CHEMICAL ENGINEERING TRANSACTIONS

VOL. 58, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone

ISBN 978-88-95608-52-5; **ISSN** 2283-9216

DOI: 10.3303/CET1758072

A Device for the Monitoring of the Cap Buoyancy during the Red Grapes Fermentation

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The pomace cap formation during the red grape fermentation is widely described in literature. However, the measurement of the cap buoyancy is a less debated issue despite it affects several oenological practices. Particularly, it could affect the pomace cap management strategy and the related operations in order to achieve the extraction of compounds from the skins of the berries. In fact, buoyancy affects the volume of the cap submerged by the juice, and consequently contact between the skins and the must. Thus, understanding the changes in cap buoyancy could help to improve the pomace cap management.
In our test we set up a measurement device able to record, with a load cell and a data-logger, the buoyancy of the pomace cap at different times. Afterward, we test the measurement device at laboratory scale.
The measurements show the relationship between the buoyancy and the juice density, the berries density (i.e. both real, and apparent density), and the carbon dioxide emission during the alcoholic fermentation.
During the alcoholic fermentation, the cap changes the force against the load cell as results of the change in cap buoyancy. At the beginning of the fermentation the berries skins are on the bottom of the fermentation vessel. Then, after roughly one day, the pomace cap raise up and start to float and to push against the load cell. The buoyancy force reaches its maximum in our conditions roughly between the fourth and the fifth days, and finally it decreases until the end of the fermentation.
Furthermore, the carbon dioxide escaping from the fermentation vessel produces a vibration on the pomace cap. This vibration is detected by the load cell, and could be related to the fermentation speed. Thus, the measurement of the vibration magnitude allows the monitoring of the flux of the carbon dioxide and, consequently of the fermentation speed. In fact, as expected the maximum has been recorded during the day 3 of the fermentation, namely during the tumultuous phase and when the decrease of the density is maximum. Coherently, the vibration magnitude increases until the third day and decrease up to roughly zero at the end of the fermentation. The relationship between the latter parameter and the buoyancy allows us to monitor the fermentation kinetic.
The control of the fermentation kinetic still remain an open issue in oenology, and the development of simple systems for its measure could lead to kept this objective. The presented results could encourage implementing the measurement system in the future vintages. However, further studies are required before the adoption of this system at industrial scale.

1. Introduction

The peculiarity of the red wine productive process compared to the other winemaking techniques is the presence of the berry skins for the whole duration of fermentation. During the winemaking process, the crushed berry skins arrange themselves to form the pomace cap. After a while, the cap starts to float on the top of the fermentation vessel. A key aspect in the red wine productive process is the extraction, from the pomace cap of compound valuable for the wine quality, as pigments, tannins, and flavonoids (Boulton et al., 1996). To promote the extraction of these substances from the pomace cap, three macerations are usually done: the prior to fermentation maceration, the conventional maceration, and the maceration after the fermentation. During the maceration, the extent of the extraction is a function of time (Boulton et al., 1996).

Please cite this article as: Guerrini L., Masella P., Angeloni G., Cini E., Parenti A., 2017, A device for the monitoring of the cap buoyancy during the red grapes fermentation, Chemical Engineering Transactions, 58, 427-432 DOI: 10.3303/CET1758072

