Co-pelletization of sewage sludge and agricultural wastes

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Abstract: This paper is concerned with the production and properties of fuel pellets for using in thermal processes. Especially the process of co-pelletization of sewage sludge and another biomass material such as animal and olive waste was presented.

The aim of the present study was to identify the key factors affecting on the sewage sludge and biomass pelletization processes conditions. The impact of raw material type, pellet length, moisture content and particle size on the physical properties was investigated. The technic and technological aspects of co-pelletization were discussed in detail.

The physical parameters of pellets, i.e.: drop strength, absorbability and water resistance were determined. Among others, also energy parameters: low and high heat value, content of ash and volatiles were presented.

Results showed the range of raw materials moisture, which is necessary to obtain good quality fuels and also ratio of sewage sludge in pelletizing materials.

The analysis of the energetic properties has indicated that the fuel generated on the basis of the sewage sludge and another biomass materials can be applied in the processes of co-combustion with coal. Those fuels are characterized with adequate properties enabling its transport and storage.

INTRODUCTION

Agricultural residues

By-products from agricultural production may be e.g. straw, seed and cereal shells, remains of fruit processing and animal excrements.

It is estimated that over three billion tonnes of agricultural residues were generated world-wide [1]. The types of agricultural by-products depend on the location of the site in the world. For instance, Europe takes the first place in the production of straw from cereals (wheat and barley) while the highest share in the global agricultural discard balance belongs to rice husks (around 43%), which are produced by Asian countries [1].

Turkey is a country which has great agricultural potential with 23.07 million ha arable land. Total amount of agricultural solid waste is about of 50–65 million tonnes [2]. Agricultural activities are concentrated on the production of industrial plants used for example for the production of industrial products such as wheat, barley, maize, cotton, olive and sunflower oils, hazelnut, etc. These food-processing industries produce residues, which could be utilized for energy production.

Table 1 illustrates selected types of agricultural by-products.

Table 1 Characteristics of selected agricultural residues

Parameter	**Moisture %**	**Ash % d.m.**	**Volatiles % d.m.**	**C**	**H**	**O % d.m.**	**N**	**S**	**HHV MJ/kg**
Corncob[1]	0	6.4	n.d.	45.53	6.15	41.11	0.78	0.13	17.81
Barley straw[1]	15	4.9	n.d	46.8	5.53	41.9	0.41	0.06	18.79
Oats straw[1]	15	4.9	n.d.	46	5.91	43.5	1.13	0.015	18.09
Wheat straw[2]	7.75	6.22	15.68	46.95	5.355	1.05	0.51	0.22	18.5
Grape waste[3]		7.5	67.9	50,0	6.0	34.4	2.0	0.1	22.1
Almond shells[3]		1.2	79.3	49.2	6.0	43.4	0.2	0	19.7
Sunflower straw[1]	40	3		52.9	6.58	35.9	1.38	0.15	20.82
Olive oil waste[3]		7.1	77.3	48.9	6.2	36.2	1.4	0.2	21.6

[1] – source [3], [2] – source [4], [3]– source [1], d.m. – dry mass; n.d. – no data

The breeding and agricultural activity, especially livestock production on an industrial scale, is seen as one of the main sources of natural environment pollution. Depending on the farming system, animal farms generate solid (dung) and liquid (liquid manure) animal excrements. In this day and age, no-mulch system is becoming more and more popular, particularly in the livestock production on a large scale. Excrement in this system is the so-called liquid manure, i.e. liquid, or semiliquid mixture of faeces, urine, water and feed leftovers.

It is estimated that the available agricultural and animal residues in Turkey can be roughly equal to 22–27% of energy consumption in Turkey [5].

Table 2 presents total amount of animal wastes production in Turkey and their energy characteristic.

Table 2 Total amount and energy characteristic of animal waste production in Turkey [6]

Animal waste	**Waste quantity tonnes/year**	**Total dry manure tonnes/year**	**Available dry manure tonnes/year**	**Heating value MJ/m^3**
Cow	127,654,932	16,211,033	10,535,172	22.7
Sheep	24,558,323	6,139,581	758,146	22.7
Poultry	7,731,694	1,932,924	1,913,594	22.7

In terms of energy generation, agricultural products made particularly for that purpose may be used (maize, sugar beetroots, rape, oat and other) as well as unclassified assortments of cereals, i.e. cereals which cannot be used for consumption due to mechanical damage, biological infection or low quality.

