Sub-micron size spherical wax beads using a t-junction microfluidic device

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Abstract

Waxes are employed in toner to improve its anti-offset characteristic at low or high temperature and fixability at a low temperature. Addition of monodisperse wax nano particles can enhance the toner performance by precise control of composition, which enables finer printing. This study aims the production of spherical sub-micron size wax beads in a microfluidic system. T-junction microfluidic device was fabricated using standard photolithography techniques for wax particles formation just above the melting temperature of wax. The size of the particles could be tuned by controlling the flow conditions and temperature of the microfluidic device.

Keywords: Microfludics, T-junction, Wax beads, toner, monodisperse, photolithography

Introduction

The wax has found unique applications in cosmetics, pharmaceuticals, foods, various kinds of lubricants, water proof paints, adhesives, fruit preservatives and the electronic material field. Especially the utilization of wax in the electronic field such as printing has drawn a great attention of the researchers [1]. Recently, the methods for making the toner mostly focused on the chemical routes to obtain the reasonable size wax particles. These routes include the suspension polymerization, solution-dispersion processes and aggregation. The smaller size particles are of great interest for different reasons such as better printing resolution, good yield of the cartridge and lower chances of paper curling. The shape of the toner deeply affects the printing process. Earlier the toner was produced by the common milling process which has very low transfer efficiencies because of the irregular shape. Since, wax is a compulsory constitutes of the toner and the film formation on the substrate is highly important. The most common failures occur in toner are the paper wrapping and poor printing. It is highly appreciated to produce such type of toner that can satisfy many requirements simultaneously in one package. These requirements include fixing the substrate at the low temperature and it should be capable to work at wide range of fusion temperatures. The above should be fulfilling in a way by adding the wax or the internal release agent in the toner. Melted wax acts as a release agent for the toner and it also overcome the need for silicon oil. The role of wax is to melt by heat, seep out of toner resin and help toner resin to fix on the paper and to release it from heating roll [2].

Different methods have been used to produce the wax particles or the wax emulsions such as electrospray emulsification [3] and water-in-oil emulsion methods [4]. In electrospray and water-in-oil emulsification methods the micron sized wax particles were produced. In order to have better printing quality toner the wax particles should be of sub-micron size. Microfluidic technology holds great promise as it can perform typical laboratory operations using a fraction of the volume of reagents in significantly less time than compared with conventional batch experiments [5]. Recent studies on droplet-based microfluidics have drawn great attentions with the development of new methods and applications in various fields of lab-on-a-chip technology [6,7]. A number of methods are available that can produced the monodisperse droplets in microfluidics [8]. One of the most popular microfluidic emulsion devices is to use a T-junction channel [9-11].

In the present study, monodispersed sub-micron size wax particles were produced using a T-junction microfluidic device. The effects of both of continuous and the dispersed phase flow rates were examined on the average wax particles size. The particles size decreases linearly with the increase of continuous phase flow rate. The produced wax particles were monodispersed compared to the particles produced by conventional method. No report is available for the production of sub-micron size wax particles by using a T-junction microfluidic device.

Experimental Section

The droplet based microfluidic T-junction device was fabricated using a standard photolithography technique as illustrated in Fig. 1a. The width of both of the continuous and the disperse phase channels was 5o µm. The depth of the microchannel was also 50 µm. Water was used as a continuous phase and the mixture of melted wax and water was used as dispersed phase. Two peltier heaters were attached at the bottom of the microfluidic device to maintain the temperature of both the continuous and the disperse phases. For the proper heating of water, a coiled microchannel was made. A heating tape used to keep the disperse phase in the melted state. Two additional streams (cooling streams) of water exist for cooling the wax particles.

First of all, a microfluidic device was bound to Peltier heater using thermo conductive grease in order to have a better contact between device and heater. Electric power was supplied to the peltier heaters and waited for 10 minutes in order to get steady state temperature. Temperature of the peltier devices could be controlled easily by changing the values of current and voltage from the DC power supply(SM techno, South Korea). A thermocouple (OMEGAETTE, HH308, type K) was used to measure the temperature of the hot surface of the Peltier device (Cryotherm, Russia) and heating tape (HT 2506, 200W) which is further connected to temperature controller (TC 9201,220 volts). The disperse phase and the continuous phases were introduced into the

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device with the help of syringe pump (KD Scientific, Holliston). The melting temperature of wax about 71-72 °C.

