Preparation of Ethylcellulose Latex by Aqueous Dispersions: Importance of the Particle Size and Plasticizer

[1]MAHMOOD IQBAL*, [2]CHENGZHI CHUAI, [3]KALSOOM MAHMOOD, [2]YAN HUANG,
[2]HUI LIU, [3]MUHAMMAD AIJAZ
[1]*School of Materials Science and Chemical Engineering, Tianjin University of Science and Technology, Mail Box186, Tianjin 300457, P.R China.*
mahmoodkhattak_57@hotmail.com*
[2]*Tangshan College, 38 Huayan Beilu, Tangshan, Hebei 063000, P.R.China.*
[3]*PCSIR Labs Complex, Karachi.*

(Received on 29th September 2010, accepted in revised form 3rd January 2011)

Summary: Based on phase transfer processes ethylcellulose (EC) latex was prepared using dibutyl sebacate (DBS) as plasticizer and oleic acid, ammonia water as an emulsifier to evaluate film-formation properties. Atomic force microscopy was used to characterize the surface features, practical size and differential scanning colorimetry was employed to investigate the effect of plasticizer on glass transition temperature of the resulting materials. The influences of emulsifier concentration on the particle size and on the viscosity were studied. The viscosity initially showed a decreased tendency and then increased linearly with increasing emulsifier concentration. On the other hand, the surface tension decreased considerably up to about 4 wt%, and then it almost remains unchanged with increasing emulsifier concentration. The polymer particle size was identified to be a very crucial formulation parameter, determining the resulting film coating structure and properties. Importantly the particle size decreased systemically with increasing emulsifier concentration up to about 2 wt% and then increased markedly with increasing emulsifier concentration. In addition, the results indicated that the incorporation of polymeric plasticizer substantially reduced the glass transition temperature (Tg) and softening temperature. Moreover, the home-synthesized EC latex could be used effectively to coat materials for drug release.

Introduction

To avoid the hazards effects associated with organic solvent-base coating, aqueous polymer dispersions are widely used for application in controlled-release delivery systems. Aqueous polymer coatings are often applied to polymer films for sustained release, taste masking and protection against light [1-3]. Because of safety and environmental concerns and a lower viscosity at the same solids content, aqueous ethylcellulose dispersions are preferred over organic solutions for film coating processes [4, 5]. Ethylcellulose is hydrophobic and has been successfully formulated into commercially available aqueous coating dispersions. These commercially available aqueous coating dispersions contain discrete ethylcellulose spheres. Each of these ethylcellulose spheres, with less than 1mm in diameter, contains hundreds of ethylcellulose chains. During deposition of this discrete sphere onto the surface, the water evaporates, the dispersion is condensed and the ethylcellulose particles become closely packed. If the condition favors coalescence, these particles would become deformed and fused together to form continues film [6, 7]. Lehmann [8] developed aqueous colloidal polymer dispersion (latexes and pseudolatexes) to overcome the toxicity associated with organic solvent based coating. The addition of plasticizers is required for polymer dispersion having a minimum film formation temperature above the coating temperature. During the plasticization of aqueous dispersions, the plasticizer will partition into and soften the colloidal polymeric particles [9] thus promoting particle deformation [10] and coalescence into a homogeneous film. Plasticizer–polymeric interaction has been studied by various methods including thermal analysis to measure the glass transition temperature [11-15] and viscosity determinations [16, 17]

Various studies have been reported in the literature, investigating the effects of plasticizers on the physicochemical properties of polymeric systems and film formation from aqueous polymer dispersions [18–20]. In a latex dispersion, the polymer is dispersed as small particles rather than fully-entangled chains as it is in the solution. Particle deformation must occur in order to achieve coalescence. The driving force for fusion comes from the capillary forces caused by high interfacial tension

---

*To whom all correspondence should be addressed.

between water and the polymer, and between water and air as water is evaporated. The plasticizer enhances the relative movement of polymer chains by increasing the free volume or intermolecular space, and by reducing the minimal film formation temperature [21, 22].

A theory of plasticization for synthetic paint latex was developed by Dillon et al. [23] in terms of three phase's system comprised of the water phase, polymer particle, and plasticizer droplets. The type of plasticizer used in polymer blends for the coating of solid dosage forms is of major importance for the resulting film coating properties and, thus, drug release kinetics.

