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Full Length Article

# Light-induced gasification of the coal-processing waste: Possible products and regimes

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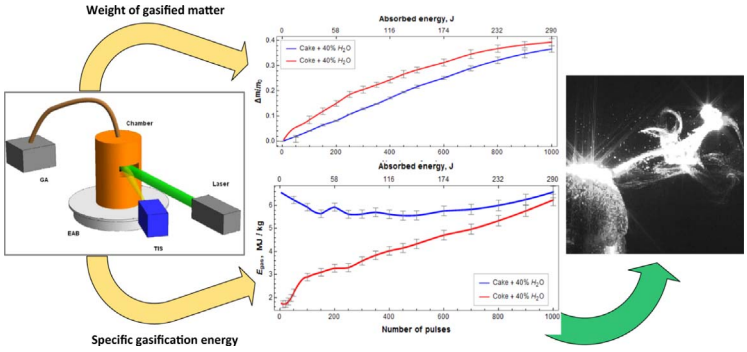
## GRAPHICAL ABSTRACT

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## ABSTRACT

The laser processing becomes more and more popular for different objects and purposes including different fuels and combustibles. We have investigated experimentally some details of the light-induced conversion of the waste-derived coal-water slurry into the syngas. The process was "cold" enough (the temperature of the fuel was less than 350 K). The specific gasification energy strongly depends on the chosen content of the raw fuel and does not exceed the 6 MJ/kg. It was shown that there are two possible alternative processes with dominant production of the hydrogen or methane. The production of the combustible gases is accompanied with generation of certain amounts of $SO_2$ and much less amount of $CO$.

## 1. Introduction

Current trends about the widespread introduction of the recycling of industrial waste require the intensive research paving the new ways to preparation of the industrial fuel [1–3]. The waste of coal- and oil-processing are the very attractive sources of combustible raw materials for preparation of the suitable secondary fuel [4,5]. However, their usage in conventional heaters is conjugated with certain problems. The rheological and thermal properties of such composite fuels differ a lot from the traditional ones [6,7] and, therefore, an essential modifications of the heater furnaces is needed together with adaptation of the fuel feeding infrastructure [3].

The principally another way is a special pre-processing of the fuel composition which allows effective transformation of the waste-derived fuel into the combustible gas [8]. The gasification of different solid or liquid combustibles is the well-known way of their adaptation for the industrial applications or even for usage in the car engines [9]. Combustion chambers of such systems do not need the global modifications

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for the usage of different gasified fuel.

Various schemes of the thermo-chemical processes were developed for fuel gasification during the last century [10,11]. However, the most of them need the high temperature (~ 1000–1600 K) or/and high pressure (up to 80 bar) processing of the raw fuel like Bergius process, Sabatier process or the very popular Fischer-Tropsch process [12]. All mentioned processes as well as a lot of other similar consist of carbon oxidation reactions supplemented by the set of hydrogenization channels making as result the mixture of $CO$,$CO_2$,$H_2$, saturated hydrocarbons and water steam, called the synthesis gas or syngas [10].

The years of investigations in fuel related area show that the hydrogen is an ideal fuel from energetic and ecological point of view. It has highest calorific value per unit mass (~ 142 MJ/kg) together with production of the usual water as result of combustion [9]. Therefore, the possibility to convert the waste-derived fuel into the gas mixture with high hydrogen content is always of interest for scientists.

The most popular ways of the relatively cheap industrial production of the pure hydrogen are connected with thermal conversion of the hydrocarbons by different processes or its catalytic conversion [13]. There are some thermochemical processes that make the hydrogen from the fossil fuels (like a steam-reforming, auto-thermal reforming and thermal partial oxidation) as well as hydrogen production from biomass by thermochemical and biological processes [14]. The component ratio of products of the hydrocarbon fuel conversion strongly depends on physical conditions of the gasification and initial chemical content of the fuel.

The early mentioned thermal decomposition processes are conjugated with essential risks of fire and explosion together with technical complexity of realization of the durable high-temperature processing. Thus, the typical gasification systems are big and expensive stationary facilities with corresponding fire-protection design. Another limitation of traditional gasification techniques is their low suitability for highly viscous waste-derived fuel compositions (like tar) which are a very problematic for recycling.

*In this paper* we continue the investigations of light-induced gasification of the waste-derived fuel compositions that was started in [15]. The aim of this investigation is to clarify the effect of the raw fuel content on the results of the laser gasification of the waste-derived coal-water slurry (CWS). Additionally, we observe the effect of the trivial fuel heating by the laser pulses and corresponding losses of an energy.

