrasion for each sample of *Miscanthus x giganteus* is displayed in the Graph 7. Briquettes pressed from pure *Miscanthus x giganteus* were marked as the least solid briquettes. On the other hand, briquettes made from *Miscanthus x giganteus* mixed with wood shavings were identified as briquettes with the best mechanical durability. They were the most solid. See Graph 8. The highest abrasion was achieved upon first manipulation with briquettes.

Explanatory Notes:

- MG – *Miscanthus x giganteus*; MS – *Miscanthus sinensis*
- 1 – pure *Miscanthus*
- 2 – *Miscanthus* mixed with sawdust
- 3 – *Miscanthus* mixed with wood shavings

Graph 7: Average abrasion – *Miscanthus x giganteus*

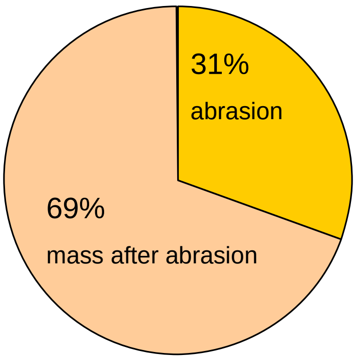


Source: Author

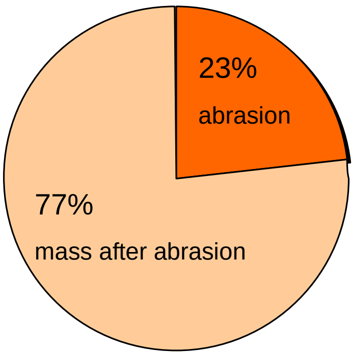
Total abrasion of briquettes makes almost a quarter of the mass of the sample. See Graph 8.

Graph 8: Pie Charts – *Miscanthus x giganteus*

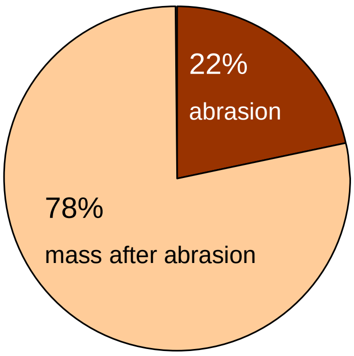
Pure *Miscanthus x giganteus*



Miscanthus x giganteus mixed with sawdust



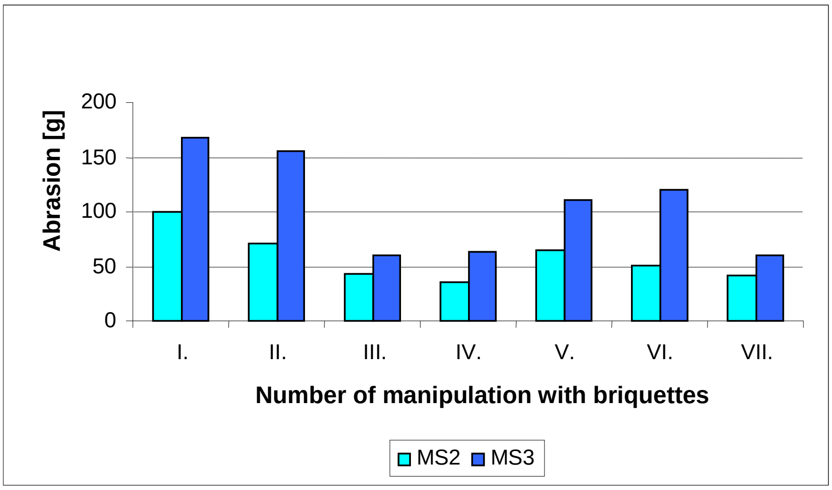
Miscanthus x giganteus mixed with wood shavings



Average abrasion of briquettes produced from *Miscanthus sinensis* mixed with sawdust and *Miscanthus sinensis* mixed with wood shavings is shown in Graph 9. Pure *Miscanthus sinensis* is missing in the results because these briquettes broke up after the first manipulation. The highest abrasion was also achieved upon first manipulation with briquettes.

It was further found out that by the fourth manipulation there is a downward trend. Significant increase of the abrasion was observed in the fifth manipulation with sample of briquettes. That is caused by six-month break between manipulations with briquettes. Until the fourth manipulation, each sample of briquettes was abraded in one month frequency.

Graph 9: Average abrasion – *Miscanthus sinensis*

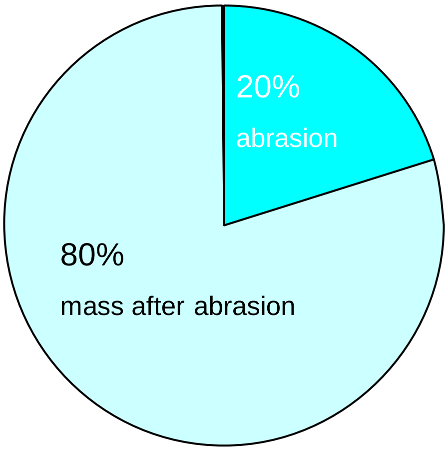


Source: Author

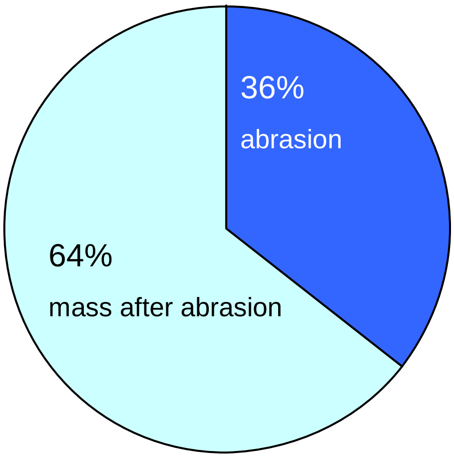
The highest mechanical durability was observed in the sample briquettes pressed from *Miscanthus sinensis* with sawdust. See Graph 10. These briquettes had the lowest abrasion. They lost 20% of its original weight.

Graph 10: Pie Charts – *Miscanthus sinensis*

Miscanthus sinensis mixed with sawdust



Miscanthus sinensis mixed with wood shavings



6. DISCUSSION

The resulting briquettes had very high quality, after the mechanical durability test was done. Briquettes made from three materials (digestate, digastate mixed with zeolite and diqestate with addition of dolomitic limestone) had the highest grade of mechanical durability (all of them DU ≥ 95%). Kratzeisen et al. (2010) point out that digestates pellets and their mechanical durability also fulfilled the requirements of standards for pellets. Brožek et al. (2012) did research which was focused on quality evaluation of briquettes made from wood waste and they draw a conclusion that briquettes made from shavings, sawdust and poplar chips had the same value of mechanical durability as digestate briquettes. Therefore digestate briquettes after drying seem to be a convenient alternative fuel for wood briquettes.

Briquettes pressed from digestate with the addition of mineral fertilizers were dried in dryer which was located in other place than biogas plant. Kratzeisen et al. (2010) recommend digestate to dry close to the biogas plant in order to reduce costs for transport, drying and storage. “The waste heat of the power station can be used to dry digestate up to a dry matter content of around 80-90%” (Kratzeisen et al., 2010).

The research shows that in the first manipulation with briquettes there is the bigger abrasion than in the fourth manipulation of them. Hojná (2012) summarizes that the biggest abrasion occurs immediately after the processing of briquettes. The abrasion could be related to the shape of briquettes. Previous graph 6 shows mechanical durability of briquettes with which were handled four times. It is apparent that in the first manipulation occurs the largest abrasion. This was caused by the fact that at first manipulation the sharp edges were destroyed. This opinion is also confirmed by Hojná (2012).

Černá (2013) published in the thesis about properties of partially dehydrated digestate from biogas plants that the addition of mineral fertilizers like zeolite and dolomitic limestone does not have significant effect on the mechanical properties of the obtained briquettes. In my opinion there exist differences because the accomplished analysis of variance determines that the factor of composition of briquettes has with the 95% probability statistically significant impact on the abrasion. Karunanithy et al. (2012) published that “the differences in durability between briquettes might be due to chemical composition including lignin, extractive, cellulose and hemicellulose.” The lowest DU had briquettes made from digestate mixed with dolomitic limestone. Granules of dolomitic limestone are not mechanically durable (fixed). Granules that are added into admixture with digestate could break during pressing in the briquetting press. Briquettes that results from this process are more susceptible to mechanical violation, i.e. in a rotation drum is bigger piece of briquettes broken off than in the briquettes made from pure digestate. Karunanithy et al. (2012) summarize that mechanical durability depends also on compressibility. Increasing pressure is responsible for increasing the quality of biomass briquettes, namely abrasive resistance (Kaliyan et al., 2009).

Further formulated hypothesis claims that there is no statistically significant difference in the abrasion between four size groups of briquettes. The hypothesis was accepted in case of briquettes made from pure digestate and digestate with addition of dolomitic limestone. It was discovered that the size groups of briquettes does not depend practically on the briquettes abrasion. Temmerman et al. (2006) made research focused on comparative study of durability test methods for pellets and briquettes. They found out that there does not exist any relationship between the density and the durability of the biomass briquettes. Brožek et al. (2012) carried out part of the test of briquettes made from wood waste where both the briquettes dimensions (diameter and length) and their mass were measured. They discovered also that "the rupture force does not depend practically on the briquettes density." Briquettes with specific dimension are not suitable to be produced from this reason.

In the case of briquettes pressed from digestate mixed with zeolite it was proved that statistically significant difference in a small and maximum group size of abrasion exists. The smallest abrasion was connected with briquettes which were divided into small size groups (mass of briquettes less than 130 grams). On the other hand, the biggest abrasion was recorded by the maximal size groups (mass of briquettes more than 190 grams). Larger abrasion in the bigger briquettes may be caused by the fact that heavier briquettes have higher kinetic energy in a rotary drum. According to Tesař et al. (2011) this kind of energy is dependent on the speed and mass of moving body. The higher is the mass of briquette, the higher is its kinetic energy. This energy is in the fall of briquette on the bottom of the rotary drum converted into mechanical work. More use of power causes larger abrasion, on the contrary, less power has an effect on the lighter briquettes and it results in lower abrasion.

Digestate briquettes can be used either for combustion or in agriculture as an amendment material for lightening of heavy clay soils (Kužel, 2010). These types of briquettes have quite good properties of water sorption (Černá, 2013). Fertilizer nutrients such as phosphor, potassium and calcium remain in the ash after combustion of digestate fuel briquettes. This ash which includes high concentration of nutrients would be used as a valuable fertilizer (Karunanithy et al., 2012). In the case of adding a mineral fertilizer into soil, the soil properties will be positively changed (Černá, 2013). For instance, zeolite affects levels of biogenic elements in the soil (BIOCLEAN, 2013).

