Industrial processing of red and white grapes assisted by Pulsed Electric Fields

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Abstract— **The results of industrial scale processing of nearly 200 tons of red and white grapes assisted by monopolar pulsed electric fields, PEF, are discussed in this paper. An industrial equipment, comprising a 10 kV/ 3kW solid-state pulse modulator connected to a two gaps co-field treatment chamber, was used to apply approximately 500 V/cm pulsed field protocol to different grape varieties with the aim of improving the extraction of flavor precursors, enhancing the phenolic content and increasing the yield of juice extraction process. Preliminary results show that PEF can increase value on industrial scale, but there are a number of variables difficult to control in this environment.**

Keywords—solid-state modulator; instustrial scale prcessing; Pulsed Electric Fields; grapes

I. INTRODUCTION

The processing of food through the application of Pulsed Electric Fields, PEF, for enhancing the extraction of the inner plant cells content, is today one of the most promising civil applications of pulsed power. In fact, during the last decade much work has been done in the field of electroporation, related to the improving of mass transfer in different processes of the food industry [1-2]. One of these, related to the application of PEF to grapes in the winemaking industry, for improving the extraction of flavor precursors, enhancing the phenolic removal during the maceration process and increasing the yield of juice extraction, is closer to industrial application [3-5].

Nevertheless, limited results on an industrial scale are an evidence of the complex path necessary to meet up with industrial specifications. These comprise the usual cost and profit variables, the existence of industrial partners open to new technologies and willing to share some risks, having an industrial modulator to do the job, and finally the flexibility to adjust it to the industrial process, which includes additional variables.

In this paper a 10 kV/3 kW monopolar pulse solid-state modulator developed for industrial environment is incorporated in the winemaking process of the João Portugal Ramos winery from the Alentejo region of Portugal. About 200 tons of different grape varieties of white and red grapes were processed with PEF with the aim of: 1) extracting the same quantity of juice from white grapes but with a lower time and pressure on the presses; 2) reducing the extraction time of polyphenols (i.e. phenolic content) on red grapes during the maceration process; 3) identifying the main problems with the implementation of the technology in the industry and quantify the added value of the PEF equipment.

II. INDUSTRIAL SCALE EQUIPMENT

In order to implement an industrial scale process for applying pulsed electric fields to tons of grapes several aspect should be taken into consideration: i) one no longer have control over many parameters that influence the process, as in a laboratory experience; ii) the incoming technique must be adapted to the process in progress and not the other way around; iii) the proposed technology must be installed with minimum changes to the running process.

Considering the later, an industrial 10kV/ 3kW solid-state pulse modulator, with 800x600x400 mm^3 and 80 kg was assembled. The modulator is connected to a co-field treating chamber, with 120 mm diameter and two 80 mm width gaps, through a 3 m coaxial cable. The size of the chamber was defined by the industrial standard tubes installed. Fig. 1 shows a picture of the modulator connected to the treatment chamber, in operation in one of the locations used. The operator can set the PEF protocol in the modulator via a touch screen display, which shows also the essential process parameters.

Figure 1. Photography of the industrial equipment for PEF; the pulse modulator connected to the treatment chamber.

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The power of the modulator was conditioned by its size, which was defined in order to have a portable equipment, compact so as to fit narrow spaces and to move between several locations in a few minutes. Other characteristics were taken into consideration when designing and assembling the modulator; reliability, modularity, operation flexibility and energy efficiency. In fact, today's requirements for industry are more focus in environmental and energy efficiency issue than ever before, which impose new challenges to technology.

To accomplish the desire characteristic, the modulator was based on a solid-state Marx type generator, which simplified circuit is shown in Fig. 2. This circuit is discussed in detail elsewhere [6]. In order to reduce the cost of the equipment it was decided to use 1200 V semiconductor devices that are commercially available in an off-the-shelf basis.

