Utilization of the energy potential of waste meal and creating of “green” workplaces

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Abstract. The issue of finding a suitable eco-technological approach for the utilization of waste meals generated in the production of vegetable oil is extremely relevant in terms of achieving a high "non-waste" degree in modern oil production. In practice, the direction related to the application of the meal as a material resource in animal husbandry is widely known – mainly for feeding of farm animals. At the same time, there are alternative areas related to other economic sectors, such as composting, biodiesel production, heat treatment and others, whose economic efficiency is still not sufficiently substantiated. Along with the topic of waste recovery, the measures for prevention of workers and ensuring safe and healthy working conditions are considered. The creation of "green" jobs, which directly or indirectly contribute significantly to the protection and restoration of the environment and to the reduction of the consumption of energy and raw materials, is extremely relevant in this direction.

1. Introduction
World olive oil production is concentrated in the Mediterranean region, with Spain, Greece and Italy being the three main producers, amounting to about 80% of world production. Olive oil production is one of the major sectors of agriculture, whose growth is expected to continue in the future. This industry generates significant amounts of waste and by-products (olive meal wastes) during the olive processing. This type of waste is a serious environmental problem for olives and olive oil producing countries, mainly due to emerging soil and water pollution [1-5]. According to [6], 35-40% of the processed olives are turned into waste meal (cake). We can point out that depending on the type of production process used, the generated quantities of the olive mill wastewater can be achieved up to 1.8 m³/ton olives at continuous process and up to 0.5 m³/ton olives at discontinuous process [7].

The use of the generated meal as a raw material or energy resource will help to achieve a positive economic effect for processing enterprises in two directions: reducing the price of produced olive oil and reducing the cost of treatment of the generated meal. The use of the meal as a material resource is realized mainly for feeding farm animals [8, 9], but it is possible to apply other methods such as composting, biodiesel production, direct application in soils to restore organic carbon stocks, etc. [10, 11]. Opportunities for the use of this type of waste as an energy resource are the biogasification, incineration, etc. [1, 4, 5, 12, 13].

Meal is characterized by high residual oil content and high humidity. For this reason, its utilization for energy production must be carried out after pre-treatment in order to reduce the moisture content or with mixed with additional mass of combustible materials with low humidity. In [14] was reported that for this purpose, the combination with wood particles would be extremely appropriate.
Balancing economic growth and the need to protect the environment are challenging goals to increase energy efficiency and to promote renewable energy, as well as to reduce waste. In the occupational safety sector, this has led to the emergence of a wide range of "green" workplaces – jobs that contribute to protecting the environment or restoring it to its original state. "Green" workplaces cover a wide range of different jobs in different sectors and include a diverse workforce. These may include workplaces that protect ecosystems and biodiversity or reduce energy and raw material consumption, or reduce waste and pollution [15]. However, for "green" workplaces to be sustainable, they must provide safe, healthy and worthy working conditions.

Work in agriculture and manufacturing is among the most dangerous occupations, and as a type of work, agriculture and forestry rank third or fourth among the most dangerous occupations in the European Union [16]. According to the International Labor Organization (ILO), about two million people die each year as a result of work-related accidents and occupational illnesses. It is estimated that 160 million people suffer from work-related illnesses, and 270 million fatal and non-fatal work-related accidents occur each year [17, 18]. This requires an in-depth workplace risk analysis to be considered at each stage of a work cycle, which in turn will lead to higher efficiency and better economic performance.

In the present study, emphasis is placed on the possibility of using the generated waste meal from olive production in energy production and the possible dangers for workers, which need to be taken into account for the creation of "green" workplaces.

2. Materials and methods

The production of olive oil is directly related to the production and cultivation of olive plants. A diagram illustrating this connection, summarized with the hazards for workers at each stage of the process, is shown in figure 1.

Calculation of the combustion process. When a material is considered a fuel, only some of the main elements that play a role in the combustion process are taken into account. Carbon (C), "free" hydrogen (H-free) and volatile sulfur (Sl) (contained mainly in the organic compounds of the fuel) are
considered as "valuable" elements for the process, and for the purposes of calculating the combustion the so-called "working mass" (WM), are taking into account [19, 20]. This mass includes the contents of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), ash (A) and moisture (W), the sum of which must be equal to 100%:

\[ X^W \equiv 100\% = C^W + H^W + O^W + N^W + S^W + A^W + W^W \]  

(1)

For the purposes of the calculations presented in this article, data on the thermal characteristics of two types of olive meal are taken into account, according to the results presented by Mladenov et all. [21] and Miranda et all. [14] – see table 1.