The production of energy from biomass should proceed without harm to the production of food. Therefore, agricultural waste and residue should be ones used for the production of energy in the first place.

The potential of agricultural by-products is very high and it seems reasonable to use it for such purpose. The reason for this is the production of renewable fuels, which allow reducing carbon dioxide emission and make it possible to use agricultural by-products.

Sewage sludge

Municipal sewage sludge, is waste which is generated in process of cleaning water in wastewater treatment plants. Amount of it cannot be prevented and reduced according to the requirements regarding the quality of treated sewage. Sewage sludge constitutes the main type of waste related with sewage treatment and its amount is about 1-2% of volume of treated sewage.

The problem with its neutralisation arises from the amount of generated sludge and its properties. The amount of generated sludge depends on many factors - mainly on the pollutant content in sewage and applied treatment technology.

In Turkey, in 2012 wastewater discharge from sewerage systems per person was 0.182 m^3 per day. The State Statistical Institute has estimated that the population will reach to 90 million by 2025. It is expected that the amount of annually usable water per person may decrease to 1,222 m^3 by the year 2025 [7].

According to the results of Municipal Wastewater Statistics Survey in 2012 [7], out of 4.1 billion m^3 of wastewater was discharged via sewerage, 3.3 billion m^3 was treated in wastewater treatment plants. The rate of advanced treatment was 38.3%, while the rate of biological treatment was 32.9%, the rate of physical treatment was 28.5% and the rate of natural treatment was 0.3%. 52.7% of the treated wastewater was discharged into sea, 39.2% was discharged into river, 1.9% was discharged into dam, 1.1% was discharged into lake and artificial lake, 0.3% was discharged onto land and 4.8% was discharged into other receiving bodies.

The properties of municipal sewage sludge result in the fact that it is technically difficult to manage it. The fundamental parameter that has an impact on this fact is high hydration of sludge, which in the case of raw sludge is over 99% and in the case of mechanically dehydrated sludge 80 to 65%. The feature of sludge is also a good ability to decompose due to considerable content of easily rotting organic substances.

Municipal sewage sludge usually contain various micro impurities [8,9], a particularly broad group is the group of heavy metals, which accumulate in sludge upon sewage treatment [10,11].

The organic compound content in sewage sludge allows for using it in energy production processes. The influence of organic compound content on the calorific value of sewage sludge is widely discussed in the literature [12-16], where correlations may be found of change of sewage calorific value depending on the degree of fermentation and water content.

Several ranges of calorific values for various types of sewage sludge may be defined: and so for fresh sludge the calorific value is 16-20 MJ/kg d.m and for fermented sludge it drops to 10-15 MJ/kg d.m and in the case of very well performed fermentation even to 6.3-10.5 MJ/kg d.m. [13,16,17].

High hydration results in the fact that municipal sewage sludge after mechanical dehydration has greasy and semiliquid consistence, which makes mechanical operations more difficult. Hence, it is suggested to use it together with other waste and subject it to the process of pelletization to achieve adequate properties allowing for its easy transport and dosing in energy production processes.

Technical and technological aspects of the production of fuel from waste and biomass

The basic processes employed in processing waste and biomass into fuel is pressing into bales, briquetting, pelletization, granulation and grinding or milling to dust.

In techniques of processing waste into fuels, thickening (compacting) processes are employed which may be carried out as a result of use of increased pressure (pressure granulation, pressing, briquetting), in adequately high temperature (sintering) or without pressure in pouring or stirred layer of material.

Pellets and briquettes are mostly solid cylindrical, differing solely in their dimensions. Briquettes have diameters between 50 and 90 mm and lengths between 75 and 300 mm, while pellet diameters are less than 10 mm with no more than 35 mm length [18].

The array of waste that may be used in fuel production is very wide. Some types of waste have properties which allow for direct combustion without any interference in its properties and physical form while other types require processing.

