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Pattern Formation in Evaporation Coffee Droplets: Influence of Temperature and Salt†

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In this study, some factors influencing pattern formation in evaporation coffee droplets were investigated, such as temperature, the concentration of coffee and the mass of salt. Polarizing microscope and zoom monocular video microscope were used to investigate the pattern of coffee-ring. The results showed that the edge width of coffee-ring increased as coffee concentration increased. While the edge width of coffee-ring decreased as increased salt concentration. The results indicated that styles of pattern crystals depended on salt concentration.

Keywords: Droplets, Coffee-ring, Pattern formation.

INTRODUCTION

After the evaporation of coffee droplets which drops on a solid substrate, there will be a ring-liked shape left on it. Most of the dispersed solid matter deposits along the perimeter. This is known as the coffee-ring effect[1]. Besides coffee, some solution can make this ring-like structure such as nanoparticles, polymer colloidal particles, bacteria and DNA. By tuning the interfacial interaction between the polymer and the substrate, intriguing, ordered dissipative structures can be produced as a result of synergy of controlled self-assemblies of the polymer[2]. When combine with inkjet printing. It can also form a transparent conductive pattern by the mutual interaction of ring[3]. Moreover, the coffee-ring effect can be used to medical diagnosis such as detecting biomarker in saliva, blood and other body fluids[4].

Deegan *et al.*[5] had studied the formation mechanism of the coffee-ring effect. They considered this phenomenon come from the capillary flow toward the edge of droplets. Sangani discovered that whether the contact line was pinned not only depended on the size of particles but also relied on the concentration of the particles, the radius of the droplet, the speed of the evaporation and the matrix of the wetting properties, *etc*. Wong and his co-workers discovered there was a size limit for coffee-ring effect if particles concentration in droplets reaches critical value. Yunker *et al.*[1] has studied suppression of the coffee-ring effect by shape-dependent capillary interactions and indicated that ellipsoidal particles were deposited uniformly during evaporation. Thus, the coffee-ring effect can be simply controlled by changing particles shape. In addition, Kaya *et al.*[6] investigated pattern formation in drying droplets of polyelectrolyte and salt and found the width of the coffee-ring varies in relation to the change of salt concentration.

In the present study, some factors influencing pattern formation in evaporation coffee droplets, such as temperature and salt were investigated.

EXPERIMENTAL

Preparation of coffee-ring pattern: In the experiments, the concentration of pure nestle coffee (Nestle coffee company, Shanghai, China) were varies from 1/20-1/240 g/mL. Parent solution of 1/80 coffee was prepared. 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 g of potassium chloride (Beijing Chemical Reagents Co., Beijing, China) were added in 200 mL per parent solution. Then 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 g of sodium chloride were added in 200 mL per parent solution. The coffee droplets were deposited on the glass substrates, the process of evaporation were investigated at different temperature which ranges from 40-120 ºC.

Characterization: The coffee-ring patterns were captured by Zoom Monocular Video Microscope HSA10 (Guangxi

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Wuzhou Encouragement Optical Instrument Co., Ltd., Wuzhou, China) and Polarizing microscope XP3A (Guiyang Xintian Oetech Co., Ltd., Guiyang, China). Image-pro plus 6.0 software was used to analysis pictures which were taken under microscope.

RESULTS AND DISCUSSION

Effect of concentration of pure coffee: In the picture, the vertical distance between two green lines was the ring diameter. As shown in Fig. 1, the coffee-ring patterns were formed at different concentration of coffee. The edge width of coffee-ring was the vertical distance between green line and intersection of blue line and y = 100. The width of coffee-ring increased as increased concentration of coffee at the same temperature. And the higher the temperature, the width of coffee-ring was bigger.

