WATER SORPTION BY BRIQUETTES FROM BIOMASS

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Abstract. The work deals with the effects of water sorption by plant biomass briquettes. The influence of water sorption was studied especially in relation to the briquette material and their volume and shape changes. It was found that the weight of water absorbed by a briquette can be up to more triple then the initial weight of the dry briquette. Changes in the density and shape of briquettes were observed, depending on the amount of water catch by briquette. The water sorption by briquette is an irreversible process. The biggest changes of briquette, caused by sorption water, are the volume and shape changes. The volume change is always positive. Laboratory and field experiments proved that the decreasing initial density of briquettes increases its water sorption capacity as well. Individual particles of compacted materials create connections among them in the shape of the network. It causes greater mechanical firmness of briquette and its handling causes minimal damage.

Keywords: briquettes from biomas, water sorption,digestate, changes of volume, miscanthus.

Introduction

Digestate is another product from the fermentation process in BGSs (Agricultural Biogas Stations). Digestate is originally liquid, very thin almost porridge-like substance with 6-8 % of dry solids. By mechanical separation, the liquid part with 5-6 % of dry solids and partially dehydrated (dried) digestate usually with 75-85 % moisture (for economic reasons, mechanical dehydration can be conducted up to approx. 70 % moisture) is produced. The further treated separated part of the digestate can be used for various purposes, such as combustion, fertilization, production of stock bedding [1]. Part of the liquid component is returned to the BGSs to the fermentation process of newly inserted material [1; 2] and the remains are often used as fertilizer [3; 4]. Agricultural BGSs usually process various vegetable material, cattle slurry, pig slurry, or remains of animal origin.

The main objective of the paper was to acquire selected findings concerning the qualities and behaviour of compressed digestate in the form of briquettes for their non-energetic use in agriculture, in particular for targeted treatment of soil mechanical properties and the water regime in soil. For better comparison of non-energetic properties of the briquettes from digestate, briquettes from other vegetable materials, *Miscanthus × giganteus* and *Cannabis sativa* L. were tested at the same time. All briquettes were produced in an identical way and had the same shape. By comparing the tested materials, the differing quantities of briquettes from different materials stood up distinctively. Partially dehydrated digestate, such as *Miscanthus × giganteus* or *Cannabis sativa* L. has great sorption qualities and could be used as a sorbent to contain liquids. After sorption, this material can be combusted or put in soil, if it does not contain absorbed hazardous substances. In soil, it decomposes quickly.

If briquettes from the mentioned three tested materials (and it will be similar for a number of other biomaterials) are exposed to water, the water is absorbed by the briquettes up to a limit. As a consequence, the briquette volume and its weight increase. From the physical point of view, these are in particular processes occurring at the border of solid matter and liquid [5]. It is therefore mechanical and physical sorption. Water first fills the bigger spaces between individual briquette particles (mechanical sorption) and penetration into of smaller cavities between particles and the particles of the briquette themselves is caused predominantly by the forces of the surface tension, i.e., physical sorption. The increase of the briquette volume in limited space (e.g., in soil) is accompanied by the occurrence of extensive and stable pressure (smaller than 1 MPa), leading to visible deformation of this space and to the occurrence of tension in this space. After placement in soil, briquettes from the tested materials with moisture up to 10 % very actively and quickly absorb water from their surroundings in soil (in the form of liquid or water vapour). According to the type of material, the briquettes in soil show stable resulting moisture that is maximum four times higher than the moisture of the surrounding soil. Therefore, briquettes become water containers and the water is released depending on the moisture of the surrounding soil, in particular when it decreases. It must be noted that the speed of water sorption by briquettes differs and depends in particular on the kind of the material and the size of its particles. Also, the degree of compression of the material in the shape of briquettes and the temperature created during compression play important roles [5]. A number of other circumstances have smaller impact on water sorption and its speed.

