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## Experimental and Numerical Analysis of Coffee Husks biomass Gasification in a Fluidized bed Reactor

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### Abstract

A two-dimensional computational model was developed in order to describe the biomass gasification process in a fluidized bed reactor using coffee husks within the commercial CFD code FLUENT. Both, gas phase and solid phase, were described using an eulerian-eulerian approach exchanging mass, energy and momentum. Results from the numerical model were later compared with experimental data. The study was conducted in a pilot thermal gasification plant, installed at Portalegre's Industrial Park based on the fluidized bed technology, with a processing capacity of 70 kg/h, and operating at around 800°C. The gasification tests were performed continuously for several days in order to optimize the heat value and composition of produced syngas. The simulated syngas composition is in good agreement with the experimental ones although slight deviation was shown especially on CO and H<sub>2</sub>. This was mainly due to kinetics were taken from literature and, and there for may differ greatly from one source to another. Also devolatilization was assumed instantaneous and no particular attention was paid to char conversion.

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Keyword: Biomass Gasification; CFD; Fluidized Bed; Syngas; Pilot Plant

### 1. Introduction

Agroindustry is one of the most important economic activities in the Portugal's Alentejo region, generating large amounts of residues, in particular, vine pruning, bagasse, coffee husk, and forest residues, among others, which require treatment or an adequate recovery to minimize environment impacts and increase the economic value of these wastes. A large variety of technologies has been developed over the past decades to deal with this problem. Among the proposed technologies, those oriented towards energy recovery, including combustion and gasification of biomasses has attracted much interest [1].

Gasification appears to be a promising process to convert biomass in syngas containing methane and hydrogen to be used directly as energy source or as raw material for the production of liquid fuels and other chemicals [2,3].

The gasification system includes a set of phenomena, such as, fluid flow, heat transfer and complex chemistry that could only be solved applying several governing mathematical equations mostly based on conservation equations, i.e., mass, heat and momentum. This level of complexity can be achieved using CFD tools. The recent improvement of state-of-the-art computational fluid dynamics (CFD) models allow for the design and optimization of these processes.

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This paper aims at presenting a numerical methodology within the framework of the commercial CFD code Fluent applied to the gasification of biomass residues from the Portuguese agro industry carried out in a bubbling fluidized pilot unity. The numerical simulation results were compared and validated versus a set of runs using coffee husk residues.

## 2. Experimental

The experiments were performed in a gasification pilot plant (Figure 1), which is based on an up-flow fluidized bed gasifier, operated up to 850 °C, under a total pressure below 1 bar and at a maximum pellet feeding rate of 70 kg/h. In the present work, the results of gasification experiments of different compositions of mixtures of coffee husks.

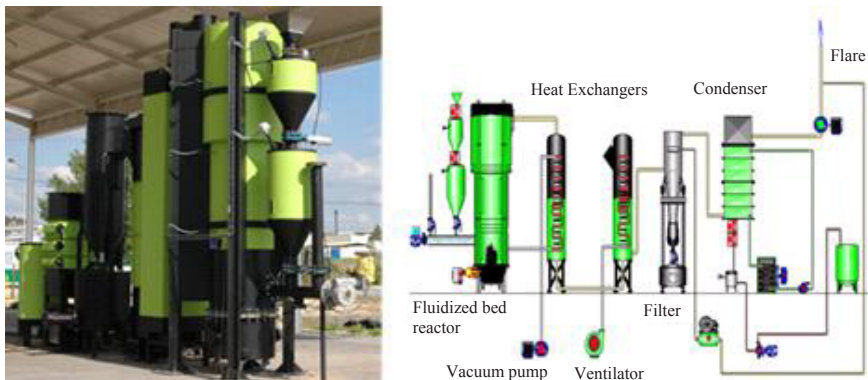


Fig. 1. Biomass gasification pilot scale plant at the School of Technology and Management of the Polytechnic Institute of Portalegre, Portugal. The main components of the unit are described in the text.

Figure 1 displays a diagram of the biomass gasification pilot scale plant used in the experiments. Main components of the unit are the following: a) Biomass feeding system; b) Fluidized bed reactor that is a tubular reactor 0.4 m in diameter and 2.5 m height, internally coated with ceramic refractory materials; biomass c) Gas cooling system consisting of two heat exchangers.

Tests were made using feeds of different coffee husk, at 800°C. Feedstock admission rates of 40 and 63 kg/h were tested in order to study syngas composition as a function of feedstock composition and operational conditions. Biomasses tested have the elemental composition, in terms of carbon (C), hydrogen (H) and oxygen (O), presented in Table 1. Table 1 presents also some other parameters for the characterization of the biomasses used, namely, humidity, density and Net Heat Values (NHV). The NHV of biomass was determined with an IKA Laboratory Equipment C 200 Calorimeter system.

Table 1. Biomass Properties

Elementary Analysis (%)				Humidity (%)	Density (Kg/m <sup>3</sup> )	Net Heat Value (MJ/Kg biomass)
N	C	H	O			
5.2	40.1	5.6	49.1	25.3	500	20.9

## 3. Model Set Up

According to experimental data gathered from Portalegre's gasifier a numerical model was built. In order to simulate the gasification process a Multi-phase (gas and solid phase) model from Fluent database was used. In the comprehensive two-dimensional numerical model, the gas phase is treated as continua and the solid phase is described through an Eulerian granular model. Interaction between both phases must be modeled as well, since both phases exchange heat by convection, momentum (given the drag between gas phase and solid phase) and mass (given the heterogeneous chemical reactions).

