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Feasibility investigation and combustion enhancement of a new burner functioning with pulverized solid olive waste

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Abstract
This article describes an experimental study on solid olive residue (olive cake) combustion in form of pulverized jet. This is a contribution to the valorization of olive residue as a source of renewable energy available in the majority of mediterranean countries. A sample of olive cake from Tunisian origin is prepared for the experiment; this sample is crushed, dried and sifted in order to obtain the desired particles form. A new burner made up of a coaxial cylindrical tube is especially designed and fabricated. In order to start the combustion of olive cake and maintain the main flame, two types of pilot flame were used: a central premixed flame of methane/oxygen and an annular diffusion flame of methane. This paper shows the conditions for an efficient olive cake burner operation in free air. The effects of particle size and pilot flame position have been discussed. The olive cake combustion is possible only with particles at a size below 200 μm. Moreover, the combustion maintained by the annular pilot flame ensures better burning conditions than the central pilot flame. Finally, the inserted preheating system has improved the olive cake combustion.
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Keywords: Pulverized jet; Olive cake combustion; Solid fuels; Biomass.

1. Introduction and state of the art

The upward technological and demographic developments imply an increase in demand of energy in the world. In addition, the air pollution due to the intense use of fossil energies threatens the environment and human habitat. The dangerous emissions of these energy carriers create an increasing environmental awareness. Because of the mentioned issues, studies and researches on new and renewable energies as energy solutions for the future have been encouraged. The present study carries an interest on the biomass valorization as a renewable energy, more particularly the solid olive residue. The conscious use of the olive cake in the energy production allows solving two problems: clean energy production and an effective treatment of waste coming from the oil mills. Olive cake can be burned alone or can contribute in combustion with other biomass and coal [1]. Olive residue is regarded as a good alternative to other fossil energies in the Mediterranean countries. In particular, in Tunisia, there are more than 67 million olive trees [2] and the amount of solid olive residue is about 350-450 thousands of tonnes per years [3]. Thus, Tunisia can benefit from the very significant renewable energy source. Olive cake is obtained after oil extraction from olive fruits. The types of the olive residue depend on the treatments that they underwent. Thus, the olive cake coming from traditional oil mills (by press) contains between 8 and 12 weight percent (wt%) of oil, otherwise the exhausted olive cake, which underwent a double extraction by pressing and by extraction with hexane, contains a quantity less than 5wt% oil. The raw olive cake stored in open sky has a water content varying from 15 to 50 wt%. This solid olive residue contains between 40 and 60 wt% of carbon and its lower heating value ranging from 12,500-26,000 kJ/kg; these values are comparable with the heating values of the other biomasses like wood (≈17,000 kJ/kg) and some types of coal (23,000-26,000 kJ/kg [4-6]). The range of sulfur content in the olive cake is 0.05-0.1 wt% [4, 6].

1.1 Processes of olive cake valorization

The energy valorization of the olive cake can be carried out according to three principal processes:

- The first is the pyrolysis which is a thermochemical decomposition of solid matter in an inert atmosphere (low in oxygen). The principal gases generated are CO, CO_2, H_2, CH_4, C_2H_4 and C_2H_6 [3]. In general, pyrolysis produces gas (volatiles) and liquid products (tars) and leaves a solid char residue with high carbon content. The greatest commercial interest of the solid products is due to its low sulphur and phosphorus contents [7].
- The gasification technology: This process is used for fuel gas production by treatment of solid fuel. Gasification is achieved by oxidation of organic material at high temperatures without combustion and thereafter gaseous species like CO, H2 and CO2 are produced. Vera et al. [8] have obtained a fuel gas which has a low calorific value around 4350 kJ/kg. Moreover, gasification of the char can improve its porous structure to produce activated carbon, which is widely used as adsorbent [6].
- The third process is the direct combustion of the olive cake. In this process, a combustion reaction occurs and a flame is generated. In general, the combustion of solid can be subdivided in five steps: heating up, devolatilization, combustion of volatiles, combustion of char leaving ash and inert heating of ash. Technologies of solid fuel combustion are: fixed bed fluidized bed and pulverized jet.

1.2 Previous studies on olive cake combustion

Several studies have an interest concerning the energy production starting from the direct combustion of olive cake (alone or mixed with other fuels). Abu-Qudais [9] has studied the olive cake combustion of 0.53 mm average size in a fluidized bed reactor. The temperature of the fluidized bed varied between 775 and 935°C for mass ratios air/olive-cake ranging between 2.30 and 4.30. In addition, this author has noted that the quantity of unburned oil cakes can be decreased and the fuel output has been improved from 85 to 95% for optimal air velocities.

