COMBUSTION-DYNAMICS OF WOOD-CHIPS CONGERIES

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Abstract. This article presents a method, which, irrespective of the blast conditions of the furnaces, can investigate the combustion process of the ligneous chips congeries. With the help of homogeneous and artificial mix structures, the authors tentatively demonstrate, that the combustion speed of wood-chips is not depend on only the surface area of sample (size of pieces), but the order of the parts of pile too. Consequently: the combustion process will be optimum in the case of a purpose structure with suitable size distribution only. This research project is supported by the Hungarian Scientific Research Fund (OTKA-K-68103).

1. INTRODUCTION

With the full knowledge of the chemical composition of the fuels, their combustion heat can be calculated easily by Dulong's formula. This method takes into consideration that a certain part of the fuel material is originally already oxidized in organic compounds. After deducting the evaporation heat of the original water content of the material, the calorific value can be determined. If the chemical composition of the material is unknown, the combustion value (otherwise gross calorific value) of the material can be experimentally measured by a calorimetric-bomb test as well. However, in this case, the fuel (or heating) value is only estimated; the moisture content of the sample can be determined by the drying-box test but the exact calculation requires the value of the hydrogen content of material [2], too. Both the combustion heat and the heating value mean the maximum withdrawn energy from the unit of fuel during its perfect burning; accordingly, it supposes the use of ideal furnaces (boilers) with no loss. The so-called condensation boilers utilizing the total combustion-heat recover the heat content of the vapour in the off-gas. Their theoretical efficiency referred to the fuel heating value may achieve the value 108.8 %. Nowadays these types are widely used in gas-fired systems but they have not spread in the multi-fuel furnace technology yet because of the high sulphur content of the solid fuels, more exactly the formed aggressive acidic condensates from the off-gas.

When burning wood or other grown biomass plants, the complete oxidation cannot take place alone – it requires especial technical and firing requirements to be fulfilled. The necessary volume of air (oxygen) must be provided in more stages – in the form of primary, secondary and (maybe) tertiary air supply at the different points of the combustion space. Since the hot wood-gas hardly intermixes with the cold air, practically an air excess of 70 % (λ = 1.7) is required to provide the stoichiometric combustion-gas to combustion-air ratio. The design of the combustion chamber of the boiler and the quantitative control of the induction of combustion air basically influences the utilization efficiency of the solid fuel matter. The dual goal of the control is –

1 the power control for matching the heat performance of the boiler with the power demand of user and

2 the control of the combustion process for decreasing the harmful-matter content of the flue gas

Since the control takes place by throttling the combustion air flow, the rated efficiency of 72 to 86 % given by the boiler manufacturer can be referred only to the planned heat power and even this ideal value is lower than the 92-% efficiency of the traditional gas boilers – not to mention the achievable value of the condensation technique.

The firing control must provide such a combustion quality in all boiler-load states which ensures a low polluting-matter emission. Beside the combustion-air control, the application of the feed-back of flue-gas as well as the mechanical fuel feeding helps to perform this goal. However, the required solid fuel must be homogeneous as to its material, particle-size composition, moisture content and heating value.

Practically, the ground or chopped fuels are considered as homogeneous matters. Amongst the wood-chips firing large devices, the control of the fluid boilers is the simplest. The boilers with underfeed or overfeed firing are more sensitive to the particle-size distribution of the chips mass due to the spreader stoker [3].

2. MATERIALS AND METHODS

The international trends of researches on biomass firing can be briefly summarized as follows:

- The fundamental researches are focused on the chemical description of the combustion process, the measurement and comparison of the calorific values of biomass fuels and their mixtures.
- The applied researches concentrate on determining the size range of fuel chips to be burned in the different boiler (furnace) types.

In the first case, the experiments are carried out with samples of some grams so the after-grinding of the bulk – in this way changing the combustion properties – is unavoidable. These types of measurement have an integrating effect; accordingly, they do not provide information about the course of the process and the effect of the original structure.

In the second case, the biomass congeries is optimized according to the demands of the boiler (furnace) type. Taking the combustion properties into consideration is only one of the points of view in the optimization. With a chain-grate boiler type, for example, the grate pitch limits the minimum size of the fuel chips.

Consequently, it can be established that both the calorimetric tests and the firing experiments carried out in in-plant conditions are insufficient for qualifying fuel chips. The condition of the reproducibility is the use of an independent laboratory measuring system from the blast patterns of the actual boilers.

