



## Research article

# The effect of carbon dioxide on flame propagation speed of wood combustion in a fixed bed under oxy-fuel conditions

J.K. Tanui<sup>a,\*</sup>, P.N. Kioni<sup>a</sup>, T. Mirre<sup>b</sup>, M. Nowitzki<sup>b</sup>

<sup>a</sup> Department of Mechanical Engineering, Dedan Kimathi University of Technology, P.O. Box 657-10100, Nyeri, Kenya

<sup>b</sup> Fachbereich Ingenieur- und Naturwissenschaften, Technische Hochschule Wildau, Hochschulring 1, 15745 Wildau, Germany

## ARTICLE INFO

## Keywords:

Oxy-fuel  
Flame front  
Propagation speed  
Fixed bed  
Wood combustion  
CFD-DEM

## ABSTRACT

This paper presents an investigation of wood combustion in a laboratory-scale fixed bed with an aim of establishing the effect of CO<sub>2</sub> environment on flame propagation speed and flame structures. Different oxy-fuel combustion atmospheres in which the composition of O<sub>2</sub> in CO<sub>2</sub> was varied from 21% to 50% by volume were tested and compared to air-fuel condition. Euler-Lagrange (Computational Fluid Dynamics - Discrete Element Method, CFD-DEM) approach which captures information of individual particle processes is used to model wood conversion in a packed bed. Results show that flame front propagation speed in oxy-fuel atmosphere reduced to 78% of that of the air-fuel condition with similar O<sub>2</sub> concentration. For oxy-fuel conditions, propagation speed increased with increase in O<sub>2</sub> concentration. The CFD-DEM model agrees very well with experimental values for mass loss, propagation speed and flame front positions. However, peak temperatures are poorly predicted at lower oxygen concentrations. The accuracy of temperature prediction improves at higher oxygen concentrations. During initial and devolatilization stage, mass fraction of tar predicted in CO<sub>2</sub> environment are smaller than in N<sub>2</sub> environment, while the amount of CO predicted is almost equal in both environments. However, during char combustion stage a high amount of CO is observed in oxy-fuel conditions.

## 1. Introduction

Biomass fuel is still the major source of energy for a significant proportion of the world population. Conventionally, biomass is burned in combustors that use air as oxidizer. The need for efficiency and reduced emissions has led to development of clean combustion technologies such as oxy-fuel combustion. In this technique, fuel is burnt in condition in which CO<sub>2</sub> replaces N<sub>2</sub> as the inert gas. CO<sub>2</sub> is obtained from recycling of exhaust gas. It is a strategy of reducing or capturing CO<sub>2</sub>. This technique is applied to both gaseous, Marsh et al. [1], and solid fuels, Bhunia et al. [2] and Álvarez et al. [3]. It has been identified as the most competitive carbon capture technology for retrofitting of the existing power plants, Scheffknecht et al. [4].

Previous works on oxy-fuel combustion range from laboratory research to actual test of the power plants. Tests have been carried out in pilot scale, industrial scale and full scale power plant [4]. Large scale oxy-fuel power plants of sizes between 30 and 300 MW<sub>th</sub> have been established and installed worldwide [4]. Most of these power plants are coal-fired, but a few others use biomass or are co-fired [5, 6]. Thus there is need for better understanding of oxy-fuel combustion in a CO<sub>2</sub> rich environment. Shan et al. [7] study of single biomass pellet reported

that CO<sub>2</sub> environment increases ignition delay time. A similar behavior has been observed for oxy-coal combustion [8, 9]. This was attributed to a decrease in particle surface heating rate due to decreased co-flow temperature associated with the higher specific heat capacity of CO<sub>2</sub> than N<sub>2</sub> and low oxygen diffusion rate in CO<sub>2</sub>. According to Molina et al. [8], other possible reasons for increased ignition delay time are suppression of radical formation by CO<sub>2</sub> chemical effects and thermal decomposition of CO<sub>2</sub>. It has been observed that internal ignition temperature of the pellet decreases with increase in O<sub>2</sub> concentration [7]. However, Shan et al. [7] concluded that the effect of oxidation temperature on internal ignition temperature is more than the effect of oxygen concentration.

