Letter to the Editor

Developments in the design and construction of continuous full-scale ultrasonic devices for the EVOO industry

Riccardo Amirante[1] and Maria Lisa Clodoveo[2]

[1] Department of Mechanics, Mathematics and Management (DMMM), Polytechnic University of Bari, Via Orabona, Italy

[2] Department of Agricultural and Environmental Science, University of Bari, Via Amendola, Bari, Italy

The road of scientific research from the pilot scale plant to the industrial applications is often long and winding. The introduction of an ultrasound device able to replace the malaxers into the virgin olive oil extraction plants is a matter deeply discussed. However, a full-scale industrial plant able to work in an effectively continuous mode is still lack in the market of olive oil extraction industrial plants. In order to overcome one of the main weaknesses of olive oil extraction plants, the discontinuity of the process due to the presence of the malaxer, a batch machine placed between the crusher and the decanter, effectively continuous ultrasonic full-scale solutions for the extra virgin olive oil industry have been developed.

Practical applications: High power ultrasound for the treatment of olive paste represents a system to replace the malaxing phase, the weakest link of the chain in the VOO extraction process. The malaxer is a batch machine, which works between two continuous devices, the fruit crusher and the decanter. It is also a bad heat exchanger due to a not favorable ratio between the big volume of olive paste that should be warmed and the small surface for the heat exchange. New devices need to be developed in order to optimize the extraction plant, reducing the time of process, the resource consumption without compromise the oil quality, in order to guarantee a right profit for the olive millers.

Keywords: Batch process versus continuous process / Emerging technologies / Heat exchanger / Innovative equipment / Ultrasound / Virgin olive oil

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1 About the ultrasound devices for the EVOO extraction process

We read with great interest the article by Bejaoui et al. [1], entitled "Continuous high power ultrasound treatment before malaxation, a laboratory scale approach: Effect on virgin olive oil quality criteria and yield." Published in 2016 in the journal "European Journal of Lipid Science and Technology."

Correspondence: Maria Lisa Clodoveo, Department of Agricultural and Environmental Science, University of Bari, Via Amendola 165/A 70126, Bari, Italy.
E-mail: marialisa.clodoveo@uniba.it
Fax: +39 080 5442504

Abbreviations: DT&E, developmental test and evaluation; **TRL,** technology readiness level

In this very interesting paper, the authors presented an innovative approach to the virgin olive oil (VOO) extraction process: they developed a continuous application of high power ultrasound on olive paste before malaxation at laboratory scale for VOO extraction, with the aim to study its effect on process yield and the VOO quality. They effectively demonstrated that sonication treatment improved the industrial oil yield by 1% and the oil extractability by 5.74%, quickly heating of the paste from 20 to 28°C, without causing changes in the quality indices, such as fatty acid composition and volatile aromatic compounds of the VOO, and enhancing tocopherol, chlorophylls, and carotenoids. The introduction of an ultrasound device able to replace the malaxers into the virgin olive oil extraction plants is a matter deeply discussed [2–9]. However, a full-scale industrial plant able to work in an effectively continuous mode is still lack in the market of olive oil extraction industrial plants.

Few years ago, we already discussed the advantages to develop an effectively continuous system able to replace the