Beside time, the amount of berries submerged in the juice is, obviously, another driver for the extraction: for example, in the *Salasso* technique, to improve the final concentration of pigments, tannins, and flavonoinds an aliquot of juice is removed and the remaining part is in contact with more berry skins. Furthermore, in order to enhance the leaching effect, several strategies for the pomace cap management have been proposed: physical, chemical, biochemical, and mechanical. Physical methods include the duration of maceration, the temperature control, the control of carbon dioxide pressure, while the additions of sulphur dioxide and of maceration enzymes are the main common chemical and biochemical methods, respectively (Bosso et al., 2009). The mechanical methods have the aim of the improvement of the contact between berries and juice. They are pump-overs, delestage, and punchdowns (Guerrini et al., 2017). Particularly, in pump-overs and punchdowns the aim is the improvement of the contact between berries and juice. In fact, during pump-overs the juice is drawn from the base of the tank and pumped to the top where it is sprayed onto the pomace cap. In punchdowns the cap is submerged to break the pomace cap and to allow the juice to reach all the berries. Thus, the contact between berry and juice during the fermentation has to be controlled to manage the wine properties. However, the measurement of the cap buoyancy is a less debated issue despite it affects the above cited oenological practices. In fact, buoyancy affects the volume of the cap submerged by the juice, and consequently the contact between the skins and the must. Understanding the changes in cap buoyancy could help to improve the pomace cap management. In order to better understand the flotation behaviour of the pomace cap, in this work we set up a device able to record its buoyancy.

2. Material and Methods

A device able to record the buoyancy of the pomace cap during the alcoholic fermentation has been set up. The device is composed by a two-plate system, a load cell, and a data-logger (bmcm, Testreport USB-AD16f). The used load cell has been a Futek LBB200, with 8.8 N of full-scale. The two-plate system is shown in Figure 1. The pomace cap stays between the two plates: when the cap does not touch no one of the plates the measured force value is zero, when the berries sank on the bottom the load cell measures negative values, while when the cap push against the upper plate positive values.

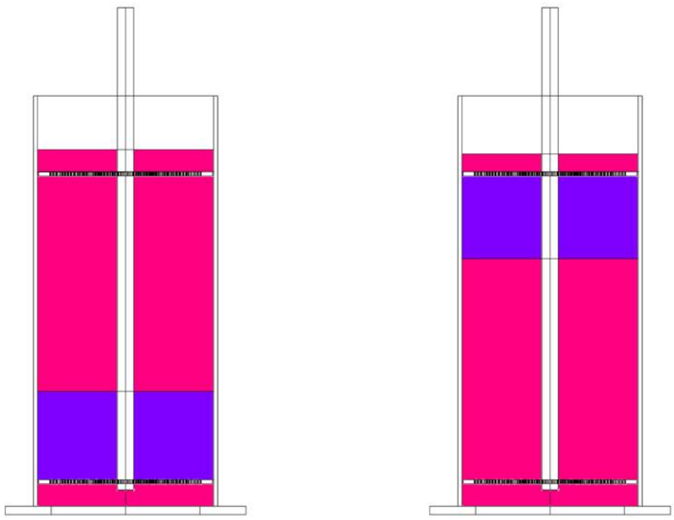

Figure 1: Representation of the two-plate measurement system. In the picture the juice is represented in red, while the cap in purple. The left picture shows the case of sank berries (negative force values), while the right picture the case of floating pomace cap (positive force values).

The instrument has been calibrated using 4 polystyrene samples of known weight and volume in the range between 0 N and 2 N.

The test has been carried out at laboratory scale, using a glass beaker of 1L capacity as fermentation vessel. The force recorded refers to the vat diameter of 0.114 m (surface of $1.02 * 10^{-2}$ m^2) and 0.46 kg of solid pomace. The plate's diameter is 0.085 m. Both plates are completely perforated to allow the escaping of carbon dioxide and the juice movements.

As better described below in the results section, a certain noise of the force values has been observed during measurement. At first glance, the magnitude of this noise seemed to be time-dependent (fermentation time). Hence the idea to relate the observed force noise to the fermentation kinetic, by establishing a relationship between the noise assessed in terms of a dispersion index around the mean force value during a given time interval, and the fermentation speed assessed in terms of must density variation during time. At this purpose, standard deviation was computed as dispersion index of the mean force values recorded during a 10 minutes time interval, once a day at scheduled time until the end of fermentation (every fermentation day, at 11.00 AM). ANOVA methodology has been used to test the linear model between the standard deviation and the fermentation speed.

3. Results and Discussion

The monitored fermentation is shown in Figure 2 in terms of density vs time. The fermentation lasts about 8 days, and the juice density decreases during that time as widely described in literature (Riberau-Gayon et al., 2000).

