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Kinetics of tea infusion. Part 3: the effect of tea bag size and shape on the rate of caffeine extraction from Ceylon orange pekoe tea

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Abstract

The rate of infusion of caffeine from Ceylon Orange Pekoe tea of leaf size 1.4–2 mm in loose form and inside a tea bag membrane was determined at 80°C. The tea bags were varied in size and shape. It was found that the rate constant increased significantly with an increase in tea bag size until the ratio of tea leaf to tea bag size was 1:10. The results also indicate that the shape of a tea bag had no influence on the rate of infusion, and that the tea bag membrane offered some hindrance to the infusion of caffeine.

Keywords: Leaf; Bag; Tea; Infusion

1. Introduction

Millions of cups of tea are consumed everyday around the world. Most of these are brewed using tea bags, because of their convenience in handling and disposal. Different shapes and sizes of tea bags exist in the market, all with the aim of capturing the attention of the consumer. The quality of a cup of tea remains dependent on the quality of tea leaf and water used. Therefore, the shapes of tea bags used by the manufacturers are aimed at improving the rate of tea infusion and customer convenience.

In a previous paper (Spiro & Jaganyi, 2000), it has been shown that the rate-controlling step during infusion is the rate of diffusion of the soluble species through the Nernst diffusion layers on each side of the tea bag membrane. This is common to all the shapes of tea bags. We have also reported that the rate of infusion of caffeine from tea leaf into aqueous medium is influenced by the method of manufacturing (Jaganyi & Price, 1999), and that the tea-bag material slows the rate of infusion by 29% when compared with loose tea (Jaganyi & Mdletshe, 2000). The present paper reports, for the first time, a detailed study on how the rate of infusion of caffeine depends on the size of the tea bag. It also compares the influences of the different shapes of tea bags on the rate of infusion.

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2. Materials and methods

Black Ceylon Orange Pekoe tea was used in this investigation. The tea was first sieved using a mechanical Endecott test sieve shaker, fitted with a set of stainless sieves. The particle size selected was the fraction in the range 1.4–2 mm.

To study the tea bag effect, different tea bag sizes and shapes were made, using material manufactured by Dexter Nonwoven. The details of how these were made are similar to those described by Jaganyi and Mdletshe (2000). The sizes of the tea bags, made were 16, 36, 49 and 64 cm^2 for square tea bags, and 49 cm^2 for round and rectangular tea bags. These figures represent the surface areas of one side of the tea bag.

The kinetic experiments were carried out in 400 ml of distilled water, to ensure that the big tea bags were completely immersed in water. The flask with its content was placed inside the thermostat bath, which was set to give a temperature of 80°C inside the flask with an accuracy of ± 0.1°C. The introduction of the tea-bag into the flask, and the precaution taken to ensure that no air was trapped inside and that it remained flat on the wire mesh fully immersed in water, is as reported by Jaganyi and Mdletshe (2000). Experiments were also carried out using loose tea leaves as well. The addition of loose tea into the flask was by means of a tea holder device (Jaganyi & Price, 1999; Spiro & Siddique, 1981). The sampling of the tea solution was by means of 5-ml syringes (Jaganyi, Varmare, & Clark, 1997, 1999). The

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plastic tube attached to the syringe was always flushed with air before any sample was taken. At least six samples of 2 cm^3 were removed at 30 s intervals for the first 3 min and later at longer time intervals. The equilibrium samples were taken after 60 and 120 s for loose tea and tea in the bag, respectively. In this experimental set-up, it is assumed that the tea leaf and the tea bag material, when placed in the flask, attain the liquid temperature on contact and that the leaf swells instantaneously, followed by infusion of caffeine (Spiro, 1997; Spiro & Jago, 1982). All samples were diluted to 10 cm^3 in small vials and analysed for caffeine content using HPLC. The instrumental conditions, including the mobile phase, were as described previously (Jaganyi & Price, 1999); the column used was always calibrated with a number of caffeine solutions of known concentration. The average retention time for the caffeine peak was 15.8 min.