It was also discovered that the storage time depends on the abrasion of the biomass briquettes. According to Technical Directive No. 14 from the year 2009, which the Ministry of the Environment of the Czech Republic issued, briquettes must not change their size, density and moisture content during 9 months by more than 10% (Česko, 2009). Briquettes made from *Miscanthus* are not decomposed after 9 months (even after 16 months) but they changed their size by more than 10%. These briquettes were stored in the dry place in the laboratory. In comparison with the literature (Hojná, 2012) where the author measured mechanical durability of briquettes stored both outside and inside I can judge that storage conditions of briquettes have also an influence on abrasion. Hojná (2012) published that all briquettes made from *Miscanthus* that were stored in the laboratory had in the end of manipulation larger mass and larger mechanical resistance in comparison with briquettes stored outside. Despite this fact, *Miscanthus* briquettes are not suitable for long time storage.

7. CONCLUSION AND RECOMMENDATIONS

The objective of this thesis was to find out and evaluate whether there exists dependence between the abrasion and composition of briquettes, the abrasion and the mass of briquettes and between the abrasion and the storage time. Further aims were to determine regression function with the tightness of dependence and test the mechanical durability of the research samples. Microsoft Office Excel and software STATISTICA version 10 were used to process and evaluate experimental data. The most of hypothesis were tested by using non-parametric tests. Analysis of variance, Kruskall-Wallis test, Scheffé's method and Friedman test were applied to evaluate the dependency, as well.

From the results of the Kruskall-Wallis test and Scheffe's method, it is apparent with the 95% probability that the factor of composition of briquettes has statistically significant difference on the abrasion. A difference between abrasion of briquettes made from pure digestate, digestate mixed with zeolite and digestate with addition of dolomitic limestone was detected. The best mechanical durability was exhibited by briquettes pressed from pure digestate. On the contrary, the largest abrasion was observed in briquettes made from digestate with addition of dolomitic limestone. The formulated null hypothesis expressed, that between size groups of briquettes there is no statistically significant difference in the abrasion that was accepted only in case of briquettes made from pure digestate and digestate with addition of dolomitic limestone. In the case of briquettes pressed from digestate mixed with zeolite it was proven that statistically significant difference in a small and maximum group size of abrasion exists. With the 95% confidence it is possible to say that each month of storage affects the abrasion of briquettes. This hypothesis was tested by using Friedman test for samples that are interdependent.

Regression function was calculated for three kinds of biomass briquettes. As a dependent variable abrasion of briquettes and as an independent variable mass of briquettes were used. For briquettes pressed from digestate the regression function was determined in the form of $y = 3.0587 – 0.0121x$. This implies negative and weak dependence, because the correlation coefficient had value 0.25. The abrasion was explained by the linear function of 66%. For briquettes made from digestate with addition of zeolite regression function in the form of $y = - 3.2110 + 0.0325x$ was calculated. The correlation coefficient of 0.75 determines medium dependence. The abrasion of briquettes was explained by the linear function of 57%. Regression function for the briquettes produced from digestate mixed with dolomitic limestone had the form of y = 0.4651 + 0.0131x. Regression coefficient of 0.0131 implies positive dependence and correlation coefficient of 0.46 implies medium dependence. The abrasion was explained by the linear function only of 22%.

According to the results of determination of mechanical durability can be concluded that digestate from biogas station is suitable for briquettes production and that the briquettes pressed from *Miscanthus* are not advisable for long time storage.

There were 88 biomass briquettes used for the research purposes. Briquettes were classified by composition and size groups. This caused low number of observation (the sample size). The results may be distorted by circumstances. It would be remarkable to compare these results with a new research with enough samples. Next experiment could be concerned to study of properties digestate briquettes which are long time stored (i.e. 9 and more months). The different storage conditions could also be very interesting for research. Although, this diploma thesis is not focused on economic profitability of digestate briquettes, I recommend that this part of the issue should be further investigated.

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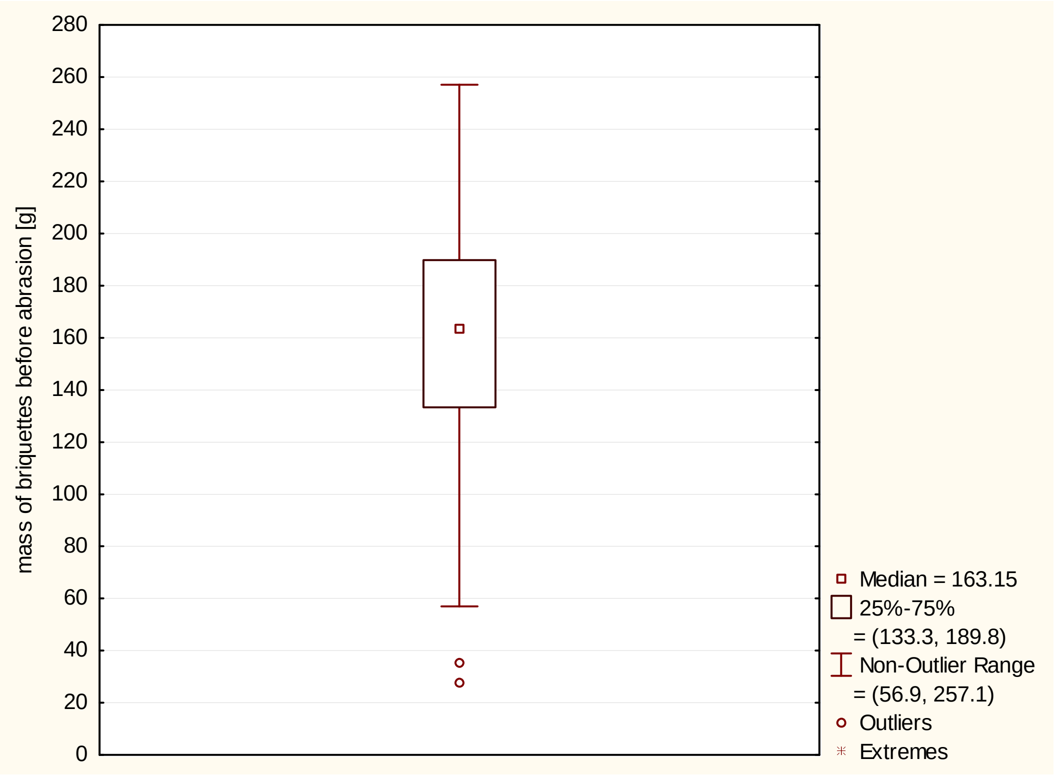
9. APPENDICES

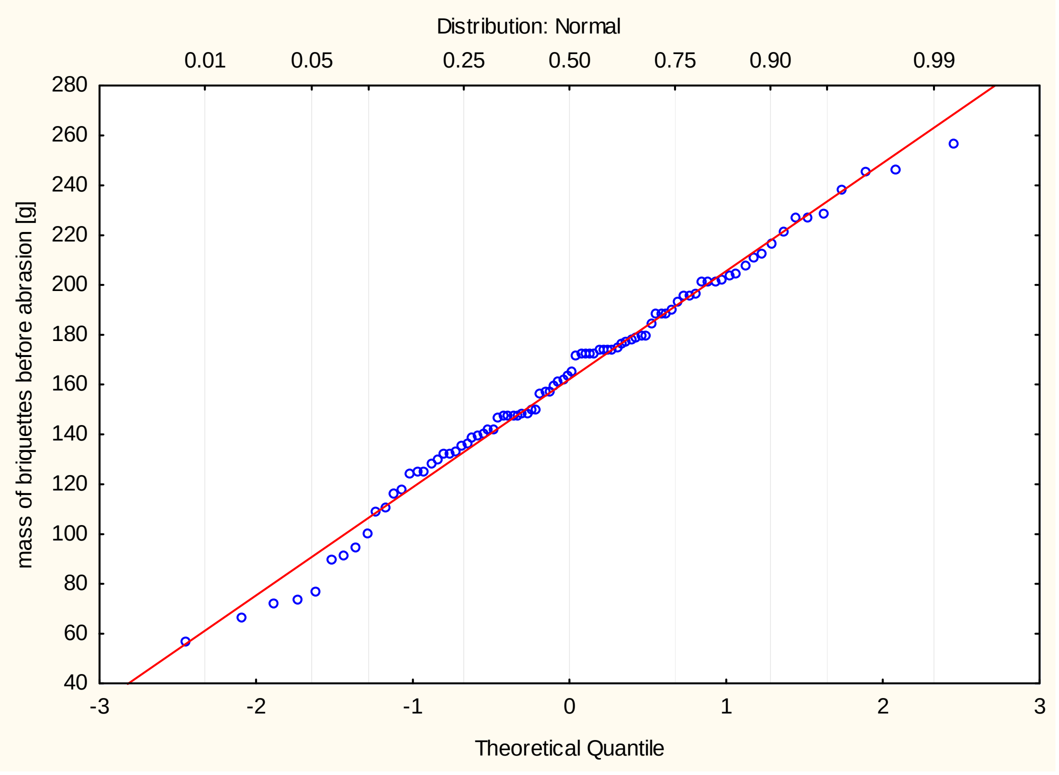
List of Appendices

Appendix 1: Box Plot of mass of briquettes, 90 values



Source: Author

Appendix 2: Quantile – Quantile Plot of mass of briquettes



Source: Author

Appendix 3: Descriptive Statistics – mass of briquettes

Variable	Descriptive Statistics [g]											
	Valid n	Mean	Confidence -95.000%	Confidence 95.000%	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Variance	Std.Dev.	Coef.Var.
Mass of briquettes	88	162.2102	153.0837	171.3368	164.6500	56.9000	257.1000	135.9500	191.4500	1855.377	43.07408	26.55448
Digestate	47	158.8957	146.9852	170.8062	157.5000	56.9000	257.1000	136.4000	179.4000	1645.567	40.56559	25.52969
Digestate + zeolite	18	167.1556	151.2827	183.0284	168.2000	111.0000	245.7000	148.1000	188.3000	1018.810	31.91880	19.09527
Digestate + dolomitic limestone	23	165.1130	141.2042	189.0219	178.2000	73.6000	246.0000	109.4000	207.6000	3056.888	55.28914	33.48563

Source: Author

Appendix 4: Descriptive Statistics – manipulation with briquettes

I. manipulation with briquettes

Variable	Descriptive Statistics [g]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
Digestate	47	1.92	0.50	12.4	2.25
Digestate + zeolite	18	6.62	1.60	53.6	11.85
Digestate + dolomitic limestone	23	6.51	0.80	38.0	7.57