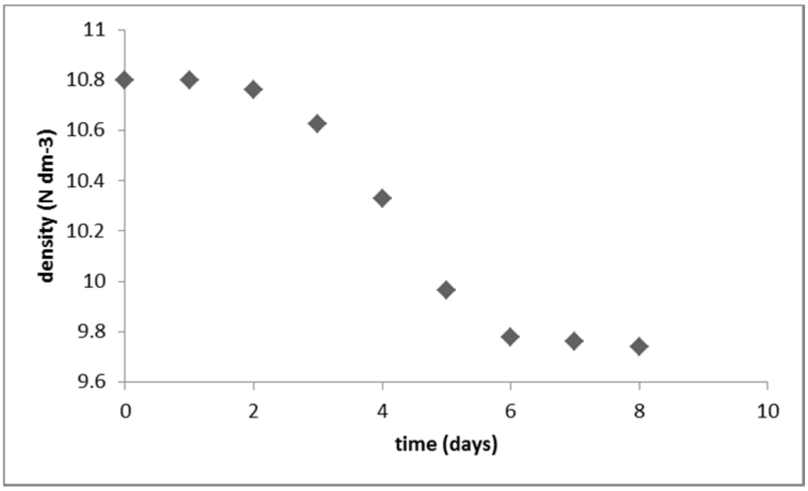

Figure 2: Measured density during the alcoholic fermentation as a function of time.

The buoyancies data recorded during the alcoholic fermentation have been shown in Figure 3. According to the measurement device design illustrated in the previous section, positive values describe a floating pomace cap, while negative values sinking berries.

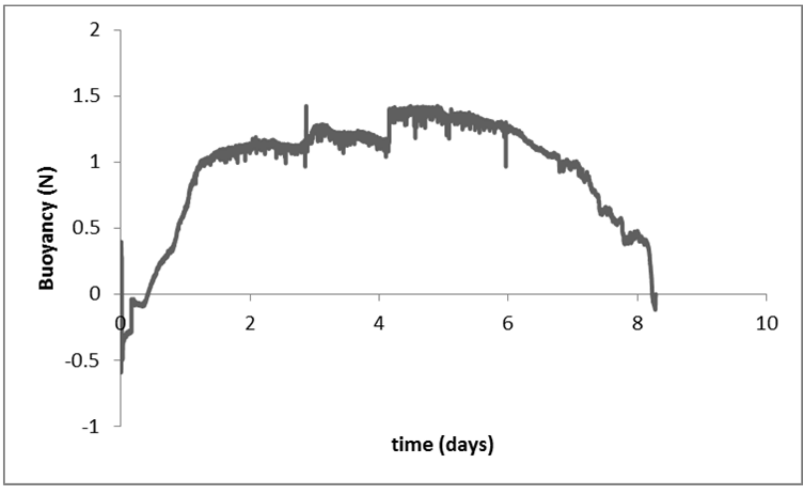

Figure 3: Recorded buoyancy of the pomace cap during the alcoholic fermentation.

As previously described in literature, the berry skins raise after roughly 1 day from the beginning of the fermentation, and start to push against the upper plate. The recorded buoyancy force rises until the maximum, after 5 days of fermentation. Then, the buoyancy decreases, and the fermentation became slower.
The measured force shown in Figure 3 (F_m) is the resulting force between the weight of the pomace cap (F_w), and the buoyancy force (F_b).

$$F_m = F_b - F_w \quad (1)$$

According to the Archimedes' principle, the buoyancy is the product between the displaced volume of juice (i.e. the submerged pomace volume - V_p) and the juice density (ρ).

$$F_m = V_p \rho - F_w \quad (2)$$

During the fermentation, the pomace volume undergoes to some changes due to the formation of carbon dioxide inside the pomace cap. Thus the V_p could be treated as the sum of the starting volume of berries (V_s) and the carbon dioxide volume (V_{co2}).