The project aims to study the combined effect of plasticizers on the glass transition temperature and evaporation rate and to get information from the thermal history of the sample for the extent of polymer-plasticizer interaction. Another objective is to investigate the influence of emulsifiers concentration on the particle size and viscosity. In this work, a cost effective technique is used to prepare ethylcellulose latex through aqueous dispersion.

Results and Discussion

Effect of Plasticizer Content on Glass Transition Temperature (Tg)

The result for plasticizer effect on Tg is presented in Fig. 1. It is seen from the results that the amount of plasticizer had a significant influence on Tg. Polymer is transformed from a glassy state, through a Tg, to a rubbery state while increasing temperature. When the temperature is above Tg, the polymer is able to show micro-Brownian movement. When water evaporates, the latex particles become closely packed above Tg, the particles are deformed and fuse to form a continuous film. The addition of plasticizer results in a decrease in the glass transition temperature and softening temperature, which refers to an improved molecular mobility. It is assumed that as the dibutyl sebacate concentration increases there is a corresponding increase in the free volume of the polymer as therefore the total volume occupied by a certain number of molecules will increase. This will allow more movement of molecular groups and side chains, because plasticization results in a decrease in the intermolecular forces between the polymer chains, generally causing a decrease in the glass transition temperature. These results are consistent with the experiment of Lin et al [24]. In their study, it was found that the glass transition temperature of $PCL_{60\%}/PEG_{40\%}$-blended films plasticized by different types and levels of plasticizers decreased with increasing plasticizers concentration. From the above discussion so far it is indicated that DBS penetrated into polymer domains to disturb their crystallization, because DBS provide flexibility and penetrated into polymer domains greatly and the miscibility of DBS is greater than other classes of plasticizers.

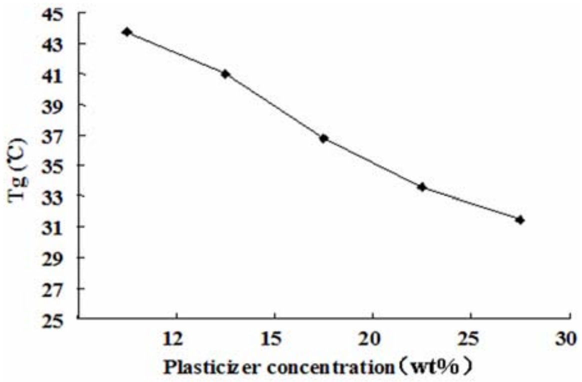

Fig. 1a: Effect of plasticizer concentration on the glass transition temperature Tg of ethylcellulose film.

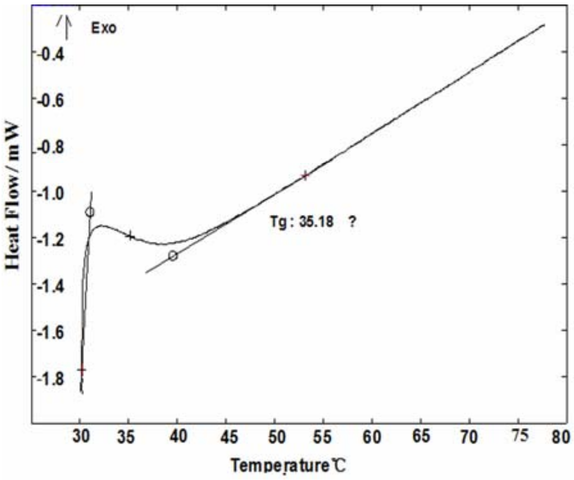

Fig. 1b: Effect of plasticizer concentration on the glass transition temperature Tg of ethylcellulose film.

Effects of Emulsifier on Particle Size and Viscosity

We used oleic acid and ammonia water as emulsifier in the preparation of ethylcellulose aqueous dispersion. In fact quite obviously, emulsifiers play a fundamental role in the preparation of ethylcellulose aqueous dispersion. Although the emulsifiers do not participate in the reaction directly, their type and concentration have very pronounced influences on the initiating rate, the forming and transferring speed of the chain. The emulsifier level affects not only the forming number of emulsification micelle, but also the resulted latex particle size and viscosity [22]. The influence of the emulsifier concentration on the latex properties is presented in Fig. 2, and was found to support further topographic observation. When increasing the emulsifier concentration, the micelle number increases, the reaction and initiating rates are also faster, so the latex particle size decreases. Consequently, the total specific surface area and the mutual forcing between the particles both increase, that the flowing-resistance of particles also increases, which leads to the latex viscosity increase and stabilization of the polymerization process. The results are shown in Fig. 2 with an observation that initially the particle size decreases gradually with increasing emulsifier concentration but later increases linearly with increasing emulsifier concentration. Similar profiles were obtained for the latex viscosity. When the emulsifier level is increased the particle size was also increased contributing to net enhancement in the viscosity of the materials. Therefore, from this discussion it is evident that the latex viscosity has strong correlation with the particle size.