Purohit et al. [19] divided raw agricultural residues, which can be used for briquetting, into three categories (i) fine granulated, (ii) coarse granulated, and (iii) stalky.

Some waste requires only a small physical processing, e.g. size reduction and mixing with another ingredient, and other need more developed technological systems to acquire the proper physical form in the processes of drying and forming into briquette or pellet.

The literature provides information on briquetting [19,20,21,22] and pelletizing of agriculture residues [18,23,24], including sewage sludge and other waste [17,25,26].

The idea behind providing waste and biomass with physical form is to acquire proper energy-related and physical properties meeting the technological prerequisites, which are necessary for the proper course of combustion or co-combustion in a given installation.

However, it is not always possible to use an already existing technology and the development of a new one requires solving a range of issues, some of which are as follows:

- selection of fuel components which influence the properties, energy generation parameters in particular, including the selection of binding additives,
- selection of a waste forming method,
- adjustment of working parameters of the forming device so as to achieve the proper quality of the product.

This article aims to address the above issues as regards the production of fuels based on sewage sludge and agricultural residues.

MATERIALS AND METHODS

The studies were based on municipal sewage sludge (SS) from a mechanical and biological sewage treatment plant covering 115,000 PE.

In order to assess the influence of other waste on physical parameters of pellets made from sewage sludge, the studies included waste from cattle breeding and from olive oil production as well.

Olive waste (OW) was produced by the three-phase decanting method. In those systems process water is added and three phases (oil, wastewater, solid wastes in the form of an olive cake) are produced. However, animal waste (AW) came from a farm breeding milk cattle. Table 3 shows selected parameters of components used in the studies.

Table 3. Selected properties of components of pellets

Parameter	**Unit**	**SS**	**OW**	**AW**
Water	%	85	65	90
HHV	MJ/kg	11.22	18.79	8.85
Voltaire matter	% d.m.	35.03	48.18	24.84
Ash	% d.m.	41.02	22.02	9.52

d.m. – dry mass

The selection criterion for waste was its availability and - particularly - the problem with their neutralisation in the same area (in Aydin province).

Due to the fact that all of the waste is characterised by high moisture content, which influences the greasy consistence of waste, the conducted studies aimed to develop a forming method fit for that waste.

In order to identify the pellets, individual symbols were attributed to them:

- SOW – pellets which were based on the sewage sludge and olive waste,
- SAW – pellets obtained from the sewage sludge and animal waste.

For comparison, pellets from sewage sludge alone were also made, which were marked with the SS symbol.

The pellets were subjected to studies taking their energy and physical parameters into consideration.

The energy properties, i.e. high calorific value (HHV) was conducted by using Oxygen Bomb Calorimeter KL-Mn (PN-EN 14918:2010), the ash content, the volatile matter content and moisture by differential thermal analyser Netzsch Jupiter STA 449 and the ultimate analysis of pellets were performed via Elementar Analyzer type Elementar Vario MACRO Cube – in accordance with PN-EN 15104:2011 (C,H,N) and PN-EN 15289:2011 (S).

The research also involved the testing of physical properties as:

- drop strength (according to the PN-G-04651),
- water - resistance (PN-G-04652),
- absorbance (PN-G-04652).

RESULTS AND DISCUSSION

Selection of a waste forming method

When selecting a method for waste forming, on an experimental basis, a relationship is sought between the starting parameters of the material, structural parameters of the forming device and target parameters of the product so that the material can be processed in line with the assumed requirements (size, shape and durability of fuel).

The basic starting parameter of the material decisive in the forming method is its moisture content. It influences physical features and, in the case of polished materials, defines their consistence. Acquiring the proper water content of the material for briquetting is crucial from the point of view of conducting the forming process.

Due to the fact that all fuel components are characterised by high moisture content, a technology of their pelletization was selected and developed, which technology consists in initial mix of the components and then forming in a special devices illustrated in Figure 1.