The objective of this paper is to draw attention to the possibility of non-energetic use of digestate from agricultural BGSs and other biomass to support the effort to return organic matter back to the soil, where it came from and which generally shows lack of it. The other two materials for comparison in testing the sorption qualities of the treated digestate were chosen with regard to the similarity of the selected qualities with the digestate and also with regard to their availability in the Czech Republic. *Miscanthus × giganteus* is grown in the CzechRepublic and used mainly for energetic purposes [6]. After *Miscanthus × giganteus* harvest (February – March), when its moisture amounts to approximately 22-35 %, minimal additional drying is needed after its compression. *Miscanthus × giganteus* is a perennial plant, which provides on one site the annual production of up to 30 t/ha of green matter for the period of approximately 15 years. The yield is stable after the third year of growing. This plant, put into soil, can provide organic matter for a longer period, and with the addition of mineral fertilizers, its fertilizing effect is almost immediate. If grown, it must be taken extensive care of for the first two years since its planting. The second tested plant, *Cannabis sativa* L., is going through a renaissance period in the Czech Republic [7; 8] and other countries. The waste after processing of the fibre – hards are easy to combust, and compressed, it shows similar sorption qualities as the compressed digestate. Briquettes from hards, for instance, with the addition of mineral substances, could become an excellent organic fertilizer with combined effects. All the above stated materials allow a decrease of the volume during compression in the ratio of approximately 1:6. The volume compression is within the limits 1:4 to 6. This is partially influenced by the used working pressure of the pressing machine.

Materials and methods

The lab experiments with the briquette water sorption were conducted for three kinds of briquettes (digestate from the agricultural BGS, *Miscanthus × gigantheus*and *Cannabis sativa* L., and for three various environments of sorption (limited, unlimited, in the soil). The briquettes were pressed from the stated materials without other additives, the moisture of the pressed materials varied between 12.2 and 14.1 %. The dry stems of *Miscanthus × giganteus* and *Cannabis sativa* L. with the initial length of up to 3 m were, prior to pressing, crushed using the hammer crusher 9FQ40C with 8 mm diameter sieve. Thus, the same size of particles was achieved prior to pressing. Partially crushed digestate needed no treatment, since the particles were sufficiently small for crushing. All briquettes were produced under the same working conditions on the BrikStar CS25 press. The initial diameter of all briquettes was 60 mm. The mechanical strength of briquettes was determined according to the CEN/TS 15210-2 standard. Briquette water sorption took place for the stated briquette materials in the following three different sets of conditions.

- "**Unlimited water sorption**". Each briquette was inserted in a metal basket (Figure 1) and dipped into a flat container with water. The water level in the container was maintained at 5 to 10 mm from the basket bottom. Water sorption was not limited by time or space. The value of sorption was determined directly from the increment of the briquette weight by weighing the briquette in the selected intervals. The changes of the briquette dimensions were taken directly by a length meter. Thus, three or four briquettes were monitored at the same time.
- "**Limited water sorption**". The briquette was placed in a tube with the inner diameter a few mm bigger than the briquette diameter (Figure 1). The briquette was inserted in the tube and this set (the briquette and the tube) was placed into a basket in a flat container with water. The water level was 5 – 10 mm from the basket bottom. The value of sorption was constant, determined by the inner diameter of the tube, so only the difference in the length of the briquette in the tube was measured depending on time.
- "**Sorption of water by briquettes in soil**". This experiment took place in two flower boxes 70 cm length with 30x30cm cross section filled with soil and horizontally placed briquettes. The arrangement of the experiment was to represent, up to a point, real conditions of water sorption in soil. A continuous row of briquettes was placed at the bottom of the flowerbox along its whole length, with the initial moisture 8.2%, and their bases were in contact (Figure 2). This row was covered in soil and tamped down to the height of 30 cm above the

flower box bottom. The surface of the soil was levelled and on top of the soil in the flower box, 4 kg of water were added to achieve the usual soil moisture. Subsequently, layers of soil were removed (always vertical levels) from the whole flower box profile including the briquettes. At the same time, the soil and briquette moisture in the removed layer was repeatedly measured as well as the dimensions of the briquettes. From the data, the volume and density of the briquettes were ascertained.