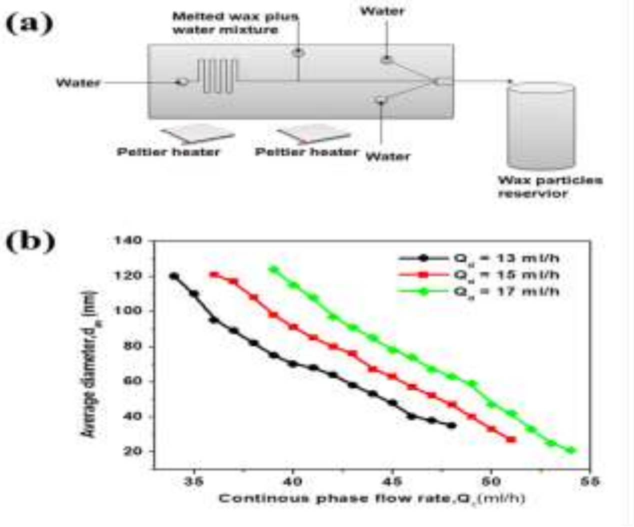

Figure 1. Schematics of droplet-based microfluidic syste m, and (b) average particles size as a function of Qc a nd Qd

The precise operating temperature of the microfluidic device during particle formation was near the melting point of wax which is 75 °C. Approximately, 6-7 % (w/w) melted wax plus water mixture was prepared by pouring about 3.5g the solid wax, wax esters (WE-4) into the hot water while heating and stirrer the solution by magnetic stirrer for 10 minutes at low speed. The flow rate of the cooling streams was maintained at 2ml/h. Wax particles were collected in the wax particles reservoir filled with cold water for the quick solidification of was droplets.

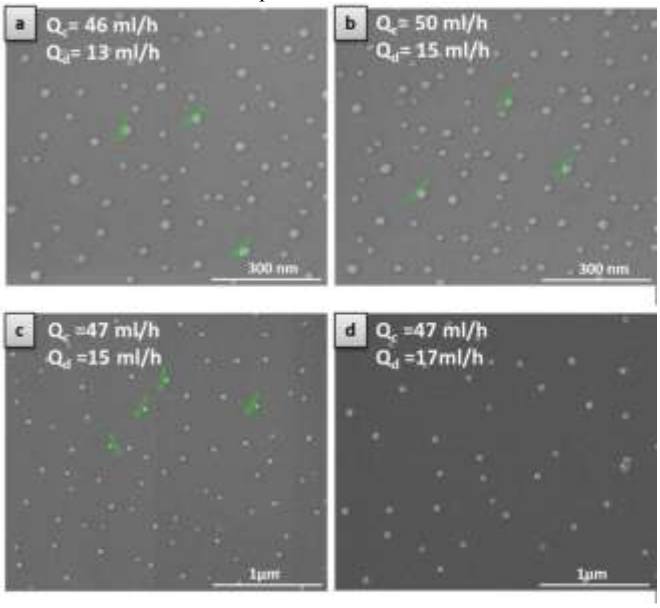

Figure 2. SEM images; (a-d) showing the monodisperse d wax particles in the size range of 25-40±10 nm for various Qc and Qd.

Conventional approaches for making wax particles simply in a beaker assembly, mainly in wax diffusions, comprise of melt cooling technique, where wax is melted in a solvent like water and then chilled to precipitate fine particles.

The surface morphologies were recorded on an Scanning electron microscopy (SEM)-4800 field-emission SEM.

Results and discussion

In Fig. 1b, we show the variations in average particle size by changing the continuous phase flow rate (Q_c) at some constant fixed disperse phase flow rates (Q_d). With the increase in Q_c, the particle size linearly decreases and average wax particles size varies from 21-67 nm. At much higher Q_c, smaller particles (20-30 nm in diameter) can be produced. The SEM images in Fig. 2, exhibit the successful formation of spherical wax beads in the range of 25 to 40 ±10 nm for certain Q_c and Q_d. It can be seen clearly that increase in Q_c, will definitely reduce the particle size.

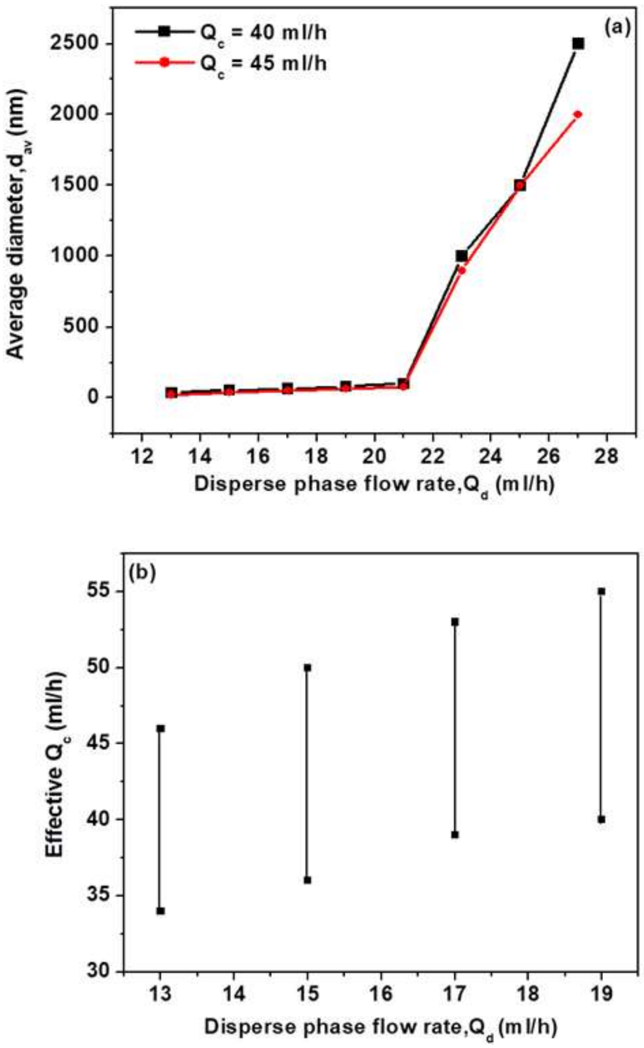

Figure 3. (a) Average Particles size as a function of Q d for fixed Qc, and (b) effective Qc for various Qd.

