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Optimization of Air Flow in the Gasification Chamber of the Gasification Boiler Using the PIV Method

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Abstract. The article deals with the optimization of biomass combustion in a small heat source using the optimal distribution of combustion air. Uneven distribution of combustion air was observed during certification tests and in real operation of the used heat source and has an impact on uneven combustion of biomass in the gasification chamber, on increasing emissions and combustion losses. In the first phase of the research, optimization was carried out using CFD simulations, then a transparent model of a real heat source was created, on which the real distribution of combustion air in the gasification chamber was observed using the Particle Image Velocimetry (PIV) method. The results of CFD simulations and the PIV method led to the optimization of the cross-sectional profiles of the four supply channels for gasification air supply. CFD simulations and subsequent PIV measurements on the experimental device were carried out without real combustion, only the air flow in the empty gasification chamber was investigated. This approach was chosen in order to simplify calculations and experiments and on the assumption that with optimal distribution of combustion air in the empty chamber, there will be an optimal even during real combustion. The flow of primary air in the gasification chamber in real operation is influenced by the size and shape of the inserted biomass and its location in the chamber, and this influence is random and difficult to verify. After optimization, the distribution of the primary combustion air in the gasification chamber is uniform and the same amount of air flows into the chamber through the four combustion air inlets.

1 Introduction

Gasification heat sources are a modern method of energy use of biomass, in which combustion takes place with high efficiency and low emissions. During gasification, pyrolytic distillation takes place, during which all combustible parts of the fuel are gasified. Combustion takes place in a three-stage process and can be divided into three zones. In the first zone, the drying and gasification of wood takes place under the access of primary combustion air, volatile substances from the fuel are released. Gasification is basically the thermal decomposition of organic and inorganic substances in a closed chamber of the boiler

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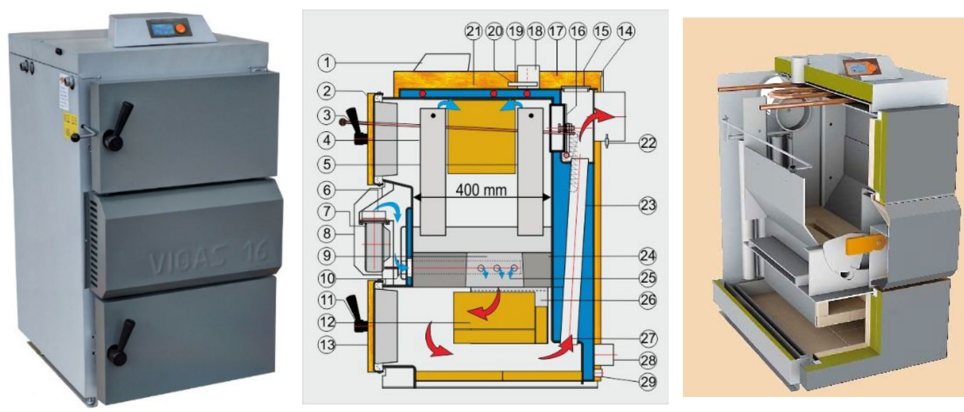
under a slight overpressure, which is created by a combustion air fan. This gasification process takes place in the boiler reservoir, above the concrete nozzle. In the second zone, the released gases are mixed with preheated secondary air in the nozzle space and form a burning mixture of gases. In the third zone, the gases in the uncooled combustion chamber of the boiler are completely burned and the flue gases are discharged through the tubular heat exchanger into the chimney. This controlled method of combustion guarantees high efficiency - 80-90 %, the heat output of the boiler is continuously adjustable in the range of 40-100 % of the nominal output. [1, 2]

Test operation on a real device pointed to incomplete combustion of the fuel in its gasification chamber, unburned fuel remained in the gasification chamber, which indicated an uneven distribution of operating conditions, such as an uneven distribution of the primary combustion air. Increased emissions and a decrease of nominal power were also recorded. It was assumed that the cause is an eccentrically located combustion air fan and unequal local and longitudinal losses in the channels leading to the combustion air outlets in the gasification chamber. Therefore, according to the construction documentation, a computational CFD model and a model of a real gasification boiler were created, on which the distribution of combustion air in the gasification chamber was experimentally verified using the PIV method. The used Vigas 16 gasification boiler is shown in Fig. 1.



