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COMBINED CFD AND INFRARED THERMAL ANALISYS OF A WOOD REFUSE AND DI-METHYL-ETHER CO-FIRED FLAME

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Abstract

This paper presents some numerical and experimental tests concerning two systems of co-firing small pieces of wood refuse (maximum of 20 mm) together with di-methyl-ether inside the industrial wood platforms on some local areas in Romania rich both in oil reserves and woods (Prahova, Transilvania and Oltenia regions). The first system consists in a concentric injection of the two fuels and the second in different injection places. To establish the right process parameters infrared technology to acquire data for thermal distribution inside the flame has been used. According to these data the whole process has been tuned.

1. Introduction

Di – methyl – ether (CH_3OCH_3), (D.M.E.) is one of the by-product of some industrial platforms located in the Romanian oil fields.

In the neighbourhood of these regions are also a lot of wood industrialization utilities, producing an important amount of industrial refuse. Several wood types of refuse (such as sawdust, wood pieces, etc.) have been considered to be burned, in order to be able to realise a continuous significant main fuel flow rate for the incinerator and di-methyl-ether as a supplementary fuel in case of starting up and other transition periods.

Present research has as principal purpose to establish the best possibilities to co-fire both wood refuse and di-methyl-ether in order to a maximum reduction of NOx and mechanical heat losses. This paper presents theoretically and experimental study of possibilities to incinerate different kinds of wood refuse, using D.M.E. as a supporting fuel. This type of incinerator has been designed to operate in the neighbourhood of the Prahova Valley in Romanian Sub-Carpathians region, where a lot of oil refineries are in operations to offer C_2H_6O as a by-product, together with a strong wood local industry.

Trying to improve both the flame's characteristics and the furnace general assembly of performances, 3D CFD simulations together with infrared analysis of the flame have been carried out, as they are further described.

2. General conditions and assumptions

Wood refuse has been considered of different types, having the main characteristics from the Table 1. In the Table 2, principal dimensions of this refuse are also presented, together the average values.

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Table 1: Principal characteristics of the wood biomass refuse.

Case	Type	C % dry	H % dry	O % dry	N % dry	A % dry	Q_s, MJ/kg
1	High altitude	52.3	6.3	40.5	0.1	0.8	21.050
2	Medium altitude	51.64	6.26	41.45	0	0.65	20.375
3	Low altitude	50.44	6.59	42.73	0	0.24	20.492

Table 2: Granulometric characteristics of the wood biomass refuse.

No.	Maximal diameter mm	Minimal diameter mm	Average value mm
1	10.0	0.01	2.0
2	20.0	1.00	10.0

Results have been obtained concerning the minimum supplementary di-methyl-ether flow rate and the best place to be injected in order to realize a constant regime of the flue gas at the end of the furnace, when changing the main fuel.

One of the main problem to be solved was the different times delay of ignition for the two fuels. Due to this aspect different distributions of oxygen concentration are required, or different velocities of injection are to be used.

3. Preliminary tests to adopt a co-firing technology

Two main strategies for co-firing technology have been considered: the first one (the cheapest) when the wood refuse is co-injected with DME from the same location and the second one with two different locations for each of the two fuels. From the beginning it was considered that the second solution would not involve any problems regarding the flame stability, due to the fact that the two fuels would be introduced with their own air jet flow.

3.1. Experimental system

The first solution has to be tested to see if the temperature created in the flame zone is sufficient to ignite the wood refuse also. An experimental installation has been adapted to analyse the ignition phenomena of the mixture between DME and wood refuse (fig.1). The experimental study includes calibration and ignition experiments under different operating conditions (different starting pressure, controlled ignition, etc.).

3.2 Experimental procedure

Di-methyl-ether has been introduced into a special calorimetric bomb, provided with two quartz windows and a spark ignition plug, together with some fine wood pieces, pre-selected under the microscope at a constant dimension of 100, 200 and 300 microns (± 10 μm), in an oxygen atmosphere of 4.4 bar [1] (calibration experiments have been

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carried out but higher pressure did offer neither realistic results, nor useful conclusions). A high speed camera (FastVision13) has been attached on the bank in a proper position. In general, the calibration and ignition experiments have been repeated three to four times, and a fair reproducibility has been obtained. Several experiments where carried out to choose the optimum value for the average dimension of the wood particles. Greater were the particles, the longer were delaying periods and all DME was burned before the particles to ignite. On another part, to choose smaller particles, that meant to use only a small granulometric class of the wood refuse to participate at the ignition process under normal conditions. Another problem to be solved at the level of calibration experiments was to establish the minimum DME concentration in the bomb atmosphere, in order to realize 20 kW/m^2 at least as the heat flux upon the wood particles [2,3]. This value has been realized at DME volumetric concentrations between 4.9% and 46.7%. At heat flux values surpassing the 64 kW/m^2 supplementary nitrogen content has to be introduced into the bomb in order to avoid the DME auto-ignition. Ignition delay values for the wood particles have been obtained as it can be seen in the Fig.2.

