Studies on preparation and application of nanosized chitosan

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ABSTRACT

This study was divided into two parts. The first part included the preparation of chitosan nanopowders spray-drying. A modified spray drier was used to manufacture chitosan (cs) nanopowders (nps). The spray-drying of 1% (w/v) cs suspensions produced cs nps when an ultrasonic atomizer was utilized; however, the cyclone collector could only accumulate microparticles. The electrostatic attractive force through the electrostatic cloth proved that nps existed in the hot airflow. Accordingly, a prototypical electrostatic precipitator (esp) was connected to the exit of the cyclone collector to collect nps. When the spray drying conditions were set as follows: the sample ’ s feeding rate was 30 mL/min, the highly pressurized air was 4 kgw/cm2, and the hot airflow rate was 500 L/min, its inlet temperature being 180°C. The obtained cs nps were round without aggregation. The size of nps produced in this study was between 60 and 2000 nm. The second part included preparation of gold nanopowders and nanoparticles using chitosan suspensions. Simple methods for preparation of gold nanopowders and nanoparticles are reported. Gold/chitosan nanoparticles were prepared by using basic chitosan suspension as a dispersant and as a reductant. The resulting nanoparticles were processed by pyrolysis and thus obtain black gold nanopowder. The FESEM images indicate that most diameters of the nanopowder prepared were in the range of 50 and 200 nm. Hydrolysis is another quick decomposition method for chitosan. Acetic acid was adopted to implement the hydrolysis. The AEM images of the auberginic suspension show that the average gold nanoparticle diameter was less than 40 nm with good dispersion. Use of chitosan suspensions can produce gold nanopowder as well as gold nanoparticle without using toxic organic chemicals.

Keywords : Chitosan、Nanopowder、Nanoparticle、Ultrasonic atomizer、Electrostatic precipitator、Pyrolysis、Hydrolysis

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REFERENCES

1.Adamczyk, Z. 2003. Particle adsorption and deposition: role of electricstatic interactions. Adv. Colloid Interface Sci. 100-102: 267-347. 2.Adler, M. and Lee, G. 1999. Stability and Surface activity of lactate dehydrogenase in spray-dried trehalose. J. Pharm. Sci. 88(2): 199-208. 3.Adlim, M., Bakar, M. A., Liew, K. Y., and Ismail, J. 2004. Synthesis of chitosan-stabilized platinum and palladium nanoparticles and their hydrogenation activity. J. Mol. Catal. A-Chem. 212: 141-149. 4.Arrascue, M. L., Garcia, H. M., Horna, O., and Guibal, E. 2003. Gold sorption on chitosan dericatives. Hydrometallurgy 71: 191-200. 5.Artur Stankiewicz, B., Briggs, D. E. G., Evershed, R. P., Flannery, M. B., and Wuttke, M. 1997. Preservation of chitin in 25-million-year-old fossils. Science. 276(5318): 1541-1543. 6.Asada, M., Takahashi, H., Okamoto, H., Tanino, H., and Danjo, K. 2004. Theophylline particle design using chitosan by the spray drying. Int. J. Pharm. 270: 167-174. 7.Assaad, E., Azzouz, A., Nistor, D., Ursu, A. V., Sajin, T., Miron, D. N., Monette, F., Niquette, P., and Hausler, R. 2007. Metal removal through synergic coagulation-flocculation using an optimized chitosan-montmorillonite system. Appl. Clay Sci. 37: 258-274. 8.Augsten, C. and Mader, K. 2008. Characterizing molar mass distributions and molecule structures of different chitosans using asymmetrical flow field-flow fractionation combined with multi-angle light scattering. Int. J. Pharm. 