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DIPLOMA THESIS

Mechanical strength of the briquettes from digestate

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DECLARATION

I honestly declare that I have elaborated this diploma thesis called "Mechanical strength of the briquettes from digestate" by myself and guided by my supervisor doc. Ing. Josef Pecen, CSc. All sources of the secondary data used in this thesis are listed in references.

Prague, 24 April 2015

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Anna Brunerová

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ABSTRAKT

Brikety z biomasy jsou považovány za obnovitelný zdroj energie a za environmentálně šetrné řešení produkce odpadů. Jejich spotřeba roste a požadavky na jejich kvality s ní; brikety, musí být schopni konkurovat ostatním druhům paliv. Tato diplomová práce se zabývá potenciálním vlivem různých podmínek skladování a hmotností briket na jejich kvalitu. Praktický výzkum této práce byl zaměřen na mechanickou odolnost briket (n = 113), která je jedním z hlavních ukazatelů mechanické pevnosti, tedy i kvality briket. Pro splnění cílů této práce byla použita experimentální testování. V rámci pokusů, které byly provedeny podle normy ČSN EN 15210-2: 2010, byly brikety rozděleny do dvou skupin, které byly uloženy v různých skladovacích podmínkách; vnitřní a vzorky. Získaná data, ve formě hmotností briket, před a po každém testování mechanické odolnosti, byly statisticky zpracovány a výsledky popisují celkovou mechanickou odolnost briket z digestátu a následně vztah mezi mechanickou odolností a odlišnými podmínkami skladování, váhami briket a počtu nutných testů mechanické odolnosti. Konkrétně bylo prokázáno, že celková mechanická odolnost všech vzorků byla 99,40%, což je považováno za vysokou úroveň kvality briket, také bylo zjištěno, že vnitřní vzorky briket měly vyšší úroveň mechanické odolnosti (99,46%) než venkovní vzorky. Dále bylo potvrzeno, že lehčí brikety mají vyšší úroveň trvanlivosti (99,47%) a mechanická odolnost lze stanovit po třetím testování mechanické odolnosti, protože míra odrolu klesla a při dalších měřeních byla téměř konstantní. Veškeré výzkumné experimenty byly provedeny pouze s jedním typem briket, vyrobených z digestátu, z čehož vyplývá, že je nutné provést další rozšířené výzkumy pro stanovení trendů s širším rozsahem působnosti.

KLÍČOVÁ SLOVA:

biomasa, pevná biopaliva, kvalita briket, odrol, mechanická odolnost, anaerobní digesce

ABSTRACT

Biomass briquettes are considered as the renewable source of energy and also the environmental friendly solution of the waste production. Their utilization increases and the demand on their quality increases to, briquettes must be able compete with other types of fuels. This diploma thesis deals with the potential influence of the different storage conditions and weight of briquettes on their quality. Practical research of this thesis was focused on mechanical durability of briquettes samples (n = 113), as one of the main indicators of the mechanical strength, consequently the briquette quality. To achieve the objectives of this thesis the experimental method was used. Within the experiments, which were performed in accordance to ČSN EN 15210 - 2:2010 standard, the briquettes were distributed in two groups stored in different conditions; indoor and outdoor samples. Collected data, in the form of the briquette weights before and after every DU testing, were statistically processed and the results describe the mechanical durability of briquettes from digestate itself and subsequently the relation between the mechanical durability and different storage condition, weights of briquettes and the appropriate number of the DU tests. Specifically was proved that the overall mechanical durability of all samples were 99.40 %, which is considered as high level of briquette quality, than was found out that the indoor briquettes had higher level of mechanical durability (99.46 %) than the outdoor samples. Furthermore it was investigated that the lighter briquettes have higher durability level (99.47 %) and the mechanical durability can be stated after third DU testing because the level of abrasion decreased and within subsequent testing became nearly constant. All measurements were performed with one type of briquettes made from digestate, which implies further extended researches are needed to investigate statement with the wider scope.

KEY WORDS

biomass, solid biofuels, briquette quality, abrasion size, mechanical durability, anaerobic digestion

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Per Cent
α	Alpha, Significance Level
AD	Anaerobic Digestion
BGP	Biogas Plant
BGS	Biogas Plant
C	Carbon
CEN	European Committee for Standardization
Cl	Chlorine
cm	Centimeter
CULS	Czech University of Life Sciences Prague
CV	Calorific Value
ČSN	České technické normy
dB	Decibel
DC	Developing Country
DU	Mechanical Durability
EPA	United States Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FE	Faculty of Engineering
FTA	Faculty of Tropical AgriSciences
g	Gramm
h	Hour
H	Hydrogen
ISO	International Organization for Standardization
kg	Kilogram
mm	Millimeter
N	Nitrogen
n	Quantity
O	Oxygen
S	Sulphur
t	Ton

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1 INTRODUCTION

"*Less waste, better result*."

Zanjani *et al*., 2014

Rapidly increasing population growth brings inter alia higher requirements and demands on amount of food production. It causes larger amount of residues and wastes which human population have to deal with. Raises need and duty of sustainable and environmental friendly storage, handling, recycling and reusing of the wastes (Hiloidhari *et al.*, 2014). Wastes originate from agriculture can be considered as a biomass which according to the Kendry (2009) is a source of renewable energy and utilization of biomass can be important aspect in reducing the negative environmental impact caused by burning fossil fuels in the world (Mc Kendry, 2002). Utilization of the agriculture residues, the potential biomass material is difficult task because of uneven and problematic characteristics of them, for example high moisture content, big size, irregular shape and low bulk density. Those problems can be solved by compaction of wastes into the products with higher bulk density, than the original raw material. This technology is known as densification (Bhattacharya *et al.*, 1989).

One of the potential densified biomass materials is digestate which can be defined as a waste which left in the biogas plants after the biogas is produced and anaerobic digestion process ends. This material has to be processed first and then can be used as a raw material for the densification process whose outputs are solid biofuels – briquettes (Eriksson and Prior, 1990; Pecen *et al.*, 2014). Using of the digestate is one of the most suitable materials for the briquettes production because it is environmentally friendly ecological fuel and it solves the residual issue (Strašil, 2005) in compare with the energy crops which are sometimes considered as a controversial source of renewable energy (Stecker, 2014). In response to the fact that the production of briquettes increase and it became a market product, the demands of the quality increase too. Briquettes have to be able to compete with other bio-fuels (Ivanova *et al.*, 2014). Process of the quality control can be provided by the individual chemical and physical - mechanical properties of the briquettes which include mechanical strength, very important attribute of briquette quality (Ivanova, 2012). Mechanical strength describes the success of the densification process and measures the resistance and abrasion of the products during storage, transportation and handling (Alakangas *et al*., 2007). It is also used for characterization of the force which is necessary for the destruction of the briquettes (Brožek, 2001) or as a material resistance to the deformation of products and violation of external forces (Richards, 1990). According to the Nasrin *et al*. mechanical strength can be measured by the level of durability (i.e., abrasion resistance) which is one of the forms of measurement and expression of briquette quality. This indicator evaluate possible loses and damage of briquettes (Nasrin *et al.*, 2008). Procedures for assessment the durability or abrasive resistance use test simulation by the mechanical or pneumatic handling which is called DU (durability) test. Therefore, testing of briquettes by the DU test would estimate the amount of damage, help select the suitable parameters for production and optimize densification processes to produce high quality products (Kaliyan and Morey, 2009). Vinterback (2002) showed that mechanical durability is the prevalent form of measurement and expression of physical quality of briquettes (Vinterback, 2002). According to the Kaliyan and Morey (2009):

"*High durability means high quality briquettes*."

(Kaliyan and Morey, 2009)

2 LITERATURE REVIEW

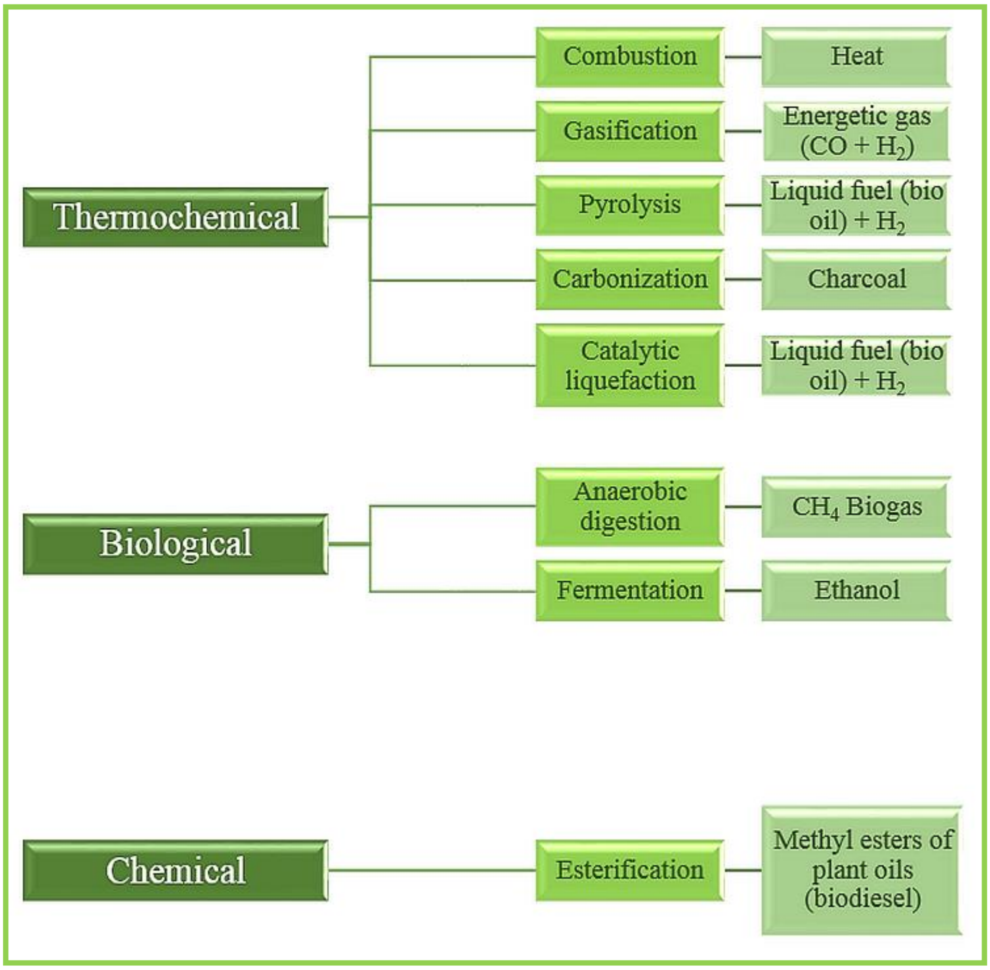
2.1 BIOMASS

According to the norm EN 14588:2010 (Solid biofuels) biomass is defined as "*an organic material that is plant or animal based, including but not limited to dedicated energy crops, agricultural crops and trees, food, feed and fibre crop residues, aquatic plants, algae, forestry and wood residues, agricultural wastes, processing by-products and other non-fossil organic matters*" (EN 14588, 2010), as well as wastes from municipal and consumer processes (EPA, 2014).

2.1.1 Characteristics of Biomass

From the viewpoint of origin, the biomass can be divided into two groups, namely waste biomass (agricultural and livestock wastes, forest, wood and municipal solid waste, organic waste streams) and biomass cultivated for producing energy (energy crops) (Pastorek *et al*., 2004; Sims *et al*., 2006). Main types of biomass are considered woody plants, herbaceous plants/grasses, aquatic plants and manures. There are several ways how to convert the biomass into the different types of energy; basic distribution is shown in the Figure 1 below. Biomass can be used to generate the electricity, heat energy, transport fuels and chemical feedstock. If we consider the final products, we can divide them according to the state of aggregation: solid fuels (briquettes, pellets, chips), gaseous fuels (synthesis gas, biogas, hydrogen) or liquid fuels (methanol, ethanol, diesel) (Mc Kendry, 2002).

Figure 1: Scheme of the biomass processing methods



Source: Havrland *et al*., 2011; Bechník, 2009; Ochodek *et al*., 2006; Celjak, 2008

2.1.2 Biomass Energy Production

Utilization of renewable source of energy increases and the biomass is considered as one of the most common source of renewable energy not only in developing countries but all over the world. With increasing popularity of the biomass the higher attention has been dedicate to the suitable biomass kinds that can provide higher energy output. Nowadays biomass estimates about 10 – 14 % of the word´s energy production in the world (Mc Kendry, 2002) and covers about 35% of primary energy in DCs as a source of energy for cooking and producing heat (Jakubes *et al.*, 2006). Using biomass for producing biofuels has again advantages and disadvantages. Biofuels made from biomass are considered as an environmentally friendly alternative to fossil fuels because raw material used for its production originates from renewable resources and production of electricity and heat is not harmful for environment. Disadvantages of the biomass use as a high moisture content, irregular shape, low bulk density, difficult to handle and transport are straight reasons of using the densification process because it solve them (EPA, 2014)**.** The market with the biomass and its products is very specific because the biomass resources are nature decentralized and dependent on natural conditions. The production of biomass products depends on economic development, demographics and establishing of prices of competing fuels (Jakubes *et al.*, 2006). To capture the wider public in the issue of the benefits of biomass it is necessary to produce high quality biofuels competitive with fossil fuels. That is why the biofuels quality must be monitored, appropriate processes for the production must be strictly adherence and the correct physical - mechanical and chemical characteristics of used raw material must be complied (Heneman, 2004). Main properties related to the interest of population about the briquettes production are: moisture content, calorific value, proportions of fixed carbon and volatiles, ash/residue content, alkali metal content and cellulose/lignin ratio (Jakubes *et al.*, 2006).

2.2 Digestate

In these days of increasing of livestock production a large amount of agriculture wastes are produced, too. It has got a negative impact on the environment and the soil lifecycle. It is necessary to find out the best way how to reuse or recycle the wastes. One of the successful and functioning ways how to dispose the wastes environmental friendly and safely is to use it as feedstock to biogas plants (BGS - Agricultural Biogas Stations) (Gong, *et al*., 2010; Bond and Templeton, *et al*., 2011).

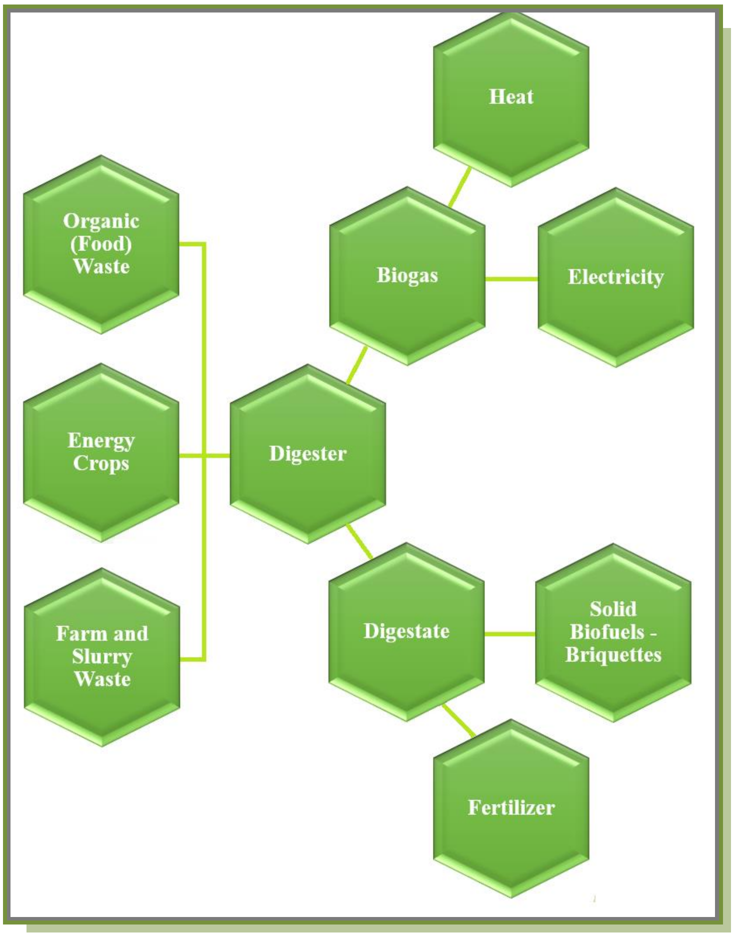
2.2.1 Characteristics of Digestate

Feedstock for the BGSs can be animal slurry, sludge from wastewater treatment plants, stillage, fruits and vegetables, chicken manure, beet or husk. Biogas plants use anaerobic digestion (AD) technology which is based on the principle that animal and plant materials are broken down by micro-organisms with the absence of air (Jakubes *et al.*, 2006; Holm-Nielsen *et al.*, 2009). The output of this technology are two main products, namely biogas, directly used as a source of renewable energy and digestate, the residue material which left in the BGSs after fermentation process is finished. It can also be a source of the renewable energy when it is processed further (Abdullahi *et al.*, 2008, Pecen *et al.*, 2014). It has better nutrient properties than the raw biomass material and can be used as a fertilizer (Jakubes *et al.*, 2006).

2.2.2 Digestate Production and Utilization

The amount of digestion material results in about 90% of total volume of the material fed into the biogas stations. Therefore the need of subsequent reusing of the digestate is important, too. Digestate is defined as a nutrient-rich substance in the form of liquid with only 6 % - 8 % of dry solids (Pecen *et al.*, 2014). In this state of aggregation the digestate material can be used as an agriculture fertilizer (Alexander, 2012) but in case it goes thru the process of dehydration which separate about 75 – 85 % of liquid part it can be used as a raw material for producing solid biofuels - briquettes - by the densification process (Pecen *et al.*, 2014). Different kinds of feedstock, process and the products from the digester are shown in the Figure 2 below.