Alwidyan et al. [10] have studied the direct combustion of olive cake in pulverized form in a vertical tube furnace. The maximum flame temperature reached 980°C and the combustion efficiency was about 82%. Moreover, Alkhamis and Kablan [11] studied the effect of the olive cake grain size on its calorific value. The highest value of the calorific heat was 37.300 kJ/kg and it corresponds to size particles between 125 and 250 µm. Thus, olive cake can be considered as a good fuel and a potential source of energy.

Atimtay and Topal [6] have studied the co-combustion of olive cake (diameter d=2.3mm) with lignite coal (diameter d=0.46mm) in a circulating fluidized bed. The results have shown that as the percentage of olive cake in the mixture increases, the combustion mainly occurs in the upper regions of the main column. The maximum temperature reaches 900 °C. The minimum carbon monoxide emissions are observed at an excess air ratio about 1.5. The mass percentage of olive cake in the mixture fuel is suggested to be below 50 wt% in order to be within the European Union limits for emissions. Their results suggest that olive cake is a good fuel that can be mixed with lignite coal for cleaner energy production. Later, Atimtay and Varol [12] studied the co-combustion of coal and olive cake in a bubbling fluidized bed with secondary air injection. They determined that as the amount of olive cake in the fuel mixture increases, sulfur dioxide emissions decrease because of the very low sulphur content of olive cake. The conditions of optimum operating with respect to NOx and sulfur dioxide emissions were found to be 35% for primary excess air and 30L/min for secondary air flow rate when a fuel mixture composed of 75 wt% olive cake and 25 wt% coal is burned in the bed. The system reached its highest combustion efficiency of 99.8 % when 25 wt% olive cake and 75 wt% coal mixture is combusted with a primary excess air of 70% and a secondary air mass flow of 40L/min.

Abu-Qudais and Okasha [5] have realized an important experimental study of the direct combustion of a diesel and olive cake slurry in the form of a jet-blast atomizer in a vertical cylindrical water-cooled combustor. These authors have approved that olive cakes can be a significant source of energy. The combustion efficiency was improved as the percentage of olive cake in the fuel mixture was increased to

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7wt%. Stable flames were observed for the combustion of fuel mixture composed of up to 20 wt% of olive cake.

In addition, olive cake is used as a fuel in several tunisian applications: boilers in oil mills, driers in factories of oil extraction from olive cake, furnaces in brickyards. Masghouni and Elhassayri [13] have studied the substitution of No. 2 heavy fuel (a heavy fuel oil containing 4% of sulphur) by olive cake in a static furnace of a tunisian brick factory. The lower heating value of No. 2 heavy fuel and olive cake were 43.500 kJ/kg and 16.500 kJ/kg, respectively. A financial comparison of the costs of No. 2 heavy fuel and olive cake shows a reduction of 63.8% in the cost of energy. The combustion of olive cake was less polluting than the combustion of No. 2 heavy fuel;

solid particles, black carbon, carbon monoxide and sulphur oxides in the flue gas are negligible [13].

In order to set up favorable conditions of olive cake combustion it's necessary to have reliable knowledge concerning olive cake properties and major processes such as ignition, drying, devolatilization, and volatile and char reactions.

Chouchene et al. [14] have studied the thermal degradation behavior of olive solid waste by thermogravimetric experiments. The phenomenon of olive cake pyrolysis under oxidative conditions (10% O2 and 90% N2) has proceeded with three major stages: the first weight loss is due to drying of the sample. The second stage corresponds to volatiles release. A char is formed following this step. The last stage corresponds to the oxidation of the formed char. At the end, ashes and some residual char were remained. For the sample having a size below 0.5mm, the second step named volatilization is carried out for the temperatures range 180-290°C. Thereafter, the char oxidation step has taken place between 290°C and 470°C. Chouchene et al [14] noted that the amounts of remaining ashes at the end of pyrolysis with particle sizes ranging between 1 mm and 1.5 mm is close to that obtained during agriculture residues combustion. Based on both study of Chouchene et al [14] and Gani and Naruse [15] the behavior of pyrolysis and the combustion of biomass have a large similarity. Moreover, kinetic parameters during devolatilization step and char oxidation step for different particle size and under inert and oxidative atmosphere are presented in reference [14].

1.3 Interest of pulverization technique

At present, the majority of coal power plants use the technique of pulverized coal combustion. In pulverization method solid fuel is pulverized into fine particles of several tens of micrometers in diameter. For the great installations combustion (>100MW) of coal and of co-combustion (mixture of coal and biomass), the more practical technology is the pulverization [16]. Pulverization technique is privileged because it improves the economic and environmental performance of these plants by reducing combustible consumption and increasing productivity and minimizing pollutants emissions. In fact, the combustion becomes faster thanks to the increase in the contact surface between the particles and the oxidant. In addition, the problem of the incomplete combustion of solid fuel that causes poor gas emission can be solved by using very small particles [17]. In this context, Alwidyan et al. [10] concluded that under certain local conditions, olive cake on its pulverized form can be considered as the most practical renewable energy among solid fuels.