$$F_m = (V_s + V_{CO2})\rho - F_w \quad (3)$$

According to the equation 3, since the V_s, and the F_w terms are constants, and the density has been measured during the whole fermentation, we are able to calculate the changes in the volume of carbon dioxide inside the berries from the measured buoyancy force.

$$V_{CO2} = \frac{F_m}{\rho} + \frac{F_w}{\rho} - V_s \quad (4)$$

The carbon dioxide volume inside the pomace cap is shown in Figure 4, and reaches the maximum of roughly the 45% (v/v) when the maximum buoyancy value has been recorded.

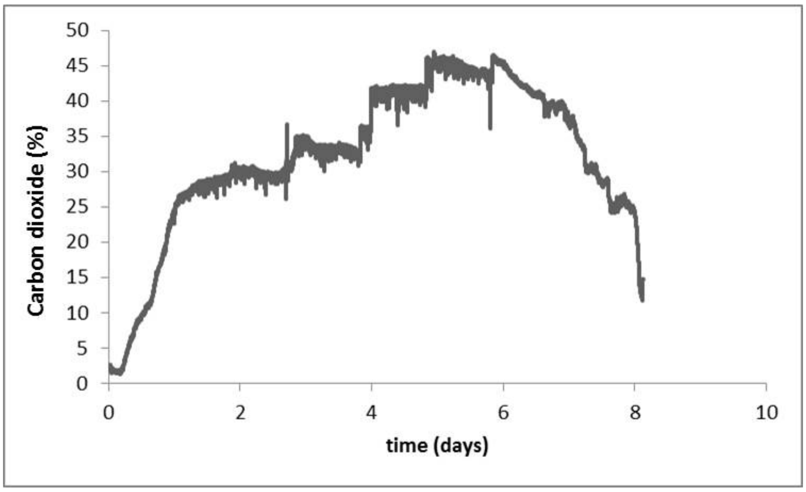

Figure 4: Calculated volume (%) occupied by the carbon dioxide in the pomace cap.

Thus, the apparent density of the pomace changes during the whole fermentation process as result of the increase of the volume of carbon dioxide produced by the fermentation inside the cap. It is supposable that the capability of pomace cap to retain carbon dioxide could be related to cap's integrity. In literature there are strong indications that berry integrity affects the extraction of positive compounds such as skin and seed proanthocyanidins (Cerpa-Calderón and Kennedy, 2008), tannins, and sensorial attributes (Sparrow et al., 2016a and 2016b). Further investigations could clarify if the buoyancy is a good indicator to monitor the extraction kinetic of these compounds.
Furthermore, changes in the buoyancy force leads to changes in the proportion between the berries wetted by the juice and the berries outside it. In literature, many works point out the importance of the submersion of the cap on the final composition of the wine (Bosso et al., 2011; Chittenden et al., 2015). Thus, the understanding of the ratio between submerged and non-submerged berries could lead to an aware choice of the cap management technique (i.e. pump-over length, type and number of punch-downs, delestage timing, etc.).
The release of the carbon dioxide from the fermenting juice and the cap occurs continuously during the whole fermentation process. Carbon dioxide, to escape from the fermentation vessel, has necessarily to pass through the pomace cap and the measurement systems. Thus, both carbon dioxide bubbles from the juice and

from inside the cap has to hit the measurement system before escaping, producing a noise on the measured force value. Hence, we test if the noise magnitude is related to the fermentation kinetic.
A dispersion index (i.e. the standard deviation) to assess the variations of the measured force around the mean value has been calculated. For example the particular of the recorded values at day 1 and 3 are shown in Figure 5.