Figure 2: Process of digestate production and utilization



Source: Monnet, 2003

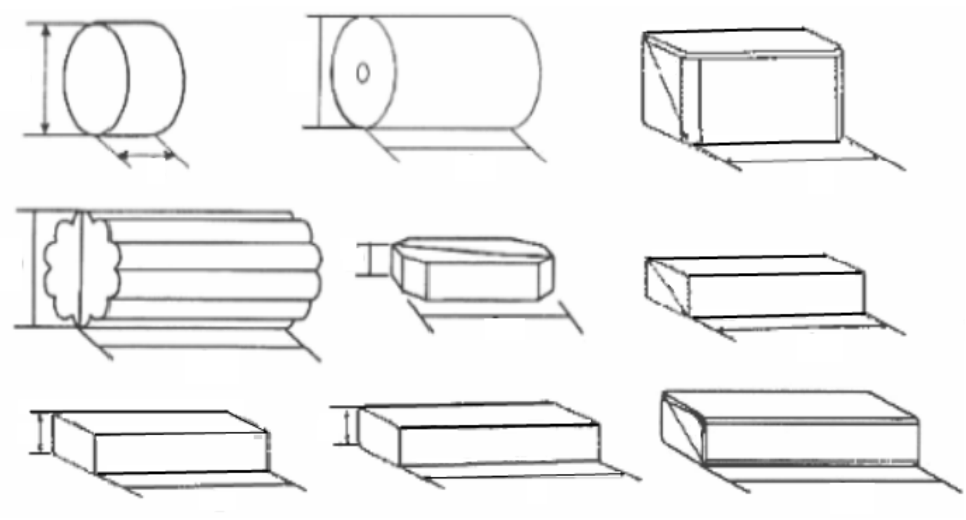
2.3 BRIQUETTES

The briquette is a block of finely ground mass of flammable material pressed or molded into convenient units without using a binder and can be used as a fuel.

2.3.1 Characteristics of Briquettes

Generally, there are many various materials that can be used for briquettes´ production like sawdust, paper waste, wood waste, cardboard. Nevertheless, the most frequent material used is a biomass along with charcoal. The biomass briquettes contain waste originate from agriculture production and this kind of briquettes can replace fossil fuels like coal or oil. Biomass briquettes have got a major potential and applications also in DCs. Biomass briquettes are a renewable source of energy and avoid adding fossil carbon to the atmosphere (Pecen *et al.*, 2014). Briquettes are commonly produced in the shape of a squares and rectangles or it can be produced in the form of lumps or other molded shapes (Alexander, 2012). Variety of shapes are shown in the diagram below and standard properties values of briquettes are shown in the Table 1 also below.

Figure 3: Variety of briquettes shapes



Source: Havrland *et al.*, 2011

Table 1: Standard properties of briquettes

Properties	Values
Sulphur content	< 0.07 %
Net calorific value	18 - 20 MJ.kg-1
Moisture content	5 - 9 %
Density	800 -1000 kg.m-3
Ash content	< 1.2 %

Source: Havrland *et al.*, 2008

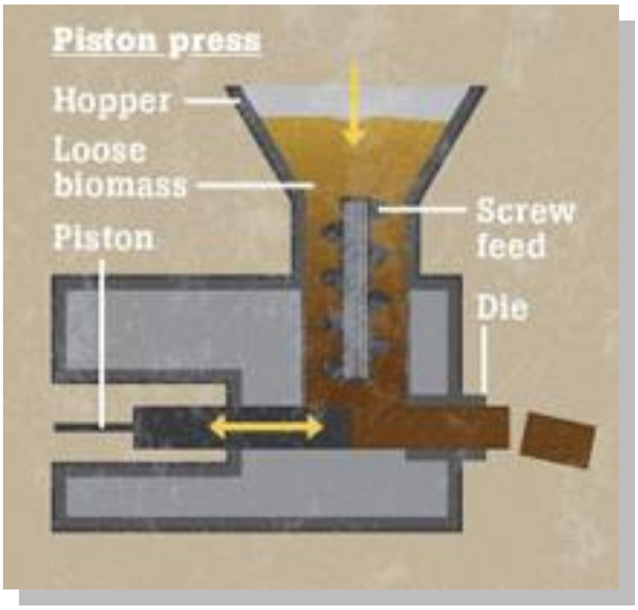
2.3.2 Briquettes Production

Technology used for producing briquettes is called densification or simply briquetting (Plíštil, 2004; Plíštil *et al*., 2005). Eriksson and Prior say that densification means the use of some form of mechanical pressure to reduce the volume of raw material and its conversion to a solid form that is easier to handle and store than the original material. It describes the transformation of the combustible matter into the product of higher density, different shapes and size than the original material caused by using different pressure and binding agents for its use in energy production (Eriksson and Prior, 1996). Densification has been applied all over the world also in DCs in recent years as a technique of beneficiation of residues for utilization as an energy source. The first patent for densification was issued in USA in 1880. Initially it was the technology mostly used for production of animal feed (Bhattacharya *et al*., 1989). Technological process called densification is used for improving the conditions avoiding possible loses and damaging of the densified products, and thereby makes the production more effective and economical friendly by reducing the costs. Namely it can solve problems caused by handling, storage, transportation and utilization. Production of briquettes contains several processes as a collection, preparation, drying, grinding, mixing and pressing – compaction (Ivanova *et al*., 2010). Process of densification can reduce the bulk density from 40 – 200 kg/m^3 to 600 – 800 kg/m^3 (Holley, 1983; Mani *et al*., 2003; McMullen *et al*., 2005) and briquettes are separated and easily handled on the end of the production process when it leaves the machine (Pietsch, 2002).

2.3.2.1 Types of presses

According to the FAO (1996) recently there are also two main high pressure technologies used for producing briquettes, piston press and screw press machines. Those two technologies differ in many attributes. Piston press works on the principle of the discontinuous fashion, raw material is fed into a cylinder that is compressed by a piston and to the lightly-tapering die. The material which is heated by frictional forces is pushed out through the die (FAO, 1996). Piston press pushes raw material into a tapered die, it is compacted there and adheres against the material remaining in the die from the previous stroke. The main parts are the piston head, die and tapered cylinder. A controlled expansion and cooling of the continuous briquette is allowed in a section following the actual die. Final product is still warm after leaving the press so it needs to be cooled before it is broken into pieces of the briquettes of the desired length. Piston press is robust and heavy machine, thus it has a long production life and if the technical services are provided, service life can be about 500 to 1000 hours (Grover and Mishra, 1996; Clarke and Preto, 2011; Reichardt and Schonert; 2004).

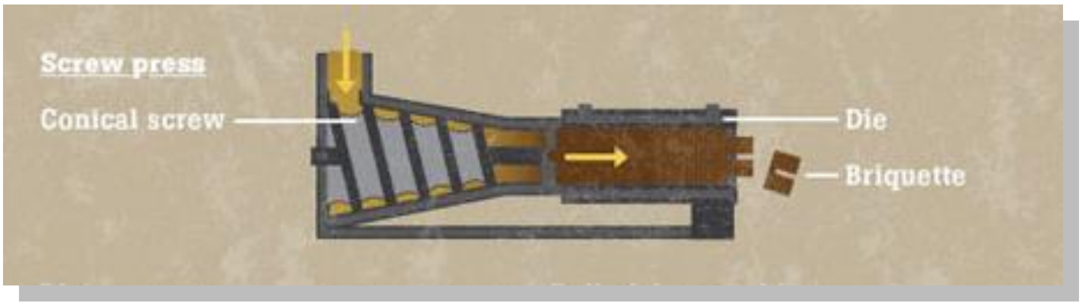
Figure 4: Drawing of Piston press



Source: Fulford and Wheldon, not dated

The material produced by the screw presses machines is continuously fed into a screw and it forces the material into a cylindrical die. According to the FAO the briquettes made by screw press machines are harder and better quality than briquettes made by piston press machines (FAO, 1996). Screw presses were originally developed for briquetting sawdust but the results of the field researches show that this type of press work well also for densifying for example rice husks. This type of press operates with forcing raw material into a die with a feeder screw. Regarding the piston press, this type has got disadvantage in the serious wear of the die head and that causes high maintenance costs. (Grover and Mishra, 1996; Clarke and Preto, 2011).

Figure 5: Drawing of Screw press



Source: Fulford and Wheldon, not dated

Different properties of those two briquettes technologies are shown in the Table 2 which is displayed below.

Table 2: Properties of the high pressure technology presses

	Piston press	Screw press
Raw material size	3 - 20 mm	3 – 5 mm
Optimal raw material moister	10 – 15 %	8 – 9 %
Product profile	Φ=70 mm	Φ= 40, 50, 60, 70 mm
Product density	1.0 – 1.2 g/cm3	1.0 – 1.4 g/cm3
Capacity	800 – 1200 kg/h	180 – 1000 kg/h
Energy consumption	37.4-77 kWh/t	36.8–150 kWh/t
Mold lifetime	1000 h – 1500 h	1500 h – 2000 h
Manufacturing noise	> 85 db	80 db

Environmental potential	Dust free	With smoke and ash
Carbonization of charcoal	Not possible	Quality
Homogeneity of densified biomass	Not homogenous	Homogenous

Source: Clarks and Preto, 2011; Reichardt and Schonert; 2004, Pobedinschi *et al*., 2009; Havrland *et al*., 2011)

2.3.2.2 Densification process

Success of the densification process can be expressed by the quality of the final densified products (briquettes, pellets) that is usually measured by the level of the durability. It can be expressed besides others by the abrasive resistance. The tests indicate the maximum force and stress that briquettes can withstand and the amount of losses produced during handling, transportation and storage. The final effect of the densification process, the level of quality, can be influenced by several factors. First part of the factors are properties of the raw material - particle size and moisture content, content of fibre, fat, lignin. Next factors are related to the pre-conditioning processes like a steam preheating or addition of the binders. The equipment used for the densification process can also affect the final product quality, namely forming pressure and type of roll press. Last group of factors are the post-production conditions, cooling and air humidity. All those factors are influencing the level of mechanical strength and durability of the final densified products. On the other hand those factors can be used for increasing the products quality if they are managed well. Considering those factors and their impact on quality of briquettes, it is necessary to optimize the procedures and all its components to prevent incorrect production of bad quality briquettes (Kaliyan and Morey, 2009; Grover and Mishra, 1996).

The densification process is categorized into two different groups; first is hot and high-pressure densification (100 MPa) and second is cold and low-pressure densification (0.2 - 5 MPa). Those two categories differ by the aspects of densification, like a mechanism of densification, machinery for densification, raw material preparation, factors affecting densification or binders. Converting residues into the densified products has got several advantages, like a process increase of the net calorific content of material per unit volume. The final product is easy to transport and store, the fuel produced is uniform in size and quality, the process often helps to solve the problem of residue disposal and reduce deforestation by providing a substitute for fuel wood. Disadvantages regarding the densification are high investment and energy input into the process, undesirable combustion characteristics (poor ignitability, excessive smoke production (Bhattacharya *et al.*, 1989). Indicators of the quality of the briquettes, mechanical strength and durability, depends on the physical forces used for bonding the particles of the raw material together (Pietsch, 2002; Rumpf, 1962). The manufacturing process consists of drying, cutting or crushing of raw material, compressing it and subsequently forcing it into a machine. The material is heated and subsequently extrudes in the form of the briquettes (Pecen *et al.*, 2014).

2.4 BRIQUETTE QUALITY CONTROL

There are standardized criteria related to the acceptance levels for strength and durability (i.e., abrasive resistance) of the densified products made from the biomass materials. There are also several technical specifications created for the briquette production. The most extensive complex was designed by the European Committee for Standardization (CEN) which determines the standards for defining, observing and testing the densification products. Basic specification which defines solid biofuels is described in standard Solid biofuels – Fuel specifications and classes – Part 1: General requirements. Consequently, there were six standards ČSN EN 14961 released. General standard ČSN EN 14961-1 from 2010 defines the classification of solid biofuels according to origin (ČSN EN 14961-1, 2010). Quality properties of the briquette can be divided to pre-production, production and post- production properties according to its role in the briquette production processes (Ivanova, 2012).

2.4.1 Factors affecting quality of briquettes:

Quality of briquettes can be expressed by its properties which can be divided into two groups, chemical and physical – mechanical properties (Ivanova, 2012). Several ways how to divide the factors which can affect the quality properties of the briquettes are used in surveys. For the purpose of writing this thesis it was used the following distribution:

2.4.1.1 Pre – production factors:

Factors in this group are related to the parameters of used raw material. They can be divided into two groups:

2.4.1.1.1 Chemical parameters:

- Ash content
- Ash fusibility
- Content of Cl, N, S, H, C, O, heavy metals
- Volatile matter content

2.4.1.1.2 Physical – mechanical parameters:

- Moisture content

Moisture content is directly affected by the moisture level of used raw material. The optimal moisture content ranges from the 5 – 10 %. Higher or lower values can be the reason of the low durability of the briquettes.

- Calorific value (CV)

Is the amount of energy released by a unit weight produced by the complete combustion of a material or fuel. With the increasing of the calorific value, increase the ability of briquettes burning too (Pobedinschi *et al*., 2009; FAO, 1993).

- Density

According to the ISO the density is defined like a ratio of mass to volume or ratio of energy content to volume (EN 14588, 2010). Otherwise Holm-Nielsen *et al*. (2009) say that density itself is defined as the degree of compactness of a substance (Holm-Nielsen *et al*., 2009). Level of the density shows the effectiveness of the densification process and quality of the final product (Nasrin *et al*., 2008). This value can be measured by the procedure of compressive, impact, water and abrasive resistance. It is necessary to define the kind of the density; because of that there is a bulk density, solid density, particle density and energy density. Particle density is a parameter commonly used for measurement of mechanical durability. Study of Temmerman *et al.* shows that high particle density leads to a high mechanical durability (Temmerman *et al*., 2006).

- Particle size distribution

Important factor influencing the durability of the briquettes is particle size. MacBain (1966) shows that finer grinded material means higher durability. Large particles do not accept enough moisture in compare to the small particles and also cause the fissure point, which cause fractures and cracks in briquettes (MacBain, 1966).

- Mechanical durability (DU)

This factor expresses how well the briquettes were formed and how dense they are. This parameter was identified as the main indicator for measuring the quality of the briquettes (Ivanova, 2012; Ivanova *et al*., 2014; Vinterback, 2002; Kaliyan and Morey, 2009) thus it will be described in detail below in subsequent chapter.

- Dimensions

As it was mentioned the briquettes can be produced in different diameters (25 mm ≤ diameter ≤ 125 mm) and different length (50 mm ≤ length ≤ 400 mm). Those dimensions can influence quality of the briquettes by good or bad, it strictly depends on the other factors that influence briquette quality as the type of the raw material and associated properties (Plíštil, 2004).

2.4.1.2 Production factors:

Production factors are directly related to the properties of densification process and used equipment.

2.4.1.2.1 Pressing temperature

Strength of the briquettes is directly related to the pressing temperature as it is influenced by the excretion of the natural binder lignin. About 150 °C is considered as an optimal pressing temperature. At the lower temperatures there is a higher risk of instability of briquettes (Chin and Siddiqui, 2000).

2.4.1.2.2 Compacting pressure

With increasing the compacting pressure, it increases the mechanical durability of the briquettes. Pressure developed during the densification process by the densification equipment enables different binding mechanisms. Increasing the pressure, it is also increased the abrasive resistance and the strength of the briquettes (Chin and Siddiqui, 2000).

2.4.1.3 Post – production factors:

Factors summarized in this group of factors are related to the storage conditions of the briquettes. Study of Khoshtaghaza *et al*. shows that quality of briquettes got worse with the increasing of air temperature and air humidity. When the temperature and humidity were constant there was no effect on quality (Khoshtaghaza *et al*., 1999).

2.4.1.3.1 Air temperature and air humidity

Briquette quality can be influenced by the air temperature and humidity, because the binders (usually lignin) are water soluble. A water vapour which releases during the combustion causes quickly crumbling of the material and thereby losing the particles which will not burn and block the airflow (Mina-Boac *et al*., 2006).

2.4.2 Quality testing

2.4.2.1 Mechanical durability (DU)

"*High durability means high quality briquettes*"

(Kaliyan and Morey, 2009)

In response to the fact that the production of briquettes increase and it became a market product, the demands of the quality increase, too. Also briquettes should be able to compete with other bio-fuels (Ivanova *et al.,* 2014). Vinterback (2002) says that durability is the prevalent form of measurement and expression of physical quality of briquettes (Vinterback, 2002). Huang also said that the effectiveness of the briquetting process and subsequently quality of the briquettes is straight influenced by physical parameters such as compacting pressure, pressing temperatures and moisture content (Huang, 2014). Kaliyan and Morey, (2009) describe the factors affecting the strength and durability of the briquettes as a properties of feedstock (fiber, protein, fat, lignin, moisture content), pre-conditioning processed (steam conditioning and addition of binders) and densification equipment (forming pressure and roll press variables). According to the Ivanova (2012) durability is one of the main parameters which affects the quality of briquettes (Ivanova, 2012). Nevertheless, all the authors agree that the mechanical durability is important indicator for measuring the quality of the briquettes.

According to the Technical Specification CEN/TS14588 is mechanical durability quality parameter which is defined as the ability of densified biofuels or fuel units (briquettes) to remain intact during handling, storage and transportation (ČSN EN 14588, 2010). According to the Ivanova *et al*. (2014) mechanical durability depends on used raw material and its structure, compaction pressure and raw material moisture content (Ivanova *et al*., 2014). It can be measured by the level of resistance towards shock and friction. One of the ways for the measuring of the durability of the briquettes is using the mechanical handling simulation. This manner helps control the process of densification and, thus, quality of briquette (Kaliyan and Morey, 2009).

