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Mass and energy flows of cardoon oil in a prototype system for seeds milling and vegetable oil treatment and cogeneration

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Abstract

The experimentation was carried out in a prototype for the production of vegetable oil from seeds. The system consists of seeds storage, mill, filtration system, oil tanks and diesel engine for combined heat and power production. The vegetable oil tested is cardoon oil; cardoon biomass is the main topic of BIT3G project, that aims to develop biorefineries integrated in the territory through the use of biomass residues or sustainable energy crops (cardoon, black locust, miscanthus) in marginal lands. In this study the milling step was monitored in order to evaluate mass and energy flows; input biomass was separated into biomass residues and seeds, and each part was evaluated in terms of mass, moisture, low heating value. The milling products, vegetable oil and solid panel, were evaluated in terms of mass, moisture and energy content, estimating oil efficiency in the press and main characteristics. Finally an energy balance was performed monitoring the process energy consumption and energy potential using all obtained products, oil, panel and residues for power, heat and cooling purposes.

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Keywords. Vegetable oil, cardoon, residual biomasses, seeds milling

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1. Introduction

Producing energy from non-food-competitive biomass is an emerging effective strategy allowing both to save resources and to protect the environment [1]. One of the more experienced field deals with the production of gaseous and liquid bio-fuels i.e. biogas and bio-methane, bio-ethanol, and bio-oils.

According to this, the European Commission have promoted the role of the bio-fuels to reach the new carbon dioxide reduction targets beyond 2030 [2]. Indeed, it is expected that up to the 34% CO_{2eq} reduction will derive from the further diffusion of the bio-fuels across Europe [3]. Concerning biogas and bio-methane, several small, medium and large sized plants are operative spread all over Europe, allowing the conversion of both organic and structured matrices into energy [4]; also bio-ethanol is going to be considered attractive if produced from third generation biomasses and in a bio-refinery vision [5].

Additionally, a new no-completely-investigated opportunity can arise from the use of the marginal and residual ligno-cellulosic biomasses in order to obtain energy (electricity and heat) from oils and bio-oils [6]. A particular focus is needed concerning the process of oil extraction from seeds; generally, it can be accomplished through chemical systems (by solvents), or mechanical ones. The first has the highest efficiency and it is therefore the most widely used method, especially for industrial applications; with this system the average yield in oil are about 59 kg to 100 kg of seed [7]. The alternative to the chemical process is the mechanical extraction (only possible with an oil content higher than 20%), which allows a maximum oil yield of 33 kg per 100 kg of seed [7].

The two extraction procedures originate different products, also in terms of energy content and chemical quality. The chemically obtained oil is an intermediate product, which must necessarily be treated by refining it to any forms of by-products deriving from building blocks such as bio-oils, bio-plastics and more; instead, the crude oil obtained by mechanical pressing, after filtration or decantation, can be used as such in diesel engines (properly modified) for the production of electricity or in agricultural tractors; however there is the possibility for it also to be refined as well as the first case, obtaining biodiesel [8].

In both cases, the extraction process generates a "no-waste" by-product so called "panel" that differs especially for energy content, much higher with the mechanical extraction and that is rich in proteins content. This is a convenient chance for animal feeding.

Concerning economical sustainability of the over-mentioned technologies, the solvent extraction techniques appear to be sustainable only in an industrial scale; on the contrary, the mechanical extraction process can be suitable also for smaller scale applications, such as the agro-industrial regional realities [9].

This paper presents both the layout and the mass-energy flows of the mechanical milling stage of a pilot plant located in the peripheral land of Umbria (Central Italy); the experimental facility has been arranged by CRB/CIRIAF during the implementation of the FACEB research project, financially supported by the Italian Ministry of Agriculture. The innovative plant is located in the historic value building location (i.e. Rocca Benedettina di Sant'Apollinare di Marsciano) and the case study represents a best practice of fully sustainable and architectural integration of renewable energy systems and buildings shape preservation.

Furthermore, the milling section of the plant has been shared by CRB for the BIT3G project purposes, allowing the evaluation of the mechanical and energy performances of this plant part with respect to the features of the used feedstock i.e. cardoon.

2. Experimentation

2.1 The case study layout

The facility layout is equipped allowing to process each phase of the agro-industrial energy chain i.e. starting from the loading and storage of the raw material (incoming seeds) to the storage of the finished products (oil tanks) and by-products such as panel. These components are fully integrated within the historic building (Fig.1 (a), (b)).

