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Acoustic cavitation by means ultrasounds in the extra virgin olive oil extraction process

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Abstract

The virgin olive oil extraction process has changed very little over the past 20 years when the mechanical crushers, malaxers, horizontal and vertical centrifuges, took place in the olive mills. However, malaxation process remains the main critical step due to the discontinuity of this process. In previous activities, the same authors demonstrated how application of new emerging technologies could offer an interesting number of advantages to remove this bottleneck and, among the others, the ultrasound (US) technology is the most promising one, due to its mechanical and thermal effects due to the acoustic cavitation phenomenon. Acoustic cavitation, provided by means of low frequency high power ultrasounds, increases the quality, the work capacity and efficiency of the extraction plant, guaranteeing the sustainability. The paper shows how the authors have designed, realized and tested the first in the world continuous ultrasonic full-scale device for the extra virgin olive oil industry, with the aim to obtain the best product quality at the highest efficiency. Considering the heterogeneity of the olive paste, which is composed of different tissues, and considering the large number of parameters able to influence the process, a 3D multiphase CFD analysis was used as auxiliary tool in the design a so-called Sono-Heat-Exchanger (SHE). This innovative device, to be placed between the crusher and the decanter, is a combination of a heat-exchanger with plate-shape ultrasonic transducers. Finally, experimental results about yields and phenols contents demonstrated the relevance of this innovation.

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Keywords: Virgin olive oil, cavitation; batch process versus continuous process; emerging technologies, ultrasound, heat exchanger.

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1. Introduction

Ultrasound (US) is a promising emerging technology that has already found application in the food industry [1–3] due to its significant effects on the processes, such as higher product yields, shorter processing times, reduced operating and maintenance costs, improved taste, texture, flavour and colour [4]. Recent findings reported in the literature have highlighted that US has promising application in the field of virgin olive oil industry as well, due to the mechanical and thermal effects useful to guarantee adequate oil yields, thus reducing the process time and improving the process efficiency [5–7]. The thermal effect occurs when kinetic energy of the ultrasound waves is converted into the thermal energy due to the turbulence increment in the matter [8,9]. The mechanical effect is due to the cavitation phenomena. In other words, when ultrasound is applied on a continuum fluid, it produces sinusoidal acoustic waves and tiny gas bubbles grow within the fluid when the local pressure falls below the vapour pressure of the liquid [10,11]. If the bubble growth reaches a critical size, it implodes causing the phenomenon of cavitation, the most important effect in high-power ultrasound. Generally speaking, the phenomenon of violent bubble implosions is characterized by extreme local conditions, such as high pressure differentials, shock waves and liquid jets [12], that promote the rupture of the solids that are in the liquid medium, thereby increasing both the total solid surface in contact with the liquid phase and the mass transfer [10,13–16]. In the case of the olive paste, cavitation, by means of ultrasounds, promotes the disruption of 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 [17,18] . Thus, the application of ultrasound-waves to olive paste can effectively enhances the release of soluble compounds from the plant tissue and improves mass transfer also in the olive tissues [19]. Moreover, ultrasound 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 [18,20]. It has been also demonstrated that, at low frequencies (<30 kHz), ultrasound can split the emulsion into its component, aqueous and oily phases. [17].

Currently, the mechanical methods used to extract virgin oils from olives is generally made up of a mechanical crusher, a few malaxers and horizontal (decanter) and vertical-axis centrifugal separators. The mechanical crusher and the centrifugal separators operate continuously, while, the malaxer is a batch machine, which works between continuous devices. For this reason, the malaxation represents the bottleneck of the continuous extraction process [21]. Moreover, the malaxer is an inefficient heat-exchanger due to a not favourable ratio between its large volume and small surface [6].

Olive trees represent an economic and social resource in the Mediterranean area [22–25] since virgin olive oil (VOO) is the main component of the Mediterranean diet due to its excellent sensory and nutritional qualities [26]. Therefore, it is of interest to develop innovative and sustainable plant solutions able to increase both the yield and the quality of the VOO extraction process [21,27,28]. And the development of a fully continuous process presents some tangible, positive features that can help to achieve this aim [29]. As consequence, increasing research efforts have been put into the design of advanced machines able to transform the discontinuous malaxing step into a fully continuous phase [6,20,30]. For the abovementioned reasons, high power ultrasound for the treatment of olive paste represents a practical solution able to reduce the duration of malaxation and, at the same time, increase both the yield and the quality of the resulting VOO.

Following this intuition, innovative and continuous ultrasonic devices for the extra virgin olive oil industry have been developed. For instance, Pieralisi [31] proposed to accelerate the oil extraction process applying ultrasound directly in contact with the olive paste with the synergetic effect of a heater-conveyor; Masotti et al. [32] patented an ultrasound device useful to improve the quantity of polyphenols the turbidity stability of the EVOOs. Other research activities, such as the works made by Amirante et al. [8], Veneziani et al. [33], and Balzano et al. [34], concerned the effects of heat-exchange, in order to exploit the multiple combinations between different sonication power intensities and temperatures.

Clodoveo et al. [12], in 2013, tested at pilot scale the ultrasound treatment both on olive fruits submerged in a water bath (before crushing) and on olive paste before the malaxation (immediately after crushing). The ultrasound technology allowed a reduction in the duration of malaxing phase improving oil yields and its minor compounds content. Between 2015 and 2016, confirmed the results obtained by Clodoveo et al. [12], as also reported in [17]. They observed that the ultrasound treatment caused an improvement of the oil yield of about 1% and the oil extractability equal to approximately 5.7%. Furthermore, a slightly heating of olive paste can be obtained by high-power ultrasound and it can be considered an alternative at the traditional warming system based on the conductive and convective systems occurring in the malaxers. Evaluations regarding the effect of ultrasound on oil quality parameters, nutritional