This is why the effect of the structure of the fuel congeries was analysed by the method of derivatography. Originally, this technique was elaborated for measuring the volatile and ash content of fuels. The test device is a program-controlled burning furnace with standard parameters, connected with a digital scale. With the help of the test process, the mass decrease of a fuel substance with unknown composition can be continuously measured and recorded as a function of the programmed temperature zones and time. Even a 300-g sample can be put in the furnace so the after-grinding or chopping is not necessary. In accordance with the standard CEN/TS 14775:2004 elaborated for lignocelluloses, the sample desiccates in the first period of 105 °C and then, between 250 and 550 °C, the dry distillation of the biomass takes place. In the course of this, volatile matters (hydrogen, nitrogen, sulphur, oxygen, carbon monoxide, methane and other light hydrocarbons – together composing wood-gas) as chemical reaction products leave the sample and a certain amount of charcoal (similar to the coke) remains and its dominant part is chemically pure coal. Finally the charcoal burns between 550 and 850°C and only some percents of ash remains from the sample. Accordingly, the processes of drying-degasification-burning are carried out in three temperature stages, and drawing apart in the time. With this method, an accidental explosion caused by an intensive gasification can be prevented but it cannot be considered a single-variable process because the combustion takes place mainly during the heating-up. Consequently, the standard test is suitable only in part to answer the questions of the authors. For eliminating the transient processes, it is reasonable to place the sample in the burning space of the preheated furnace.

In order to protect the measuring instrument of the accredited laboratory, a new (and cheaper) device had to be constructed. Such an annular furnace was purchased where the heating coils were built in the sidewall of the device so the top cover could be bored through and, by a drop-in device mounted on the cover, the sample could be inserted into the preheated furnace. With the process of derivatography because of the small amount of sample, instead of the weight of the complete furnace, the weight of the incinerator pot has to be directly measured. It was solved by a precision scale mounted under the furnace, equipped with transmission elements made of heat-resistant ceramics. The method of measurement was as follows: The prepared, photographed and documented sample was dropped in the preheated furnace. The scale was tared and the measurement was carried out up to the mass constancy (ash content). Without emptying the incinerator pot, after dropping the following sample in, the scale was tared again. So the furnace did not cool down and, utilizing its thermal inertia, a large amount of data could be collected in a short time. Against the recommendation of the standard, the temperature of the furnace was chosen to 450 °C. Several preliminary experiments were carried out before selecting the temperature value during which it was established that the full combustion of the sample took place at this temperature and, at the same time, the explosion of the vapour from the remnant moisture content of the air-dry sample and wood-gas developed by a quick degasification should not be expected.

