Microencapsulation of *l*-menthol by spray drying and its release characteristics

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Abstract

The microencapsulation of *l*-menthol was studied by spray drying, using gum arabic (GA) and modified starch (CAPSUL, HI-CAP 100) as capsule materials. The results showed a higher retention of *l*-menthol with the increasing of initial solid concentration. HI-CAP 100, showed a higher retention than the other capsule materials. However, it also showed a higher residue of *l*-menthol on the surface of powder especially at the high concentration of *l*-menthol in the feed emulsion. That might be from the interaction between the wall materials and *l*-menthol which can re-crystallize to form whisker after the spray drying. Furthermore, the release characteristics of *l*-menthol were also investigated. The release rate increased upon elevation of relative humidity and temperature. The activation energies of the release of *l*-menthol from GA wall matrices at 75 and 83%RH were 140 and 48 kJ/mol, respectively.

Keywords: Spray drying; Encapsulation; Release; *l*-Menthol

Industrial relevance: Controlled release of food constituents is currently receiving highest interest. This study aimed to better understand some of the processing and storage conditions. Decrease in emulsion droplet size led to increased flavor retention during spray drying. Interesting electron-micrographs of the spray dried capsules are provided as well as data on water absorption isotherms and release rate constants vs. storage temperatures. Clear industrially relevent data regarding capsule size, matrix, material, water activity and temperature during storage are provided.

1. Introduction

l-Menthol, a cyclic terpene alcohol found in high concentrations in oils of peppermint and corn mint, occurs widely in nature and it is endowed with the peculiar property to be a fragrance and flavor compound. For this reason it has been widely used in over-the-counter medications, cosmetics, and food for over a century. *l*-Menthol is normally available in the form of crystals or granules with the melting point 41–43 °C. However, its high volatility and whisker growth are very important problems for its applications and shelf life. As reported by Yuasa, Ooi, Takeshima, and Kanaya (2000), especially in the medical preparation, the whisker caused the reduction of the mixing degree and fluidity in powder and granules, the lowering of the medicine quantity in tables, mistaking them for mold, and the lowering of commodity value due to the damaged aesthetic appearance. The micro-encapsulation method seems to be useful to solve these problems.

Microencapsulation of flavors in carrier matrices is of great importance in the flavor and food industries. It can provide protection against the degradative reactions, prevent the loss of volatile flavors, and enhance the stability of the flavor core materials. Various techniques are employed to form the capsules, including spray drying, spray chilling or

spray cooling, extrusion coating, fluidized bed coating, liposome entrapment, coacervation, inclusion complexation, centrifugal extrusion, and rotational suspension separation. The most common way to carry out microencapsulation of flavors is spray drying, which is the transformation of a feed from a liquid state (solution, dispersion, emulsion) into dried particulates by spraying the feed into hot air. Numerous papers have been published about the encapsulation of liquid flavors by spray drying (Bhandari, Dumoulin, Richard, Noleau, & Lebert, 1992; Buffo & Reineccius, 2000; Finney, Buffo, & Reineccius, 2002; Liu et al., 2001; McNamee, O'Riordan, & O'Sullivan, 2001; Reineccius, 1988; Rosenberg, Kopelman, & Talmon, 1990; Soottitantawat, Yoshii, Furuta, Ohkawara, & Linko, 2003). However, only a few papers have reported the encapsulation of solid flavors such as *l*-menthol as model flavors. Liu, Furuta, Yoshii, Linko and Coumans (2000) reported the encapsulation of *l*-menthol in cyclodextrin by single droplet drying method.

In addition to the primary means of stabilization and protection of flavors, a controlled release of flavors from the capsule matrices seemed to be a useful application. Rosenberg et al. (1990), Soottitantawat et al. (2004), Whorton (1995), and Yoshii et al. (2000) have reported the release of encapsulated liquid flavors.

