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Coke combustion in fluidized bed: A multi-disciplinary lab experiment

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ABSTRACT

A multi-disciplinary pilot-scale setup was assembled with the purpose of studying coupled mass transport and chemical reaction phenomena during coke combustion in a fluidized bed. Such experimental work has been integrated in the program of a laboratory course (4th year) of the Integrated Master in Chemical Engineering at FEUP (Faculty of Engineering—University of Porto). This way students deal with a systematic multi-variable study of a complex system involving heterogeneous (solid–gas) non-catalytic reaction. In addition to describing the setup and the theory behind the involved phenomena, this paper lists the main pedagogical objectives, and exemplifies the experimental procedures and mathematical treatments involved in the student work.

Considering the successful results reported in the literature in what concerns the student's engagement and improvements in the learning process while using technological pedagogic support, a video on the procedure of this lab experiment has been produced and made available to students.

A two-part inquiry was made at the end of the class term, assessing the students' feedback on general aspects of the work (part 1) and on the demonstrative video (part 2). It was concluded that most students consider this work highly relevant for the better understanding of the involved concepts. Also, all the students who watched the video (87%) considered this kind of pedagogical support quite relevant, with 67% of these students voting 5 in a scale of 1 (non-relevant) to 5 (very relevant).

1. Introduction

Q2 Fluidized beds are often used in industrial operations such as gaseous reactions catalyzed by solid surfaces, adsorption, Q3 ion exchange and chromatography (Welty et al., 2001). A bed can be defined as a set of solid particles of regular or irregular shape, which present a unique size or a particle size distribution, and that are confined to a container and subject to a downward or upward flux of liquid or gas. When a fluid flows upwards through a bed of particles, as the flow rate increases, the upward drag force exerted by the fluid on the particles increases as well, until it equals the apparent weight of the particles in the bed making it fluidized for further increases of the flow rate (Rhodes, 2008). Q4

The combustion of carbonaceous particles in fluidized beds is often performed in beds of small particles of inert materials (e.g. sand or ashes), which are in suspension in an ascending air stream, at a temperature typically in the range between 700 and 1000 °C. The mass fraction of fuel present at any instant is usually lower than 5% of the total bed mass. The inert particulate phase promotes convection, thus creating a stirring action in the vicinity of the fuel particles, which enhances both mass and heat transfer in the bed (Middleman, 1998).

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The experimental work described here consists on operating a fluidized bed setup for coke combustion. Usually two models are used to describe the non-catalytic reaction of particles with the surrounding fluid: the progressive-conversion model and the shrinking-core model (Levenspiel, 1999). Taking into account the reasons presented by Levenspiel (namely the fact that it is a simple model that represents most real situations of reacting gas/solid systems), the second model is preferably used (Levenspiel, 1999). It considers that the process can be controlled by two mechanisms: chemical reaction at the carbon surface or oxygen diffusion toward the particle surface, in the surrounding stagnant film (cf. Fig. 1). One of the main goals of the targeted work is to determine the controlling mechanism for each specific set of tested conditions. This involves operating the setup under different temperatures and air feed flow rates, and using different particle diameters. The theory behind the controlling mechanisms is detailed in Supporting information section. Such information is provided to the students attending the course as a manual/lab protocol. From the experimentally measured histories of carbon dioxide concentration (and carbon monoxide, if produced in significant concentrations) at the reactor outlet, students can determine the coke particle conversion along time. Graphical analysis allows them to infer the nature of the controlling mechanism (chemical reaction or mass transfer), by comparing the results to theoretical curves (Levenspiel, 1999). The calculation of coke conversion and mass transfer coefficient (in the diffusional regime) along time, for a set of specific conditions, is also addressed in the work. Detailed supporting theory for these calculations is also presented in Supporting information. Finally, a comparison of the experimentally obtained mass transfer coefficients with the ones calculated by correlations available in the literature is also required.

Taking into account important pedagogical aspects, specifically:

- The previous fundamental theoretical framework, core in Chemical Engineering curricula and not absent to be classified as complex material by an average student;
- The lack of published works focused on lab experiments addressing the concepts illustrated herein, namely competition between mass transfer and reaction;
- The fact that students are often not fully prepared to perform the experimental work in the class since they are just aware of a text description without any visual contact with the experimental setup, and even considering that most of them do not have any idea of how the coke particles can be produced;
- The lack of published studies regarding the effects of technological pedagogical support strategies, such as video, on the Chemical Engineering education field, specifically on mass transfer phenomena with diffusion/reaction competition; and
- The pedagogical will of creation of conditions to student's proactive learning commitment and success.

The authors decided to implement this work, whose main goals are (i) to present the application of this multidisciplinary lab experiment in a laboratorial subject, and (ii) the assessment of the pedagogical effects of the curricular unit traditional elements, such as the lab protocol and teachers support, as well as non-conventional pedagogical support such as videos, on the overall student's engagement and performance. For that purpose, complementary but distinct surveys were carried out, presented in Sections 4.1 (for the lab work and curricular unit) and 4.2 (regarding the demonstrative videos).

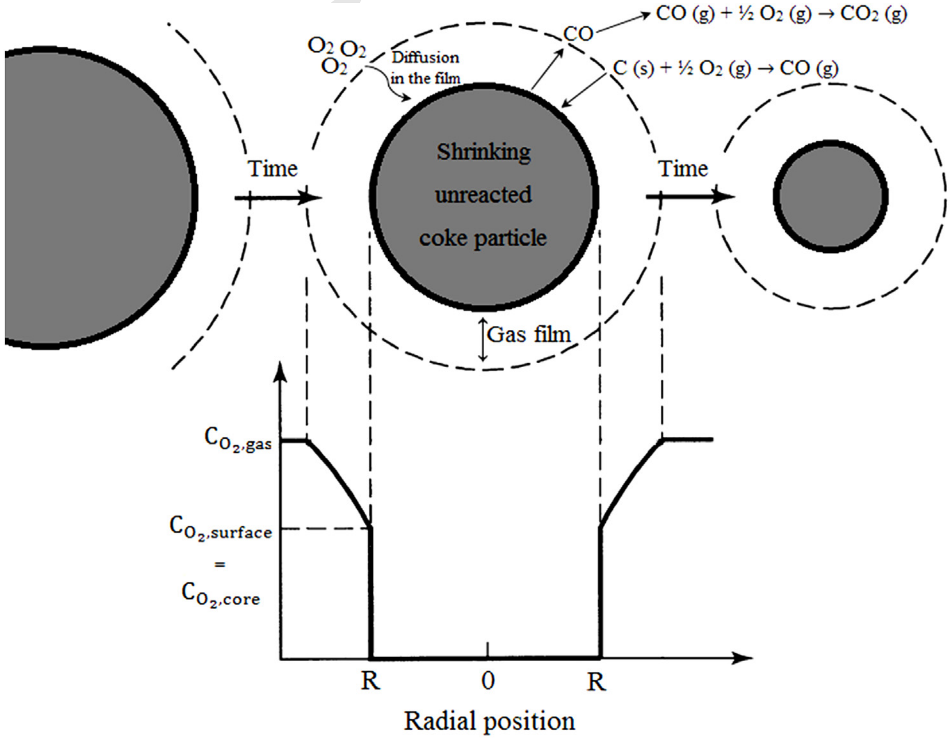

Fig. 1 – Representation of the concentration profile of O_2 around and inside a shrinking solid coke particle during the reaction between O_2 and coke.
Adapted from Levenspiel (1999).

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