Journal of Cleaner Production 89 (2015) 87–98

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Environmental and technical improvement of a grape must concentration system via a life cycle approach

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A R T I C L E   I N F O

Article history:
Received 18 July 2014
Received in revised form
4 November 2014
Accepted 5 November 2014
Available online 13 November 2014

Keywords:
Sustainable industrial production
Wine must concentration
Wine LCA
Reverse osmosis membranes

A B S T R A C T

Irregularities in grape yields can often affect wine production both quantitatively and qualitatively. Hence concentration systems, such as those based on reverse osmosis, are often employed to overcome such problems. The present study illustrates the results of a life cycle assessment approach implemented as means to improve the existing performance and sustainability of a specific industrial reverse osmosis concentration system used in a southern Italian winery to concentrate a specific must. The application of lifecycle approaches to reverse osmosis must concentration is sparsely documented in scientific literature with little or no specific data. The life cycle assessment of this study, developed using large amounts of inventory data and other novel information gathered from industrial testing, has highlighted the use phase as the most impacting one due to the energy consumption during the concentration operations and due to the membrane cleaning operations. In view of these results, the machine setup was improved and tested by varying the feed-flow velocity and the resulting new setup re-assessed via a life cycle approach. The final results exhibit the relationship between permeate production and feed flow velocity that does not appear to have been sufficiently investigated in other work found in literature regarding wine must. Specifically, the curve fitted to the experimental readings indicates that the maximum performance of the reverse osmosis system under analysis is achieved with a feed-flow velocity of approximately 2 m/s. Furthermore the new optimised setup of the machine lowered the environmental profile of all impact categories within a range from a minimum of 25.3% to a maximum of 26.7%, due to lower energy consumption, higher permeate production and reduced cleaning operations for the membranes. Concurrently to the environmental optimisation a technical improvement was identified, namely the substitution of the over-dimensioned piston pump, together with a potential reduction of purchase, running and labour costs of the optimised reverse osmosis system. Overall the study highlights the utility of analysing industrial machinery, such as reverse osmosis must concentration systems, from a life cycle analysis perspective, that can bring about not only environmental sustainability improvements but also technical and economic developments.

1. Introduction

Wine making dates back to ancient times and is now a worldwide industrial practice responsible for the production of a large variety of wines deriving from different grapevines. The world geographical distribution of such grapevines is determined by the baseline climate of the wine producing region. The variability of the baseline climate determines the weather conditions for each grape growing season and hence the vintage quality of the wine. Climate change is undeniably altering the base line climate but it is also increasing its variability (Bindi et al., 1996; Jones, 2007) and hence the irregularity of the yields of the crops not only quantitatively but also qualitatively in terms of grape sugar content, acid level and

Abbreviations: LCA, Life Cycle Assessment; RO, Reverse Osmosis; ELCD, European Reference Life Cycle Database; ADP, Abiotic Depletion Potential; ADP – FF, Abiotic Depletion Potential – Fossil Fuels; GWP, Global Warming Potential; ODP, Ozone Depletion Potential; POCP, Photochemical Ozone Creation Potential; HTP, Human Toxicity Potential; AP, Acidification Potential; NP, Eutrophication Potential; MAETP, Marine Aquatic Ecotoxicity Potential; FAETP, Freshwater Aquatic Ecotoxicity Potential; TETP, Terrestrial Ecotoxicity Potential.

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http://dx.doi.org/10.1016/j.jclepro.2014.11.020

phenolic content which represent important parameters for the production of quality wines. Consequently over the last decades, in order to overcome such yield problems, the wine industry has developed various technical approaches (Bird, 2007) for the enrichment, concentration and acidification of the wine or its musts. Among these are the membrane processes based on Reverse Osmosis (RO), used for the concentration of the sugar content of wine musts. Such technical approaches are vital for the main producing wine countries such as Italy, France and Spain, responsible for nearly 50% of the world production (FAO, 2012), where the wine sector remains of paramount importance for their national economies.

The contribution of food and drink products to the environmental impact of private consumption is estimated to be between 22 and 34% (Tukker et al., 2006) and wine production is no exception (Notarnicola et al., 2003; Christ and Burritt, 2013). The increase in consumer awareness of such environmental issues is slowly creating a demand for sustainable beverage production practices and is beginning inevitably to direct the consumer choice towards more sustainable wine (Forbes et al., 2009). Such market demand is thus driving the wine industrial sector to integrate environmental aspects to the economic and technical aspects of wine production via the design of ecologically compatible industrial systems (Gabzdylova et al., 2009; Szolnoki, 2013). Over the last decade this has brought about the development of methods used to study sustainability issues of the food and drink sectors (Settanni et al., 2010; Notarnicola et al., 2012a). These methods include the holistic life cycle based ones, also applied to the wine product systems (e.g. Vázquez-Rowe et al., 2013; Amienyo et al., 2014), such as Life Cycle Assessment (LCA) which represents a powerful tool that can clearly identify the environmental burdens of a product system throughout its lifecycle. Such a tool, that was formally introduced in the European regulations back in 1992 as a means for the assignment of an ecological quality label, is now one of the mainstream analytical instruments of the European Integrated Product Policy used for the environmental management of products, in particular as a means for the assignment of Eco-labels and EPDs, for Green Public Procurement, for eco-compatible design and for the identification of significant environmental aspects of product systems (Notarnicola et al., 2012b).