351: 23-30. 9.Austin, P. R., Brine, C. J, Castle, J. E., and Zikakis, J. P. 1981. Chitin: New facets of research. Science. 212(4496): 749-753. 10.Balogh, L. P., Minc, L. D., and Berka, M. 2007. Novel synthesis of radioactive gold/dendrimer composite nanoparticles for the treatment of cancer. Nanomedicine. 3(4): 338. 11.Banerjee, T., Mitra, S., Kumar Singh, A., Kumar Sharma, R., and Maitra, A. 2002. Preparation, characterization and biodistribution of ultrafine chitosan nanoparticles. Int. J. Pharm. 243: 93-105. 12.Baxter, A., Dillon, M., and Anthony Taylor, K. D. 1992. Int. J. Biol. Macromol. 14: 166-169. 13.Benhamou, N., Kloepper, J. W., and Tuzun, S. 1998. Induction of resistance against Fusarium wilt of tomato by combination of chitosan with an endophytic bacterial strain: ultrastructure and cytochemistry of the host response. Planta 204: 153-168. 14.Biskos, G., Reavell, K., and Collings, N. 2005. Unipolar diffusion charging of aerosol particles in the transition regime. J. Aerosol. Sci. 36: 247-265. 15.Blackwell, J., Parker, K. D., and Rudall, K. M. 1967. Chitin fibers of diatoms Thalassiosira fluviatilis and Cyclotella cryptica. J. Mol. Biol. 28: 383-385. 16.Bough, W. A., Salter, W. L., Wu, A. C. M., and Perkins, B. E. 1978. Influence of Manufacturing Variables on the characteristics and effectiveness of chitosan products. I. chemical composition, viscosity, and molecular-weight distribution of chitosan products. Biotechnol. Bioeng. XX: 1931-1943. 17.Brugnerotto, J., Lizardi, J., Goycoolea, F. M., Arguelles-Monal, W., Desbrieres, R., and Rinaudo, M. 2001. An infrared investigation in relation with chitin and chitosan characterization. Polymer 42: 3569-3580. 18.Byeon, J. H., Hwang, J., Park, J. H., Yoon, K. Y., Ko, B. J., Kang, S. H., and Ji, J. H. 2006. Collection of submicron particles by an electrostatic precipitator using a dielectric barrier discharge. Aerosol Sci. 37: 1618-1628. 19.Chandra, M., Indi, S. S., and Das, P. K. 2006. First hyperpolarizabilities of unprotected and polymer protected copper nanoparticles prepared by laser ablation. Chem. Phys. Lett. 422: 262-266. 20.Chen, W., Cai, W. P., Liang, C. H., and Zhang, L. D. 2001. Synthesis of gold nanoparticles dispersed within pores of mesoporous silica induced by ultrasonic irradiation and its characterization. Mater. Res. Bull. 36: 335-342. 21.Chen, R. H. and Hwa H. D. 1996. Effect of molecular of chitosan with the same degree of deacetylation on thermal, mechanical, and permeability properties of the prepared membrane. Carbohydr. Polym. 29: 353-358. 22.Chen, X. G., Liu, C. S., Liu, C. G., Meng, X. H., Lee, C. M., and Park, H. J. 2006. Preparation and biocompatibility of chitosan microcarriers as biomaterial. Biochem. Eng. J. 27: 269-274. 23.Chen, S. H., Wu, Y. C., Mi, F. L., Lin, Y. H., Yu, L. C., and Sung, H. W. 2004. A novel pH-sensitive hydrogel composed of N,O-carboxymethyl chitosan and alginate cross-linked by genipin for protein drug delivery. J. Control. Release 96: 285-300. 24.Chognot, D., Leonard, M., Six, J. L., and Dellacherie, E. 2006. Surfactive water-soluble copolymers for the preparation of controlled surface nanoparticles by double emulsion/solvent evaporation. Colloid Surf. B-Biointerfaces 51(1): 86-92. 25.Coral-Hinostroza, G. N. and Bjerkeng, B. 2002. Astaxanthin from the red crab langostilla (Pleuroncodes planipes): optical R/S isomers and fatty acid moieties of astaxanthin esters. Comp.

