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Biomass Co-Combustion Process Assessment Using Series of Flame Images

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Оценка совместного сжигания биомассы на основе очереди изображения пламени

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Оцінка сумісного спалювання біомаси на основі черги зображення полум'я

The article presents the way of assessment of biomass coal mixture combustion using information in a form of flame area changes determined for image sequences. The images were captured by a dedicated visual system equipped with CMOS camera and a borescope that enabled observing flame zone located near burner at 45° to flame axis. Several laboratory combustion experiments were carried out when thermal power and excess air coefficient were set independently for fuel mixtures with biomass content of 10% and 20%.

Key words: biomass co-combustion, flame, image processing.

В статье представлен метод оценивания сжигания смеси биомассы и угля при использовании площадей пламени, которые определенные в сериях изображений. Изображения были зарегистрированы специальной видео-системой, состоящей из КМОП камеры и бароскопа. Поэтому можно было наблюдать зону пламени непосредственно около горелки под углом 45 градусов к её оси. Проведено серию экспериментов, в которых независимо изменялись тепловая мощность установки и коэффициент избытка воздуха для смесей с содержанием 10% и 20% биомассы.

Ключевые слова: совместное сжигание биомассы, пламя, обработка изображений.

У статті представлений метод оцінювання спалювання суміші біомаси та вугілля при використанні площ полум'я, які визначені в серіях зображень. Зображення були зареєстровані спеціальної відео-системою, що складається з КМОП камери і бароскопа. Тому можна було спостерігати зону полум'я безпосередньо близько пальники під кутом 45 градусів до її осі. Проведено серію експериментів, в яких незалежно змінювалися теплова потужність установки і коефіцієнт надлишку повітря для сумішей з вмістом 10% і 20% біомаси.

Ключові слова: спільне спалювання біомаси, полум'я, обробка зображень.

Introduction

The European Union have expressed that policy by endorsement a firm commitment of individual countries to reduce greenhouse gases by at least 20% by 2020, in comparison with the 1990 level. The main goal of this climate package is to make changes in the European industry and energy sectors, regarding to the development and implementation of low-carbon renewable energy technologies as well as energy efficiency. The package, known as “3x20”, includes CO_2 emissions reduction by 20%, energy consumption drop by 20% and increase in the renewable energy share the EU up to 20% (from the current 8.5%) by the year 2020. Achieving these objectives of the climate and energy package requires development and implementation of a large-scale portfolio of low carbon technologies

Co-firing of coal and biomass is one the easiest and cheapest way of using renewable energy source for the possibility of using existing combustion facilities. Biomass-coal co-combustion can be quickly adapted in large-scale systems. Combustion process is stabilized by presence of coal in fuel mixture. Moreover, substituting biomass for coal reduces SO_2 emissions as well as NOx due to the low sulfur and low nitrogen contents of biomass [1]. Another advantage of biomass co-firing is higher volatile contents and high reactivity of both fuel and resulting char [1], [2].

On the other side, biomass-coal co-firing has significant drawbacks. Biomass contain less carbon and more oxygen than coal, that results in lower heating value. High moisture as well as ash content can be a reason of possible combustion stability problem. On the other side, higher chlorine contents rise corrosion rate. The melting point of the ash can be low. It causes increased slagging and fouling of combustor surfaces that reduce heat transfer and result in corrosion and erosion problems. Comparing to coal, biomass has lower density and friability that results in possible stratification of fuel mixture contents during its conveyance to burners. What is more, both physical and chemical biomass parameters of biomass are unsteady in time.

All the mentioned above factors affect the boiler operation and make combustion process course difficult to lead. Thus, application of a proper monitoring system is essential to ensure proper operational conditions.

Flame, being the main reaction zone of a combustion process is the quickest source of information. The measurable physical attributes of a flame, such as magnitude and shape of luminous area, flicker frequency provide vital information of the combustion process. Optical sensing methods conjoined with advanced signal analysis allow relatively cheap, non-intrusive characterization of combustion process, that can be held in real-time [3]. Analysis of flame images allows to determine various parameters of flame such as geometric (e.g. size, position), radiation properties (e.g. emission spectrum, irradiation distribution) [4-9].

This paper presents investigation of flame area using imaging techniques obtained for different states of combustion process. Laboratory tests were carried out a few settings of secondary air flow and thermal power for two different coal-biomass mixtures.

2 Laboratory Combustion Facility

Combustion tests were done in a 0.5 MW_{th} (megawatt of thermal) research facility, enabling scaled down (10:1) combustion conditions. The main part is a cylindrical combustion chamber of 0.7 m in diameter and 2.5 m long. A low-NOx swirl burner about 0.1 m in diameter is mounted horizontally at the front wall. The stand is equipped with all the necessary supply systems: primary and secondary air, coal, and oil. Pulverized coal for combustion is prepared in advance and dumped into the coal feeder bunker. Biomass in a form of straw is mixed with coal after passing through the feeder.