Source: Author

II. manipulation with briquettes

Variable	Descriptive Statistics [g]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
Digestate	47	1.46	0.60	3.00	0.58
Digestate + zeolite	18	2.46	0.40	9.10	1.92
Digestate + dolomitic limestone	23	3.84	0.20	11.20	2.72

Source: Author

III. manipulation with briquettes

Variable	Descriptive Statistics [g]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
Digestate	47	1.16	0.40	2.60	0.44
Digestate + zeolite	18	1.87	0.50	5.30	1.21
Digestate + dolomitic limestone	23	2.84	0.60	7.10	1.83

Source: Author

IV. manipulation with briquettes

Variable	Descriptive Statistics [g]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
Digestate	47	1.23	0.40	12.30	1.84
Digestate + zeolite	18	1.64	0.70	5.60	1.19
Digestate + dolomitic limestone	23	2.40	0.50	5.40	1.46

Source: Author

Appendix 5: Size groups overview

Composition of briquettes	Number of observation in each category				Total
	S	M	L	MAX	
Digestate	8	25	5	9	**47**
DGST + zeolite	3	8	4	3	**18**
DGST + dol. lim.	7	3	3	10	**23**
Total	**18**	**36**	**12**	**22**	**88**

Source: Author

Appendix 6: Descriptive Statistics - size groups, digestate

I. manipulation

Variable – size groups	Descriptive Statistics [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	8	1.40	0.53	5.75	1.79
M	25	0.91	0.51	2.64	0.46
L	5	2.52	0.54	9.89	4.12
MAX	9	2.19	0.34	12.13	3.77

Source: Author

II. manipulation

Variable – size groups	Descriptive Statistics [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	8	0.87	0.35	1.41	0.38
M	25	0.95	0.46	2.45	0.43
L	5	0.88	0.68	1.52	0.36
MAX	9	1.44	0.57	4.63	1.26

Source: Author

III. manipulation

Variable – size groups	Descriptive Statistics [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	8	0.75	0.53	1.36	0.27
M	25	0.73	0.23	1.98	0.32
L	5	0.84	0.61	1.37	0.33
MAX	9	1.31	0.51	5.46	1.60

Source: Author

IV. manipulation

Variable – size groups	Descriptive Statistics [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	8	0.73	0.50	1.07	0.20
M	25	0.56	0.30	1.27	0.26
L	5	2.69	0.32	11.44	4.90
MAX	9	2.00	0.35	13.22	4.21

Source: Author

Appendix 7: Descriptive Statistics - size groups, digestate mixed with zeolite,

I. manipulation

Variable – size groups	**Descriptive Statistics** [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	3	1.46	1.44	1.48	0.02
M	8	2.26	1.62	2.59	0.29
L	4	2.69	1.59	3.45	0.86
MAX	3	10.87	1.74	27.42	14.36

Source: Author

II. manipulation

Variable – size groups	**Descriptive Statistics** [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	3	1.48	1.13	1.67	0.31
M	8	1.23	0.66	1.95	0.45
L	4	1.84	1.26	2.57	0.57
MAX	3	1.69	0.29	3.89	1.93

Source: Author

III. manipulation

Variable – size groups	**Descriptive Statistics** [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	3	0.92	0.76	1.02	0.14
M	8	1.01	0.60	1.71	0.39
L	4	1.55	0.73	2.04	0.61
MAX	3	1.27	0.36	2.37	1.02

Source: Author

IV. manipulation

Variable – size groups	**Descriptive Statistics** [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	3	0.87	0.61	1.01	0.23
M	8	0.88	0.57	1.15	0.20
L	4	1.35	0.63	1.73	0.49
MAX	3	1.25	0.52	2.59	1.18

Source: Author

Appendix 8: Descriptive Statistics - size groups, digestate mixed with dol. lim.

I. manipulation

Variable – size groups	**Descriptive Statistics** [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	7	4.83	1.04	17.93	6.32
M	3	1.73	1.36	2.18	0.42
L	3	2.21	1.20	3.70	1.32
MAX	10	4.81	2.41	18.91	4.98

Source: Author

II. manipulation

Variable – size groups	**Descriptive Statistics** [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	7	4.31	0.27	12.66	4.84
M	3	3.25	1.11	7.25	3.47
L	3	1.66	0.83	2.53	0.85
MAX	10	2.02	0.87	2.94	0.68

Source: Author

III. manipulation

Variable – size groups	**Descriptive Statistics** [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	7	2.59	0.54	8.99	3.08
M	3	1.32	1.04	1.48	0.24
L	3	1.54	0.66	2.37	0.86
MAX	10	1.93	0.78	3.11	0.77

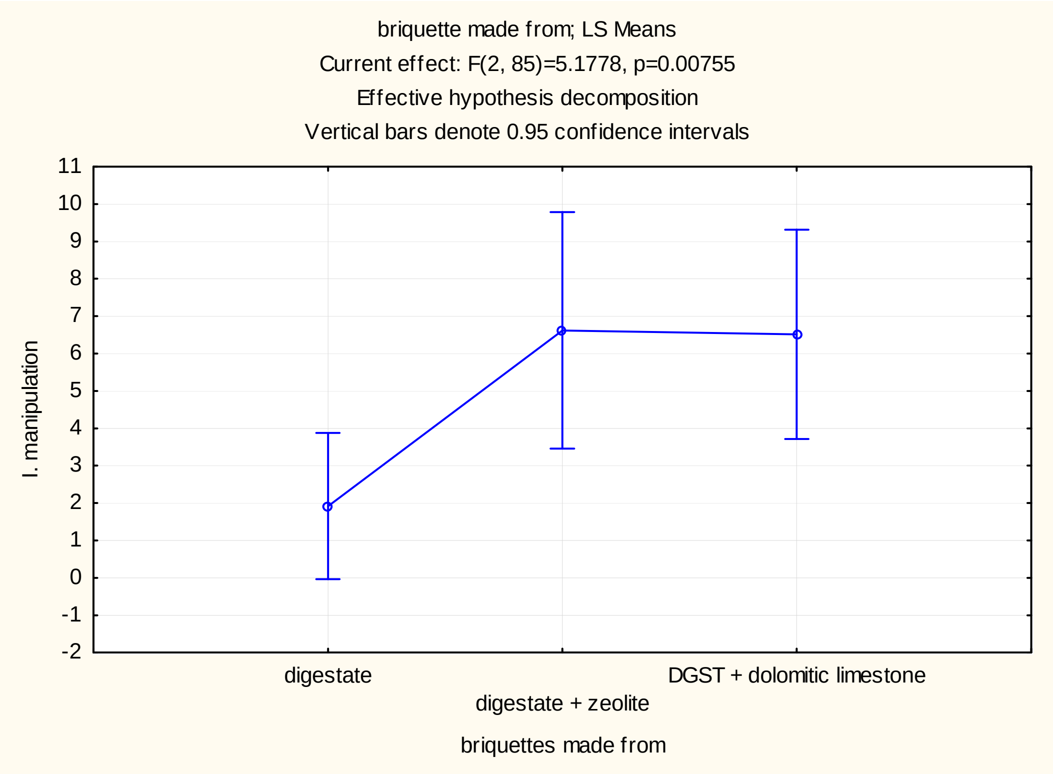
Source: Author

IV. manipulation

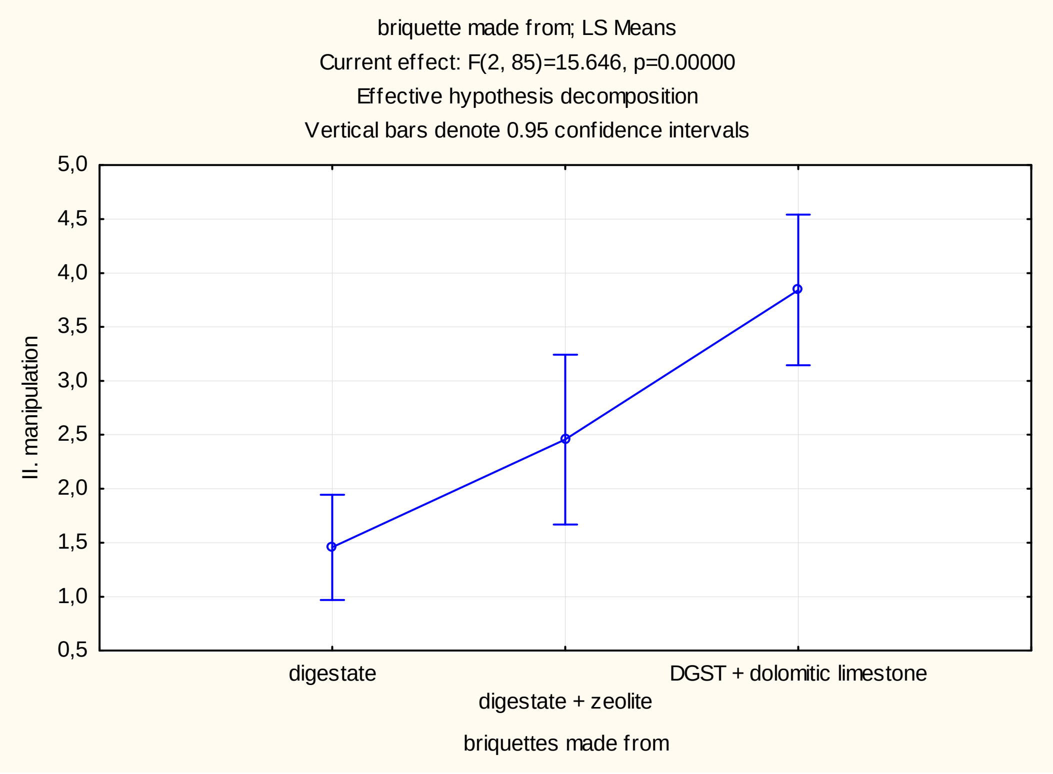
Variable – size groups	**Descriptive Statistics** [%]				
	Valid n	Mean	Minimum	Maximum	Std.Dev
S	7	2.53	0.64	9.94	3.34
M	3	1.17	0.87	1.64	0.41
L	3	1.11	0.67	1.76	0.57
MAX	10	1.72	0.75	2.62	0.58