In this study, the encapsulation of *l*-menthol was carried out by spray drying. The contents of initial wall material in the feed emulsion, the *l*-menthol concentration in the feed liquid, and the type of wall materials on the flavor retention and surface oil content in the powder were investigated. The whisker growth of the encapsulated *l*-menthol in each wall capsule was also measured. Scanning electron microscope (SEM) was used to observe the internal and external structures of encapsulated powder. Furthermore, the release characteristics of encapsulated *l*-menthol from the powder were studied. The effects of different types of wall material and storage conditions (relative humidity and temperature) were also investigated.

2. Materials and methods

2.1. Materials

l-Menthol and gum arabic (GA) were purchased from Soda Aromatic (Tokyo, Japan). The modified starches (CAPSUL and HI-CAP 100) were obtained from Nippon NSC (Tokyo, Japan). Encapsulating modified starches involve the addition of lipophilic groups. Both of CAPSUL and HI-CAP 100, which were derived from waxy maize base, were modified with *n*-octenyl succinic anhydride (OSA) for using in the flavor encapsulation process. HI-CAP 100 is blended with high-dextrose equivalent (DE) corn syrup solids with the final of 32–37 DE and designed for the high load encapsulation agent. The other organic chemicals used were of analytical grade.

2.2. Preparation of the emulsified l-menthol liquid

To study the effect of initial solid content on the retention of *l*-menthol, wall material (HI-CAP 100) was added to distilled water to obtain a 10–40% w/w mixture and allowed to hydrate overnight. *l*-Menthol was melted by heating up to 55 °C and added to the solution at 55 °C in a mass ratio to wall material solid of 0.25. The mixture was homogenized by using a Polytron homogenizer (PT-6100, Kinematic GA, Littau, Switzerland) at a rotational speed of 8000 rpm for 3 min. The *l*-menthol emulsion was kept at 55 °C and immediately fed to the spray dryer. The emulsion droplets were observed by an optical microscope. Furthermore, to study the effect of *l*-menthol concentration in emulsion and release characteristics, wall materials of GA, HI-CAP 100, and CAPSUL were used. The feed liquid emulsion of *l*-menthol was prepared at 30% w/w of total solid content (including wall materials and *l*-menthol). The mass ratio of *l*-menthol to the wall materials was 1:9, 2:8, and 3:7. The homogenization was performed in the same manner.

2.3. Preparation of encapsulated l-menthol powders

The *l*-menthol emulsion was fed through a spray dryer Ohkawara-L8 (Ohkawara Kakouki, Yokohama, Japan), equipped with a centrifugal atomizer as explained previously (Soottitantawat et al., 2003). The operational conditions of the spray drying were as follows: inlet air temperature: 180 °C, outlet air temperature: 100±5 °C, feed rate: 45 ml/min, air flow rate: 100 kg/h (at outlet temperature), rotational speed of atomizer: 30,000 rpm. Finished powder was stored in a hermetically sealed bottle at −80 °C until analysis. Retention of *l*-menthol during spray drying was defined as the ratio of the flavor in the powder to the original flavors in the feed liquid.

2.4. Quantification of encapsulated l-menthol in the powder

The amount of *l*-menthol in the powder was measured as follows. One tenth of a gram of the spray dried powder was dispersed in 1 ml of water in a glass bottle, and 4 ml of acetone with cyclohexanone (1 $\mu l \cdot ml^{-1}$) as internal standard was added, followed by forceful mixing with a vortex mixer for 1 min. To extract encapsulated *l*-menthol into the organic solvent, the mixture was heated in a heating block at 90 °C for 30 min with intermittent shaking. Then, after cooling down, 2 μl of the supernatant was injected twice for each sample to gas chromatograph (GC-14B, Shimadzu, Kyoto, Japan) equipped with a PEG-20M packed glass column (2 m×3.2 mm) and a flame ionization detector. The temperature of detector and injection was set at 230 °C and 200 °C, respectively. The column temperature was controlled at constant values of 170 °C with N_2 as the carrier gas at 150 kPa of inlet pressure. The internal standard method was used to calculate the amount of *l*-menthol. All of the samples were analyzed in duplicate and the data were presented as an average.