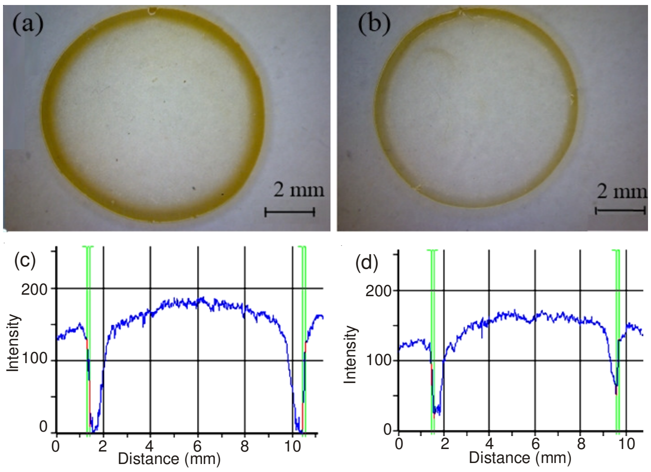

Fig. 1. Coffee-ring pattern taken at 80 ºC with concentration of coffee (a), (c) 1/100 (g/mL), (b), (d) 1/180 (g/mL)

Effect of salt: As shown in Fig. 2(a, b), the coffee-ring effect was influenced obviously by sodium chloride and potassium chloride. The influence of sodium chloride was more signifigent than potassium chloride. The width of coffee-ring of KCl was smaller than width of coffee-ring of NaCl. In condition of the same temperature, the width of coffee-ring also decreased with the mass of sodium chloride and potassium chloride decreasing. The pictures suggested the structures in coffee-ring have changed after the evaporation because the mass of NaCl was different. The research indicated particles of crystals change to dendritic with salt content increasing.

Effect of temperature: Looking at the Fig. 3(a), the edge width of coffee-ring increased with concentration of coffee-ring increasing at 40 ºC. Similar measurements were performed at different temperature in the same trends. There was a trend that the edge width of coffee-ring increased with increasing of temperature when pure coffee in a cerain concentration. However, the result was completely differrent when NaCl and KCl were added to coffee drops. As excepted, it kept the same trend while the mass of KCl increased in the coffee drops. As shown in Fig. 3b, these data were the same trend at the different temperature. The edge width of coffee-ring increased as the temperature increased coffee concetration. While the edge width of coffee-ring decreased as the temperature increased salt concetration.