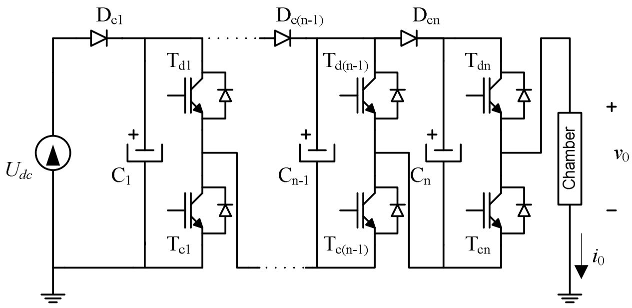


Figure 2. Simplified circuit of the solid-state based Marx type generator used in the modulator for producing the high-voltage pulses.

One of the advantages of using a capacitive type discharge pulse modulator is the weak dependence of the voltage waveform on the impedance of the load, as long as the energy stored in the modulator (i.e. in the electric field of the capacitors) is high compared to the energy delivered in each pulse, normally greater than 5 to 10 times, in order to have a voltage droop in the voltage pulse lower than 10 %. This is very important because normally when processing food, the density and conductivity of the material that is passing through the treating chamber can vary greatly.

Fig. 3 shows a typical voltage and current pulse waveform of the Fig. 1 modulator; 10 kV / 100 A pulse, 24 µs width and 100 Hz repetition rate, considering a resistive load, which is the typical condition when processing the grapes.

III. Experimental Procedure

About 195 tons of grapes were processed with PEF, in the João Portugal Ramos winery, from Alentejo region of Portugal, using the equipment shown in Fig. 1 and described in the last section. The grapes arrive in trucks and are dumped into pumps that take off the stem, afterwards the grapes are crushed in presses and the grape mash is injected into fermentation tanks. The PEF treatment chamber is connected just outside the pumping systems, before the presses.

The experimental protocols used are presented in Table 1, where different varieties of red and white grapes were subjected to PEF. The third column shows, per grape variety, the quantity of grapes subjected to PEF, where approximately the same amount was taken as control sample. Considering Table 1, in average roughly 195 tons were processed with a flux of 18.6 T/h at 21ºC, with 12 Pulses/kg.

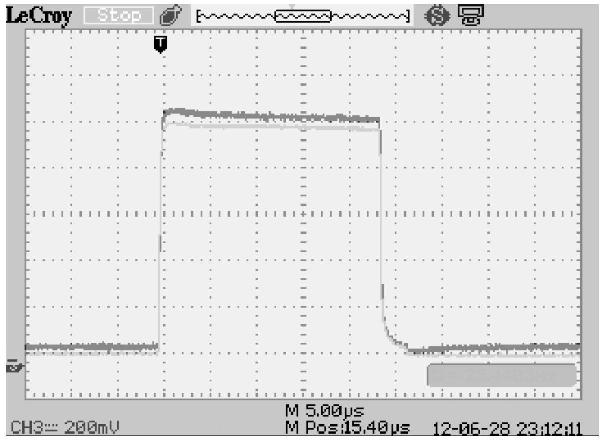


Figure 3. (dark trace) voltage pulse 2 kV/div and (light trace) current pulse 20 A/div from the modulator, with 5µs/div.

TABLE I. Experimental Protocols

Wine	*Grape variety*	*T*	*ºC*	*T/h*	*J/kg*	*Pulses/ kg*
Red	Alfrocheiro	18.5	19	15.4	390	12
	Trincadeira	63	19	20.7	390	18
	Touriga	20	20	14.9	460	12
	Cabernet	19,5	18	24	300	8
	Aragonés	19,8	25	28	345	6
White	Antão Vaz	17,9	22	11	475	13
	Arinto	22,7	22	17,2	400	11
	Verdelho	13,6	24	17,4	426	13
#		195	21	18,6	400	12

Considering that 6000 V amplitude pulses were applied in the center ring of the co-field treatment chamber, with 85 µs pulse width, and 50 Hz repetition rate, the grapes were subjected to a field of 500 V/cm and 400 J/kg. The average field was calculated through simulation, considering the shape and dimension of the treatment chamber, as shown in Fig. 4, where one gap of the treatment chamber is represented. It is observed that the main flux passes through an area of 400 to 600 V/cm field.