2.5. Retaining of l-menthol on the surface of powder

One tenth of a gram of powder was washed in 2 ml of hexane containing internal standard cyclohexanone (1 $\mu l \cdot ml^{-1}$) in a glass bottle. The mixtures were slowly mixed on a rotary shaker for 30 s at ambient temperature (Soottitantawat et al., 2003). The solvent was then filtered. The *l*-menthol content in the organic phase was measured by gas chromatography as described above. The results are the average of the triplicates in each sample.

2.6. Fourier-transform infrared spectroscopy (FT-IR)

The IR spectra of *l*-menthol and encapsulating powder were measured by the salt pellet technique. The spray dried powder, which were prepared from the 30% w/w total solid content with *l*-menthol:wall materials mass ratio of 2:8, was used. Two milligram samples were diluted in a 200 mg of IR-transparent salt, potassium bromide (KBr). Then, the pellet was made and placed in a Fourier-transform infrared spectroscope (FTIR-8300, Shimadzu, Kyoto, Japan).

2.7. Observation of emulsion droplets by optical microscope

The emulsion droplet, produced at 55 °C, was observed to investigate the emulsion and the size of emulsion droplet. An optical microscope (Olympus BH-2, Olympus Optical, Tokyo, Japan) was used to acquire the emulsion droplet which was dispersed with the warm water at the ratio 1:10. The picture of emulsion was taken at 40× magnification.

2.8. Morphological characterization by scanning electron microscopy (SEM)

The external and internal structures of the encapsulated powder were studied by SEM (JSM 5800, JEOL, Tokyo, Japan). The powders were placed on the SEM stubs using a two-sided adhesive tape (Nisshin EM, Tokyo, Japan) and then analyzed at 15 kV acceleration voltage after Pt–Pd sputtering by MSP-1S magnetron sputter coater (Vacuum Device, Tokyo, Japan), as described previously (Soottitantawat et al., 2003).

2.9. Release of l-menthol from the spray-dried powder

The release characteristics of flavors have been reported in our previous work (Soottitantawat et al., 2004; Yoshii et al., 2001). The spray dried powder, which were prepared from the 30% w/w total solid content with *l*-menthol:wall materials mass ratio of 2:8, was used to study the release characteristics. One tenth of a gram of each dried powder was weighed and spread in thin layers in 15 ml glass bottles (20 mm I.D.×48 mm), and placed in a desiccator with saturated salt solution in order to maintain a constant relative humidity at 8±5%, 33±5%, 51±5%, 75±5%, and 83 ±5% (Rockland, 1960). The temperature was kept constant in an air bath at 30 °C, 37 °C, 43 °C, and 50 °C. An accelerate method for the flavor release was employed. Humid air of the same relative humidity was blown into the desiccator at 6 h intervals to purge the gas for 10 min. At prescribed time intervals, bottles were picked out of the desiccators. The residual amount of *l*-menthol in the powder was measured by the solvent extraction method described above. The retention of *l*-menthol in the releasing experiment was expressed as the ratio to the initial flavor content. Avrami's equation, Eq. (1), also called Weibull distribution function, which was successfully applied to describe the shelf life failure (Gacular & Kubala, 1975), and later applied to the release time-courses of the encapsulated flavors (Soottitantawat et al., 2004; Yoshii et al., 2001) was also employed in this work.

$$R = \exp[-(kt)^n] \quad (1)$$

where R is the retention of *l*-menthol, t is the storage time, k is the release rate constant, and n is a parameter representing the release mechanism.

3. Results and discussion

3.1. Effect of wall material contents in feed emulsion on l-menthol retention

The effect of wall materials concentration in the feed emulsion on the retention of *l*-menthol during spray drying is shown in Fig. 1. HI-CAP 100 was used as the wall material with a ratio of *l*-menthol to the wall material of 0.25. The retention was improved with increasing in wall material concentration. Similar results have also been reported for liquid flavors by others (Bhandari et al., 1992; Ré & Liu, 1996; Rosenberg et al., 1990). The higher wall material content increased the rate of formation of a semipermeable membrane resulting in the reduction of flavor loss during drying according to the selective diffusion theory (Thijssen & Rulkens, 1968). As Thijssen and Rulkens (1968) noted that the water concentration at the droplet surface decreases, the