Fig. 1. **Briquette in a metal basket ready for "unlimited water sorption" (left), briquette in a tube ready for "limited water sorption" (right)**

Fig. 2. **Briquettes in a flower box ready for "sorption of water by briquettes in soil"**

Results a discussion

Three series of lab experiments were conducted. For each way of water sorption and the corresponding sorbent, at least 5 repetitions were conducted. All measured results were statistically processed and are clearly shown in the following figures and tables including additional or explanatory comments. For all experiments, the stated results are always the results of multiple repeating and thus the stated data always represent the average value of the monitored quantity with various inaccuracy. The greatest inaccuracy applies to the determination of the volume of briquettes in all cases of water sorption, since briquettes do not have a regular shape due to their internal inhomogeneous. The emphasis was focused on determining the sorption qualities of the dehydrated digestate and also of two materials with similar properties for the purpose of comparison. The executed experiments showed, apart from other things, that outer conditions have significant impact on the volume of water absorbed by the briquettes, and in particular on the speed of sorption. Each sorption is always limited in a particular way, predominantly by the limited source of water for sorption and also by other inconvenient (differing) physical conditions of the environment where the sorption takes place (great mechanical tension – pressure in the place of sorption, temperature, etc.). Therefore, various conditions of sorption were chosen for the sorption of the three stated original materials in the whole experiment.

Table 1, Figure 3 and Figure 4 show clearly the results of "unlimited water sorption", where all briquettes absorbed water from a container under identical conditions and as needed. The time progress of water sorption and the speed of sorption correspond to the expectations, with regard to the similar texture of the briquette materials. The time progress of sorption is lower only with digestate, as shown in Figure 3. This is apparently caused by finer particles creating the briquette texture and therefore smaller spaces between them. That is why physical sorption with smaller progress of sorption and smaller decrease in its speed in time (Figure 4) applies. It must also be observed that water is absorbed (in this kind of sorption) by the briquette only through its bottom, which is getting bigger with the increasing diameter of the briquette. The result of the sorption process is the increase of the briquette volume (by three or four times) corresponding to the volume of the absorbed water. Depending on the texture and the kind of their material, briquettes mechanically fall apart. Figure 3 shows that sorption is practically completed under these conditions in 20 minutes. The reason is probably bigger spaces between particles, as proven by [4]. Bigger time delay was only ascertained for the digestate. Also, it was found repeatedly that if the briquette fully absorbed with water (with three or four times bigger volume) is let to dry, its volume decreases approx. by 10% and it becomes mechanically very strong. The briquette density in this state is comparable with the density of the original material before compressing. This briquette can repeatedly absorb water and dry up in the described way while maintaining mechanical strength. Therefore, it functions as a water container. This quality applies to all tested materials regardless of the sorption conditions.

Table 1

Results of "unlimited water sorption"

Order of sampling	1	2	3	4	5	6	7	8
Sampling interval τ_{i+1}, s	0	300	300	300	300	600	1800	1800
Total sorption time, s	0	300	600	900	1200	1800	3600	5400
Briquettes from *Miscanthus × giganteus* m_0 = 166 g								
Total mass of briquette m_i, g	166	344.3	452.4	509.6	544.3	594.0	609.1	631.4
Mass of absorbed water $m_i - m_0$, g	0	178.3	286.4	343.6	378.0	428.3	443.0	465.0
Mass fraction $m_i - m_0/m_0$	0	1.074	1.725	2.069	2.280	2.580	2.669	2.803
Addition of water $m_{i+1} - m_i$, g	0	178.3	108.4	57.2	34.4	50.3	14.8	22.3
Sorption speed $m_{i+1} - m_i/\tau_{i+1}$, g·s^{-1}	0	0.590	0.361	0.175	0.114	0.083	0.008	0.012
Briquettes from *Cannabis sativa* L. m_0 =123 g								
Total mass of briquette m_i, g	123	347.8	388.4	422.9	443.3	481.5	498.6	505.8
Mass of absorbed water $m_i - m_0$, g	0	224.8	265.4	299.9	320.3	358.5	375.6	382.8
Mass fraction $m_i - m_0/m_0$	0	1.827	2.157	2.438	2.604	2.914	3.053	3.112
Addition of water $m_{i+1} - m_i$, g	0	101.8	40.6	34.5	20.4	38.2	17.4	7.20
Sorption speed $m_{i+1} - m_i/\tau_{i+1}$, g·s^{-1}	0	0.339	0.135	0.115	0.068	0.063	0.009	0.004
Digestate briquettes m_0 = 141.3 g								
Total mass of briquette m_i, g	141,3	230.9	287.1	332.8	373.1	419.6	512.2	600.0
Mass of absorbed water $m_i - m_0$, g	0	89.6	145.8	191.5	232	278.3	370.9	458.7
Mass fraction $m_i - m_0/m_0$	0	0.634	1.031	1.355	1.641	1.969	2.624	3.246
Addition of water $m_{i+1} - m_i$, g	0	89.6	56.2	45.7	40.5	46.3	92.6	87.8
Sorption speed $m_{i+1} - m_i/\tau_{i+1}$, g·s^{-1}	0	0.298	0.187	0.152	0.135	0.077	0.051	0.048