In this paper, an experimental study of feasibility of a burner functioning with the pulverized olive cake in free air is presented. The experimental conditions to enhance combustion of pulverized olive cake in new burner at open air have been studied. In order to achieve this aim, the olive cake is preliminary prepared, a special burner is fabricated and a new pilot plant is designed and associated. Thus, a turbulent and reactive two-phase jet of air loaded with olive cake particles is formed. Particle size of olive cake samples is below 200 μm. In order to start the combustion and ensure the persistence of the main flame in ambient air, two types of pilot flame are used: a central premixed flame of methane/oxygen and an annular diffusion flame of methane. A preheater is inserted in the inlet air line in order to study its effect on the main flame.

2. Experimental study

2.1 Presentation of experimental device

The experiment principle consists of producing a jet of air loaded with olive cake particles having sizes below 200 μm the two-phase jet discharged in free air. The pulverized jet flame is ignited by a pilot flame which can be placed at the port center or around the main port. Figure 1 illustrates the schematic diagram of the pilot plant used for pulverized olive cake combustion.

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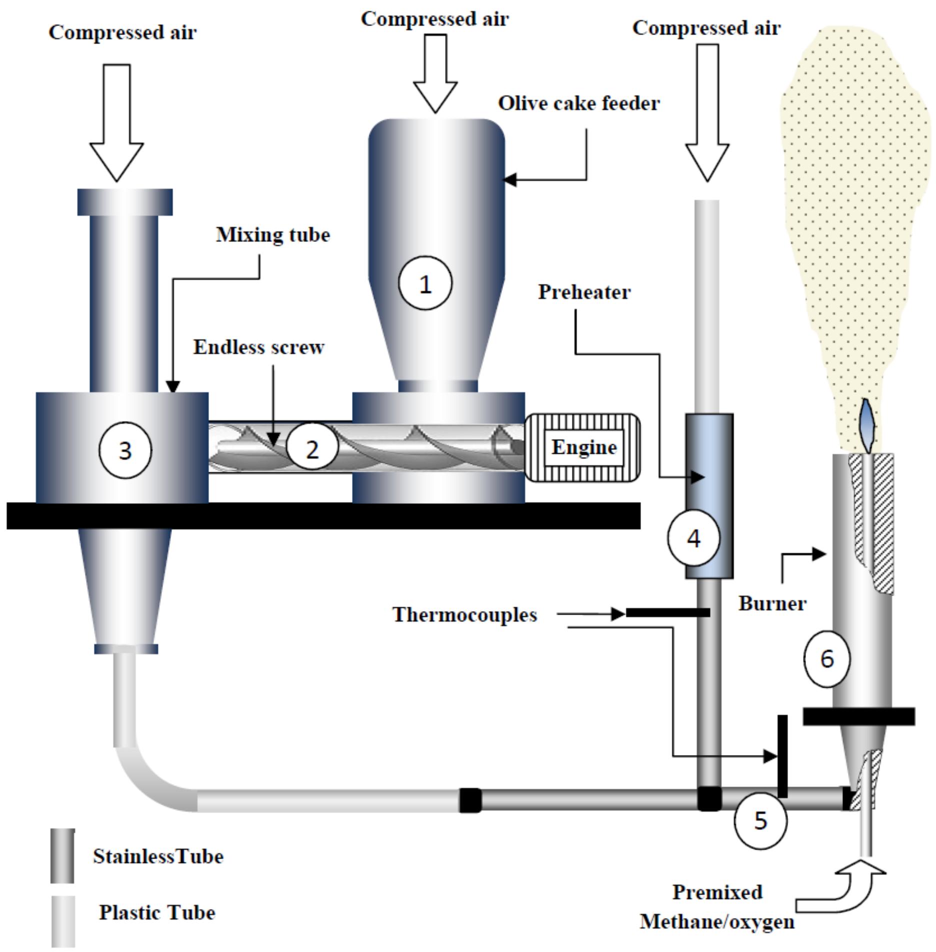

Figure 1. Schematic diagram of the pilot plant used for pulverized olive cake combustion

The olive cake particles are initially stored in the storage tank (1). Then, they are moved by an endless screw (2) towards mixing tube (3). Compressed air is injected into the particles feeder (1) with an aim to improve the movement of particles. Another flow rate of compressed air is injected into the tube (3) in order to entrain the particles towards the burner (6). If the preheating is necessary, a hot air coming from the preheater (4) should be mixed with the cold mixture of air and olive cake. In the both case, the mixture of air and olive cake goes in the burner (5). The main injector tube (5) has an inner diameter of 30 mm and a height of 210 mm. The mixture of air and olive cake passes through tubes with different geometry before being introduced in the straight main injector tube.
Each gas line is consisted by the following essential elements assembled in series: a valve, a pressure regulator, a manometer and a colsonic.

