# THE IMPACT OF EM FIELD ON COMBUSTION

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**Abstract:** The results of an experimental study of the biomass pellets combustion processes using a 20 kW model are presented. In the experimental model, the maximum stationarity of the combustion process is achieved by varying the parameters (geometry, primary and secondary airflow). The effects of electric current at 50 Hz and 13.56 MHz frequencies were studied. Theoretical problems and further investigations aspects are discussed.

## 1. Introduction

There are many experimental investigations of electromagnetic (EM) field influence on the combustion processes in gases. It is found that it is possible to control the gas combustion flame form applying an EM field at the flame starting region [1]. The optimal value of electric field voltage is 80-100 kV. The effect is positive when the central electrode is positive, which drives away the negative charges from the flame. Actually, the flame is electrically polarized and the EM forces can control the flame form [1]. However, the high voltage is connected with technical and safety problems. In the present study, we tried to find methods to reduce EM voltage but maintain the positive electromagnetic field influence on the combustion process.

## 2. Presentation of the problem

There is an essential difference between the combustion processes in gas and in the case of pellets. In gases, there is good mixing of the burning mass at the flame starting point and the combustion process is stable in time that makes easier the investigation of EM field effects. In the pellet case, it is hard to achieve a stable combustion in time because there is a non stationarity of feeding, ash problem, and others. In order to have a stable combustion process, a 20 kW experimental setup (Fig.1) was produced. A result was achieved by using uniform pellet feeding and optimizing the primary and secondary air supply. Fig 2 illustrates the temperature, $O_2$, $CO_2$, CO and $H_2$ mass fraction variations in time. The measurements were made by Testo-350 at the top part of the burner (Fig.1) and the combustion process was stable. In order to choose an optimal EM method, the electrical resistance in the flame and in the pellet zone was measured. The resistance in the flame zone was hundreds of MΩ, but in the pellets' carbonized zone it decreased to hundreds Ω. So, if compared with the gas combustion, where there is only the flame zone with large resistance, high voltage is necessary to have EM effect. In our case, there is possibility to realize an EM interaction through the low resistance zone (carbonized pellets). Another argument is the specific electron transition effects in structured carbon like graphene that has been intensively investigated lately [2]. Electrons in such structures become massless and their motion, which in fact is a current, is ultrafast. As in the carbonized pellet zone there also are carbon structures, some analogy could be found there.

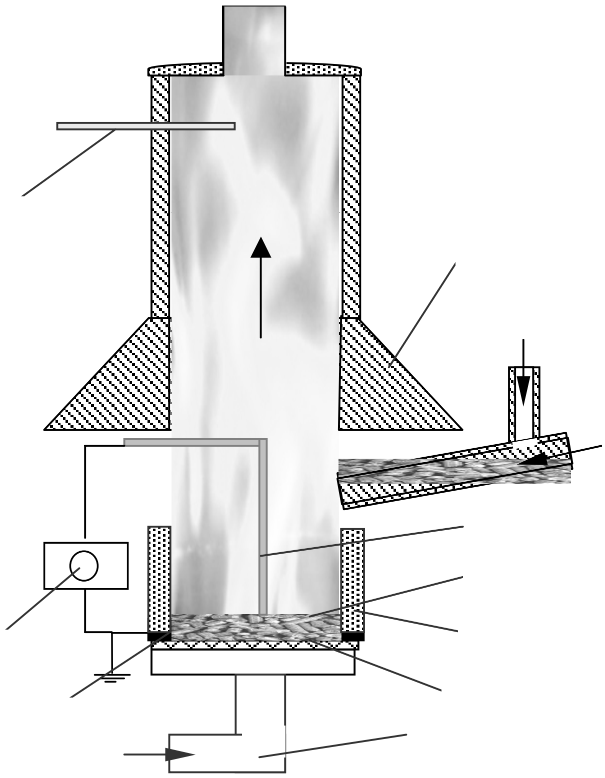

**Figure 1:** Experimental setup:
1 - gasifier with pellets
2 - quartz cylinder
3 - ceramic grate
4 - primary hot air feed
5 - infeed of pellets
6 - secondary hot air feed;
7 – combustion chamber
8 - diagnostic sensor for to measure gas composition and temperature.
9 - generator
10 - central axial electrode;
11 - circular ground electrode.