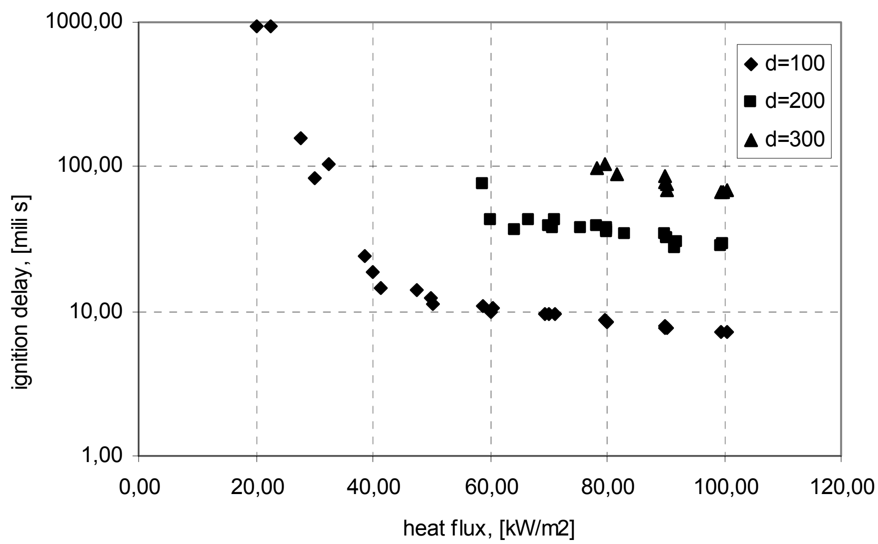

***Fig.2**. Ignition delay of the wood refuse versus DME.*

From the images that have been taken, it can be seen the moment when spark occurs (a), the flame initiation (b), di-methyl-ether flame propagation (c) and (d), and the moment of wood small piece ignition (e) on the left side. Between the (c) frame and (e) frame there was an average of time difference of 18.7 milliseconds. Non the less the first preliminary conclusion has considered that the simultaneous injections of the di-methyl – ether and wood refuse in small pieces cannot fundamentally block the ignition process of the solid fuel.

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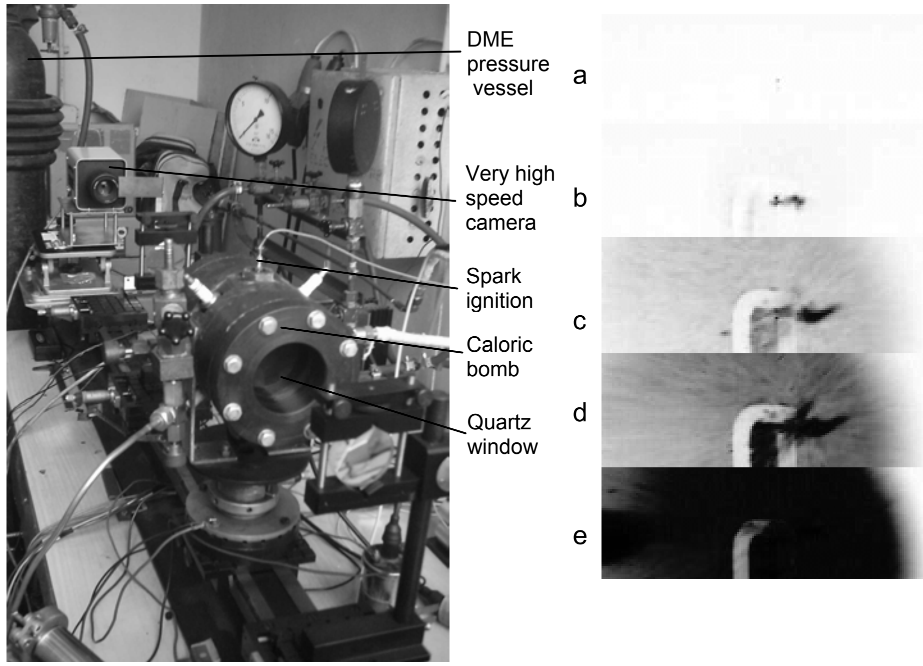

Fig.1. *Experimental installation to test the ignition parameters for the mixture wood refuse and di-methyl-ether and a series of obtained images at 16500 frames/second.*

This cautiously preliminary conclusion has been motivated by the very special conditions realised inside the bomb, versus the real furnace conditions, but anyway the first strategy of co-firing got a green signal to be tested.