Biochem. Physiol. B-Biochem. Mol. Biol. 133(3): 437-444. 26.Corrigan, D. O., Healy, A. M., and Corrigan, O. I. 2006. Preparation and release of salbutamol from chitosan and chitosan co-spray dried compacts and multiparticulates. Eur. J. Pharm. Biopharm. 62: 295-305. 27.Cui, Z. and Mumper, R. J. 2001. Chitosan-based nanoparticles for topical genetic immunization. J. Control. Release 75: 409-419. 28.Curry, J. D. and Kohn, A. J. 1976. Fracture in the crossed-lamellar structure of Conus shells. J. Mater. Sci. 11: 1615-1623. 29.Debbaudt, A. L., Ferreira, M. L., and Gschaider, M. E. 2004. Theoretical and experimental study of M2+ adsorption on biopolymers. III. Comparative kinetic pattern of Pb, Hg and Cd. Carbohydr. Polym. 56: 321-332. 30.Ding, S. J. 2007. Biodegradation behavior of chitosan/calcium phosphate composites. J. Non-Cryst. Solids 353: 2367-2373. 31.Domszy, J. G. and Roberts, G. A. 1985. Evaluation of infrared spectroscopic techniques for analyzing chitosan. Makromol. Chem. 186: 1671-1677. 32.Eaton, P., Doria, G., Pereira, E., Baptista, P. V., and Franco, R. 2007. Imaging gold nanoparticles for DNA sequence recognition in biomedical applications. IEEE Trans. Nanobiosci. 6(4): 282-288. 33.Esumi, K., Takei, N., and Yoshimura, T. 2003. Antioxidant-potentiality of gold- chitosan nanocomposites. Colloid Surf. B-Biointerfaces 32: 117-123. 34.Fellows, P. 1988. Food processing technology: principles and practice. Ellis Horwood, Chichester, UK. 35.Gades, M. D. and Stren, ScD, J. S. 2005. Chitosan supplementation and fat absorption in men and women. J. Am. Diet. Assoc. 105(1): 72-77. 36.Gamage, A. and Shahidi, F. 2007. Use of chitosan for the removal of metal ion contaminants and proteins from water. Food Chem. 104: 989-996. 37.Garitaonandia, J. S., Insausti, M., Goikolea, E., Suzuki, M., Cashion, J. D., Kawamura, N., Ohsawa, H., de Muro, I. G., Suzuki, K., Plazaola, F., and Rojo, T. 2008. Chemically Induced Permanent Magnetism in Au, Ag, and Cu Nanoparticles: Localization of the Magnetism by Element Selective Techniques. Nano Lett. 8(2): 661 – 667. 38.Gavini, E., Rassu, G., Muzzarelli, C., Cossu, M., and Giunchedi, P. 2008. Spray-dried microspheres based in methylpyrrolidinone chitosan as new carrier for nasal administration of metoclopramide. Eur. J. Pharm. Biopharm. 68: 245-252. 39.Georgetti, S. R., Casagrande, R., Souza, C. R. F., Oliverira, W. P., and Fonseca, M. J. V. 2008. Spray drying of the soybean extract: Effect on chemical properties and antioxidant activity. LWT 41: 1521-1527. 40.Goortani, B. M., Proulx, P., Xue, S., and Mendoza-Gonzalez, N. Y. 2007. Controlling nanostructure in thermal plasma processing: Moving from highly aggregated porous structure to spherical silica nanoparticles. Powder Technol. 175(1): 22-32. 41.Grenha, A., Remunan-Lopez, C., Carvalho, E. L. S., and Seijo, B. 2008. Microspheres containing lipid/chitosan nanoparticles complexes for pulmonary delivery of therapeutic proteins. Eur. J. Pharm. Biopharm. 69: 83-93. 42.Guo, S. and Wang, E. 2007. Sythesis and electrochemical applications of gold nanoparticles. Anal. Chim. Acta. 598: 181-192. 43.Hadinoto, K., Phanapavudhikul, P., Kewu, Z., and Tan, R. B. H. 2007. Dry powder aerosol delivery of large hollow nanoparticles aggregates as prospective carriers of nanoparticles drugs: Effects of phospholipids. Int. J. Pharm. 333: 187-198. 44.Hamilton, V., Yuan, Y., Rigney, D. A., Chesnutt, B. M., Puckett, A. D., Ong, J. L., Yang, Y., Haggard, W. O., Elder, S. H., and Bumgardner, J. D. 2007. Bone cell attachment and growth on well-characterized chitosan films. Polym. Int. 56: 641-647. 45.He, Y. 2005. Study on the formation mechanism of cerium oxalate nanoparticles from the coupling route of homogeneous precipitation with microemulsion. Mater. Lett. 59: 3010-3013. 