a) b) c)

Fig. 1. a) Vigas 16 gasification boiler, **b)** gasification boiler section : 1. AK 4000 regulation, 2. upper door, 3. chimney damper rod, 4. gasification chamber, 5. primary air line, 6. damper actuator, 7 . combustion air fan, 8. fan cover, 9. hot concrete block, 10. secondary air flap, 11. door cap, 12. fireclay lining, 13. lower door, 14. chimney neck, 15. heat exchanger cover, 16. heating flap . 26. combustion chamber, 27. flue gas direction, 28. return water neck, 29. filling neck, **c)** 3D cross-section of the Vigas 16 gasification boiler. [8].

Important factors that influence the formation of emissions and ash are the dividing of combustion air into primary and secondary, its distribution into the inputs channels (the heat source has four primary and six secondary air inputs) and the speed of the combustion air [9]. The optimal flow of primary combustion air in the gasification chamber and secondary combustion air in the nozzle at the entrance to the combustion chamber has a fundamental influence on the process of gasification and subsequent combustion of biomass. The supplied amount of combustion air is determined by the speed of the fan, part of the total amount of air is taken as secondary air and the rest is primary combustion air. The amount of secondary air is determined by the setting of the secondary air flap [7].

2 Methods

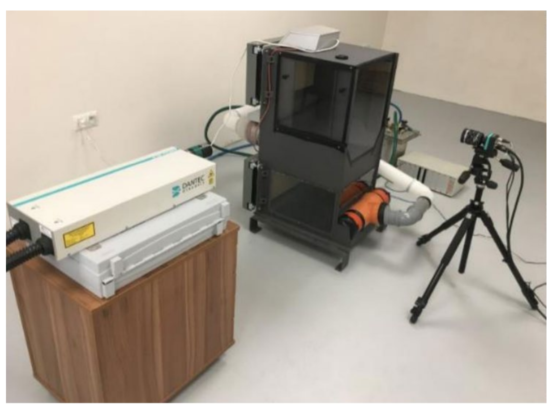
To visualize the flow of combustion air in the gasification chamber of the boiler we use the 2D PIV method, the following components were used:

- Litron Nd-YAG pulsed laser with two cavities, maximum light output 1200 mJ, wavelength 532 nm or 1064 nm.
- Flowsense EO high-speed camera, CCD sensor, resolution 2448px x 2050px, working in double-frame mode.
- FT 700 CE oil particle generator, particle size 2-5 μm.
- Dantec DynamicStudio software. [3, 4, 5, 6]

3 Experimental setup

For the experimental verification of the combustion air distribution, a Vigas 16 biomass gasification boiler was used, which was modified for the needs of using the 2D PIV method. The modification consisted in the removal of the flue gas-water exchanger, which was located in the rear part of the boiler, the covers and thermal insulation were removed from the sides of the boiler, peepholes were made in the side and rear walls of the gasification chamber - for laser illumination and recording with a high-speed camera, on the internal surface of the gasification chamber an anti-reflective black coating was applied. The modified boiler is shown in Fig. 2. The measurement took place with an empty gasification chamber, without combustion. The original exit of the flue gas into the heat exchanger was led through a pipe to the intake of the combustion air fan, oil droplets were fed into this pipe, the movement of which was then monitored using the PIV method. Air flow through the combustion air fan was measured with a propeller anemometer.

a)



b)

Fig. 2. a) Modified gasification boiler Vigas 16, **b)** Assembly of the measuring system.

The entire studied volume of the gasification chamber was divided into several evaluated parts. Looking from the side at the evaluated areas in the middle (area II.) and two near the rear (area I.) and front air intake (area III.), when looking from the back at three evaluated areas near the right combustion air intake (area A), in the center (area B) and near the left air intake (area C), the marking of the parts is shown in Fig. 3. The exact designation of the evaluated area is then marked with a combination of Roman numerals and letters (Tab. 1).