2.2 Fuel preparation
In order to carry out the experiment, the primary particles of olive cake have to be converted on small particles having sizes lower than 200 µm. Firstly, several alternate operations of crashing and garbling are carried out. Crash operation is done by a grinding mill with steel plates. The desired size is obtained by a screen with granulometry having meshes of 200µm in accordance with AFNOR French norm.
Researches of Kurose et al. [18] show the negative effects of moisture on the coal combustion effectiveness. Based on the above mentioned result, we carried out the drying of the olive cake particles until a water content of 1.85 %. Drying is carried out by a conventional furnace.
A sample of olive cake particles thus sifted and dried underwent a microanalysis (see Table 1).
The results of ultimate analysis allow calculating the volume of air needed to burn 1 kg of olive cake. The stoichiometric air/fuel ratio is about 4.45 Nm^3 of air per kg of olive cake. The High and the Lower Heating of olive cake are HHV=18800 kJ/kg and LHV=17510 kJ/kg, respectively.

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Table 1. Properties of olive cake (Sample coming from the Tunisian Sahel region, 2011)

Parameter		Value
Ultimate analysis	Carbon	47.15 wt%
	Hydrogen	6.03 wt%
	Oxygen*	41.3 wt%
	Nitrogen	1.34 wt%
	Sulfur	< 1 wt%
Ash		2.36 wt%
Moisture**		1.85 wt%
Oil content**		2.25 wt%
Lower Heating Value		17510 kJ/kg

* Value determined by difference
**Analysis carried out just after drying stage

2.3 First configuration with a central pilot flame

This configuration represents the selected parameters running the first test. The air which is supplied into the main injector tube represents the mass flow rate calculated at the stoichiometry.

The pulverized jet thus created is highly diluted with a volume fraction of olive cake is about 0.032%. The mass loading of the discrete phase is equal to 0.15.

In this configuration, combustion reaction is induced by a central pilot flame; it is a small premixed flame of methane and oxygen located in the center of the main injector tube. Experimental parameters are listed in Table 2.

Table 2. Experimental conditions

Flame type	Parameter	value
Premixed pilot flame	O_2 flow rate (m^3/s)	10.5 x 10^{-6}
Diffusion/ Premixed pilot flame	CH_4 flow rate* (m^3/s)	4.5 x 10^{-6}
	Thermal input of CH_4^* (W)	145
Pulverized jet	Air flow rate (m^3/s)	2.01x 10^{-3}
	Velocity of pulverized jet (m/s)	2.84
	Reynolds number, *Re* (-)	5838
	Pulverized olive cake feed rate (kg/s)	3.67 x 10^{-4}
	Thermal input of olive cake (W)	6426
	Mass loading of olive cake (-)	0.15
	Volume fraction of olive cake (%)	0.032

*same value for the two types of pilot flame

The inner and outer diameters of the pilot flame pipe are 2 and 4 mm, respectively. In order to vary the velocity of pilot flame gases, nozzles of diameters ranging between 0.2 to 1.5 mm as shown in Figure 2. A nozzle diameter of 1 mm has used for this configuration and that can increase the pilot flame velocity until 19.10 m/s.

2.4 Second configuration with annular pilot flame

A new pilot flame was designed and it is installed outside of the main burner. This flame is fed by methane which is supplied to the annular slit having a width of 0.5mm.

The methane jet is inclined towards center at an angle of 60 degrees to horizontal in order to allow best contact with pulverized particles (see Figure 3).

2.5 Third configuration: Burner with a preheating system

This part of the present study aims to improve the combustion by using a preheating system. Indeed, preheat olive cake particles before being supplied to the burner allows them a drying stage and the combustion becomes more quickly. Pulverized particles can also begin the devolatilization stage inside tubes.

The inserted preheater is equipped with regulator and it aimed at providing hot air for the air and olive cake mixture. In this configuration, the line of combustion air was divided into two fractions; one of these crosses the preheater and the other fraction drives the olive cake particles. The two fractions meet after preheater and before being supplied in burner tube.