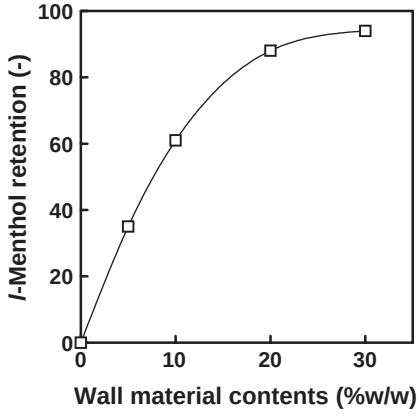

Fig. 1. Effect of initial solid content on *l*-menthol retention when HI-CAP 100 was used as wall material at 20% w/w *l*-menthol of wall material in feed emulsion.

diffusion coefficients of the volatile components decrease by several orders of magnitude, more sharply than that of water. While water continues to diffuse at a significant rate, the volatiles diffuse at a negligible rate. Therefore, this dry surface acts as a semipermeable membrane permitting the continued loss (or diffusion) of water, but efficiently retaining (or stopping) volatile molecules.

3.2. Effect of concentration of *l*-menthol in the feed liquid for different types of wall materials

The higher content of flavor in the spray-dried products is advantageous for the powder products. Therefore, the effect of *l*-menthol content on the retention during spray drying and surface oil content was studied and shown in Tables 1 and 2, respectively. The powder was prepared at a constant total solid content of 30% w/w. There was no effect of *l*-menthol load on the retention at low concentrations of *l*-menthol, but the retention of flavor decreased when the mass ratio of *l*-menthol to wall materials increased to 3:7 especially with GA and CAPSUL. This indicates that the flavor load capacity depended on the type of wall material. As for the effect of the type of wall material on the flavor retention, HI-CAP 100 showed higher *l*-menthol retention than the other wall materials. That might be explained by the emulsifying properties of each type of wall materials. HI-CAP 100 facilitated the formation of a smaller size of emulsion droplets than GA and CAPSUL at the same homogenized conditions, which could be observed by the photo of emulsion droplets in the following section. The decreasing of emulsion droplet size increased the flavor retention during spray drying (Soottitantawat et al., 2003). Further, at a higher *l*-menthol concentration, the surface *l*-menthol content was also increased as shown in Table 2. The modified starch, CAPSUL and HI-CAP 100, as wall material showed higher surface *l*-menthol contents, especially in the higher *l*-menthol concentration in feed liquid, even though higher retentions were reported in comparison to GA. This might be explained by the interaction between the wall materials and *l*-menthol which can re-crystallize to form whisker after spray drying as explained in the following section.

3.3. The change in the IR spectrum of *l*-menthol after the encapsulation

According to Yuasa et al. (2000), when *l*-menthol is mixed with the excipient with whisker growth, the peak of the hydroxyl group-stretching band of *l*-menthol shifts to a higher wave number. The wave number of stretching vibration of *l*-menthol hydroxyl group is 3232.5 cm^{-1} in IR spectrum as shown in Table 3. The shifts of the wave number of the encapsulated *l*-menthol were also reported. Encapsulated *l*-menthol in CAPSUL showed a higher shift wave number than the others. It indicates higher whisker contents in CAPSUL than GA and HI-CAP 100, respectively. It might be said that the growth of whisker of *l*-menthol causes the high surface oil content which was measured by the washing method as shown in Table 2. Although, the data at the higher concentration of *l*-menthol (*l*-menthol: wall materials at 3:7), at which the modified starch showed the 3 times higher of surface *l*-menthol content than GA, were not reported.

Table 1
Effect of *l*-menthol content on the retention during spray drying

l-Menthol concentration (mass ratio of *l*-menthol:wall materials)	Retention of *l*-menthol (%)[a]		
	GA	CAPSUL	HI-CAP 100
1:9	72	85	87
2:8	72	85	85
3:7	68	79	85

[a] Measurements were done in duplicate.