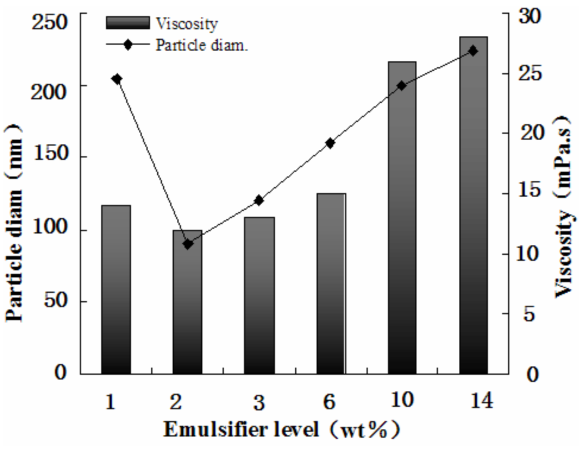

Fig. 2: Effects of emulsifier content on the ethylcellulose latex viscosity and diameter.

The effects of emulsifier content in dispersion formulation on particle behavior are presented in Fig. 2. It can be seen from Fig. 2 that the particle size first decreases obviously and distributes widely with the increasing emulsifier percentage then obviously increases above 2wt% of emulsifier concentration. Fig. 2 clearly demonstrated that the particle size of our laboratory EC latex is 93nm, when emulsifier contents is 2wt%.These results are consistent and in some instance better than work reported by Siepmann et al [12]. In their study blends of aqueous dispersion of a water soluble and an enteric polymer, namely ethyl cellulose:hydroxyl -propylmethylcellulose acetate succinate (EC:HPMCAS) and ethylcellu- lose:methacrylic acid ethyl acrylate copolymer (CE:Eudragite L),was used as coating materials to control theophylline release from matrix pellets. Interestingly it is observed from outcomes that both the particle size and the latex viscosity were at their minimum value, when emulsifier/plasticized polymer ratio was 2/100 w/w%.

Atomic force microscopy (AFM) was employed in our research to promote the study of the detailed morphology of ethylcellulose N-7 latex particle. The advantage of this approach is that it can reveal the structure with very high resolution as depicted in Fig. 3 and provide an overview of a typical ethylcellulose N-7 latex particle. It is clear from the Fig. 3a and b that the latex particle configuration with a diameter of 93 to 163nm and with a surface that appears to be uniform and rather rough. These results are completely similar with that by the particle size analyzer as above. This suggested that oleic acid and ammonia water could be a better emulsifier to prepare ethylcellulose N-7 latex by aqueous dispersion technique. Obviously, a high concentration of emulsifier leads to an increased size of the latex particle. It is easy to understand that surplus amount of the emulsifier would fail to uniform and stabilize all the particle size and thus some of them would tend to aggregate. As a result, particle with large size would be produced.

Effect of Plasticizer on Evaporation Rate

The film formation mechanism of the latex dispersion involves the evaporation of water followed by the coalescence of polymeric spheres. Latex particles become closely packed as water evaporates and they come into contact with each other. The driving force exerted mainly by capillary action between particles overcomes repulsive forces between the closely packed particles, deforms the particles and causes the spheres to fuse. But coalescence of particles is incomplete at this stage. However volatilizing could increases polymer chain entanglement and furthers the process of coalescence and then we can obtain a complete coalescence [25]. The influence of DBS concentration on the evaporation rate is depicted in Fig. 4. It can be observed that the evaporating rate decreased with the increasing of DBS content. The results demonstrate that plasticizer restricts the evaporation of water in the latex system, therefore, the film is cure slowly.

