Modeling of Fluid Flow and Heat Transfer During a Steam-Thermolysis Process for Recycling Carbon Fiber Reinforced Polymer

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Abstract

Introduction
The global demand for carbon fibre in 2011 was estimated at 46,000 tonnes, and is forecast to rise to 140,000 tonnes by 2020, therefore an increasing amount of carbon fiber reinforced polymer (CFRP) waste is generated [1]. The environmental and economic aspects are today the driving force for the development of recycling routes. The aim is to recover the carbon fibers, as close as possible to their initial state, in order to envisage a reuse in others applications. Different types of technologies have been studied, for example: pyrolysis, solvolysis and steam-thermolysis. The steam-thermolysis is a process that combines pyrolysis and superheated steam at atmospheric pressure to decompose the organic matrix of the composite [2]. The waste is introduced into a bench-scale reactor heated at high temperatures (400-600 °C) under nitrogen atmosphere. A humidity generator is coupled in the reactor gas inlets to provide a flux of superheated steam.

Use of COMSOL Multiphysics®
This work is focused on the numerical modeling of different physical-chemical phenomena that occur during the steam-thermolysis within the reactor. A 3D model (Figure 1) was built using COMSOL Multiphysics® Software to better understand velocity and temperature profiles in the furnace. Initially, the fluid flow and the heat transfer within the furnace were model without considering the composite materials. This model aims to simulate the flow and the temperature profile before introduction of the samples in the reactor. Later, the simulation was done taking into account the composite (carbon fiber/epoxy). The influence on the velocity and temperature profiles of two important operating parameters (temperature of the furnace and steam flow rate), as well as the number and the arrangement of composite pieces were also studied.

The results predict, from the model without composites, that the velocity profile becomes parabolic after traversing a distance of approximately 6 cm in the crucible. The average fluid velocity is more sensitive to steam flow rate changes than the furnace temperature changes (Figure 2). Figure 3 presents the temperature distribution at two different inlet flow rates (50 and 200 g/h). It can be seen that the temperature decreased when the flow rate was increased from 50 to 200 g/h, however the average temperature between them was about 8 °C. The introduction of composites causes effects on the velocity and temperature profiles (Figure 4). It produces an

increase of the fluid velocity at crucible inlet. However, it was still observed a laminar profile besides the effective velocity changes. The behavior of temperature profile displayed that when the number of composites pieces increases the environment around the composite becomes colder.

The decomposition reaction of the composite polymer resin will be further integrated in the model. The 3D COMSOL Multiphysics® model is a useful tool for gaining a better insight into temperature and velocity profiles in the furnace [3]. A series of experiments will be carried out to verify and validate the model.

Reference

1. Anthony Roberts, The Carbon Fibre Industry Worldwide 2011-2020: an evaluation of current markets and future supply and demand, Materials Technologies Publications, UK, 2011.
2. Sheng Yin Ye, Yannick Soudais et al., Valorisation de déchets composites à matrices polymériques renforcées de fibres de carbone par un procédé de vapo-thermolyse, thesis, Université de Toulouse, France, 2012.
3. Xiangmei Meng, Wiebren de Jong et al., Combustion study of partially gasified willow and DDGS chars using TG analysis and COMSOL modeling, Biomass and Bioenergy, vol 39, pp 356 – 369, 2012.

Figures used in the abstract

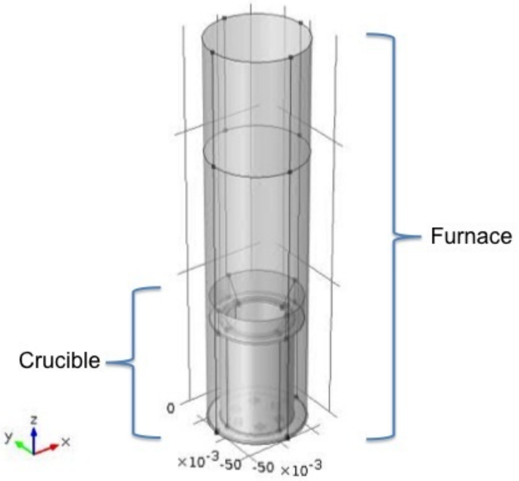

Figure 1: 3D reactor geometry

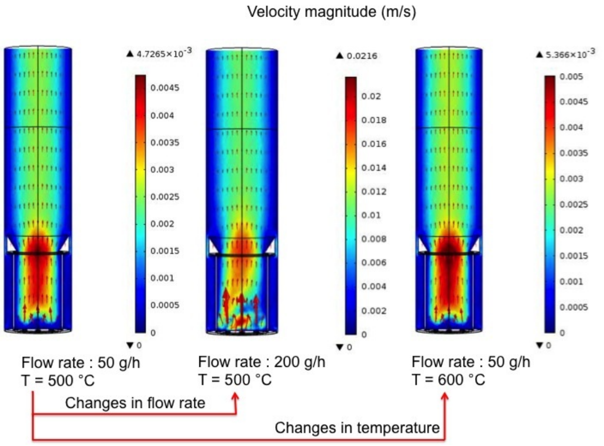

Figure 2: Effects of different flow rates and different temperatures on velocity profile

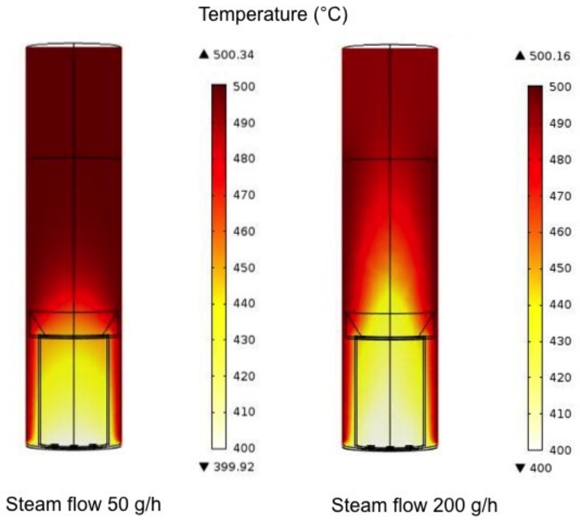

Figure 3: Effects of different flow rates on temperature distribution within the furnace

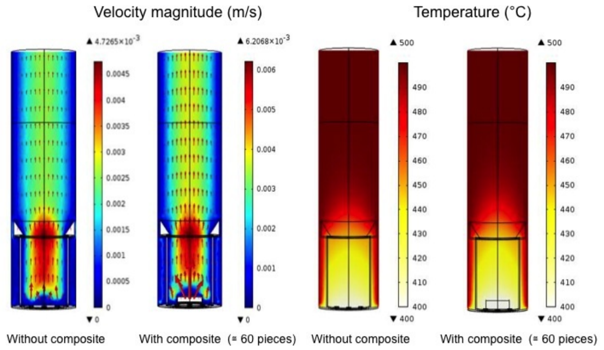

Figure 4: Effects of the composite introduction on velocity and temperature profiles