The objective of the work described in this paper is that of improving the existing performance of a particular RO must concentration machine setup, used in southern Italian wineries, via an LCA approach, in order to improve its sustainability in economic, environmental and technical terms.

The next section of this paper will provide an overview of must enrichment and concentration techniques together with a review of RO concentration applications and LCA studies of RO. The subsequent section describes the industrial RO must concentration system object of the present study. Following is a description of the LCA of such RO system. The final section details the performance and optimisation of the must concentration system in terms of improved environmental and economic sustainability.

2. Grape must enrichment and concentration

Grape must enrichment and concentration techniques have been developed to solve the problems arising from a rainy and not particularly sunny season which does not allow the grapes to develop the desired sugar content. Fermentation of a must with a low sugar content will produce a wine with undesirably low alcohol content with no or little market value.

Enrichment techniques entail the addition of sugar to the must in the form of sucrose or of highly concentrated grape must. In Europe the use of sucrose is allowed only in certain northern countries leaving concentrated grape must as the only enrichment additive for the southern European countries. However, it is argued that the addition of a concentrated must (in the form of syrup) will dilute the effects of other elements of the must that determine the organoleptic properties of high quality wines (Dupuy, 1985).

Concentration techniques involve the removal of volatile components from the must, in particular water, in order to concentrate the solute sugar levels. The main modalities for such concentration approaches involve the boiling or freezing points of the solution or the molecular dimensions. By heating a must, typically at pressures below atmospheric and at temperatures below 30 °C, it is possible to remove water from the must and hence increase the sugar content. Alternatively, by exploiting the different freezing temperatures of the different elements of the must, it is possible to filter and remove the ice crystals resulting from a must that has been cooled down to temperatures below 0 °C.

Recently concentration techniques have been developed, such as RO separation, involving filtrating membranes. In such approaches the must is forced under pressure to pass through modules containing membranes that are able to separate the water molecules from the must. These methods do not involve a change of state of the must or the use of heat that might alter the final organoleptic properties of the resulting wine (Echavarría et al., 2011). The next section details the RO membrane separation approach.

2.1. Reverse osmosis

Reverse osmosis involves the application of an opposing pressure to the osmotic pressure which is naturally generated by the different concentrations of two solutions, separated by a semipermeable membrane (selectively permeable only to certain solvent molecules e.g. water). Such opposing pressure, if higher than the osmotic one, will invert the natural solvent flow from a diluted solution to a more concentrated one. By exploiting such phenomenon it is possible to set up mechanical systems that use RO membranes to separate a solvent, such as water, from a solution which in turn increases its solute concentration.

With the development of asymmetric cellulose acetate membranes (Loeb and Sourirajan 1962), in the early 1960s, RO became an effective means of separating salt from sea water. Further recent development in this field, in particular the use of many possible different polymers and improved manufacturing techniques, has brought about film composite membranes (TFCM) that are durable, that can tolerate higher temperatures, wide pH ranges and severe chemical environments, and that have highly improved solvent and solute separation characteristics (Williams, 2003).

RO is now a standard alternative to vacuum distillation for the desalination of sea water (Jeppesen et al., 2009) and can be used for the improvement of drinking water, in large urban areas, as in the case of the metropolitan area of Barcelona in Spain (Raich-Montiu et al., 2014). Furthermore RO is also a best available technique (BAT, 2003) for waste water management due to the excellent membrane capabilities of removing nitrates and organic and synthetic compounds deriving from fertiliser use, fluorides, heavy metals radionuclides, arsenic and some viral pathogens. RO can also be used in other applications (Bhattacharyya et al., 1992) including those of the food, dairy and beverage industry, in particular for the concentration of fruit juice (Jiao et al., 2004) and wine musts (Mietton-Peuchot et al., 2002). Fruit juices are concentrated to allow economy in storage, transportation, distribution and commercial operations, as well as conservation due to water activity reduction (Jesus et al., 2007), whereas, as already mentioned, wine must concentration is carried out to increase the sugar contents. Generally fruit juice requires higher levels of concentration, with