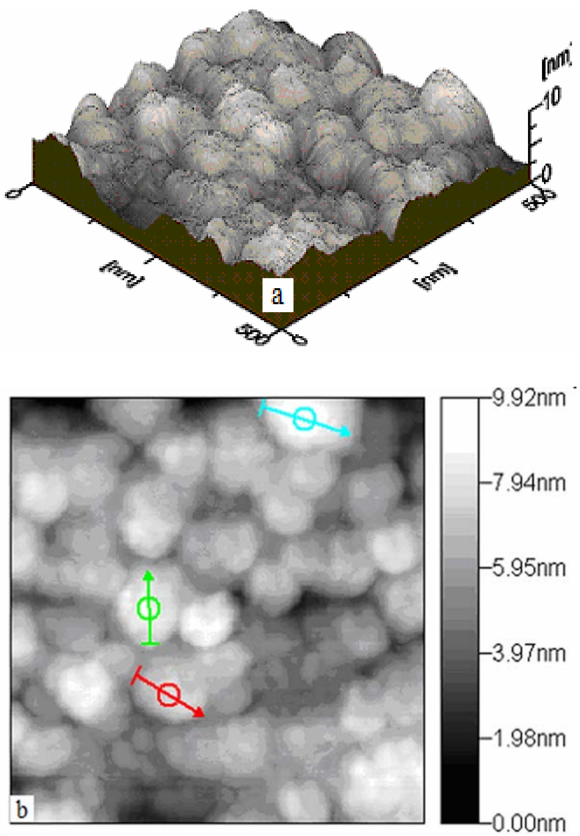

Fig. 3: AFM images of particles of the ethylcellulose N-7 latex.

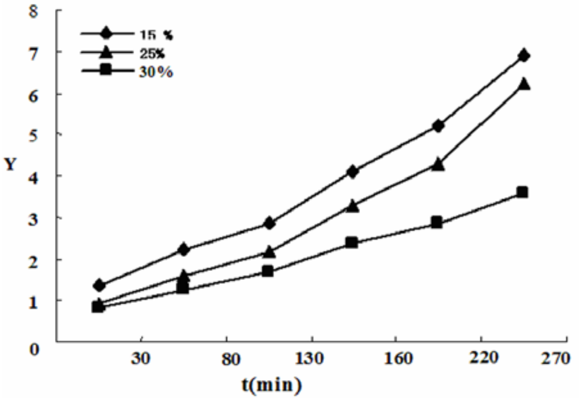

Fig. 4: Effects of the addition of DBS concentration on evaporation rate.

Effect of Emulsifier on Surface Tension

The influence of emulsifier concentration on the latex properties is depicted in Fig. 5. In fact quite obviously, the combination of emulsifier and ethylcellulose produced by the initiation and polymerization in water can give surface active substances (SAS). The polymer particles containing more emulsifier have lower surface charge density (SCD), they need to absorb more SAS for stabilization, therefore, the free SAS in latex is less, and the surface tension of latex is higher. The results displayed in Fig. 5 indicated that the surface tensions of latex decreased with increasing emulsifier content up to 4wt% ; later it almost remain unchanged with increasing emulsifier concentration. These results are consistent with the experiment of Wang et al. [26] in which the surface tension of latex initially showed a decreased tendency while increasing the amount of emulsifier, thereafter, it almost remains unchanged with increasing emulsifier content.

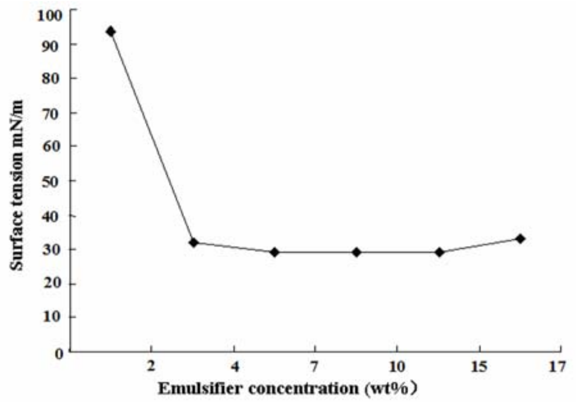

Fig. 5: Effect of the addition of emulsifier concentration on surface tension of ethylcellulose -N7 latex.

Experimental

Materials

The materials used in the present work were commercially available. Dibutyl sebacate (DBS) was kindly supplied by National Chemical Reagent Co., Ltd Tiaijin China. Oleic acid and ammonia water were purchased from Yingdaxigui Chemical Company China. N-type ethylcellulose was provided by Chemical Plant of Luzhou China. Ethanol (analytical grade) was obtained from Yingdaxigui Chemical Company Tianjin China. Table 1 reflects the properties of two ethylcellulose samples. The viscosities of samples were assessed using a 5%w/w solution at 25°C in a mixture of 80% toluene and 20% ethanol, and the ethoxyl content of each sample were determined by the standard tests (United States

National Formulary, XV, 1980). The molecular weight of each sample was calculated using the procedure and equation derived by Rowe et al [27]. All other chemicals were of analytical grade and were used as received.