2.4.2.2 DU Test

Testing of the durability, effectiveness of a briquetting process or abrasive resistance, by the other words, can be measured by the DU test which is performed by the norms ČSN P CEN / TS 15210-2 and it helps control quality of the briquettes and the densification process (ASABE, 2003). Durability, i.e. abrasive resistance is the prevalent form of the measurement and expression of the briquette quality so it can be viewed from the results of durability testing – abrasion size. DU test indicates the highest stress that the briquettes are able to resist and the amount of abrasion material during the potential handling, transportation and storage (Kaliyan and Morey, 2009). During the DU test samples are spun in the drum, where the impact on the blades, which drum is divided, and thus leads to abrasion (Kotlánová, 2009). Detail description of the DU test, its processes and equipment, is presented in the chapter of Durability test from the Methodology part. The briquette abrasion size is the share of the briquettes tested sample expressed in the weight percentage of the original briquette batch (ASABE, 2003; Plíštil *et al*., 2005). Allowed values are shown in the Table 3 below.

Table 3: Specification of mechanical durability of briquettes according to ČSN EN 14961-1: 2010

Mechanical durability (DU)	Weight in % after treatment
DU 95.0	≥ 95.0 %
DU 90.0	≥ 90.0 %
DU 90.0	< 90.0% (actual value to be stated)

Source: (ČSN EN 14961-1, 2010)

2.4.2.3 Related Standard

This European Standard specifies the requirements and method for determining the mechanical durability of the briquettes. Mechanical resistance measures resistance of compressed solid biofuels to shocks and abrasion due to handling and transportation. It describes namely biofuels, solid fuels, biomass, fuels, particulate materials, briquettes, mechanical testing, durability, endurance testing, wear tests, impact testing (ČSN EN 15210-2:2010).

2.4.2.3.1 *ČSN EN 15210 - 2:2010*

To be able to use this standard it is necessary to mention the following referenced documents showed in the Table 4. For data references, only the edition cited applies.

Table 4: National standards of the Czech Republic - Solid biofuels - Sampling

Standard number	Standard name
EN 15210 – 2:2010	Solid biofuels – Determination of mechanical durability of pellets and briquettes - Part 2: Briquettes
EN 14588:2010	Solid biofuels – Terminology, definitions and descriptions
CEN/TS 14778 - 1	Solid biofuels – Sampling – Part 1: Methods for sampling
CEN/TS 14780	Solid biofuels – Methods for sample preparation
EN 147740 – 1:2009	Solid biofuels – Determination of moisture content – Oven dry method – Part 1: Total moisture – Reference method
EN 14774 – 2:2009	Solid biofuels – Determination of moisture content – Oven dry method – Part 2: Total moisture – Simplified method
ISO 3310 – 1	Test sieves – Technical requirements and testing – Part 1: Test sieves of metal wire cloth

Source: (ČSN EN 14778, 2011; Kukačková, 2013)

3 OBJECTIVES

3.1 Main objective

The main objective of this thesis was to monitor and evaluate the changes of the weights of the briquettes which were submitted to the DU test, six times in the course of ten months. The main objectives were fulfilled by achieving two specific objectives that are described below.

3.2 Specific objectives

3.2.1 Mechanical strength vs. storage conditions

First specific objective was to investigate which storage conditions had better effects on the durability of briquettes and to find out the potential relation between the mechanical strength and the different storage conditions of briquette samples.

3.2.2 Mechanical strength vs. weight of the briquettes

Second specific objective was to investigate which weight range of the briquettes had better effects on the durability of briquettes and to find out the potential relation between the increasing and decreasing the mechanical strength in compare with the different weights of briquettes.

4 METHODOLOGY

Methodology of this thesis contains two parts: theoretical and practical part. Theoretical research contained the review of the secondary data mainly from the scientific articles found in the scientific databases such as Sciencedirect and Scopus. The articles were found with the help of the key words: Biomass, biofuels, briquettes, digestate, mechanical strength, solid biofuels quality, abrasion, durability. The majority of used impacted articles were in English language and rest of the articles were in Czech language. Second part, practical research formed the dominant part, its methodology is described below.

4.1 Material and samples

4.1.1 Material properties

Material used for production of the briquette samples used for the research purposes of this thesis was digestate originated from the biogas plant (BGP) located at the farm in the city Krásná Hora nad Vltavou. Material from the BGS was processed in laboratory of Faculty of Tropical AgriSciences (FTA) and the specific briquettes were produced in laboratories of Faculty of Engineering (FE), Czech University of Life Sciences (CULS), Prague. Compositional properties of used digestate are listed in Table 5 below.

Table 5: Nutrient content of used digestate material (%)

	Dry matter	Ash	N x 6,25	Fat	Fibre	Organic matter	Nitrogen-free extract
BGP output	5.97	1.02	0.78	0.02	1.86	4.95	2.28
Processed material	91.31	10.90	11.20	0.27	31.74	80.41	37.21
100 % dry matter	100.00	11.93	12.27	0.30	34.76	88.07	40.75

Source: doc. Ing. Josef Pecen, CSc.

4.1.2 Sample properties

Final samples, 113 pieces of briquettes, were produced at 8th April 2014 by a hydraulic piston briquetting machine BrikStar model 50 -12 (Briklis, Ltd., Malšice, Czech Republic) which is located in the laboratories of FE, CULS, Prague. Properties of the final samples were described in following Table 6:

Table 6: Properties of the briquette samples

Shape	Cylindrical
Diameter	50 mm
Length	40 - 60 mm
Weight	72.00 - 142.45 g

Source: Author

Figure 6: Briquette samples before DU testing 1

Source: Author

Figure 7: Briquette samples before DU testing 2

Source: Author

4.1.3 Distribution of the samples

The briquette samples were divided into two groups and stored in the different conditions; indoor group (n = 58), samples of briquettes were stored inside the building in the laboratory (FTA) and outdoor group (n = 55), which were stored outside the building, under the roof and covered only by plastics bags. Those briquette samples were exposed to air temperature and humidity changes.

Each group was subsequently divided into three groups because of the DU testing, in accordance with CEN / TS 14778-1 and CEN / TS 14780 standards. It was necessary to keep the rule, which said that the minimum test portion of the sample must be 2 kg and the sample material must not contain any small broken particles. These must be separated from the sample by sieving through a sieve or by manual sorting (ČSN EN 14778, 2011).

4.2 Methods

4.2.1 Testing of durability (DU Test)

Whole practical research of mechanical durability (DU), all testing processes and testing equipment were conducted directly according to the ČEN 15210 – 2:2 standard, named Solid biofuels – Determination of mechanical durability of pellets and briquettes, which describes all the attributes necessary to fulfill the DU test.

Research contains six DU tests which were held in the laboratory of FE, CULS Prague during the time period from 6th May 2014 to 29th January 2015.

Table 7: Time period of the DU testing

Date of abrasions					
I.	II.	III.	IV.	V.	VI.
7.5.2014	29.5.2014	3.7.2014	1.9.2014	19.11.2014	29.1.2015

Source: Author

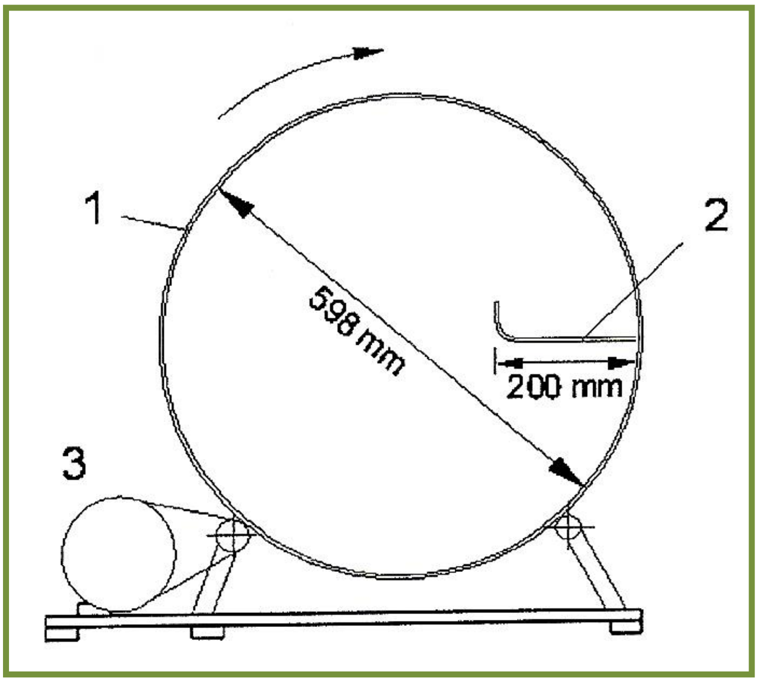
For the research purposes of this thesis the process of mechanical handling was selected. According to the mentioned standard the briquette samples were subjected to a controlled mutual pushing to the wall of the drum caused by rotation of the drum in a precisely defined time, i.e. 4 minutes and 27 seconds. The weight of the sample remaining after separate between grazed and finely shredded part is calculated mechanical resistance. Every single briquette was weighed separately but the samples were abraded as the group (ČSN EN 15210-2, 2010).

4.2.1.1 Used Equipment and instruments

4.2.1.1.1 Drum for briquette testing

Special rotating drum (abrasion drum) was used for determining the mechanical resistance during the DU test. According to this standard the drum is cylindrically shaped, with a nominal capacity of 160 liters and dimensions of inner length and depth were 589 mm and inner diameter was also 589 mm. Design of the drum is shown on the Figure 8 and photo of the drum in reality at Figure 9.

Figure 8: Drawing of rotating drum used for DU testing: 1 – drum, 2 – baffle, 3 – motor



Source: EN 15210-2

Figure 9: Photo of the rotation drum in reality

Source: Author

The drum is made from steel plate with a thickness of 1 mm. The inner surface of the drum was smooth, without any inequalities. The drum for testing the mechanical resistance must comprise a rectangular baffle, also made from steel, with the dimensions of length of 589 mm, height of 200 mm and thickness of 1 mm. The drum was openable at one side that was equipped by a dust proof cover with the same diameter as the outer diameter of the drum. The cover had to be made of steel thicker than 1 mm. The cover must be secured by fixing screws which are mounted on the outer side of the drum. The drum was powered by an electric motor constantly at 21 - 0.1 rpm, with suitable chains and gears to prevent vibrations. Also the drum was connected to the tachometer for easier observance the exact time of rotation (ČSN EN 15210-2, 2010).

4.2.1.1.2 Sieve

After every rotation process ends the briquettes were removed from the drum with the help of special sieve with apertures of size approximately equal to 2/3 of the diameter or diagonal of the briquettes.

4.2.1.1.3 Laboratory scale

All briquettes were weighed separately one by one by the laboratory scale type KERN model EMB 600-2 with precision of 0.01 g. The properties of the mentioned scale are shown in the Annex X.

Figure 10: Weighing-machine KERN type EMB 600-2

Source: http://www.scales-measuring.com

4.2.1.2 Procedure

Prepared test portion of the sample of a minimum weight about 2 kg was placed into the drum. Special rotation drum used for the research within this thesis was modified to keep the standards regulation of the 105 turns, the rotating time was changed to 4 minutes and 27 seconds. When the drum started to rotate the briquettes were faced with a steel partition and it lead to abrasion. Then the sample was carried out through the sieve manually, for oscillation, which allows complete separation of the particles. In the process of sifting it was paid attention to the fact that the handling during screening can affect the final result. The sample which remained on the sieve was considered and then the percentage of the abrasion ratio was noted.

4.2.1.3 Calculation of mechanical strength

Mechanical resistance (durability) of the briquettes was calculated from the measured weights of every briquette sample before and after each DU test. The calculation was performed using the following formula:

Figure 11: Formula of the durability calculation

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

Source: Repsa *et al*., 2014

where:

- DU is a mechanical resistance in percent (%);
- m_E is the mass of briquettes before the abrasion process, in grams (g);
- m_A is the mass of briquettes after the abrasion process, in grams (g)

The results of six parallel determinations were calculated and registered to the nearest 0.01%.

4.3 Data processing

4.3.1 Microsoft Office Excel software

To organize and clean data obtained from laboratory measurement as well as creating the tables and graphs the Microsoft Office Excel software was used.

4.3.2 Statistica 12 software

For subsequent statistical analysis the Statistica 12 software was used. The measured data were subjected to descriptive statistics which summarized and identified the information. By using those statistical methods the calculation of the numerical characteristics like mean, median, variance, lower quartile, upper quartile, variance, standard deviation and coefficient of variation was found. In order to continue with the research the data were initially subjected to the test of normality and test of homoscedascity, null hypotheses were not rejected, thus assumption of normal distribution and homoscedascity was fulfilled and parametric tests were used. Result data are listed in the Table X. in chapter Results and discussion below.

To compare results of indoor and outdoor abrasion sizes, two-sample T-test was used with significance level 0.05. To compare abrasion sizes among weigh groups (divided below), test ANOVA was used (significance level 0.05).

To find out dependency between initial weights of briquettes and average abrasion size, regression and correlation analyses were done. Processed data were formed into the tables and graphs and together with the data processed by the Microsoft Office Excel were used as a support documents for the results and discussion of this thesis. Tukey´s honest significance difference test (HSD). It can be used on raw data or in conjunction with an ANOVA (Post-hoc analysis) to find means that are significantly different from each other. Processed data were formed into the tables and graphs and together with the data processed by the Microsoft Office Excel were used as a support documents for the results and discussion of this thesis.

5 RESULTS AND DISCUSSION

5.1 Mechanical strength vs. storage conditions

In the question of the relation between the mechanical strength and the different storage conditions in which the briquette samples were stored the data showed higher mechanical durability observed in indoor samples. Evidence of this statement proves measured data which were processed into the tables and the graphs below.

5.1.1 Storage conditions

5.1.1.1 Indoor samples

Air temperature and air humidity values, related to the indoor storage condition, were stated as a constant. The average air temperature was measured, during whole time of the researching, approximately from 19 - 24 ºC and air humidity ranged approximately from 30 to 60 %.

5.1.1.2 Outdoor samples

Second group of briquettes, the outdoor sample, was subjected to the weather changes. The air humidity average varied between 60 to 80 %, while air temperature average varied between 2 to 18°C, during the testing time periods. The average of the stored conditions changes are listed in Table 8 and displayed in the BoxPlot Graphs 1 and 2 below.

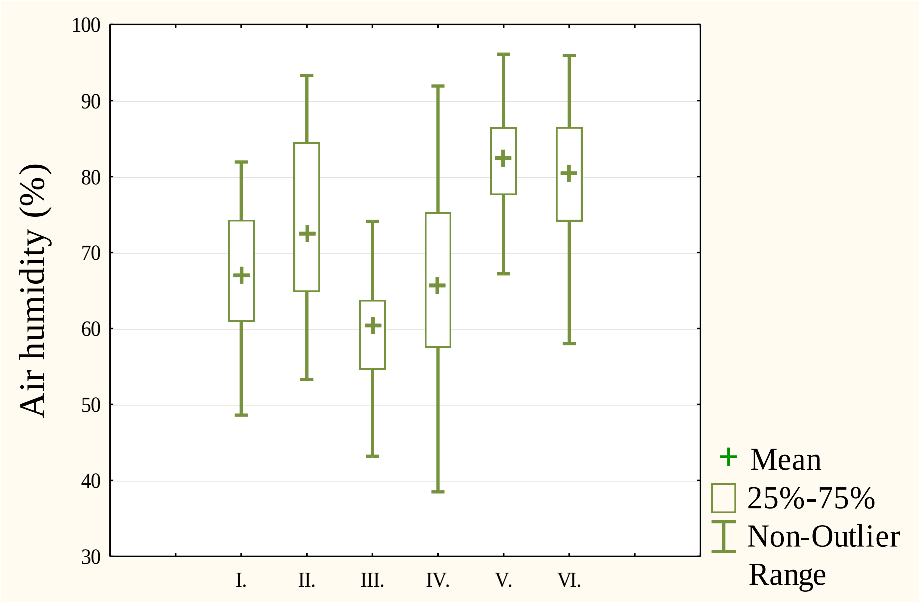
The data used for processing the air humidity and temperature originates from the meteorological station located and owned by the CULS, Prague. All values of the air humidity and temperature are listed in the Annexes 3 and 4.

Table 8: Means of the air humidity and temperature changes (%)

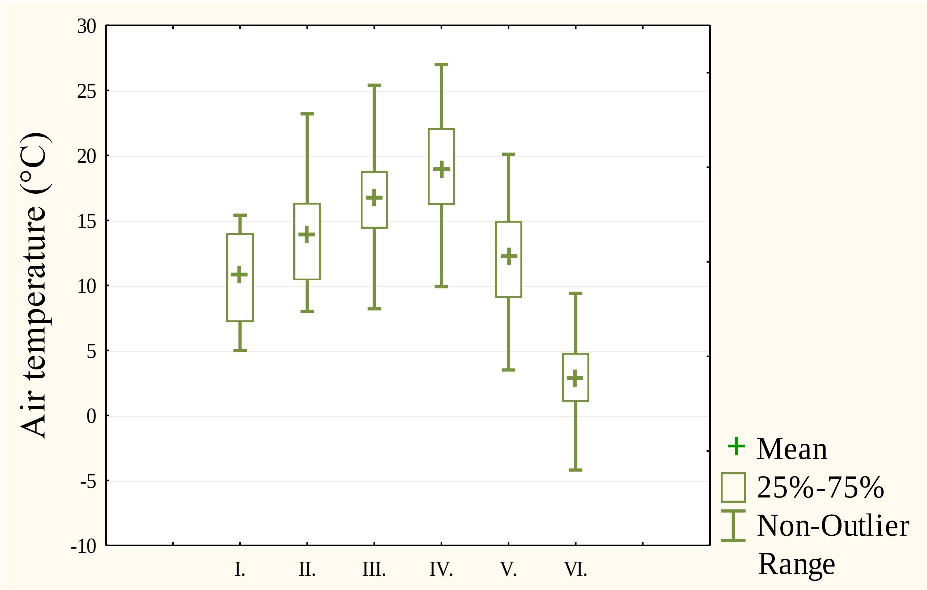
	I.	II.	III.	IV.	V.	VI.
Humidity	67.07	72.61	60.55	65.68	82.42	80.49
Temperature	10.84	13.94	16.78	18.93	12.28	2.83

First row of the Table c shows sequence of the DU tests, second row describes the air humidity changes during the numbers of DU testing and third row shows the same changes within the air temperature. As is evident from the measured values, the highest air humidity was measured during last two DU testing, performed in the November and January and the highest air temperature was measured during the third and fourth DU testing, performed in July and September, which corresponds to the weather conditions in the place of storage, Czech Republic.

