World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:16, No:01, 2022

A Microwave Heating Model for Endothermic Reaction in the Cement Industry

Authors : Sofia N. Gonçalves, Duarte M. S. Albuquerque, José C. F. Pereira

Abstract : Microwave technology has been gaining importance in contributing to decarbonization processes in high energy demand industries. Despite the several numerical models presented in the literature, a proper Verification and Validation exercise is still lacking. This is important and required to evaluate the physical process model accuracy and adequacy. Another issue addresses impedance matching, which is an important mechanism used in microwave experiments to increase electromagnetic efficiency. Such mechanism is not available in current computational tools, thus requiring an external numerical procedure. A numerical model was implemented to study the continuous processing of limestone with microwave heating. This process requires the material to be heated until a certain temperature that will prompt a highly endothermic reaction. Both a 2D and 3D model were built in COMSOL Multiphysics to solve the two-way coupling between Maxwell and Energy equations, along with the coupling between both heat transfer phenomena and limestone endothermic reaction. The 2D model was used to study and evaluate the required numerical procedure, being also a benchmark test, allowing other authors to implement impedance matching procedures. To achieve this goal, a controller built in MATLAB was used to continuously matching the cavity impedance and predicting the required energy for the system, thus successfully avoiding energy inefficiencies. The 3D model reproduces realistic results and therefore supports the main conclusions of this work. Limestone was modeled as a continuous flow under the transport of concentrated species, whose material and kinetics properties were taken from literature. Verification and Validation of the coupled model was taken separately from the chemical kinetic model. The chemical kinetic model was found to correctly describe the chosen kinetic equation by comparing numerical results with experimental data. A solution verification was made for the electromagnetic interface, where second order and fourth order accurate schemes were found for linear and quadratic elements, respectively, with numerical uncertainty lower than 0.03%. Regarding the coupled model, it was demonstrated that the numerical error would diverge for the heat transfer interface with the mapped mesh. Results showed numerical stability for the triangular mesh, and the numerical uncertainty was less than 0.1%. This study evaluated limestone velocity, heat transfer, and load influence on thermal decomposition and overall process efficiency. The velocity and heat transfer coefficient were studied with the 2D model, while different loads of material were studied with the 3D model. Both models demonstrated to be highly unstable when solving non-linear temperature distributions. High velocity flows exhibited propensity to thermal runways, and the thermal efficiency showed the tendency to stabilize for the higher velocities and higher filling ratio. Microwave efficiency denoted an optimal velocity for each heat transfer coefficient, pointing out that electromagnetic efficiency is a consequence of energy distribution uniformity. The 3D results indicated the inefficient development of the electric field for low filling ratios. Thermal efficiencies higher than 90% were found for the higher loads and microwave efficiencies up to 75% were accomplished. The 80% fill ratio was demonstrated to be the optimal load with an associated global efficiency of 70%.

Keywords : multiphysics modeling, microwave heating, verification and validation, endothermic reactions modeling, impedance matching, limestone continuous processing
Conference Title : ICMMSD 2022 : International Conference on Materials Modelling, Simulation and Design
Conference Location : Tokyo, Japan
Conference Dates : January 07-08, 2022