4. Pilot tests of co-firing wood refuse and d.m.e.

Pilot installation consists of a vertical 1.5MWt furnace of 10 m^3, as it can be seen in the fig.3. First, solid fuel is crushed and then is milled into a rapid ventilator mill of 5000 rot/min, at a maximum flow rate of 300 kg/h. To dry the solid fuel, a special descending tower is provided to extract a part of the flue gas from the end of the furnace and to lead it down into tube for the crushed fuel towards the mill elbow. On the back wall of the furnace a special inspection hole (3) has been provided to offer the possibility to take infrared images of the burning process inside.

The first strategy to co-fire have been tested in order to introduce both wood refuse and D.M.E. by the main burner (4) and the second co-firing strategy to use the (6) feeder and the inspection hole at the level of 3.450 mm for the wood refuse and the burner P10 for the D.M.E.

First, some numerical simulations of the burning process of co-firing have been performed with Fluent 6.1 in order to reduce the costs of experiments; in this way the best places of di-methyl-ether injections have been identified on the experimental 1.5MWt

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furnace of the Politechnica University of Bucharest, relatively to the second strategy of co-firing. At the same time a special burner (4) for di-methyl –ether has been developed in order to create an extended core of the flame to touch as much as possible the cloud of the wood refuse.

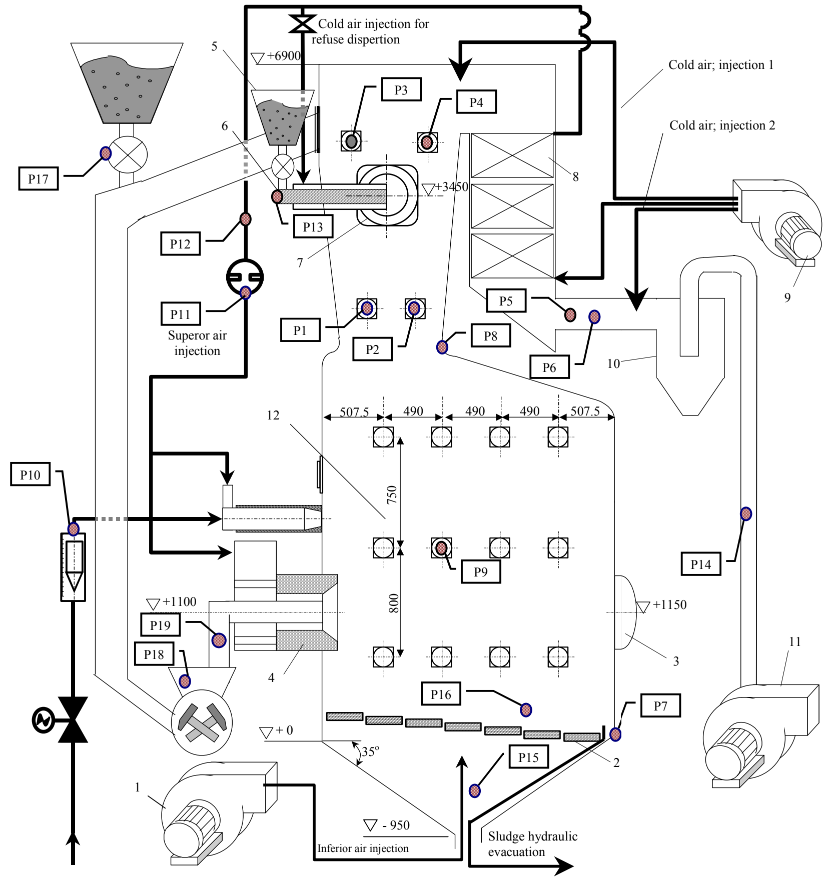

***Fig. 3**: Pilot installation of 1.5 MWt used to test the combustion process of mixture of wood biomass refuse and di-methyl-ether. (1)Cold air ventilator ; 2)Post combustion grate ; 3) Visit hole; (4) Main burner; (5) secondary wood bunker; (6) Secondary feeding installation; (7)Secondary feeding orifice; (8) Tubular air preheater; (9) Main air ventilator; 10) Flying ash separator; (11) Flue gas ventilator; (12) Burning chamber; (P10) – secondary di-methyl –ether injection, (P19) – main di-methyl-ether injection.*

Geometrical 3D model of the pilot furnace has been developed in GAMBIT 2.0 (Fluent 6.1.18 packet) considering all the principal dimensions of the real installation. Adopted strategy of building consisted in respecting the technical schema in the fig. 3.