Table 2
Effect of *l*-menthol content in emulsion on surface oil content during spray drying

l-Menthol concentration (mass ratio of *l*-menthol:wall materials)	Surface *l*-menthol content[a] (% of total menthol)		
	GA	CAPSUL	HI-CAP 100
1:9	2.75	3.37	2.74
2:8	5.16	9.57	13.04
3:7	15.65	41.56	42.79

[a] Measurements were done in duplicate.

3.4. Internal and external microstructure of encapsulated *l*-menthol powder

Optical microscope and SEM were used to investigate the emulsion droplet in the feed emulsion, and external–internal structure of encapsulated *l*-menthol in the matrices, respectively. The powders were prepared from the 30% w/w total solid content with *l*-menthol: wall materials ratio at 2:8. As shown in Fig. 2a-1, b-1, and c-1, the emulsion of *l*-menthol was prepared at 55 °C with GA, CAPSUL, and HI-CAP 100, respectively. Emulsion droplet size in the modified starch, CAPSUL and HI-CAP 100, seemed to be smaller than in GA at the same homogenization conditions. That could explain why a higher retention of *l*-menthol in the modified starch matrices was observed as mentioned before. As Soottitantawat et al. (2003) mentioned, the increasing emulsion droplet decreased the retention of flavors. The larger emulsion droplets would be changed in size during atomization, resulting in the decrease flavor retention.

Table 3
Shift of wave number of stretching vibration of *l*-menthol hydroxyl group in IR spectrum in *l*-menthol and encapsulated *l*-menthol[a]

Wall materials	Wave number (cm^{-1})	Shift wave number
l-Menthol	3232.5	0.0
HI-CAP 100	3294.2	+61.7
GA	3338.6	+106.1
CAPSUL	3367.5	+135.0

[a] The powder were prepare from the 30% w/w total solid content with *l*-menthol:wall materials mass ratio of 2:8.

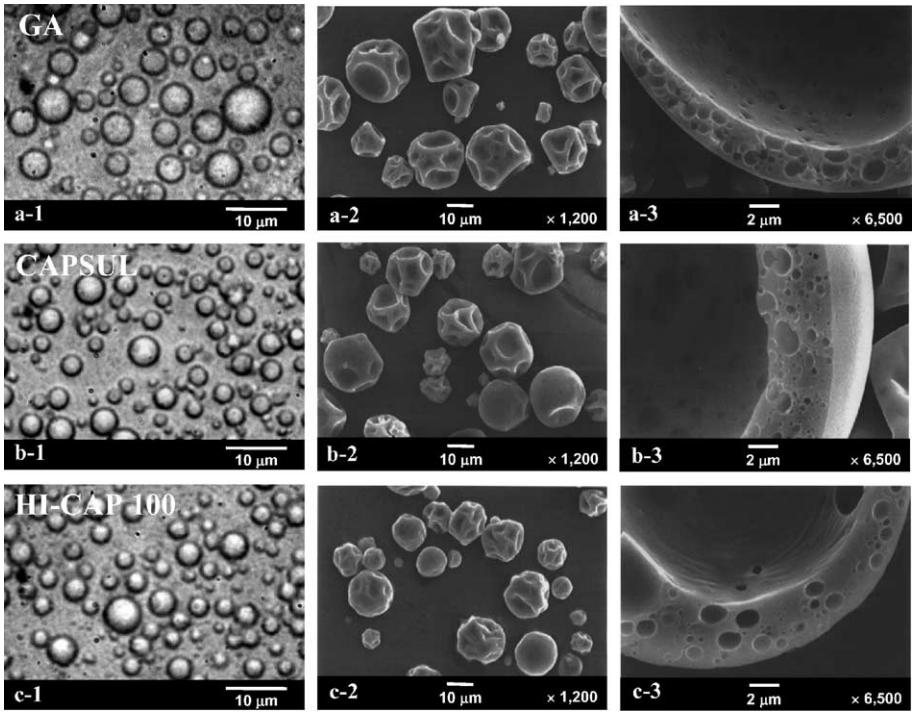

Fig. 2. Structure of emulsion droplet (a-1, b-1, and c-1), internal (a-2, b-2, and c-2), and external (a-3, b-3, and c-3) structure of encapsulated *l*-menthol powders. GA, CAPSUL, and HI-CAP 100 was used as wall materials in a, b, and c, respectively. The powders were prepared from the 30% w/w total solid content with *l*-menthol:wall materials mass ratio of 2:8.

