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Analysis of thermal properties of coffee grounds left over from coffee percolation

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Abstract. Coffee is one of the most popular beverages worldwide. The goal of this work is an estimation of the qualities of waste coffee grounds as a material used in biofuel production. There were selected two most popular coffee beans mixtures: arabica and arabica with robusta, as well as chocolate-flavoured coffee and green coffee (unroasted coffee beans). All types of coffee had approximately the same ash value its average oscillating between 2,59-3,21%. Calorific value of the dried waste coffee grounds after coffee percolation places it among very good energy materials

1 Introduction

Coffee is one of the most popular beverages worldwide. Rich aroma, the content of stimulating substances and availability make coffee continuously popular. Taking into account its popularity and the amount of coffee drunk every day, we might consider management of waste coffee grounds left over from coffee percolation, which we usually do not pay attention to, treat as undesirable waste, and throw away together with other rubbish [1].

Between 2014-2016 nearly 3.8 million tons of green coffee beans were imported to Europe (in 2016 nearly 4 million tons were imported excluding Belarus and Georgia). The most important coffee exporters to the European Union were Brazil and Vietnam. In the above-mentioned period the import of coffee from these countries exceeded half of the whole tonnage of imported coffee. A statistical citizen of the European Union drinks coffee infusion from 4 kilograms of coffee annually. In Scandinavian countries the consumption of coffee is the highest, in Finland 10.3 kg/person and in Sweden 9.2 kg/person. The smallest amount of coffee is consumed in Ireland (1.2 kg/person) and Great Britain (1.8 kg/person) according to the data for 2016. The data for Poland show that the consumption of coffee is below the average – 3.2 kg/person [2].

The demand for energy is growing every year resulting in the modification of legal and economic regulations. The aim of energy and economic efficiency is achieved by intensifying production in compliance with the environmental law. In the case of waste biomass, the energy outlay for biomass production and the cost of production is estimated as zero, due to the fact that the raw material is used for a different purpose, and it is no longer needed after it had been used. The main cost to estimate is the outlay for transport, storage and processing (initial processing, e.g. drying) of the material. As a result of processing biofuel is obtained, which may further be used in numerous fields of industry such as power industry, construction industry, communications and agriculture. It may be transformed in the process of conversion where its chemical energy changes into different forms of energy i.e. mechanical, thermal and electrical energy [3].

2 Goal and scope

The goal of this work is an estimation of the qualities of waste coffee grounds as a material used in biofuel production. The work comprises laboratory research: convective drying, estimation of the heat of combustion and ash content in waste coffee grounds. The analysis of thermal properties of the material being examined is based on the estimation of the time required for drying the samples of the material, ash content determination and calculation of the calorific value.

The experiments described in this paper were conducted in the drying laboratory at the Faculty of Production Engineering and in the laboratory at the Faculty of Food Sciences of the Warsaw University of Life Sciences. They were conducted using two most popular coffee beans mixtures: arabica and arabica with robusta, as well as chocolate-flavoured coffee and green coffee (unroasted coffee beans).

Arabica is the most popular type of coffee available on the market. It is characterised by a delicate flavour and aroma. The content of caffeine in Arabica beans oscillates between 1-1,5% [4]. Its cultivation is difficult as it grows on plantations located at a height of 1000-2000 m above sea level. A blend of arabica and robusta coffees, with the ratio 80-20, was also used in the experiments. Robusta is characterised by a bitter-muddy bouquet. It contains between 2,4-2,8% of caffeine. Its cultivation is easier than the cultivation of arabica – it can grow at a height of 200 m above sea level. It is also much more disease-resistant, and, for this reason, much cheaper [5,6]. Another material was arabica coffee mixed with some chocolate-flavour aromatizing substances. Traces of these substances could be seen on the beans. The so-called raw coffee – unchanged by any roasting process, was also used. It is characterized by a yellow-green colour, with a slightly bitter flavour and characteristic aroma.

3 Preparing coffee for the experiment

Prior to the experiments, the material for research i.e. coffee waste left over from coffee percolation was stored in the refrigerator at the temperature of approx. 4°C for the period of two weeks in tightly sealed bags made from polyethylene in order to find out whether mould, which may have a negative impact on persons processing biomass (may cause respiratory diseases), would form [7]. As the research proved, temperatures below approx. 5°C inhibit the growth of bacteria and mould while preserving significant biological properties of the material. Coffee was size-reduced (ground) into dust in an electric grinder. Due to the hardness of coffee beans it had to be size-reduced in a mortar. It was percolated in a moka pot – a type of coffee-maker, which works on the principle of pressure-induced percolation of coffee [8].

