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Kinetics of tea infusion. Part 2: the effect of tea-bag material on the rate and temperature dependence of caffeine extraction from black Assam tea

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Abstract

Extraction experiments of tea inside tea-bag material were carried out at different temperatures. The rates of extraction were measured for caffeine from black orthodox Assam tea into distilled water. The leaf size used was 1.18–1.40 mm and the results obtained were compared with those of loose tea. The first order rate constants for the tea-bag tea were found to be 29% smaller than those of loose tea. The activation energies were found to be 45 ± 2 and 43 ± 2 kJ mol^{-1} for loose tea and tea-bag tea, respectively. These results show that the tea-bag material slows the infusion.

1. Introduction

The series on kinetics and equilibria of tea infusion by Spiro and co-workers, has concentrated on the rate of extraction of caffeine and mineral ions from both black and green teas. Investigations on how the rate is affected by the leaf size, manufacturing method (Jaganyi & Price, 1999; Price & Spiro, 1985a), composition of the aqueous extracting medium (Spiro & Price, 1985b), and temperature dependence (Spiro, Jaganyi & Broom, 1992) have been carried out. Despite the fact that most tea is brewed using tea-bags, little has been published on their effect on the rate of extraction. The only result which has been reported involving the effect of the tea-bag material on tea brewing is that it does not affect the formation of tea scum in hard water (Spiro & Jaganyi, 1994). It is well known that the tea-bag material does slow down the infusion process, but no data have appeared in the public domain. In practice, smaller tea leaves, which infuse faster, are used inside tea-bags so that the overall infusion rate is increased over that with larger-sized loose tea leaf. Also tea-bags have many practical advantages: the tea is easier to handle and simpler and less messy to dispose of. The present paper looks at the hindrance effect of the tea-bag material on the rate of extraction of caffeine from black tea.

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2. Material and methods

The tea used was black orthodox Assam, which was sieved into different particle sizes using a set of stainless steel Endecotts sieves. The leaf size range chosen for this investigation was 1.18–1.40 mm. A plastic flask containing 200 ml of distilled water was allowed to equilibrate to the temperature of the water bath before adding 4.0 g of tea leaves. The addition was performed with the help of a glass funnel having a wide spout, a modification of Spiro and Siddique (1981). The mixture was stirred by an underwater magnetic stirrer. A total of 12 samples (1 ml) were withdrawn at 30 s intervals for the first 3 min and later at longer time intervals. The equilibrium sample was taken after 60 min. These samples were transferred into vials containing 9 ml of distilled water. This was to avoid evaporation of the sample and to prevent cream formation. The sampling was done with the help of a 5 ml disposable syringe fitted to a thin plastic tube as described by Jaganyi, Vanmare and Clark (1997).

The tea-bag was made from the material manufactured by Dexter Nonwoven. This was cut into equal pieces which were folded into two, making sure that the heat-seal was on the inside. Two sides were then sealed using a hot iron. Using the remaining side, 4 g of the loose tea were transferred into the bag and the side sealed. The final size of the tea bag was 7 cm by 8 cm. To ensure that the tea bag was not going to interfere

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with the movement of the stirrer bar inside the flask, a stainless steel wire gauze was cut into a circle and the side was bent by 1 cm. It was then squeezed into a round-bottom flask and flattened to form a flat base in the bottom of the flask with the stirrer bar below it. To ensure that the tea bag remained flat on the wire mesh and immersed in water at all times, two small stainless steel bolts were attached to the opposite sides of the tea-bag. It was ensured that these were far apart when the tea-bag was added into the infusion flask. The tea-bag was added into the flask in such a way that one end was in the water and the opposite side allowed air to escape as it was dipping into the water. Through this process no air was trapped in the bag. The sampling procedure was similar to that for loose tea.

The samples were then analysed for caffeine using high performance liquid chromatography; the type of instrument as well as the column and the mobile phase used were similar to those reported in the literature (Jaganyi & Price, 1999). The concentrations were corrected for evaporation and sampling (Jaganyi, 1992; Spiro & Jago, 1982).

