Applied Thermal Engineering 112 (2017) 621–626

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Thermal effects of pump-overs during red wine fermentation

Lorenzo Guerrini *, Giulia Angeloni, Fabio Baldi, Alessandro Parenti

Department of Management of Agricultural, Food and Forestry System, University of Florence, Italy

HIGHLIGHTS

- Thermal effects pump-overs have been evaluated at industrial scale.
- Pump-overs were able to significantly decrease the juice temperature.
- The overall heat transfer coefficient was used to predict the temperature decrease.

ARTICLE INFO

Article history:
Received 20 July 2016
Revised 24 October 2016
Accepted 24 October 2016
Available online 25 October 2016

Keywords:
Cooling system
Heat transfer
Must thermal control
Temperature gradient

ABSTRACT

The aim of this paper is to measure the thermal effect of pump-overs during winemaking. Temperature control is a key issue in red grape alcoholic fermentation. Aerated and non-aerated pump-overs are usually performed during fermentation in order to improve the extraction of flavanols, tannins and anthocyanins. They have two main effects on grape juice temperature: they reduce the temperature gradient within the juice (homogenizing effect), and they increase the efficiency of heat exchange, thus they reduce the juice temperature.

The experiment compares the effect of pump-overs on fermentation temperature in various conditions. It finds a decrease ranging from 1.9 ± 0.5 °C in Test 1 to 4.6 ± 2.7 °C in Test 3. Thus, enhanced heat exchange during the pump-over results in faster juice cooling.

This heat exchange is modeled mathematically. The overall heat transfer coefficient (*U*) has been calculated. It is based on the tank's characteristics (i.e. the materials used and the thickness of the wall) and two convective coefficients: the first between the juice and the tank's wall, and the second between the tank's wall and the environment. Pump-overs increase the first coefficient, and consequently *U*. Therefore, the effect of a pump-over on grape juice temperature can be easily predicted if *U* has been calculated.

Furthermore, if the overall heat transfer coefficient and the exchange surface are known, the pump-over temperature decrease depends only by the temperature difference between the juice and the environment (or cooling system). Once this temperature decrease is known, pump-overs can be used to improve the temperature control during red grape fermentation. For instance, the frequency of pump-overs can be used when the temperature control with the cooling systems is more difficult.

1. Introduction

Ethylic alcohol, carbon dioxide and heat (983 kJ per mole of sugar) are produced during the alcoholic fermentation of red grapes. The heat production changes during the whole fermentation process and it reaches the maximum in the tumultuous phase, usually occurring in the early stages of the process (i.e. roughly 1/3 of the fermentation total time) [1]. The temperature increase of the fermenting must has several effects on the final wine quality. First of all, temperature regulates the fermentation speed. Fast fermentation, at temperature too high, may be detrimental for wine quality, and slow fermentation, at temperature too low, delays the subsequent processes and increases the risks of wine damages [2]. Furthermore, excessive heat can damage or kill yeasts, which can slow down or even stop fermentation [3]. Wine color becomes more intense at higher fermentation temperatures [4], while flavanol and tannin extraction is higher [5]. On the other hand, anthocyanins form polymeric pigments and their concentration decreases [6]. As flavanols and tannins are responsible for bitterness and astringency, their extraction without anthocyanins could

* Corresponding author at: Department of Management of Agricultural, Food and Forestry System, University of Florence, Piazzale delle Cascine 16, 50144 Firenze, Italy.

E-mail address: lorenzo.guerrini@unifi.it (L. Guerrini).

http://dx.doi.org/10.1016/j.applthermaleng.2016.10.155
1359-4311/

result in unbalanced wines. Hence, temperature control is a key issue in red grape fermentation.

The temperature control during fermentation is achieved by the use of external cooling jackets on the tank, or by internal plates placed within the vat. These solutions are the most spread among the winemakers. However, Boulton et al. [7] point out that both arrangements a low effectiveness in the removal of fermentative metabolic heat. Thus, despite the control devices, the actual temperature of the fermenting juice is often different than the set temperature desired by the oenologists. Particularly, during the tumultuous phase of fermentation this temperature difference can reach up to 10 °C and leads to uncontrolled processes. Thus, Sablayrolles [2] in a recent review, point out that technological innovations should improve the fermentation control and the tank management.

The carbon dioxide produced during fermentation forms a rising flow of gas bubbles. This carries grape solids (i.e. skins) to the liquid-air interface (the pomace cap), which contains tannins and anthocyanins [1]. Several methods have been developed to manage the pomace cap. The most common are physical (duration of maceration, temperature control, carbon dioxide pressure), chemical (the addition of sulfur dioxide), biochemical (maceration enzymes), and mechanical (pump-overs, delestage, and punch-downs) [8]. In 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. This can be done in non-aerated conditions (with almost no air contact), aerated conditions (must is splashed into a vat before its reintroduction into the fermentation tank), or with an in-line Venturi tube [9]. Whatever the specific procedure, pump-overs are performed during red winemaking because they provide several benefits: they promote color and flavor extraction, and homogenize sugar and yeast concentrations [1]. The homogenizing effect can be extended to temperature, as the must temperature is different in different parts of the tank. In particular, the temperature attained to the pomace cap is higher than the rest of the juice [10]. For these reasons, pump-overs are very widespread (they could be considered as the standard), because they are simple, quick, and cheap to implement.