46.He, P., Davis, S. S., and Illum, L. 1999. Chitosan microspheres prepared by spray drying. Int. J. Pharm. 187: 53-65. 47.Henriksen, I., Green, K. L., Smart, J. D., Smistad, G., and Karlsen, J. 1996. Bioadhesion of hydrated chitosans: an in vitro and in vivo study. Int. J. Pharm. 145: 231-240. 48.Hernandez, R. B., Franco, A. P., Yola, O. R., Lopez-Delgado, A., Felcman, J., Recio, M. A. L., and Merce, A. L. R. 2008. J. Mol. Struct. 877: 89-99. 49.Hino, T., Shimabayashi, S., Ohnishi, N., Fujisaki, M., Mori, H., Watanabe, O., Kawashima, K., and Nagao, K. 2000. Development of a new type nozzle and spray-dried for industrial production of fine powders. Eur. J. Pharm. Biopharm. 49: 79-85. 50.Hirano, S. 1999. Chitin and chitosan as novel biotechnological materials. Polym. Int. 48(8): 732-734. 51.Hirano, S., Inui, H., and Yamamoto, K. 1995. The mineralization of CO3-2 ions in crab shells, and their mimetic composite materials. Energy Conv. Manag. 36(6-9): 783-786. 52.Huang, M., Ma, Z., Khor, E., and Lim, L. Y. 2002a. Uptake of FITC-chitosan nanoparticles by A549 cells. Pharm. Res. 19(10): 1488-1494. 53.Huang, H. and Yang, X. 2003. Chitosan mediated assembly of gold nanoparticles multilayer. Colloid Surf. A-Physicochem. Eng. Asp. 226: 77-86. 54.Huang, Y. C., Yeh, M. K., and Chiang, C. H. 2002b. Formulation factors in preparing BTM – chitosan microspheres by spray drying method. Int. J. Pharm. 242: 239-242. 55.Huang, H., Yuan, Q., and Yang, X. 2004. Preparation and characterization of metal-chitosan nanocomposites. Colloid Surf. B-Biointerfaces 39: 31-37. 56.Huang, H., Yuan, Q., and Yang, X. 2005. Morphology study of gold-chitosan nanocomposites. J. Colloid Interface Sci. 282: 26-31. 57.Hummel, R. E. and Wi β mann, P. 1996. Handbook of optical properties: volume II optics of small particles, interfaces, and surfaces, CRC Press, Florida, USA. 58.Ieva, E., Trapani, A., Cioffi, N., Ditaranto, N., Monopoli, A., and Sabbatini, L. 2009. Analytical characterization of chitosan nanoparticles for peptide drug delivery applications. Anal. Bioanal. Chem. 393: 207-215. 59.Iskandar, F., Nandiyanto, A. B. D., Yun, K. M., Hogan Jr., C. J., Okuyama, K., and Biswas, P. 2007. Enhanced photocatalytic performance of brookite TiO2 macroporous particles prepared by spray drying with colloidal templating. Adv. Mater. 19: 1408-1412. 60.Ismail, A. A. 2005. Synthesis and characterization of Y2O3/Fe2O3/TiO2 nanoparticles by sol – gel method. Appl. Catal. B-Environ. 58: 115-121. 61.Janes, K. A., Calvo, P., and Alonso, M. J. 2001a. Ploysaccharide colloidal particles as delivery systems for macromolecules. Adv. Drug Deliv. Rev. 47: 83-97. 62.Janes, K. A., Fresneau, M. P., Marazuela, A., Fabra, A., and Alonson, M. J. 2001b. Chitosan nanoparticles as delivery systems for doxorubicin. J. Control. Release 73: 255-267. 63.Joachim, C. 2005. To be nano or not to be nano?. Nat. Mater. 4: 107-109. 64.Kanatt, S. R., Chander, R., and Sharma, A. 2008. Chitosan glucose complex-A novel food preservative. Food Chem. 106(2): 521-528. 65.Ken, B. 2006. What's in a name? Nano experts seek definitions. Met. powder rep. 61(11): 24-26. 66.Kiang, C. H. 2003. Phase transition of DNA-linked gold nanoparticles. Physica A 321: 164-169. 67.Kim, K. B. and Yoon, B. J. 1997. Field charging of spherical particles in linear electric field. J. Colloid Interface Sci. 186: 209-211. 68.Knaul, J. Z., Kasaai, M. R., Tam Bui, V., and Creber, K. A. M. 1998. Characterization of deacetylated chitosan and chitosan molecular weight review. Can. J. Chem. 76: 1699-1706. 69.Ko, S. H., Choi, Y., Hwang, D. J., Grigoropoulos, C. P., Chung, J., and Poulikakos, D. 2006. Nanosecond laser ablation of gold