Preparation of Plasticized EC

The extruder used in this study was Brabender plasticorder couple with single screw extruder of 16mm in diameter with L/D 25:1 working here mainly as melting and conveying machine to allow continuous strip. Dibutyl sebacate (DBS) and ethyl cellulose (EC) in the ratio of 25/100 were mixed in a twin-shell dry blender for about 1 to 2 minutes with rotation speed of 30 rpm and processed in an extruder. The temperature profile of the extruder from the feed zone to the die were kept at 60/75; 90/ 100^{o}C at rotational speed 50 rpm and the extrudate was obtain in the form of strip, severed into granules about 4mm long.

Preparation of Aqueous EC Dispersion

50 g plasticized EC was mixed with 31.47 g ammonia, 110g distilled water and 8.0 g oleic acid in 500 mL three-necked round bottom flask equipped with mechanical stirrer a thermometer and a dropping funnel. The temperature was raised to 95^{o}C using water bath, while the reaction mixture was continuously stirred for approximately three hours to ensure the completion of an aqueous dispersion reaction. Plasticized polymer and emulsifiers stabilizes the resulting dispersion under the force of shearing and then disperses them into the aqueous phase. The viscosity was measured by a NXS-11A Viscometer (Chengdo instrument company China) at a shear rate of 10rpm.

Thermal Analysis

Polymeric films were prepared using a solvent casting method. EC dispersions were cast in Petri dishes and dried in an oven at 60^{o}C for 24 hour. The films were removed from the Petri dishes and further dried in a desiccator for 3 hour to evaporate the residual solvent. Each dried film was then determined their thermal properties. A Setaram DSC-141 (France) calorimeter (scan rate: 20^{o}C /min; scan range: from 10 to 100^{o}C) was used to record DSC thermograms of samples 8 mg sealed in aluminum pans. The temperature and energy were calibrated with indium and tin standards. The glass transition temperature was registered from the midpoint of the specific heat increment.

Measurement of Particle Size

The particle sizes of the latex were assessed by laser light scattering with particle size analyzer, (90 Puls Brookhaven Instruments Huntsville, NY, and USA). The measurement of particle size was accomplished when the latex was diluted before use to 1 %. The particle size was the average of three measurements. The samples of Atomic Force Microscope (AFM) measurements were prepared by 20 µl of the solution spinning coated on a cleaved freshly mica surface and the solvent was evaporated at the room temperature. Later, AFM images of particles were obtained by scanning prob microscope (JEOL JSPM-5200, Japan) in tapping mode. The cantilever oscillated at its proper frequency (158 KHz) and the driven amplitude was 0.430 V.

Measurement of Evaporation Rate

Ethylcellulose latex was used for the evaluation of curing rate. The sample (1gm) was placed in Petri dishes and dried in an oven at 60^{o}C until the weight of the product was constant. Evaporation rate was calculated according to the following equation (1)

$$\ln(W_t \square W_\infty)/(W_0-W_\infty) = -bt \qquad (1)$$

W_0 - the initial mass;
W_t- the mass of the sample at the time t;
W_∞- the balance mass (the mass difference of the sample is less than 0.01g);
b-the volatilization constant of the solvent;
and the data was plotted, against Y vs t
$Y = -\ln (W_t - W_\infty)/(W_0 - W_\infty)$.
$\ln (W_t - W_\infty)/ (W_0-W_\infty)$
so the above equation can be written as
$Y = bt$
plot of Y vs t, will develop a curve as shown in Fig. 5.

Conclusions

It was concluded from the results that both plasticizer and emulsifier content have proved to be more effective for the particle size, viscosity and glass transition temperature. The viscosity decreased systematically until 2wt % value; but later, it increased continuously with increasing emulsifier content. Interestingly, the particle size decreased primarily and then increased when increasing of emulsifier concentration. In addition, it was testified that plasticizer restrict the evaporation of water in the latex system and thus the evaporating rate increased. The particle size of the latex material was 93 to 163nm.

The results of Tg analysis indicated that the addition of polymeric plasticizer consequently decreased the glass transition temperature and softening temperature.

Acknowledgements

The author's gratefully acknowledged the financial support of National Foundation of Tianjin University of Science and technology (No.20040107), PR China.