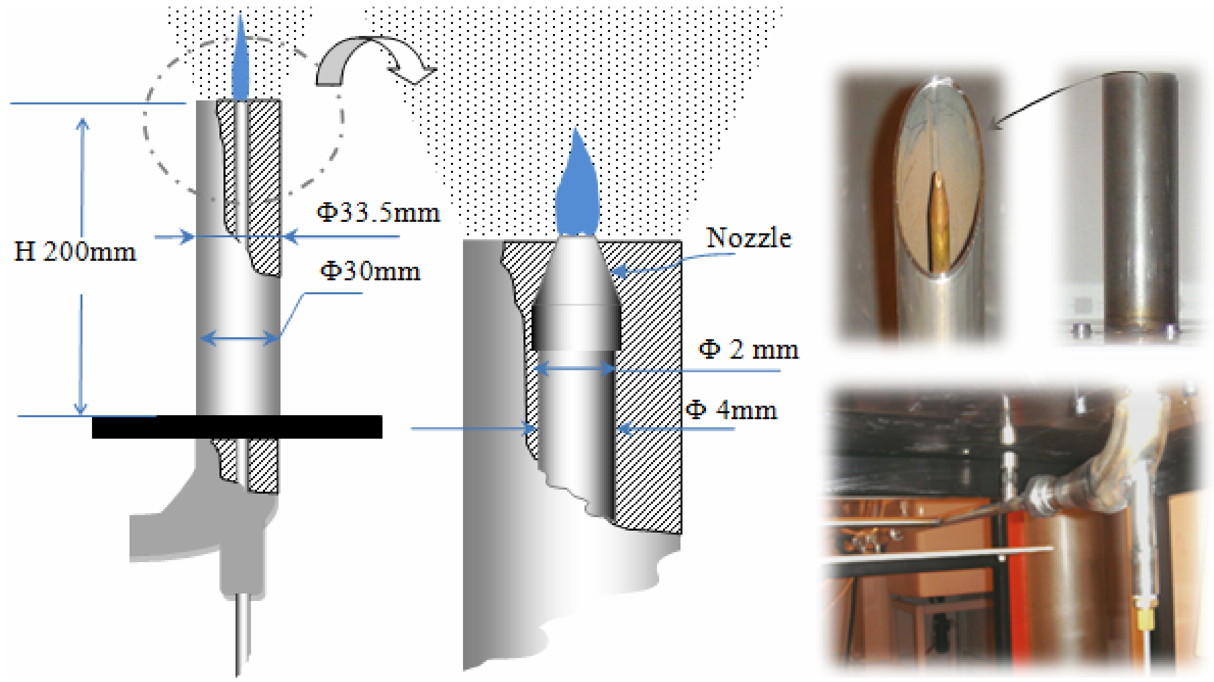

Figure 2. Dimensional details of the main burner and the central premixed pilot flame

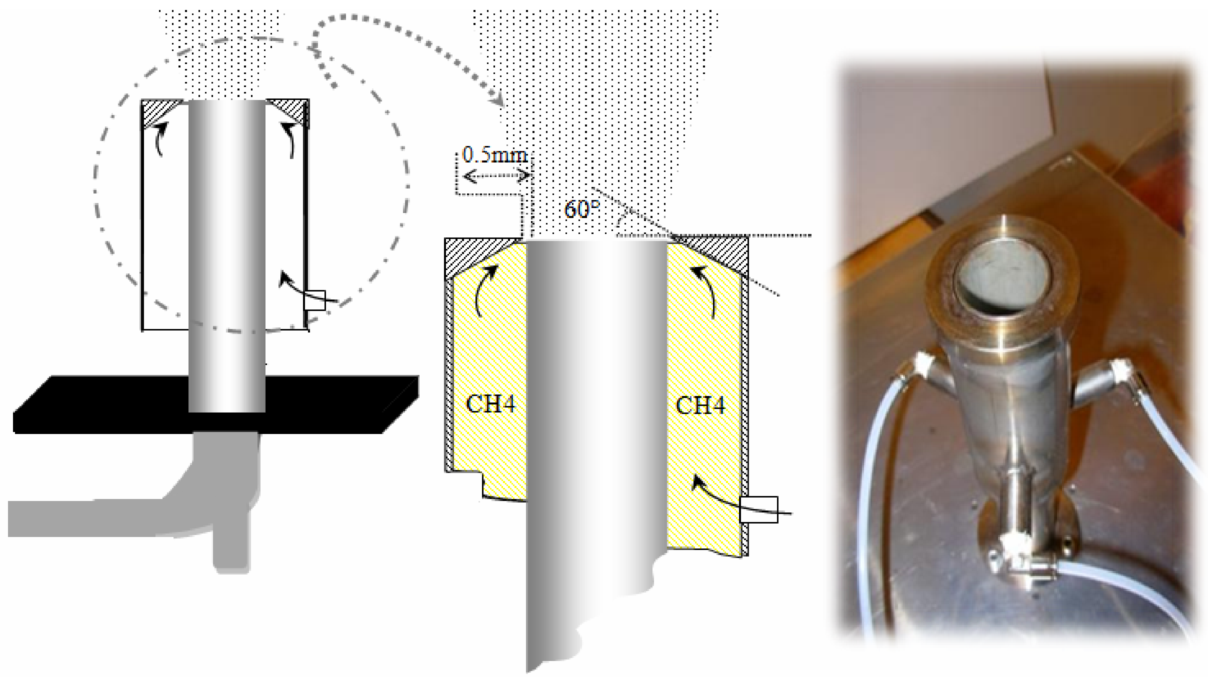

Figure 3. Schematic of the annular diffusion pilot flame

3. Results and discussion

3.1 Test of feasibility (First configuration)

With a central pilot flame, the flames generated by the combustion of the pulverized olive cake jet with particles having sizes below 200 µm are quite stable. Figure 4 shows a real pictures series of the flame, recorded in an interval of time equal to 1 second. These pictures confirm that the obtained flame is not an

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impulsive but it is a persistent flame. However, the pilot flame is vital to ensure the persistence of the olive cake flame. The reading order of the photos is from the left to the right and from the top to the down.