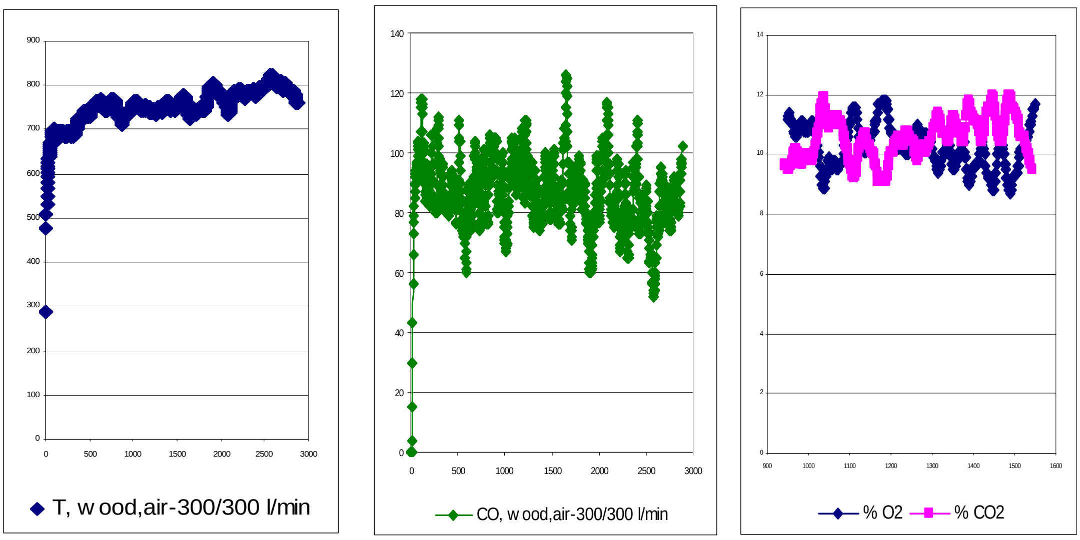


Figure 2: Time-dependent variations of temperature, mass fractions of CO and $O_2$ $CO_2$.

So, in experiments, the current was generated just in the pellets' carbonized zone. There 50 Hz, DC and also 13.56 MHz EM fields were used. In the 50 Hz case, the maximum voltage was 220 V, the maximum current 20-25 A. In the 13.56 MHz case, the EM processes were limited by the generator power (600 W). The common characteristics in the all cases are the electrical current distribution non-stationarity and the existence of discrete bright spot formations. There is some analogy with known plasmons or **spasers** (surface plasmon application by stimulated emission radiations) [3]. In the 50 Hz case, when the current mean value increases, instead of stationary character, near the central electrode the spots start to explode, and the discharging process extends from the pellets to the flame zone. The flame becomes much brighter and corona discharging appears. Qualitatively, the EM process can be characterized by a theoretical model [4]. The central electrode has a definite voltage and the earth potential is near the cylinder surface (Fig.1).

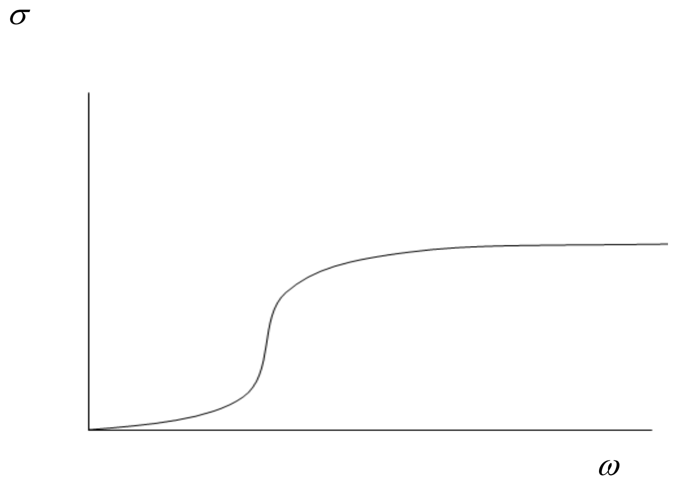


Figure 3: The electrical conductivity as a function of $\omega$.

The electric field in the combustion zone is

$$E = \varphi \Big/ r\ln \frac{r_a}{r_i}\,, \tag{1}$$

where $\varphi$ is the potential difference, r is the distance from the central electrode, $r_a$ and $r_i$ are the radii of the cylinder and electrode, respectively. The electrical field (1) in the pellets' carbonized zone induces an electric current

$$j = \sigma E\,,\ \sigma = \varepsilon_0\omega \frac{\omega/\upsilon}{1+(\omega/\upsilon)^2}\,,\ \omega = e\sqrt{n_e/\varepsilon_0\, m}\,, \tag{2}$$

where $\sigma$ is the conductivity , e is an electron charge, $n_e$ denotes the charged particles density, m is the mass, $\upsilon$ is the collisions frequency, $\omega$ is the Langmuir frequency. When $\omega$ is small, $\sigma \sim \omega^2$, and $\sigma$ = const when $\omega$ is large (Fig.3).

