

Study of the Application of Pellets from Textile Material Waste and Biomass Mixture in Industrial and Residential Heating Systems

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Abstract. The efficient waste management hierarchy is based on four priorities, reuse, recycle, energy recovery, deposit.

Efficient energy recovery from non-recyclable textile materials (waste to energy) principles we study in this paper. Energy recovery from the fuel pellets consisting of waste textile materials and biomass depends on many factors. One of the main is to create a competitive form for the newly offered fuel (pellets from a mixture of biomass and textile), as well using a new generation of small-scale energy production facilities. Using already existing applications for efficient waste management is one of the circular economy aspects we lay on in this paper.

Roughly estimated that the quantities of textiles separately collected will increase from 65 000 to 90 000 tons per year across the EU-27 from 2025. Reuse and recycling outlets will need to be created, as the current sorting and recycling capacities are not sufficient to process the anticipated volumes. However, it is also expected that at least half of these additional volumes will comprise non-reusable textile waste with specific flame retardant (FR) treatment. It is known that flame retardant is hazardous by its adverse environmental impacts of FRs in their production and disposal phases.

The objective of the paper is to review opportunities of elaboration a new type of the fuel pellets, and using them in industrial heat pellet boilers and combined heat and power CHP systems.

Elaborated the new pellets from biomass (prepared by plasticization method) and chopped textile waste sized till 2-3 mm (by method separate milling) were tested in controlled combustion processes.

Experiments were carried out by adding different proportions of textile waste to biomass pellets and the results obtained are summarized in the article

Keywords: Efficiency, waste to energy, sustainability introduction.

Latvia is on its way to achieve the European union EU climate neutrality goals – by 2050 40 % of the energy produced from Renewable Energy Sources (RES) from total energy consumption (EU average goal for 2030 is 20 %) [1]. A significant part of the energy produced by RES, is wood biomass (in 2018 62.6 PJ or 80.4 % of the

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total RES consumption)[2]. Energy production from biomass, although less than from fossil energy sources, causes greenhouse gases (GHG) emissions [3].

Use of energy recovered from waste materials promotes implementation of circular economy principles in household sector [4] [5].

Circular economy principles are present on Fig.1, Efficient use of municipal waste to energy is one of the ways to decrease landfill of textile[5].

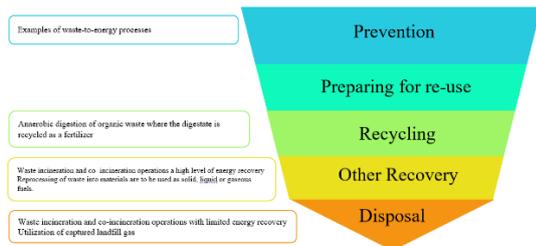


Fig 1. Circular economy principles of waste to energy[5].

In the field of textile material recycling, as a one part of the renewable energy source [6] it can be seen that most of the waste is burned in specifically constructed waste incineration factories, but only the smallest part is used for transplanting [5], [7], unless share of waste for recycling is annually growing [5].

It is indicated that a significant amount of textile materials is stored in landfills for future recycling[8].

The guidelines of the European Green Course [1] promote the use of RES in the production of heat and electricity, as a result of which an increase in the use of biomass can be observed. An increase in the use of granulated biomass in the production of heat and electricity is observed [9]. Pellet heating equipment is one of the most efficient currently available technologies for obtaining energy from biomass[10]. The directives and policy documents of the European Union on the use of biomass for heating promote the efficient and sustainable use of this resource, as a result of which energy sector companies that use biomass as fuel for heat and electricity production are expected to face greater competition for the extraction of raw materials for fuel production [10], [11].

In this perspective, the boundaries of using composite materials for recycling can be expanded, including polymer structures with various inclusions of natural/synthetic particles [12] [13], [14] [14], [15] [16] including nanomaterials[13], [17] [18], as well as widely used polymer matrix composite materials, such like concrete reinforced with fibrils [19]–[21].

Textile waste incineration currently takes place in specialized waste incineration plants, but no waste incineration is observed in heating facilities[22]. Taking into account that a significant part of textile waste is deposited for later processing, it can be assumed that in the future technologies and opportunities for efficient processing of textile waste will be available. Therefore, the preparation of new type the pellets and responding of the EU ISO 17225-2:2021 standard is very relevant and timely.

By developing a new type of fuel, which would consist of biomass/wood processing residues and a mixture of waste textile materials, it would be possible to use the waste to efficiently process it in already existing heating facilities, without using specialized waste incineration plants.

As the significant part of landfill after some period of time is to be planned for recycling and there are indications that in near future textile materials recycling process will be more common and specially build textile waste incineration factories become useless.