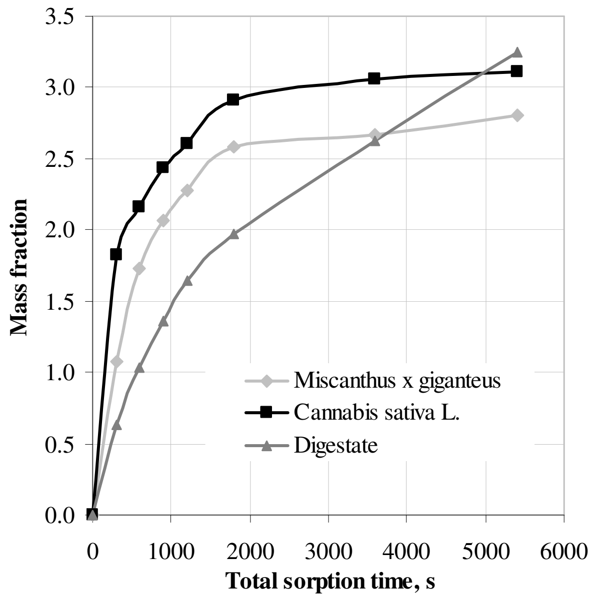

Fig. 3. **Mass fraction of "unlimited water sorption by briquettes"**

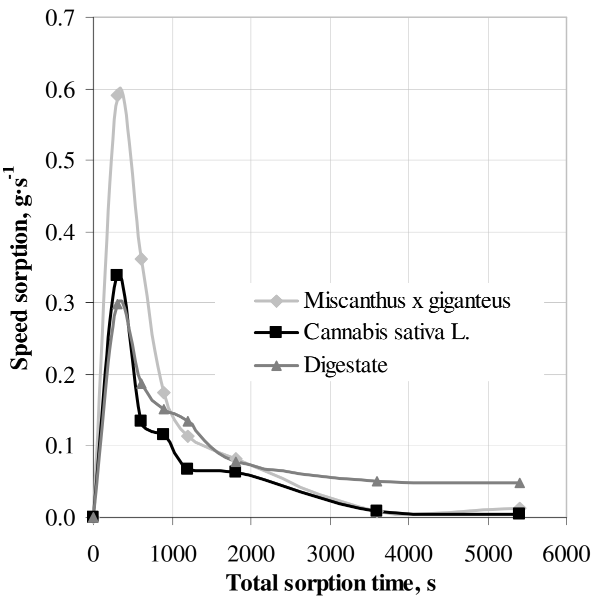

Fig. 4. **Speed sorption of "unlimited water sorption by briquettes"**

Similar progress of sorption applies to "limited water sorption" as shown in Table 2 and Figure 5 and 6. In the monitored time, the highest sorption was ascertained for *Miscanthus × giganteus* and *Cannabis sativa* L., the speed of sorption is the smallest with the digestate. The character of the progress of the monitored properties in time is basically the same, identical to "unlimited water sorption". Small differences in the development of the properties in time can be caused by the constant size of the briquette bottom through which the water is absorbed (the briquette is placed in a metal tube with internal diameter 4mm bigger than the diameter of the briquette). Another reason can be the pressure inside the briquette caused by the increase of volume during sorption. This volume increase is limited and is only possible by prolongation of the briquette in the tube. This is, with regard to the friction between the briquette surface and the internal surface of the tube, the cause of the strength causing the internal pressure in the briquette. This impacts all of the briquette particles causing decrease of the spaces between them that would be otherwise taken up by the absorbed water. This conclusion is also confirmed by Figure 5 compared to Figure 3.