References

1. J. W. McGinity, Aqueous polymeric coatings for pharmaceutical dosage forms,second ed., Marcel Dekker: New York, pp 276-268. (1997).
2. C. R. Steurangel and T. A. Whaetely, Latx equeous emulsion for controlled drug delivery. In J.W. (McGinity Ed.).Aqueous Polymeric coating for Pharmaceutical Application, Dekker:New York, pp 1-54. (1997).
3. K. H. Bauer, K. Lehmann, H. P. Osterwald and G. Rothgang, Coated Pharmaceutical dosage forms, CRC Press, Medphram, Boca Raton, FL, pp 81-89 (1998).
4. J. Siepmann, P. Ornlanksana and B. Roland, *International Journal of Pharmacy*, **165**, 191 (1995).
5. P. Mathey, J. Guillot, *Polymer*, **32**, 934 (1991).
6. J. B. Dressman, G. M. Derbin, G. Ismails, C. Jarvis, A. Ozturk, B. O. Palsson and T. A. Whealey, *Journal of Controlled Release*, **36**, 251 (1995).
7. F. Siepmann, S. Muschert, B. Leclercq, B. Carlin and J. Siepmann, *Journal of Controlled Release*, **119**, 182 (2007).
8. K. O. R Lehmann, Chemistry and application properties of polymethacrylate coating system. In J W. McGinity (Ed.),Aqueous Polymeric coating for Pharmaceutical Application, Dekker, New York, pp.101-168 (1989).
9. F. Ahmed, M. A. Abbasi, Aziz-Ur-Rehman, M. A. Awan, M. A. Iqbal, S. A. Yousaf, M. J. Iqbal, V. U. Ahmad, *Journal of the Chemical Society of Pakistan*, **32**, 277 (2010).
10. C. Feng, J. L. Ruan, Y. L. Cai, *Journal of the Chemical Society of Pakistan*, **32**, 34 (2010).
11. Si-Shen Fenga and G. Huang, *Journal of Controlled Release*, **71**, 53 (2001).
12. F. Siepmann, J. Siepmann, M .Walther, R, J. MacRae and R. Bodmeier. *Journal of Controlled Release*, **105**, 226 (2005).
13. F. Lecomte, J. Siepmann, M. Walther, R. J. MacRae and R. Bodmeier, *Journal of Controlled Release*, **89**, 457 (2003).
14. C. W. Leong, J. M. Newton, A. W. Basit, F. Podczeck, J .H. Cummings, S. G.. Ring, *European Journal of Pharmaceutics and Biopharmaceutics*, **54**, 291 (2002).
15. H. Lu, C. Su, Y. C. Wang, C. F. Huang, Y.C. Sheen and F. Chang, *Polymer*, **49**, 4852 (2008).
16. H. E. Burch and E. S. Chris, *Polymer*, **42**, 7313 (2001).
17. D. Hutchings, M. Nicklasson, S. Singh and A. Sakr, *Pharmaceutical Research*, **8**, 116 (1991).
18. G. R. Bardajee, V. Cedric, J. C. Haley, A. Y. Li, M. A. Winik, *Polymer*, **48**, 5839 (2007).
19. E. Princi, S. Vicini, E. Pedemonte, G. Gentile, M. Cocca and E. Martuscelli, *European Polymer Journal*, **42**, 51 (2006).
20. H. Kang, W. Liu H. Benqiao, D. Ma. L. Shen and Y. Huang, *Polymer*, **47**, 7927 (2006).
21. M. Tarvainen, S. Peltonen, H. Mikkonen, M. Elovaara, M. Tuunainen, P. Paronen, J. Ketolainen and R. Sutinen, *Journal of Controlled Release*, **96**,179 (2004).
22. V. Gallardo, M. E. Garcia, M. A. Riuz and G. Hui, *Macromolecular Chemistry and Physics*, **202**, 2412 (2001).
23. R. E. Dillon, E. B. Bradford, R. D. Andrews, *Industrial and Engineering Chemistry Research*, **45**, 728 (1953).
24. P. R. Sakellariou, C. Rowe and E. F. T White. *International Journal of Pharmacy*, **27**, 267 (1985).
25. W. J. Lin, H. K. Lee and D. M. Wang, *Journal of Controlled Release*, **99**, 415 (2004).
26. R. O. Williams and III. Liu, *European Journal of Pharmaceutics and Biopharmaceutics*, **49**, 243 (2000).
27. Z. Wang, Anthony, J. Paine and A. Rudin, *Journal of Polymer Science*, Part A: Polymer Chemistry Ed. **33**, 1597 (1995).