The processes in the combustion zone can be described by the system of equations:

$$\begin{aligned} &dn_e/dt = n_1 n_e \beta - n_e^3\alpha \\ &\tfrac{3}{2} n_e dT_e/dt = \sigma E^2 - Q_{el} - Q_R - W_1\, dn_e/dt \\ &\tfrac{3}{2}(n_1 + n_e)dT/dt = Q_{el} \end{aligned} \tag{3}$$

where $W_1$ is the energy of ionization, $n_1$ is the neutral particles' density, $n_e$ is the electron density, $\beta$ is the coefficient of ionization, α is the recombination coefficient , $Q_{el}$, $Q_R$ are energy losses due to elastic collisions and radiations, $T_e$, T are the temperatures of electrons and other particles. In our experiments, with the smallest current, the electric resistance values were of 1-2 kΩ. When the current increases to 15-20 A, the resistance decreases to tenths of Ω.

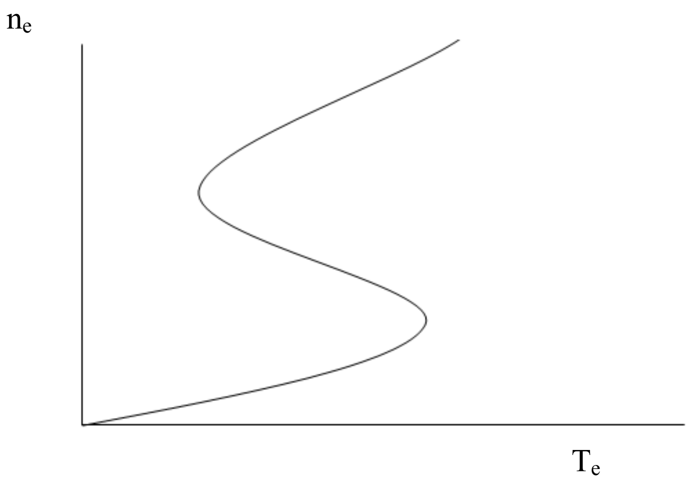


Figure 4: S- type electron density as a function of the temperature $T_e$.

The current distribution in the pellets zone is non-homogeneous, as shows the picture with bright hot spots. The quasi-stationarity of the hot spots' character changes when the current increases (15-20 A) and there are observed some spots exploding near the central electrode. In fact, the electric current process from the carbonized pellets' zone extends to the flame, and there is a transition from the small branch of $n_e$ concentrations to the higher one (Fig.4).

The characteristic distributions of hot spots in the burner are illustrated in Fig. 5.

**a** **b**

Figure 5: Distribution of hot spots in the burner (a: 50 Hz, 5 A; b: 50 Hz with rectifier, 8 A).

Visual observation shows that the characteristic life-time of the hot spots is some seconds and dimensions (1-10) mm. In order to estimate the current distribution, stability experiments with an external magnetic field ($B_z$) were performed. In that case, we had a force field $f_\varphi \sim j_r B_z$. The experimental results show that the number of hot spots decreases as well as the total current mean value. It means that the resistance of the pellet zone increases. It looks as if the current paths are disturbed by the force field. Some experiments were performed under a radial magnetic field when j || B. In that case, both the stability of the current distribution picture and the total current value increase.

**3. Discussion and conclusions.**

In the case under discussion, there are some analogies with the known effects in good conducting graphene when it attracts H or O to the free bonds and becomes graphane with high resistance [5-7]. In our case, the situation is opposite. At the starting point, the pellets' bounds are saturated and there is large resistance. When the volatiles (these are H and O) go out (carbonizing process), the resistance decreases.

The question about the physical mechanisms of hot spots and their influence on the combustion process arises. This also can be regarded as an opposite situation of the known effect when a concentrated laser beam enhances the thermo-current processes in graphene. In our case, the external current generates bright hot spots.

One of the results is that in the 20 kW model the stable combustion regime was achieved.

The electric current through the pellet zone stimulates a gradual evolution of the volatiles. The electric resistance changes in the pellet zone correlate with the rate of volatiles pick on.

The specific pattern of currents' distribution and their influence on the combustion processes need further investigations.

## 4. References


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