Convective drying

Drying is a technological process aimed at reducing the content of water in the given material [9]. Water is evaporated from its surface if the moisture of the material being examined exceeds the critical moisture. Water removal is compensated in the process of water diffusion from the inner layers of the material.

For research related to drying coffee waste left over from coffee percolation, a German dryer Memmert UFP 400 with an option of fan-forced circulation. Two racks mounted in the dryer were connected with the weighing machines fitted to the ceiling of the dryer, and the measurements taken by the weighing machines were recorded by the desktop computer.

The content of water in the samples was calculated from the following formula:

$$U=(m(\tau)-mds)/mds \tag{1}$$

where:
U - content of water in the sample [kg H_2O/kg d.s.],
m(τ) - mass of sample [kg],
mds - mass of dry matter [kg].

Furnace combustion

The examinations involved using a chamber furnace produced by LAC L operating within the maximum temperature range of 1150°C.

The measurement of ash content in the grounds left over from coffee percolation was performed according to PN-ISO 1171:2002 norm, according to which roasting is to take place in the temperature t=815±15°C for 25 min. Three samples of each type of coffee were prepared for the examinations. The ash content was calculated according to the following formula:

$$A=(m1-m2)/(m3-m2)\times 100\% \tag{2}$$

where:
A - ash content [%]
m1 - mass of vessel with the remains after roasting [g],
m2 - mass of vessel [g],
m3 - mass of vessel with the sample [g].

Total ash is the inorganic matter residue left over from fuel combustion in strictly specified conditions. It is the percentage of the dried fuel matter. The method of determination of total ash involves the total combustion of a fuel sample in the given time, necessary for the stabilization of matter, and temperature. It results in the formation of inorganic matter residue [10].

Results analysis

According to PN-77/D-04100 norm the furnace was heated to 105°C. Mass of dry matter for each type of coffee was equal (after conversion to 100 grams of coffee): Green: 20.11g of dry matter, Arabica: 18.68g of dry matter, Mixed: 19.23g of dry matter, Chocolate-flavoured: 18.5g of dry matter.

4 Kinetics of the process of drying coffee

The process of drying waste coffee grounds left over from coffee percolation was conducted in constant conditions with air temperature Tp= 60°C±0.5°C. Drying was conducted in free convection conditions (without forced circulation of the drying agent). The examination of each raw material lasted 20 hours (1200 min).

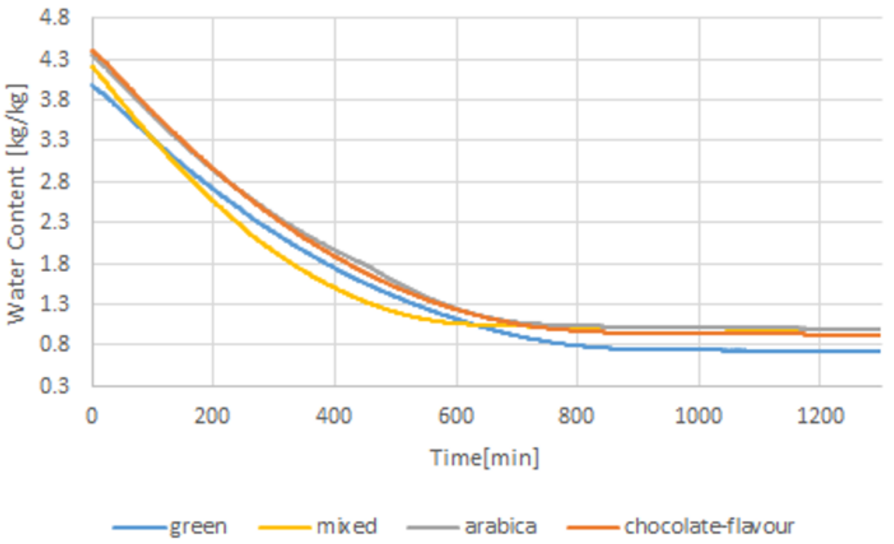


Fig. 1. A summary chart of the processes of drying coffee

At the initial stage of the process of drying arabica coffee the content of water in the waste coffee grounds left over from coffee percolation was approx. 4.35 [kg H2O/kg d.s.]. The process became effective within approx. 800 min., when the content of water in the waste coffee grounds reached 1.03 [kg H2O/kg d.s.]. After this time the value stabilized and reached 1.004 [kg H2O/kg d.s.] at the final stage of the process (1200 min).