Graph 1: Air humidity changes during the time periods between DU testing



Graph 2: Air temperature changes during the time periods between DU testing



5.1.2 Weight of briquette samples

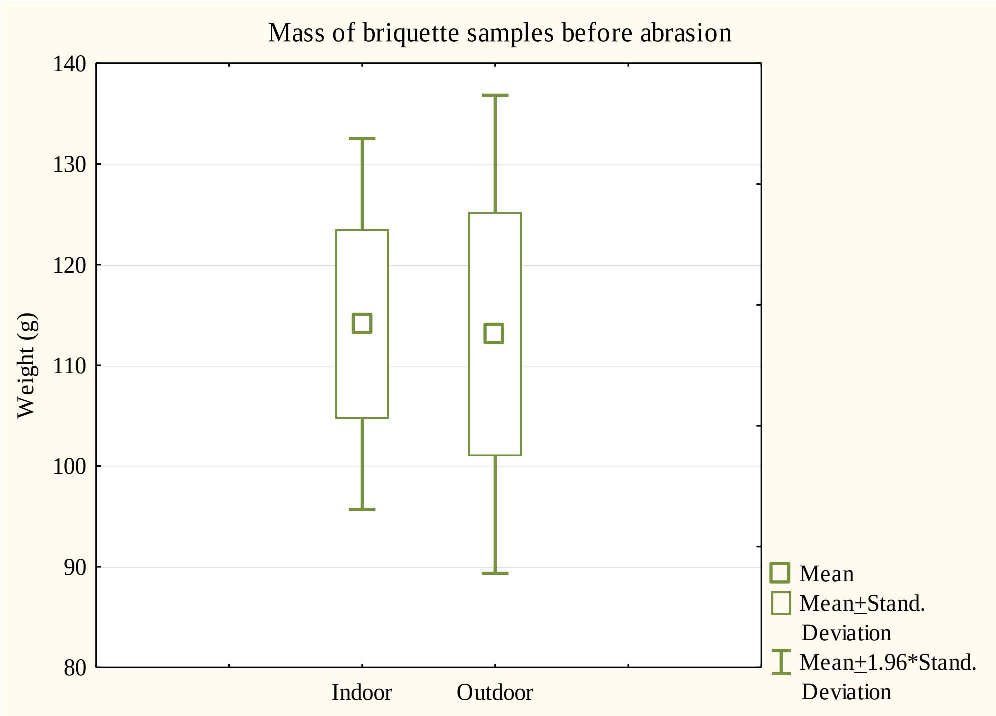
For the purpose of result calculations and data processing, the measured values were processed by the descriptive statistics and the result values are displayed at the Table 9 below. Table is divided by the specific storage conditions and the values are stated before and after all abrasion (DU) tests. For the purpose of this calculation were used measured values (weight, abrasion size, durability) of all 113 briquette samples before and after six DU tests. All used values are presented in the Annexes 1, 2 and 5, 6. In first two columns are shown measured data related to the briquettes samples stored in the constant conditions and third and fourth column show values of the outside briquette groups. Mean and median of interpreted values are closely similar to each other so it indicates that the data has normal distribution.

Table 9: Descriptive statistics of initial briquettes weight before DU tests (g)

	Indoor		**Outdoor**	
Valid n	**58**		**55**	
Valid n	**Initial**	**Result**	**Initial**	**Result**
Mean	114.10	107.95	113.09	109.79
Median	114.64	108.44	112.95	109.97
Minimum	92.62	83.53	72.00	69.8
Maximum	140.27	132.96	142.45	134.87
Lower quartile	108.47	102.02	109.61	107.17
Upper quartile	118.95	112.93	117.56	114.77
Variance	88.29	84.60	146.67	132.75
Stand. deviation	9.40	9.12	12.11	11.52
Coefficient Var.	8.23	8.52	10.71	10.49

For the better comparison of the basic values, related to the abrasive size and level of durability, the data were converted in to BoxPlot Graphs 3 a displays difference between the indoor and outdoor sample weights. The view of the Graph 3 shows that the briquette samples from outdoor group had bigger weight range.

Graph 3: BoxPlot of mass of briquettes before abrasion in g



5.1.3 Mechanical durability of briquettes

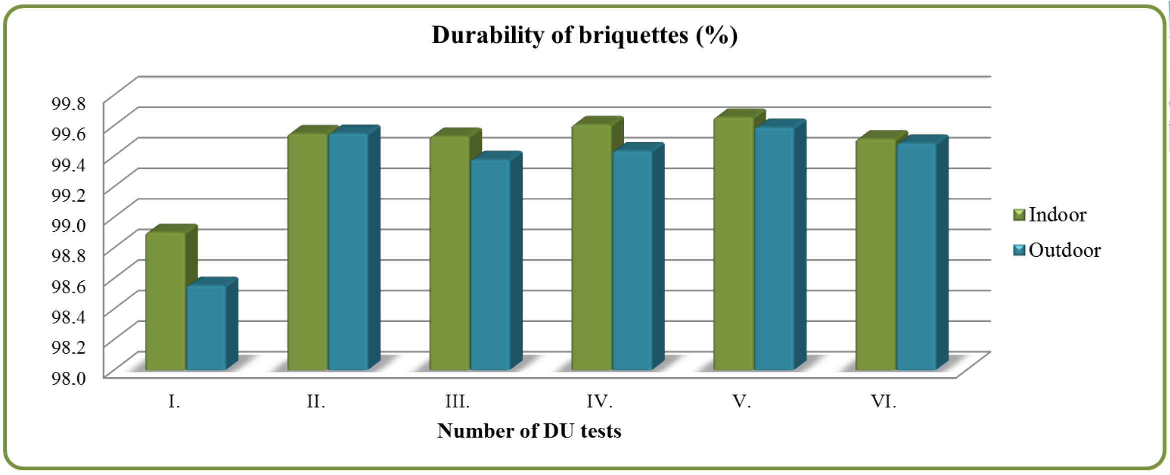
Result data related to the mechanical durability of all briquette samples and the entire storage group altogether were processed and listed in Table b and subsequently used as an input data for the creation of Graph 4 and Graph 5 below. Those were used for better view and easier orientation in the issue of comparison the level of durability of indoor and outdoor samples in specific DU testes. A line Graph 4 was used for better comparison of overall progress of DU level changes between the different stored samples, during all time periods of testing. Those clearly show the numbers of the durability testing and the higher values of the durability in percentage (%) in the <u>indoor samples</u>. As was mentioned mechanical durability indicates the amount of the material which was not crumbled away from the briquette during the durability testing and thus it says a lot about the quality briquettes. It implies that the constant storage conditions ensure the briquette quality and prevents the damages which can cause losses and decreasing the briquette quality and thus its value. According to the results it can be concluded that in order to maintain the high quality briquettes it is better to store it inside, on a place with constant air temperature and air humidity.

Table 10: Mechanical durability of different stored briquette groups in %

	I.	II.	III.	IV.	V.	VI.
Indoor	98.90	99.55	99.53	99.60	99.65	99.51
Outdoor	98.55	99.55	99.38	99.43	99.59	99.48

From the Table 10 is evidently that the mechanical durability was higher and had lower range in indoor group.

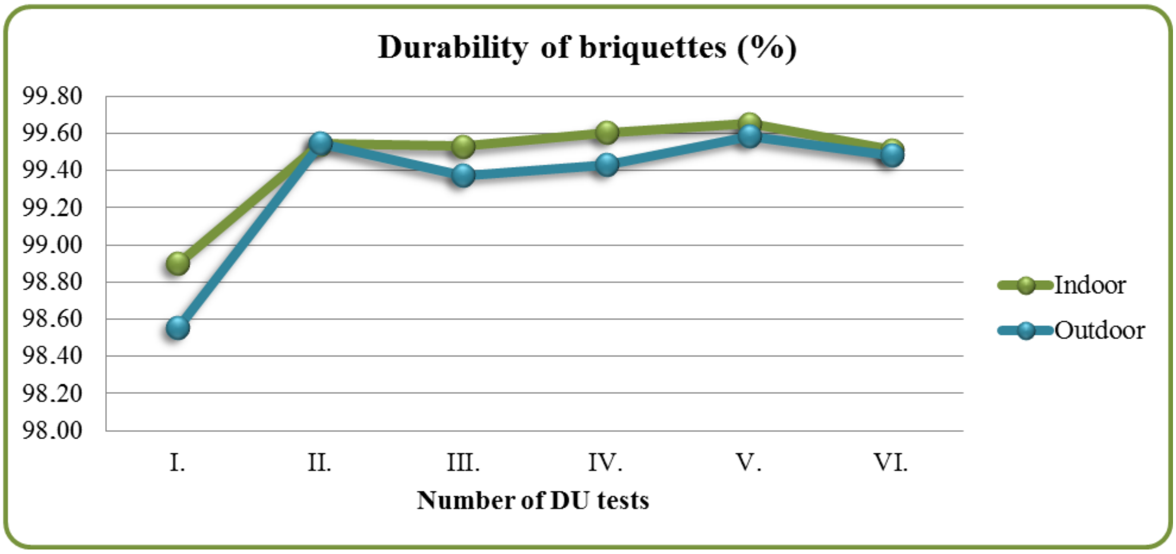
Graph 4: Mechanical durability of different types of briquettes storage conditions according to number of DU tests 1



Result data showed that the higher difference between the durability of indoor and outdoor samples were measured during the first DU test. In other cases the differences were not as obvious as in the first case.

The same results can be seen in the line Graph 5, which also shows the progress of durability but there is better view of the difference between the whole progress of the indoor and outdoor samples. The lines showed that the outdoor samples had lower durability level than the indoor samples.

Graph 5: Mechanical durability of different types of briquettes storage conditions according to number of DU tests 2



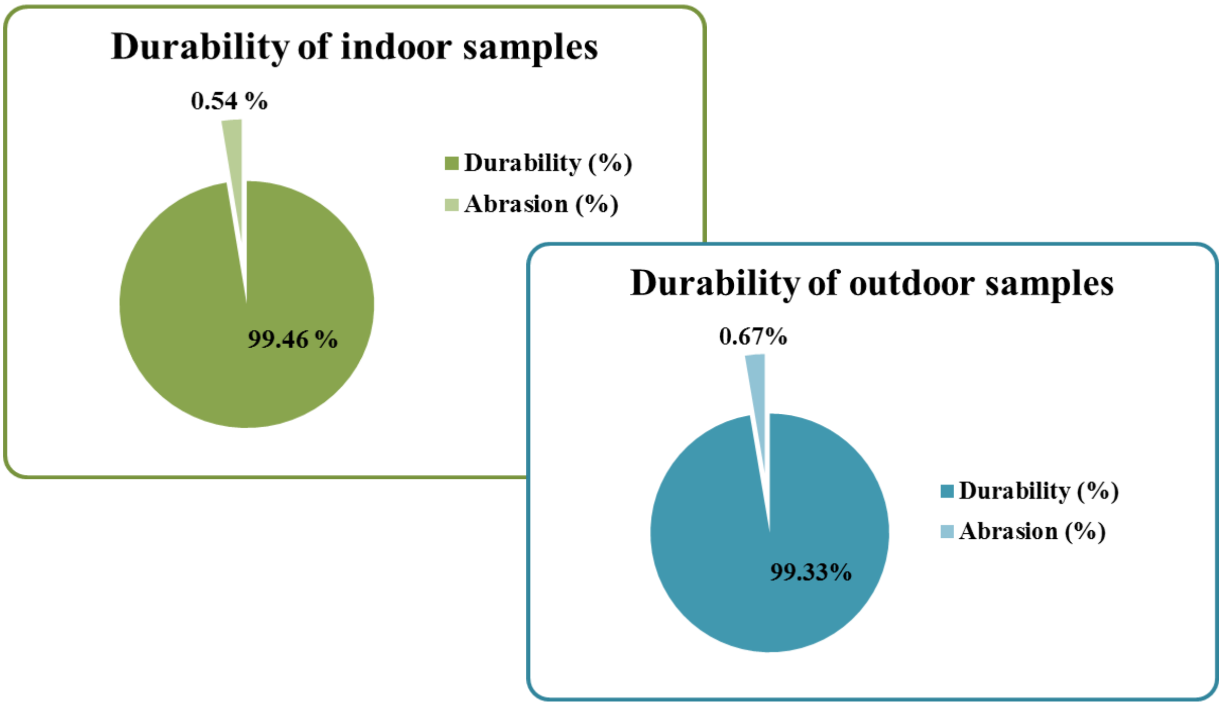
During the detailed data processing the means of all indoor and outdoor durability values were calculated. Graphical representation of the percentage values can be seen in pie charts, which promote the data from Table 11.

Table 11: Mechanical durability mean values of briquettes

	Durability (%)	Abrasion (%)
Indoor	99.46	0.54
Outdoor	99.33	0.67

When comparing these two mean values it is clear that there is no big difference, nevertheless the percentage of durability of the outdoor samples is lower. It confirms previous result data and graphs.

Graphs 6, 7: Durability of briquettes in different storage conditions in %



Average value mechanical durability of all examined briquette samples were stated at 99.395 %. Which was considered as a very good result. In compare with the result of other authors which proved that average value of mechanical durability of briquettes from pure hemp was above 95 %. Also the mixed briquettes from *Miscanthus x giganteus* and wood sawdust and briquettes mixed from sweet sorghum and wood shavings exhibited this level of mechanical durability. Another material used for briquette production like pure *Miscanthus x giganteus* and *Miscanthus sinensis* exhibited mechanical durability above 90 % which is still lower that the mechanical durability of the briquettes made from digestate (Ivanova, 2012).

5.1.4 Statistical analysis

To compare abrasion level of indoor and outdoor samples, two-sample t-test was done, to determine if there if the abrasion means are equal for the two samples. The results from the t-test you can see in Table 12.

Table 12: t-test results comparing of means indoor and outdoor samples

Indoor vs. Outdoor	
Mean indoor	0.54
Mean outdoor	0.57
t-value	0.6776
Df	676
p-value	**0.4982**
N valid indoor	348
N valid ourdoor	330
Std. Error. indoor	0.4309
Stand. Error. outdoor	0.5136

As the results of shows, p-value 0.4982 is higher than set significance level 0.05, thus we cannot rejected the null hypothesis that the means are equel, so we can say, that there is no statisticaly significant difference between abrasion means of indoor and outdoor samples.

5.2 Mechanical strength vs. briquette weights

5.2.1 Distribution of briquettes

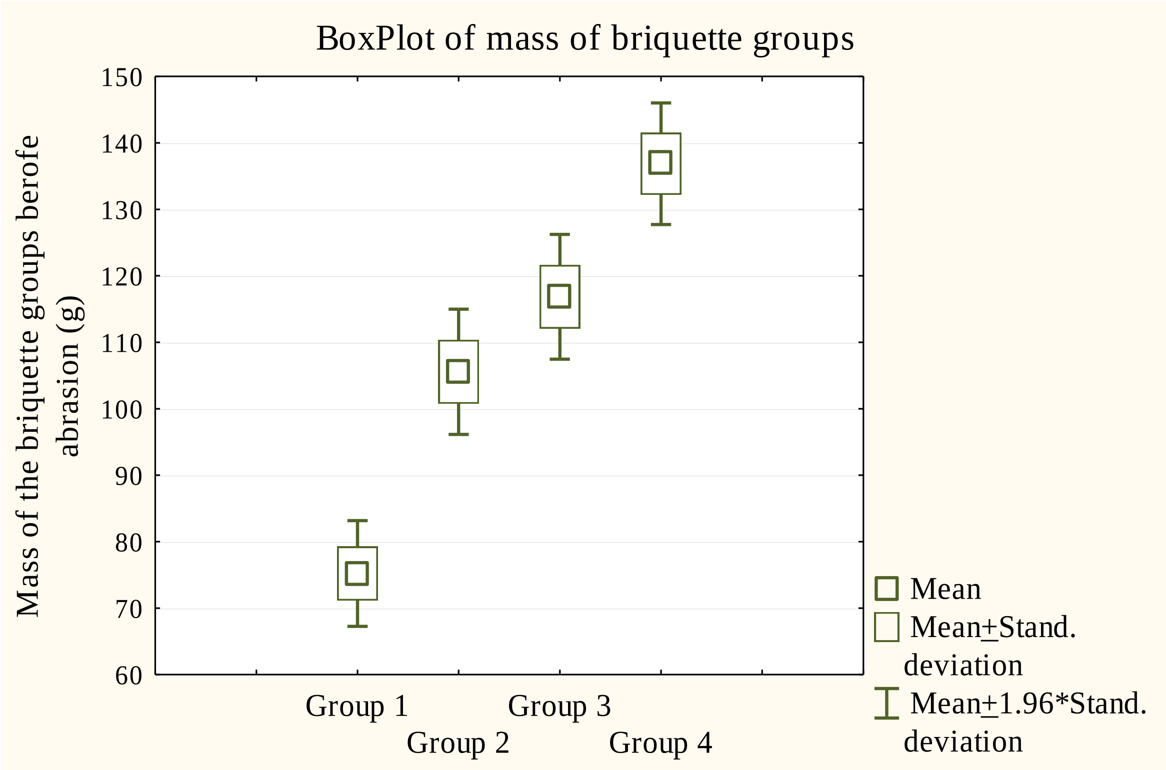
For easier and faster orienting in the result values of abrasion size and briquette weights the descriptive statistics were used. Graphical and tabular outputs, with its description, are provided below. The data presented in the Table 13 showed the values of the weight and abrasion mean of the specific weight groups. The comparison of the abrasion means showed that the lowest abrasion size mean about 0.53 %, thus highest mechanical durability, was measured in the Group 1 which contained briquettes with the lowest weight. From which directly derived that the highest abrasion size mean about 0.70 % was observed in Group 4.