Source: Author

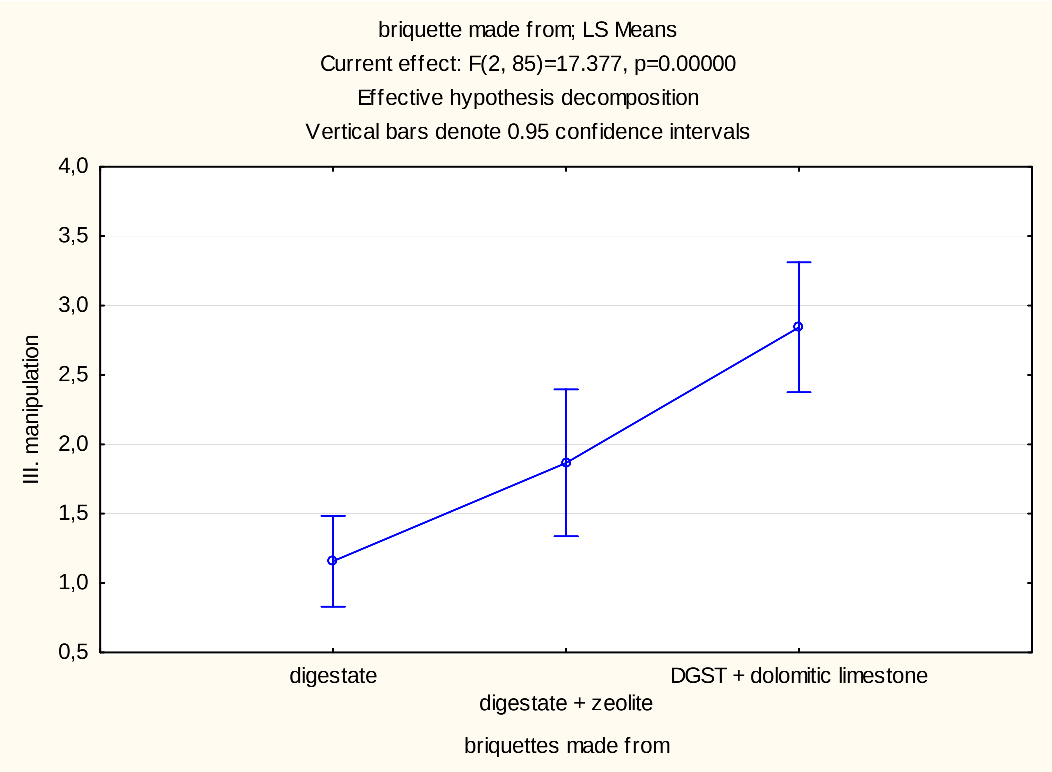
Appendix 9: ANOVA results for effect “briquettes made from”



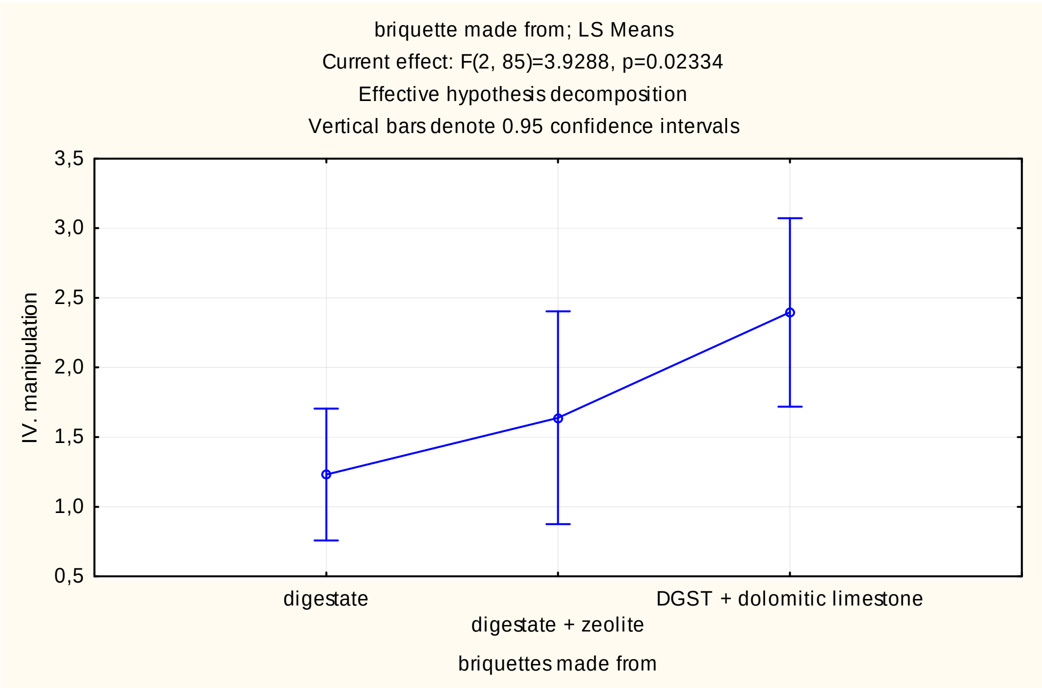
Source: Author



Source: Author



Source: Author



Source: Author

Appendix 10: Tests of Homogeneity of Variances

	Tests of Homogeneity of Variances (Data.sta) Effect: "**briquette made from**"				
	Hartley F-max	Cochran C	Bartlett Chi-Sqr.	df	p
I. abrasion	27.76585	0.692572	75.6650	2	0.000000
II. abrasion	21.80896	0.646958	70.7859	2	0.000000
III. abrasion	17.19157	0.666588	61.0255	2	0.000000
IV. abrasion	2.406570	0.488646	4.67567	2	0.096536

Source: Author

Appendix 11: Tests of Homogeneity of Variances - Levene's Test

	Levene's Test for Homogeneity of Variances (Data.sta) Effect: "**briquette made from**" Degrees of freedom for all F's: 2. 85			
	MS Effect	MS Error	F	p
IV. abrasion	1.772705	1.794154	0.988045	0.376538

Source: Author

Appendix 12: Kruskal-Wallis test

I. manipulation

Depend.: **I. abrasion**	Multiple Comparisons p values (2-tailed); **I. abrasion** (Data.sta) Independent (grouping) variable: **briquette made from** Kruskal-Wallis test: H (2, N= 88) =34.84312 p =0.0000		
	digestate R:29.489	digestate + zeolite R:61.778	DGST + dolomitic limestone R:61.652
digestate		0.000015	0.000002
digestate + zeolite	0.000015		1.000000
DGST + dolomitic limestone	0.000002	1.000000	

Source: Author

II. manipulation

Depend.: **II. abrasion**	Multiple Comparisons p values (2-tailed); **II. abrasion** (Data.sta) Independent (grouping) variable: **briquette made from** Kruskal-Wallis test: H (2, N= 88) =19.84346 p =0.0000		
	digestate R:33.585	digestate + zeolite R:51.667	DGST + dolomitic limestone R:61.196
digestate		0.032003	0.000065
digestate + zeolite	0.032003		0.707758
DGST + dolomitic limestone	0.000065	0.707758	

Source: Author

III. manipulation

Depend.: **III. abrasion**	Multiple Comparisons p values (2-tailed); **III. abrasion** (Data.sta) Independent (grouping) variable: **briquette made from** Kruskal-Wallis test: H (2, N= 88) =17.96592 p =0.0001		
	digestate R:34.309	digestate + zeolite R:50.000	DGST + dolomitic limestone R:61.022
digestate		0.080098	0.000119
digestate + zeolite	0.080098		0.511198
DGST + dolomitic limestone	0.000119	0.511198	

Source: Author

Appendix 13: Scheffe test

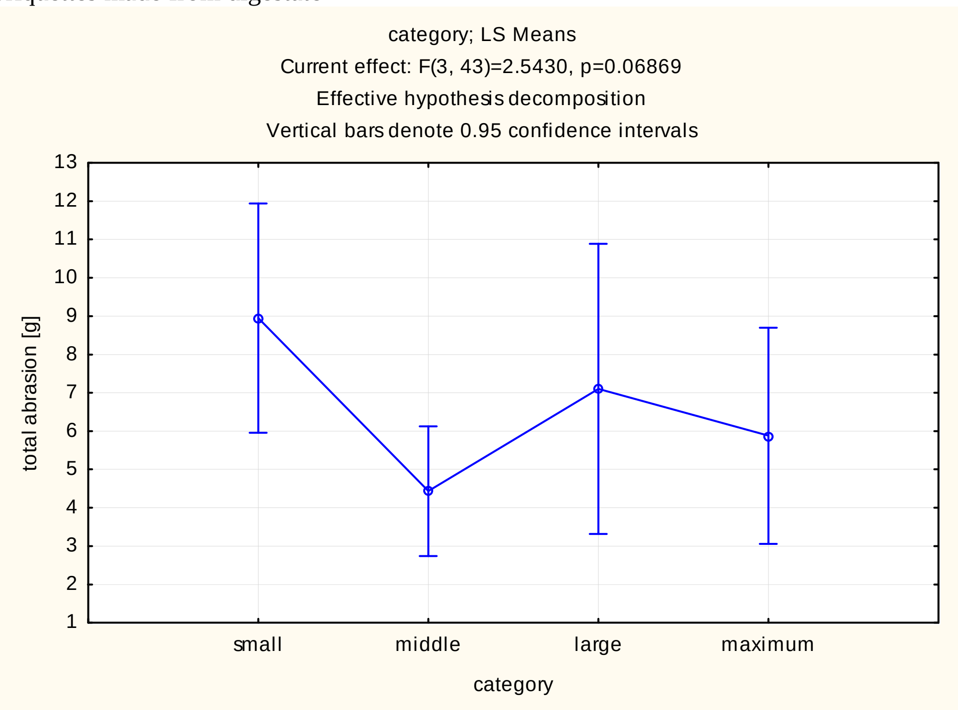
IV. manipulation

Cell No.	Scheffe test; variable **IV. abrasion** (Data.sta) Probabilities for Post Hoc Tests Error: Between MS = 2.6628, df = 85.000			
	briquette made from	1 1.2319	2 1.6389	3 2.3957
1	digestate		0.6684	0.0234
2	digestate + zeolite	0.6684		0.3422
3	DGST + dolomitic limestone	0.0234	0.3422	