However, the literature reports few studies of the effects of pump-overs on fermentation temperature. In 1951, Ribereau-Gayon et al. [1] demonstrated that pump-overs could decrease fermentation time, as increased temperatures increased yeast activity. Boulton et al. [7] focused on the use of pump-overs for temperature homogenization and describe a procedure to remove fermentation metabolic heat. Juice is cooled by passing it through an external heat exchanger before its re-insertion into the tank. Finally, Zenteno et al. [11] developed a mathematical model considering the thermal effect of pump-overs during red grape fermentation. Nevertheless, despite the importance of fermentation temperature, the literature does not provide a detailed picture of the effect of pump-overs on this parameter and does not describe how pump-over could be used to control properly the fermentation temperature.

2. Material and methods

In order to characterize the thermal effect of pump-overs during red grape fermentation we performed industrial-scale tests of temperature changes in three tanks in different conditions. During each test the effect of eighth pump-overs were measured. The company oenologists have been left free to choose between aerated and non-aerated conditions on the basis of their experiences. Similarly, they can choose the pump-overs length in order to optimize the extraction from berries.

2.1. Test 1

For this test, a cylindrical, 20 m^3 nominal capacity (base radius 1.45 m, 3 m high) stainless steel tank was used. The tank was equipped with an automatic pump-over system consisting of a hydraulic pump controlled electronically and two cooling jackets. The first jacket was placed at the bottom of the tank (0–60 cm in height), and the second was placed at 130 cm (to 190 cm). The temperature was set to 24 °C. Two poles were inserted, each equipped with three temperature probes (WatchDog DataLogger, Spectrum, US). The first pole was placed at 60 cm, and the second at 124 cm from the base of the tank. Temperature probes were placed 20 cm from the edges, and in the middle of the pole. Data was collected every five minutes. The average temperature of the six probes was calculated, while their standard deviation highlighted temperature homogenization due to pump-overs. The tank was filled with 18,500 kg of destemmed red grape (cv. Merlot) and eight pump-overs were monitored. Pump-over 1 was aerated and lasted 40 min; pump-overs 2, 3 and 4 lasted four minutes (non-aerated); pump-over 5 lasted 15 min (aerated); and pump-overs 6, 7 and 8 lasted six minutes (non-aerated). The initial sugar content of grapes was 216 g/l. *Saccharomyces Bayanus* (BO213) yeast was used. Fermentation was measured by must density (BABO) three times a day.

2.2. Test 2

A cylindrical, 3 m^3 nominal capacity (0.56 m base radius, 3 m high) stainless steel tank was filled with 2700 kg of red grape (cv. Sangiovese). A temperature probe was fixed in the middle of the tank, 30 cm below the pomace cap (WatchDog DataLogger, Spectrum, US). Temperature was recorded every five minutes. A second probe was placed near the tank to record the ambient temperature at the same acquisition frequency. The initial sugar content of grapes was 204 g/l. *Saccharomyces Bayanus* yeast was used. Fermentation was measured by must density (BABO) twice a day. Eight pump-overs (one in the morning and one in the evening) were monitored, each lasting six minutes. Two pump-overs (3 and 5) were aerated, while the remainder was not.

2.3. Test 3

A cylindrical, 5 m^3 nominal capacity (0.70 m base radius, 3.25 m high) stainless steel tank was filled with 4100 kg of red grape (cv. Cabernet Sauvignon). The tank was equipped with a plate heat exchanger measuring 140 cm × 37 cm. A temperature probe was fixed in the middle of the tank, 30 cm below the pomace cap (WatchDog DataLogger, Spectrum, US). Temperature was recorded every five minutes. A second probe was placed near the tank to record the ambient temperature at the same acquisition frequency. The initial sugar content of grapes was 275 g/l. *Saccharomyces Bayanus* yeast was used. Fermentation was measured by must density (BABO) three times a day. The first eight pump-overs were monitored: four with the plate heat exchanger and four without it. All pump-overs were non-aerated and lasted five minutes.

3. Results

3.1. Test 1

Fermentation and average temperature recorded during Test 1 are shown in Fig. 1a. The average juice temperature ranged from 20.2 °C to 26.0 °C, while the cooling jacket was set to a temperature of 24 °C. Hence, the set temperature diverged from the average must temperature by a maximum of 2 °C and in principle, thermal