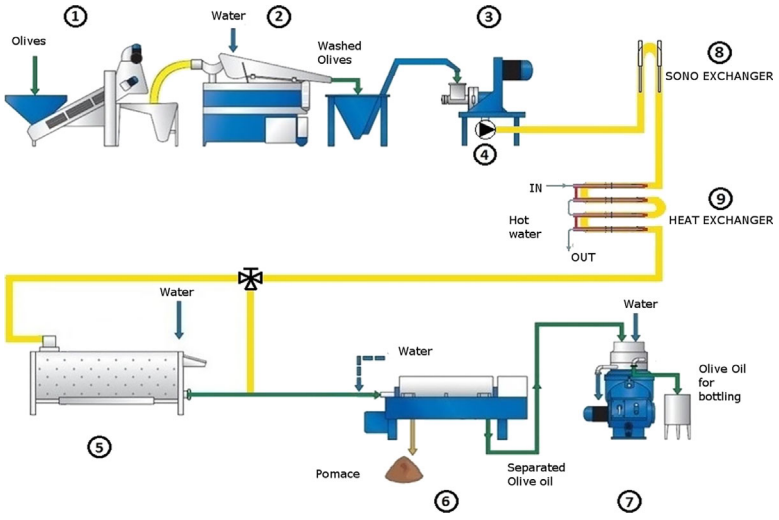

Figure 1. The sono-exchanger built employing the rod-style transducers in a full-scale EVOO industrial plant. 1, reception stage; 2, washing stage; 3, crushing stage; 4, pump; 5, malaxing stage; 6, separation stage; 7, clarification stage; 8, ultrasonic probes; 9, heat exchanger.

malaxation [10, 11], considered the bottleneck of the virgin olive oil extraction process (i.e., the stage in a process that causes the entire process to slow down). In fact, a continuous process presents some tangible, positive features such as minor operating costs, minor capacity limitations, faster return on investments, lower cost of production, reduced energy demands, reduced work-in-progress, faster and easier cleaning, real-time quality control, and significantly reduced footprint facility.

Different prototypes have been developed by our research team simultaneously with the work of Bejaoui and co-authors, with the same aims and the additional ambition to remove the malaxer from the VOO extraction line [1]. Ultrasound are a promising technology which can disrupt the tissue structures, including membranes of elaioplasts (i.e., specialized leucoplasts protected by a cellular membrane, responsible for the storage of lipids) freeing the trapped oily phase [12, 13]. Moreover, ultrasound, by means of cavitation, can increase the hydrophobic effect, improving the kinetic of the coalescence phenomena by enhancing the probability of particles collision leading to an increase of coalescence and oil recovery.

Figure 2. The sono-exchanger system built employing the rod-style transducers.

At low frequencies (<30 kHz), ultrasound can also split the emulsion into its component, aqueous and oily phases.

Condensing the theoretical insights gained from the examination of most recent patents with the newest scientific researches, innovative and effectively continuous ultrasonic devices for the extra virgin olive oil industry have been developed. The main considered patents were three, in particular (i) by Jimenez and co-inventors [14], which protected the idea of a system for the control of applied ultrasound based on the information provided by the temperature sensors; (ii) by Pieralisi [15], which proposes to accelerate the oil extraction process applying ultrasound directly in contact with the olive paste with the synergetic effect of a heater-conveyor; and (iii) by Masotti and co-authors [16] which patented an ultrasound devices useful to improve the quantity of polyphenols the turbidity stability of the EVOOs. While, the considered research activities concerned the effects of heat-exchange [17], both warming and cooling, in order to exploit the multiple combinations between different sonication power intensities and temperatures, in particular the works made by Amirante et al. [18], Veneziani et al. [19], and Balzano et al. [20].

The critical reading of the state of the art has lead to two different setups of full-scale ultrasonic devices based on the employment of the two different kind of ultrasound transducers: (i) the rod-style transducer (Figs. 1 and 2) and (ii) the plate shape transducer (Figs. 3 and 4). The two devices are named sono-heat-exchanger due to the combination of a heat-exchanger with ultrasonic transducers.

