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Pyrolysis in screw reactors: a 1-D numerical tool

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Abstract

This paper is focused on the numerical analysis of a screw pyrolyzer with special attention on kinetics, heat and mass transfer phenomena by means of a computational 1D tool. A steady-state model has been developed to generate temperature profiles and conversion patterns over the reactor axis. Residence time distribution capabilities have been considered to take into account the axial dispersion. The framework, including heat transport processes, is based on a 4 parallel Distributed Activation Energy Model. Its structure includes the three major biomass pseudo-component occurring in the biomass thermal degradation. The results of a generic biomass are then analyzed in terms of products distribution and heat transfer characteristics.

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Keywords: pyrolysis; DAEM ; screw reactor ; heat transfer,;RTD

1. Introduction

The conversion of solid biomass into liquid or gaseous products, through biochemical [1, 2] or thermochemical processes, is one of the possible approaches to improve the energy density issue in biomass utilization. However, the strong dependence of performance parameters on feedstock characteristics [3], conversion technology and specific components [4], makes the design process challenging.

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Nomenclature					
A	cross section	m^2	χ	thickness of gas film	m
C	specie concentration	-	ΔH	specific heat of reaction	J/kg
Cp	specific heat	J/kg·K	**Subscripts**		
D	cylinder diameter	m	add	added	
Dp	particles diameter	m	a-ua	added per unit area	
E	emissive power	W/m^2	a-ul	added per unit length	
F	mass flux, view factor	kg/s, -	ax	axial	
h	heat transfer coefficient	W/m^2K	bio	biomass	
H	enthalpy	J/kg	c	char	
HR	heating rate	K/s	cw	covered wall	
J	radiosity	W/m^2	eb	exposed bed	
k	thermal conductivity	W/m·K	ew	exposed wall	
m	mass	kg	exc	exchange	
n	screw run per second	-	g	gas, gaseous phase	
pitch	screw pitch	m	G	generic gas species	
Q	heat flux	W	i	solid velocity index	
$\dot{q}$	unit length heat flux	W/m	j	biomass fractions (cell, hemi, lign)	
t	time	s	k	generic index	
T	temperature	K	m	moisture	
V	velocity	m/s	N	nitrogen	
x	char mass fraction	-	reac	reaction	
y	char fraction in bed	-	s	solid	
z	axial coordinate	m	t	tar	
α	screw angle	rad	tot	total	
ε	char and biomass porosity	-	vb	virgin biomass	
ϵ	emissivity	-	w	water, wall	
ρ	density	kg/m^3	**Apexes**		
Φ	moisture %	-	cd	conductive coefficient	
τ	transmissivity	-	cv	convective coefficient	
			r	radiative coefficient	

The analysis of detailed information collected from small to full scale experiments have demonstrated to be key in the design support. In parallel, the availability of modeling tools is of utmost importance as well to guide the design process itself.
In the last decades, numerical models for wastes[5] and biomass conversion[6, 7], have been presented to describe, among the other processes, the torrefaction [8, 9] the gasification[10, 11], such as fixed bed systems[12, 13], and pyrolysis ones [14, 15]. The last process exploitation, which has been especially studied for bio-oil production by means of fast pyrolysis, is rapidly increasing as a reliable solution, for residual materials conversion such as biomasses [16] and wastes [17]. A number of numerical fast pyrolysis models can be then found in literature, mainly focused on the improvement of bio-oil production by varying operating parameters such as biomass flow rate, maximum temperature, heating rate [18]. Within this background, the paper aim is to describe a 1-D tool realized for pyrolysis modeling in screw reactors. Continuous reactors present in general variable residence time distributions due to stratification or undesired back mixing effects. In this paper then, the prediction of such distribution, has been faced with an axial dispersion model to support an heat and mass transfer framework built for screw reactors[19].

2. Modeling framework

A screw reactor for fast pyrolysis is mainly composed of the following parts: a feeder controlling the biomass flow rate, a tube reactor where the pyrolysis process takes place and a recovery section in which the products are collected before analyses. The screw carries the biomass particles from the injection point to the char collector bucket. Biomass pyrolysis gives three main products: char, condensable vapors and gas. Samples of biomasses have to be characterized by means of ultimate proximate and polymeric components analysis [14]. To determine the optimal design parameters, reaction rates and transport phenomena characterization have to be represented carefully. In literature a number of kinetic frameworks have been proposed with one or two step subsequent reactions[20]. In this work a Distributed Activation Energy Model [21] has been considered. The implemented kinetic framework is based on the model proposed by Miller & Bellan [22] where the energy required to activate the chemical reactions, and in general the three macro-components namely cellulose hemicellulose and lignin, are taken into account. According to [22], the amount of extractive is here summed with the hemicellulose pseudo-component for their