Table 2

Results of "limited water sorption"

Order of sampling	1	2	3	4	5	6	7	8
Sampling interval τ_{i+1}, s	0	300	300	300	300	600	1800	1800
Total sorption time, s	0	300	600	900	1200	1800	3600	5400
Briquettes from *Miscanthus* × *giganteus* m_0 = 81.8 g								
Total mass of briquette m_i, g	81.8	173.2	196.1	211.5	217.9	223.7	228.4	229.8
Mass of absorbed water $m_i - m_0$, g	0	91.4	114.3	129.7	136.1	141.9	146.6	148.0
Mass fraction $m_i - m_0/m_0$	0	1.117	1.397	1.585	1.663	1.734	1.792	1.809
Addition of water $m_{i+1} - m_i$, g	0	91.4	22.9	15.4	6.4	5.8	4.7	1.000
Sorption speed $m_{i+1} - m_i/\tau_{i+1}$, g·s^{-1}	0	0.304	0.076	0.051	0.0213	0.009	0.002	0.000
Briquettes from *Cannabis sativa* L. m_0 =113 g								
Total mass of briquette m_i, g	113	213	229	237	242	252	272	285
Mass of absorbed water $m_i - m_0$, g	0	100	116	124	129	139	159	172
Mass fraction $m_i - m_0/m_0$	0	0.884	1.026	1.097	1.141	1.230	1.407	1.522
Addition of water $m_{i+1} - m_i$, g	0	100	16	8	5	10	20	13
Sorption speed $m_{i+1} - m_i/\tau_{i+1}$, g·s^{-1}	0	0.884	0.141	0.070	0.044	0.088	0.176	0.115
Digestate briquettes m_0 =149g								
Total mass of briquette m_i, g	149	206	228	236	238	248	264	284
Mass of absorbed water $m_i - m_0$, g	0	57	79	87	89	99	115	135
Mass fraction $m_i - m_0/m_0$	0	0.382	0.530	0.583	0.597	0.664	0.771	0.906
Addition of water $m_{i+1} - m_i$, g	0	57	22	8	2	10	16	20
Sorption speed $m_{i+1} - m_i/\tau_{i+1}$, g·s^{-1}	0	0.19	0.073	0.026	0.0066	0.016	0.008	0.011