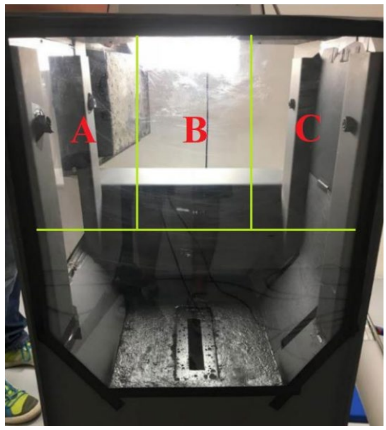


Fig. 3. Marking of evaluated areas when viewed from behind of gasification boiler.

Table 1. Marking of evaluated areas and description.

I-A	rear right air intake
I-B	rear wall in the middle
I-C	left rear air intake - furthest from the combustion air fan
II-B	the center of the gasification chamber
III-A	front right air intake - closest to the combustion air fan
III-B	at the door of the gasification chamber in the middle
III-C	left front air intake

4 Results and discussion

Measurement and visualization took place in the power range of 50 to 100 % of the nominal power of the gasification boiler, which corresponded to the setting of the combustion air fan speed. The results obtained at the nominal performance were used for the evaluation. Fig. 4 shows the progress of the experimental measurement and visualization of the combustion air flow for the evaluated area I-A.

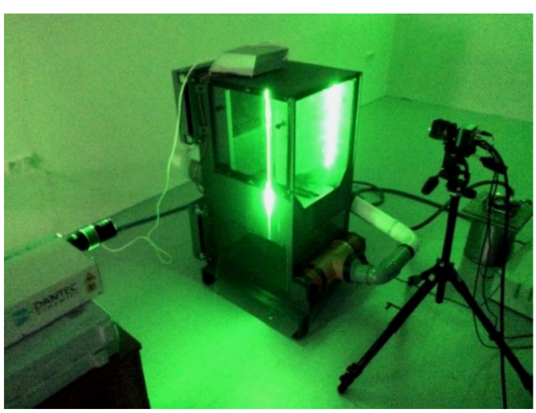


Fig. 4. The experiment.

The result of visualization of the flow in the gasification chamber are velocity profiles, which are further used to calculate the distribution of the amount of combustion air entering the gasification chamber. The measurement was carried out for each area separately at the same setting of the combustion air fan speed. An example of the measured values of the flow velocity in the I-C area is shown in Fig. 5. The calculated redistribution of combustion air in the gasification chamber is in Tab. 2. Most of the combustion air entered the gasification chamber through the air inlet that was closest to the combustion air fan – III-A, the smallest portion through the air inlet that was farthest from the fan – I-C.

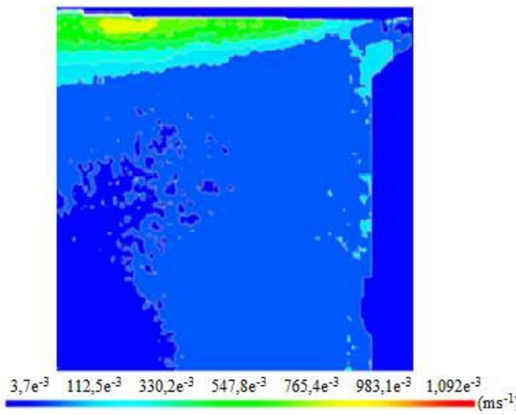
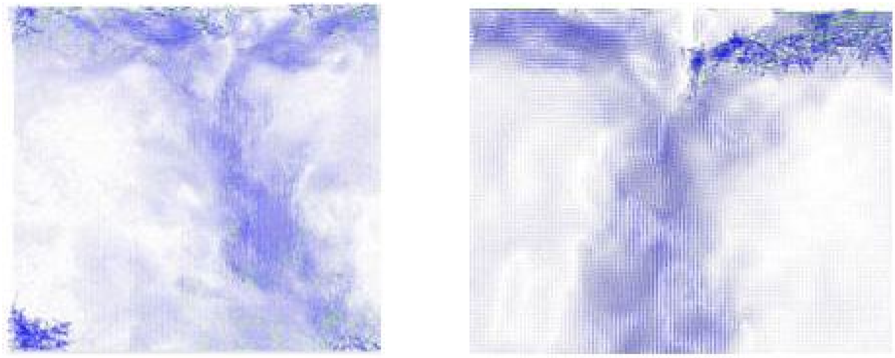


Fig. 5. The velocity scalar map in the evaluated area I-C.