The external structures of each powder were almost the same for each type of wall materials. The groove and smooth surfaces of powders were observed in Fig. 2a-2, b-2, and c-2 for GA, CAPSUL, and HI-CAP 100, respectively. However, a smooth powder surface was more observed in the HI-CAP 100 and CAPSUL. The internal structures are shown in Fig. 2a-3, b-3, and c-3. Small holes were observed in the shell of wall matrices. Generally, small holes should contain with the droplets of flavors in the case of encapsulated liquid flavor (Rosenberg, Kopelman, & Talmon, 1985; Rosenberg et al., 1990; Soottitantawat et al., 2003). Therefore, in the same manner with this work, *l*-menthol could expect inside the hole. Furthermore, *l*-menthol is solid at the room temperature and can re-crystallize to form the whisker as explained before. From SEM photo, the whisker growth from the emulsion droplet could not be observed inside the hole. That might be the loss of *l*-menthol during Pt–Pd coating of the cut sample under the vacuum condition for the SEM observation. Further, the whiskers might be located in the other site not in the holes.

3.5. Release time course of encapsulated l-menthol from spray-dried powder

The release time course of *l*-menthol in spray-dried powder was measured at 43 °C and at various humidities (8–83%RH) as shown in Fig. 3. The relative humidity shows a pronounced effect on the release rate of *l*-menthol, especially in GA and HI-CAP 100 wall matrices. In order to study the release characteristics of encapsulated *l*-menthol in

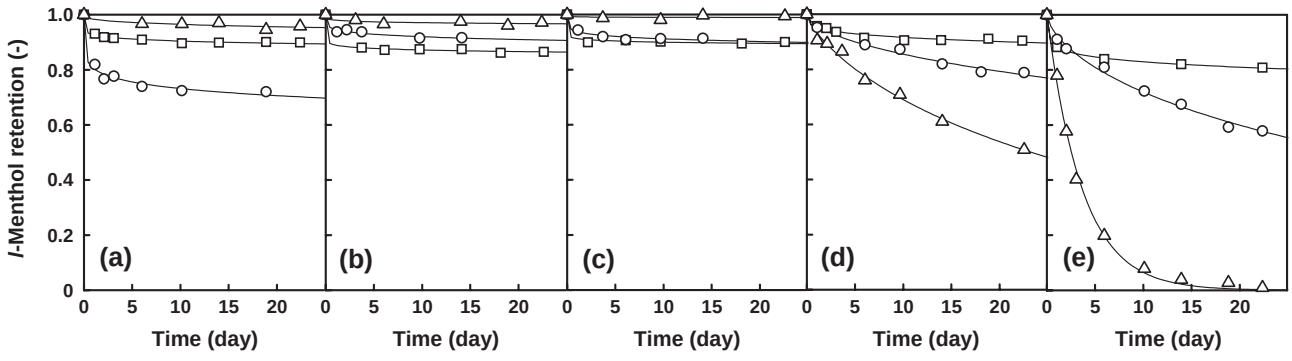

Fig. 3. Release time-course of encapsulated *l*-menthol in spray dried powder at various humidity conditions and 43 °C storage. (a) 8%RH, (b) 33%RH, (c) 51%RH, (d) 75%RH, (e) 83%RH. (△), GA; (□), CAPSUL; (○), HI-CAP 100.