nanoparticle films. Appl. Phys. Lett. 89: 141126. 70.Kocik, M., Dekowski, J., and Mizeraczyk, J. 2005. Particle precipitation efficiency in an electrostatic precipitator. J. Electrost. 63: 761-766. 71.Kozma, G., Kukovecz, A., and Konya, Z. 2007. Spectroscopic studies on the formation kinetics of SnO2 nanoparticles synthesized in a planetary ball mill. J. Mol. Struct. 834-836: 430-434. 72.Kuroiwa, T., Noguchi, Y., Nakajima, M., Sato, S., Mukataka, S., and Ichikawa, S. 2008. Production of chitosan oligosaccharides using chitosanase immobilized on amylose-coated magnetic nanoparticles. Process Biochem. 43(1): 62-69. 73.Labuza, T. P., Le Roux, J. P., Fan, T. S., and Tannenbaum, S. R. 1970. Engineering factors in single-cell protein production. II. Spray drying and cell viability. Biotechnol. Bioeng. XII: 135-140. 74.Lai, M. K., Chang, C. Y., Lien, Y. W., and Tsiang, R C. C. 2006. Application of gold nanoparticles to microencapsulation of thioridazine. J. Control. Release 111(3): 352-361. 75.Lavertu, M., Xia, Z., Serreqi, A. N., Berrada, M., Rodrigues, A., Wang, D., Buschmann, M. D., and Gupta, A. 2003. A validated 1H NMR method for the determination of the degree of deacetylation of chitosan. J. Pharm. Biomed. Anal. 32(6): 1149-1158. 76.Learoyd, T. P., Burrows, J. L., French, E., and Seville, P. C. 2008a. Modified release of beclometasone dipropionate from chitosan-based spray dried respirable powders. Powder Technol. 187: 231-238. 77.Learoyd, T. P., Burrows, J. L., French, E., and Seville, P. C. 2008b. Chitosan-based spray-dried respirable powders for sustained delivery of terbutaline sulfate. Eur. J. Pharm. Biopharm. 68: 224-234. 78.Lee, K. M., Park, S. T., and Lee, D. J. 2005. Nanogold synthesis by inert gas condensation for immuno-chemistry probes. J. Alloy. Compd. 390: 297-300. 79.Lefebvre, A. H. 1989. Atomization and sprays, Hemisphere Publishing Corporation, Washington, USA. 80.Lima, I. S., Lazarin, A. M., and Airoldi, C. 2005. Favorable chitosan/cellulose film combinations for copper removal from aqueous solutions. Int. J. Biol. Macromol. 36: 79-83. 81.Lisiecki, I., Billoudet, F., and Pileni, M. P. 1997. Syntheses of copper nanoparticles in gelified microemulsion and in reverse micelles. J. Mol. Liq. 72: 251-261. 82.Liu, H. B., Ascencio, J. A., Perez-Alvarez, M., and Yacaman, M. J. 2001. Melting behavior of nanometer sized gold isomers. Surf. Sci. 491: 88-98. 83.Liu, X. F., Guan, Y. L., Yang, D. Z., Li, Z., and Yao, K. D. 2001. Antibacterial action of chitosan and Carboxymethylated chitosan. J. Appl. Polym. Sci. 79: 1324-1335. 84.Luo, Y. 2006. Preparation of single-crystalline gold nanoparticles through a thermal process. Mater. Lett. 60(28): 3361-3363. 85.Ma, Y., Li, N., Yang, C., and Yang, X. 2005. One-step synthesis of water-soluble gold nanoparticles/polyaniline composite and its application in glucose sensing. Colloid Surf. A-Physicochem. Eng. Asp. 269: 1-6. 86.Maa, Y. F., Nguyen, P. A. T., and Hsu, S. W. 1998. Spray-drying of air-liquid interface sensitive recombinant human growth hormone. J. Pharm. Sci. 87(2): 152-159. 87.Madihally, S. V. and Matthew, H. W. T. 1999. Porous chitosan scaffolds for tissue engineering. Biomaterials 20: 1133-1142. 88.Maekawa, A. and Okuyama, F. 2001. Nano and microcrystallites of gold grown by argon-ion bombardment. Surf. Sci. 481: L427-L432. 89.Magnusson, M. H., Deppert, K., Malm, J. O., Bovin, J. O., and Samuelson, L. 1999. Size-selected gold nanoparticles by aerosol technology. Nanostructured Materials 12: 45-48. 90.Marcotte, E., Hart, P. J., Boucher, I., Brzezinski, R., and Robertus, J. D. 1993. Crystallization of a Chitosanase from Streptomyces N174. J. Mol. Biol. 232(3): 995-996. 91.Masters, K. 1991. Spray drying handbook. (5th ed.), Longman, Essex, UK. 92.Mi, F. L., Kuan, C. Y., Shyu, S. S., Lee, S. T., and Chang, S. F. 2000. The study of gelation kinetics and chain-relaxation properties of glutaraldehyde- cross-linked chitosan gel and their effects on microspheres preparation and drug release. Carbohydr. Polym. 