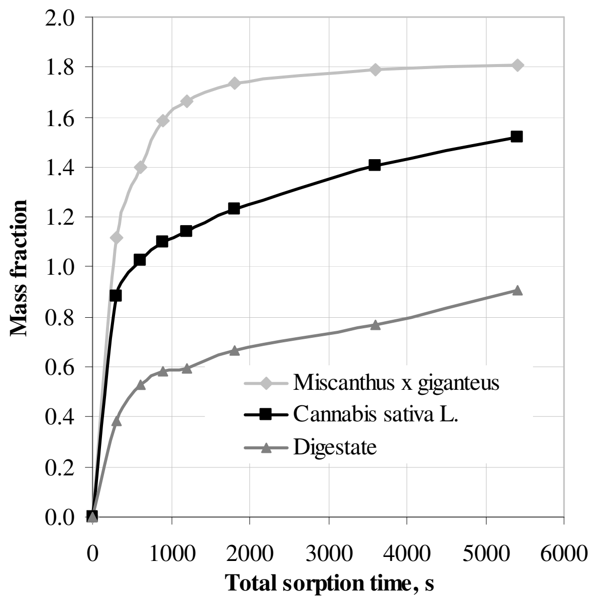

Fig. 5. **Mass fraction of "limited water sorption by briquettes"**

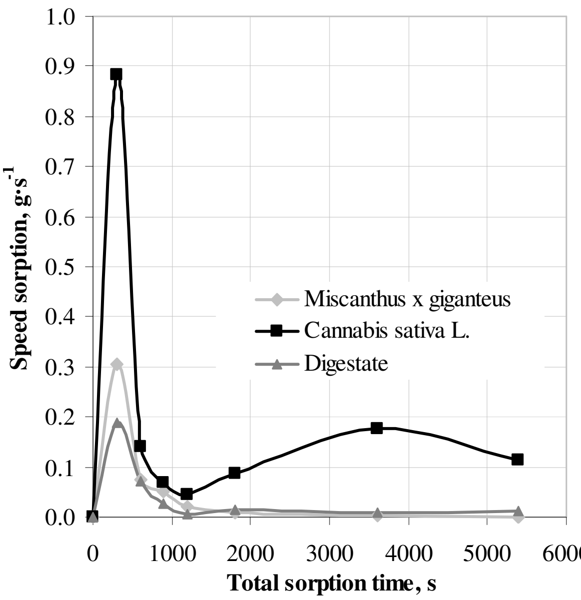

Fig. 6. **Speed sorption of "limited water sorption by briquettes"**

"Sorption of water by briquettes in soil" is, in its character, closer to the conditions of "limited water sorption", but the availability of water in the soil where the briquettes are placed is always limited. This depends on the soil moisture and volume. The water is often absorbed by the briquette through its whole surface, which has differing physical properties depending on the way of production. There is always universal, differing pressure of the soil on the briquette depending in particular on the type of soil, its compacting and moisture. Therefore, generally, water sorption by briquettes in this environment takes much longer – days – before achieving constant volume of absorbed water. That is why other criteria of evaluation of the water sorption by briquettes were chosen. The changes of soil moisture and corresponding change of the briquette moisture and diameter was monitored in time (days). Figure 7 summarizes the processed values that were measured. The initial soil moisture was adjusted by adding a calculated amount of water to the top of the soil covering the briquettes in the flower boxes. The moisture of the soil in the flower box amounted from 16.5 to 20.5 %; median value being 18.1%. Almost regardless of the soil moisture and the kind of material, the briquette moisture stabilized at 60%, i.e., the value four times higher than the soil moisture. It must be noted that this state was achieved safely in 7 days with *Miscanthus × giganteus* briquettes. With *Cannabis sativa* L. and digestate briquettes, it was achieved approx. two days later (Figure7). The increase of the diameter of the briquettes in soil (while achieving the status of constant sorption value) was from 14 to 21%. The length of the briquette increased on average by 25 % of its original value. The increase of the briquette volume in soil was from 31 to 42 % of its original value. The increase of the volume of the briquette in soil is, compared to "Unlimited water sorption", very small. With higher compacting of the soil, the increase of the briquette volume and the briquette moisture remains almost the same. Therefore, the reason of such differing moisture of soil and briquettes cannot be sufficiently explained by different porosity of materials as stated in [5]. Figure 7 also shows that with the same soil moisture, digestate and *Cannabis sativa* L. have almost identical sorption progress. Among other things, this is also caused by similar texture of the materials of both briquettes [7; 8], which is, compared to *Miscanthus × giganteus*, much finer and with smaller spaces between elements. All described kinds of water sorption cause the increase of the volume of the absorbing objects. This property has a potential for further use, as well as the fact that briquettes from the stated materials (but also from other biomass) can contain an extensive volume of water. Last, but not the least, the tested materials can be used as sorbents as mentioned in the beginning of the paper.

Table 3

Results of "sorption of water by briquettes in soil"

Briquettes from *Miscanthus × giganteus*									
Order of sampling	1	2	3	4	5	6	7	8	9
Total sorption time, days	0	2	6	8	11	12	13	15	20
Sampling interval, days	0	2	4	2	3	1	1	2	5
Diameter briquettes, cm	6.6	7.4	7.7	7.7	7.7	8.0	7.8	7.8	7.8
Moisture briquettes, %	9.2	53.4	62.6	60.4	62.6	60.3	62.0	62.7	54.9
Soil moisture in flow. box, %	16.5	17.6	20.0	18.74	21.0	20.5	20.3	19.7	18.1
Briquettes from *Cannabis sativa* L.									
Order of sampling	1	2	3	4	5	6	7	8	-
Total sorption time, days	0	2	4	9	11	14	15	16	-
Sampling interval, days	0	2	2	5	2	3	1	1	-
Diameter briquettes, cm	6.6	7.0	7.4	7.2	8.0	7.9	8.0	7.9	-
Moisture briquettes, %	8.5	16.5	40.4	61.2	61.0	64.0	58.8	59.0	-
Soil moisture in flow. box, %	17.1	17.8	17.8	17.5	17.9	17.2	19.5	19.6	-
Digestate briquettes									
Order of sampling	1	2	3	4	5	6	7	8	-
Total sorption time, days	0	2	5	6	8	10	13	15	-
Sampling interval, days	0	2	3	1	2	2	3	2	-
Diameter briquettes, cm	6.8	7.0	7.8	7.6	7.6	7.8	7.8	7.9	-
Moisture briquettes, %	10.1	20.8	52.0	55.9	54.9	58.2	59.1	59.7	-
Soil moisture in flow. box, %	17.2	18.4	17.8	16.2	15.7	16.4	17.2	17.8	-