Table 1. Thermal properties of olive meal, in the work mass.

| Material                      | W^w | A^w | O^w | C^w | H^w | N^w | S^w |
|-------------------------------|-----|-----|-----|-----|-----|-----|-----|
| Olive meal [21]               | 71.80 | 1.67 | 15.72 | 6.29 | 4.28 | 0.21 | 0.03 |
| Olive meal (20 \% moisture)¹ | 20.00 | 4.72 | 44.6 | 17.86 | 12.14 | 0.60 | 0.09 |
| Olive meal (pomace) [14]      | 6.86 | 5.55 | 27.53 | 51.42 | 6.56 | 1.98 | 0.1 |

¹ The parameters are calculated theoretically on the basis of tolerance for reduced moisture content of 20\% and no losses with the emitted gases from the other elements.

The calculations are made for one kilogram of the working mass of the meal, under the following prerequisites:

- dry atmospheric air in proportion \( k (k = %N_2/%O_2 = 3.76) \), are use
- stoichiometric calculations are converted to normal conditions (\( P=1 \) atm, \( t=0^\circ C, V=22.4 \) m\(^3\))
- the absolute humidity value is assumed to be 13 [20] - \( g_{H_2O} = 13 [g \text{ water }/m^3 \text{ dry air}] \)
- the combustion reactions that going at actual combusting process, are:
  \[ C + O_2 = CO_2; \quad 2H_2 + O_2 m = 2H_2O \text{ (vapour)}; \quad S + O_2 = SO_2 \]

The calculating of theoretical (stoichiometric) combustion, before calculating the actual combustion, must be done. That stage is intermediate. Actual combustion is a process that requires an amount of oxygen that is actually necessary for the chemical reactions to take place to produce complete combustion products. It is always higher than the theoretical one and for its calculation an air flow rate value (\( \alpha \)) is used, which depends on various factors. In the present study, in order to ensure comparability between the obtained results, a value for this coefficient equal to 1.40 is accepted.

In the present study, the formula (2) proposed by M. Ioelovich [22] for the calculation of heat of combustion (heating value) was used.

\[ q (MJ/kg) = 0.344 \cdot C + 0.105 \cdot S - 0.110 \cdot O - 0.015 \cdot N \]  

(2)

where C, H, S, O and N is percentage of the corresponding elements in the raw material.

The calculation of the saved energy for households was made on the basis of an assumption for the average monthly electricity consumption for an average family of four, equal to 350 kWh and assuming that the generated meal is burned in small combustion plants up to 30 tons per year.

3. Results and discussion

The description of figure 1 gives an idea of the two main stages for the production of olive oil and its main waste product – olive meal. The first stage includes the agricultural activities for the establishment and maintenance of the olive groves and the dangers to which the workers in the sector are exposed. The main dangers are the when working with machines and equipment, musculoskeletal disorders, exposure to dangerous chemicals – fertilizers, pesticides and insecticides. Last but not least, the exposure to atmospheric influences - mainly solar radiation - must be taken into account. There is also a risk of exposure to biological agents when working in agriculture, and the various skin infections are very common. Prolonged contact with biological agents, soil, plants, pesticides and fertilizers, animals, manure and timber, can lead to a number of infections, tumors, scars and the development of fungal diseases. The second stage, related to the processing of the harvest and the
production of the final product, in addition to the above-mentioned hazards for workers, also includes the exposure to physical hazards - such as noise and vibration. All this requires an analysis of the risk in the workplace for each stage, to take into account the dangers and to take the necessary measures to ensure safe and healthy working conditions for workers.

The life cycle assessment (LCA) of olive oil production "from cradle to grave" includes consideration of all processes and operations from the arrival of the harvested olives in the factory in the beginning of the olive processing process to the extraction and use of the olive oil, and also treatment of the packaging waste in which it is stored and distributed, which are generated after consumption. Schematically such production is presented in figure 2.

![Figure 2. LCA of olive oil production process.](image)

In order to prepare "extra virgin" olive oil, the harvested olives are subjected to a preliminary treatment, during which the fallen branches, leaves and inorganic impurities are removed, after which they are washed. In the next stage, the cleaned olives are ground and pressed together with the stones, at which stage the grounded mass (pulp) are produced. To this mass is added warm water (up to 25 degrees), which is mixed with the pulp for 30-60 minutes. This is followed by a step in which the olive oil is separated (usually by centrifugation) from the rest of the mass, which is the waste olive meal, and then packed. Packaged olive oil is distributed in the commercial network and after its consumption, waste is generated from packaging in which it was stored and transported. The following tables present the results of the performed calculations.