Such approach allows an effective utilization of numerous wastes by the most ecological way [3]. It makes numerous wastes the very suitable for utilization in most of the industrial heaters without expensive modifications. In contrary to the catalytic techniques, it does not need the expensive catalysts as well as the pressurization. The modern laser systems allow creation of the cheap fuel gasification system with high-performance based on the semiconductor laser diodes. The huge variety of working regimes can be realized by such systems, covering any needed conditions of the energy delivery.

## 2. Materials and methods

We have prepared two types of the samples: with high content of the volatiles and good wettability (based on filter cake of fiery coal, containing flocculants and surfactants) and the samples which does not contain the significant amounts of volatiles and with weak interaction with water (based on the coal coke with water). In both cases the coal particle size was less than 100 $\mu$.

The first type of fuel samples for gasification were the droplets of a coal-water slurry that consists of ~ 60 wt% of fiery coal powder with 40 wt% of water. The filter cake contains up to 36 wt% of combustible volatiles in bound state (like in [16]). Therefore, we have the rich mixture of various hydrocarbons with water and ash components. The second type of the samples is mostly pure carbon with inclusions of ash components filled by ~ 40 wt% of water. The water content was especially done almost equal for both types of samples to avoid the strong differences in heat exchange processes during the laser processing.

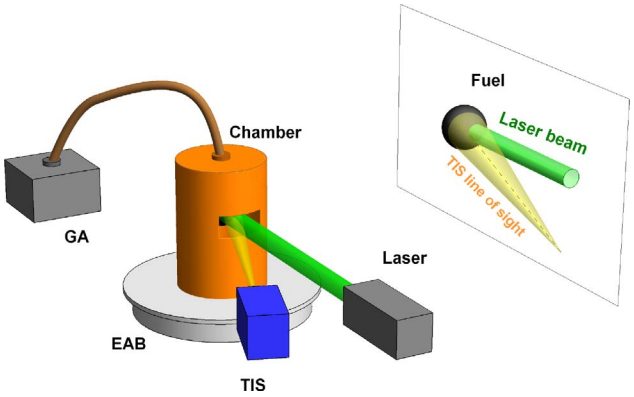


**Fig. 1.** The scheme of the experimental setup. The fuel portion is inside of copper chamber staying on the plate of electronic analytical balance (EAB). The laser and thermal imaging system (TIS) are working through the window of chamber. The gas analyser (GA) is connected to the chamber by the thin pipe. The inset shows the light paths inside the chamber.

The initial weight of the fuel sample always was near 0.15 g that was controlled by the electronic balance.

We have used the slightly modified earlier reported [15] approach when collimated laser beam ($\lambda$ = 533 nm, light spot diameter at the sample ~ 3 mm) was illuminating the fuel sample that was placed inside special chamber. The chamber with inner volume approx. 2 $cm^3$ was staying on the sensor plate of the electronic analytical balance to check the weight changes during the gasification. The analytical balance allows quasi real-time measurement of the sample weight with precision up to 10 μg.

The gas products of the conversion can get out easily through the hole at the top of the chamber. The soft pipe can be connected to this hole when we start the gas analysis. It is worth noting, that precise and simultaneous measurements of the sample weight and pyrolysis gas content are impossible. This is because the huge errors of weighing introduced by the elasticity of the pipe.

The principal scheme of the setup is shown in Fig. 1. Inner volume of the chamber was used for accumulation of the gas products and its following analysis by the gas-analyser “Boner” Test-1 specially adapted for analysis of the gas flows with low expiration rate (~ 7–10 $cm^3$/min) at atmospheric pressure.

The typical errors of the gas concentration measurements do not exceed the 6% of the detected value for oxygen and 12–14% for other gases.

The laser beam was injected inside the chamber through the side hole which also was used for optical control of the sample temperature. The laser was working in pulsed mode to prevent the intensive regular heating of the sample. Together with this, such mode allows the very high peak power to satisfy the ablation conditions. Therefore, we have realized the situation when the main mechanism of the gasification is an ablation instead of traditional pyrolysis going through the inductive volume heating.

The pulse energy was near 290 mJ and the pulse duration was ~10 ns. The pulse repetition rate was 2.5 Hz, therefore, the average power of the light radiation was 0.725 W. These parameters differ enough much from the earlier described in [15]. We have switched to the higher peak power and lower average one to decrease the effects of fuel heating together with stimulation of the ablation. The driving software allows generation of an exact amount of pulses, therefore, the weight control in process of the fuel conversion was accompanied with an exact control of the absorbed energy (laser has a drift of the pulse energy <2%).

The thermal imaging system (TIS) Testo 885-2 allows remote measurements in range from room temperature up to 1470 K with error level approx. 2% of measured value. The TIS was used to check the