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Gold nanoparticles formation via gold(III) chloride complex ions reduction with glucose in the batch and in the flow microreactor systems

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ABSTRACT

In these studies, the flow microreactor system was used as a valuable tool for controlled synthesis of gold nanoparticles (AuNPs) with the narrow size distribution. As a method of synthesis, the reduction of gold(III) chloride complex ions using glucose as a reducing agent was carried out. Synthesis was performed in the presence of different amount of PVP (polyvinylpyrrolidone) as a stabilizing agent. The optimal conditions inside the microreactor system (concentrations and the flow rate of components) were established as a results of kinetic measurements in the batch reactor. In these studies the rate constants of AuNPs formation (nucleation and growth) as a function of different reductant concentration as well as temperature were determined using UV–Vis spectrophotometry and Dynamic Light Scattering (DLS) method. Experimentally obtained kinetic data gave us the chance to formulate the rate law of AuNPs formation which further was used to establish synthesis conditions. Applying T-type geometry of microchannels connection, for different reactant and PVP flow rates the injection of PVP at the proper time of AuNPs growth was done. It was found that applied method is promising one for the stabilization and preparation of gold nanoparticles with well-defined shape (spheres) and with narrow size distribution.

1. Introduction

Gold in the form of nanoparticles have the unique physico-chemical properties, e.g. optical or catalytic, in comparison with their bulk counterpart [1–5]. This fact makes them to be interesting structures for application in biology [2,6], medicine [6], catalysis [2,7,8], nanoelectronics [9], etc. For all these applications the proper size (and its distribution), sometimes shape as well as interactions between surface atoms and stabilizing ligands must be strictly established and controlled. These factors are crucial for stability of gold nanoparticles (AuNPs) and their final application in practice. For this reason, there are still many different studies to develop or improve existing methods for synthesis of stable AuNPs.

From a large variety of methods for AuNPs synthesis, most common and the simplest one is chemical reduction [10–16]. In this method positively charged gold complex ions are reduced to the zero valence state and form a colloidal solution. However, in many cases colloidal particles are unstable in time and due to the presence of attractive interactions between them tend to agglomerate. A number of different factors, such as kind of reductant, precursor and solvent used in the synthesis of AuNPs may influence stability of these nanostructures [16–18]. To prevent them from agglomeration, addition of the proper stabilizer into reaction mixture at the proper stage of their growth must be done [19–22]. This can be achieved by using the flow microreactor system with the special geometry of channels.

The second important problem during synthesis is associated with the accuracy of reactants mixing. It seems to be that homogeneous composition of solution influence better gold nucleus distribution in the reaction volume which affect the smaller size of nanoparticles and the narrower size distribution, as well. Such conditions can be reached in the restricted geometry of reactor, e.g. in microreactor system.

Taking together both of these two important factors (geometry and restricted size of reactor) the flow microreactor system seems to be a promising tool for controlled synthesis of AuNPs. Controlling of their growth by the change of the flow rate and possibility of stabilization during the reaction give the chance to reach the uniform size of particles with narrow size distribution.

This technique was successfully used in nanoparticles synthesis by Wagner et al. [23–25], Köhler et al. [26], Sönnichsen et al. [27] and others [28–30]. Köhler [26] and Luty-Błocho [31] showed influence of the fast mixing and flow rate on the size and size distribution of obtained nanoparticles. Recently, we have also demonstrated that in the gold(III)–ascorbic acid system [32] appropriate adjustment of the flow rate gives a chance to inject a stabilizer at the proper time of the redox reaction. This procedure let us to control the size of gold nanoparticles during the synthesis. Summarizing

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