41: 389-396. 93.Mi, F. L, Wong, T. B., Shyu, S. S and Chang, S. F. 1999. Chitosan microspheres: modification of polymeric chem-physical properties of spray-dried microspheres to control the release of antibiotic drug. J. Appl. Polym. Sci. 71(5): 747-759. 94.Mima, S., Miya, M., Iwamoto, R., and Yoshikawa, S. 1983. High deacetylated chitosan and its properties. J. Appl. Polym. Sci. 28: 1909-1917. 95.Mizoe, T., Ozeki, T., and Okada, H. 2007. Preparation of drug nanoparticles-containing microparticles using a 4-fluid nozzle spray drier for oral, pulmonary, and injection dosage forms. J. Control. Release. 122: 10-15. 96.Muzzarelli, R. A. A. 1977. Chitin. (1st ed.), Pergamon Press, Oxford, England. 97.Muzzarelli, R. A. A. and Rocchetti, R. 1985. Determination of the degree of acetylation of chitosans by first derivative ultraviolet spectrophotometry. Carbohydr. Polym. 5: 461-472. 98.Nakaso, K., Han, B., Ahn, K. H., Choi, M., and Okuyama, K. 2003. Synthesis of non-agglomerated nanoparticles by an electrospray assisted chemical vapor deposition (ES-CVD) method. J. Aerosol. Sci. 34: 869-881. 99.Newman, J. D. S., Roberts, J. M., and Blanchard, G. J. 2007. Optical organo- phosphate/phosphonate sensor based upon gold nanoparticle functionalized quartz. Anal. Chim. Acta 602: 101-107. 100.Nguyen, T. T. T., Loiseau, G., Icard-Verniere, C., Rochette, I., Treche, S., and Guyot, J. P. 2007a. Effect of fermentation by amylolytic lactic acid bacteria, in process combinations, on characteristics of rice/soybean slurries: A new method for preparing high energy density complementary foods for young children. Food Chem. 100: 623-631. 101.Nguyen, T. T. T., Guyot, J. P., Icard-Verniere, C., Rochette, I., and Loiseau, G. 2007b. Effect of high pressure homogenization on capacity of Lactobacillus plantarum A6 to ferment rice/soybean slurries to prepare high energy density complementary foods. Food Chem. 102: 1288-1295. 102.Nie, H., Lee, L. Y., Tong, H., and Wang, C. H. 2008. PLGA/chitosan composites from a combination of spray drying and supercritical fluid foaming techniques: new carriers for DNA delivery. J. Control. Release 129: 207-214. 103.No, H. K., Park, N. Y., Lee, S H., and Meyers, S. P. 2002. Antibacterial activity of chitosans and chitosan oligomers with different molecular weights. Int. J. Food Microbiol. 74: 65-72. 104.Oh, K. S., Kim, R. S., Lee, J., Kim, D., Cho, S. H., and Yuk, S. H. 2008. Gold/chitosan/pluronic composite nanoparticles for drug delivery. J. Appl. Polym. Sci. 108: 3239-3244. 105.Okuyama, K., Noguchi K., Kanenari M., Egawa T., Osawa, K., and Ogawa, K. 2000. Carbohydr. Polym. 41: 237-247. 106.Oungbho, K. and Muller, B. W. 1997. Chitosan sponges as sustained release drug carriers. Int. J. Pharm. 156: 229-237. 107.Pal, U., Bautista-Hernandez, A., Koshizaki, N., Sasaki, T., and Terauchi, S. 2001. Synthesis of GaAs nanoparticles embedded in SiO2 matrix by radio frequency co-sputtering technique. Scr. Mater. 44: 1841-1846. 108.Pal, A., Shah, S., and Devi, S. 2007. Preparation of silver, gold and silver-gold bimetallic nanoparticles in w/o microemulsion containing TritonX-100. Colloid Surf. A-Physicochem. Eng. Asp. 302: 483-487. 109.Peukert, W. and Wadenpohl, C. 2001. Industrial separation of fine particles with difficult dust properties. Powder Technol. 118: 136-148. 110.Rajamathi, M. and Seshadri, R. 2002. Oxide and chalcogenide nanoparticles from hydrothermal/solvothermal reactions. Curr. Opin. Solid State Mat. Sci. 6(4): 337-345. 111.Ravi

