

Multifunctional Nanocomposite Systems

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ABSTRACT

A method to produce multifunctional nanocomposite materials is presented. Polymer stabilized nanoparticles (e.g. hydroxides, oxides, metals, salts, etc.) are incorporated into a bulk inorganic matrix (zinc oxide/hydroxide, aluminum oxide/hydroxide, ferric oxide, silica, ceria, etc) through the formation of an inorganic phase around the polymer stabilized nanoparticles. This results in the precipitation of a porous nanocomposite that possesses multiple functionalities that come from the different combinations of components of the composite. Nanocomposites that can be used as catalysts, sorbents for heavy metals and arsenic, ion exchangers, and pigments have been made, and data illustrating these properties will be shown

Keywords: nanoparticles, nanocomposite, sorbents, ion exchange, oxidation catalyst

1 SYNTHESIS AND CHARACTERIZATION OF MULTIFUNCTIONAL NANOCOMPOSITES

The nanocomposite system is composed of two distinct components: polymer coated nanoparticles and an inorganic phase. The synthesis of the polymer coated nanoparticles is illustrated in Figure 1.

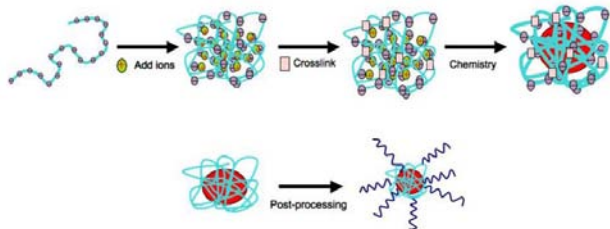


Figure 1. Schematic of Vive Nano's nanoparticle synthesis

Water dispersible nanoparticles are produced using counterion-induced collapsed polyelectrolyte chains. Polyelectrolytes are polymers having monomer units with ionizable groups such as amines, carboxylic acids, or sulfonic acids. Their conformation in aqueous solution is

governed by electrostatic interactions between the charged moieties in the chain. Under conditions of high ionization and low ionic strength, the individual polyelectrolyte chains assume a highly extended, swollen coil conformation arising from repulsive electrostatic interactions along the chain. The addition of ionic species results in the screening of these repulsive interactions by the counterions, causing the highly extended polyelectrolyte coils to collapse into globules [1]. These globules contain the counterions used to induce collapse, and can range in size from ~ 1 -50 nm. Crosslinking the collapsed polymer chain results in a stabilized globular structure thereby forming a template in which to synthesize nanoparticles. Nanoparticles are formed from the trapped counterions in the globules. For example, if we use Ag^+ ions to collapse the polyelectrolyte, the trapped Ag^+ ions can be reduced to form Ag^0 nanoparticles. This method is very versatile and can be used to synthesize different noble metal, metal oxide, semiconductor and alloy nanoparticles encapsulated inside a charged polymer template.

These polymer encapsulated inorganic nanoparticles can then be embedded in a porous matrix support comprising of various inorganic oxides, effectively creating a supported multi functional nanocomposite with a very high active surface area. The formation of nanocomposite can be simplified into three steps and is summarized in Figure 2 below.

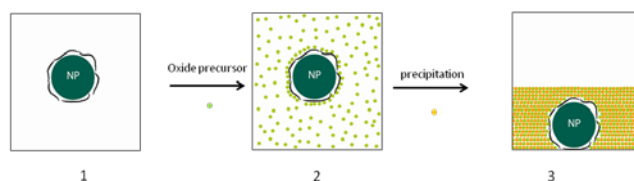


Figure 2. Steps outlining the formation of the multifunctional nanocomposite.

The polymer coated nanoparticles are first dispersed in water (1). An inorganic oxide precursor (e.g. salts) is then added to the solution of nanoparticles. These oxide precursors coordinate with the functional groups of the polymer through either ionic, donor-acceptor or hydrogen bonds (2). Finally, the insoluble oxide is formed by changing the pH of the solution to form an insoluble solid

inorganic hydroxide/oxide phase wherein the nanoparticles are entrapped as part of a composite product (3).

Electron microscopy characterization done on polymer encapsulated Fe_2O_3 nanoparticles embedded in a Fe_2O_3 matrix ($\text{Fe}_2\text{O}_3/\text{PAA}$ on Fe_2O_3) have shown that these systems have porosity of ~ 10 nm and that the nanoparticles retain their structural integrity even after nanocomposite formation. Dye adsorption tests on the nanocomposite system have also shown that the functional groups of the encapsulating polymer (i.e. from the nanoparticle) still remain accessible. A high resolution electron microscopy image (FE-SEM) of the Fe_2O_3 -based nanocomposite system is shown in Figure 3.

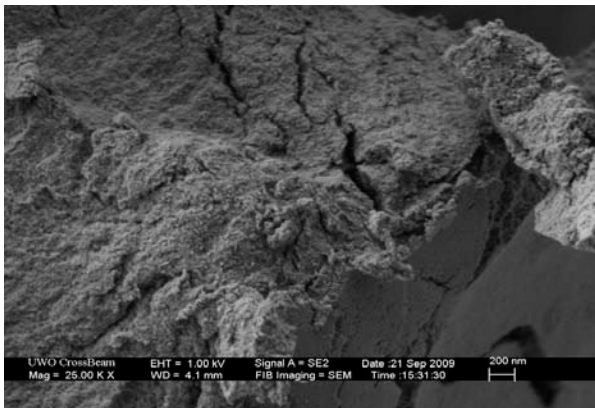


Figure 3. FE-SEM image of Fe_2O_3 nanoparticles embedded in a Fe_2O_3 matrix.