The effect of Q_d between 13-27 mL/h was also studied on the average particles size for the fixed Q_c of 40 and 45 mL/h in a T-junction microfluidic device at low temperature as plotted in Fig. 3a. With the increase in Q_d, the particles size gets larger even at very high continuous phase flow rates. In order to get the particles of the desired size an effective range of the Q_c exits for certain Q_d is shown in Fig. 3b. Moreover, the microfluidic device temperature plays a crucial role in terms of solidification of the wax particles which will finally affect the particle size. The low temperature facilitates the quick solidification of the wax particles and no agglomeration, eventually the produced particles are monodispersed with a negligible variation in their sizes.

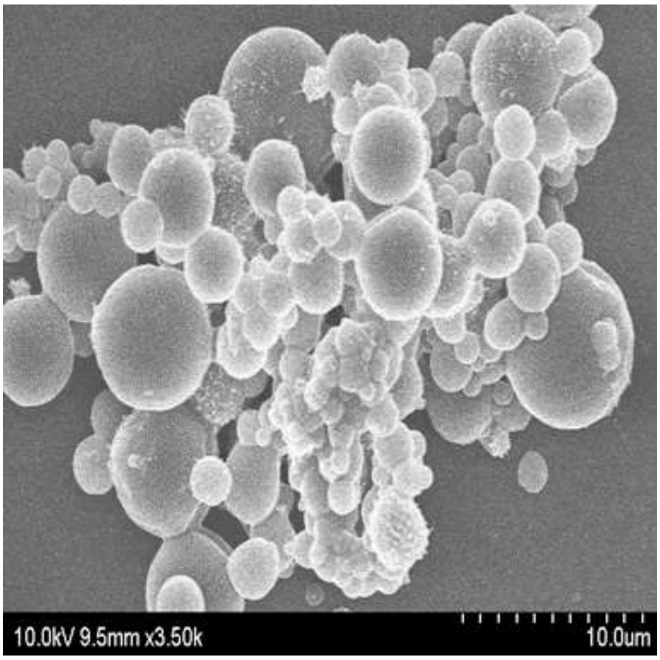

Figure 4. SEM image for the wax particles produced b y conventional technique

The versatility of the microfluidic generated monodispersed wax particles was further checked by preparing the wax particles using a conventional method. The dispersed-phase solution was heated to its melting point and then quenching was carried out to make the solid wax particles. It can be seen clearly (Fig. 4) that the most of the particles are much larger in size and no proper size distribution compared to the wax particles produced by microfluidic technique. Furthermore, the size of the particles could be tuned very easily just by adjusting the continuous and disperse phase flow rates.

Conclusions

A novel method has been presented for generating the sub-micron size spherical wax beads using a T-junction in a microchannel network. Particles size decreases linearly with the increase in continuous phase flow rate. Effective range of the continuous phase flow rate describe for various disperse phase flow rate in order to get the smaller and uniform size particles. Above a certain threshold flow rates of the continuous phase and below the disperse phase flow rate the system does not generate the particles. Near the melting point of wax particles are monodisperse because the solidification is efficient. The sub-micron sized wax particles will improve the toner quality in view of printing and energy-saving. The advantages of producing the sub-micron size wax particles with narrow size distribution will initiates the reduction in size of toner plus the improvements in printing and electronic field.

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References

1. M .Yamada, J. Oil Palm Research, 50-57 (2006).
2. D.P. Morris, M.R. Edwards, US Patent NO. 7,323,280 (2008).
3. A.F. Mejia, P. He, D. Luo, M. Marquez , Z. Cheng, J. Colloid Interface Sci., 334, 22-28 (2009).
4. B.P. Binks, A. Rocher, J. Colloid Interface Sci., 335, 94-104 (2009).
5. D. R. Reyes, D. Iossifidis, P.A. Auroux, A. Manz. Anal. Chem., 74, 2623 (2002).
6. D. Belder, Angew. Chem. Int. Edit., 44, 3521-3522 (2005).
7. S.Y. Teh, R. Lin, L.H. Hung, A. P. Lee, Lab. chip., 8, 198-220 (2008).
8. J. H. Xu, S. W. Li, J. Tan, Y. J. Wang, and G. S. Luo , AICHE J., 52, 3005, (2016).
9. T. Nisisako, T. Torii, T.Higuchi, Lab. Chip., 2, 26 (2012).
10. T. Kawakatsu, Y. Kikuchi and M. Nakajima, J. Am. Oil Chem. Soc., 74, 317 (1997).
11. S. Ekström, D. Ericsson, P. Önnerfjord, M. Bengtsson, J. Nilsson, G. Marko-Varga and T. Laurell, Anal. Chem., 73, 214 (2015).