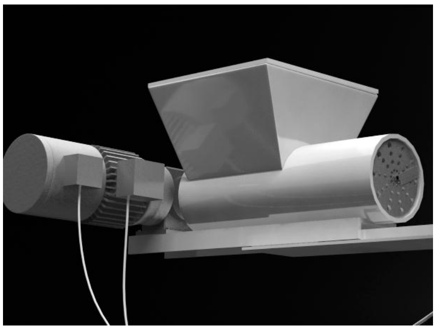

Fig.1. The forming device.

The mixture is fed into a dosing funnel equipped with a feeding screw and ending in a replaceable sieve, behind which a cutting part is fixed that is compatible with the feeding screw shaft. The material being formed, after going through the sieve and being cut with a knife, is formed into the shape of pellet.

The replaceable sieve with meshes in various sizes allows to create pellets with the diameter from 10 to 35 mm.

In the case of obtaining high-quality pellet and the course of the forming process, it was observed that what is extremely important is the initial moisture content of the mixture of sludge and waste subjected to forming. Properly set moisture content of the mixture allows for acquiring the proper consistence of the mixture, which consistence makes it possible to squeeze it through the forming dye, thus obtaining the desired shape of the product.

The influence of the moisture content in the mixture being formed on the quality of fuel is shown in Fig. 2.

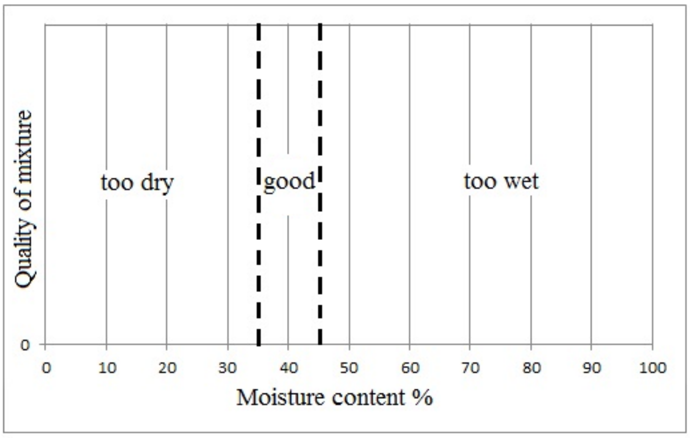

Fig. 2. The influence of the moisture content of the mixture being formed on the quality of fuel.

The most beneficial range of the initial moisture content was defined - i.e. 35-45% - which the mixture should have so that the forming process proceed correctly, ultimately leading to the production of homogeneous pellets.

Such moisture content leads to the production of such pellets that are plastic, which may lead to shape loss during storage. Moreover, high water content favours biological activity of the produced fuels and reduces their energy-generation and durability parameters. Hence, pellets should be dried to the water content of about 10%. Such moisture content was obtained in 1 to 3 days by drying pallets with solar power.

Properties of pellets

The studies covered pellets with the sewage sludge content of 20% (SOW20, SAW20) and 30% (SOW30, SAW30) and pellets made of SS only.
The analysis of energetic properties of pellets in comparison with hard coal is shown in Table 3.

Table 3 Energy properties of pellets

Parameter	**Unit**	**SOW20**	**SOW30**	**SAW20**	**SAW30**	**SS**	**Hard coal [27]**
Water	%	5.89	6.22	6.05	5.18	5.09	5.0-10.0
Voltaire matter	% d.m.	30.17	29.73	30.78	29.67	37.88	25.0-40.0
Ash	% d.m.	39.65	30.92	41.91	42.69	45.73	8.5-11.3
LHV	MJ/kg	12.41	14.52	10.78	8.58	10.08	23.7-28.3
HHV	MJ/kg	13.41	15.80	11.85	9.46	11.03	26.0-28.3
Elementary composition							
C	% d.m.	30.79	35.81	30.79	24.01	27.24	76.0-87.0
H		4.49	5.16	4.211	3.47	3.77	3.5-5.0
N		1.54	1.38	1.8	1.71	2.11	0.8-1.5
S		0.55	0.79	1.98	0.94	1.97	0.5-3.1

d.m. – in dry mass

Pellets are characterised by the calorific value of 8.6÷14.58 MJ/kg. The SOW30 fuel is comparable with the RDF fuel, which is made from inflammable fraction of municipal waste and - according to Genon et al. [28] - it may range from 13 to 18 MJ/kg.

