DOI: http://doi.org/10.21698/simi.2019.fp27

METHODOLOGY FOR QUICKLY DETERMINING THE QUALITY OF PELLETS

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Abstract
A methodology for quickly and easy determination the quality of pellets offered on the market is developed on the basis of "theory of graphs". The pellet quality assessment is performed in two ways - by direct control (non-destructive measurements) and by combustion. The following pellets parameters are determined at the direct control stage: friability, homogeneity, presence of dark stains and moisture content. The experimental measurement of following parameters of the combustion process is carried out at the stage of pellet burning assessment under real conditions: temperature in the combustion chamber, time for complete combustion of the pellets and the amount of ash after pellets combustion. The calorific value of the tested pellets is determined on the basis of the experimentally obtained parameters of the combustion process. The the obtained parameters values are statistically processed according to the described in the paper equations at the next stage. Then the results for the investigated pellet parameters are compared with the normative values. The proposed methodology could be calibrated by experimental determining the calorific value of investigated pellets by a calorimeter. Practical application of this methodology is that by not so complicated measurements and calculations the required amount of pellets for heating a building with a certain energy consumption for heating season could be determined.

Keywords*: biomass, green energy, energy efficiency, pellet quality*

Introduction
Global energy policy aims at limiting climate change, energy security and competitiveness. In accordance with (Treaty on the Functioning of the EU 2012), promoting renewable forms of energy is one of the goals of the Union energy policy. The increased use of energy from renewable sources represents an important part of the package of measures needed to reduce greenhouse gas emissions and comply with the Union's commitment under the 2015 Paris Agreement on Climate Change and with the Union 2030 energy and climate framework, including the Union's binding target to cut emissions by at least 40 % below 1990 levels by 2030. The increased use of energy from renewable sources also has a fundamental role in

promoting the security of energy supply, sustainable energy at affordable prices, technological development and innovation (Directive (EU) 2018/2001).

Energy consumption for heating and domestic hot water accounts more than 70% of the total energy consumption of the household, so the type of energy source and the efficiency of energy conversion systems are of exceptional importance. The final energy consumption for space heating in Bulgaria is as follows: wood and coal - 52.6%, electricity - 38.5%, natural gas - 2.4% and natural gas for district heating - 6.5% (Guidance for Household Energy Auditors 2015). The use of renewable energy sources is negligible, but more and more people living at houses choose pellets as heating fuel for their homes.

In domestic heating with non-efficient stoves and solid fuel boilers and the use of coal containing ash and sulfur and wet wood, pollutants such as sulfur dioxide, nitrogen dioxide, carbon monoxide and fine particulate matter are the main problem in cities (Angelov at al 2018, Valtchev 2012). Analyses indicate that this type of heating causes at least 85% of fine particulate emissions, so measures to improve air quality are mostly targeted in this area (Guidance for Household Energy Auditors 2015).

Nearly 11 % of the EU's population cannot adequately heat their homes at an affordable cost (https://ec.europa.eu/energy/en/news/energy-poverty-may-affectnearly-11-eu-population). The situation is estimated to affect more than 50 million households in the European Union. The scale of the problem is due to rising energy prices, low household incomes, a lack of access to finance, and inefficient buildings and appliances (Good Practice in Energy Efficiency 2018). Energy poverty is particularly prevalent in Central, Eastern and Southern Europe, with more than 30% of households in South-Eastern European countries experiencing energy poverty (EU Fuel Poverty Network 2015).

Energy poor people could replace solid fuels (wood and coal) with pellets to heat their homes. The production of pellets from solid biomass is a technology which transforms biomass to an energy carrier efficiently. Biomass is milled, dried and densified under high temperature and pressure. The result is a homogeneous solid fuel with a much higher energy density. State-of-the art technology of pellet production can achieve overall conversion losses both for drying, milling and densification that are lower than 10 %. Excess heat from the production is recycled and used for drying the row material for new pellets (Renewable energy in Europe 2010).