Table 2. Distribution of combustion air into air inputs.

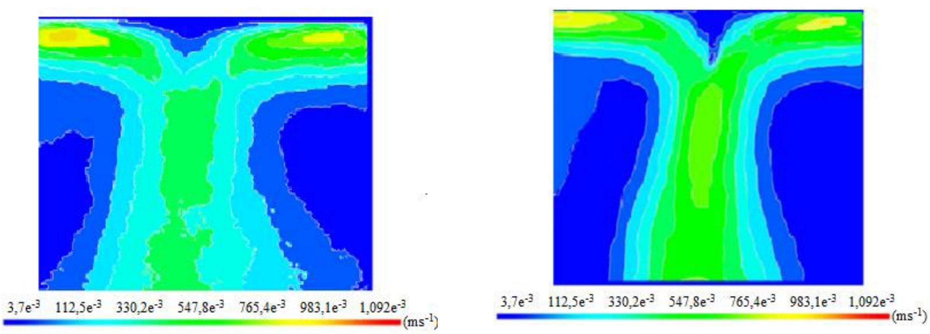
Inlet	Proportion of combustion air [%]
I-A – rear right air intake	20.4
I-C – rear left air intake (furthest from the combustion air fan)	17.6
III-A – front right air intake (closest to the combustion air fan)	33.8
III-C – left front air intake	28.2

Two variants were used to optimize the combustion air distribution. The first optimization variant was a change in the cross-section of the supply channels for the air supply. The air intakes are structurally formed by standardized U-shaped steel profiles and it is not economically advantageous to manufacture each channel by bending separately in order to achieve a change in the cross-sectional area. Therefore, a damper was placed in the outlet of each channel, which reduced the cross-section of the outlet of each channel to achieve the same flow of combustion air through each inlet channel. The second optimization variant was the placement of a low longitudinal partition in the middle of the upper wall of the gasification chamber. The purpose of the partition was to ensure that the streams of combustion air meet exactly in the center of the gasification chamber. By comparing the velocity fields in the center of the gasification chamber (I-B, II-B and III-B) before and after optimization, it can be seen that the air flow before optimization is deviated from the geometric center of the gasification chamber and does not direct axially to the combustion nozzle located at the bottom of the chamber. After optimization, the combustion air is directed exactly along the axis of the gasification chamber.



a) b)

Fig. 6. The combustion air flow in the gasification chamber - vectors, **a)** before optimization, **b)** after optimization.



a) b)

Fig. 7. The combustion air flow in the gasification chamber – scalar velocity maps, **a)** before optimization, **b)** after optimization.

The result of the optimization steps was the equalization of the air supply to the gasification chamber, the results of the optimization of the cross-sectional areas of the combustion air inlet channels are shown in table 2.

Table 3. Distribution of combustion air into air inputs.

Inlet	**Proportion of combustion air [%]**
I-A – rear right air intake	24.1
I-C – rear left air intake (furthest from the combustion air fan)	23.8
III-A – front right air intake (closest to the combustion air fan)	27.1
III-C – left front air intake	25.0

5 Conclusions

Real operation of the biomass gasification boiler showed problems with redistribution of combustion air in the gasification chamber. This assumption was confirmed by experimental measurement and visualization of the flow using the PIV method. The uneven distribution of the combustion air was manifested by the unequal speed in the mouths of the air inlets and by entrainment of the air stream after mixing in the center of the chamber away from the axis of the gasification chamber. By optimizing the cross-sectional areas of the combustion air supply channels and using a low partition in the middle of the gasification chamber, a more even flow in the chamber was achieved. Although the operation of the gasification boiler is largely influenced by the operator - the way wood is placed in the gasification chamber, we assume that the optimal distribution of the combustion air will result in the improvement of the operating parameters of the heat source.

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