The examination of the process of drying the arabica-robusta blend was carried out in the same way. At its initial stage the waste coffee grounds left over from the percolation of the coffee blend had the content of water of 4.19 [kg H2O/kg d.s.]. This value stabilized at 1.002 [kg H2O/kg d.s.] at the final stage of the process.

Chocolate-flavoured coffee showed the highest water content, reaching a level of 4.405 [kg H2O/kg d.s.]. The process of drying this coffee was longer than that of roasted coffees unmixed with any additional substances. At the end of the process the content of water content dropped to approx. 0.932 [kg H2O/kg d.s.].

Green coffee had the lowest initial content of water, i.e. 3.973 [kg H2O/kg d.s.]. The result of drying this type of coffee differed from that of roasted coffees. The effective drying of each sample lasted nearly 900 min. After this time the content of water in the coffee dropped to 0.738 [kg H2O/kg d.s.].

For the examinations of the process of convective drying the coffees were divided into two groups: roasted coffees and unroasted ones, i.e. green coffee. The results of drying the roasted coffees were similar as regards different types of coffee – the content of water in all coffees being dried oscillated at approx. ±1.0 [kg H2O/kg d.s.]. Chocolate-flavoured coffee, where aromatizing substances were applied onto the surface in the form of liquid, reached the lowest value of 0.932 [kg H2O/kg d.s.]. The time required to dry roasted coffees oscillated between 700-800 min. Green coffee reached the lowest moisture level oscillating at approx. 0.731 [kg H2O/kg d.s.]. This type of coffee was most amenable to the process of drying, which, however, lasted longer than in the case of other types of coffee – approx. 900 min.

5 Determining the calorific value of the coffee waste left over after percolation

The heat of combustion is the amount of heat released during the total combustion of a sample of material being examined and its cooling to the temperature of the surrounding. It is based on the assumption that water present in the exhaust fumes in the form of gas condenses, with the final products of the process being molecules of nitrogen, oxygen, carbon monoxide (IV), sulphur monoxide (IV), water (liquid form) and ash. If the material being examined contains sulphur and/or nitrogen, their oxides, released during the process, reacted with water to form sulphuric acid and nitric acid. The heat of synthesis released in the process is deducted from the obtained calorific effects produced during the combustion of the sample of the material.

The calorific value is the heat of combustion minus the value of the evaporation of water obtained during the process of combustion of the given material. The calorific value is calculated from the formula:

$$Qj=Qs-r \times mw/ms \quad [kJ/kg] \tag{3}$$

where: Qj – calorific value, [kJ/kg]
Qs – heat of combustion, [kJ/kg],
r - heat of vaporization $H2O$, [kJ/kg],
mw – mass of $H2O$ forming as a result of hydrogen combustion [kg],
ms- mass of the sample being examined, [kg]. [11, 12]

During examinations in the calorimeter the following calorific values were obtained for the examined types of coffee: Arabica: 22.3 MJ/kg, Mixed: 21.3 MJ/kg, Chocolate-flavoured: 21.3 MJ/kg, Green: 21.4 MJ/kg.