3. Results

3.1. Effect of tea bag size

It has been shown by Jaganyi and Mdletshe (2000), that infusion of caffeine from tea, through the tea bag membrane, can be quantified using Eq. (1), first derived by Spiro and Jago (1982) for loose tea. The variation of concentration, c, with time, t, was again found to fit the first-order kinetic equation with small intercepts, a:

$$\ln\left(\frac{c_\infty}{c_\infty - c}\right) = k_{obs}t + a \quad (1)$$

where c_∞ is the equilibrium concentration and k_{obs} is the observed rate constant. The concentration values used in Eq. (1) were all corrected for volume lost due to evaporation and sampling (Spiro & Jago, 1982). The average equilibrium concentrations for loose tea and tea in a bag were similar in magnitude as shown in Table 1. The difference was in the time taken to attain equilibrium. The extraction from 16 cm^2 tea bags took the longest time followed by the 36 and then the 49 cm^2 bags. The time taken by the 64 cm^2 tea bag was similar to that of the 49 cm^2 one.

Rate constants and intercepts were obtained from the linear plots of the ln function against time as illustrated in Fig. 1. The values, including their standard deviations obtained from the scatter of the points on the plots, are shown in Table 1, the surface area for loose tea being taken as 0 cm^2.

3.2. Effect of tea bag shape

The results tabulated in Table 1 indicate that after a surface area of 49 cm^2, an increase in area has little effect on the rate constant. Therefore, this surface area was chosen to study the effect of the different shapes of tea bags. In addition to the square tea bags used for the size effect, two more shapes, round tea-bags of diameter 7.9 cm and rectangular tea bags of dimension 8×6.1 cm were used. The rate constants obtained at 80°C are summarized in Table 2.

4. Discussion

The results show that the infusion of caffeine from loose tea is much faster than from tea in a bag. This is an indication that the tea bag membrane offers some hindrance to the infusion of caffeine. The k_{obs} for loose tea reported here is comparable with results in the literature. The value of 4.83×10^{-3} s^{-1} reported is equivalent to a value of 4.58×10^{-3} s^{-1} reported by Jaganyi and Mdletshe (2000), taking into account the particle size. But the value is half that for CTC Kapchorua Pekoe Fannings (Price & Spiro, 1985). This can be due to the fact that the teas are different and also their method of manufacturing (Jaganyi & Price, 1999).

The results in Table 1 show an increase in k_{obs} with the increase in tea bag size. The increase is about 25% from 16 to 36 cm^2, with smaller increases as the area becomes still bigger. Looking at the ratio of the rate constants between the tea bag (k_{TBT}) and loose tea (k_{LT}), it is clear that k_{obs} approaches a maximum value as the size of the tea bag increases. This is due to the increase in space for movement of the tealeaf inside the tea bag. It has been reported in the literature (Spiro & Price, 1985a) that a tea leaf swells by a factor of 4.25 in water. The theory used for the analysis (Spiro & Jago,

Table 1
The effect of tea-bag size on the rate of extraction of caffeine at 80°C in comparison with loose tea

Surface area (cm^2)	k_{obs} (10^{-3} s^{-1})	Ratio (k_{TBT}/k_{LT})	Ratio (mass of tea/ surface area)	c_∞ (mM)	Intercept (a)
0	4.83±0.1	–	–	3.71	0.03
16	2.15±0.20	0.45	1:4	3.64	0.02
36	2.85±0.31	0.59	1:9	3.55	−0.01
49	2.99±0.32	0.61	1:12.3	3.61	0.02
64	3.14±0.24	0.65	1:16	3.43	0.01