Pellets are as convenient to use as fossil fuels. Due to their high energy content and the convenient delivery and storage feature, pellets are an ideal fuel for replacing also heating oil or gas. They are a key technology for increasing biomass use in Europe and thus replacing fossil fuel, natural gas or electricity in the heating sector. Pellets meet the need for high-calorific fuel and are also environmentally friendly. When burning pellets, less carbon dioxide is released than if the wood from which they are produced is left to rot (Renewable energy in Europe 2010).

Heating with pellets has advantages compared to heating with solid fuels. The solid fuel (coal and wood) requires more storage space. Pellets are more calorific than solid fuels. Their calorific value is 4.8 kWh/kg pellets. When burning pellets, less carbon dioxide is released. Pellets have one more advantage - this fuel pollutes much less. When burning, they release much less soot and ash (Renewable energy in Europe 2010).

Pellets are successfully used for heat production and are especially suitable in small scale heating systems (stoves and boilers) due to their automatic heating process, easy storage, relatively low cost and a very low amount of ash and other emissions released. The advantages of biofuels over traditional fuels are expressed in greater energy security, reducing harmful effects on the environment, financial savings and socio-economic aspects related to rural development (http://ener-supply.eu 2012).
Pellets have a cylindrical shape with a diameter of 6 mm and a length of up to 30 mm. The efficiency of combustion systems using pellets as fuel ranges from 85% to 95%. For comparison, the efficiency of combustion systems using wood as fuel is about 79%. The ash content of the pellets is very low, at most 1.5%, as they burn almost completely. Coniferous pellets are more preferred because they have a higher heat output, and the ash content after burning is less. Most pellet burning equipment are designed to work with pellets from both types of wood. Practice shows that the efficiency of combustion systems depends more on the quality of the pellets and less on the type of wood from which they are produced.
In this respect, the purpose of this paper is to develop a methodology for quickly and easily determine the quality of the pellets offered on the market.

Materials and Methods

The methodology is based on the "theory of graphs" as the interconnections between the different elements of the methodology are shown in fig. 1.
The first element of this methodology is the 'aim of experiments' (AE). At this stage, the purpose of the developed methodology is clearly stated, namely that it is easy and precise determine the quality of the pellets.
The second element of this methodology is the 'introduction' (I). Due to the wide variety of pellets available on the market, it is necessary to formulate several indicators and to monitor their quality. Not always the quality of the pellets stated on the package corresponds to the real quality. As a result, burned biomass releases more harmful substances and ash content, resulting in increased consumption and clogging of the outlet system. Frequent stops for prevention and cleaning of the heating system are necessary. On the other hand it is reasonable to buy biomass in the form of pellets before the start of the heating season. The price of pellets increases significantly during the heating season due to their increased demand. So, the current methodology is designed to avoid buying such unsuitable biomass (pellets).
The next element in this methodology is the correct formulation of the 'tasks to be performed' (PT). In the present case, the pellet quality assessment is to be carried out in two ways - by direct measurement (non-destructive control) and by combustion.
In the stage 'direct control ' (DC) a package of 15 kg of pellets is to be evaluated for external signs. These indicators illustrate the state of the pellet, its density and possibilities for cumbastion as well as the presence of impurities. The external characteristics that can be used to assess the quality of the pellets are:

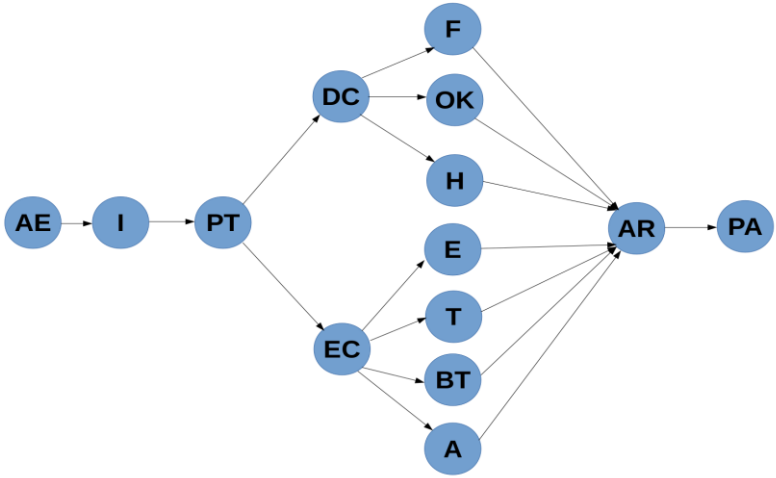

Figure 1. Multigraph of the interrelations between the main elements of the methodology: AE – purpose of study; I - introduction; PT – performed tasks; DC – direct control; EC – experimental control; F - friability; OK – optical control; H - humidity; E – energy; T - temperature; BT – burning time; A - ash; AR – analysis of results; PA - practical application