Finding new opportunities and technologies to The research explores in an experimental way the possibilities of creating fuel that could be used in already existing pellet heating facilities.

Objectives of the research:

- Develop novel pellets from the waste of synthetic/natural textile materials and biomass, which cannot be recycled into new textile material, for using in household pellet heating boilers.
- To reach the objective, a new manufacturing approach from the waste synthetic/natural textile with biomass will be developed, the prototype of the pellets will be manufactured and experimentally tested (mechanical and thermal characterizations according to EN 14961-2; ISO 17225-2:2021).

I. MATERIALS AND METHODS

A. Test sample preparation

To prepare the textile fibers (organic/synthetic textile material) of short length was used an experimental laboratory module: high-speed grinding-separation system DS - 37/21 (TalTech, EE), that provides the high-speed separative milling of small volumes of various types of textile waste in order to obtain fibres of the required length.

The method of dry high-speed grinding-separation of worn-out textile materials was applied to prepare a short length textile fibers or powdered fibers (3±1 mm).

The concept of fiber preparation using high-speed grinding-separation (HSGS) consists of the following main stages: fiber processing goes through the feeding and mechanical pre-treatment stage, following grinding and the final separation.

The feeding system consists of a screw conveyor that transports the pieces of the material through a unit of preliminary mechanical processing. The drive power is 1.5 kW, the power of the pre-treatment systems is 2 kW, the maximum length of the pieces of material was about 0.5-1 m.

The prepared material was milled in the grinding system, and the obtained fibers flied to the separation unit with the airflow. The power of the grinding drive was 3 kW. The maximum engine speed was 3000 rpm. The range of linear processing speeds was 70 m/s.

Then, the milled fibers were divided in the separation system. The fibers of the required size (3 ± 1 mm) were separated (under the influence of inertial force) and fed to the finished product collector. Large/insufficiently chopped/milled fibers were fed for re-processing.

The performance of the system (depends on the degree of preliminary processing, material properties) was organic/synthetic textile material - 2 kg/h, cotton material - 1.5 kg/h. Other characteristics (in first approximation), like as type of weaving, relative humidity, structure and thickness of the thread, linear speed and configuration of the milling cutter and the required particle size of the product did not take in consideration in this manuscript, and were regarded like a constant.

Cotton material was used: woven fabric; purchased in the store of illiquid raw materials shop "Abakhan", Tallinn, Estonia; plain weave, surface density 244 ± 5 g/m². The specimens of the powdered fibers (24 h were technological deposit, room temperature $22\pm 1^\circ\text{C}$; moisture content 60%, according to ISO 139:1973) were used to prepare the pellets. PES (Polyester) material was used: knitted fabric; purchased in the store of illiquid raw materials shop "Abakhan", Tallinn, Estonia; combined knitted weave, surface density 185 ± 5 g/m². The specimens of the powdered fibers (24 h were technological deposit after the grinding process, room temperature $22\pm 1^\circ\text{C}$; moisture content 60%, according to ISO 139:1973) were used to prepare the pellets. Final grinded textile material used for mixture with biomass see on Fig. 1



Fig. 1. Grinded textile, left cotton, right synthetic.

Pinewood chips were received from woodworking factory. The equipment to prepare the pellets is the pellet machine ZLMP400, Fig. 2.



Fig. 2. Pellet mashine and process.

Four combinations of the pellets and one type from the pure pine wood chips were prepared Tab 1.

TABLE 1 PELLETT SAMPLES

Nm	Types of combination	Composition, %
1	Pinewood chips and powdered fibers (Cotton material)	87.5% & 12.5%
2	Pinewood chips and powdered fibers (Cotton material)	80% & 20%
3	Pinewood chips, powdered fibers (Cotton, and PES material)	90% & 5%; 5%
4	Pinewood chips and powdered fibers (PES material)	90% & 10%
5	Pinewood chips	100%



Fig. 3. Pellet specimens.

B. Testing procedure

To determine the length and diameter of the received pellets was used the Electronic digital calliper (Resolution: 0.1 mm/0.01"; Accuracy: ± 0.1 mm/ 0.01"; Battery: SR44/LR44 1.5 V; GE).

Moisture content of all five specimens was detected according to the standard LVS EN ISO 18134-1.

Clean, dry container was weighed with an accuracy of up to 0.1 g. The mass of the specimens should be at least 300 g (it is the weight of the container with the specimens).

To determine the floating effect, before drying, the weight an identical empty and clean reference container with an accuracy of up to 0.1 g.

The dish with the specimen and the reference dish were placed in a drying oven with a temperature of $105\pm 2^\circ\text{C}$, the drying process lasts until the mass of the specimen becomes constant, but no longer than 24 hours (to prevent the release of volatile compounds).