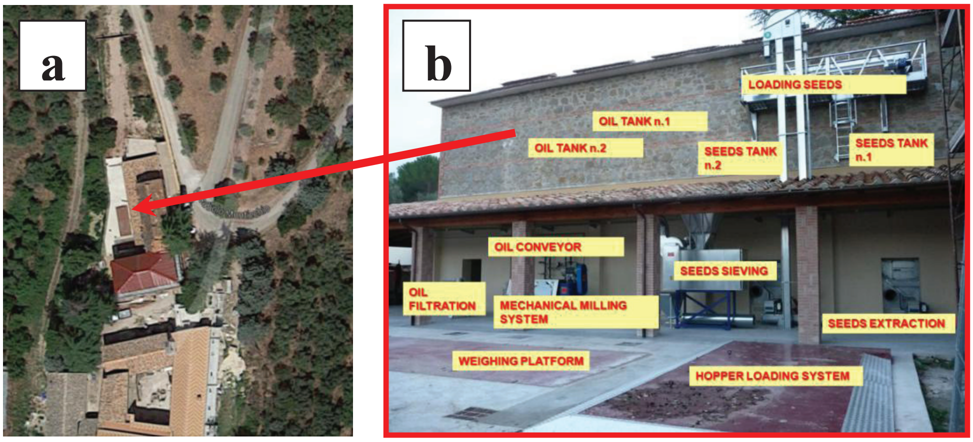

Fig.1 (a) Aerial view of the case study location; (b) vegetable oil pilot plant and its components.

The milling section (Fig. 2 (a, b)), that is the part in charge of the experimentation is composed of:

i. a system of vibrating sieves;
ii. a mechanical press;
iii. a filtration section.

The reasons explaining the larger diffusion of the mechanical pressing process are due to limited maintenance efforts and to its flexibility, allowing to use different types of product. The process is carried out in a continuous mode; in this case the press is working due to a compression process between the inner walls of a cylindrical chamber and the internal squeezing screw, rotating internally on its longitudinal axis. The mechanical extraction using discontinuous compression cycles is carried out by means of a piston sliding within a cylinder and it is mainly used for the production of high quality oils (olive oil, cocoa butter) and in small sized plants[10].

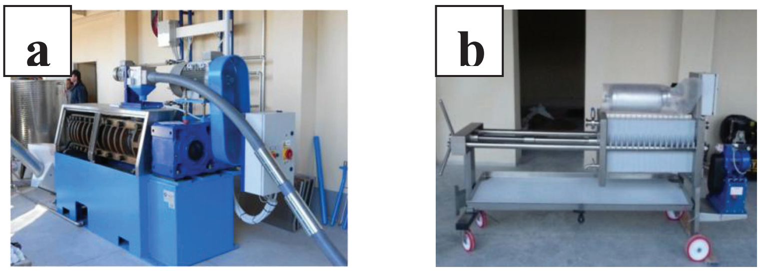

Fig.2. (a) the mechanical milling section; (b) the filtration section

Further to the crude vegetable oil, other two by-products (a oil-rich panel mixture and the pure panel) with a variable oil content have been obtained during the running phase.To this respect, there are two types of continuous presses screw possible to be used, mainly differing concerning the way in which the oil comes out from the cylindrical chamber. In the first type, that is the technology used in the experimental campaign, the oil flows out through some slots that are placed in the cylindrical chamber and the panel is ejected in the tangential direction of the general movement of the screw and close to its final part.In the second type, the oil flows out from the bore within small cavity and the filter cake is ejected in the axial direction to the screw, through an interchangeable nozzle on the head of the press.

The energy enhancement section of the vegetable oil plant (not employed within this research)is composed of a CHP engine of 100 kWe and 150 kWt, operating for up to 8000 h/y.

2.2 The mass-energy flows of the cardoon seeds milling phase

The experimental campaign was carried out from 19th to 21st of May and during this period, 3.002 kg of raw material (cardoon seeds) were treated. The complete mass-energy balance of the whole process is reported in Fig.3.

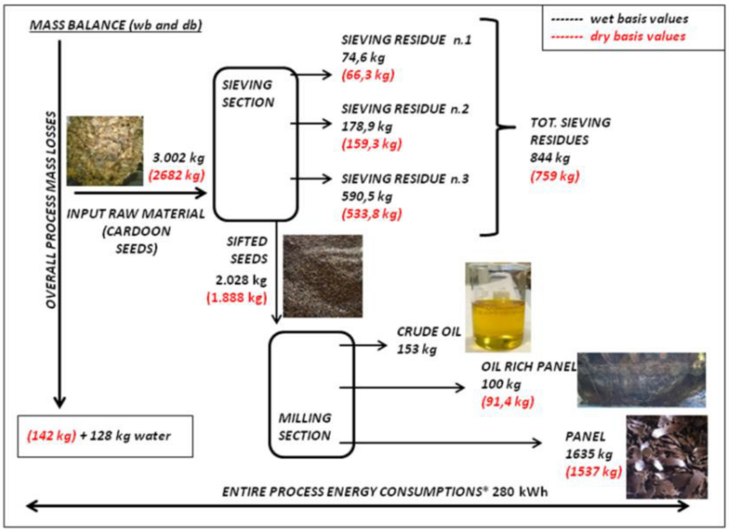

Fig. 3 Mass-energy balance of the sieving- milling facility for a 14h working period and with a 160 kg/h input raw material flux.