Another observation [7, 10] is that volatile combustion time increases while combustion temperature decreases [10] when N<sub>2</sub> is replaced with CO<sub>2</sub> (21% oxygen). Riaza et al. [10] noted that the intensity of combustion of a single biomass particle is reduced in CO<sub>2</sub> environment with 21% O<sub>2</sub>. As O<sub>2</sub> is increased, combustion intensity also increases.

Oxy-fuel combustion of biomass co-firing with coal has also been studied [11–13]. Biomass and coal blends are preferred because it results in reduction of CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>x</sub> emission when compared to a

\* Corresponding author.

E-mail address: [josephat.tanui@dkut.ac.ke](mailto:josephat.tanui@dkut.ac.ke) (J.K. Tanui).

**Nomenclature**

$A_s$	Particle surface area [m <sup>2</sup> ]
$C_1$	Permeability [m <sup>2</sup> ]
$C_2$	Inertia loss coefficient [m <sup>-1</sup> ]
$c_p$	Specific heat [J kg <sup>-1</sup> K <sup>-1</sup> ]
$D$	Diffusivity [m <sup>2</sup> s <sup>-1</sup> ]
$d_p$	Particle diameter [m]
$G$	Incident radiative heat flux [W m <sup>-2</sup> ]
$g$	Gravity [m s <sup>-2</sup> ]
$H_i$	Enthalpy of formation of species $i$ [J kg <sup>-1</sup> ]
$h$	Enthalpy [J kg <sup>-1</sup> ]
$J$	Diffusion mass flux [kg m <sup>-2</sup> s <sup>-1</sup> ]
$m_p$	Particle mass [kg]
$N_g$	Number of gas species [–]
$p$	Pressure [Pa]
$Q_{a,p}$	Particle absorption coefficient [–]
$q_R$	Radiative heat flux [W m <sup>-2</sup> ]
$S_E$	Energy source term [J m <sup>-3</sup> s <sup>-1</sup> ]
$S_m$	Momentum source term [kg m <sup>-2</sup> s <sup>-2</sup> ]
$T$	Temperature [K]
$t$	Time [s]
$\mathbf{v}$	Velocity [m s <sup>-1</sup> ]
$w_i$	Rate of production of species $i$ [kg m <sup>-3</sup> s <sup>-1</sup> ]
$Y$	Mass fraction [–]

**Greek symbols**

$\alpha$	Exponent factor [–]
----------	---------------------

$\theta$	Particle porosity [–]
$\lambda$	Thermal conductivity [W m <sup>-1</sup> K <sup>-1</sup> ]
$\mu$	Viscosity [kg m <sup>-1</sup> s <sup>-1</sup> ]
$\rho$	Density [kg m <sup>-3</sup> ]
$\sigma$	Stefan-Boltzmann constant [W m <sup>-2</sup> K <sup>-4</sup> ]
$\tau$	Shear stress tensor [Pa]
$\chi$	Region porosity [–]

**Subscripts**

$0$	Initial state of the particle
$e$	Effective
$g$	Gas
$i,g$	Gaseous species
$i,s$	Solid-phase species
$s$	Solid

**Superscripts**

$gs$	Heterogeneous reaction
------	------------------------

**Operators**

$\nabla$	Gradient operator
$\nabla$	Divergence operator

pure coal plant. In addition, alkali metals present in biomass fuel provides catalytic effects on oxidation and gasification reactions. Indeed, the catalytic effect has been found to be more pronounced under oxy-fuel combustion conditions [11]. Irfan et al. [14] observed that there were improved ignition properties for coal/biomass blends in both oxy-fuel and air-fuel conditions.