The results for the calculated amounts of oxygen required for the actual combustion process and the amounts of excess air required for combustion show that these amounts are directly dependent on the composition of the feedstock and especially on the moisture content of the olive meal (table 2).

| Material                      | Oxygen required for actual combustion, m³ O₂/kg. meal | Excess air, m³ EA/kg. meal |
|-------------------------------|-------------------------------------------------------|---------------------------|
| Olive meal [21]               | 0.247                                                 | 0.478                     |
| Olive meal (20 % moisture)¹ [21] | 0.701                                                 | 1.358                     |
| Olive meal (pomace) [14]      | 1.135                                                 | 2.196                     |

EA – excess air,

For example, in the case of raw meal, the required amounts of oxygen and excess air are 0.247 m³ O₂/kg meal and 0.478 m³ EA/kg meal, respectively, at a moisture content of 71.8%. When the
moisture is partially removed and reaches a value of 20.0%, the required amounts of oxygen and excess air increase almost three times to 0.701 m³ O₂/kg meal and 1.358 m³ EA/kg meal.

The calculations for the composition of the generated flue gases are given in the table 3.

| Material                       | CO₂    | H₂O    | SO₂     | N₂     | Excess oxygen from combustion products |
|--------------------------------|--------|--------|---------|--------|----------------------------------------|
| Olive meal [21]               | 3.71   | 44.21  | 0.0066  | 48.95  | 3.13                                   |
| Olive meal (20 % moisture) [21]| 4.98   | 25.16  | 0.0094  | 65.66  | 4.19                                   |
| Olive meal (pomace) [14]      | 10.13  | 9.95   | 0.0074  | 75.11  | 4.80                                   |

The results of table 3, as expected, show that the share of generated water vapour in the flue gases decreases with decreasing humidity of the meal – the lowest is the content of generated water vapour in the meal with the lowest humidity. Simultaneously with the decrease in humidity, there is an increase in the share of the other components – mainly nitrogen gases and CO₂, which is why during the construction of the facilities cleaning facilities for these gases must be provided. The SO₂ content is directly related to the sulphur content of the original olive meal.

The calculations for the energy value, the amount of energy produced and the possible amount of saved energy produced from conventional fuels given in table 4 are performed without taking into account the heat losses of the heat generator due to incomplete combustion of the fuel due to chemical or mechanical reasons [14, 21]. These calculations give a sufficient idea of the potential of meal to be used for energy production.

| Material                      | Heating value, MJ/kg | Electricity, kWh/ton | Electricity at combusting of 30 t, MW/year | Economizes electricity from conventional sources for 10 household, about months* |
|-------------------------------|----------------------|-----------------------|-------------------------------------------|---------------------------------------------------------------------------------|
| Olive meal                    | 4.7145               | 1309.6                | 32.3                                      | 11                                                                             |
| Olive meal (20 % moisture)    | 13.378               | 3716.2                | 111.5                                     | 32                                                                             |
| Olive meal (pomace)           | 21.20                | 5889.2                | 176.7                                     | 50                                                                             |

The results of the calculations of heating value confirm the requirement for reduced humidity of the raw material intended for combustion – e.g. olive meal [21] with a moisture content of only 20% generates 2.8 times more heat, and meal with a moisture content of 6.86% (according to [14]) has the potential to generate 4.5 times more heat than wet.

The obtained results show significant differences between the values obtained for heating value and the electricity obtained from the combustion of a ton of meal, with the highest values expected to be obtained from the meal with the lowest humidity – 21.2 MJ/kg and 5 889.2 kWh/t, respectively. Burning low-moisture meal can save electricity produced by conventional fuels to cover the needs of 10 families in 4 years and 2 months. However, achieving such low humidity requires the use of additional energy, which can be partially or completely provided by the combustion of meal.

On the other hand, burning high-moisture meal can lead to energy savings from fossil fuels to cover the needs of 10 households with an average monthly electricity consumption of 350 kWh for 11 months, without the need to invest additional energy to reduce humidity. However, this is accompanied by additional technological complications related to difficulties in the combustion process, the need for the addition of materials for mechanical reduction of humidity, specific requirements for burners and many others.

4. Conclusions
The results of the calculations show that the use of waste meal for energy production is not only possible but also economically justified in order to save energy extracted from fossil fuels. The highest
values for heating value and electricity were obtained when calculating the combustion of tonnes of meal with low humidity (6.86%) – 21.2 MJ/kg and 5 889.2 kWh/t, respectively.

It is recommended that the combustion of the meal be carried out in specialized combustion plants in combination with combustible materials with low humidity and equipped with specialized equipment for capturing and cleaning the generated waste gases.

The description of the production process and the identified hazards for the workers show that the “green” from an ecological point of view manufactures are not always “safe” for the workers.

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