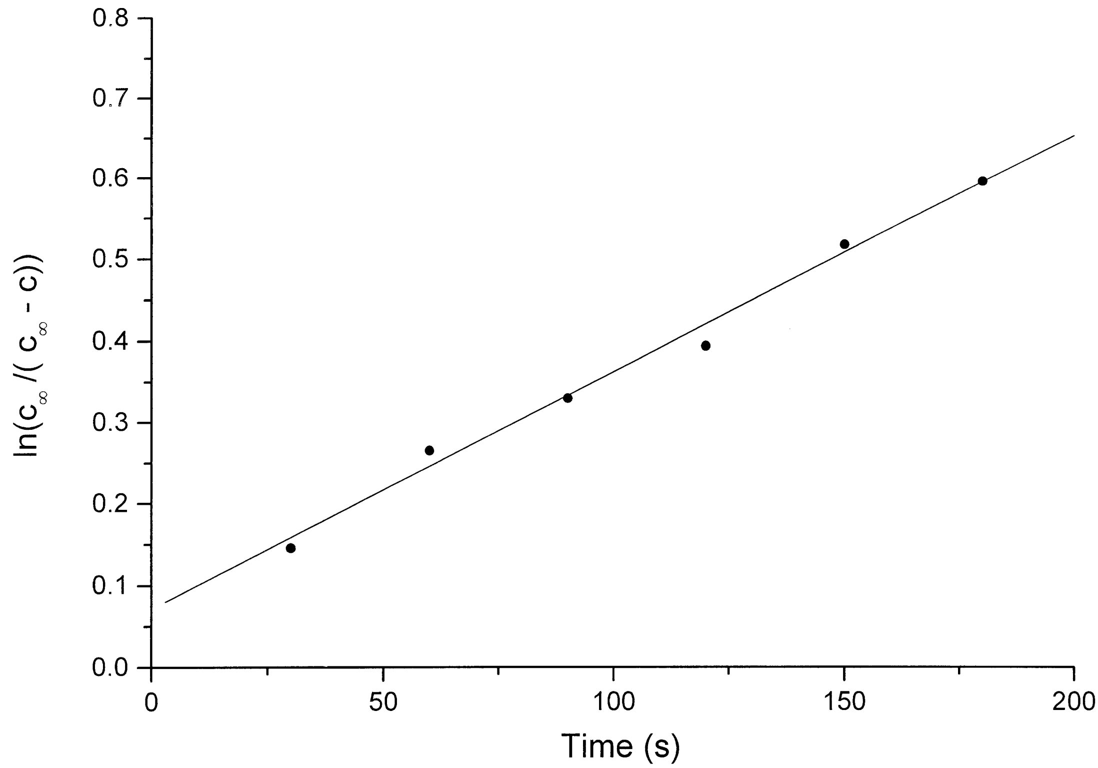

Fig. 1. Plot of $\ln(c_\infty/(c_\infty - c))$ against time for extraction of caffeine from Ceylon orange pekoe tea leaf (1.4–2 mm) in a 7×7 cm square tea-bag at 80°C.

Table 2
The effect of tea-bag shapes of size 49 cm^2 on the rate of extraction of caffeine at 80°C[a]

Tea-bag shape (49 cm^2)	Square	Rectangular	Round
$k_{obs}/10^{-3}$ s^{-1}	2.99±0.32	3.16±0.28	3.05±0.31

[a] The surface area for loose tea was taken as 0 cm^2.

1982) assumes that when the leaf comes into contact with water it swells first, and then infusion follows. This means that the swelling of a tea leaf is not changing with time. It is therefore clear that the only variable in this study is the volume inside the tea bag. In the case of the 16 cm^2 tea bag, the space is small; as a result, the tea leaves, after swelling, are compacted together. This makes the penetration of water to the leaf, in the centre of the tea bag, more difficult. Moreover, the extracted caffeine from the middle of the tea leaf to the bulk of the solution has to follow a more tortuous passage within the leaf particles. This results in a slow infusion process, as seen from the k_{obs} values.

The difficulty in penetration by water decreases with the increase in tea bag size. This is because the tea leaves are less compacted together and have more room to move around. The results indicate that this effect approaches a maximum, after which an increase in size of the tea bag has little or no significant effect on the rate. The results can also be considered from the ratio of the mass of tea leaves to tea bag size. As this ratio becomes smaller, the infusion rate increases, becoming less significant when the ratio is approximately over 1:10.

A second explanation can be offered to account for the cause of hindrance to caffeine infusion from tea in a bag into the bulk of the solution. This is the diffusion through the Nernst diffusion layers, both inside and outside the tea bag membrane. The Nernst diffusion layer on the inside decreases with the increase in tea bag size because of an increase in free movement of tea leaves and solution inside the bag. This explains the observed increase in k_{obs} with tea bag size. These processes also explain why the infusion of caffeine from loose tea is faster than that from a tea bag.

Regarding the effect of tea bag shapes, the results in Table 2 indicate that the shapes have no significant influence on the rate of infusion. This is not surprising because the rate-controlling step in this process is the diffusion through the Nernst diffusion layers of the tea bag. Other factors, upon which the rate of tea brewing in a tea bag is dependent, include transfer of the constituents through the membrane, diffusion towards and away from the membrane plus through the swollen leaf (Spiro & Jaganyi, 2000). These effects are common to all shapes of tea bag. It would therefore seem, even though no experiments were carried out, that the shape of the pyramidal tea bag alone cannot increase the rate of infusion. The crucial factor is that the bag must have enough space for the free movement of tea leaves to take place. It is also noteworthy that, in making the round and pyramidal tea bags, much tea bag membrane is wasted. This makes the cost of their production much higher than that for square and rectangular tea bags.

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