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ON SURFACE TENSION OF A BUBBLE UNDER PRESENCE OF ELECTROSTATIC FORCE

by

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Short paper
DOI: 10.2298/TSCI141214149C

The surface tension of a bubble is described by Young-Laplace equation, which becomes, however, invalid under the presence of electrostatic force, and a modified one is obtained, which can be widely applied for Bubbfil spinning process.

Key words: *bubble electrospinning, humidity, nanofibers, surface tension*

Introduction

The surface tension of a bubble can be described by the well-known Young-Laplace equation [1, 2]:

$$\sigma = \frac{1}{4} r(P_{\mathrm{i}} - P_{\mathrm{o}}) \tag{1}$$

where r is the radius of a bubble, and P_{i} and P_{o} are the air pressures inside and outside the bubble, respectively.

Liu and Dou [3] suggested a modification of eq. (1) by considering the effect of humidity, which is an important factor in the Bubbfil spinning process [4, 5]. Their modification can be expressed as [3]:

$$\sigma = \frac{1}{4} rR_{\mathrm{d}} [(1+0.61q_{\mathrm{i}})T_{\mathrm{i}}\rho_{\mathrm{i}} - (1+0.61q_{\mathrm{o}})T_{\mathrm{o}}\rho_{\mathrm{o}}] \tag{2}$$

where R_{d} is the dry air constant, T – the temperature, ρ – the density, q – the specific humidity, defined as $q = m_{\mathrm{v}}/(m_{\mathrm{d}} + m_{\mathrm{v}})$, where m_{v} and m_{d} are the mass of water vapor and dry air, respectively; the subscripts i and o mean the inner and outer of the bubble, respectively.

Both equations, eqs. (1) and (2), were obtained in absence of electrostatic force, which is the acting force in Bubbfil spinning process (*e. g.* bubble electrospinning) [2, 4, 5]. It is necessary to have a modified equation under presence of electrostatic force for optimal design of the Bubbfil spinning process [4, 5].

Surface tension of a non-hemisphere bubble

The Bubbfil spinning [4, 5] including the bubble electrospinning [2], blown-bubble spinning [6] and membrane-spinning [7] is to use an electronic field or a blowing air or a me-

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chanical force or their couple to overcome the surface tension of a polymer bubble. Though there are many mathematical models for electrospinning [8], but the most useful model for electrospinning and bubble electrospinning is the Liu-Wang model [9].

During the spinning process, a bubble will not appear in a sphere form as illustrated in fig. 1(a). Under such case, the force balance can be written as:

$$2\cdot 2\pi R\sigma \sin\alpha = \pi R^2 (P_\mathrm{i} - P_\mathrm{o}) \tag{3}$$

where R is the radius of the bottom section of the bubble, and α – the slope angle, which satisfies:

$$\tan\alpha = \frac{\mathrm{d}y}{\mathrm{d}x}(x = R) = y' \tag{4}$$

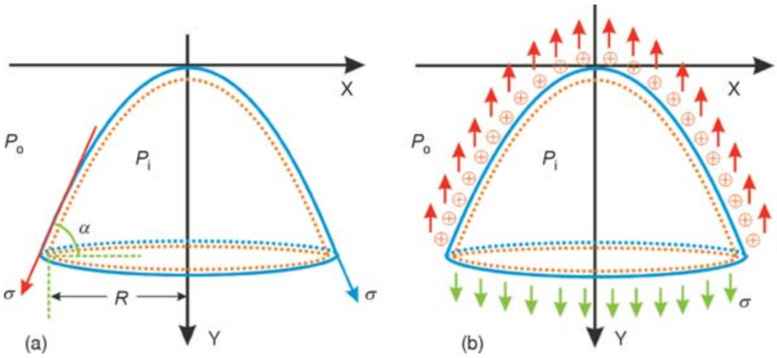

Figure 1. Force balance in a non-sphere bubble, (a) without electrostatic field, (b) with electrostatic field

The surface tension of a non-hemisphere bubble can be, therefore, written as:

$$\sigma = \frac{R(P_\mathrm{i} - P_\mathrm{o})}{4\sin\alpha} = \frac{R(P_\mathrm{i} - P_\mathrm{o})\sqrt{1 + y'^2}}{4y'} \tag{5}$$

For a hemisphere bubble, we have $\alpha = \pi/2$, and we have eq. (1).