Table 13: Weight distribution of briquettes and weight means of groups

	Range (g)	Weight Mean (g)	Abrasion mean (%)
Group 1	< 90.00	75.21	0.53
Group 2	90.01 – 110.00	105.57	0.55
Group 3	110.01 – 130.00	116.85	0.62
Group 4	> 130.01	136.86	0.70

For better understanding and comparison of the briquette initial weight range and subsequent distribution into four groups, was the BoxPlot Graph 8, based on this information, created.

Graph 8: Mass of briquettes before abrasion tests



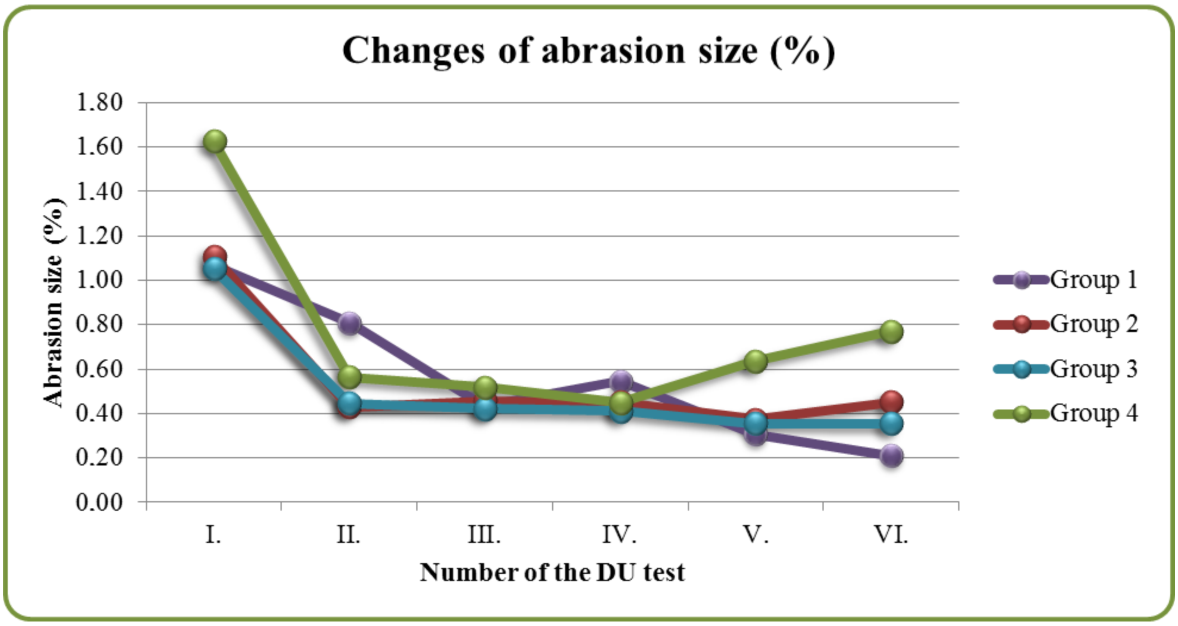
5.2.2 Mechanical durability

Changes in the abrasion size during the durability testing are observed in Graph 9 in which the different weight groups were also distinguished**.** As mentioned graph indicates the abrasion sizes were highest at the first durability testing, which is frequently occurring statement. From the first DU testing the values decreases rapidly and then the values continue constantly until the fourth test. In this point the values started differ. Nevertheless, as is evident from the graph, the highest abrasion size was observed in the Group 4, which belongs to the heaviest weight range > 130.01 g, according to the previous distribution, showed in Table 14. This result indicates that the briquettes with higher weight have higher abrasion size, thus lower mechanical durability and are to greater potential damages. But this assumption must be further subject to subsequent research.

Table 14: Evolution of the abrasive size during DU tests in %

	I.	II.	III.	IV.	V.	VI.
Group 1	1.06	0.81	0.43	0.54	0.31	0.21
Group 2	1.11	0.43	0.46	0.45	0.37	0.45
Group 3	1.05	0.45	0.42	0.41	0.36	0.35
Group 4	1.63	0.57	0.52	0.45	0.64	0.77

Gragh 9: Progress of changes of abrasion size in different groups

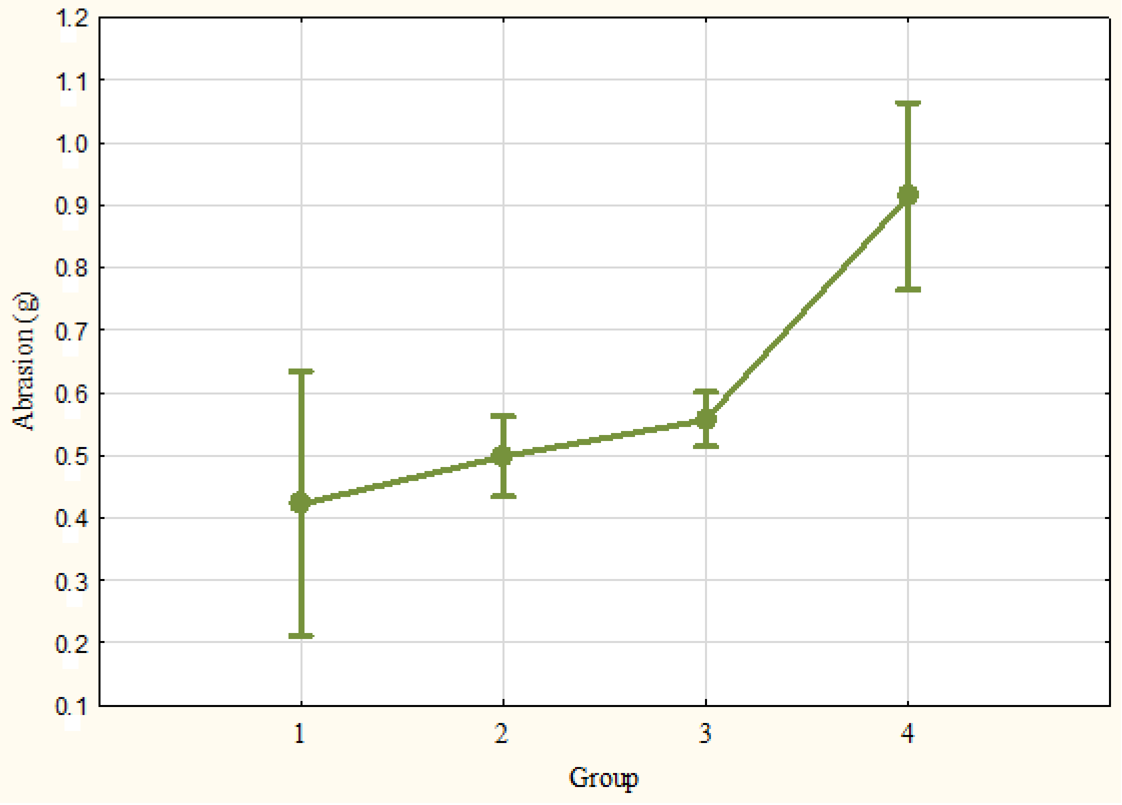


5.2.3 Statistical analysis

5.2.3.1 One-Way Analysis of Variance for Independent Samples (ANOVA)

Result values of the ANOVA test (with significance level 0.05) which was used to compare abrasion sizes (g) among different weigh groups (g) are displayed in the Graph 10 and categorized in the Table 15, 16 below.

Graph 10: The one-ways Analysis of Variance (ANOVA)



In the different parts of result output of the analysis of variance (Graph 10) there is an evaluation of the statistical significance of the differences between the average abrasion values at four different groups of briquette weights. In the basic results of the ANOVA analysis of variance there is a Table 15 of intermediate results with the critical value of F-test ($F = 8.9106$). In the row "Group" it is evident that value of the tested F criteria corresponds to the calculated level of significance $p = 0.0000$. According to the p-value which is significantly lower than the specified value $\alpha = 0.05$ (also than $\alpha = 0.01$) it is taken alternative hypothesis according to which at least one pair of averages compared statistically differ significantly at the both levels of α (and corresponding confidence). The conclusion is identified by the red colour, so the acceptance of alternative hypotheses for the analysis of variance is visually evident. So the means of abrasion size among different weigh groups are not equal, there is statistically significant difference between the weigh groups in terms of abrasion size. Also from the graph III it is evident that the largest abrasion was in weight Group 4 (heaviest briquettes), followed by Groups 3, 2, 1.

Table 15: ANOVA testing results (abrasion size vs. briquette weights)

Source	SS	df	MS	F	Sig.
Between groups	62.9520	1	62.95202	301.9375	0.000000
Within groups	5.5734	3	1.85780	8.9106	0.000009
Error	140.5247	674	0.20849		

where:

Df – degree of freedom

SS – Sum of Square

MS – Mean Square

With such a conclusion, there is a need to make more detailed assessment of the analysis of variance. It is necessary to detect which means respectively, which groups between themselves differ significantly. For a more detailed assessment Tukey´s HSD test was chosen for multiple comparisons.

Table 16: Tukey HSD test for the Post-ANOVA testing

	{1} 0.42222	{2} 0.49828	{3} 0.55718	{4} 0.91389
Group 1		0.906320	0.608603	0.001115
Group 2	0.906320		0.445310	0.000011
Group 3	0.608603	0.445310		0.000046
Group 4	0.001115	0.000011	0.000046	

The table 16 shows where the statistically significant differences between weight groups lies. This table contains a more detailed evaluation are calculated level of significance of p-value to the real difference was found between each pair of averages $\bar{x}1$ = 0.42222, $\bar{x}2$ = 0.49828, $\bar{x}3$ = 0.55718, $\bar{x}4$ = 0.91389. The p-value, lower than the value of the significance level $\alpha = 0.05$, are identified by red colour and show a statistically significant difference between a given pair of mean of weight groups (α significance level = 0.05). Other p-values, which are not highlighted by red colour, are higher than the selected $\alpha = 0.05$ and did not demonstrate a statistically significant difference (at the chosen significance level) between a pair examined diameters or weight groups. Thus, we can see, that there are significant differences between group 4 and the rest of Groups (1, 2 , 3). The differences among Groups 1, 2, 3 are not significant. This conclusion is supported by Graph III.

5.2.3.2 Regression and correlation

For the expression of the relation between size of abrasion and initial weight of the briquettes samples, which were divided into four groups, were the regression and correlation analysis used. Research and the data processing showed that there is relation between those two parameters which says that with the increasing of the sample weights the abrasion size increases, too. However according to the Graph 11 which displays very low gradient of the trend line it can be deduced that the relation is very poor.

Graph 11: Regression between briquettes weights and durability in indoor samples

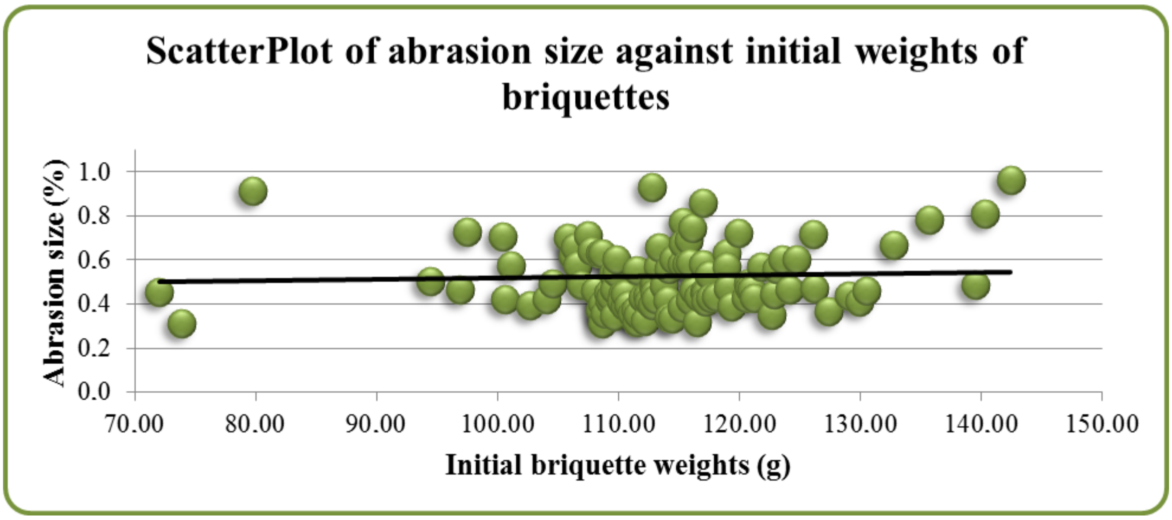


Table 17: Equation of the correlation between mechanical durability and weight groups

$y = 0.0006 * x + 0.4583$
$R^2 = 0.0014$

The equation of the correlation coefficient R^2 generated during the data processing also showed very low values, namely $R^2 = 0.0014$, which means equals to 0.14 %. From this statement it can be concluded that the correlation between abrasion size and weights of briquettes from digestate is very low from the statistical point of view.

6 CONCLUSION

In order to fulfill the objective of this study, the changes in the mechanical strength of the briquette from digestate were monitored and evaluated. Total amount of briquette samples (n= 113) used for research were divided in to two groups according to the different storage conditions. One group of briquettes (indoor samples) were stored inside the building, where the conditions were identified as constant while the second group of briquettes (outdoor samples) were stored outside the building and were exposed to weather changes. Those two groups were subjected to six controlled durability (DU) tests during the time period of 10 month in an attempt to measure the level of durability (%). Result data, related to the weight of each briquette separately before and after durability testing, were processed and used for the calculation of the mechanical durability. Those result data were subsequently divided by different ways according to two points of interest, namely two different storage conditions and four weight groups.

Research, related to storage conditions, was performed by comparing the level of durability in different stored groups and proved that higher level of durability were observed in indoor samples, namely 99.46%. Level of durability in outdoor samples was 99.33 %, which was determined as a worse result value, despite the fact that the difference between compared values was not statistically significant. Second researched statement was related to the durability level and briquette weight. Processing of the data showed that the highest durability level was reached in the group with the lightest briquettes, specifically 99.47 %. Comparison of the result values of all weight groups also proved the trend of decreasing mechanical durability with the increasing of briquette weight. Research of this thesis also proved that the lowest durability level was measured during the very first DU testing, than the rate of durability significantly increased. After third DU test the rate stabilized and became almost constant.

Overall, it can be conclude that the briquettes, made from digestate, exhibited very satisfactory results in the issue of the durability level and thereby of mechanical strength; mean value of all durability values was 99.40 % which is considered as very good.

7 RECOMMENDATION

Research and subsequent result of this thesis was related only to the one of the physical – mechanical factor which influences the briquette quality. It indicates that more researches are needed to be done in other quality properties of briquettes, both physical – mechanical and chemical. Chemical properties are just as important as the physical – mechanical ones, for example ash content and fusibility.

Furthermore it would be useful to examine the influence of the storage conditions with the different air temperatures and different air humidity. This research was conducted under the conditions without the extreme differences in air temperature and air humidity, so if the briquettes were stored in another location with larger differences between day and night temperatures and humidity, or between summer and winter months, the measurement results could be different.

Last recommendation is related to the weight of briquettes, which is directly dependent on the length of the briquettes. The result proved that higher durability was observed in the groups with the lighter briquettes, i.e. shorter briquettes, which have got lower level of abrasion, losses and damages. It would seem, therefore, that it is more economically preferable to make shorter briquettes, but there is another production aspect which has to be considered. Production of every single briquette costs a specific sum of money and with increasing numbers of the produced briquettes the production costs increases to. It would be very interesting to define the exact length of briquettes, which is beneficial from both economic and qualitative terms.