Source: Author

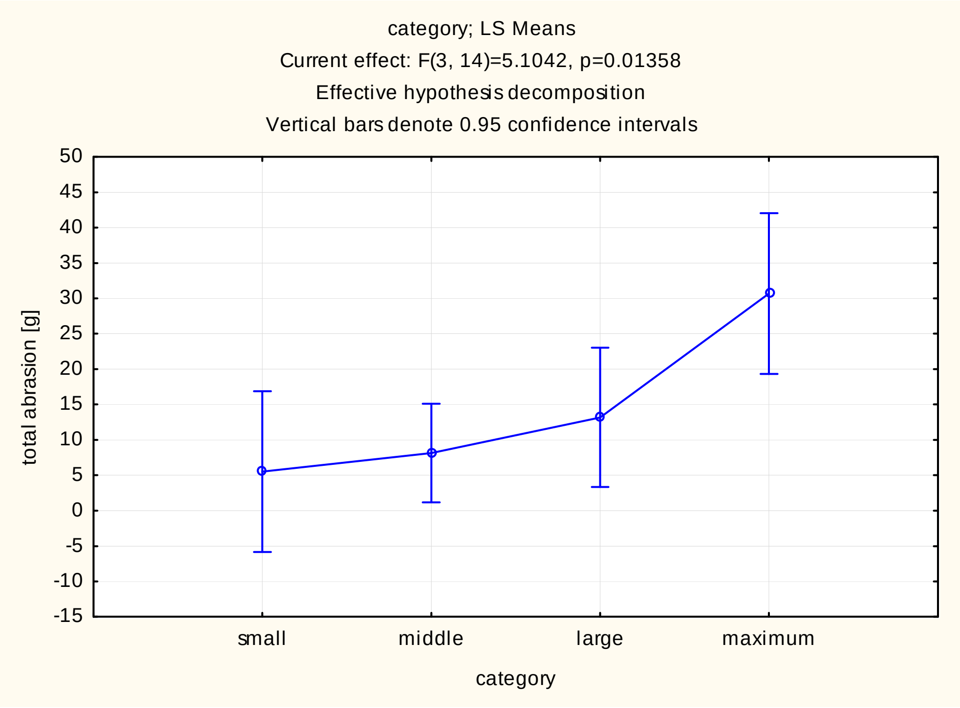
Appendix 14: ANOVA results for effect "size group"

briquettes made from digestate



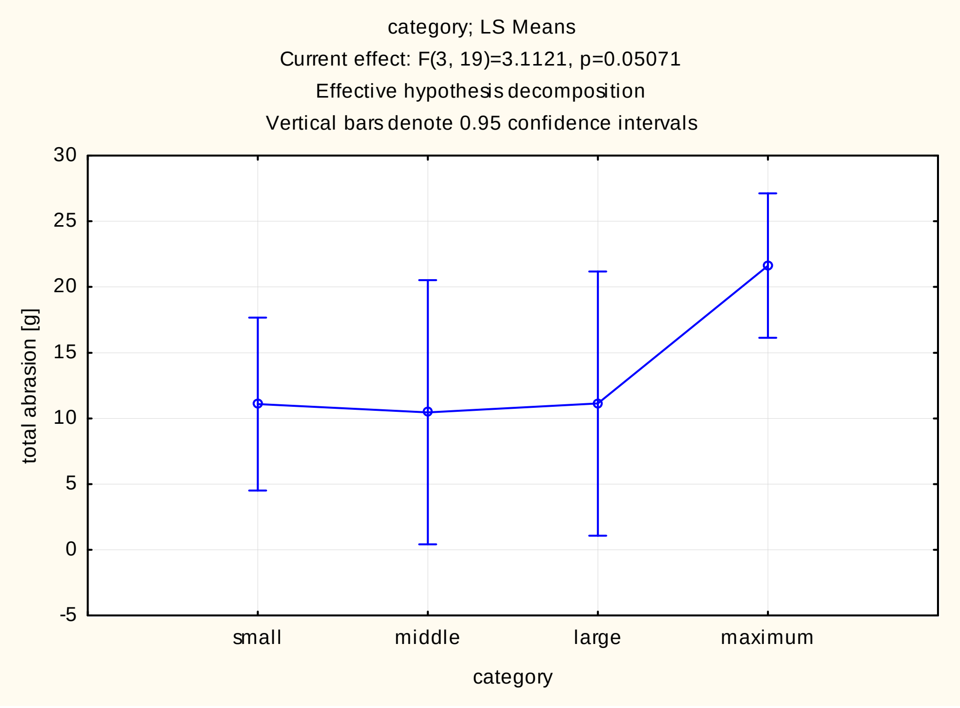
Source: Author

briquettes made from digestate mixed with zeolite



Source: Author

briquettes made from digestate mixed with dolomitic limestone



Source: Author

Appendix 15: Kruskal-Wallis test - "size group", digestate mixed with zeolite

Depend.: total abrasion	Multiple Comparisons p values (2-tailed); total abrasion (digestate+zeolite) Independent (grouping) variable: category Kruskal-Wallis test: H (3, N= 18) =11.10234 p =0.0112			
	small R:2.6667	middle R:8.0000	large R:13.250	maximum R:15.333
small		0.840215	0.056652	0.021970
middle	0.840215		0.649762	0.254732
large	0.056652	0.649762		1.000000
maximum	0.021970	0.254732	1.000000	

Source: Author

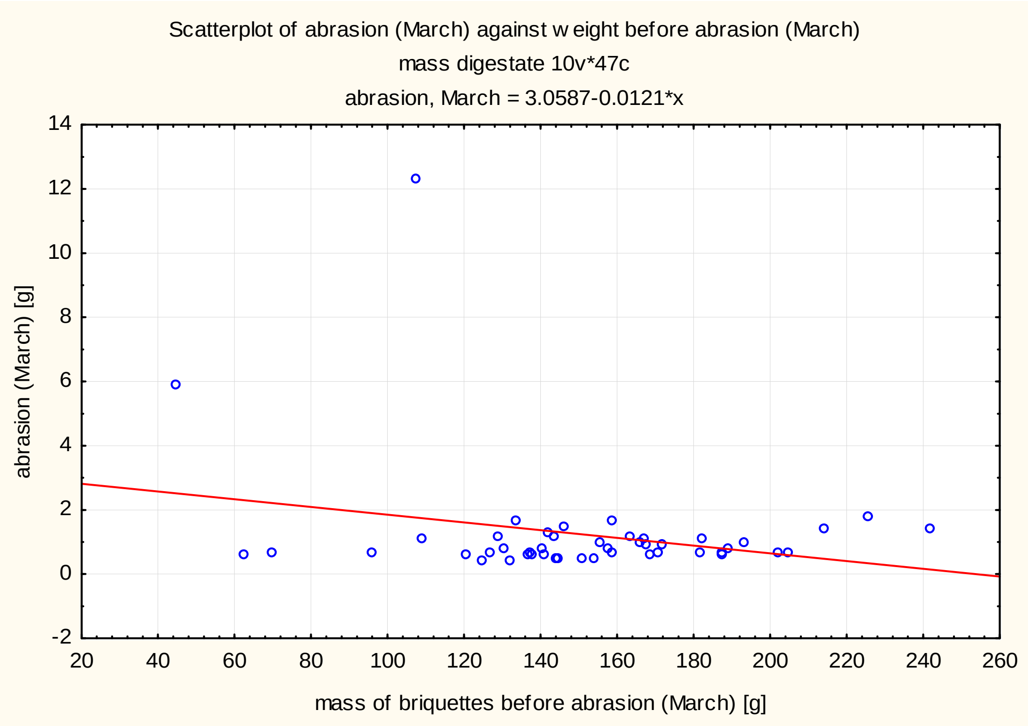
Appendix 16: Abrasion of briquettes [g]

briquettes made from	no. sample	I. manipulation	II. manipulation	III. manipulation	IV. manipulation
digestate	1/1	1.0	1.3	0.9	0.9
digestate	1/2	2.7	0.8	1.4	1.2
digestate	1/3	10.2	2.2	2.2	1.7
digestate	1/4	1.3	0.6	0.9	1.1
digestate	1/5	0.8	1.2	0.8	0.6
digestate	1/6	1.2	1.0	1.0	1.3
digestate	1/7	0.8	2.1	1.1	1.2
digestate	1/8	1.0	1.6	1.0	1.0
digestate	1/9	0.8	1.9	0.9	0.8
digestate	1/10	1.1	0.8	0.8	0.6
digestate	1/11	0.9	0.8	1.2	1.7
digestate	1/12	0.7	0.9	0.5	0.4
digestate	1/13	0.5	1.0	0.8	0.7
digestate	2/1	0.9	1.0	0.6	0.7
digestate	2/2	2.2	2.0	1.6	1.5
digestate	2/3	1.2	1.0	0.9	0.6
digestate	2/4	1.3	1.4	1.1	0.8
digestate	2/5	1.8	1.7	1.3	1.1
digestate	2/6	2.0	2.7	1.8	1.4
digestate	2/7	1.5	1.3	1.0	0.7
digestate	2/8	1.3	1.3	1.2	0.7
digestate	2/9	2.4	1.4	0.4	0.7
digestate	2/10	1.2	1.6	0.9	0.8
digestate	2/11	0.9	1.0	1.1	0.9
digestate	2/12	0.8	1.3	1.0	0.6
digestate	3/1	1.8	1.5	1.3	1.0
digestate	3/2	2.0	1.4	1.2	0.7
digestate	3/3	1.7	1.5	1.5	0.7
digestate	3/4	1.3	1.2	1.3	0.7
digestate	3/5	1.1	1.3	0.8	0.5
digestate	3/6	3.1	2.8	2.2	1.1
digestate	3/7	2.8	2.6	1.4	0.7
digestate	3/8	1.5	1.4	1.1	0.5
digestate	3/9	0.9	0.9	0.8	1.2
digestate	3/10	0.9	1.1	1.4	0.5
digestate	3/11	0.7	0.9	0.8	0.4
digestate	3/12	12.4	1.7	1.5	12.3