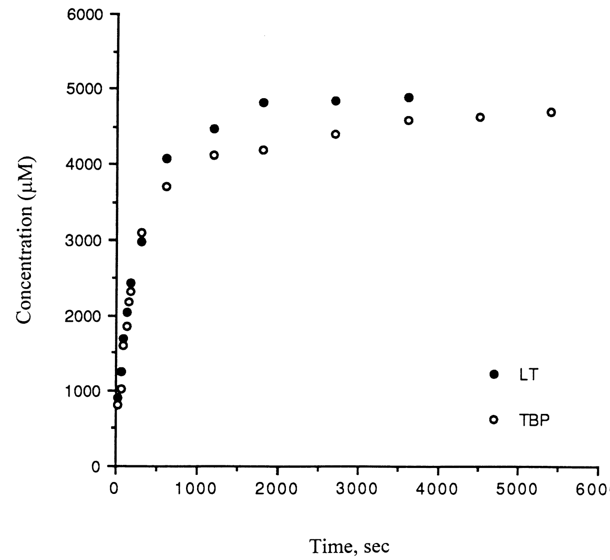

Fig. 1. Plots of concentration versus time for the extraction of caffeine from loose tea and tea-bag tea.

Table 1
Kinetic and equilibrium data for caffeine infusion from loose and tea-bag tea over a temperature range

Temperature °C	Type of tea	k_{obs}/ 10^{-3} s^{-1}	Ratio $k_{(TBP)}/k_{(LT)}$	$t_{1/2}$	a	c_∞/ mM
60	LT[a]	2.43		277	0.02	4.62
	TBT[b]	1.70	0.70	425	−0.03	4.66
65	LT	2.94		232	0.01	4.74
	TBT	2.27	0.77	305	0.00	4.73
70	LT	3.79		159	0.09	4.72
	TBT	2.74	0.72	253	0.00	4.68
75	LT	4.79		132	0.06	4.73
	TBT	3.37	0.70	206	0.00	4.68
80	LT	6.04		110	0.03	4.71
	TBT	4.17	0.69	161	0.02	4.69

[a] LT, loose tea.
[b] TBT, tea-bag tea.

3. Results and discussion

3.1. Rate constants

It has been shown (Spiro & Jago, 1982) that the rate of infusion of caffeine from loose tea leaves is a first-order process, dependent upon the rate of diffusion within the leaves themselves. With tea leaves inside tea-bags there will be a further first-order process of caffeine flow through the tea-bag membrane (Jaganyi, 1992; Spiro & Jaganyi, submitted for publication). The results have, therefore, been analysed using the overall first-order rate law employed previously:

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

where c is the corrected concentration at time t, while k_{obs} is the observed rate constant and a is a semi-empirical intercept. The corrected concentrations were plotted against time. Typical plots showing the extraction of caffeine with time from loose tea as well as from tea-bag tea are shown in Fig. 1. The curves show that, even in the presence of a tea-bag, there is an initial rapid increase in the concentration of caffeine with time. This tails off towards an equilibrium value c_∞; these values are tabulated in Table 1. The values for loose tea and for tea-bag tea were found to be of a similar magnitude. It is clear from Fig. 1 that the c_∞ value for tea-bag tea is attained after a long time when compared with that for the loose tea. The equilibrium concentrations obtained were independent of temperature and the values agree well with those reported in the literature (Spiro et al., 1992; Spiro & Lam, 1995).

The data were found to fit very well into Eq. (1) as can be seen in Fig. 2 showing the least square plots, representing the extraction of caffeine at 80°C through the loose tea and tea-bag tea. Similar plots were obtained for the other temperatures. Table 1 summarises the rate constants calculated from the slopes of these first-order plots at various temperatures plus the ratios of $k_{(TBT)}/k_{(LT)}$. Included in Table 1 is the time taken for the concentration of caffeine to reach a value of half its equilibrium concentration, the half-life $t_{1/2}$, which was calculated from the equation

$$t_{1/2} = (\ln 2 - a)/k_{obs} \tag{2}$$

The intercepts, a, from Eq. (1) were very small in all cases and some of the plots for the tea-bag tea passed