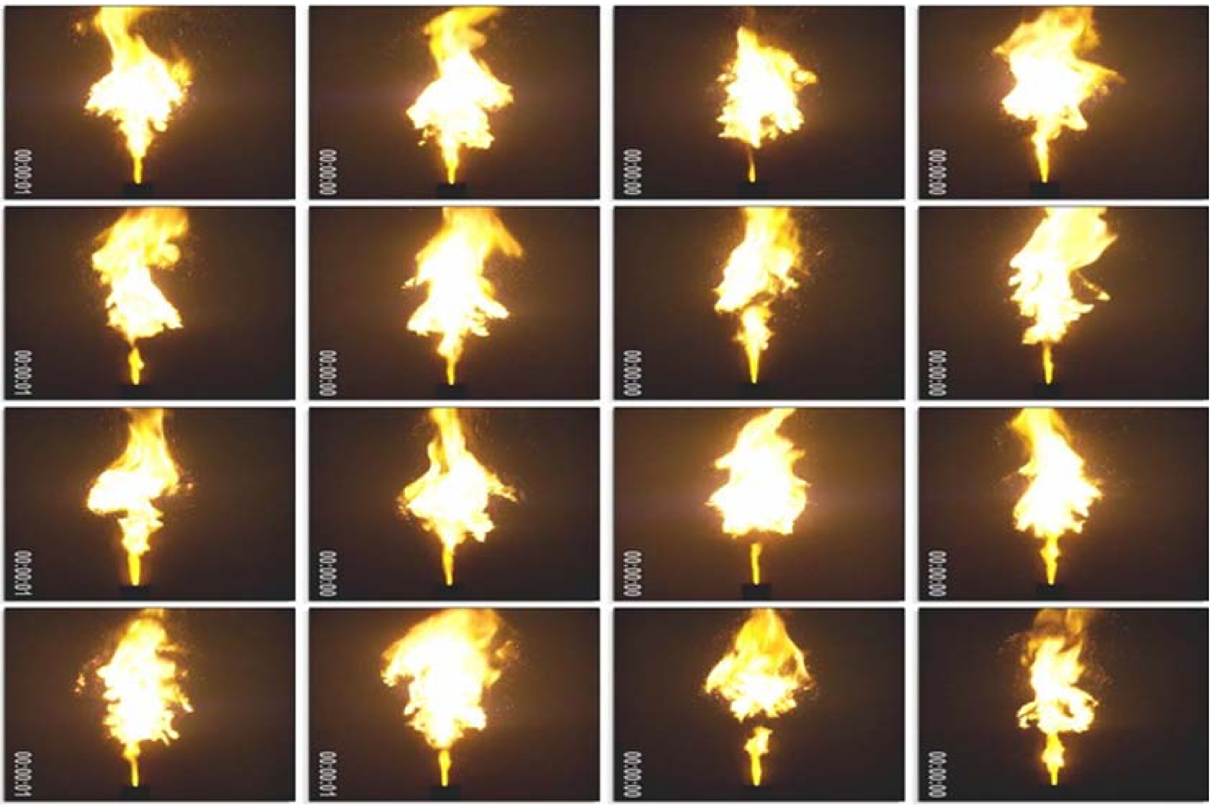

Figure 4. Photographs series of olive cake flame

In order to investigate the combustion enhancement of the pulverized jet flame, not only the feasibility of the designed burner, position of the pilot flame nozzle have been tested. In fact, combustion efficiency can be improved by sliding the tube of pilot flame inside the main injector. Thus, the combustion begins inside the burner. The quantity of unburned olive cake particles is greatly reduced and therefore more energy is recovered in the main jet flame. It's important to note that the most considerable heat losses are due to the bad combustion near the burner periphery.

3.2 Effect of the annular pilot flame (Second configuration)

In order to enhance combustion near the burner periphery, the new annular pilot flame has been installed. The second configuration aims at replacing the central pilot flame by another annular. The new used configuration is a methane diffusion flame. Tests showed that this pilot flame with a thermal power of 145 W was able to ignite and maintain the pulverized jet. Figure 5 represents a comparison between of the jet flame obtained for the second configuration and the first one.