Kumar, M. N. V. 2000. A review of chitin and chitosan applications. React. Funct. Polym. 46: 1-27. 112.Rege, P. R., Garmise, R. J., and Block, L. H. 2003a. Spray-dried chitinosans: Part I: preparation and characterization. Int. J. Pharm. 252(12): 41-51. 113.Rege, P. R., Garmise, R. J., and Block, L. H. 2003b. Spray-dried chitinosans: Part II: in vitro drug release from tablets made from spray-dried chitinosans. Int. J. Pharm. 252(12): 53-59 114.Rehg, T., Dorger, C., and Chau, P. C. 1986. Application of an atomizer in producing small alginate gel beads for cell immobilization. Biotechnol. Lett. 8(2): 111-114. 115.Reindl, A., Cimpean, C., Bauer, W., Comanici, R., Ebbers, A., Peukert, W., and Kryschi, C. 2007. Dispersing silicon nanoparticles with a stirred media mill and subsequent functionalization with phenyl acetylene. Colloid Surf. A-Physicochem. Eng. Asp. 301: 382-387. 116.Rudall, K. M. 1963. The chitin/protein complexes of insect cuticles. Adv. insect physiol. 1: 257-313. 117.Sham, J. O. H., Zhang, Y., Finlay, W. H., Roa, W. H., and Lobenberg, R. 2004. Formulation and characterization of spray-dried powders containing nanoparticles for aerosol delivery to the lung. Int. J. Pharm. 269: 457-467. 118.Shantha, K. L. and Harding, D. R. K. 2002. Synthesis and characterization of chemically modified chitosan microspheres. Carbohydr. Polym. 48: 247-253. 119.Shen, M., Du, Y., Hua, N., and Yang, P. 2006. Microwave irradiation synthesis and self-assembly of alkylamine-stabilized gold nanoparticles. Powder Technol. 162: 64-72. 120.Shi, L. and Bayless, D. J. 2007. Comparison of boundary conditions for predicting the collection efficiency of cyclones. Powder Technol. 173: 29-37. 121.Shih, C. M., Shieh, Y. T., and Twu, Y. K. 2009. Preparation of gold nanopowders and nanoparticles using chitosan suspensions. Carbohydr. Polym. Article in press. 122.?ljuki?, B., Baron, R., Salter, C., Crossley, A., and Compton, R. G. 2007. Combinatorial electrochemistry using metal nanoparticles: From proof-of-concept to practical realisation for bromide detection. Anal. Chim. Acta. 590(1): 67-73. 123.Stahl, K., Claesson, M., Lilliehorn, P., Linden, H., and Backstrom, K. 2002. The effect of process variables on the degradation and physical properties of spray dried insulin intended for inhalation. Int. J. Pharm. 233: 227- 237. 124.Suh, Y. J. and Kim, S. S. 1996. Effect of obstructions on the particle collection efficiency in a two-stage electrostatic precipitator. J. Aerosol. Sci. 27(1): 61-74. 125.Sun, C., Qu, R., Chen, H., Ji, C., Wang, C., Sun, Y., and Wang, B. 2008. Degradation behavior of chitosan in the “green” synthesis of gold nanoparticles. Carbohydr. Res. 343: 2595-2599. 126.Tamil Selvan, S., Nogami, M., Nakamura, A., and Hamanaka, Y. 1999. A facile sol-gel method for the encapsulation of gold nanoclusters in silica gels and their optical properties. J. Non-Cryst. Solids 255: 254-258. 127.Tamou, Y. and Tanaka, S. I. 1999. Formation and coalescence of tungsten nanoparticles under electron beam irradiation. Nanostructured Materials 12: 123-126. 128.Tan, S. C., Khor, E., Tan, T. K., and Wong, S. M. 1998. The degree of deacetylation of chitosan: advocating the first derivative UV-spectrophotometry method of determination. Talanta 45: 713-719. 129.Thompson, D. T. 2007. Using gold nanoparticles for catalysis. Nano Today 2(4): 40-43. 130.Toei, K. and Kohara, T. 1976. A conductometric method for colloid titrations. Anal. Chim. Acta. 83: 59-65. 131.Tsaih, M. L. and Chen, R. H. 1997. Effect of molecular and urea on the conformation of chitosan molecules in dilute solutions. Int. J. Biol. Macromol. 20: 233-240. 132.Twu, Y. K., Chen, Y. W., and Shih, C. M. 2008. Preparation of silver nanoparticles using chitosan suspensions. Powder Technol. 185: 251-257. 