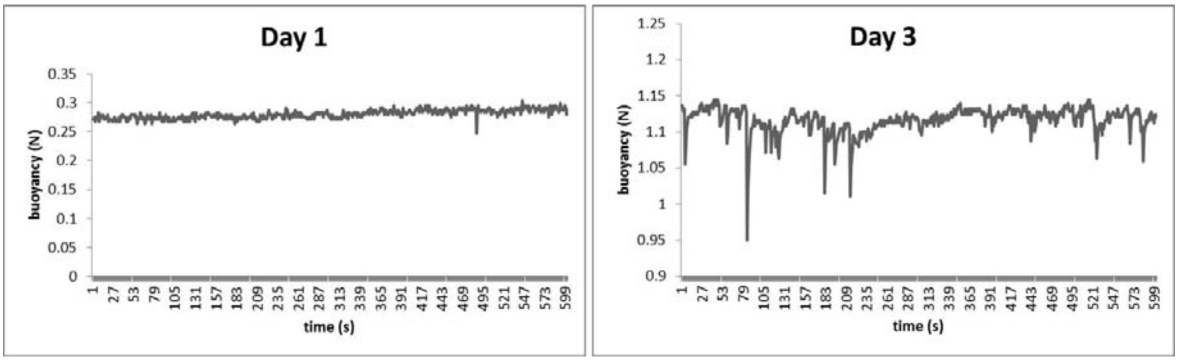

Figure 5: 10 min of buoyancy values recorded at day 1 and day 3.

The recorded standard deviations change during the different days of fermentation. Coherently with the previously described data, the maximum has been recorded during the day 3 of the fermentation, namely during the tumultuous phase and when the decrease of the density is maximum. The vibration magnitude increases until the third day and decrease up to roughly zero at the end of the fermentation (Figure 6). The relationship between the standard deviation and the fermentation speed has been tested with a linear model. The fermentation speed has been calculated as the difference between the densities of two consecutive days. Data allow building the linear model shown in the lower part of Figure 6. In our test the linear model has intercept of 2.597e-04 (significant with p= 0.004), and slope of 1.238e-03 (p=0.005). The multiple R-squared of the model is 0.8183.

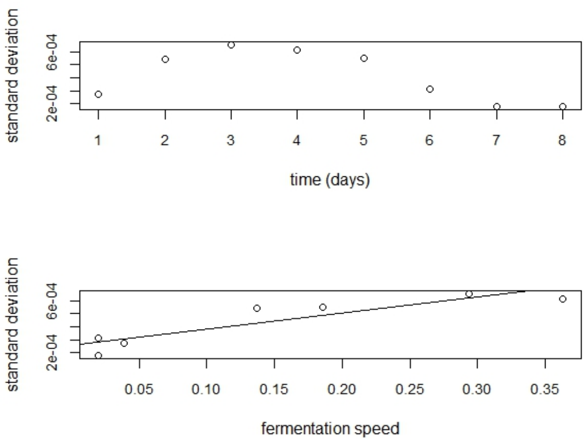

Figure 6: In the upper graph the changes of the standard deviation as function of time is shown. In the lower graph the model with the relationship between the standard deviation and the fermentation speed is represented.

The control of the fermentation kinetic still remain an open issue in oenology, and the development of simple systems for its measure could lead to kept this target (Sablayrolles, 2009). The presented method belongs to the group of techniques using carbon dioxide to monitor fermentation speed (Boulton et al., 1996; Guerrini et al., 2016). However, this method could provide a simultaneous evaluation of the physical state of the cap, a measure of the portion of pomace submerged and an assessment of the fermentation speed. Despite further studies are mandatory before the adoption of this system at industrial scale, in the authors opinion the reported results could encourage implementing the measurement system in the future vintages.

4. Conclusions

The tested device allows the measurement of the buoyancy force due to the pomace cap, and the assessment of the ratio of carbon dioxide emission during the fermentation. The buoyancy could help to understand the proportion between the berries inside and outside the pomace, the cap integrity, and to measure the amount of carbon dioxide trapped in the cap. These knowledge could lead to a more aware decision making process during the red grapes fermentation. The relationship between the recorded force noise and the fermentation speed appear to be promising to monitor the fermentation kinetics. However, further studies are required to improve the predictive model.

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