The container with the specimens and the empty reference container were weighed on the scale within 10-15 seconds after removing them from the drying oven; a heat-resistant plate must be placed on the scale.

The specimens should be placed in the drying oven so that air can freely flow between them, and moisture has somewhere to evaporate.

Ash content for dry mass was detected according to standard LVS EN ISO 18122.

Empty and cleaned crucibles are placed in a muffle furnace and heated for at least 60 minutes at a temperature of $550 \pm 10^\circ\text{C}$;

Place the crucibles in a desiccator fitted with a thermocouple and allow to cool for 25 minutes to reach a constant crucible mass, after which the temperature is recorded, which is recorded in the work report. The cooling time of the dishes is determined to reduce the mass changes caused by temperature and to reduce the measurement error. When the crucibles have cooled, determine their mass with an accuracy of 0.1 mg. The sample materials were mixed and put about 1 g in the specimen crucible in an even layer, no more than 0.1 g/cm².

Crucibles with specimens were placed in a muffle furnace and heated within 30 to 50 minutes, heat the muffle furnace evenly to 250°C (temperature rise $4.5\text{--}7.5^\circ\text{C}/\text{min}$), maintained at 250°C for 60 minutes to evaporate volatile substances before igniting. The temperature was raised evenly to $550 \pm 10^\circ\text{C}$ during 30 minutes and maintained at $550 \pm 10^\circ\text{C}$ for at least 120 minutes.

As soon as the specified temperature is reached in the desiccator, previously recorded in the work protocol, the mass of the crucibles and ash begins to be determined.

Gross and Net calorific value was detected according to standard LVS EN ISO 18125.

The determination of the heat of combustion consists of two separate experiments.

The calorimeter is first calibrated using a benzoic acid calibrant, which has a known highest heat of combustion. Calibration is necessary to ensure accurate measurements.

After the calibration of the calorimeter, a test to determine the heat of combustion of the fuel is performed. At least two replicates are required for a representative result. The value of the heat of combustion of the analyzed specimen cannot differ by more than 120 J/g for both replicates.

To determine the amount of heat [J] produced by the combustion of an acetobutyrate capsule or crucible, they must be weighed on an analytical balance and their mass [g] multiplied by the heat of combustion [J/g] of the acetobutyrate capsule or crucible. The calorific value of combustion of auxiliaries is excluded from the calorific value of fuel.

The mass of the pellet of the fuel specimen is indicated in the calorimeter, as well as, if necessary, the heat of combustion of the used ignition aids (cotton thread, acetobutyrate capsule, ignition crucible) is entered.

After the test work, the heat of combustion H_0 [J/g] of the specimen burned in the calorimetric bomb is recorded in the protocol.

Pellet combustion test ware performed in pellet boiler, Fig. 4.



Fig. 4. Combustion test stand.

II. RESULTS

In the first phase of research the physical parameters of the pellets were measured according to the standard ISO 17892. We researched the average length (from 15.3 mm to 21.51 mm) and diameter (from 6.19 mm to 6.62 mm) of the pellets, and the results were compared with the standard ISO 17892, where it is seen that physical parameters of the pellets are in a proper range allowed in the standard for all five specimens. Studies have shown that, the powdered fibres (both types: cotton and PES powder) added in pinewood chips are not influencing on the pellets size (as follow from testing results shown in Table 2).

TABLE 2 THE PHYSICAL PARAMETERS OF THE PELLETS

N m	Types of pellets	Average length, $n_{al} = \frac{\sum n_{100}}{100}$; (mm)	Length (mm) according to standard ISO 17829	Average diameter, $n_{ad} = \frac{\sum n_{100}}{100}$; (mm)	Diameter (mm) according to standard ISO 17829
1	Pinewood chips and powdered fibers (Cotton material)	15.45	$3,15 < L \leq 40$	6.62	6 ± 1
2	Pinewood chips and powdered fibers (Cotton material)	17.84	$3,15 < L \leq 40$	6.19	6 ± 1
3	Pinewood chips, powdered fibers (Cotton, and PES material)	15.57	$3,15 < L \leq 40$	6.28	6 ± 1

4	Pinewood chips and powdered fibers (PES material)	15.3	3,15 < L ≤ 40	6.27	6 ± 1
5	Pinewood chips		3,15 < L ≤ 40		6 ± 1

fibers (Cotton, and PES material)	12.50			
Pinewood chips, powdered fibers (PES material)	12.59	0.43	20.39	16.34
Pinewood chips	12.68	0.35	20.48	16.87