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8 APPENDIXES

List of Appendixes:

Appendix 1: Table of abrasion size of briquettes (%)

Abrasion size of briquettes (%)

Indoor samples

Group	Weight (g)	I.	II.	III.	IV.	V.	VI.
1	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	92,62	0,93	0,84	2,26	0,96	0,67	0,50
	94,47	0,85	0,40	0,38	0,55	0,33	0,52
	97,46	1,56	0,49	0,46	0,60	0,46	0,80
	100,42	1,34	0,58	0,51	0,50	0,29	1,03
	101,07	1,38	0,39	0,41	0,49	0,28	0,51
	102,70	0,87	0,30	0,25	0,56	0,23	0,15
	104,02	1,03	0,33	0,31	0,19	0,17	0,51
	104,52	1,08	0,39	0,28	0,38	0,30	0,54
	105,78	1,17	0,51	0,45	0,87	0,32	0,87
	106,24	1,13	0,53	0,34	0,34	0,41	0,95
	106,42	1,43	0,33	0,30	1,23	0,22	0,43
	106,63	1,13	0,47	0,38	0,35	0,36	0,76
	106,87	0,81	0,31	0,60	0,26	0,26	0,67
	108,09	0,79	0,34	0,61	0,47	0,26	0,30
	108,47	1,40	0,58	0,50	0,42	0,34	0,54
	108,49	0,71	0,61	0,29	0,23	0,15	0,23
	108,63	1,46	0,28	0,46	0,59	0,28	0,70
	108,89	0,74	0,22	0,34	0,20	0,17	0,48
	109,33	0,87	0,38	0,52	0,34	0,27	0,24
	109,85	1,23	0,62	0,49	0,48	0,41	0,40

Outdoor samples

Group	Weight (g)	I.	II.	III.	IV.	V.	VI.
1	72,00	0,90	0,73	0,43	0,31	0,16	0,20
	73,86	0,81	0,01	0,25	0,34	0,27	0,19
	79,77	1,48	1,68	0,62	0,98	0,49	0,24
2	96,86	0,89	0,02	0,46	0,68	0,41	0,34
	100,64	1,16	0,61	0,24	0,19	0,21	0,12
	107,46	0,85	0,54	0,43	0,49	1,68	0,28
	107,79	1,27	0,08	0,42	0,60	1,10	0,36
	108,68	0,70	0,02	0,30	0,34	0,28	0,25
	108,69	1,00	0,28	0,32	0,28	0,27	0,26
	109,18	0,74	0,48	0,33	0,34	0,37	0,43
	109,26	0,72	0,33	0,36	0,36	0,44	0,28
	109,50	1,11	0,65	0,60	0,31	0,30	0,26
	109,60	0,89	0,02	0,34	0,25	0,26	0,31
	109,61	1,07	0,65	0,32	0,31	0,27	0,19
	109,84	0,84	1,22	0,40	0,34	0,22	0,23
3	110,30	1,06	0,04	0,40	0,48	0,41	0,30
	110,47	0,96	0,48	0,28	0,29	0,17	0,17
	110,56	0,90	0,71	0,35	0,31	0,20	0,18
	110,82	0,87	0,33	0,34	0,31	0,29	0,24
	111,07	0,63	0,56	0,17	0,27	0,33	0,18
	111,37	1,03	0,34	0,26	0,23	0,20	0,18

	110,25	1,08	0,27	0,26	0,37	0,17	0,33
	111,45	0,68	0,32	0,22	0,25	0,22	0,23
	111,96	0,77	0,25	0,35	0,33	0,32	0,53
	112,48	0,77	0,28	0,23	0,35	0,31	0,51
	112,81	1,34	0,51	1,82	0,50	0,60	0,82
	112,93	1,03	0,67	0,36	0,24	0,29	0,39
	113,30	1,47	0,41	0,35	0,43	0,35	0,41
	113,35	1,67	0,86	0,50	0,46	0,34	0,12
	114,07	0,78	0,35	0,25	0,27	0,33	0,52
	115,21	1,22	0,51	0,81	0,23	0,22	0,50
	115,25	0,89	0,31	0,26	0,26	0,15	0,44
	115,35	1,21	1,31	0,41	0,32	0,23	0,56
3	115,58	1,01	0,57	0,41	0,49	0,52	0,49
	115,80	1,40	0,33	0,40	0,35	1,10	0,55
	115,88	0,79	0,34	0,30	0,24	1,02	0,83
	115,95	0,97	0,32	0,34	0,42	0,18	0,27
	116,60	1,07	0,32	0,20	0,26	0,19	0,55
	117,03	1,44	0,50	1,37	0,62	0,61	0,60
	117,17	0,86	0,41	0,27	0,26	0,25	0,62
	117,19	0,69	0,45	0,27	0,24	0,13	0,69
	117,45	1,28	0,29	0,34	0,25	0,23	0,81
	118,04	0,94	0,34	0,43	0,24	0,18	0,47
	118,92	1,12	0,49	0,28	0,35	0,76	0,78
	118,95	0,97	0,46	0,96	0,42	0,29	0,32
	119,38	0,64	0,41	0,33	0,26	0,16	0,52
	119,95	1,65	0,49	0,87	0,41	0,47	0,46

	111,49	1,15	0,67	0,22	0,85	0,25	0,18
	111,61	0,65	0,02	0,46	0,42	0,40	0,16
	112,15	0,75	0,02	0,33	0,38	0,23	0,24
	112,35	0,66	0,01	0,50	0,42	0,69	0,34
	112,77	0,89	0,03	0,56	0,32	0,31	0,29
	112,86	1,16	0,36	0,36	0,44	0,32	0,26
	112,95	0,75	0,03	0,39	0,67	0,33	0,52
	113,08	0,94	0,27	0,30	0,63	0,29	0,13
	113,79	1,22	0,33	0,33	0,44	0,33	0,24
	114,12	0,81	0,05	0,32	0,38	0,28	0,20
	114,18	1,16	0,82	0,32	0,38	0,34	0,34
	114,41	0,66	0,02	0,44	0,44	0,26	0,19
	114,54	1,70	0,72	0,30	0,42	0,30	0,18
	115,28	1,84	0,86	0,67	0,41	0,34	0,51
	116,08	1,17	1,70	0,60	0,49	0,27	0,23
	116,17	1,10	0,64	0,41	0,26	0,24	0,14
	116,17	0,83	0,72	0,33	0,23	0,44	0,19
	116,49	0,82	0,01	0,30	0,31	0,30	0,17
	116,97	1,18	0,57	0,47	0,49	0,43	0,34
	117,06	0,88	0,04	0,52	0,42	0,42	0,46
	117,56	0,68	0,63	0,47	0,29	0,28	0,22
	119,05	1,08	0,42	0,51	0,41	0,22	0,20
	119,59	1,58	0,39	0,99	3,75	1,35	0,50
	120,49	1,01	0,06	0,39	0,45	0,35	0,29
	120,96	0,90	0,56	0,33	0,46	0,33	0,24
	121,79	1,17	0,45	0,39	0,61	0,42	0,36

	120,73	0,77	0,43	0,31	0,32	0,85	0,30
	120,77	1,13	0,44	0,38	0,25	0,27	0,37
	121,22	1,02	0,49	0,35	0,25	0,21	0,24
	122,65	0,76	0,36	0,31	0,24	0,20	0,23
	123,57	1,07	0,43	0,37	0,46	1,03	0,25
	124,10	1,35	0,37	0,24	0,21	0,22	0,43
	126,05	2,57	0,43	0,28	0,25	0,27	0,52
	126,23	0,99	0,65	0,33	0,52	0,19	0,14
	129,05	1,25	0,41	0,31	0,27	0,18	0,21
4	130,48	0,97	0,40	0,28	0,35	0,24	0,53
	139,52	1,02	0,32	0,81	0,45	0,19	0,14
	140,27	1,73	0,97	0,61	0,57	0,48	0,49

	122,82	0,82	0,70	0,22	0,40	0,32	0,21
	123,03	1,30	1,07	0,23	0,26	0,29	0,20
	124,70	0,98	1,04	0,78	0,29	0,21	0,33
	127,40	1,11	0,02	0,27	0,26	0,32	0,23
	129,96	0,72	0,79	0,44	0,19	0,19	0,16
4	132,77	2,33	0,49	0,42	0,30	0,20	0,26
	135,66	1,36	0,01	0,60	0,42	0,48	1,84
	142,45	2,34	0,60	0,40	0,67	0,43	1,35

Appendix 2: Table of abrasion size of briquettes (g)

Abrasion size of briquettes (g)															
								Outdoor							
Group	Initial	I.	II.	III.	IV.	V.	VI.	Group	Initial	I.	II.	III.	IV.	V.	VI.
1	0	0,00	0,00	0,00	0,00	0,00	0,00	1	72,00	0,65	0,52	0,30	0,22	0,11	0,14
2	92,62	0,91	0,75	0,81	0,53	0,57	0,12		73,86	0,60	0,01	0,18	0,25	0,20	0,14
	94,47	0,80	0,37	0,35	0,51	0,30	0,16		79,77	1,18	1,32	0,48	0,75	0,37	0,18
	97,46	1,02	0,47	0,44	0,57	0,43	0,23	2	96,86	0,86	0,02	0,44	0,65	0,39	0,38
	100,42	1,35	0,57	0,50	0,49	0,28	0,18		100,64	1,17	0,60	0,24	0,19	0,21	0,12

	101,07	1,39	0,48	0,34	0,83	0,64	0,20
	102,70	0,89	0,31	0,25	0,56	0,63	0,15
	104,02	1,07	0,34	0,32	0,19	0,17	0,11
	104,52	1,13	0,40	0,29	0,39	0,31	0,15
	105,78	1,24	0,53	0,47	0,90	0,32	0,17
	106,24	1,20	0,56	0,35	0,35	0,42	0,35
	106,42	0,56	0,35	0,31	1,27	0,22	0,13
	106,63	1,21	0,50	0,40	0,37	0,37	0,08
	106,87	0,33	0,63	0,27	0,27	0,27	0,18
	108,09	0,85	0,36	0,65	0,50	0,27	0,21
	108,47	1,52	0,62	0,53	0,44	0,36	0,16
	108,49	0,77	0,66	0,31	0,24	0,16	0,14
	108,63	1,59	0,30	0,49	0,62	0,29	0,22
	108,89	0,81	0,24	0,36	0,21	0,18	0,10
	109,33	0,95	0,41	0,56	0,36	0,28	0,15
	109,85	1,35	0,67	0,53	0,51	0,43	0,12
	110,25	1,19	0,29	0,28	0,4	0,18	0,15
	111,45	0,76	0,35	0,24	0,27	0,24	0,14
	111,96	0,86	0,28	0,39	0,36	0,35	0,17
	112,48	0,87	0,31	0,26	0,39	0,34	0,16
3	112,81	1,51	0,57	1,99	0,53	0,63	0,14
	112,93	1,16	0,75	0,4	0,26	0,32	0,22
	113,30	1,66	0,46	0,39	0,48	0,38	0,25
	113,35	1,89	0,96	0,55	0,5	0,37	0,13
	114,07	0,89	0,39	0,28	0,3	0,36	0,27

	107,46	0,91	0,57	0,45	0,52	1,76	0,29
	107,79	1,37	0,08	0,45	0,63	1,16	0,38
	108,68	0,76	0,02	0,32	0,36	0,30	0,27
	108,69	1,09	0,30	0,34	0,30	0,28	0,27
	109,18	0,81	0,52	0,35	0,36	0,40	0,46
	109,26	0,79	0,36	0,39	0,39	0,47	0,30
	109,50	1,21	0,70	0,64	0,33	0,32	0,28
	109,60	0,98	0,02	0,37	0,27	0,28	0,34
	109,61	1,17	0,71	0,35	0,33	0,29	0,20
	109,84	0,92	1,33	0,43	0,36	0,23	0,25
	110,30	1,17	0,04	0,43	0,52	0,44	0,32
	110,47	1,06	0,52	0,30	0,31	0,18	0,18
	110,56	1,00	0,78	0,38	0,34	0,22	0,20
	110,82	0,96	0,36	0,37	0,34	0,32	0,26
	111,07	0,70	0,62	0,19	0,30	0,36	0,20
	111,37	1,15	0,37	0,29	0,25	0,22	0,20
	111,49	1,28	0,74	0,24	0,93	0,36	0,20
3	111,61	0,73	0,02	0,50	0,46	0,44	0,17
	112,15	0,84	0,02	0,37	0,42	0,25	0,26
	112,35	0,74	0,01	0,56	0,46	0,77	0,37
	112,77	1,00	0,03	0,62	0,35	0,35	0,32
	112,86	1,31	0,40	0,40	0,49	0,35	0,29
	112,95	0,85	0,03	0,43	0,75	0,37	0,58
	113,08	1,06	0,30	0,33	0,70	0,32	0,14
	113,79	1,39	0,37	0,37	0,49	0,37	0,27

	115,21	1,4	0,58	0,91	0,26	0,24	0,35
	115,25	1,03	0,35	0,29	0,29	0,17	0,19
	115,35	1,4	1,49	0,46	0,36	0,25	0,11
	115,58	1,17	0,65	0,47	0,55	0,58	0,05
	115,80	1,62	0,38	0,45	0,39	1,23	0,41
	115,88	0,92	0,39	0,34	0,27	1,14	0,31
	115,95	1,13	0,37	0,39	0,47	0,2	0,15
	116,60	1,25	0,37	0,23	0,29	0,22	0,12
	117,03	1,68	0,58	1,57	0,71	0,69	0,26
	117,17	1,01	0,48	0,31	0,3	0,29	0,2
	117,19	0,81	0,52	0,31	0,27	0,15	0,08
	117,45	1,5	0,33	0,39	0,28	0,26	0,19
	118,04	1,11	0,4	0,5	0,28	0,2	0,13
	118,92	1,33	0,58	0,32	0,4	0,87	0,27
	118,95	1,15	0,54	1,12	0,49	0,33	0,16
	119,38	0,77	0,49	0,39	0,3	0,18	0,09
	119,95	1,98	0,58	1,02	0,48	0,54	0,22
	120,73	0,93	0,51	0,37	0,37	0,98	0,14
	120,77	1,37	0,28	0,45	0,3	0,31	0,23
	121,22	1,24	0,58	0,41	0,29	0,24	0,18
	122,65	0,93	0,44	0,38	0,29	0,24	0,07
	123,57	1,32	0,53	0,45	0,55	1,23	0,19
	124,10	1,67	0,45	0,29	0,25	0,26	0,11
	126,05	3,24	0,53	0,34	0,3	0,33	0,12
	126,23	1,25	0,81	0,41	0,64	0,23	0,16

	114,12	0,93	0,06	0,36	0,43	0,32	0,23
	114,18	1,32	0,92	0,36	0,42	0,37	0,37
	114,41	0,75	0,02	0,50	0,50	0,29	0,22
	114,54	1,95	0,81	0,33	0,47	0,33	0,20
	115,28	2,12	0,97	0,75	0,46	0,38	0,56
	116,08	1,36	1,95	0,68	0,55	0,30	0,26
	116,17	1,28	0,73	0,47	0,30	0,27	0,16
	116,17	0,97	0,83	0,38	0,26	0,50	0,22
	116,49	0,96	0,01	0,34	0,36	0,35	0,19
	116,97	1,38	0,66	0,54	0,56	0,49	0,39
	117,06	1,03	0,05	0,60	0,48	0,49	0,53
	117,56	0,80	0,74	0,54	0,34	0,32	0,25
	119,05	1,28	0,49	0,59	0,47	0,25	0,23
	119,59	1,89	0,46	1,16	4,33	1,51	0,55
	120,49	1,22	0,07	0,47	0,54	0,42	0,34
	120,96	1,09	0,67	0,39	0,54	0,39	0,28
	121,79	1,43	0,54	0,47	0,73	0,50	0,42
	122,82	1,01	0,85	0,27	0,48	0,38	0,25
	123,03	1,60	1,29	0,28	0,31	0,35	-1,75
	124,70	1,22	1,28	0,95	0,35	0,25	0,39
	127,40	1,41	0,02	0,34	0,32	0,40	0,29
	129,96	0,93	1,01	0,56	0,24	0,24	0,20
	132,77	3,10	0,64	0,54	0,38	0,26	0,33
4	135,66	1,84	0,02	0,80	0,56	0,64	2,45
	142,45	3,33	0,84	0,55	0,92	0,59	1,85

	129,05	1,61	0,52	0,39	0,34	0,22	0,15
4	130,48	1,26	0,53	0,36	0,45	0,31	0,17
	139,52	1,43	0,44	1,11	0,61	0,25	0,09
	140,27	2,43	1,33	0,83	0,77	0,64	0,25

Appendix 3: Table of air humidity from 8. 4. 2014 to 29. 1. 2015

Air humidity (%)											
I.		II.		III.		IV.		V.		VI.	
Date	Value	Date	Value	Date	Value	Date	Value	Date	Value	Date	Value
8.4.	61,6	7. 5.	80,6	29. 5.	89,7	3. 7.	46,8	1. 9.	85,3	19. 11.	93,3
9.4.	50,9	8. 5.	64,8	30. 5.	74,1	4. 7.	38,5	2. 9.	88,7	20. 11.	87,8
10.4.	72,1	9. 5.	68,9	31. 5.	55,4	5. 7.	64,9	3. 9.	80,9	21. 11.	79,4
11.4.	60,9	10. 5.	64,9	1. 6.	55,8	6. 7.	53,2	4. 9.	74,7	22. 11.	77,8
12.4.	66,4	11. 5.	62,6	2. 6.	60,2	7. 7.	64,2	5. 9.	71,6	23. 11.	87,7
13.4.	62,8	12. 5.	59,3	3. 6.	64,6	8. 7.	79,6	6. 9.	67,2	24. 11.	86,1
14.4.	64,0	13. 5.	79,4	4. 6.	63,1	9. 7.	79,8	7. 9.	74,6	25. 11.	89,9
15.4.	70,7	14. 5.	67,7	5. 6.	55,8	10. 7.	87,6	8. 9.	77,8	26. 11.	87,1
16.4.	56,1	15. 5.	69,3	6. 6.	52	11. 7.	74,4	9. 9.	75,4	27. 11.	74,0
17.4.	48,6	16. 5.	66,6	7. 6.	45,5	12. 7.	59,3	10. 9.	72,9	28. 11.	82,4
18.4.	78,9	17. 5.	87,3	8. 6.	43,2	13. 7.	76,8	11. 9.	79,9	29. 11.	86,2
19.4.	59,5	18. 5.	87,8	9. 6.	46,8	14. 7.	64,6	12. 9.	93,9	30. 11.	85,6
20.4.	60,1	19. 5.	71,3	10. 6.	48,2	15. 7.	57,7	13. 9.	83,6	1. 12.	86,8
21.4.	68,7	20. 5.	67,9	11. 6.	63,2	16. 7.	60,4	14. 9.	93,5	2. 12.	95,1
22.4.	80,1	21. 5.	56,5	12. 6.	59,6	17. 7.	64,9	15. 9.	81,2	3. 12.	95,2
23.4.	66,6	22. 5.	53,3	13. 6.	57,3	18. 7.	54,2	16. 9.	76,4	4. 12.	80,6