With regard to the fact that the tested materials are also used for combustion, we state the average values of a number of properties from the overall characteristics of these materials that were ascertained in the lab. Apart from the acquired thermal energy, also ash from these materials can be used in agriculture, in particular the ash from *Miscanthus × giganteus* includes a high share of K (up to 130 mg in 1 kg of green plant). Similarly, the ash from digestate is constituted. There is lower heating value compared to *Miscanthus × giganteus* and *Cannabis sativa* L. with digestate, also the energy necessary for drying to a moisture necessary for pressing (the moisture of partially dehydrated

– mechanically separated digestate is usually around 75 %, so without further treatment, the digestate is not convenient for combustion) must be also considered.

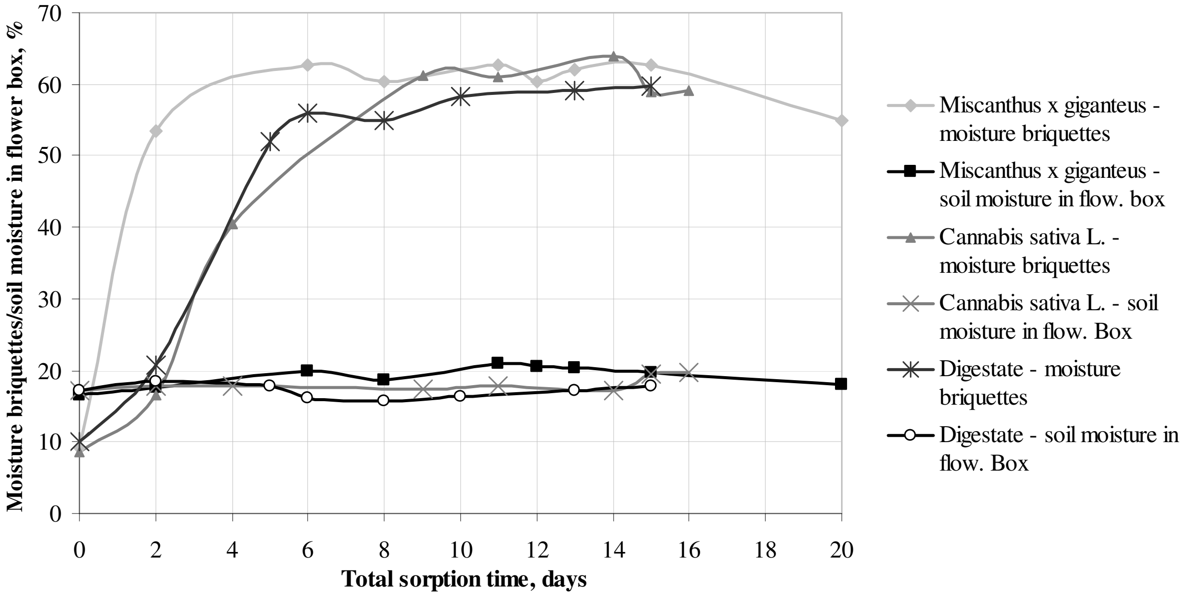

Fig. 7. “**Sorption of water by briquettes in soil”**

Conclusions

1. All tested materials of vegetable origin in the form of briquettes showed good water sorption and with moisture up to 14 %, their density was smaller than 950 kg·m^{-3} and their mechanical strength was very high (in form the briquettes).
2. Briquettes from *Cannabis sativa* L. and *Miscanthus × giganteus* are compact during all types of sorption and in particular in soil they are mechanically stable.
3. For all briquettes from the tested materials, it can be observed that the increased volume of the briquette caused by water sorption remains even after removal of the water from the briquette almost the same. A briquette dehydrated in such a way is, even with the increased volume, mechanically strong and capable of repeated sorption.
4. The speed of water sorption by briquettes in soil is approximately the same for all tested materials, and is approximately 200 times smaller compared to the speed under the “unlimited water sorption” conditions.
5. During “unlimited water sorption”, all briquette materials absorb up to four times of their original weight. During “unlimited water sorption” and “limited water sorption”, 50 % of water is absorbed by the briquette during the first 6 or 7 minutes. The smallest speed of water sorption was ascertained for the digestate briquettes, the highest for *Cannabis sativa* L. briquettes.

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