Several cardoon samples were preliminary analyzed in order to determine the humidity rate of the feedstock and the total weight of water within the total charge. The collected samples were characterized in lab in terms of water content and percentage of scrapped seeds over the total weight. These measurements quantified an average value of water content equal to 10.67% within the raw material. Afterwards, the seeds were stored inside the loading seeds tanks (Fig. 1(b)) and progressively charged across the sieving section, composed of n° 3 sieves characterized by the following features: (i) a coarse sieve with mesh size equal to 7-8 mm; (ii) and air flux sieve (exporting medium sized impurities), and (iii) a fine sieve with mesh size equal to 3 mm.

All the residues were weighed properly, allowing to make mass balance considerations. The hourly feedstock flow was fixed to 160 kg/h (even if the maximum admissible flow for the sieving and the milling sections is 300 kg/h). The start-up phase of the pilot facility was carried out using some rape seeds as well as the shutdown phase. For each processing phase, the weight of the products, by-products and residues were measured, together with the electrical consumptions of the system.

The average scrapped seeds fractions were then quantified in lab over a dry basis for both the input raw material and for the sifted seeds (after sieving separation); concerning this aspect, the results shown that: (i) about the 47% of the input raw material cardoon seeds was scrapped; (ii) about the 42% of the sifted seeds was scrapped. Concerning the water content of the residues, an average value of 10.5% was measured, while the water content in the panel and in the oil rich panel fluxes was equal to 6%.

During the running phase of the facility, some thermo-graphic analyses using the IR camera were carried out, in order to monitor the panel temperature stability. The maximum temperature for the panel was equal to 101°C.

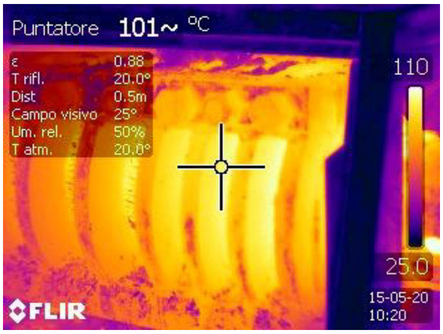

Fig.4 IR camera picture of the produced panel.

2.3 Process yields, overall mass losses, and energy evaluations

Globally, after monitoring of each input and output material fluxes, the overall yields and mass losses of the whole process were calculated. To this aim, also the density of the obtained oil was measured in lab and it resulted equal to 0.91 kg/l. The oil yield for the sifted seeds (dry basis) is equal to the 11.6% and the oil yield for the initial raw material (dry basis) is equal to the 10.8%. The oil yield for the sifted seeds (wet basis) is equal to the 10.8% and the oil yield for the initial raw material (wet basis) is equal to the 9.6%. Concerning mass losses, the balance demonstrated that 142 kg of dry matter (corresponding to the 5% of the initial raw material) was lost together with about 128 kg of water, representing the 4% of the initial raw material (wet basis).

After mass-energy balance of the system, some additional energy evaluations have been done. In particular, the energy obtained from the mechanical extraction of the crude oil is equal to 1602 kWh, obtainable from 153 kgof product and considering about 37 MJ/kg as crude oil LHV, while the energy spent for the mechanical extraction of the same quantity of oil is equal to 280 kWh. The process produced a net energy gain of about 1322 kWh (approximately 18% of oil energy is consumed in the process).

3. Conclusions and future perspectives

The paper presented the main results of the experimental campaign concerning the milling phase of the cardoon seeds. The seeds were sampled, stored and introduced to the CRB milling facility that is located in the Rocca Benedettina di Sant'Apollinare di Marsciano. The running phase of the facility allowed to determine the overall mass-energy balance of the whole process, including the mass losses. Further to this work, a parallel experimental campaign is going on in the lab facilities of the CRB section of CIRIAF, aiming at quantifying the chemical extraction potential for the oil content of the residues (panel and oil rich panel). The future aim of the research concerns the possibility to optimized the operative conditions of the facility and to reduce the overall energy-mass losses of the process.

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Biography

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