The combustion chamber has two lateral inspection openings on both sides, which enable image acquisition. A high-speed camera with CMOS area scan sensor was placed near burner’s nozzle, as shown in fig.1.

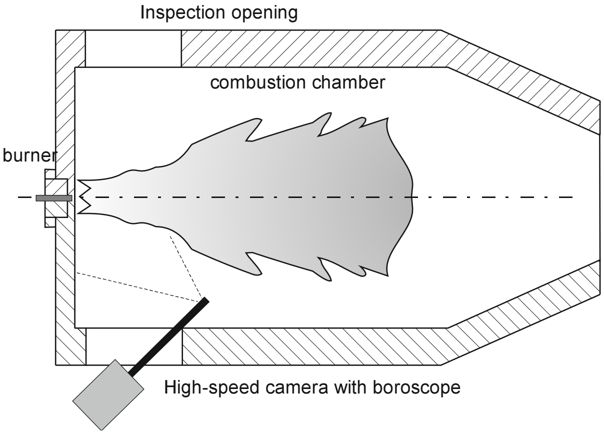

Fig. 1 – Combustion chamber with camera mounting

Flame images were transferred from the interior of the combustion chamber through a 0.7m borescope. The camera was capable to acquire up to 500 frames per second at its full resolution (1280×1024 pixels). The optical system was cooled with water jacket. Additionally, purging air was used to avoid dustiness of optical parts.

3 Combustion tests

Combustion tests consisted in initial warming up the combustion chamber with oil burner, that lasts about 10 minutes. When temperature inside the combustion chamber reached the appropriate level (~200°C), coal- biomass mixture was delivered to the burner. After reaching the proper temperature level, the oil was switched off. The fuel mixture was delivered by, so called, primary air. Excess air coefficient was determined through secondary air flow, whereas primary air was used only for fuel feeding.

Combustion testes were done for different combinations (variants) of the combustion facility, where thermal power (P_{th}) and excess air coefficient (λ) were set independently for known biomass content, where λ is defined as quotient the mass of air to combust 1kg of fuel to mass of stoichiometric air. The exact values of thermal power and excess air coefficient are collected in Table 1.

Table 1 – The variants of biomass-coal combustion tests

Variant #	1	2	3	4	5	6	7	8	9
P_{th} (kW)	250	250	250	300	300	300	400	400	400
λ	0.75	0.65	0.85	0.75	0.65	0.85	0.75	0.65	0.85

The tests were performed for two fuel mixtures containing 10% and 20% of biomass (straw) respectively. During the combustion tests, physical properties of biomass (particle size, inherent moisture, etc.) remained unchanged as well as the all image acquisition parameters, such as camera gain, frame rate, exposure time. Flame images were captured for every variant of the combustion facility and different fuels mixtures. The images were converted to 8-bit grayscale, thus pixel amplitude was ranging from 0 to 255. Flame area within each frame of the acquired image sequence was determined on the basis of pixel amplitude. Such an assumption was possible to accept for the flame was far brighter than any other objects within field of view of the borescope applied. Flame area was defined as a sum of all the pixels that were contained within the flame region.

4 Experiment results

Changes of flame area that were obtained for fuel mixtures with 10% and 20% content of biomass obtained for different values of thermal power and excess air coefficient are presented in Fig. 2 and 3, respectively. Every combustion state defined by set of constant values of P_{th}, λ, and biomass content was represented by 2000 images.

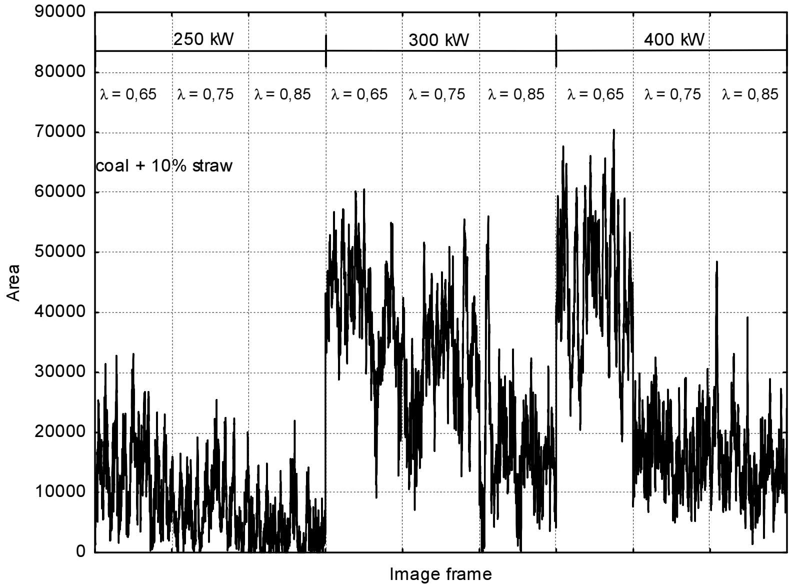

Fig. 2 – Flame area obtained for different states of combustion process – coal with 10% of biomass (straw)

Generally, raise of thermal power of combustion facility cause increase of flame area, as shown in Fig. 2 and 3. It could be also observed in Fig. 4-7 for mean values of flame areas.