Treating times vary from 610 µs to 1.53 ms, due to differences in the flux, from 11 T/h to 28 T/h, which are mainly dependent on how the grapes are picked. If the harvesting is mechanical, the grapes come without stems and the pumps impose high flux to the grape mash, but if it is a manual harvesting the grape stem removing machine slows down the flux of the grape mash. Also, the temperature of the grapes vary from 17ºC to 31ºC, depending on the period of the day or night when the grapes are picked, and the ratio of liquid to solid content in the tubes was not always the same.

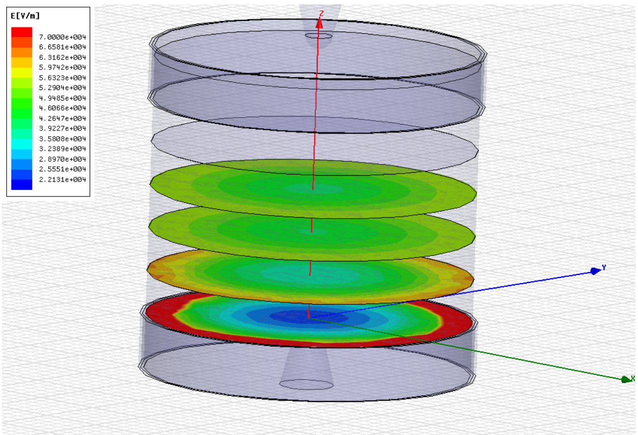


Figure 4. Simulated electric field gradient for the co-field transducer used.

In addition, in average, the power delivered to the grapes by the modulator was 2 kW, with pulse currents from 50 A to 115 A, which was dependent on the conductivity of the mash, affected by the temperature, solid content and grape variety.

IV. Experimental Results

Regarding the white grapes, while in the laboratory an increase in the juice from white grapes treated with PEF, is normally obtained, because the press in the industry extracts almost all the juice from the grapes, and it was not feasible during the harvest to decrease its pressure, it was not possible to verify the same effect in the winery.

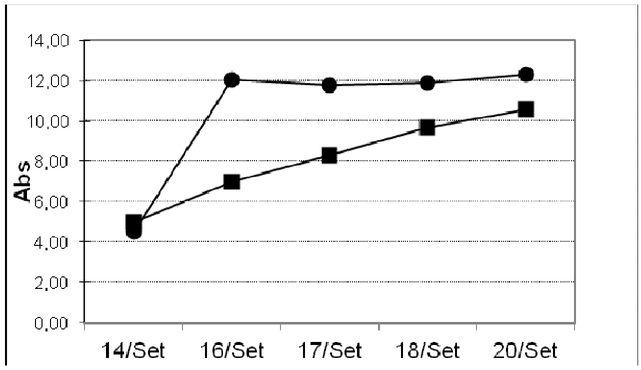
Nevertheless, in situ results after pressing the white grapes show that that the solid content after PEF application was drier in comparison with the control samples. The grape mash will be dumped into barrels and future analysis of the aging of the wine is expected.

Concerning the red grapes, the best results are shown in Fig. 5, for the Alfrocheiro grape variety, where one can see two lines representing the evolution of the grape mash characteristics of the PEF mash and on the untreated grape mash, measured on six consecutive days after the grape mash has been deposit on the fermentation tanks. There are no error bars in the graphics because only one test was made for each point, i.e. per day.