24.4.	66,1	23. 5.	73,6	14. 6.	60,1	19. 7.	48,4	17. 9.	68,5	5. 12.	88,0
25.4.	76,0	24. 5.	84,5	15. 6.	59,1	20. 7.	46,4	18. 9.	69,8	6. 12.	93,7
26.4.	74,3	25. 5.	62,4	16. 6.	49,5	21. 7.	71,1	19. 9.	73,4	7. 12.	85,4
27.4.	74,1	26. 5.	65,4	17. 6.	62,6	22. 7.	57,5	20. 9.	90,6	8. 12.	77,3
28.4.	78,3	27. 5.	93,3	18. 6.	47,6	23. 7.	49,6	21. 9.	83,4	9. 12.	95,9
29.4.	79,6	28. 5.	93	19. 6.	58	24. 7.	70,5	22. 9.	95,8	10. 12.	83,3
30.4.	57,6	29. 5.	89,7	20. 6.	69,6	25. 7.	56,1	23. 9.	72,3	11. 12.	80,2
1.5.	71,1			21. 6.	61,2	26. 7.	56,8	24. 9.	77,5	12. 12.	66,8
2.5.	81,9			22. 6.	60,4	27. 7.	62,6	25. 9.	74,7	13. 12.	58,0
3.5.	80,3			23. 6.	53,8	28. 7.	76,5	26. 9.	82,1	14. 12.	82,3
4.5.	63,3			24. 6.	55,4	29. 7.	82	27. 9.	73,5	15. 12.	75,5
5.5.	61,4			25. 6.	90,2	30. 7.	80,5	28. 9.	79,7	16. 12.	84,8
6.5.	52,9			26. 6.	64,3	31. 7.	66,3	29. 9.	80,6	17. 12.	77,8
				27. 6.	56,6	1. 8.	66,4	30. 9.	87,2	18. 12.	82,0
				28. 6.	61,7	2. 8.	59,8	1. 10.	85,3	19. 12.	76,9
				29. 6.	84,9	3. 8.	65,8	2. 10.	77,5	20. 12.	75,7
				30. 6.	77,5	4. 8.	84,4	3. 10.	83,4	21. 12.	67,2
				1. 7.	65	5. 8.	79,2	4. 10.	82,5	22. 12.	73,9
				2. 7.	57,6	6. 8.	69,7	5. 10.	83,6	23. 12.	68,8
				3. 7.	46,8	7. 8.	64,5	6. 10.	76,2	24. 12.	70,0
						8. 8.	58,5	7. 10.	80,3	25. 12.	73,7
						9. 8.	58,7	8. 10.	81,7	26. 12.	72,9
						10. 8.	55,8	9. 10.	79,5	27. 12.	74,2
						11. 8.	84,7	10.10.	88,9	28. 12.	73,9
						12. 8.	64,9	11. 10.	86,6	29. 12.	84,5
						13. 8.	76,3	12. 10.	85,1	30. 12.	83,4
						14. 8.	68,5	13. 10.	86,6	31. 12.	93,5
						15. 8.	69,6	14. 10.	86,2	1. 1.	91,1

						16. 8.	75,3	15. 10.	90,2	2. 1.	80,6
						17. 8.	66,8	16. 10.	83,3	3. 1.	80,6
						18. 8.	56,8	17. 10.	86,5	4. 1.	77,8
						19. 8.	57,1	18. 10.	84,8	5. 1.	76,8
						20. 8.	49,8	19. 10.	80,7	6. 1.	87,3
						21. 8.	44,5	20. 10.	77,1	7. 1.	91,3
						22. 8.	57,8	21. 10.	71,9	8. 1.	82,4
						23. 8.	57,7	22. 10.	84,3	9. 1.	68,0
						24. 8.	59,5	23. 10.	86,1	10. 1.	74,2
						25. 8.	51,7	24. 10.	86,4	11. 1.	60,4
						26. 8.	91,9	25. 10.	85,2	12. 1.	70,5
						27. 8.	69,5	26. 10.	78,2	13. 1.	48,6
						28. 8.	63,1	27. 10.	79,4	14. 1.	66,5
						29. 8.	73,4	28. 10.	80,3	15. 1.	71,8
						30. 8.	81,3	29. 10.	85,1	16. 1.	81,6
						31. 8.	86,9	30. 10.	79,6	17. 1.	91,0
						1. 9.	85,3	31. 10.	83,5	18. 1.	86,2
								1. 11.	85,7	19. 1.	83,7
								2. 11.	95,6	20. 1.	83,0
								3. 11.	84,6	21. 1.	86,0
								4. 11.	79,8	22. 1.	93,8
								5. 11.	84,7	23. 1.	94,5
								6. 11.	92,4	24. 1.	85,9
								7. 11.	89,7	25. 1.	80,7
								8. 11.	77,6	26. 1.	82,7
								9. 11.	96,1	27. 1.	85,9
								10.11.	87,1	28. 1.	72,9
								11. 11.	87,2	29. 1.	65,0

								12. 11.	85,5		
								13. 11.	83,1		
								14. 11.	84,6		
								15. 11.	75,1		
								16. 11.	75,4		
								17. 11.	92,0		
								18. 11.	91,5		
								19. 11.	93,3		

Appendix 4: Table of air temperature from 8. 4. 2014 to 29. 1. 2015

Air temperature (°C)											
I.		II.		III.		IV.		V.		VI.	
Date	Value	Date	Value	Date	Value	Date	Value	Date	Value	Date	Value
8.4.	12,1	7. 5.	15,1	29. 5.	8,2	3. 7.	19,6	1. 9.	13,6	19. 11.	4,7
9.4.	8,4	8. 5.	12,4	30. 5.	11,1	4. 7.	23,6	2. 9.	13,4	20. 11.	4,8
10.4.	7,1	9. 5.	13,6	31. 5.	14,8	5. 7.	22,3	3. 9.	15,0	21. 11.	4,6
11.4.	8,2	10. 5.	15,2	1. 6.	14,2	6. 7.	24,4	4. 9.	18,8	22. 11.	2,9
12.4.	9,1	11. 5.	13,5	2. 6.	14,1	7. 7.	23,2	5. 9.	19,1	23. 11.	4,2
13.4.	11,2	12. 5.	11,7	3. 6.	14,8	8. 7.	20,7	6. 9.	20,1	24. 11.	4,9
14.4.	7,2	13. 5.	10,5	4. 6.	16,1	9. 7.	15,0	7. 9.	18,7	25. 11.	3,1
15.4.	5,3	14. 5.	9,5	5. 6.	15,9	10. 7.	13,6	8. 9.	18,3	26. 11.	1,1
16.4.	6,0	15. 5.	8,0	6. 6.	18,6	11. 7.	17,9	9. 9.	15,9	27. 11.	2,4
17.4.	6,6	16. 5.	10,6	7. 6.	22,5	12. 7.	17,6	10. 9.	14,3	28. 11.	1,8
18.4.	5,0	17. 5.	10,1	8. 6.	25,4	13. 7.	16,8	11. 9.	13,8	29. 11.	1,7
19.4.	13,6	18. 5.	10,0	9. 6.	25,0	14. 7.	20,0	12. 9.	14,9	30. 11.	1,7

20.4.	13,4	19. 5.	10,3	10. 6.	26,1	15. 7.	21,3	13. 9.	16,6	1. 12.	-0,8
21.4.	13,2	20. 5.	15,6	11. 6.	23,9	16. 7.	21,6	14. 9.	16,0	2. 12.	-1,0
22.4.	12,8	21. 5.	17,1	12. 6.	19,3	17. 7.	22,1	15. 9.	18,1	3. 12.	1,6
23.4.	15,2	22. 5.	19,9	13. 6.	16,3	18. 7.	23,7	16. 9.	17,5	4. 12.	5,8
24.4.	15,4	23. 5.	23,2	14. 6.	14,8	19. 7.	25,5	17. 9.	17,3	5. 12.	4,6
25.4.	14,0	24. 5.	19,3	15. 6.	14,4	20. 7.	27,0	18. 9.	16,7	6. 12.	3,9
26.4.	14,9	25. 5.	15,2	16. 6.	16,9	21. 7.	22,3	19. 9.	17,9	7. 12.	3,7
27.4.	15,0	26. 5.	17,7	17. 6.	16,0	22. 7.	23,2	20. 9.	16,4	8. 12.	1,4
28.4.	14,3	27. 5.	19,0	18. 6.	19,0	23. 7.	21,2	21. 9.	15,8	9. 12.	-2,8
29.4.	13,6	28. 5.	15,3	19. 6.	17,1	24. 7.	17,9	22. 9.	23,8	10. 12.	0,1
30.4.	15,3	29. 5.	13,5	20. 6.	12,9	25. 7.	21,6	23. 9.	9,1	11. 12.	4,3
1.5.	12,7		8,2	21. 6.	13,5	26. 7.	22,9	24. 9.	9,8	12. 12.	7,0
2.5.	8,7			22. 6.	14,9	27. 7.	22,3	25. 9.	11,9	13. 12.	9,4
3.5.	6,0			23. 6.	16,0	28. 7.	20,4	26. 9.	13,4	14. 12.	7,8
4.5.	6,7			24. 6.	16,4	29. 7.	20,0	27. 9.	13,1	15. 12.	7,9
5.5.	8,4			25. 6.	11,9	30. 7.	21,0	28. 9.	12,3	16. 12.	4,9
6.5.	15,1			26. 6.	14,4	31. 7.	19,2	29. 9.	14,3	17. 12.	3,6
				27. 6.	18,0	1. 8.	21,1	30. 9.	14,9	18. 12.	9,0
				28. 6.	19,1	2. 8.	24,6	1. 10.	15,0	19. 12.	8,8
				29. 6.	16,2	3. 8.	22,1	2. 10.	14,6	20. 12.	3,5
				30. 6.	14,2	4. 8.	17,8	3. 10.	12,5	21. 12.	4,8
				1. 7.	15,5	5. 8.	17,9	4. 10.	10,8	22. 12.	7,1
				2. 7.	17,1	6. 8.	19,2	5. 10.	12,2	23. 12.	8,9
				3. 7.	19,6	7. 8.	20,2	6. 10.	11,8	24. 12.	6,5
						8. 8.	20,9	7. 10.	11,8	25. 12.	3,2
						9. 8.	22,4	8. 10.	13,7	26. 12.	-0,8
						10. 8.	24,4	9. 10.	15,2	27. 12.	-4,2

						11. 8.	17,5	10.10.	13,9	28. 12.	-5,7
						12. 8.	17,4	11. 10.	15,2	29. 12.	-5,6
						13. 8.	17,5	12. 10.	13,5	30. 12.	-4,9
						14. 8.	16,2	13. 10.	14,6	31. 12.	-1,3
						15. 8.	15,1	14. 10.	13,4	1. 1.	2,1
						16. 8.	14,0	15. 10.	11,3	2. 1.	2,1
						17. 8.	16,5	16. 10.	14,1	3. 1.	1,5
						18. 8.	16,9	17. 10.	13,4	4. 1.	1,6
						19. 8.	17,4	18. 10.	11,8	5. 1.	1,7
						20. 8.	15,9	19. 10.	14,1	6. 1.	-0,2
						21. 8.	9,9	20. 10.	14,6	7. 1.	-1,3
						22. 8.	16,1	21. 10.	12,3	8. 1.	4,4
						23. 8.	15,7	22. 10.	6,6	9. 1.	7,3
						24. 8.	12,8	23. 10.	9,2	10. 1.	10,7
						25. 8.	15,1	24. 10.	7,1	11. 1.	3,2
						26. 8.	12,9	25. 10.	6,3	12. 1.	4,8
						27. 8.	13,5	26. 10.	9,1	13. 1.	7,6
						28. 8.	14,7	27. 10.	6,0	14. 1.	6,0
						29. 8.	16,9	28. 10.	3,5	15. 1.	3,6
						30. 8.	16,2	29. 10.	4,1	16. 1.	3,3
						31. 8.	14,2	30. 10.	6,9	17. 1.	2,8
						1. 9.	13,6	31. 10.	8,9	18. 1.	2,9
								1. 11.	9,4	19. 1.	1,5
								2. 11.	6,7	20. 1.	0,3
								3. 11.	7,5	21. 1.	0,5
								4. 11.	8,6	22. 1.	3,0
								5. 11.	10,0	23. 1.	-0,3

								6. 11.	8,4	24. 1.	-0,7
								7. 11.	8,5	25. 1.	1,0
								8. 11.	7,7	26. 1.	1,0
								9. 11.	6,4	27. 1.	1,3
								10.11.	9,0	28. 1.	1,9
								11. 11.	10,9	29. 1.	1,9
								12. 11.	10,6		
								13. 11.	10,9		
								14. 11.	10,0		
								15. 11.	11,4		
								16. 11.	8,2		
								17. 11.	7,4		
								18. 11.	7,6		
								19. 11.	4,7		

Appendix 5: Table of mechanical durability of briquettes in %

Durability of briquettes (%)														
Indoor samples								Outdoor samples						
Group	Initial	I.	II.	III.	IV.	V.	VI.	Group	Start	I.	II.	III.	IV.	V.	VI.
1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1	72,00	99,10	99,27	99,57	99,69	99,84	99,80
2	92,62	99,20	99,16	97,74	99,04	99,33	99,50		73,86	99,19	99,99	99,75	99,66	99,73	99,81
	94,47	99,15	99,60	99,62	99,45	99,67	99,48		79,77	98,52	98,32	99,38	99,02	99,51	99,76
	97,46	98,44	99,51	99,54	99,40	99,54	99,20	2	96,86	99,11	99,98	99,54	99,32	99,59	99,66
	100,42	98,66	99,42	99,49	99,50	99,71	98,97		100,64	98,84	99,39	99,76	99,81	99,79	99,88

	101,07	98,62	99,61	99,59	99,51	99,72	99,49
	102,70	99,13	99,70	99,75	99,44	99,77	99,85
	104,02	98,97	99,67	99,69	99,81	99,83	99,49
	104,52	98,92	99,61	99,72	99,62	99,70	99,46
	105,78	98,83	99,49	99,55	99,13	99,68	99,13
	106,24	98,87	99,47	99,66	99,66	99,59	99,05
	106,42	98,57	99,67	99,70	98,77	99,78	99,57
	106,63	98,87	99,53	99,62	99,65	99,64	99,24
	106,87	99,19	99,69	99,40	99,74	99,74	99,33
	108,09	99,21	99,66	99,39	99,53	99,74	99,70
	108,47	98,60	99,42	99,50	99,58	99,66	99,46
	108,49	99,29	99,39	99,71	99,77	99,85	99,77
	108,63	98,54	99,72	99,54	99,41	99,72	99,30
	108,89	99,26	99,78	99,66	99,80	99,83	99,52
	109,33	99,13	99,62	99,48	99,66	99,73	99,76
	109,85	98,77	99,38	99,51	99,52	99,59	99,60
3	110,25	98,92	99,73	99,74	99,63	99,83	99,67
	111,45	99,32	99,68	99,78	99,75	99,78	99,77
	111,96	99,23	99,75	99,65	99,67	99,68	99,47
	112,48	99,23	99,72	99,77	99,65	99,69	99,49
	112,81	98,66	99,49	98,18	99,50	99,40	99,18
	112,93	98,97	99,33	99,64	99,76	99,71	99,61
	113,30	98,53	99,59	99,65	99,57	99,65	99,59
	113,35	98,33	99,14	99,50	99,54	99,66	99,88
	114,07	99,22	99,65	99,75	99,73	99,67	99,48
	115,21	98,78	99,49	99,19	99,77	99,78	99,50

	107,46	99,15	99,46	99,57	99,51	98,32	99,72
	107,79	98,73	99,92	99,58	99,40	98,90	99,64
	108,68	99,30	99,98	99,70	99,66	99,72	99,75
	108,69	99,00	99,72	99,68	99,72	99,73	99,74
	109,18	99,26	99,52	99,67	99,66	99,63	99,57
	109,26	99,28	99,67	99,64	99,64	99,56	99,72
	109,50	98,89	99,35	99,40	99,69	99,70	99,74
	109,60	99,11	99,98	99,66	99,75	99,74	99,69
	109,61	98,93	99,35	99,68	99,69	99,73	99,81
	109,84	99,16	98,78	99,60	99,66	99,78	99,77
3	110,30	98,94	99,96	99,60	99,52	99,59	99,70
	110,47	99,04	99,52	99,72	99,71	99,83	99,83
	110,56	99,10	99,29	99,65	99,69	99,80	99,82
	110,82	99,13	99,67	99,66	99,69	99,71	99,76
	111,07	99,37	99,44	99,83	99,73	99,67	99,82
	111,37	98,97	99,66	99,74	99,77	99,80	99,82
	111,49	98,85	99,33	99,78	99,15	99,75	99,82
	111,61	99,35	99,98	99,54	99,58	99,60	99,84
	112,15	99,25	99,98	99,67	99,62	99,77	99,76
	112,35	99,34	99,99	99,50	99,58	99,31	99,66
	112,77	99,11	99,97	99,44	99,68	99,69	99,71
	112,86	98,84	99,64	99,64	99,56	99,68	99,74
	112,95	99,25	99,97	99,61	99,33	99,67	99,48
	113,08	99,06	99,73	99,70	99,37	99,71	99,87
	113,79	98,78	99,67	99,67	99,56	99,67	99,76
	114,12	99,19	99,95	99,68	99,62	99,72	99,80

