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Effect of the particle size of pulverized olive cake on combustion parameters in Stirling engine in Morocco

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ABSTRACT

Morocco is one of the richest countries with olive tree. Annually, about 675,000 t of Olive Cake are produced and injected which leads to damaging the environment especially the groundwater as well as the water table itself. To remedy this problem, and because olive cake has a high caloric value, the idea of this paper comes to valorize this waste through the Stirling engine in order to produce clean energy with low greenhouse emissions.

To fulfill this purpose, the impact of the particle size of pulverized olive cake (OC) on the flow behavior and combustion parameters in a 3D vertical chamber was investigated. The spherical OC particles are injected through two injectors perpendicularly to the air inlet jets. Two particle sizes are chosen to conduct this study (PS1, PS2). The numerical approach is based on Reynolds averaged Navier–Stokes (RANS) method using the realizable k–ε turbulence model. For gas phase a non-premixed combustion model is used, and for the discrete second phase a Lagrangian approach is chosen. Temperature distribution, flow topology, velocity contours, and species concentrations profiles in the burner are obtained for the two cases. Results show that the first case particle size gives optimal results and is more suitable for this study.

1. Introduction

With the increasing energy demand and Morocco's dependency on fossil energy, Morocco has set a goal of having 20% renewable energy by 2020 like solar, wind turbine and biomass. The valorization of biomass in Morocco is still modest even if biomass fuels have an important heating value and environmentally friendly and also are renewable. Today, using biomass as a fuel for Stirling engine is a feasible alternative. The heater can be warmed up directly by the flame as in the case when using a gaseous or liquid fuel burner. However, the choice of suitable parameters for combustion is rather challenging due to heterogeneous composition of the biomass, emissions, and ash deposition. Consequently, the application of the new Computational Fluid Dynamics (CFD) tools has a very important role for the project to investigate the effect of particle size on several parameters like temperature, flow topology and emissions.

In this context, this project aims at studying the valorization of Moroccan olive waste using Stirling engine since olive waste is a premium agricultural quality of biomass fuel. It has a high calorific heating value (LHV) (12,500–22,000 kJ/kg), which is very abundant in our country (approximately 675,000 t/year) (DPV/MAEE, 1997; International Olive Council Database, 2012) [1], very

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Nomenclature

t	Time [s]
u	Instantaneous velocity [m/s]
p	The partial pressure of the gas component [Pa]
μ	Fluid dynamic viscosity [Pa s]
H	Fluid specific enthalpy [J/kg]
T	Temperature [K]
λ	Thermal conductivity of the fluid [W/m K]
Y_f	Mass fraction of components [dimensionless]
D	Diffusion coefficient of components [dimensionless]
R_f	Production rate per unit volume within the component]kg/s m^3]
S_p	Source term [kg/s m^3]
S_N	Source term [N/s m^3]
S_H	Source term [J/s.m^3]
S_Y	Source term [Kg/s m^3]
A	Constant [dimensionless]
E	Constant [dimensionless]
R	Universal gas constant [J kmol^{-1} K^{-1}]
T	Mean temperature [K]
m_p	solid fuel particle mass [kg]
$f_{v,0}$	initial volatile fraction [dimensionless]
$m_{p,0}$	initial particle mass [kg]
Φ	stoichiometric ratio for the char combustion [dimensionless]
u_p	the particle velocity [m/s]
ρ	the fluid density [kg m^{-3}]
ρ_p	the particle density [kg m^{-3}]
μ	the molecular viscosity of the fluid [kg m^{-} s^{-1}]
D_p	the particle diameter [m]
Re_p	the relative Reynolds number [dimensionless]
C_D	The drag coefficient [dimensionless]

cheap and does not contain sulfur [2]. All these characteristics make OC olive cake a good alternative to fuels. The use of OC through Stirling engine has many advantages such as the production of clean energy especially in rural villages, reducing the rate of olive solid waste, protecting groundwater as well as the water table and the decreasing of CO2 emissions. Nevertheless, like other kinds of wastes, OC can cause problems if appropriate and acceptable disposal measures are not taken during combustion; for instance, it can influence the operation and maintenance of Stirling engine (fouling, corrosion, sulphatation of alkali salts…) [3,4], among this measures there is the size of the particle of olive cake, it is necessary to investigate the effect of this particles on emissions, char deposition, operation and maintenance of Stirling engine through CFD modeling in order to improve our understanding of the processes taking place in combustion systems of solid biomass and to avoid any problem that may occur. This study can be generalized to other type of solid wastes like straw, grasses, roots, dried plants, seeds, etc.