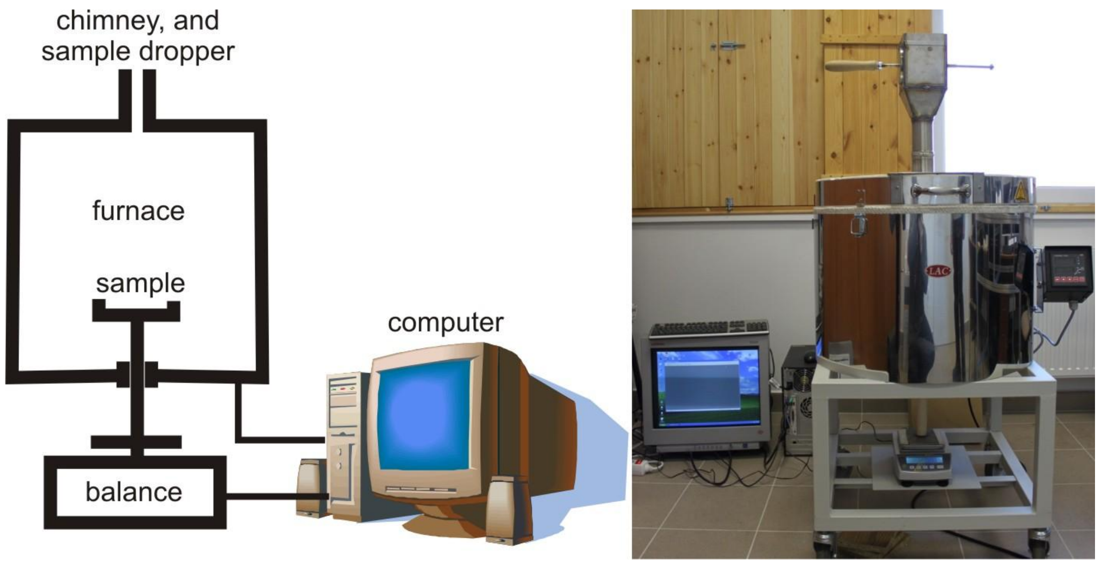


Figure 1. The modified derivatograph

The practice consider the fuel chips as homogeneous mass but, according to the experiences in this research, the congeries gained by grinding or chopping, as to their size distribution, are not quite homogeneous at all; nor the experiments are reproducible or the test results – comparable. During the laboratory tests artificial structures were mainly used because of the above described circumstances. In this article, those experiments selected from the others are presented which carried out on showing the effect of the comminution degree of the congeries, the composition of the mixture bulks upon the combustion characteristics. For these, two sample sets with different artificial structures were prepared. Their common property was that the inhomogeneity in material quality of the congeries components was precluded. The wood dowels available in do-it-yourself stores were found as the most uniform fuel material. These are made of birch duramen with an acceptable size tolerance from the view point of the tests. The congeries structure used in the investigations was made by re-cutting and mixing together the dowels. The samples containing also bigger pieces were manufactured from softwood roof battens. As the samples were cut from the same batten, the combustion properties can be considered as approximately equal here as well.

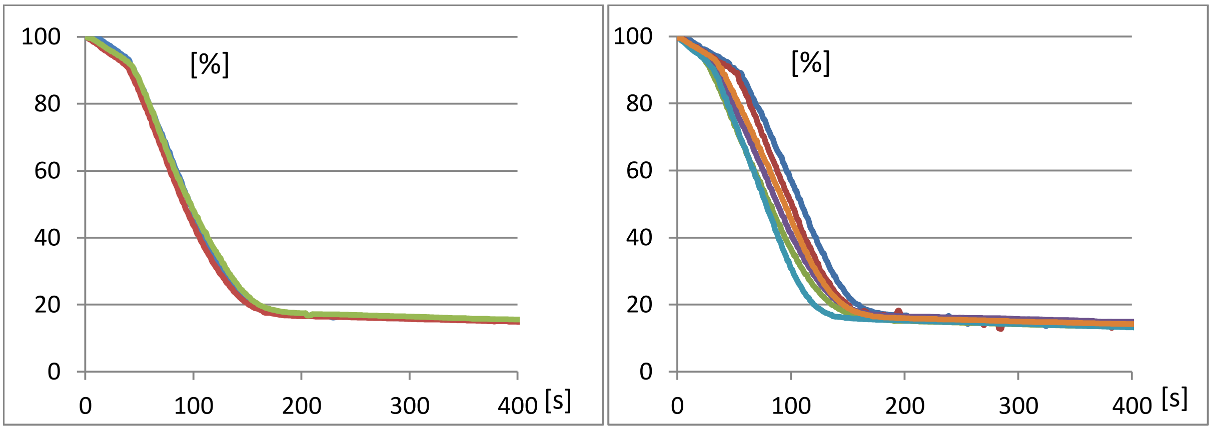
3. RESULTS

Authors searched for the reply to two basic questions with the help of the above presented experiments of derivatography:

1 Is there an optimal congeries composition existing in terms of firing? With the help of the artificial structures, authors searched for such signs indicating the dominance of composition which basically determine the combustion parameters of the congeries.

2 The combustion takes place in the form of surface-reaction so the fuel material must be ground (chopped or cut) to the possible finest particles. However, the compaction of the extremely over-ground fuel particles can cause also an air shortage in the firing equipment. Consequently, the second question can be stated in the following way: Is there an optimum existing below which it is already not expedient to decrease the size of fuel particles?

For examining the ideal congeries composition, sample masses composed of wood dowels re-cut at different degrees were selected. It was established that the theoretically predicted relationship between the comminution degree and the dynamics of combustion is valid. However, with the mixture structures, the spatial order of the particles basically influences the combustion speed. Mixing 20 to 25 % fuel particles with the size deviating even by a magnitude order in the bulk will not change the combustion characteristics of the congeries yet; the experiment takes place in the expected way according to the dominant size fraction. After mixing 50 % small fraction in the bulk, the course of the combustion process cannot be predicted.