Effect of electrostatic field on the surface tension of a bubble

Under the presence of an electrostatic field as illustrated in fig. 1(b), we have the following a force balance equation for a hemisphere bubble:

$$2\cdot 2\pi r\sigma = \pi r^2 (P_\mathrm{i} - P_\mathrm{o}) + 2\pi r^2 \varepsilon E \tag{6}$$

where E is the electric field intensity and ε – the electric charge per area. The surface tension of a bubble can be expressed in the form:

$$\sigma = \frac{r(P_\mathrm{i} - P_\mathrm{o} + 2\varepsilon E)}{4} \tag{7}$$

That means the surface tension of a bubble geometrically depends upon its size, and can be adjusted by the electrostatic field. When $P_\mathrm{i} = P_\mathrm{o} + 2\varepsilon E$, the surface tension tends to zero.

For a non-sphere bubble, we have:

$$\sigma = \frac{r(P_\mathrm{i} - P_\mathrm{o} + 2\varepsilon E)}{4\sin\alpha} = \frac{r(P_\mathrm{i} - P_\mathrm{o} + 2\varepsilon E)\sqrt{1 + y'^2}}{4y'} \tag{8}$$

Equation (8) is valid for all non-sphere bubbles under the electrostatic field.

Conclusions

This short note reveals that the surface tension of a bubble reduces significantly by adjusting electrostatic field, when it reaches a threshold value, the surface tension vanishes completely. This phenomenon is extremely useful for Bubbfil spinning process for mass-production of nanofibers.

Acknowledgment

The work is supported financially by PAPD (A Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions), Natural Science Foundation of the Jiangsu Higher Education Institutions of China (Grant No. 12KJB130002), National Natural Science Foundation of China under Grant Nos. 10802021 and 10972053, and Nantong Textile Institute of Soochow University.

References

[1] He, J.-H., Effect on Temperature on Surface Tension of a Bubble and Hierarchical Ruptured Bubbles for Nanofiber Fabrication, *Thermal Science, 16* (2012), 1, pp. 327-330
[2] He, J.-H., *et al*., Review on Fiber Morphology Obtained by the Bubble Electrospinning and Blown Bubble Spinning, *Thermal Science, 16* (2012), 5, pp. 1363-1379
[3] Liu, F. J., Dou, H., A Modified Young-Laplace Equation for Bubble Electrospinning Considering the Effect of Humidity, *Thermal Science, 17* (2013), 2, pp. 629-630
[4] He, J.-H., *et al*., Variational Iteration Method for Bratu-Like Equation Arising in Electrospinning, *Carbohydrate Polymers, 105* (2014), May, pp. 229-230
[5] Chen, R. X., *et al*., Bubbfil Spinning for Mass-Production of Nanofibers, *Thermal Science, 18* (2014), 5, pp. 1674-1675
[6] Dou, H., *et al*., Blown Bubble Spinning for Fabrication of Superfine Fibers, *Thermal Science, 16* (2012), 5, pp. 1465-1466
[7] Kong, H. Y., *et al*., Polymer Liquid Membrane for Nanofibers Fabrication, *Thermal Science, 17* (2013), 5, pp. 1479-1482
[8] Wan, Y. Q., *et al*., Thermo-Electro-Hydrodynamic Model for Electrospinning Process, *Int. J. Nonlin. Sci. Num., 5* (2004), 1, pp. 5-8
[9] Liu, H. Y., Wang, P., A Short Remark on WAN Model for Electrospinning and Bubble Electrospinning and Its Development, *International Journal of Nonlinear Science and Numerical Simulation, 16* (2014), 1, pp. 1-2

Paper submitted: December 14, 2014
Paper revised: December 17, 2014
Paper Accepted: December 18, 2014