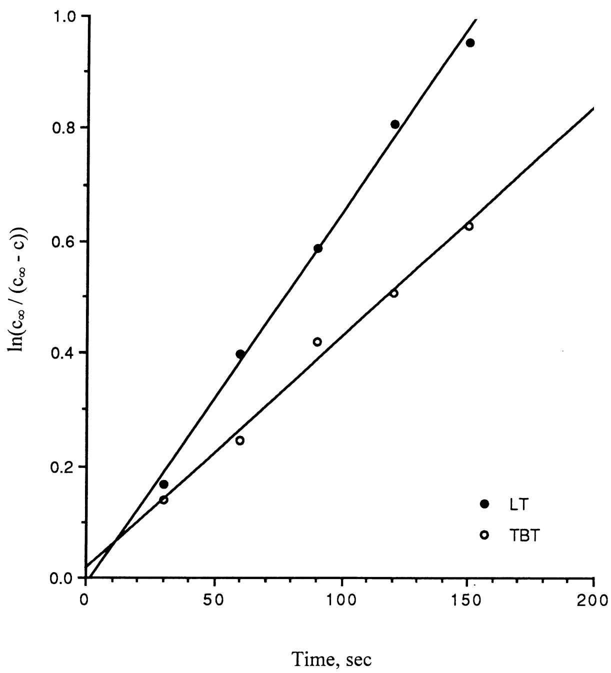

Fig. 2. Kinetic plots comparing the extraction of caffeine at 80°C from loose tea and tea-bag tea.

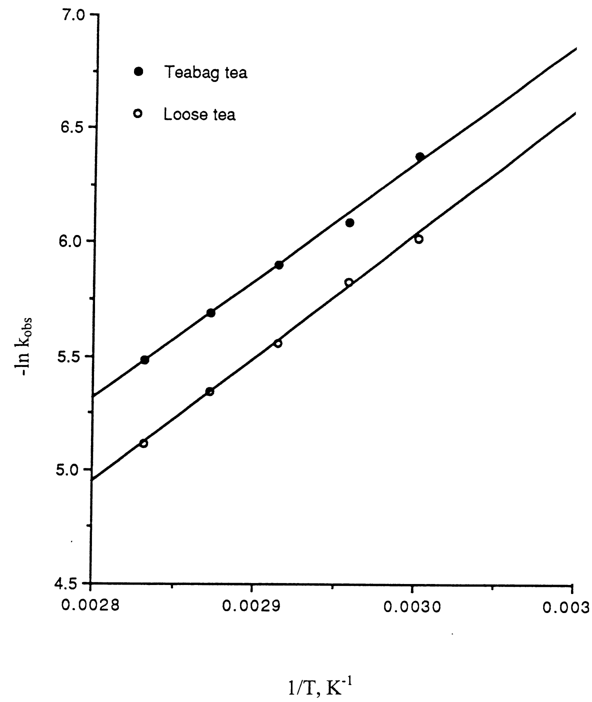

Fig. 3. Arrhenius plot for the extraction of caffeine from loose tea and tea-bag tea.

through the origin. All the kinetic data are the averages of at least three independent runs.

The observed rate constants for the tea-bag tea were 29% smaller than those of loose tea over the temperature range.

3.2. Determination of activation energy

The Arrhenius equation

$$\frac{\mathrm{d}\ln k_{\mathrm{obs}}}{\mathrm{d}(1/T)} = \frac{E_a}{R} \tag{3}$$

where R is the gas constant and T the temperature, was used to determine the activation energies, E_a, for the diffusion processes. The least square plots of $\ln k_{\mathrm{obs}}$ against $1/T$ are shown in Fig. 3. The product of the slope and the gas constant produced an activation energy of 45 ± 2 kJ mol^{-1} for the loose tea and 43 ± 2 kJ mol^{-1} for the tea in the bag. One would have expected the activation energy to be bigger in the case of the infusion through the tea-bag due to the additional resistance from the bag material. The results obtained are in agreement with earlier findings (Spiro et al., 1992).

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