The first tested external characteristic is 'friability'(F). By indirect measurement of this feature, it is possible to judge the presence of bark and impurities in the pellets, which will worsen the combustion process and reduce the calorific value of the pellets. Pellets are loaded into the sieve with a hole diameter of 4 mm. This diameter is selected so that the destroyed pellets can be separated and whole pellets with a minimum diameter of 6 mm will remain on the sieve. The pellets should be well shaken so the dust and small fractions will be separated beneath the grate. The dust content means a lower pellet density. The bulk density of the pellets must be 650 kg/m^3 (https://peleti.xyz/). The dust and broken pellets are weighed with a scale mark "Elicom" model "EVL+PK-T". It has a measuring range of 0-3 kg and accuracy 0.1 g. The percentage of friability is determined by equation (1):

$$F = \frac{M_D}{M_P} \text{, kg} \quad (1)$$

where M_D is the mass of dust and broken pellets in kg and M_P – the total mass of the pellets in the package in kg. Typically, the pellet packages have a mass of 15 kg.
The sieved pellets are then placed in a specially sized container with internal dimensions 100x100x100 mm. For sealing the pellets are pressed against the container with the pressure up to 30 N. They are weighed on scales "EVL+PK-T" and their bulk density is determined by equation 2:

$$m_{VC} = m_S - m_t \text{ , kg} \quad (2)$$

where m_S is the total mass of the pellets with the container in kg and m_t is the mass of the container in kg.

The value obtained is compared with the reference value (ISO 17225-2:2014, https://peleti.xyz/).

- The second tested external parameter is 'optical control' (OK). Already sieved pellets are subjected to optical control to check their homogeneity and the presence of dark stains. The presence of dark stains in this subjective method implies non-homogeneity of the pellet composition and the presence of bark and impurities to reduce their calorific value. After sieving 100 pellets are counted from the pile of pellets. The diameter of the pellet and its length are measured by a caliper with a range of 0-150 mm and an accuracy of 0.05 mm. A statistical survey of dimensional scattering is carried out. It is judged For the uniformity of the pellets by the scattering of a given mean value of the dimensions.
- The last external parameter tested by direct measurement is 'moisture content' (H) of the pellets. Pellets should have a moisture content of 10-12% according to (ISO 17225-2:2014, https://peleti.xyz/). The moisture content is measured directly using a moisture meter of company "Merlin", model "HM8-WS-25" with a range of 4-99% operating at pellet density up to 670 kg/m^3.

The second stage is 'experimental control' (EC) aims to determine the quality of pellets under real combustion conditions. The methodhodology for determining the energy of the pellets is indirect. It uses for this purpose a specially designed mobile combustion chamber. The mobile camera resembles a real combustion chamber in a pellet boiler but is smaller in size. The chamber is thermal-insulated with 10 cm thick rock wool to reduce the heat loss between the walls and the surrounding air. The amount of 0.05 kg of pellets are placed in the bed of the mobile combustion chamber. A precise amount of air is fed through the ventilation system of the chamber via a pressure blower so that the pellets can burn completely at a certain speed. The excess air ratio of 1.4-1.6 according to (Yossifov 2005). An electric heater mounted after the pressure blower is used to heat the air supplied to the chamber to a temperature of 90 °C. Ignition is switched off after the appearance of visible fire. The presence of a flame is counted from a photo detector, and its indication is used to initiate the data collection from input-output card of company "National Instruments", model "USB 6001". This usually occurs after 1-3 minutes. The CO content of the flue gases is monitored over a period of 30 s during the combustion process. The CO content must correspond to the reference value established by the legal regulations (ISO 17225-2:2014). A suitable gauge for measuring the CO content is portable gas analyzer of the company "Testo", Model "T 310" (https://www.testo.com/en/).