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The process of discretisation of the volume and the surfaces of the furnace has been developed under the Cooper method resulting 45738 control volumes [4,5].

The border conditions have been established as follows (as they have been used during the experiments):

- inlet orifice has been considered with normal directed mass flow of gas as an entrance surface;
- outlet surface has been considered at a depression of –90 Pa ;
- bottom surface of the furnace has been considered at a depression of –10 Pa ;
- the air entrance surface has been considered also to be a mass flow inlet one with a normal directed velocity;
- the furnace inside face has been considered full covered with refractory materials at a constant temperature of minimum 900 K;
- other details over the whole system are given in the Table 3 and Table 4;
- the fixed grate surface has been considered also at a constant temperature, being continuously washed by cold air.

Table 3: *Details over the inlet and outlet parameters of the furnace during experiments*

Preheated air temperature , [K]	523
Flue gas temperature at the end of the furnace (point P4), [K] first co-firing strategy	974
Flue gas temperature at the end of the furnace (point P4), [K] second co-firing strategy	1036
Temperature after the air preheater (point P5), [K] (constant)	833
O_2 concentration at point P2, [kg/kg]	0.025
CO concentration at point P2, [kg/m^3]	0.0058
CO_2 concentration at point P2, [kg/m^3]	0.22
DME flow rate, [kg/h]	20.5
Wood refuse flowrate, [kg/h]	225.0
Granulometric size of the fuel (refuse over the 5 mm separator) (point P10), [%]	73.5

Table 4: *Points of calibration (Fig.3)*

P2, P4, P5, P10 – range of 10%

All numerical simulations have been performed by the help of Fluent 6.1.18. and the principal considered situations are the following: in the first situation wood biomass refuse comes from a high altitude zone when the second situation concerns a medium altitude area; the third situation regards wood biomass refuse coming from low altitude area of the country.

After the burner construction experiments have been operated on the pilot furnace already been up-mentioned, regarding all three sorts of the wood refuse. No significant differences have been registered due to the fact that the whole quantities have been exposed too much time to the solar radiation and their humidity have reached the almost the same values. More than this, as it can be seen in the fig. 4 and 5, DME jet injection velocity was not well prepared (both module and direction) and the ignition process was not continued by a normal flame inside the wood refuse cloud – for the first co-firing strategy.

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All these results could be processed by using a ThermaCAM SC 1000 together with a HORIBA PG 250 S flue gas analysis and ThermaGRAM 95 Pro analysis software [6].

First, only small impacts of the di-methyl-ether injections have been detected when transient regimes of main fuel have been operated, as it can be seen in the fig.3 and 4.

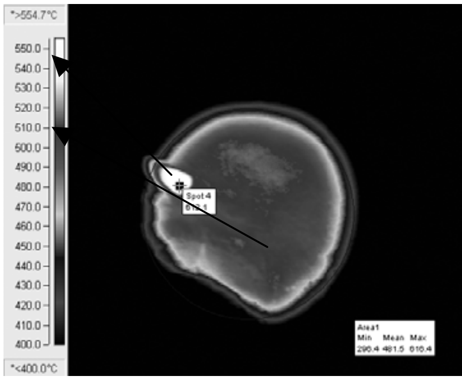

Fig.4. *Ignition moment of di-methyl-ether inside the furnace.*

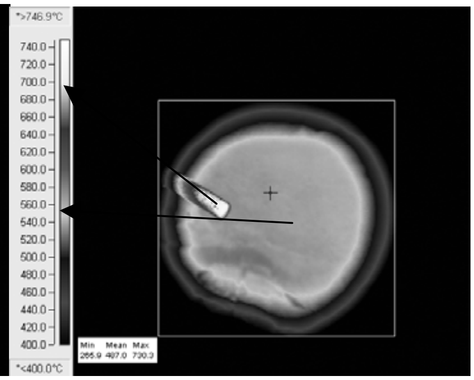

Fig.5. *Flame propagation inside the wood refuse cloud.*

As it can be seen the flame has a small influence and it is not sufficient at all to sustain the whole process (a flue gas temperature coloured scale has been attached to the pictures in original). From these two figures one can realise that the di-methyl-ether is taking the necessary air for igniting and burning, while the wood powder has not enough oxygen, in the spite of the sufficient value of temperature to burst into flame. Two arrows have been inserted into the fig.4 and 5 to indicate easier the values of the temperature at the moment of DME ignition and than for the main flame.

