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Water quality for *Espresso* coffee

L. Navarini *, D. Rivetti

Illycaffè S.p.A., Via Flavia 110, Trieste, Italy

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ABSTRACT

Espresso coffee extraction is the most common brewing method in Italy and it is becoming very popular in many other countries around the world. Water (including its ionic content) is an essential ingredient and its role in *Espresso* brewing must be taken into due consideration. It is well known that water treatment is necessary to remove possible off-flavours deriving from the disinfection performed at municipal waterworks as well as to prevent expensive professional *Espresso* coffee machine from scaling problems. However, there is little awareness of the direct effect of water composition on the quality of coffee beverages, particularly for *Espresso* coffee.

In this paper, the state of the art is reviewed with emphasis of water/coffee components interaction during the brewing process. The role played by alkalinity and selected cations on sensory properties of *Espresso* coffee is discussed.

1. Introduction

Water is the second essential ingredient for coffee brewing, and, from a quantitative point of view, it is the most important. Several early studies have been focussed at individuating possible correlation between water (and its ionic content) and coffee beverage quality (Gardner, 1958; Lockhart, Tucker, & Merritt, 1955; Pangborn, 1982; Pangborn, Trabue, & Little, 1971; Tassan & Russell, 1974). These studies have been carried out by using filter or drip coffee extraction as coffee beverage sample preparation method. In the typical set-up, a paper filter is placed in a proper cone-shaped holder. Medium ground coffee is put into the filter and the holder placed on top of a glass jug. Boiled water is poured into the filter and allowed to seep through. The resulting coffee beverage is a clean, transparent system (Petracco, 2001). In a wide range of natural mineralised drinking waters, differences in the visual attributes of brewed coffee often were greater than differences in flavour (Pangborn, 1982). However, electrolytes in both natural drinking waters and in model water systems adversely influenced the quality of the resultant beverages (Pangborn et al., 1971). In particular the carbonates were the worst offenders, resulting in a bitter, flat coffee. Moreover, although a certain degree of acidity is characteristic of brewed coffee, the sourness of coffee prepared from distilled water has been found to be excessive (Pangborn et al., 1971). The relevance of water alkalinity in influencing (neutralising) coffee acidity has been evidenced by Sivetz (1972). In particular, “for each 100 ppm of water alkalinity, the pH is raised about 0.22 unit for roast and ground coffees and about 0.33 unit for instant coffees” (Sivetz, 1972). It has been also found that the concentration and species of ions in solution change the rate at which water passes through the bed of ground coffee, thereby causing differential extraction of coffee solids (Gardner, 1958).

Carbonates and bicarbonates with excessive sodium ions have been found to affect the brewing time, both having a retarding effect in direct relation to their concentration, while all other ions normally present in municipal water supplies appeared to have little effect, if any on brewing time (Gardner, 1958). For this reason, Gardner (1958) suggested to avoid the use of ion exchange (replacement of calcium and magnesium with sodium) to treat water containing a high concentration of bicarbonate.

More recently, water quality affecting the taste of filter or drip coffee beverage has been discussed in terms of the presence of foreign flavours due to disinfecting treatments (chlorination) and of water hardness, being the latter investigated in detail (Cammenga & Zielasko, 1997). In fact, if, on one hand, possible foreign flavours directly affect the coffee taste, on the other hand, water hardness through its scaling potential, indirectly affect the beverage quality by reducing heat transfer effectiveness of heat exchangers and then affecting the extraction temperature.

In spite of the increasing popularity of the *Espresso* coffee extraction as a coffee preparation method around the world, little is known about the role played by water and its ionic content in beverage quality and acceptability. *Espresso* – the word refers to a preparation made on request expressly for the occasion – is brewed by rapidly percolating a small quantity of pressurised, heated water through a compressed cake of finely ground roasted coffee. The process is applied (brewing time) until the beverage volume in the cup meets the personal preferences of the consumer and/or the regional traditions, in Italy, for instance, this falls in the

* Corresponding author. Tel.: +39 040 3890111.
E-mail address: luciano.navarini@illy.it (L. Navarini).

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range 15–50 ml, with an optimal outcome at 25–30 ml (regular *Espresso* with a brewing time of 25–30 s). The resulting beverage, differently from drip coffee, must be topped by a velvety thick, reddish-brown foam called *crema* to be considered properly prepared and to be appreciated by connoisseurs. This peculiar brewing method requires specialised and costly equipment that can heat water to a temperature of 92–94 °C and then pressurise it to 9 ± 2 bar (Illy, 2002).

The detrimental effect of foreign flavours as well as of water hardness in *Espresso* brewing is well documented (Petracco, 2001; Schulman, 2002). However, as far as we know, only two papers reported quantitative data on the effects of water composition and water treatment on *Espresso* coffee brewing (Fond, 1995; Rivetti et al., 2001). Moreover, the role played by water composition on the *crema* properties has not yet been the subject of study. As matter of fact, the few reports on *Espresso* coffee foam mainly focused on its chemical aspects and interfacial properties neglecting the effect of water ingredient (D'Agostina et al., 2004; Ferrari, Navarini, Liggieri, Ravera, & Suggi Liverani, 2007; Navarini, Ferrari, Suggi Liverani, Liggieri, & Ravera, 2004; Nunes, Coimbra, Duarte, & Delgadillo, 1997).