CFD Modeling may help to increase our understanding of the combustion process. It can give a good approximate overview about gas and particle combustion mechanism as well as the parameters influencing temperature, turbulence, velocity and emission. Actually, in literature there are only a few numerical simulations of biomass combustion systems using detailed models for both the bed and gas phases [5,6]. In addition to that, no previous CFD study has investigated the valorization of OC using the Stirling engine. Consequently, in the recent years several CFD codes have been developed by many researchers to modeling biomass combustion in different approach; which depends on the particle model and the type of furnace (packed, fluidized, pulverized fuel); packed bed are studied by Mehrabien et al. [7–9], while others are investigated solid combustion in fluidized beds; Ravi Inder Singh et al. listed a detailed overview of the modeling technology applied to wood combustion process that contains a state-of-the-art of the different components or sub- models required in a combustion model based on Euleriane-Eulerian or Euleriane-Lagrangian approach [10]. As for pulverized fuel, Bonefacic et al. (2015) [11] published a paper in which they summarized numerical models of co-firing pulverized coal and biomass in a vertical cylindrical laboratory furnace (20 Kw),and recently Elorf et al. demonstrated that the swirl motion effects on flame dynamic of pulverized olive cake in a vertical furnace [12].

The Stirling engine is an external combustion engine developed by the Scottish Reverend Robert Stirling (1870–1978), this engine uses different types of energy source such as biomass, solar, etc. Furthermore, the use of biomass as an energy source for the Stirling engine was developed in 1999 by Mr. Eric Podesser who was the first researcher to develop and construct a biomass Stirling motor. Moreover, he proposed the following fuels: agricultural waste, log or chipped wood, shells of fruits like coffee [13]; in 2000, M.Podesser collaborated with M.Bayer to investigate the operation of Stirling engines at a biomass district heating plant in Austria [14]. Most researches regarding biomass Stirling have been carried out on wood; Akio Nishiyama et al. tested wood powder combustion in a Stirling engine and evaluated the burner design parameters for this Stirling engine [15]. Furthermore, the Technical University of Denmark has chosen wood chips as a fuel and developed two models of Stirling engine, (the four cylinder and the 8-cylinder Stirling) [16]. Finally, to determine the effects of the type of wood, Damirchi et al. analyzed the influence of geometry and size on electrical power produced by Stirling engine [17]. Other researchers studied coupling woody biomass Stirling engine with solar energy and proton exchange membrane fuel cell system (PEM-FC) [18,19]. Although most of these projects are experimental and concentrate on small plants which do not exceed 10 kW electrical power, nowadays, some European projects are focusing on engines with electrical power of 30–150 kW [20].

The aim of this paper is to discuss the effect of pulverized olive-cake size on different parameters during combustion. CFD model was developed and applied for multiphase flow, the Discrete Particle Method (DPM) of the commercial CFD FLUENT 14.5 software that is basically developed for the combustion of pulverized coal was chosen to model the olive cake combustion because the biomass particles were described as a discrete phase; before starting our study, it is very important to present the methodology followed during this work. Hence, the essay has been organized in the following way: the first point is a presentation of furnace geometry and operating conditions, the next part is in form of a detailed description of the CFD model used for simulation, the third part is dedicated to the validation of the model used in the current numerical simulation through a comparison between the experimental results obtained Chenguin Yin et al.(2009) [21] and the last part presents the findings of the study, focusing on the three key themes