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Development of a high-performance nanostructured V_2O_5/SnO_2 catalyst for efficient benzene hydroxylation

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Abstract

Nanostructured vanadium-tin oxide (V(sub2)O(sub5)/SnO(sub2)) catalysts with V(sub2)O(sub5) loading in a range of 5–20 wt% have been synthesized. The V(sub2)O(sub5)/SnO(sub2) nanostructures exhibited effective catalytic performance in the hydroxylation of benzene to phenol using H(sub2)O(sub2) as the terminal oxidant. The structure of the catalysts was studied using various techniques, such as XRD, Raman spectroscopy, SEM, EDX, TEM/HRTEM, STEM-HAADF, and H2-TPR and the adsorption/desorption of nitrogen. The Raman study supported the formation of certain monomeric and polymeric surface vanadium species and a crystalline V(sub2)O(sub5) phase on their respective dehydrated mixed V(sub2)O(sub5)/SnO(sub2) nanostructured catalysts depending on the vanadium loading. TEM studies revealed the morphology of V2O5 and SnO2 to be characterized by the formation of nanoparticles with a size of approximately 20 nm. Moreover, the dispersion of V(sub2)O(sub5) on SnO(sub2) was also found to be influenced by V(sub2)O(sub5) loading where a high loading of 20 wt% exhibited an agglomeration of particles, which affected its catalytic activity. The V(sub2)O(sub5)/SnO(sub2) catalysts resulted in modified redox properties, as evidenced by the H2-TPR results. These structural developments of mixed V(sub2)O(sub5)/SnO(sub2) presented a highly active catalyst for the hydroxylation of benzene to phenol affording up to a 34% conversion, while preserving a phenol selectivity of 96% for a sample of V(sub2)O(sub5)/SnO(sub2) containing 10 wt% V(sub2)O(sub5). The catalytic results indicated that the vanadium content in V(sub2)O(sub5)/SnO(sub2) played an important role not only in improved substrate conversion but also in preserving a high selectivity for phenol. This was also evident from the correlation of the different vanadium phases for pure and composite catalysts with their respective catalytic results. Both polymeric and monomeric vanadium species on an SnO(sub2) surface proved to be critical for the high catalytic performance of the catalyst. The high catalytic performance displayed by V(sub2)O(sub5)/SnO(sub2) can provide opportunities for further development as a green and economical protocol for direct phenol synthesis from benzene hydroxylation with excellent catalyst recyclability.