In this paper, the state of the art is reviewed with emphasis of water/coffee components interaction during the brewing process. Alkaline scale formation and sodium softening chemistry is briefly discussed in view of its relevance in *Espresso* coffee quality. Moreover, new experimental data on the effect of water composition on *Espresso* coffee foam is also reported and discussed.

2. Review on the influence of water composition/parameters on *Espresso* coffee brewing

2.1. Alkaline scale formation and sodium softening

Alkaline scale normally consists of calcium carbonate, magnesium hydroxide, or admixtures of both compounds which crystallise on heat transfer surfaces in contact with natural waters (Dooly & Glater, 1972). The resulting encrustation has long been a problem in the operation of boilers and other kinds of *Espresso* coffee equipment. Alkaline scaling can occur only in waters containing bicarbonate ion, but the chemical mechanism of this process is not fully understood, and two different mechanisms have been proposed (Dooly & Glater, 1972; Shams El Din, El-Dahshan, & Mohammed, 2002). Scaling is triggered by the thermal decomposition of bicarbonate ion. Upon heating above *ca* 45 °C, HCO_3^- breaks down according to Eq. (1).

$$2HCO_3^- \overset{\Delta}{\rightleftarrows} CO_3^{-2} + CO_2 + H_2O \quad (1)$$

Carbonate ion generated in this process can now participate in two competing equilibria. The first is the precipitation of calcium carbonate once its solubility limit is reached, as shown in Eq. (2).

$$Ca^{+2} + CO_3^{-2} \rightleftarrows CaCO_3 \quad (2)$$

A second, at still higher temperature (⩾80 °C), reaction occurring concurrently is the hydrolysis of carbonate given by Eq. (3).

$$CO_3^{-2} + H_2O \rightleftarrows CO_2 + 2OH^- \quad (3)$$

If sufficient magnesium exists in solution such that ion product exceeds solubility limit of magnesium hydroxide, a precipitate will form according to Eq. (4).

$$Mg^{+2} + 2OH^- \rightleftarrows Mg(OH)_2 \quad (4)$$

According to this mechanism alkaline scaling always involves the formation of carbonate ion at low temperature and hydroxide ion at higher temperature. However, to account for the primary precipitation of $Mg(OH)_2$ observed under certain conditions, a second mechanism has been proposed (Dooly & Glater, 1972). According to this mechanism, hydroxide ion is produced by bicarbonate ion directly without the intermediate formation of carbonate ion, as shown in Eq. (5).

$$HCO_3^- \rightleftarrows CO_2 + OH^- \quad (5)$$

After the direct breakdown of bicarbonate ion, a fast acid–base neutralisation step occurs, as shown in Eq. (6).

$$OH^- + HCO_3^- \rightleftarrows CO_3^{-2} + H_2O \quad (6)$$

The overall picture suggests that alkaline scaling is a complex process involving competitive equilibria between certain unimolecular and bimolecular rate processes which occur simultaneously.

The direct use of public waterworks' drinking water in both professional and home *Espresso* machines produces intolerable deposits in a period which, depending on water composition, may be sometimes very short. Among the several strategies which can be used to prevent *Espresso* machine from scale deposits, sodium softening is still the most chosen. Independently on the alkaline scale formation mechanism, the replacement of calcium and magnesium ions with sodium ions, without affecting bicarbonate content, is very effective in the scale prevention but also in changing dramatically the effect of the thermal decomposition of the bicarbonate ions on the water pH, due to the formation of the more basic carbonate and hydroxide ions. For the latter, the chemistry can be summarised as shown in Eq. (7).

$$Na^+ + HCO_3^- \overset{\Delta}{\rightleftarrows} CO_2 + NaOH \quad (7)$$

At 100 °C, the pH of 4% NaCl solution containing 150 ppm of sodium bicarbonate, steadily increased, as a function of time, up 10 after 4 h thermal treatment. No pH rise has been observed under identical experimental conditions on the same system added with 500 ppm of Ca^{2+} (Shams El Din et al., 2002). The rise in pH on heating sodium softened water has been found to remarkably affect the *Espresso* coffee extraction and to this point is dedicated a separate paragraph. Of course, to solve any problem related to alkaline scaling and subsequent sodium softening, very soft water (even distilled water) could be used. However very soft waters exposed to air and heated become acidic and corrosive, and therefore dangerous for *Espresso* machines. Several countries have issued non-binding recommended hardness ranges. These are usually around 80–100 mg $CaCO_3$/l hardness (corresponding to 8–10 French degrees, °f) and 50–60 mg $CaCO_3$/l alkalinity, figures calculated to minimise the combined cost of scaling and corrosion in municipal piping and domestic hot-water systems. These ranges, incorrectly, have been suggested as optimal for *Espresso* coffee preparation, but the levels required for taste can be quite different (Schulman, 2002).

2.2. Water quality and Espresso coffee brewing time

Early study addressed to understand the influence of water ions on *Espresso* coffee extraction has been reported by Fond (1995).

In his detailed investigation, a raw tap water having a bicarbonate content of 380 mg/l and a total hardness of 33 °f was treated by both softening in a single ion exchange resin column and demineralisation. These three different types of water (tap, softened and demineralised) were used for *Espresso* coffee extraction. The brewing time to get a 40 ml *Espresso* cup was found to grow, in respect to the one measured by using the raw tap water, by 10% with water after demineralisation and by 53% after softening. Moreover, it was noticed that the brewing time increased significantly when the bicarbonate ion concentration (added to demineralised water) was raised. The brewing time increase induced by softened water