The new main flame is wider and more powerful as compared to that one obtained with a central pilot flame. This is explained by the increase of the burned particles coming from burner periphery. Consequently, the combustion efficiency was increased by using an annular pilot flame.

3.3 Effect of jet velocity and the combustible feed rate

During tests of the second configuration, the effect of air velocity on the flame structure has been studied. Figure 6 shows direct photographs of olive cake flame for various input conditions; jet velocity (V_{jet}) and combustible feed rate (m_{OC}).

According to Figure 6 (a and b), we have noticed that as the mixture velocity is decreased, the pulverized jet is wider and the flame becomes brighter and more attached to the burner. Figure 6c represents a flame for a lower combustible feed rate and a high jet velocity: it's a short flame and less attached to the burner.

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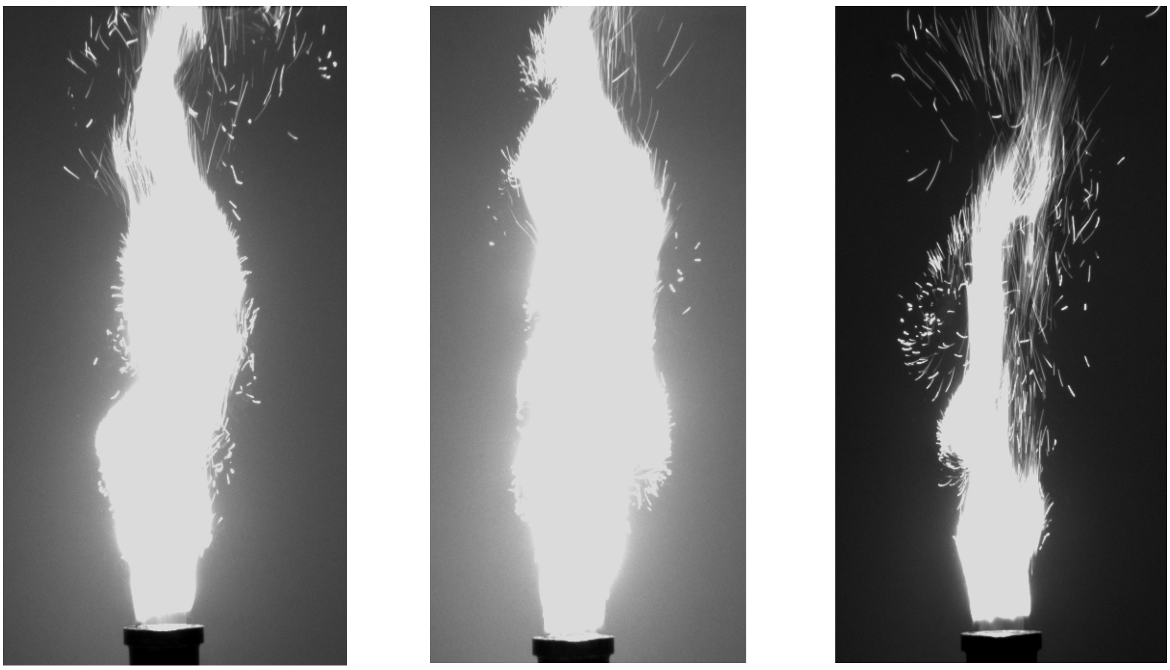
(a) (b)

Figure 5. Olive cake flame controlled by a central pilot flame (a), Olive cake flame controlled by an annular pilot flame (b)



(a) V_{jet}= 3.31m/s (Re = 6770), m_{OC}=22.96g/min
(b) V_{jet}= 1.91m/s (Re= 3898), m_{OC} =22.96g/min
(c) V_{jet}= 3.31m/s (Re = 6770), m_{OC} =13.79g/min

Figure 6. Direct photographs of olive cake flame for various input conditions

One can conclude that the combustion is enhanced by lowering the jet velocity. This is can be explained by the increase in the particles residence time and the importance of the transverse thermal diffusion compared to the axial thermal convection.

3.4 Effect of particle size

Particles size is a significant parameter in the study of two-phase jets and pulverized solids combustion. Indeed, new experiments are carried out with particles sizes above 200 microns.
The generated flame as shown in Figure 7 is very short and limited to the zone near the pilot flame.

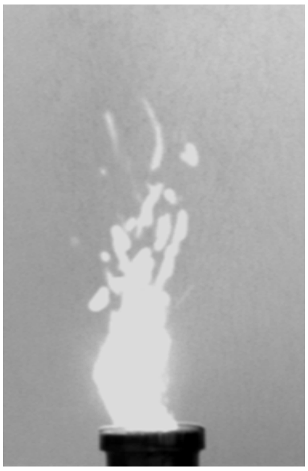


Figure 7. Combustion of olive cake particles having sizes ranging between 200µm and 350 µm

The particles having a size above 200 µm are difficult to be burned in this burner under the present experimental conditions. Thus, by comparison between combustion of particles below 200 µm and particles above 200 µm, it can be concluded that small particles can be burned better than the big particles. This is due to the effect of the thermal inertia and dynamic of the big particles.