The first controlled parameter in the pellet burning process is the 'temperature' (T) that is reached in the combustion chamber. Temperature measurement is done directly with a thermocouple mounted to the bottom of the bed in the combustion chamber. A suitable thermocouple is "TSNA-1J.T4.1" type J with a range of 0-800 ° C. The signal is logged directly from the input-output controller. The thermocouple information is recorded in every 30 seconds. Thus the energy generateted from the pellets can be analyzed.

The second controlled parameter is the 'burning time' (BT) for the complete burning of 0.05 kg of pellets. The time is recorded from the initial ignition of the pellets to their extinction. This is a complete cycle of burning and the burning rate of the pellets is determined against it. The burning rate of the pellets is determined by the equation 3:

$$V_B = \frac{m_p}{BT}\text{, kg/s} \quad (3)$$

where m_p is the mass of the pellets to be burned in kg;

The last controlled parameter is the 'ash' content of the pellets (A). The amount of ash is determined after the pellets in the bed of the mobile combustion chamber are completely burnt. The solids remaining in the bed of the combustion chamber are collected and weighed on the "EVL + PK-T" scale. The ash content is determined by the equation (4):

$$PP = \frac{M_P}{m_s}.100\text{, \%} \quad (4)$$

where M_P is the mass of ash remaining after burning the pellets in kg.

After the ash collection it is possible to determine the percentage of solid waste in the ash. The solid waste after weighing the ash is removed and weighed again on the "EVL + PK-T" scale. The percentage of solid waste is determined by equation (5):

$$HP = \frac{H}{M_P}.100\text{, \%} \quad (5)$$

where H is the mass of the solid waste in kg.

An option for determining the pellet energy potential is direct determination by a calorimeter, for example a calorimeter "KL 11 Mikado". This measurement will be calibrating to the proposed methodology in this paper. A temperature of 17-20 ^{0}C is set in the calorimeter casing. Two kg of distilled water with a temperature lower by 1 degree than that established in the housing of the calorimeter is placed in a calorimeter vessel. The inside walls of the calorimetric bomb are washed with 10 ml of distilled water for dissolving the nitrogen and sulfur oxides. A 100 mm helical semiconductor and 1 g ground pellets (with an accuracy of 0.0001 g) are measured. The ground pellets are pressed around the semiconductor. The resulting block is placed in the calorimeter and the two ends of the semiconductor engage the electrodes of the ignition system. The container closes tightly and oxygen is delivered through the valve to 30 MPa. The so prepared system is placed in the calorimeter and the automatic mode is started. The cycle time is between 10 and 30 minutes and is controlled by a microprocessor. After completion of the experiment, the calorific value of pellets is read directly from the display in Joules. The container is removed from the vessel, then opened, and unburned residues of helical wire are removed. Their mass is subtracted from the initial mass of the helical wire. The resulting value is the mass of burnt helical wire. This mass is multiplied by 6688 J/g (calorific value of the heel) and the resulting value is subtracted from the calorific value found by the pellet's sample (Todorov et all 2010).

The next stage of the methodology is the data processing and analysis of the results (AR). At this stage, a pellet quality analysis is carried out according to the applicable regulations (ISO 17225-2:2014, Yossifov 2005, https://peleti.xyz/). The energy potential of the pellets is determined based on the carried out experiments.

The final stage of the methodology is its practical application (PA). At this stage, with non-complex calculations, it is possible to determine the amount of pellets needed to heat a building with a known energy consumption.

Results and Discussion

A methodology for quickly and easy determination the quality of pellets offered on the market is developed on the basis of "theory of graphs". The practical application of this methodology is that by not so complicated measurements and calculations the required amount of pellets for heating a building with certain energy consumption for heating season could be determined. The methodology will raise consumer awareness about the benefits of using pellets to heat their homes, assist them in their choice of pellets and will lead to a possible reduction of harmful gases emited into the environment.

Conclusions

A methodology for quickly and easy determination of pellet quality has been developed. The methodology enables an effective determination of the energy potential of the investigated pellets.

The methodology can accurately determine the amount of pellets required for the heating of a building with a known energy consumption.

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