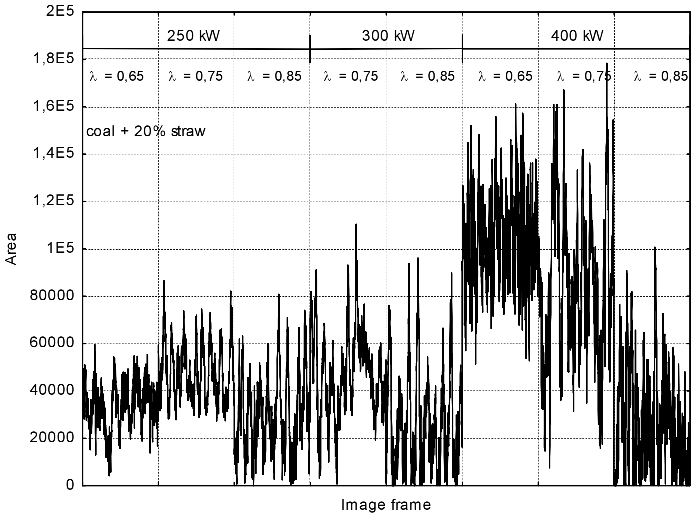

Fig. 3 – Flame area obtained for different states of combustion process – coal with 20% of biomass (straw)

Another important factor is flame area variability calculated for each combustion state. It is marked in Fig 4-7 as double standard deviation (SD) of flame area.

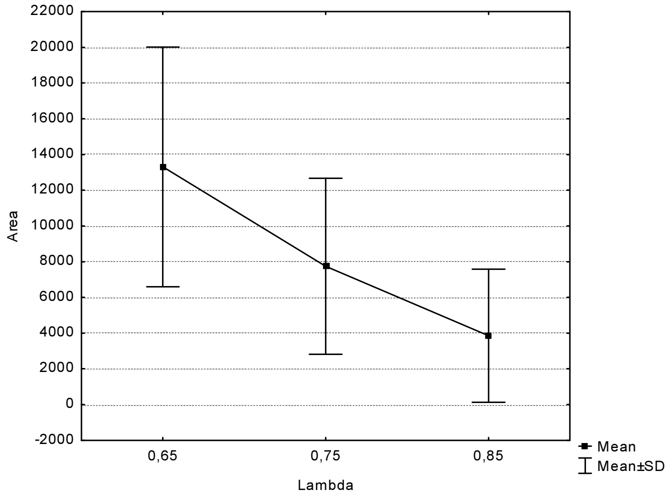

Fig. 4 – Mean values of flame area for different excess air coefficients (lambda) obtained for coal with 10% of biomass added for P_{th} = 250kW.

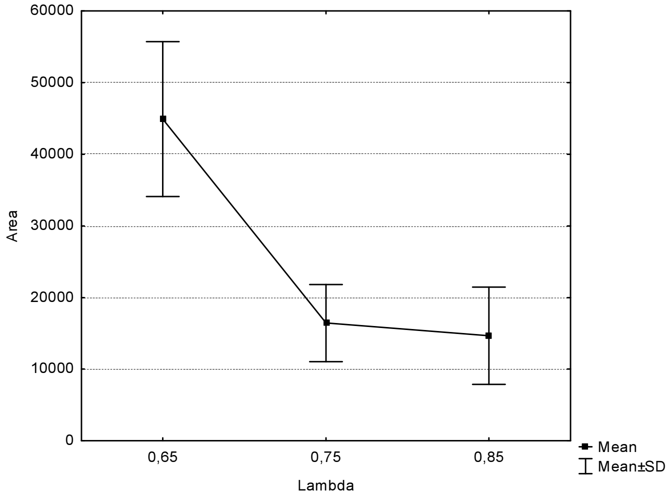

Fig. 5 – Mean values of flame area for different excess air coefficients (lambda) obtained for coal with 10% of biomass added for P_{th} = 400kW