briquettes made from	no. sample	I. manipulation	II. manipulation	III. manipulation	IV. manipulation
digestate	3/13	1.3	1.1	0.9	0.6
digestate	4/1	2.0	3.0	1.9	1.8
digestate	4/2	1.8	1.1	1.0	0.8
digestate	4/3	1.2	1.8	1.0	1.0
digestate	4/4	0.5	1.0	0.8	0.5
digestate	4/5	1.9	2.3	1.5	1.4
digestate	4/6	1.4	1.7	1.2	0.7
digestate	4/7	0.9	0.8	0.7	0.6
digestate	4/8	1.5	1.2	1.1	0.6
digestate	4/9	6.9	2.3	2.6	5.9
digestate + zeolite	1/1	1.6	1.8	0.8	1.0
digestate + zeolite	1/2	3.0	2.3	1.3	1.1
digestate + zeolite	1/3	4.6	3.6	2.6	3.0
digestate + zeolite	1/4	3.9	3.2	2.3	1.8
digestate + zeolite	1/5	1.8	2.0	1.2	0.7
digestate + zeolite	1/6	8.5	9.1	5.3	5.6
digestate + zeolite	1/7	3.3	1.9	0.9	1.2
digestate + zeolite	1/8	3.4	1.7	2.0	1.2
digestate + zeolite	1/9	4.2	2.6	2.6	1.7
digestate + zeolite	1/10	1.9	1.4	1.2	1.2
digestate + zeolite	1/11	6.2	4.4	3.3	2.5
digestate + zeolite	1/12	6.1	2.7	3.5	2.5
digestate + zeolite	1/1	4.0	1.6	1.4	1.2
digestate + zeolite	1/2	3.6	1.7	1.1	0.8
digestate + zeolite	1/3	53.6	0.4	0.5	0.7
digestate + zeolite	1/4	3.4	1.8	1.5	1.1
digestate + zeolite	1/5	3.3	1.0	1.2	1.2
digestate + zeolite	1/6	2.8	1.0	0.9	1.0
DGST + dolomitic limestone	1/1	1.1	11.2	0.8	1.0
DGST + dolomitic limestone	1/2	0.8	0.2	0.6	0.5
DGST + dolomitic limestone	1/3	1.5	0.8	1.1	0.8
DGST + dolomitic limestone	1/4	6.3	4.1	2.8	2.3
DGST + dolomitic limestone	1/5	38.0	1.4	1.6	1.9
DGST + dolomitic limestone	1/6	1.3	0.9	0.6	0.7
DGST + dolomitic limestone	1/7	2.1	1.4	1.1	1.1
DGST + dolomitic limestone	1/8	5.4	2.3	1.5	1.4
DGST + dolomitic limestone	1/9	3.8	2.3	1.7	1.6
DGST + dolomitic limestone	1/10	4.9	4.8	4.5	4.2
DGST + dolomitic limestone	1/11	3.1	2.8	2.7	1.5
DGST + dolomitic limestone	1/12	3.0	4.6	4.2	2.6
DGST + dolomitic limestone	1/13	13.2	5.5	4.8	4.8
DGST + dolomitic limestone	1/14	7.4	1.5	1.0	1.1
DGST + dolomitic limestone	2/1	2.2	9.3	1.7	1.9
DGST + dolomitic limestone	2/2	2.0	1.6	2.1	1.2
DGST + dolomitic limestone	2/3	8.3	6.2	6.0	4.0
DGST + dolomitic limestone	2/4	8.2	4.9	4.8	5.4
DGST + dolomitic limestone	2/5	7.8	4.7	4.2	3.4
DGST + dolomitic limestone	2/6	7.2	4.9	3.3	2.7
DGST + dolomitic limestone	2/7	9.0	6.0	7.1	4.6
DGST + dolomitic limestone	2/8	6.6	2.7	3.3	3.6
DGST + dolomitic limestone	2/9	6.6	4.3	3.9	2.8

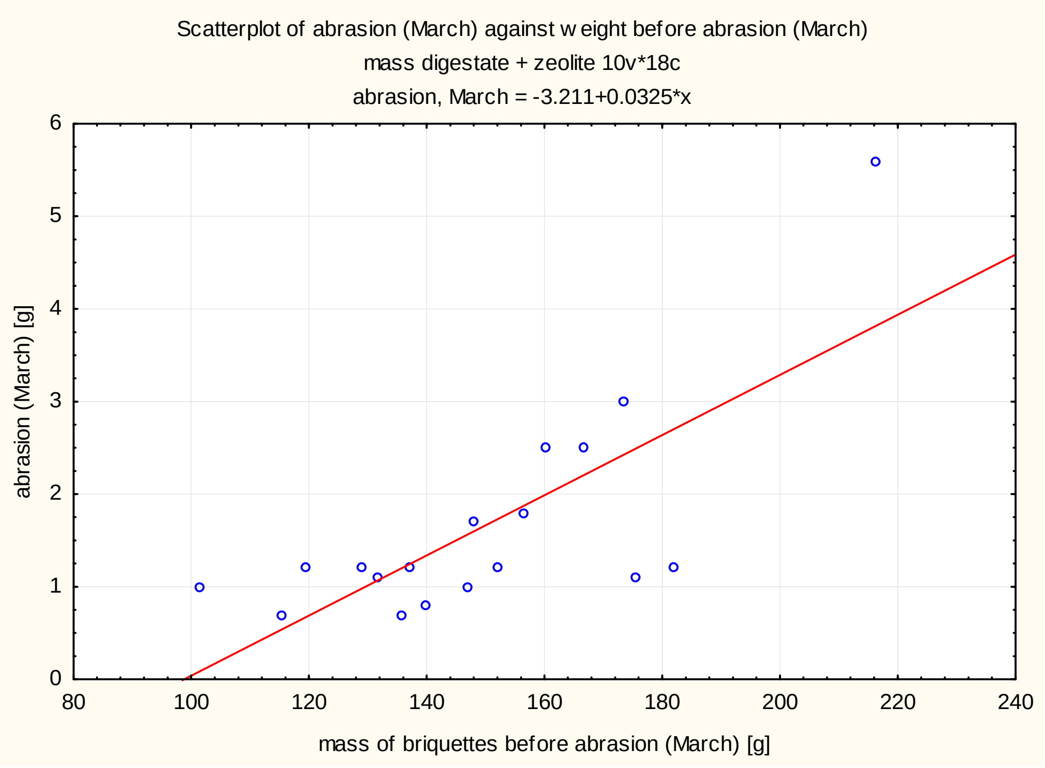
Source: Author

Appendix 17: Scatter Plot – digestate



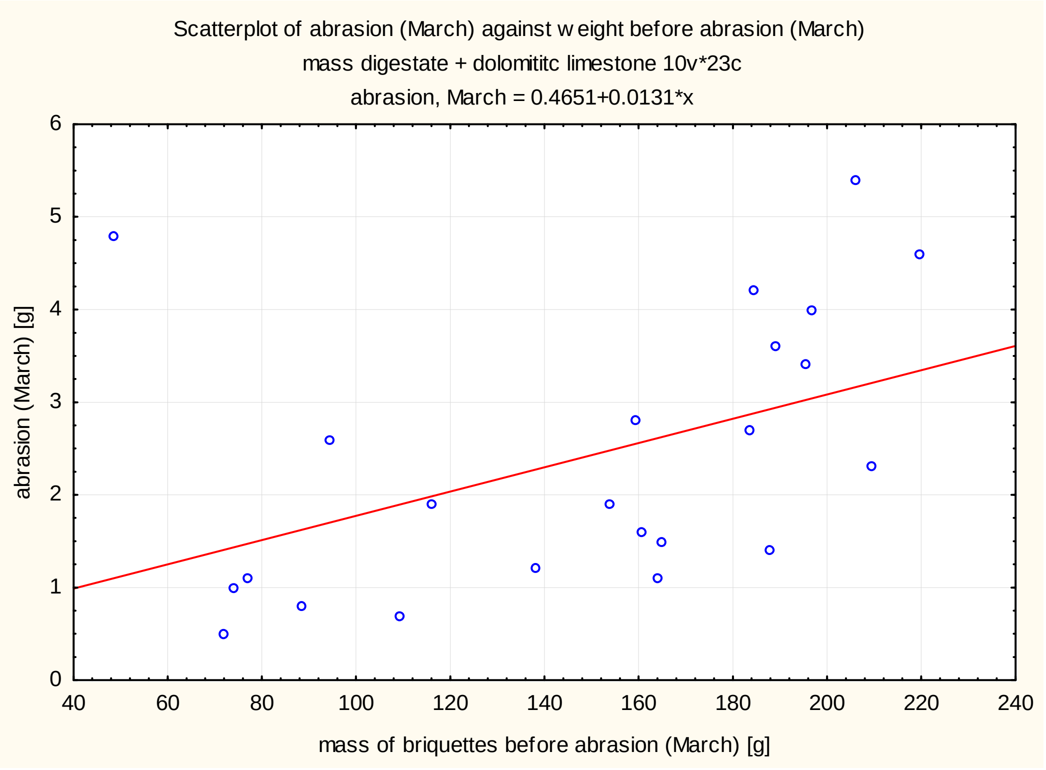
Source: Author

Appendix 18: Scatter Plot – digestate mixed with zeolite



Source: Author

Appendix 19: Scatter Plot – digestate mixed with dolomitic limestone



Source: Author

Appendix 20: Digestate

sample KU-1
press 3.12.2012

I. manipulation: 4.12.2012

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	173.9	172.9	10	0.58	99.42
2	173.9	171.2	2.7	1.55	98.45
3	177.4	167.2	10.2	5.75	94.25
4	172.8	171.5	1.3	0.75	99.25
5	125.1	124.3	0.8	0.64	99.36
6	147.9	146.7	1.2	0.81	99.19
7	149.8	149.0	0.8	0.53	99.47
8	172.4	171.4	1.0	0.58	99.42
9	135.5	134.7	0.8	0.59	99.41
10	174.0	172.9	1.1	0.63	99.37
11	139.0	138.1	0.9	0.65	99.35
12	136.4	135.7	0.7	0.51	99.49
13	72.2	71.7	0.5	0.69	99.31

Source: Author

II. manipulation: 9.1.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	172.3	171.0	1.3	0.75	99.25
2	166.6	165.8	0.8	0.48	99.52
3	165.2	1630	2.2	1.33	98.67
4	169.4	168.8	0.6	0.35	99.65
5	123.2	122.0	1.2	0.97	99.03
6	145.5	144.5	1.0	0.69	99.31
7	148.8	146.7	2.1	1.41	98.59
8	170.6	169.0	1.6	0.94	99.06
9	134.1	132.2	1.9	1.42	98.58
10	172.1	171.3	0.8	0.46	99.54
11	136.9	136.1	0.8	0.58	99.42
12	134.9	134.0	0.9	0.67	99.33
13	72.2	71.2	1.0	1.39	98.61

Source: Author

III. manipulation: 5.2.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	170.2	169.3	0.9	0.53	99.47
2	165.1	163.7	1.4	0.85	99.15
3	161.8	159.6	2.2	1.36	98.64
4	168.3	167.4	0.9	0.53	99.47
5	122.0	121.2	0.8	0.66	99.34
6	143.3	142.3	1.0	0.70	99.30
7	145.6	144.5	1.1	0.76	99.24
8	168.4	167.4	1.0	0.59	99.41
9	132.2	131.3	0.9	0.68	99.32
10	170.2	169.4	0.8	0.47	99.53
11	135.6	134.4	1.2	0.88	99.12
12	133.5	133.0	0.5	0.37	99.63
13	71.0	70.2	0.8	1.13	98.87