Due to the fact that the first strategy to approach the co-firing process has been mainly looked for, some supplementary research activity has been performed. Numerical simulations concerning the first strategy to co-fire has also been carried out, in order to establish the proper degree of swirling of the secondary air and at the same time the ratio between solid wood refuse and the di-methyl-ether has been adjusted to a sensible poor concentration.

After some more similar experimental tests [7], according to the CFD results, a better situation has been achieved, as it can be seen in the fig.6.

At the first sight, a better flue gas temperature distribution can be observed inside the combustion chamber, due to the fact that di-methyl-ether has been injected through a more complex burner (it can be seen in the down left corner of the picture) and due to the fact that the air circulation has been strongly modified after the first experiments.

Some more tests have been performed after that, trying to realise the initial humidity of the wood refuse altered by solar radiation, but results could not be mentioned until real wood refuse would be tested for validation.

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In the Fig.7, there are presented both the measured and predicted values of flue gas temperature along the furnace height.

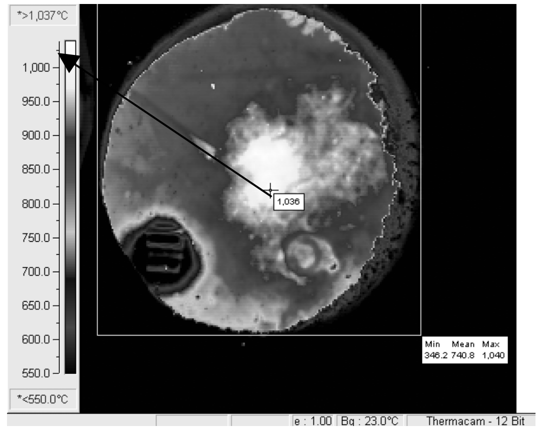

Fig.6*. The new improved aspect of the co-fired flame.*

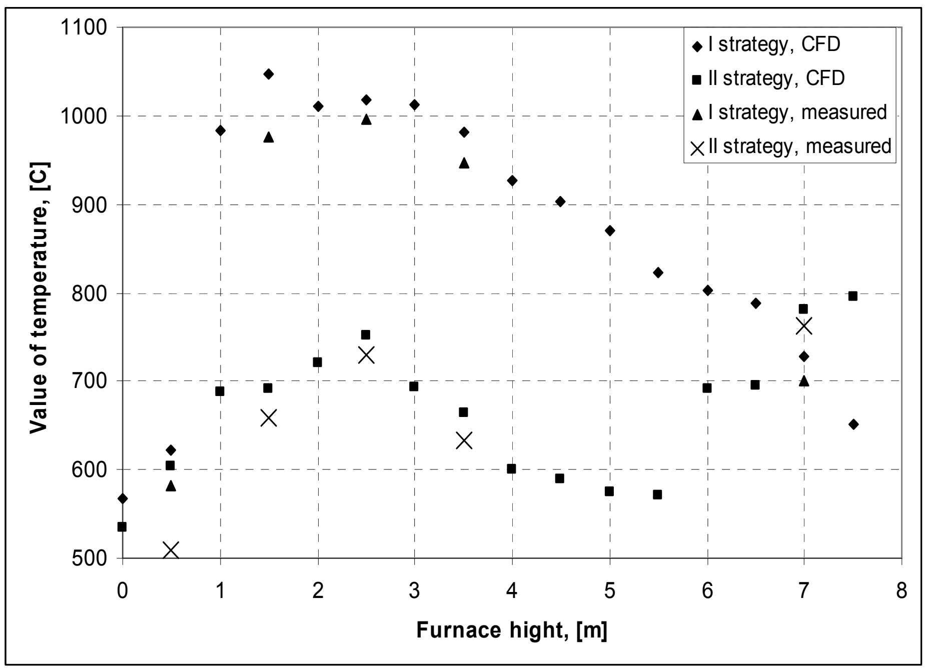

Fig.7. *Measured and CFD predicted values of the temperature along the furnace height.*

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5. Conclusions

After all these experiments and CFD simulations the following conclusions can be extracted:

- for very fine wood refuse (under 0.5mm) it is possible to realise high thermal specific loads (kW/m^3), by direct injection using co-firing technology with DME (less that 12% heat supply) to get a stabilized flame;
- different location of fuel injection, when co-firing technology is used, can only generate supplementary costs, significant NOx formation due to the high temperature at the end of the furnace and not advantage in the heat mechanical loss of the installation.

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