The addition in the form of olive waste positively influences the calorific value of pellets and fuels with this waste are most recommended for use in energy generation.

Apart from power-generating properties, what is of essence are the physical properties defining the durability of fuel, which is significant as regards transport, storage and warehousing.

One of the parameters evaluating the durability of fuel is drop strength. In the strength-by-dropping test, sample is dropped down twice from 1.5 m against a concrete surface. The strength-by-dropping factor is calculated from the formula:

$$W_{ZR} = \frac{N_1}{N} \cdot 100\%$$

where:

N – number of pellets, which were subjected to testing [pcs]

N_1 – number of pellets, which survived with no damage [pcs].

The produced pellets with 15 and 35 mm in diameter were subjected to the tests. Drop strength of pellets is presented on Fig. 3.

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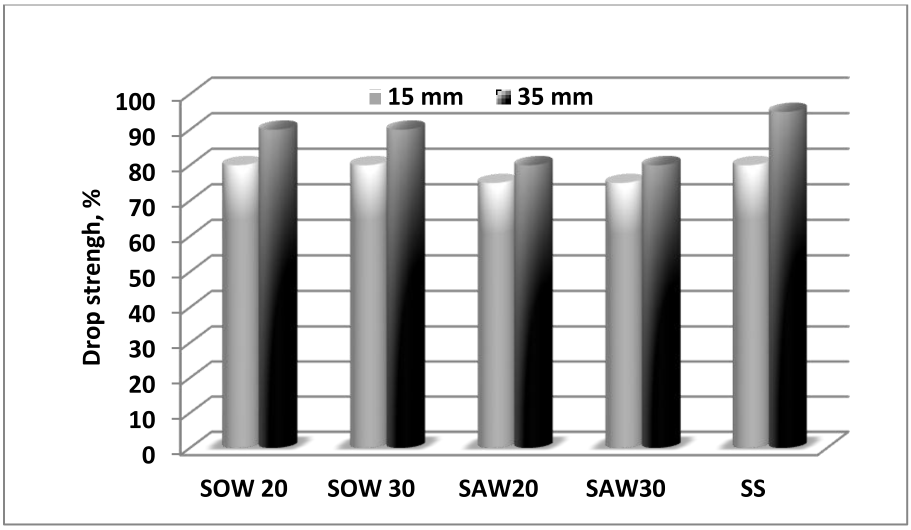

Fig. 3. Drop strength of pellets.

Pellets of the same type (but with different sewage sludge content) are characterised by similar drop strength, i.e. for the SOW fuel it is from 80 to 90% while in the case of the SAW pellets from 75 to 80%. The highest index was obtained for pellets made of sewage sludge only with the diameter of 35 mm (95%).

The obtained results showed that pellets of 35 mm in diameter are characterised by high drop strength. A similar correlation was obtained for fuels based on sludge and sawdust [17] and on sludge and meat-and-bone meal [29].

The water absorbability test was based on finding the amount of water, which had been absorbed by the pellets under conditions as defined by the standard PN-G-04652. The pellets were left to stand in water over 24 hours, and the difference between the sample weights after and before water absorption made the measure of this parameter. Absorbability of pellets is presented on Fig. 4