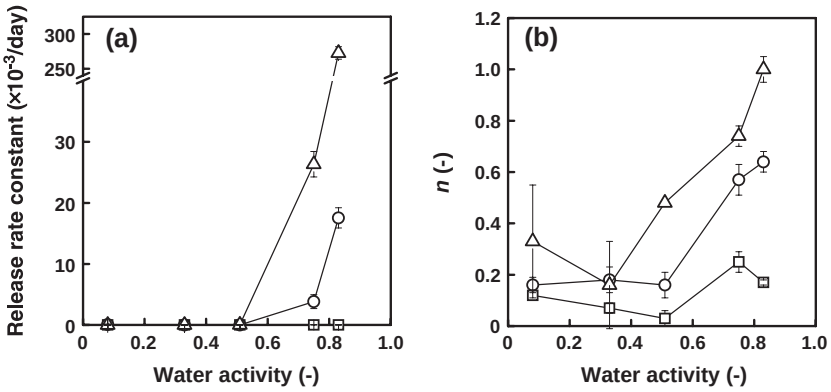

Fig. 4. Effect of water activity on the release rate constants, k (a), and n values (b) for the release of encapsulated l-menthol from spray dried powder at 43 °C storage. (△), GA; (□), CAPSUL; (○), HI-CAP 100. The error bars indicate 95% confidence levels.

response to various influence factors, the release rate constants were evaluated. The time-courses of l-menthol release were correlated with Avrami's equation (Eq. (1)) as shown by the solid line in Fig. 3. The release rate constant (k) and release mechanism parameter (n) were also calculated. The relation of the release rate constant (k) and n values against water activity (a_w=RH/100) is shown in Fig. 4a and b, respectively. At a low a_w, only a small amount of encapsulated l-menthol was released from the spray-dried powder. On the other hand, the release rate constant dramatically increased with the increasing a_w especially with GA and HI-CAP 100, when a_w was higher than 0.5. Similar results were also reported in our previous work (Yoshii et al., 2001) for the increasing of release rate of encapsulated ethyl-n-butyrate from wall matrices with an increase of relative humidity. That might be explained by the change of matrix structure as mentioned by Rosenberg et al. (1990) and Soottitantawat et al. (2004). As long as the individual structure of the capsule remains intact, high retention of volatile is maintained. At low a_w, the capsule matrix is still in the glassy state. The slower release in the low a_w region is most likely due to the lower mobility of flavor molecules in the glassy state of the capsule matrixes. Once the capsule structure is damaged by water uptake, the release rates are increased. This can be possibly the result of the higher mobility of flavor (i.e., the capsule matrix start to be plasticized). However, contrasting results were reported in our recent work (Soottitantawat et al., 2004) for a water insoluble flavor, D-limonene. In this case, the release rate increased with the increasing a_w at low water activity range (0.10–0.50), then decreased around 0.70–0.80 a_w range and dramatically increased again at the high a_w (0.96). The authors explained the high loss of encapsulated compound by the change of structure from the glassy state to the rubbery state at the range of 0.10–0.50 a_w. The decreasing of the release rate at a_w 0.70–0.80 was explained by the formation of paste like mass of powder in the rubbery state, resulting in the decreasing of effective surface area for releasing. According to the present study, although the paste like mass of encapsulated powder was also observed around a_w of 0.75, a reduction of release rate constant could not be observed as shown in Fig. 4a. This might be caused by the water-solubility of the l-menthol. For partially water soluble flavors, dissolved flavors can increasingly diffuse through the wall matrices with increasing of water activity, resulted in a higher release of flavors as shown in Fig. 4a. Similar observations have also been reported by Yoshii et al. (2001) and Rosenberg et al. (1990). Therefore, for the partly

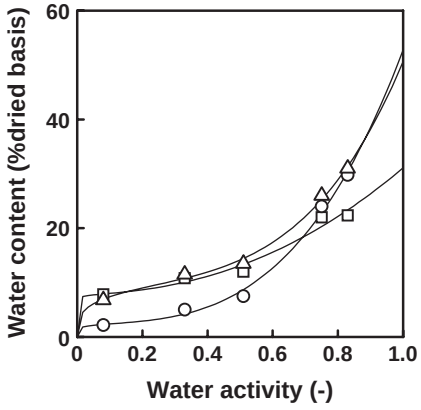

Fig. 5. Water adsorption isotherms of capsule matrices after equilibration at 43 °C. The solid lines show the fitting data by Peleg model. (△), GA; (□), CAPSUL; (○), HI-CAP 100.