133.Tyler, D. E and Black, W. T. 1990. Metals Handbook. (10th ed.), ASM International, OH, USA. 134.Valden, M., Lai, X., and Goodman, D. W. 1998. Onset of catalytic activity of gold clusters on titania with the appearance of nonmetallic properties. Science 281(5383): 1647-1650. 135.Van Miller, J. P., Hermansky, S. J., Losco, P. E., and Ballantyne, B. 2002. Chronic toxicity and oncogenicity study with glutaraldehyde dosed in the drinking water of Fischer 344 rats. Toxicology 175: 177-189. 136.Varma, A. J., Deshpande, S. V., and Kennedy, J. F. 2004. Metal complexation by chitosan and its derivates: a review. Carbohydr. Polym. 55: 77-93. 137.Varum K. M., Egelandsdal, B., and Ellekjar, M. R. 1995. Characterization of partially N-acetylated chitosan by near infra-red spectroscopy. Carbohydr. Polym. 28: 187-193. 138.Vasconcelos, H. L., Camargo, T. P., Goncalves, N. S., Neves, A., Laranjeira, M. C. M., and Favere, V. T. 2008. Chitosan crosslinked with a metal complexing agent: synthesis, characterization and copper(II) ions adsorption. React. Funct. Polym. 68: 572-579. 139.Wadley, H. N. G., Zhou, X., Johnson, R. A., and Neurock, M. 2001. Mechanisms, models and methods of vapor deposition. Prog. Mater. Sci. 46: 329-377. 140.Wang, Q., Dong, Z., Du, Y., and Kennedy, J. F. 2007. Controlled release of ciprofloxacin hydrochloride from chitosan/polyethylene glycol blend films. Carbohydr. Polym. 69: 336-343. 141.Warchol, J. B., Breli?ska, R., and Herbert, D. C. 1982. Analysis of colloidal gold methods for labelling proteins. Histochemistry 76(4): 567-575. 142.Weiser, B. L. 1933. Inorganic colloid chemistry, Wiley, NJ, USA. 143.Xie, W., Xu, P., and Liu, Q. 2001. Antioxidant activity of water-soluble chitosan derivatives. Bioorg. Med. Chem. Lett. 11(13): 1699-1701. 144.Xu, Y. and Du, Y. 2003. Effect of molecular structure of chitosan on protein delivery properties of chitosan nanoparticles. Int. J. Pharm. 250: 215-226. 145.Xu, H., Ma, L., Shi, H., Gao, C., and Han. C. 2007. Chitosan-hyaluronic acid hybrid film as a novel wound dressing: in vitro and in vivo studies. Polym. Adv. Technol. 18: 869-875. 146.Xu, X. D., Wang, Y. C., and Liu, Z. F. 2005. Large-scale fabrication of uniform gold nanoparticles in ultrahigh vacuum. J. Cryst. Growth 285: 372-379. 147.Yang, Y., Lan, J., and Li, X. 2004. Study on bulk aluminum matrix nano-composite fabricated by ultrasonic dispersion of nano-sized SiC particles in molten aluminum alloy. Mater. Sci. Eng. A-Struct. Mater. Prop. Microstruct. Process 380: 378-383. 148.Yang, T. C., Li, C. F., Chou, S. S., and Chou, C. C. 2005. Adsorption of metal cations by water-soluble N-alkylated disaccharide chitosan derivatives. J. Appl. Polym. Sci. 98: 564-570. 149.Yang, Z., Niu, Z., Lu, Y., Hu, Z., and Han, C. C. 2003. Templated synthesis of inorganic hollow spheres with a tunable cavity size onto core-shell gel particles. Angew. Chem. Int. Ed. 42: 1943-1945. 150.Yang, Z., Shu, J., Zhang, L., and Wang, Y. 2006. Preparation and adsorption behavior for metal ions of cyclic polyamine derivative of chitosan. J. Appl. Polym. Sci. 100: 3018-3023. 151.Yoo, K. H., Lee, J. S., and Oh, M. D. 1997. Charging and collection of submicron particles in two-stage parallel-plate electrostatic precipitator. Aerosol Sci. Technol. 27: 308-323. 152.Yuan, Y., Zhang, P., Yang, Y., Wang, X., and Gu, X. 2004. The interaction of Schwann cells with chitosan membranes and fibers in vitro. Biomaterials 25: 4273-4278. 153.Zhan, C., Li, D., Zhang, D., Xu, W., Nie, Y., and Zhu, D. 2004. The excited-state absorption and third-order optical nonlinearity from 1-dodecanethiol protected gold nanoparticles: Application for optical limiting. Opt. Mater. 26(1): 11-15. 154.Zhang, Y., Xue, C., Xue, Y., Gao, R., and Zhang, X.

2005. Determination of the degree of deacetylation of chitin and chitosan by X-ray powder diffraction. Carbohydr. Res. 340: 1914-1917.