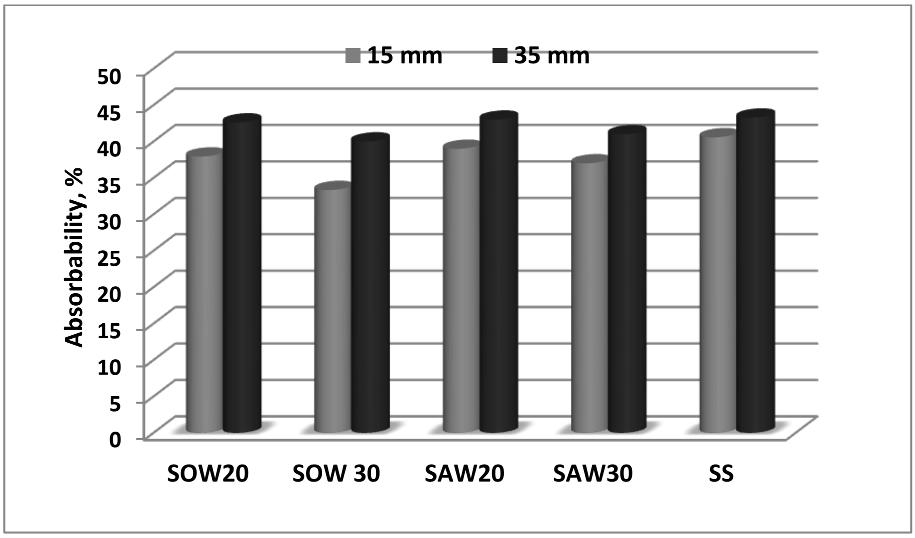

Fig. 4. Absorbability of pellets.

The lowest absorbability is found in the SOW30 pellets (33% for 15 mm). It was observed that pellets with lower diameter (15 mm) show lower ability to absorb water. High absorbability of pellets is highly adverse as due to the absorption of moisture from the surroundings, pellets may lose their durability properties and during storage the organic substance of fuel may develop biological activity.

Another parameter, which was studied, is water-resistance. It is defined as the ratio (in per cent) of the strength-by-dropping factor after absorption of water (the sample was immersed in water over 24 hours) and the original value of that factor. Water-resistance of pellets with diameter 15 mm was presented on Fig. 5.

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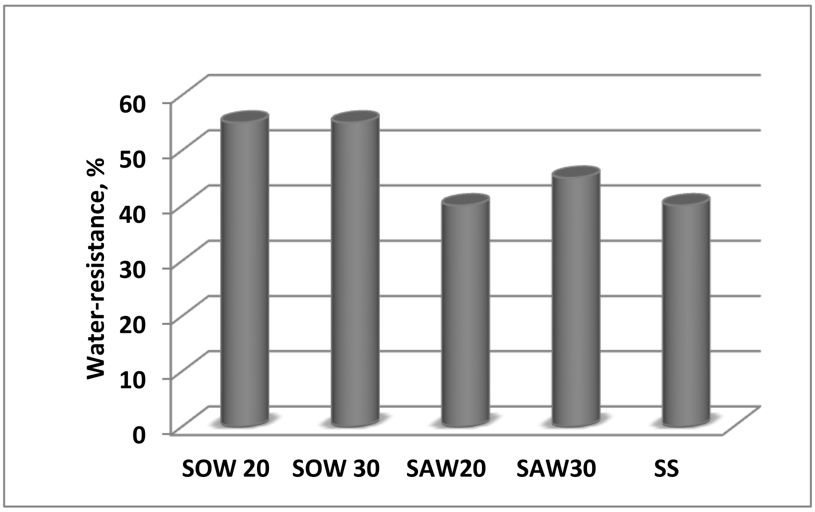

Fig. 5. Water-resistance of pellets (diameter 15 mm).

On the basis of the conducted research an observation was made that water has a destructive effect on the strength of the fuel. It was found that after the pellets absorb water its strength tends to drop dramatically. The conclusion of the following is that the fuel should be stored in the area protected from rainfall.

CONCLUSIONS

On the basis of the conducted studies, a co-pelletization method of sewage sludge and agricultural residues was developed. The developed technology of pellet production from residues consists in initially mixing sewage sludge with other waste in set proportions and then forming it into pellet and drying.

The processed and treated waste in the form of pellet allows for storing it without leading to secondary environment pollution and the assumed form of fuel facilitates transport, which increases potential for its use.

The tests for physical properties demonstrated that pellets may be subjected to mechanical handling operations which are connected with their transport, loading and unloading, etc.

However destructive effects of water on drop strength were observed for all test pellets. The fuels are characterised by high water absorbability and they should be protected against atmospheric precipitation for short-time intermediate storage.

From the point of view of power generation, the most beneficial fuels are those from sewage sludge and olive waste. They may be used in clinker baking as a substitute for hard coal and be put in a rotary furnace with transport and alternative fuel dosing systems already employed in cement plants.

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