	115,25	99,11	99,69	99,74	99,74	99,85	99,56
	115,35	98,79	98,69	99,59	99,68	99,77	99,44
	115,58	98,99	99,43	99,59	99,51	99,48	99,51
	115,80	98,60	99,67	99,60	99,65	98,90	99,45
	115,88	99,21	99,66	99,70	99,76	98,98	99,17
	115,95	99,03	99,68	99,66	99,58	99,82	99,73
	116,60	98,93	99,68	99,80	99,74	99,81	99,45
	117,03	98,56	99,50	98,63	99,38	99,39	99,40
	117,17	99,14	99,59	99,73	99,74	99,75	99,38
	117,19	99,31	99,55	99,73	99,76	99,87	99,31
	117,45	98,72	99,71	99,66	99,75	99,77	99,19
	118,04	99,06	99,66	99,57	99,76	99,82	99,53
	118,92	98,88	99,51	99,72	99,65	99,24	99,22
	118,95	99,03	99,54	99,04	99,58	99,71	99,68
	119,38	99,36	99,59	99,67	99,74	99,84	99,48
	119,95	98,35	99,51	99,13	99,59	99,53	99,54
	120,73	99,23	99,57	99,69	99,68	99,15	99,70
	120,77	98,87	99,56	99,62	99,75	99,73	99,63
	121,22	98,98	99,51	99,65	99,75	99,79	99,76
	122,65	99,24	99,64	99,69	99,76	99,80	99,77
	123,57	98,93	99,57	99,63	99,54	98,97	99,75
	124,10	98,65	99,63	99,76	99,79	99,78	99,57
	126,05	97,43	99,57	99,72	99,75	99,73	99,48
	126,23	99,01	99,35	99,67	99,48	99,81	99,86
	129,05	98,75	99,59	99,69	99,73	99,82	99,79

	114,18	98,84	99,18	99,68	99,62	99,66	99,66
	114,41	99,34	99,98	99,56	99,56	99,74	99,81
	114,54	98,30	99,28	99,70	99,58	99,70	99,82
	115,28	98,16	99,14	99,33	99,59	99,66	99,49
	116,08	98,83	98,30	99,40	99,51	99,73	99,77
	116,17	98,90	99,36	99,59	99,74	99,76	99,86
	116,17	99,17	99,28	99,67	99,77	99,56	99,81
	116,49	99,18	99,99	99,70	99,69	99,70	99,83
	116,97	98,82	99,43	99,53	99,51	99,57	99,66
	117,06	99,12	99,96	99,48	99,58	99,58	99,54
	117,56	99,32	99,37	99,53	99,71	99,72	99,78
	119,05	98,92	99,58	99,49	99,59	99,78	99,80
	119,59	98,42	99,61	99,01	96,25	98,65	99,50
	120,49	98,99	99,94	99,61	99,55	99,65	99,71
	120,96	99,10	99,44	99,67	99,54	99,67	99,76
	121,79	98,83	99,55	99,61	99,39	99,58	99,64
	122,82	99,18	99,30	99,78	99,60	99,68	99,79
	123,03	98,70	98,93	99,77	99,74	99,71	101,50
	124,70	99,02	98,96	99,22	99,71	99,79	99,67
	127,40	98,89	99,98	99,73	99,74	99,68	99,77
	129,96	99,28	99,21	99,56	99,81	99,81	99,84
4	132,77	97,67	99,51	99,58	99,70	99,80	99,74
	135,66	98,64	99,99	99,40	99,58	99,52	98,16
	142,45	97,66	99,40	99,60	99,33	99,57	98,65

	130,48	99,03	99,60	99,72	99,65	99,76	99,47
4	139,52	98,98	99,68	99,19	99,55	99,81	99,86
	140,27	98,27	99,03	99,39	99,43	99,52	99,51

Appendix 6: Table of the weight values of the briquettes in g

Weights of briquettes (g)															
Indoor samples								Outdoor samples							
Group	Initial	I.	II.	III.	IV.	V.	VI.	Group	Start	I.	II.	III.	IV.	V.	VI.
1	0	0,00	0,00	0,00	0,00	0,00	0,00		72,00	71,35	70,43	70,03	69,76	69,77	69,80
	92,62	91,71	88,84	86,92	85,75	84,78	83,53	1	73,86	73,26	73,04	72,76	72,51	72,68	72,73
	94,47	93,67	93,22	92,39	91,83	90,87	88,83		79,77	78,59	77,34	76,85	76,06	75,85	75,77
	97,46	95,94	95,50	94,58	93,91	92,90	90,54		96,86	96,00	96,08	95,7	95,09	95,24	95,18
	100,42	99,07	98,48	97,51	97,10	96,07	94,08		100,64	99,47	98,46	98,07	97,70	97,76	97,85
	101,07	99,68	99,20	98,86	98,03	97,39	96,02		107,46	106,55	105,87	105,32	104,68	103,13	102,98
	102,70	101,81	101,40	100,58	100,00	99,03	97,86		107,79	106,42	105,87	105,47	104,87	104,28	104,17
2	104,02	102,95	102,46	101,95	101,50	100,96	99,79		108,68	107,92	107,32	107,03	106,74	107,08	107,13
	104,52	103,39	103,19	102,79	102,30	101,68	100,54	2	108,69	107,60	106,63	106,04	104,97	104,91	104,72
	105,78	104,54	103,91	102,93	101,98	100,92	98,96		109,18	108,37	107,68	107,27	106,67	106,54	106,15
	106,24	105,04	104,35	103,45	102,87	101,66	99,13		109,26	108,47	107,98	107,42	106,93	106,57	106,37
	106,42	104,90	104,31	103,73	102,06	101,55	100,36		109,50	108,29	107,18	106,40	105,99	105,76	105,62
	106,63	105,42	105,07	104,55	104,05	103,40	101,95		109,60	108,62	108,46	107,99	107,84	108,16	108,15
	106,87	106,00	105,52	104,35	103,81	102,77	100,55		109,61	108,44	107,94	107,62	107,22	107,16	107,17

	108,09	107,24	107,02	106,31	105,40	104,72	103,27
	108,47	106,95	106,27	105,63	105,01	104,30	103,15
	108,49	107,72	107,01	106,04	105,51	104,44	102,78
	108,63	107,04	106,43	105,62	104,51	103,74	101,80
	108,89	108,08	107,56	106,66	106,26	105,03	103,46
	109,33	108,38	107,57	106,74	106,21	105,08	103,56
	109,85	108,50	107,38	106,83	106,08	105,15	103,89
	110,25	109,06	108,32	107,59	106,57	105,89	104,46
	111,45	110,69	109,97	108,91	108,34	107,46	105,87
	111,96	111,10	110,61	110,01	109,36	108,66	107,27
	112,48	111,61	111,32	110,75	110,21	109,46	108,21
	112,81	111,30	110,12	107,21	106,33	104,79	102,02
	112,93	111,77	111,01	110,11	109,72	108,63	106,89
	113,30	111,64	111,21	110,76	110,19	109,44	108,36
	113,35	111,46	110,07	109,28	108,38	107,46	106,52
	114,07	113,18	112,30	111,69	111,03	110,01	108,51
3	115,21	113,81	112,92	111,72	111,07	110,37	108,99
	115,25	114,22	113,76	113,25	112,64	111,98	110,21
	115,35	113,95	111,88	111,15	110,44	109,73	108,29
	115,58	114,41	113,94	113,41	112,72	111,74	110,61
	115,80	114,18	113,60	112,91	112,29	110,76	109,33
	115,88	114,96	114,08	113,55	112,64	111,01	108,91
	115,95	114,82	114,29	113,47	112,72	111,96	110,34
	116,60	115,35	114,43	113,94	113,34	112,61	111,16
	117,03	115,35	114,69	112,85	113,07	111,82	109,95

	109,84	108,92	107,26	106,71	106,30	106,31	106,20
	110,30	109,13	108,87	108,25	107,67	108,12	107,93
	110,47	109,41	108,27	107,74	107,22	107,27	107,34
	110,56	109,56	108,72	108,29	108,01	108,01	108,01
	110,82	109,86	109,60	109,22	108,82	108,66	108,53
	111,07	110,37	109,74	109,49	109,07	109,01	109,00
	111,37	110,22	109,70	109,22	108,81	108,70	108,63
	111,49	110,21	109,15	108,86	107,93	107,95	107,91
	111,61	110,88	110,08	109,24	108,69	108,83	109,05
	112,15	111,31	110,88	110,22	109,78	110,36	110,19
	112,35	111,61	111,24	110,53	110,15	110,06	109,85
	112,77	111,77	111,71	110,96	110,71	111,21	111,04
	112,86	111,55	110,81	110,42	109,81	109,54	109,35
3	112,95	112,1	111,73	111,22	110,39	110,81	110,51
	113,08	112,02	111,74	111,24	110,38	110,22	110,19
	113,79	112,40	111,90	111,40	110,95	110,77	110,60
	114,12	113,19	113,19	112,86	112,45	113,13	112,98
	114,18	112,86	111,13	110,41	109,43	109,37	109,04
	114,41	113,66	113,24	112,74	112,28	112,72	112,79
	114,54	112,59	111,49	111,08	110,57	110,65	110,63
	115,28	113,16	111,90	111,26	110,54	110,40	109,97
	116,08	114,72	112,66	111,94	111,39	111,38	111,31
	116,17	114,89	114,23	113,80	113,37	113,42	113,28
	116,17	115,20	114,43	113,98	113,60	113,43	113,42
	116,49	115,53	115,03	114,68	114,32	114,59	114,77

	117,17	116,16	115,37	114,88	114,21	113,55	112,24
	117,19	116,38	115,68	115,24	114,60	113,94	112,09
	117,45	115,95	115,10	113,85	113,52	112,53	109,87
	118,04	116,93	116,12	115,08	114,51	113,72	111,72
	118,92	117,59	116,70	115,48	114,86	112,91	110,20
	118,95	117,80	117,31	116,03	115,33	114,43	112,93
	119,38	118,61	117,92	116,82	116,26	115,18	113,35
	119,95	117,97	117,51	116,33	115,66	114,80	113,58
	120,73	119,80	118,69	117,55	116,99	114,98	112,98
	120,77	119,40	118,55	117,92	117,36	116,50	115,28
	121,22	119,98	118,80	117,96	117,07	116,28	114,84
	122,65	121,72	121,30	120,50	119,96	119,00	117,32
	123,57	122,25	121,73	121,07	120,21	118,46	117,93
	124,10	122,43	121,94	121,30	120,83	120,23	118,99
	126,05	122,81	122,05	121,51	121,03	120,25	118,96
	126,23	124,98	123,94	122,61	121,79	120,42	118,21
	129,05	127,44	126,68	125,41	124,79	123,65	121,64
	130,48	129,22	128,33	127,77	126,97	126,34	124,77
4	139,52	138,09	137,55	136,24	135,41	134,58	132,96
	140,27	137,84	136,28	135,29	134,33	133,10	131,03

	116,97	115,59	115,06	114,42	113,90	113,10	112,78
	117,06	116,03	115,72	115,06	114,61	115,10	114,68
	117,56	116,76	116,02	115,41	115,05	115,03	114,95
	119,05	117,77	116,69	115,78	115,08	114,95	114,88
	119,59	117,70	116,87	115,72	111,29	109,98	109,47
	120,49	119,27	119,26	118,67	118,22	118,49	118,5
	120,96	119,87	119,19	118,66	117,98	117,90	117,84
	121,79	120,36	119,64	119,12	118,38	117,98	117,65
	122,82	121,81	120,71	120,11	119,38	119,32	119,25
	123,03	121,43	119,82	119,21	118,83	118,77	118,78
	124,70	123,48	121,53	120,25	119,60	119,72	119,46
	127,40	125,99	125,28	124,80	124,44	124,63	124,74
	129,96	129,03	127,54	126,79	126,38	126,47	126,48
	132,77	129,67	128,76	127,97	127,29	127,37	127,18
4	135,66	133,82	133,80	132,87	132,36	132,80	130,41
	142,45	139,12	138,57	137,85	137,00	136,57	134,87

Appendix 7: Nutrient content of digestate in % (Source: doc. Ing. Josef Pecen, CSc.)

	Dry matter	Ash	N x 6,25	Fat	Fibre	Organic matter	Nitrogen-free extract
Raw material	5,966500	1,021290	0,780550	0,023098	1,860630	4,945190	2,280910
Processed material	91,791980	15,712170	12,008430	0,355349	28,625050	76,079810	35,090980

Appendix 8: Properties of material used for briquette production in % (Source: doc. Ing. Josef Pecen, CSc.)

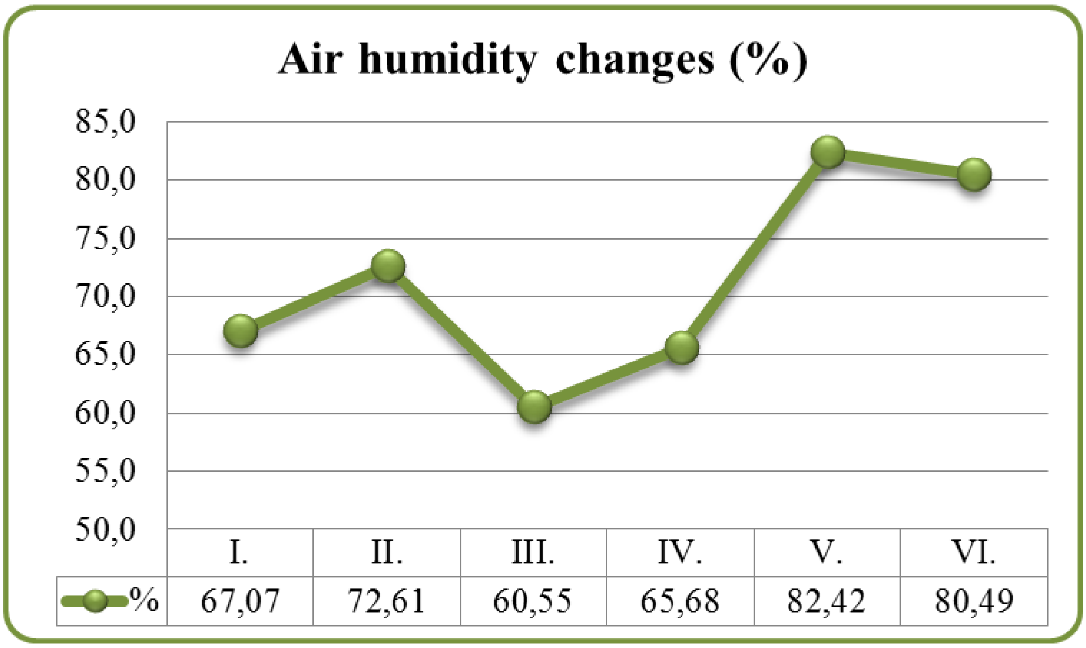
	Gross calorific value [MJ/kg]	Calorific value [MJ/kg]
Digestate material	18,55	17,02

Appendix 9: Properties of the weighing-machine KERN EMB 600-2

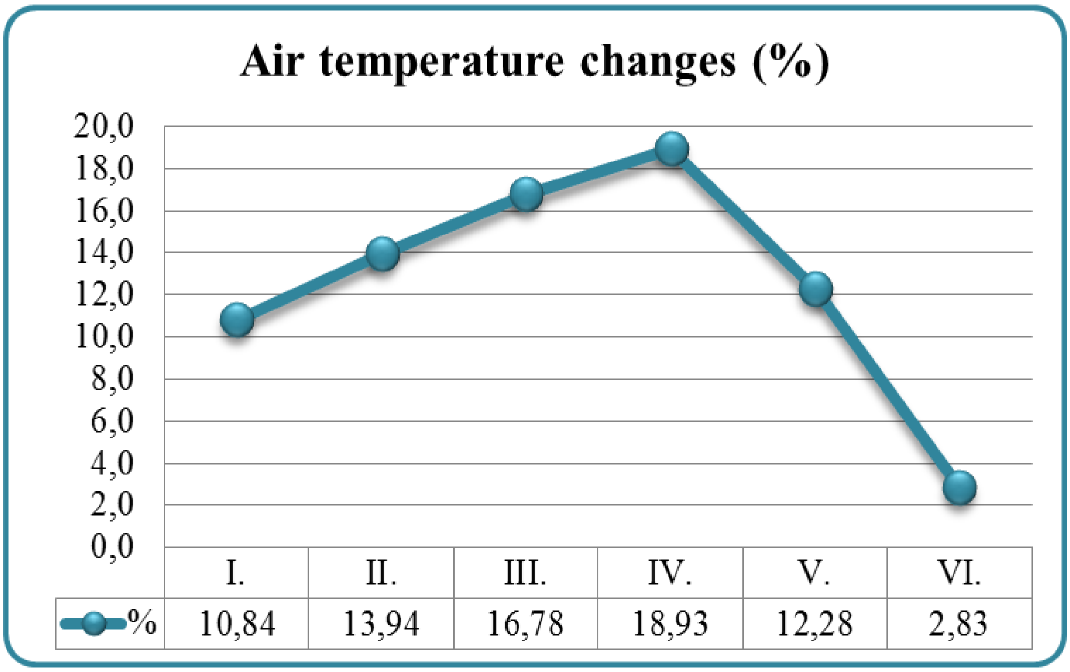
Model KERN	Weighing range (g)	Readout (g)	Linearity (g)	Dimensions housing WxDxH (mm)	Weighing plate material	DAkkS Calibr. Certificate
600-2	600	0,01	± 0,03	170 x 240 x 39	plastic	963-127

Source: http://www.kern-sohn.com/en/EMB

Appendix 10: Progression of air humidity changes during the DU tests



Appendix 11: Progression of air temperature changes during the DU tests



Appendix 12: BoxPlot of mass briquettes from different storage conditions before abrasion