Utilization of rice husk waste available from rice milling operation for production of silicon compounds

Abstract

Rice husk (RH) is a waste byproduct of rice milling operations which is generally burnt to solve the waste disposal problem and subsequently to meet the energy requirement of the rice milling operations. However, the waste disposal issue does not get solved as it produces a large amount of secondary waste, i.e. ash/char. Hence, in the present study an attempt has been made on production of silicon compounds from this secondary waste, rice husk ash (RHA). An entropy-based TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) multi-criteria decision-making (MCDM) method was employed to select most suitable RH variety for energy application. Four varieties of RHs, namely, Badsha-bhog, Lal-swarna, IR-36, and Shankar were selected for the study. Lal-swarna was the most suitable followed by Shankar, IR-36, and Badsha-bhog. The RH of Lal-swarna variety was considered for production of amorphous RHA and a hybrid RSM–BPANN–MOGA technique was employed to optimize process parameters. The optimal conditions of leaching temperature, leaching time, calcination temperature, and calcination time were 75 °C, 1 h, 550 °C, and 2 h, respectively. The optimized RHA exhibited highly porous amorphous nanoparticles with higher percentage of silica compared to the non-leached RHA. This RHA was treated with various alkalis to produce commercial-grade amorphous silica nanoparticles (SiO_2-NPs). Results revealed that Na_2CO_3 treatment followed by water washing was the best suitable treatment for recovering pure amorphous SiO_2-NPs. Moreover, SiO_2-NPs produced from RHA (RHA-silica) was eco-friendly and cost effective, and exhibited similar characteristics to commercial SiO_2-NPs. A silica extraction plant based on the experimental outcomes was proposed. The analysis showed a good commercial viability with estimated annual return on investment of 55.19%, if established adjacent to a 2 tonne/h rice mill. Furthermore, this RHA-silica was subjected to magnesiothermic and carbothermic reduction for production of pure silicon and silicon compounds. For the magnesiothermic reduction, an inert atmospheric setup was developed by adapting an existing muffle furnace, whereas the carbothermic reduction was carried out in an atmospheric tube furnace using alumina and carbon boats. Results of magnesiothermic reduction of RHA-silica showed partial reduction of silica to silicon, whereas hybrid $Si/SiO_2/SiC$ composites and β-SiC were obtained from carbothermic reduction of RHA-silica.

Keywords: Agricultural waste; Rice husk; Energy material; Pyrolysis kinetics; Entropy-TOPSIS, Rice husk ash; RSM–BP BPANN–MOGA; Alkali treatment; Amorphous silica nanoparticles; Magnesiothermic reduction; Carbothermic reduction; $Si/SiO_2/SiC$; β-SiC; Material characterization