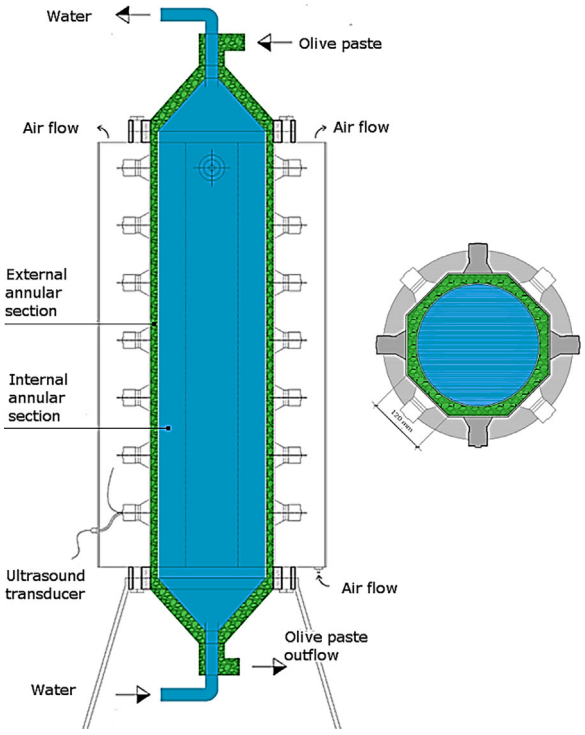

Figure 3. The sono-heat-exchanger system with the plate shape transducers.

Figure 4. The sono-heat-exchanger system projected employing the plate shape transducers.

The model built employing the rod-style transducers is made of two straight pipes connected by an elbow (Figs. 1 and 2). Two ultrasonic rod-style transducers (Sonopush Mono® 30–1500 W – 30 kHz) were plugged into the straight pipes through the bend. At last, a third ultrasound transducer (30–1400 W output power) was placed downstream the heat exchanger.

The sono-heat-exchanger, employing the plate shape transducers, is composed of a couple of annular sections (Figs. 3 and 4). The olive paste flows into the external annular section, while water flows the internal annular section to control temperature inside olive paste.

Outside the external annular flow section, a transducer for each side of an octagonal shape is set-up to provide ultrasounds. The energy per kilogram of olive paste is due to the power of each transducer and the flowrate flowing inside the sono-exchanger.

The choose of this couple of parameters should be performed keeping in mind that the best results can be achieved by means of 15–18 kJ/kg at 30 kHz [4]. The heat exchanger is necessary to control the olive paste temperature in the range of 23–27°C.

A cold-water flow (4–5°C) can be provided into the inner annular space to decrease the olive paste temperature in the geographical areas characterized by a high ambient temperature (Sicily region in Italy, North African countries and Australia). On the other hand, a warm water flow (20–50°C) can be provided into the inner annular space to warm up the olive paste in the geographical areas characterized by low temperature during the harvesting season (Umbria and Tuscany in Italy, some regions in Spain).

The main results of the effectively continuous devices that will be extensively discussed in a next paper can be briefly resumed: the sonication treatment improves the industrial oil yield by 2% and the oil extractability by 10%; the high-power ultrasound do not affect oil quality parameters, while nutritional and sensory characteristics can be significantly influenced. The bio-phenol content, as well as tocopherols (vitamin E), chlorophylls and carotenoids content can be improved.

Sensory evaluation by panel test showed higher intensity of positive attributes in oils from sonicated pastes compared to those untreated. Off-flavors were not detected in oils from sonication treatments.

2 Conclusions

The implementation of ultrasound into the olive oil extraction process is characterized by a technology readiness level (TRL) equal to 8 (System development), having been validated into a full-scale olive mill. Technology has been proven to work in its final form and under expected conditions.

This TRL represents the end of true system development. Developmental test and evaluation (DT&E) of the system useful to determine if it meets design specifications are still needed, mainly to verify the optimization conditions [21, 22], especially when the apparatuses are placed in different geographical area, characterized by a variety of olive cultivars, fruits harvested at different stage of maturity, grown varying agronomic practices in terms of watering and fertilizing.

The achievement of the TRL 9, the technology in its final form, still requires some efforts. We hope that all the researchers that from many years are working on this topic will contribute to reach the goal.

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(iii) AGER Foundation— Olive Tree and Oil: Competitive —Claims of olive oil to improve the market value of the product.

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