Pohlmann et al. [15] has studied the effects of O<sub>2</sub>/CO<sub>2</sub> and O<sub>2</sub>/N<sub>2</sub> environment on char reactivity and burnout of pulverized torrefied and carbonized biomass burned in a drop tube furnace. CO<sub>2</sub> environment increases the burnout of biomass fuel. In addition, CO<sub>2</sub> environment increases char surface area [16, 17]. Char from CO<sub>2</sub> devolatilization environment is small in size and has low reactivity [18, 19]. Improved char burnout in CO<sub>2</sub> has been attributed to contribution from CO<sub>2</sub> gasification [15, 18, 20]. Even though the burnout time is high, the release of volatile is low under the fast heating conditions in a drop tube furnace operated under oxy-fuel environment [15].

Even though different aspects of oxy-fuel combustion of biomass have been investigated, the mechanism through which CO<sub>2</sub> environment affects fundamental combustion phenomena such as flame propagation speed and flame structures in a fixed bed reactor have not been reported. Flame propagation speed is one of the main parameters to consider when designing a new burner.

Flame propagation rate in biomass fixed bed gasifiers has been investigated under different operating conditions [21–26] although not in oxy-fuel environment. It is affected by various factors such as biomass fuel type, density, size, ultimate and proximate analysis and superficial velocity. Based on superficial velocity, operation regimes have been classified either as two-regime [21] or three-regime [27]. In the two-regime classification, propagation speed increases in the fuel rich regime and decreases in the fuel lean regime. On the other hand, three-regime classification has fuel rich regime, fuel lean regime and convective cooling regime where propagation speed increases rapidly, gradually and decreases rapidly, respectively. Furthermore, the role of ash in flame propagation speed has been assessed [28]. Ash affects

radiative heat transfer to the unburnt biomass, hence affecting the flame propagation. Although numerous works on flame propagation rate of biomass combustion in fixed bed have been done, none addresses an oxy-fuel environment.

The main aim of this work is to comprehensively investigate the effects of CO<sub>2</sub> environment on flame propagation speed and flame structures. A commercial CFD software CD-Adapco (STAR CCM+ version 11.04) [29] is used to simulate thermal conversion of wood in oxy-fuel environments. Euler-Lagrange approach which captures detailed information of individual particle processes is used to model wood conversion in a packed bed. Furthermore, measurements were done in a laboratory-scaled fixed bed reactor operated under oxy-fuel conditions. CFD simulations were validated by comparing them with measured data in a laboratory set-up.

**2. Experimental set-up**

A schematic diagram and a photo of the combustion test rig used in this work are shown in the Fig. 1a and b, respectively. It is a laboratory-scale fixed bed, which has provision for regulating the flow of O<sub>2</sub>, CO<sub>2</sub> and N<sub>2</sub>. Its internal and external radius are 20 mm and 40 mm, respectively and the height is 200 mm. It has provisions for thermocouple insertions located at 10 mm intervals. Internal and external parts are made of stainless steel and between them is a 20 mm thick refractory cement for insulation. Thermal conductivity of refractory cement is 0.34 W/m·K [30]. Critical insulation radius for this material, considering typical values of convective heat transfer coefficient for air in natural convection as 10–20 W/m<sup>2</sup>·K [31], lies between 17 and 34 mm. An external radius of 40 mm used in this reactor is, therefore, sufficient for heat insulation. Fuel bed is held by a stainless steel grate.

The reactor was operated in counter-current flame propagation mode. Top fuel was ignited initially and the flame front propagates downward into the virgin fuel. Oxidizer was supplied from the bottom. For this arrangement, there is no fuel bed movement. The fuel bed was

Download English Version:

<https://daneshyari.com/en/article/11000597>

Download Persian Version:

<https://daneshyari.com/article/11000597>

[Daneshyari.com](https://daneshyari.com)