Source: Author

IV. manipulation: 5.3.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	167.7	166.8	0.9	0.54	99.46
2	163.1	161.9	1.2	0.74	99.26
3	158.7	157.0	1.7	1.07	98.93
4	167.1	166.0	1.1	0.66	99.34
5	120.4	119.8	0.6	0.50	99.50
6	141.9	140.6	1.3	0.92	99.08
7	143.3	142.1	1.2	0.84	99.16
8	165.7	164.7	1.0	0.60	99.40
9	130.6	129.8	0.8	0.61	99.39
10	168.5	167.9	0.6	0.36	99.64
11	133.6	131.9	1.7	1.27	98.73
12	132.0	131.6	0.4	0.30	99.70
13	69.7	69.0	0.7	1.00	99.00

Source: Author

sample KU-2
press 3.12.2012
I. manipulation: 4.12.2012

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	100.4	99.5	0.9	0.90	99.10
2	156.3	154.1	2.2	1.41	98.59
3	196.5	195.3	1.2	0.61	99.39
4	165.4	164.1	1.3	0.79	99.21
5	188.2	186.4	1.8	0.96	99.04
6	257.1	255.1	2.0	0.78	99.22
7	132.2	130.7	1.5	1.13	98.87
8	188.4	187.1	1.3	0.69	99.31
9	179.4	177.0	2.4	1.34	98.66
10	146.4	145.2	1.2	0.82	99.18
11	176.1	175.2	0.9	0.51	99.49
12	142.2	141.4	0.8	0.56	99.44

Source: Author

II. manipulation: 9.1.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	98.8	97.8	1.0	1.01	98.99
2	152.5	150.5	20	1.31	98.69
3	191.8	190.8	1.0	0.52	99.48
4	161.8	160.4	1.4	0.87	99.13
5	186.5	184.8	1.7	0.91	99.09
6	252.6	249.9	2.7	1.07	98.93
7	131.2	129.9	1.3	0.99	99.01
8	185.9	184.6	1.3	0.70	99.30
9	175.6	174.2	1.4	0.80	99.20
10	144.3	142.7	1.6	1.11	98.89
11	173.8	172.8	1.0	0.58	99.42
12	141.9	140.6	1.3	0.92	99.08

Source: Author

III. manipulation: 5.2.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	96.8	96.2	0.6	0.62	99.38
2	148.5	146.9	1.6	1.08	98.92
3	190.7	189.8	09	0.47	99.53
4	159.4	158.3	1.1	0.69	99.31
5	183.7	182.4	1.3	0.71	99.29
6	247.4	245.6	1.8	0.73	99.27
7	128.6	127.6	1.0	0.78	99.22
8	184.3	183.1	1.2	0.65	99.35
9	172.1	171.7	0.4	0.23	99.77
10	142.1	141.2	0.9	0.63	99.37
11	173.5	172.4	1.1	0.63	99.37
12	139.9	138.9	1.0	0.71	99.29

Source: Author

IV. manipulation: 5.3.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	95.8	95.1	0.7	0.73	99.27
2	146.1	144.6	1.5	1.03	98.97
3	187.5	186.9	0.6	0.32	99.68
4	157.4	156.6	0.8	0.51	99.49
5	182.0	180.9	1.1	0.60	99.40
6	241.5	240.1	1.4	0.58	99.42
7	126.8	126.1	0.7	0.55	99.45
8	181.6	180.9	0.7	0.39	99.61
9	170.5	169.8	0.7	0.41	99.59
10	140.1	139.3	0.8	0.57	99.43
11	171.4	170.5	0.9	0.53	99.47
12	137.8	137.2	0.6	0.44	99.56

Source: Author

sample KU-3
press 3.12.2012
I. manipulation: 4.12.2012

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	201.1	199.3	1.8	0.90	99.10
2	212.2	210.2	2.0	0.94	99.06
3	211.3	209.6	1.7	0.80	99.20
4	193.1	191.8	1.3	0.67	99.33
5	159.5	158.4	1.1	0.69	99.31
6	117.6	114.5	3.1	2.64	97.36
7	171.6	168.8	2.8	1.63	98.37
8	157.5	156.0	1.5	0.95	99.05
9	133.3	132.4	0.9	0.68	99.32
10	148.2	147.3	0.9	0.61	99.39
11	129.8	129.1	0.7	0.54	99.46
12	125.4	113.0	12.4	9.89	90.11
13	147.7	146.4	1.3	0.88	99.12

Source: Author

II. manipulation: 9.1.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	198.6	197.1	1.5	0.76	99.24
2	209.3	207.9	14	0.67	99.33
3	207.1	205.6	1.5	0.72	99.28
4	191.5	190.3	1.2	0.63	99.37
5	158.1	156.8	1.3	0.82	99.18
6	114.3	111.5	2.8	2.45	97.55
7	164.9	162.3	2.6	1.56	98.44
8	155.7	154.3	1.4	0.90	99.10
9	132.0	131.1	0.9	0.68	99.32
10	147.6	146.5	1.1	0.75	99.25
11	128.7	127.8	0.9	0.70	99.30
12	111.9	110.2	1.7	1.52	98.48
13	144.8	143.7	1.1	0.76	99.24

Source: Author

III. manipulation: 5.2.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	196.4	195.1	1.3	0.66	99.34
2	207.4	206.2	12	0.58	99.42
3	204.8	203.3	1.5	0.73	99.27
4	189.4	188.1	1.3	0.69	99.31
5	156.2	155.4	0.8	0.51	99.49
6	111.3	109.1	2.2	1.98	98.02
7	161.4	160.0	1.4	0.87	99.13
8	153.7	152.6	1.1	0.72	99.28
9	130.2	129.4	0.8	0.61	99.39
10	146.3	144.9	1.4	0.96	99.04
11	127.0	126.2	0.8	0.63	99.37
12	109.6	108.1	1.5	1.37	98.63
13	142.9	142.0	0.9	0.63	99.37

Source: Author

IV. manipulation: 5.3.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	193.3	192.3	1.0	0.52	99.48
2	204.6	203.9	0.7	0.34	99.66
3	202.1	201.4	0.7	0.35	99.65
4	187.2	186.5	0.7	0.37	99.63
5	153.7	153.2	0.5	0.33	99.67
6	109.0	107.9	1.1	1.01	98.99
7	158.6	157.9	0.7	0.44	99.56
8	150.7	150.2	0.5	0.33	99.67
9	128.7	127.5	1.2	0.93	99.07
10	144.4	143.9	0.5	0.35	99.65
11	124.8	124.4	0.4	0.32	99.68
12	107.5	95.2	12.3	11.44	88.56
13	140.7	140.1	0.6	0.43	99.57

Source: Author

sample KU-4
press 3.12.2012

I. manipulation: 4.12.2012

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	238.5	236.5	2.0	0.84	99.16
2	201.5	199.7	1.8	0.89	99.11
3	160.9	159.7	1.2	0.75	99.25
4	147.2	146.7	0.5	0.34	99.66
5	227.3	225.4	1.9	0.84	99.16
6	142.0	140.6	1.4	0.99	99.01
7	140.4	139.5	0.9	0.64	99.36
8	66.2	64.7	1.5	2.27	97.73
9	56.9	50.0	6.9	12.13	87.87

Source: Author

II. manipulation: 9.1.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	233.0	230.0	3.0	1.29	98.71
2	192.9	191.8	1.1	0.57	99.43
3	159.5	157.7	1.8	1.13	98.87
4	147.3	146.3	1.0	0.68	99.32
5	222.3	220.0	2.3	1.03	98.97
6	141.8	140.1	1.7	1.20	98.80
7	138.4	137.6	0.8	0.58	99.42
8	65.5	64.3	1.2	1.83	98.17
9	49.7	47.4	2.3	4.63	95.37

Source: Author

III. manipulation: 5.2.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	229.1	227.2	1.9	0.83	99.17
2	190.8	189.8	1.0	0.52	99.48
3	157.7	156.7	1.0	0.63	99.37
4	145.4	144.6	0.8	0.55	99.45
5	216.9	215.4	1.5	0.69	99.31
6	139.5	138.3	1.2	0.86	99.14
7	137.7	137.0	0.7	0.51	99.49
8	64.0	62.9	1.1	1.72	98.28
9	47.6	45.0	2.6	5.46	94.54

Source: Author

IV. manipulation: 5.3.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	225.6	223.8	1.8	0.80	99.20
2	189.0	188.2	0.8	0.42	99.58
3	155.4	154.4	1.0	0.64	99.36
4	144.1	143.6	0.5	0.35	99.65
5	214.0	212.6	1.4	0.65	99.35
6	137.2	136.5	0.7	0.51	99.49
7	136.5	135.9	0.6	0.44	99.56
8	62.4	61.8	0.6	0.96	99.04
9	44.6	38.7	5.9	13.23	86.77

Source: Author

Appendix 21: Digestate mixed with zeolite

sample 1
press 3.12.2012
I. manipulation: 12.12.2012

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	111.0	109.4	1.6	1.44	98.56
2	188.3	185.3	3.0	1.59	98.41
3	189.8	185.2	4.6	2.42	97.58
4	172.5	168.6	3.9	2.26	97.74
5	124.3	122.5	1.8	1.45	98.55
6	245.7	237.2	8.5	3.46	96.54
7	139.4	136.1	3.3	2.37	97.63
8	195.9	192.5	3.4	1.74	98.26
9	162.4	158.2	4.2	2.59	97.41
10	128.3	126.4	1.9	1.48	98.52
11	179.6	173.4	6.2	3.45	96.55
12	184.3	178.2	6.1	3.31	96.69

Source: Author

II. manipulation: 23.1.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	107.9	106.1	1.8	1.67	98.33
2	182.3	180.0	2.3	1.26	98.74
3	182.9	179.3	3.6	1.97	98.03
4	164.5	161.3	3.2	1.95	98.05
5	121.1	119.1	2.0	1.65	98.35
6	233.9	224.8	9.1	3.89	96.11
7	134.7	132.8	1.9	1.41	98.59
8	190.0	188.3	1.7	0.89	99.11
9	155.5	152.9	2.6	1.67	98.33
10	123.7	122.3	1.4	1.13	98.87
11	170.9	166.5	4.4	2.57	97.43
12	174.7	172.0	2.7	1.55	98.45

Source: Author

III. manipulation: 5.2.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	105.2	104.4	0.8	0.76	99.24
2	178.9	177.6	1.3	0.73	99.27
3	178.3	175.7	2.6	1.46	98.54
4	160.4	158.1	2.3	1.43	98.57
5	118.2	117.0	1.2	1.02	98.98
6	223.9	218.6	5.3	2.37	97.63
7	131.5	130.6	0.9	0.68	99.32
8	187.2	185.2	2.0	1.07	98.93
9	152.4	149.8	2.6	1.71	98.29
10	122.0	120.8	1.2	0.98	99.02
11	165.4	162.1	3.3	2.00	98.00
12	171.7	168.2	3.5	2.04	97.96