4. Conclusions

A burner of pulverized olive cake particles was successfully implemented. A stable and controlled flame is obtained. The pilot plant used for experiments is mainly constituted by the burner and, a controlled drive system of solid particles. In addition, a system of preheating is set up and two types of pilot flame have been made and tested.

This study has led to the following conclusions:

- Combustion is more effective by using an annular pilot flame than a central flame. The preheating system can enhance the combustion of pulverized jet.
- Sizes of olive cake particles must be below 200 µm to obtain an effective combustion in the free air.
- The adequate drying of particles is one of the most favorable conditions for the combustion enhancement.

We will use the present experimental device to carry out many investigations on the olive cake flame: dynamic measurements, thermal behavior and control of pollutant emissions. In the future, this pilot plant will be considered as a preferential device to validate our numerical models.

References

[1] Kalembkiewicz J. and Chmielarz U., Ashes from co-combustion of coal and biomass: New industrial wastes, Resources-Conservation and Recycling, 2012, 69, pp 109-121.

[2] Direction Générale des Etudes et du Développement Agricole (DGEDA), Patrimoine Oleicole Tunisien, Mai-9-2012 from website http://www.onh.com.tn, Ministry of Agriculture, Republic of Tunisia.

[3] Chouchene, A., Etude expérimentale et théorique de procédés de valorisation de sous-produits oléicoles par voies thermique et physico-chimique, Ph. D thesis, Ecole Nationale d’Ingénieurs de Monastir (Tunisia) and Université de Haute-alsace (France), Tunisia-France, 2010.

[4] Topal, H., Atimtay A.T., Dormaz, A. Olive cake combustion in a circulating fluidized bed, Fuel, 2003, 82, pp 1049-1056.

[5] Abu-Qudais, M., Okasha, G., Diesel Fuel and Olive-Cake Slurry: Atomization and Combustion Performance, Applied Energy, 1996, 54, pp 315-326.

[6] Atimtay A.T., Topal H., Co-combustion of olive cake with lignite coal in a circulating fluidized bed. Fuel, 2004, 83, 859-867.

[7] I. Aljundi, N. Jarrah., A study of characteristics of activated carbon produced from Jordanian olive cake. J. Anal. Appl. Pyrolysis, 2008, 81; 33-36.

[8] Vera D.., De Mena B., Jurado F., Schories G., Study of a downdraft gasifier and gas engine fueled with olive oil industry wastes, Applied Thermal Engineering, 2013, 51, pp119-129.

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online) ©2014 International Energy & Environment Foundation. All rights reserved.

[9] Abu-qudais, M., Fluidized-bed combustion for energy production from olive cake, Energy, 1996, 21, pp 173-181.
[10] Al widyan, M. I., Tashtoush, G., Hamasha, A. M., Combustion and emissions of pulverized olive cake in tube furnace, Energy Conversion and Management, 2006, 47, pp 1588-1596.
[11] Alkhamis, T. M., Kablan M.M., Olive cake as an energy source and catalyst for oil shale production of energy and its impact on the environment, Energy Conversion & Management, 1999, 40, pp1863-1870.
[12] Atimtay, A.T., Varol, M., Investigation of co-combustion of coal and olive cake in a bubbling fluidized bed with secondary air injection, Fuel, 2009, 88, pp1000-1008.
[13] Masghouni, M., Elhassayri, M., Energy applications of olive-oil industry by-products: -I. The exhaust foot cake, Biomass and Bioenergy, 2000, 18, pp 257-262.
[14] Chouchene, A., Jeguirim, M., Khiari, B., Zagrouba, F., Trouve, G., Thermal degradation of olive solid waste: Influence of particle size and oxygen concentration, Resources-Conservation and Recycling, 2010, 54, pp 271-277.
[15] Gani A, Naruse I. Effect of cellulose and lignin content on pyrolysis and combustion characteristics for several types of biomass. Renewable Energy, 2007, 32:649-61.
[16] T. FLOREA., Simulation numérique de la combustion du bois dans une chaudière automatique de 400 kW, Ph. D Thesis, Université de Valenciennes et du Hainaut Cambrésis, France, 2010.
[17] Y.C. Guo, C.K. Chan, K.S. Lau, Numerical studies of pulverized coal combustion in a tubular coal combustor with slanted oxygen jet, Fuel, 2003, 82; 893-90.
[18] Kurose, R., Tsuji, H., Makino, H., Effect of moisture in coal on pulverized coal combustion characteristic, Fuel, 2001, 80, pp 1457-1465.

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