### 3.1. Turbulence Model

The standard k-ε model in ANSYS FLUENT has become the workhorse of practical engineering flow calculations in the time since it was proposed by Launder and Spalding [4]. It is a semi-empirical model, and the derivation of the model equations relies on phenomenological considerations and empiricism. The selection of this turbulence model is appropriate when the turbulence transfer between phases plays a predominant role as in the case of gasification in fluidized beds.

### 3.2. Granular Eulerian Model

In the granular Eulerian model, stresses in the granular solid phase are obtained by the analogy between the random particle motion and the thermal motion of molecules within a gas accounting for the inelasticity of solid particles. As in a gas, the intensity of velocity fluctuation determines the stresses, viscosity and pressure of granular phase. The kinetic energy associated with velocity fluctuations is described by a pseudo-thermal temperature or granular temperature which is proportional to the norm of particle velocity fluctuations.

### 3.3. Chemical Reactions Model

The chemistry is specified as mass-action kinetics. The chemical reactions are expressed by stoichiometric equations and reaction rates are described in terms of a power-law format. The rate coefficients based on Arrhenius law are empirically fitted with experimental data.

#### 3.3.1 Homogeneous gas-phase reactions

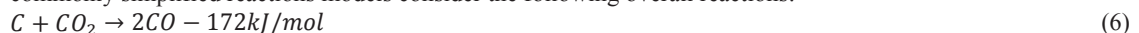
The biomass devolatilization and cracking gas species will react with the supplied oxidizer and with each other such as water gas shift reaction. The heat generated by exothermic reactions is important for the release of volatiles and ignition of char. The common homogeneous reactions are:



More reaction mechanisms and the kinetic parameters can be found from the literature [5].

#### 3.3.2 Heterogeneous Reactions

Char is the solid devolatilization residue. Heterogeneous reactions of char with the gas species such as O<sub>2</sub> and H<sub>2</sub>O are complex processes that involve balancing the rate of mass diffusion of the oxidizing chemical species to the surface of biomass particle with the surface reaction of these species with the char. The overall rate of a char particle is determined by the oxygen diffusion to the particle surface and the rate of surface reaction, which depend on the temperature and composition of the gaseous environment and the size, porosity and temperature of the particle. The commonly simplified reactions models consider the following overall reactions:



The literature positions that introduced and reviewed the char surface reactions and the kinetic relationship can be found [6, 7].

## 4. Results and Discussion

There is a lack of literature regarding comparison between numerical models and experimental data on biomass gasification in a Fluidized bed gasifier. Compositions for the syngas produced are presented in Table 2. Generally, the

results show that the produced syngas is relatively rich in carbon monoxide, hydrogen and a small amount of methane, and therefore these three gases are the main responsible for the heat content of the syngas produced. On the other hand, it can be seen that the syngas contains also large amounts of nitrogen and carbon dioxide resulting from the partial combustion process that takes place simultaneously with biomass gasification.

The thermal biomass gasification process involves a set of complex chemical reactions that lead to the formation of three fractions: the syngas, ashes (chars) and condensates. The most important fraction, amounting to more than 70 % (w) is made of light gases, namely, CO, H<sub>2</sub>, CH<sub>4</sub>, CO<sub>2</sub>, and N<sub>2</sub>. In fact it is considered that in the thermal gasification process gases leave the reactor in equilibrium condition.

Although the computed results present good agreement with the measured ones, there are several reasons for this deviation: 1) It was assumed that devolatilization is instantaneous. The authors treat the gases from devolatilization as an initial condition for further conversion in the bed. 2) No particular attention was paid to char conversion. Char reactivity is taken from coal or from other biomasses that could be different from the one under analysis. 3) The kinetics are taken from literature and, and there for may differ greatly from one source to another. 4) In general, models predict the main gaseous species at the outlet reasonably well, but the validation is supported only by a few test runs. The major disagreement is found in the concentrations of CO and H<sub>2</sub>. Sometimes, all light hydrocarbons and tar are lumped into CH<sub>4</sub>, which can explain the disagreement sometimes found in CH<sub>4</sub>. Usually, tar has not been modeled, and when it has, the disagreement tends to be high [8].

Table 2. Experimental Results

Experimental conditions	Coffee husk
Temperature (°C)	815
Admission Biomass (Kg/h)	28
Air Flow Rate (Nm <sup>3</sup> /h)	75
Ratio O <sub>2</sub> /O <sub>2</sub> Stoichiometric	2,63
Syngas fraction (dry basis)	
H <sub>2</sub>	12,4
CO	11,4
CH <sub>4</sub>	1,6
CO <sub>2</sub>	18,7
N <sub>2</sub>	52,3

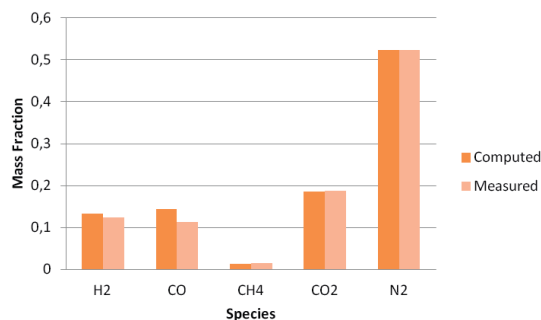


Fig. 2. Computed and Measured results

On the extended version of this paper we pretend on analyze different operation conditions such as temperature, heat fluxes, etc.

## 5. Conclusions

In this paper experimental data gathered from a semi industrial fluidized bed gasifier and a numerical model built in FLUENT was compared. Results showed good agreement although slight deviation was shown especially on CO and H<sub>2</sub>. This was mainly due to kinetics were taken from literature and, and there for may differ greatly from one source to another. Also devolatilization was assumed instantaneous and no particular attention was paid to char conversion.

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