Source: Author

IV. manipulation: 5.3.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	101.3	100.3	1.0	0.99	99.01
2	175.4	174.3	1.1	0.63	99.37
3	173.4	170.4	3.0	1.73	98.27
4	156.3	154.5	1.8	1.15	98.85
5	115.4	114.7	0.7	0.61	99.39
6	216.3	210.7	5.6	2.59	97.41
7	128.9	127.7	1.2	0.93	99.07
8	181.8	180.6	1.2	0.66	99.34
9	147.9	146.2	1.7	1.15	98.85
10	119.4	118.2	1.2	1.01	98.99
11	160.2	157.7	2.5	1.56	98.44
12	166.5	164.0	2.5	1.50	98.50

Source: Author

sample 2
press 3.12.2012
I. manipulation: 12.12.2012

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	163.9	159.9	4.0	2.44	97.56
2	150.2	146.6	3.6	2.40	97.60
3	195.5	141.9	53.6	27.42	72.58
4	148.1	144.7	3.4	2.30	97.70
5	157.1	153.8	3.3	2.10	97.90
6	172.5	169.7	2.8	1.62	98.38

Source: Author

II. manipulation: 23.1.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	159.1	157.5	1.6	1.01	98.99
2	145.6	143.9	1.7	1.17	98.83
3	140.0	139.6	0.4	0.29	99.71
4	137.8	136.0	1.8	1.31	98.69
5	143.4	142.4	1.0	0.70	99.30
6	152.4	151.4	1.0	0.66	99.34

Source: Author

III. manipulation: 5.2.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	155.3	153.9	1.4	0.90	99.10
2	142.0	140.9	1.1	0.77	99.23
3	137.2	136.7	0.5	0.36	99.64
4	134.4	132.9	1.5	1.12	98.88
5	139.7	138.5	1.2	0.86	99.14
6	149.7	148.8	0.9	0.60	99.40

Source: Author

IV. manipulation: 5.3.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	152.1	150.9	1.2	0.79	99.21
2	139.7	138.9	0.8	0.57	99.43
3	135.8	135.1	0.7	0.52	99.48
4	131.6	130.5	1.1	0.84	99.16
5	137.1	135.9	1.2	0.88	99.12
6	147.0	146.0	1.0	0.68	99.32

Source: Author

Appendix 22: Digestate mixed with dolomitic limestone

sample 1
press 3.12.2012
I. manipulation: 12.12.2012

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	91.7	90.6	1.1	1.20	98.80
2	76.8	76.0	0.8	1.04	98.96
3	94.6	93.1	1.5	1.59	98.41
4	227.3	221.0	6.3	2.77	97.23
5	201.0	163.0	38.0	18.91	81.09
6	116.5	115.2	1.3	1.12	98.88
7	174.7	172.6	2.1	1.20	98.80
8	202.3	196.9	5.4	2.67	97.33
9	174.1	170.3	3.8	2.18	97.82
10	203.5	198.6	4.9	2.41	97.59
11	179.0	175.9	3.1	1.73	98.27
12	109.4	106.4	3.0	2.74	97.26
13	73.6	60.4	13.2	17.93	82.07
14	90.1	82.7	7.4	8.21	91.79

Source: Author

II. manipulation: 23.1.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	88.5	77.3	11.2	12.66	87.34
2	74.0	73.8	0.2	0.27	99.73
3	91.5	90.7	0.8	0.87	99.13
4	218.8	214.7	4.1	1.87	98.13
5	160.2	158.8	1.4	0.87	99.13
6	113.0	112.1	0.9	0.80	99.20
7	168.0	166.6	1.4	0.83	99.17
8	194.7	192.4	2.3	1.18	98.82
9	166.1	163.8	2.3	1.38	98.62
10	195.3	190.5	4.8	2.46	97.54
11	173.9	171.1	2.8	1.61	98.39
12	104.0	99.4	4.6	4.42	95.58
13	59.4	53.9	5.5	9.26	90.74
14	79.8	78.3	1.5	1.88	98.12

Source: Author

III. manipulation: 5.2.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	76.2	75.4	0.8	1.05	98.95
2	73.0	72.4	0.6	0.82	99.18
3	90.3	89.2	1.1	1.22	98.78
4	213.7	210.9	2.8	1.31	98.69
5	157.2	155.6	1.6	1.02	98.98
6	111.0	110.4	0.6	0.54	99.46
7	166.4	165.3	1.1	0.66	99.34
8	191.1	189.6	1.5	0.78	99.22
9	163.4	161.7	1.7	1.04	98.96
10	189.9	185.4	4.5	2.37	97.63
11	169.5	166.8	2.7	1.59	98.41
12	98.9	94.7	4.2	4.25	95.75
13	53.4	48.6	4.8	8.99	91.01
14	78.3	77.3	1.0	1.28	98.72

Source: Author

IV. manipulation: 5.3.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	74.1	73.1	1.0	1.35	98.65
2	71.7	71.2	0.5	0.70	99.30
3	88.6	87.8	0.8	0.90	99.10
4	209.4	207.1	2.3	1.10	98.90
5	153.8	151.9	1.9	1.24	98.76
6	109.3	108.6	0.7	0.64	99.36
7	164.2	163.1	1.1	0.67	99.33
8	187.7	186.3	1.4	0.75	99.25
9	160.6	159.0	1.6	1.00	99.00
10	184.5	180.3	4.2	2.28	97.72
11	165.0	163.5	1.5	0.91	99.09
12	94.2	91.6	2.6	2.76	97.24
13	48.3	43.5	4.8	9.94	90.06
14	76.8	75.7	1.1	1.43	98.57

Source: Author

sample 2
press 3.12.2012
I. manipulation: 12.12.2012

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	132.7	130.5	2.2	1.66	98.34
2	147.6	145.6	2.0	1.36	98.64
3	221.4	213.1	8.3	3.75	96.25
4	228.3	220.1	8.2	3.59	96.41
5	216.5	208.7	7.8	3.60	96.40
6	204.7	197.5	7.2	3.52	96.48
7	246.0	237.0	9.0	3.66	96.34
8	207.6	201.0	6.6	3.18	96.82
9	178.2	171.6	6.6	3.70	96.30

Source: Author

II. manipulation: 23.1.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	128.3	119.0	9.3	7.25	92.75
2	144.0	142.4	1.6	1.11	98.89
3	211.1	204.9	6.2	2.94	97.06
4	217.7	212.8	4.9	2.25	97.75
5	206.7	202.0	4.7	2.27	97.73
6	195.2	190.3	4.9	2.51	97.49
7	234.4	228.4	6.0	2.56	97.44
8	198.0	195.3	2.7	1.36	98.64
9	170.1	165.8	4.3	2.53	97.47

Source: Author

III. manipulation: 5.2.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	118.5	116.8	1.7	1.43	98.57
2	141.6	139.5	2.1	1.48	98.52
3	204.1	198.1	6.0	2.94	97.06
4	211.8	207.0	4.8	2.27	97.73
5	200.9	196.7	4.2	2.09	97.91
6	188.5	185.2	3.3	1.75	98.25
7	228.0	220.9	7.1	3.11	96.89
8	194.0	190.7	3.3	1.70	98.30
9	164.3	160.4	3.9	2.37	97.63

Source: Author

IV. manipulation: 5.3.2013

sample	mass of sample		abrasion (ab.)		DU
	before ab.	after ab.	m	share	
	g	g	g	%	%
1	116.1	114.2	1.9	1.64	98.36
2	138.1	136.9	1.2	0.87	99.13
3	196.9	192.9	4.0	2.03	97.97
4	206.0	200.6	5.4	2.62	97.38
5	195.4	192.0	3.4	1.74	98.26
6	183.7	181.0	2.7	1.47	98.53
7	219.5	214.9	4.6	2.10	97.90
8	189.2	185.6	3.6	1.90	98.10
9	159.4	156.6	2.8	1.76	98.24

Source: Author

Appendix 23: ***Miscanthus x giganteus*** **and** ***Miscanthus sinensis***

Sample	**Abrasion [g]**							**total abrasion [g]**	**weight [g]**	
	I.	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**		**before abrasion**	**after abrasion**
DK-MG81-2	167	106	59.9	52.3	70.4	100.1	35.8	**591.5**	2038	1446.5
DK-MG81-1	140	113	79.1	152.3	71.0	60.8	50.9	**667.1**	2082	1414.9
DK-MG82-3	97	100	50.2	39.2	56.5	41.0	41.9	**425.8**	1988	1562.2
DK-MG82-2	86	82	53.8	41.8	59.7	41.7	35.1	**400.1**	2022	1621.9
DK-MG82-1	77	96	74.2	68.9	79.6	85.2	99.0	**579.9**	2042	1462.1
DK-MG83-5	107	98	44.7	48.2	50.7	59.9	41.4	**449.9**	2005	1555.1
DK-MG83-4	100	68	97.1	44.4	43.2	37.8	31.6	**422.1**	2003	1580.9
DK-MS82-1	83	75	33.6	30.7	69.5	46.9	26.2	**364.9**	2010	1645.1
DK-MS82-3	118	67	52.0	38.6	60.0	53.9	55.6	**445.1**	1987	1541.9

Source: Author

Appendix 24: Properties of materials

material	**gross calorific value [MJ/kg]**	**net calorific value [MJ/kg]**
pure digestate	18.55	17.02
pure *Miscanthus x giganteus*	20.36	18.80
Miscanthus x giganteus mixed with sawdust	20.39	19.02
Miscanthus x giganteus mixed with wood shavings	20.28	19.15
pure *Miscanthus sinensis*	20.86	20.04
Miscanthus sinensis mixed with sawdust	21.10	19.43
Miscanthus sinensis mixed with wood shavings	20.56	19.38

Source: doc. Ing. Josef Pecen, CSc.

Appendix 25: Nutrient content of digestate [%]

material	**dry matter**	**ash**	**N x 6.25**	**fat**	**fibre**	**organic matter**	**nitrogen-free extract**
output from the biogas plant	5.9665	1.02129	0.78055	0.023098	1.86063	4.94519	2.28091
material for the production of briquettes	91.79198	15.71217	12.00843	0.355349	28.62505	76.07981	35.09098
100 % dry matter	100.00000	17.11715	13.08222	0.387124	31.18470	82.88285	38.22881

Source: doc. Ing. Josef Pecen, CSc.