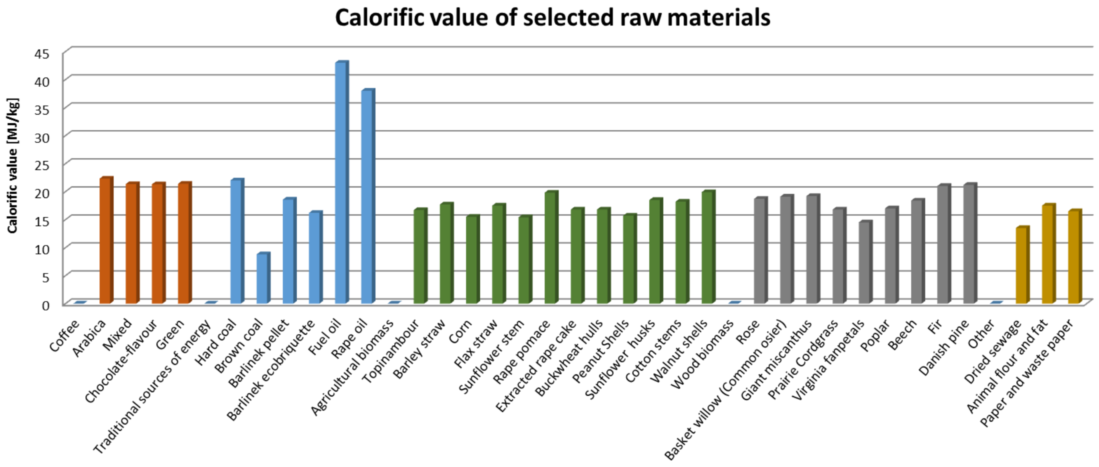


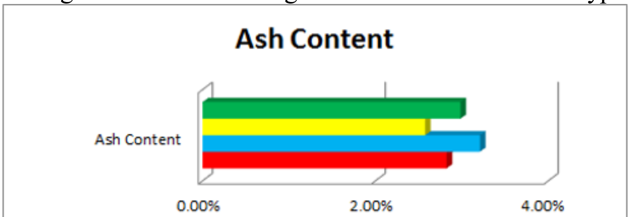
Fig. 2. Calorific value of selected raw materials**.**

Based on the literature the calorific values for other raw materials were compared with the calorific value of the material being examined. The raw materials were divided into the following categories: traditional fuels, agriculture-produced biomass, wood biomass and others [13]. The highest calorific value among the materials compared had pure fuel oil: 43 [MJ/kg] and rape oil 38 [MJ/kg]. The calorific value of all types of coffee waste left over after percolation was nearly twofold lower than the calorific value of the most energy-producing raw material and oscillated between approx. 21-22 [MJ/kg]. In comparison with other types of biomass coffee waste slightly exceeded the most energy-producing raw materials of agricultural origin or wood-derived raw materials i.e. walnut shells, having the calorific values of 19.9 [MJ/kg], and Danish pine, having the calorific values of 21.2 [MJ/kg].

6 Ash content

The measurement of ash content in the coffee waste left over after the percolation of arabica coffee showed that the third sample had the lowest ash content, i.e. 2.79%, and the third one had the highest, i.e. 3.59%. The average value was 3.21%. The measurement of ash content in the coffee waste left over after the percolation of the coffee blend showed that the third sample had the lowest ash content, and the first one had the highest, i.e. 2.32% and 2.87%. The average value was 3.21%. The results of the measurement of ash content in the coffee waste left over after the percolation of chocolate-flavoured coffee were respectively: 2.49%, 2.59%, 3.40%. The average value was 2.82%. The examination of the samples of green coffee showed that two out of three samples had approximately the same value of ash content, the difference being 0.01 percentage point (2.15% and 2.14%). The first sample being examined had the lowest ash value, i.e. 2.66%. The average value of the results was 2.99%.

The figure shows the average ash content for different types of coffee.



	Ash Content
Green	2.99%
Mixed	2.57%
Arabica	3.21%
Chocolate-flavour	2.82%

Fig. 3. Ash content**.**

All types of coffee had approximately the same ash value its average oscillating between 2.59-3.21%. It is worth to highlight that ash content was different for each sample and oscillated between 2.79-3.55% for arabica coffee, 2.79-3.55%, 2.32-2.87% for the coffee blend, 2.49-3.4% for chocolate-flavoured coffee, and 2.66-3.15% for green coffee.

7 Summary and conclusions

The popularity of coffee leads to the production of large quantities of coffee waste left over after percolation in many coffee houses in different towns and cities. However, using it as fuel becomes possible only after the process of drying as the high content of water diminishes its calorific value and slows down the process of combustion.

The results of the research led to the following conclusions:

- waste coffee grounds left over from coffee percolation may be stored in lowered temperature condition (4°C) without the risk of mould formation for at least two weeks,

- the process of drying was effective if it lasted 800-900 min for coffee grounds left over from roasted coffees, and 1000 min for green coffee. After this time the content of water in the material was reduced insignificantly.
- calorific value of the dried waste coffee grounds after coffee percolation places it among very good energy materials,
- waste coffee grounds left over from arabica percolation had the highest ash content (3.23%), and after green coffee percolation had the lowest ash content (2.21%),
- the problem of waste coffee grounds is their availability – large amounts may be obtained from facilities where coffee is percolated on a mass scale, e.g. restaurants, coffee houses, etc. Obtaining waste coffee grounds from individual consumers may be uneconomical due to the possible high cost of transport for one unit of energy produced during combustion,
- the main markets where waste coffee grounds may be obtained and become an attractive source of renewable energy are Germany and Italy, which import the largest amount of coffee, and Scandinavian countries, where annual coffee consumption per person is the highest.

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