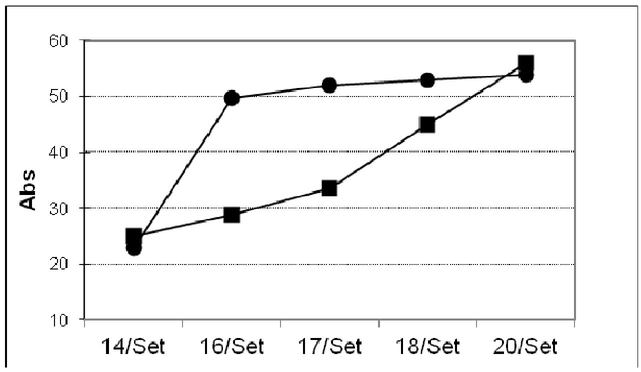
In Fig. 5 a) the color index is show, where the PEF grape mash reached a darker color just two days after, while the untreated grape mash reached a similar value on the sixth day. In Fig. 5 b) the total polyphenols index is shown, where the PEF grape mash reached approximately the same amount four days before as the untreated grape mash. Finally, Fig. 5 c) shows the grape mash density, which is related to the fermentation status. When the density reached a value near 990 the fermentation stops and the grape mash is ready to go to the next process. Also, in this graph the PEF treated material reach the final value almost 4 days after the untreated one.

The analyses of the color index (IC), and total polyphenols index (IPT) were obtained by FTIR (Fourier transform spectroscopy), with the Bacchus model equipment from Microdom.

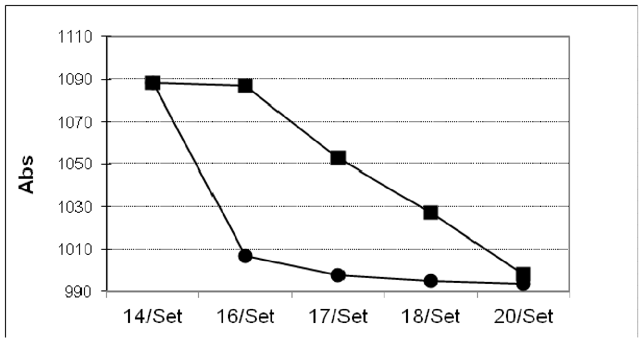
These results shows, at least for this grape variety, with the tested protocol, that the PEF treatment accelerated the process of maceration of the grapes, increasing plant capacity, which in turn can reduce the costs involved with these processes.



(a)



(b)



(c)

Figure 5. Comparison between PEF (circle) and untreated (square) grape mash characteristics, for six consecutive days: a) color index; b) total polyphenols index; c) density. Vertical axis shows the absolute value of the parameters and in horizontal axis it is represented the days when the tests were made.

However, the results shown in Fig. 5 were not the same with all treated grape varieties. In several cases there were no significant changes between the PEF and untreated mash grapes, during first preliminary tests.

The reasons why the results were not similar for all treated grapes could be explained by differences in temperature of the grapes, mass uniformity, flux, number of pulses and grape species. Some of these are not possible to control in an industrial scale facility where millions of kilograms are processed.

In comparison with the protocols from other authors [3-5] one can say that in spite the J/kg and kV/cm used were lower, the obtained results are not much different. The reason why this protocol was chosen was to have especially portable equipment, flexible to fit narrow spaces and to move between several locations in a few minutes.

A lot of results are still to come, as the percentage of flavor precursors in the wine. In fact, for the next months the grape mash processed will be closely followed.

In the future several equipments, similar to the one shown in Fig. 1, rather than one with the overall power, will be used with various treatment chambers connected in series, in order to apply different pulse protocols at the same time, which is expect to enhance the results.

V. CONCLUSIONS

The results of industrial scale processing of nearly 200 tons of red and white grapes assisted by monopolar pulsed electric fields, PEF, were presented in this paper. An industrial equipment, comprising a 10 kV/ 3kW solid-state pulse modulator connected two gaps co-field treatment chamber, was used to apply an average of 500 V/cm pulsed field protocol to different grape varieties with the aim of improving the extraction of flavor precursors, enhancing the phenolic content and increasing the yield of juice extraction process.

Preliminary results show that PEF can increase value on industrial scale, but the difficulty in controlling several parameters, such as flux and temperature, important to the electroporation of plant cells for mass transfer, lead to lack of regularity of the achieved results.

In addition, as the grape harvest is a seasonal work, extra complexity is added in order to evaluate the added value of this application to the wine making industry. Even so, this sector has never before been so available to the introduction of new technologies.

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