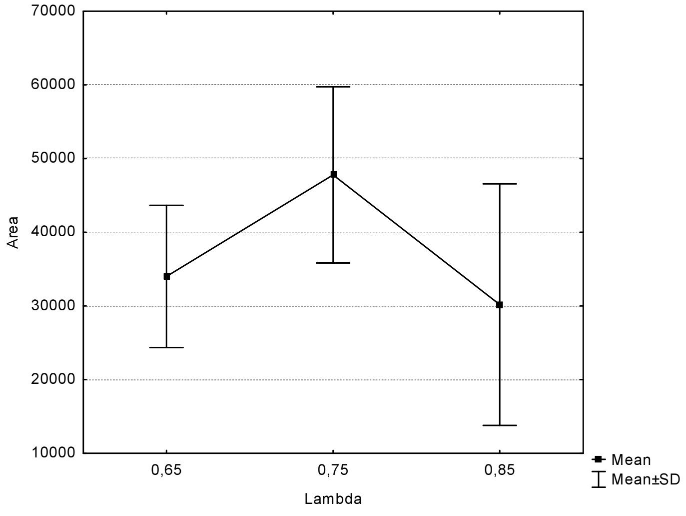

Fig. 6 – Mean values of flame area for different excess air coefficients (lambda) obtained for coal with 20% of biomass added for P_{th} = 250kW

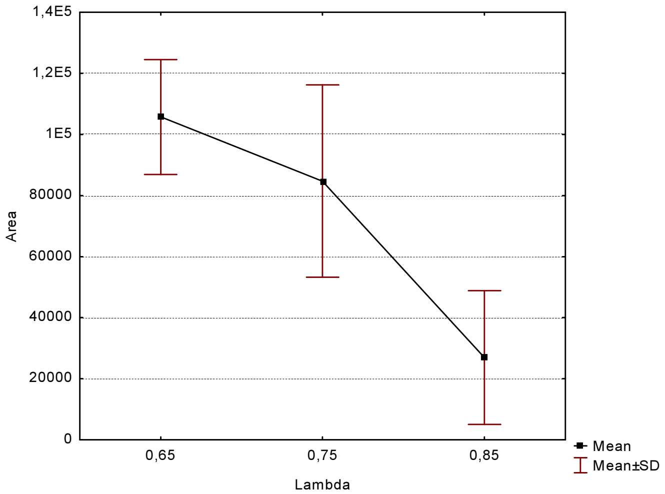

Fig. 7 – Mean values of flame area for different excess air coefficients (lambda) obtained for coal with 20% of biomass added for P_{th} = 400kW

Amount of excess air coefficient greatly affects combustion process. However, mean value of flame area has different dependences on λ for different values of thermal power. For P_{th} = 400kW flame area decreases when excess air coefficient increases for fuel mixtures with 10% and 20% of biomass (Fig.5 and Fig.7), whereas for P_{th} = 250kW they show different kind of dependence (Fig.4 and Fig.6).

Comparing the mean values of flame area for the same excess air coefficient it could be observed that flame area is larger for fuel mixtures with higher biomass content. This is due to the fact that generally biomass contain more volatile contents comparing to coal.

Flame area also points to possible unstable combustion that were reported for higher excess air coefficients regardless the thermal power (Fig.2 and Fig.3) and observed as sudden changes of the discussed parameter as well as its values equal to zero. Unstable combustion is the more serious problem the more biomass is added (Fig.3).

Conclusions

It should be noted, that the flame area strongly depends on the way the flame area was defined. Usually, during laboratory tests camera is mounted perpendicularly to burner axis [4-9]. Thus distance between burner and flame ignition point [4], [7] could be estimated as well as spread angle of the flame that provides vital information of combustion process state. However in practice, in case of existing full-scale power boilers it is nearly impossible to mount a camera close to a burner, perpendicularly to its axis for it would usually require serious interference in boiler's shield. That is why, alternative camera set-up was examined.

Flame area by many is used as one of main pointers of combustion process state [4-9]. Another important factor is it can be easily estimated in a series of images, thus it could be used in real-time applications regardless the place of camera mounting. It should be underlined that the factors investigated that were used for combustion process assessment strongly depend on burner type and size of combustion chamber and thus cannot be used directly in full scale combustion facilities.

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RESUME

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Biomass Co-Combustion Process Assessment Using Series of Flame Images

The paper presents investigation of flame area for biomass and coal co-combustion assessment. During research presented, vision techniques were applied for a series of flame images for which flame area was determined. Experiments were carried out at different states of combustion process, taking thermal power and excess air coefficient into account. Mean value as well as standard deviation of flame area was examined as a pointers of a combustion process state.

It was shown, flame area is generally larger for fuel mixtures with higher biomass content. Flame area also points to possible unstable combustion that were reported for higher excess air coefficients regardless the facility thermal power.

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