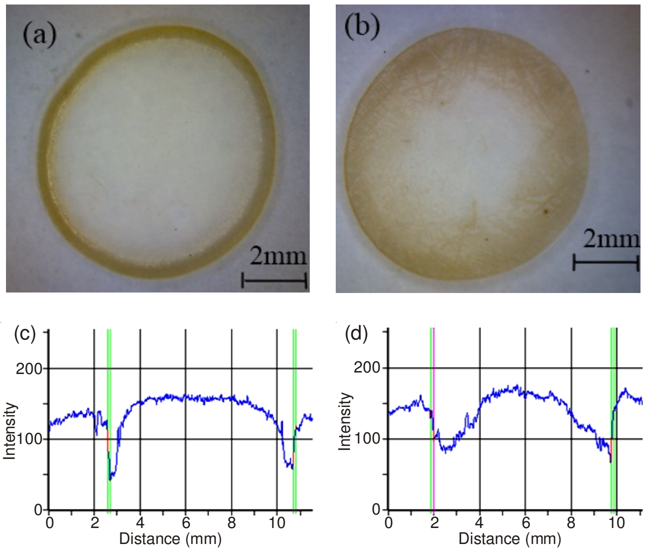

Fig. 2. Pattern formed at 60 ºC: (a) and (c) KCl, (b) and (d) NaCl

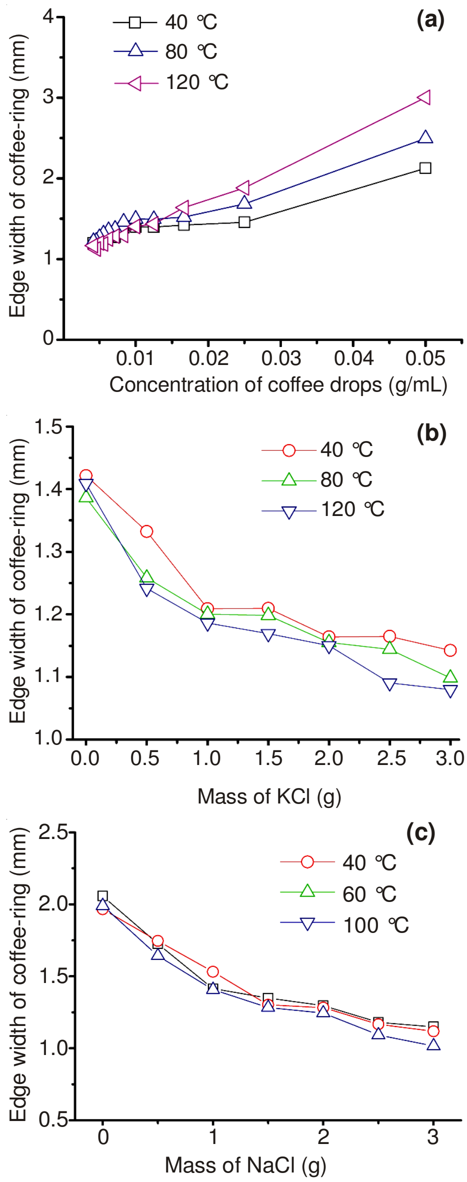

Fig. 3. Edge width of coffee-ring changs at different temperature:(a) different concentration of coffee drops, (b) the different mass of KCl, (c) the different mass of NaCl

As for coffee solution of sodium chloride and potassium chloride, there was oppsite trend compared with the pure coffee. The width of coffee-ring was smaller in higher temperature. At the same temperature, the width of coffee-ring also decreased with the mass of NaCl and KCl increasing. In the same concentration and condition, NaCl formed coffee ring width large than KCl. Besides, crystal were formed after evaporation in the solution of sodium chloride and potassium chloride as shown in Fig. 4. The crystal changed from particle to dendridic with the increasing the mass of sodium chloride and potassium chloride. But crystal also formed in pure coffee solution after evaporation. The reason was that coffee contains sugar. At the high temperature, sugar crystallized.

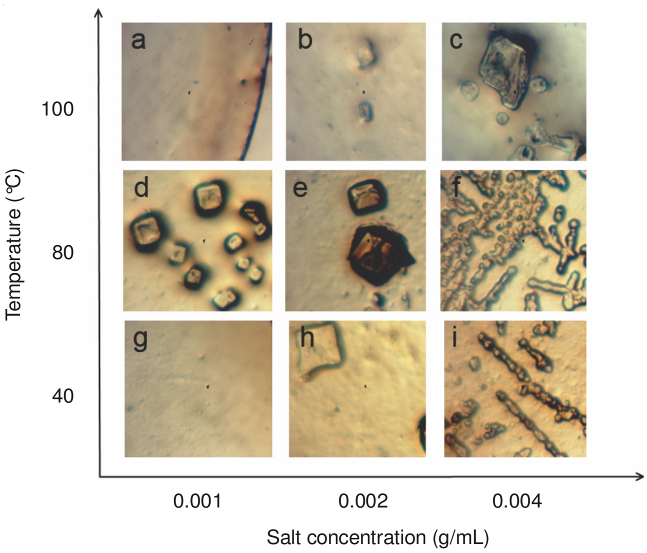

Fig. 4. Chart of different patterns

Conclusion

Pattern formation in evaporation coffee droplets were influenced by some factors. The edge width of coffee-ring increased as increased coffee concentration. While the edge width of coffee-ring decreased as increased salt concentration. The research indicated particles of crystals change to dendritic with salt content increasing. Further research should be focused on several other factors such as the ambient pressure and the hydrophilicity of the material surface.

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REFERENCES

1. P.J. Yunker, T. Still, M.A. Lohr and A.G. Yodh, *Nature*, **476**, 308 (2011).
2. S.W. Hong, J. Xia, M. Byun, Q. Zou and Z. Lin, *Macromolecules*, **40**, 2831 (2007).
3. M. Layani, M. Gruchko, O. Milo, I. Balberg, D. Azulay and S. Magdassi, *ACS Nano*, **3**, 3537 (2009).
4. J.T. Wen, C.-M. Ho and P.B. Lillehoj, *Langmuir*, **29**, 8440 (2013).
5. R.D. Deegan, O. Bakajin, T.F. Dupont, G. Huber, S.R. Nagel and T.A. Witten, *Nature*, **389**, 827 (1997).
6. D. Kaya, V. A. Belyi and M. Muthukumar, *J. Chem. Phys*., **133**, 114905 (2010).