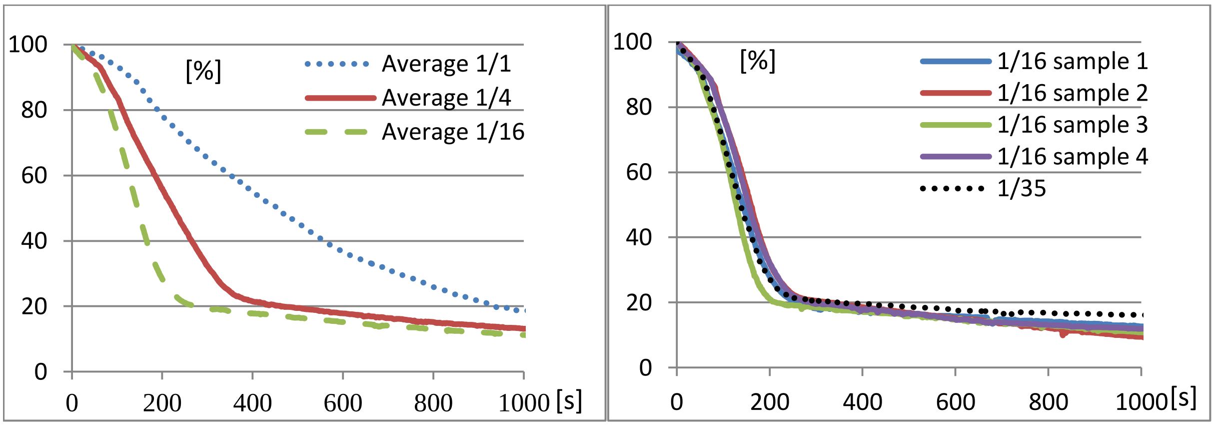
20 % small fraction   50 % small fraction

Figure 2. Derivatograms of wood dowels

During the repetition of the experiments, the results can be found anywhere between the combustion curves of the two fractions. This means that the speed of the mass decrease taking place in the course of the combustion also depends on the free surface area formed due to the stochastically ordered particles of the congeries – and not only on the total surface area of the bulk. This is denominated as channelling effect in the professional editions of English language. Along the ordered flowing paths formed in the congeries, the propagation speed of the flame front increases. The unpredictable behaviour of the fuel mixture is caused by the ventilating cavity system which is clogged when the congeries collapses but then newly formed randomly along another pathway. In a homogeneous congeries, the lengths of the clogging and the developing channels are not significantly different so the data of the repeated experiments show slight deviations. For demonstrating this observation, further experiments were carried in which the fuel particles were arranged in a wire net in such a way that the congeries could keep this order during the full combustion. With the congeries prepared in this way, the reproducibility of the combustion experiment significantly improved.

Figure. 3. Wood towels sample, and ash in the cage

When determining the optimum of comminution degree, besides the homogeneity of the fuel material, just the mentioned channelling effect was employed in reducing the impact of the random arrangement of congeries. The fuel samples were prepared by lengthwise splitting wood prisms of 40 g mass. So practically the channelling was increased up to the degree at which the increase of the free surface area already caused no change in the dynamics of mass decreasing. During the investigation the main question was whether such an optimum exists or no rather than determining the optimum particle size by measurement. By the experience of authors, the optimum exists – already no significant difference was found between the derivatograms of the sample prism split into 16 pieces and the sample split into 35 pieces.



(Specific surface of samples 1/1 = 3,4 cm^2/g, 1/4 = 6,1 cm^2/g, 1/16 = 11,5 cm^2/g)

Figure 4. Derivatograms of splitting wood prisms

The degasification and the burning process, due to the deviating time demands, might indicate different characters but the functions of mass decrease (m) vs. time (t) – even with the single-step process taking place by applying the sample-drop-in device – can be approached by the arc-tangent function introduced earlier by authors [1]:

$$m(t) = a + b\frac{\operatorname{arctg}\left(\frac{t-c}{d} + \frac{\pi}{2}\right)}{\pi}$$

The regression functions and the quality factors of curve-fitting have not been shown in the figures since the numerical indication of the parameters does not provide essential extra information for better understanding of the processes.

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