The standard LVS EN ISO 18125 controls the ash content after pellet combustion. Ash contains factor may depends on many factors[23]–[25], but our research shows correlation between cotton powder adding and ash contain[26]. The first two specimens of the pellets (Table 3) contain wood chips and cotton powder in different proportions (1st specimen - 20%, 2nd specimen - 12.5%), and show the ash content higher than in a specimen with 10% synthetic (PES) powder (4th specimen, Table 3). Test results of all five specimens indicates increasing of the ash content in the specimens with textile powder (as additives); the less ash content 5th specimen (without textile powder) is 0.35% and the highest ash content 1st specimen (with 20% cotton powder) is 1,58%. Investigation of the 4th specimen (wood chips with 10% PES powder) shows lowest ash contain 0.43% (among specimens with additives). This result of ash can be explained by the fact that in time of combustion PES powder the products comprised of carbon (C), hydrogen (H₂), oxygen (O₂), and nitrogen (N₂), where hydrogen, oxygen, and nitrogen are gases[27], [28].

TABLE 3 COMBUSTION PROCESS LABORATORY RESULTS

Types of pellets	Moisture content, %	Ash content, %	Gross heating value (GHV), MJ/kg (Tables in the standard LVS EN ISO 18125)	Net heating value (NHV), MJ/kg
Pinewood chips, powdered fibers (Cotton material)	17.23	1.58	19.7	14.77
Pinewood chips, powdered fibers (Cotton material)	14.38	1.05	19.74	15.40
Pinewood chips, powdered		0.71	20.12	17.23

In order to explain how the energy density of the fuel changes, it is necessary to take into account its constituent raw materials. Pellets energetic density values have influence by lignin content in the pellets (one of the biomass components), and concentration of the lignin in the pellets has influence on energetic density of the fuels and ash content after pellet combustion[29]. The ash content has affected by non-combustible ingredients in the fuels[32]. This follows from the research, that is, the 1st specimen has higher ash content 1.58% and the lowest fuels energetic value 14.77 MJ/kg comparing with other specimens. On energetic value has influence on the moisture of the raw material in the specimens, for example, 1st specimen: moisture is 17.23% and energetic value is 14.77 MJ/kg, 2nd specimen: moisture is 14.38%, energetic value is higher 15.40 MJ/kg (comparing with the 1st specimen). Obviously, this result was influenced by the content additionally textile cotton powder in the pellets. The first two specimens have higher moisture content, number of research[30]–[32] justify correlation between biomass moisture content and energetic value. The high moisture content of the specimen's 1st and 2nd may be affected by the hygroscopicity of the cotton fibers. It is known that cotton fibers have high hygroscopicity (the ability to absorb moisture). The fibers during swelling increases by about 40% in volume[30], [33].

The low heating value (LHV) or net heating value is the energy value of fuel combustion, obtained depending on the actual composition of the pellet material and its moisture content. The high heating value (HHV) or gross energetic value depends on fuels composition where humidity not included in calculation[33] and gross energetic value of each type of material is determined according to the tables with the standard LVS EN ISO 18125. The comparative analysis between the HHV and LHV is representing in very less difference between energetic values of the specimens, that are: 1.3% for 1st and 2nd specimens, and 1.17-1.25% for 3rd, 4th and 5th specimens. From this research follow the textile powder adding practically has not influencing on the gross energetic value. The net LHV is depending on water content in specimens[33], represents correlation between moisture content and LHV, what shown in Table 3. The

most higher 17.23 MJ/kg value of the LHV shown the 3rd specimen (90% pinewood chips, 5% of cotton powder, 5% of PES powder), as the optimal result of the content of additives for this particular study, despite on the middle ash content 0.71% (with comparison among of all five specimens). Latvian average household heat energy demand is about 170kWh/m² annual,

III. CONCLUSIONS

The powdered fibers (both types: cotton and PES powder) added in pinewood chips are not influencing on the pellets size, where average length is 17.13 mm, and average diameter is 6.37 mm.

The pellets containing pinewood chips and cotton powder (1st specimen - 20%, 2nd specimen - 12.5%) showed the highest moisture content (1st specimen - 17.23%, 2nd specimen - 14.38%) and, as a result, the LHV (1st specimen - 14.77 MJ/kg, 2nd specimen - 15.40 MJ/kg) less than other three specimens.

The ash of 1st and 2nd specimens is in 2.65% higher than the other three specimens.

The most higher 17.23 MJ/kg value of the LHV shown the 3rd specimen (90% pinewood chips, 5% of cotton powder, 5% of PES powder), as the optimal result of the content of additives for this particular study, despite on the ash content 0.71%.

Physical and mechanical parameters of the all-tested specimens meet pellet standards.

Significant amount of non-reusable textile waste might be used for heat energy production.

Gaseous and fine particle emission measurements for further research should be performed to approve compliance to the emission standards.

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