The process can provide unparalleled control over nanocomposite properties by simple and straightforward changes to the combination of nanocomposite elements and synthesis conditions. The great advantage of the proposed nanocomposite system is the multifunctionality of the material, which is derived from:

1. The inorganic nanoparticle inside the polymer template – different types of nanoparticle can easily be synthesized;
2. The charged polymer encapsulating the inorganic nanomaterials;
3. The inorganic oxide support material that serves as a structural support as well as a means to prevent sintering of the nanoparticles.

2 MULTIFUNCTIONAL NANOCOMPOSITE PERFORMANCE

Nanocomposites were tested for their ability to remove both organic and inorganic contaminants from water solution. These results are shown in figures 4 and 5. Figure 4 shows the performance of a nanocomposite

composed of $\text{Fe}_2\text{O}_3/\text{PAA}$ nanoparticles on an Fe_2O_3 support towards the removal of metal cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Ni^{2+} , Zn^{2+} , Pb^{2+} , Al^{3+} and Sb^{3+}) from solution. The data demonstrates that under certain solution conditions these nanocomposites show some selectivity towards divalent metal cations (like Ni^{2+} and Zn^{2+}) even in the presence of other cations (like K^+ and Na^+). Figure 5 shows the removal of up to 200 mg methylene blue dye using 1 g of the same Fe_2O_3 nanoparticle-based nanocomposite [2].

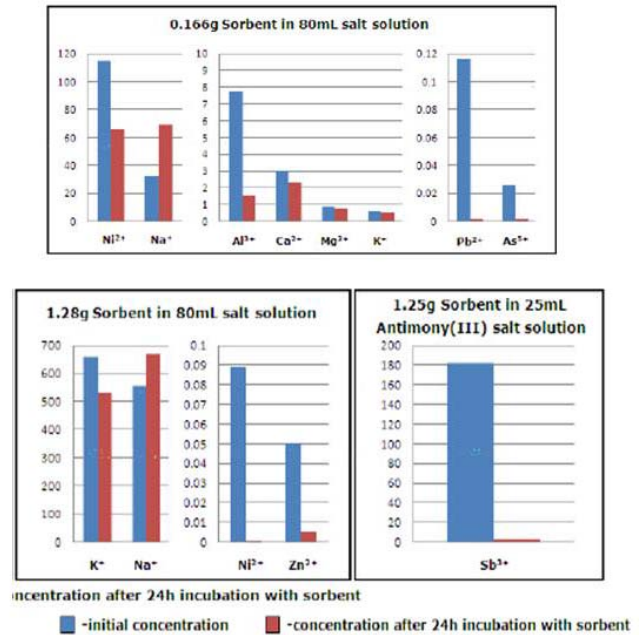


Figure 4. Removal of heavy metals, arsenic and antimony ions from aqueous solutions with $\text{Fe}_2\text{O}_3/\text{PAA}$ on Fe_2O_3 . (units in ppm)



Figure 5. Removal of methylene blue from an aqueous solution with $\text{Fe}_2\text{O}_3/\text{PAA}$ on Fe_2O_3 .

CO oxidation performance of a nanocomposite comprising (0.5%)Pt, (0.5%)Pd nanoparticles on a Ceria support is shown in Figure 6. This nanocomposite was subjected to a temperature programmed reaction protocol to compare its performance in CO oxidation against the standard (1%) Pt on Alumina support [3]. The data shows this nanocomposite exhibits improved performance over the existing standard by having lower light off temperatures for both CO and propylene oxidation.

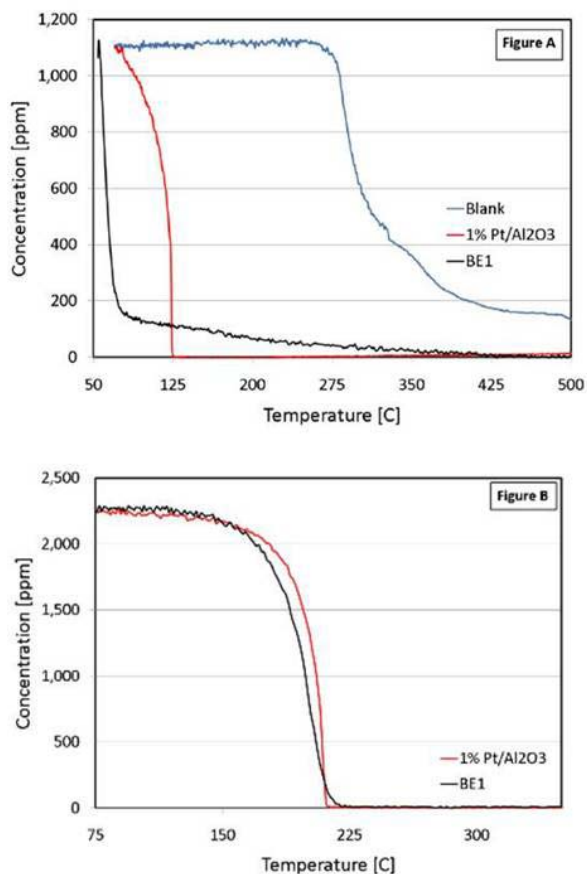


Figure 5. Catalytic converter applications of multifunctional nanocomposites. (A) CO oxidation using (0.5%)Pt (0.5%)Pd on CeO_2 (labeled as BE1 in the figure). (B) Propylene oxidation using the BE1.

3 REFERENCES

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