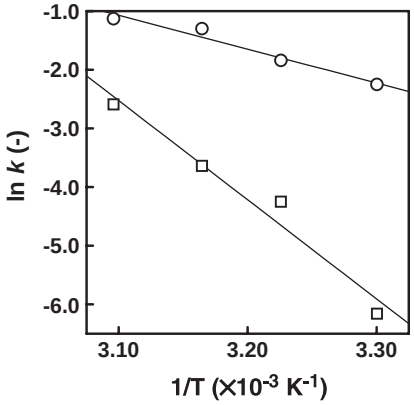

Fig. 6. Relation between release rate constant and temperature by using Arrhenius equation, with GA as wall material. (○), 75%; (□), 83%.

soluble flavors, the decreasing of flavor release rate from the paste like mass formation at a_w of 0.70–0.80 should not be observed as compared to the insoluble flavor.

Furthermore, the *l*-menthol was released more slowly from the CAPSUL compared to HI-CAP 100 and GA, especially in the high water activity range. As discussed above, the water uptake, which caused a change of matrix structure and increased the dissolution of *l*-menthol, seemed to be an important factor for the release of *l*-menthol. With respect to their water uptake properties, the water sorption isotherms of each wall matrices were determined in Fig. 5. The experimental data were fitted with the Peleg model (Peleg, 1993). At the higher water activity, CAPSUL showed a lower water uptake property than the others materials. That could explain the lower release rate of *l*-menthol from the CAPSUL wall matrices.

In Fig. 4b, the values of n for all wall materials are in the range of 0.10 to 1.00. This indicates that the release of encapsulated *l*-menthol is controlled by the diffusion mechanism through the wall of the particles, as described in our previous work (Soottitantawat et al., 2004; Yoshii et al., 2001).

3.6. Effect of the relative humidity on the activation energy

As mentioned by Vrentas (1978), the activation energy (E_a) could be an indirect quantitative means available to compare the systems. They have been suggested that the E_a for diffusion may be described as the energy required to create a "hole" large enough to accommodate a diffusing molecule. The hole is created by the separation of polymer segments as the diffusing molecule moves through them.

In order to study the effect of temperature on the release mechanisms and also to calculate E_a for the release of *l*-menthol, the release of *l*-menthol from the GA matrix was investigated at 75 and 83%RH. The release rate constants were calculated and plotted against the reciprocal of absolute temperature according to Arrhenius equation (Fig. 6). The release rate constants increased with the increase of temperature. From the Arrhenius equation, the activation energy values were 140 kJ/mol and 48 kJ/mol for 75%RH and 83%RH storage, respectively. This indicated that the release occurred easier in the higher water activity.

4. Conclusions

Whisker growth and the high volatility of *l*-menthol are problems in its application and shelf storage. Microencapsulation seems to be useful tool to overcome this problem. Spray drying was used to prepare the encapsulated *l*-menthol powders in various wall matrices. Further, the release characteristics from the matrices were investigated.

The influence of solids concentration of feed liquid and the *l*-menthol content in feed liquid on the encapsulation ability was similar as observed for liquid flavors. The high retention of *l*-menthol after spray drying was observed with high solid contents. The optimal *l*-menthol concentration in the feed emulsion, which should have a high retention of flavor and low flavor residue on the surface, was 20% w/w of *l*-menthol concentration (mass ratio of *l*-menthol:wall materials at 2:8). The high surface *l*-menthol contents were observed in the modified starch (HI-CAP 100 and CAPSUL). These should be caused by its interaction with the *l*-menthol, in which a higher whisker growth was observed. Therefore, GA seemed to be more suitable for encapsulating *l*-menthol even though the low retention was reported.

The release rate of *l*-menthol, a partly water soluble flavor, increased upon increasing water activity. The higher water uptake resulted in a damage of the matrix structure and the higher dissolution of *l*-menthol in a higher release of *l*-menthol from the matrix. At the higher a_w range, CAPSUL showed a lower release rate than HI-CAP 100 and GA, respectively. However, at the low a_w (a_w<0.5), the difference in the release rate could not be observed in the type of wall materials. Consider in the temperature storage, the release rate increase with the increasing of temperature (especially in the high range of a_w). Furthermore, the activation energy for the release of flavor decreased with the increasing of a_w.

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