EXPERIMENTAL ANALYSIS OF NEW METHODS FOR DIAGNOSTICS OF DEFLUIDIZATION PROCESSES DURING FLUIDIZED BED COMBUSTION OF BIOMASS

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Abstract

The method for diagnostics of the defluidization process, based on the comparison of values of dimensionless amplitude of pressure fluctuations in a bed, obtained at various moments of technological procedures, is proposed. It is shown that while the dimensionless amplitude of fluctuations is less than 0.1 the bed remains in a fluidized condition and defluidization does not occur. The method is experimentally verified for the fluidized bed combustion of straw pellets in a specifically developed for these purposes boiler. Reliability of the offered method is proved by means of known methods for diagnostics of defluidization: by taking into account the changes in fractional composition of the bed material, flue gas temperature measurements outside the boiler, and measurements of O_2 and CO concentrations in flue gases.

Introduction

Interest to fluidization technologies has been remaining for the last several decades due to such unique characteristics of a fluidized bed as intensive mixing of particles, high coefficients of heat and mass transfer and uniformity of the temperature field over a reactor section, etc. In such a case free moving of particles and their adequate mixing in a bed are the major advantages and requirements imposed to fluidized systems. In the course of implementation of some technological procedures (drying, particle coating, combustion and gasification of solid fuel) particle agglomeration is possible, and it leads to the complete or partial defluidization of a bed. Hence, for the processes mentioned above it is important to apply the effective methods for diagnostics of defluidization processes, which allow to make timely intervention into the technological procedures and to prevent their halt at an early stage of the process development.

Generally [1], [2] temperature measurements of a bed, space above the bed and pressure drop in a bed are taken for the identification of defluidization. However, such methods of defluidization diagnostics allow to establish the fact of defluidization when it is too late for timely intervention into the process. Meanwhile, in a number of processes, for example, in the course of fluidized bed combustion of straw pellets, defluidization can already start in 10-15 minutes after the experiment beginning [3]. As long as the defluidization process is accompanied by changes in fractional composition of a bed it must be reflected on hydrodynamics of a bed and, in particular, on the process of formation, rising and destruction of gas bubbles and on related to those processes pressure fluctuations in a bed. Therefore, bed agglomeration must influence the statistical characteristics of a random process of pressure drop in a bed [4]. However, some approaches for determination of statistical characteristics of a random process of pressure fluctuations in a bed described in the following papers [4] are suitable only for small gas velocities, beds of small particles and have not been proved under real conditions of technological procedures.

To study the defluidization we have chosen the process of fluidized bed combustion of straw pellets (table 1). A technology of combustion of straw pellets and other biopellets with low melting point in the fluidized bed formed by pellets alone and solid products of combustion was suggested [5].

Table 1. Pellet characteristics.

Characteristic name	Straw pellets
Diameter, mm	7,0
Pellet average length, mm	12,03
Pellet diameter to average length ratio	0,59
Pellet density*, ρ kg/m^3	1190
Pellet bulk density, ρ_b, kg/m^3	487,9
Bed porosity at minimal fluidization, ε ($\varepsilon = 1-\rho_b/\rho$)	0,59
Pellet heating value, mJ/kg	15,42
Ash content, %	4,38

Defluidization was simulated by changing the bed condition from fluidized to fixed, i.e. we supposed that the statistical characteristics obtained during bed sediment would be the same as during defluidization.

Experimental

To carry out the experiments we used an experimental boiler plant with an experimental hot water boiler of the capacity of 200 kW (fig. 1), a fuel storage bunker, fuel supply system, and automation and control equipment.

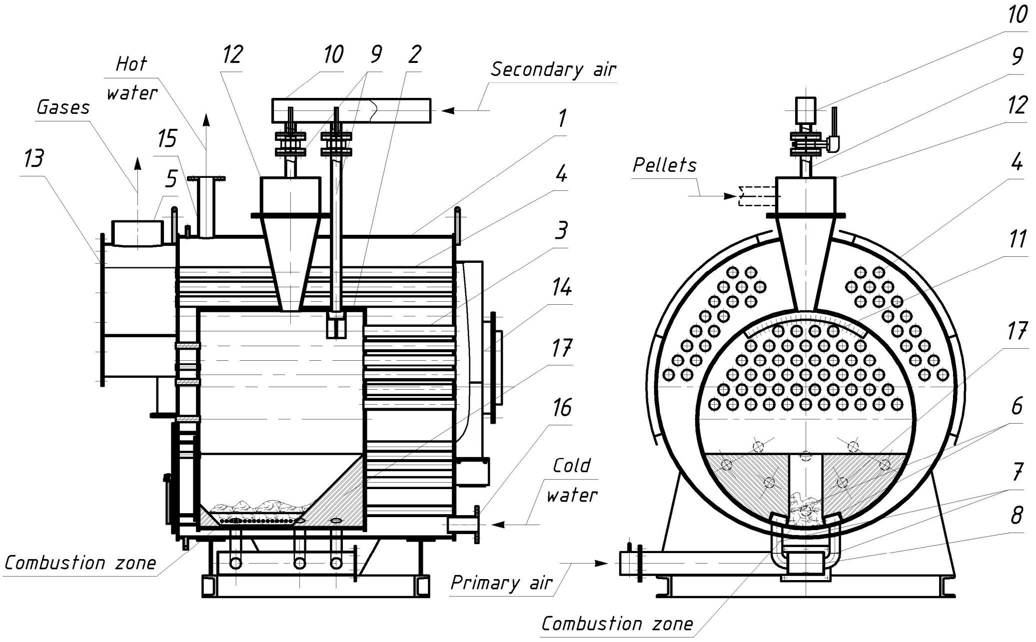
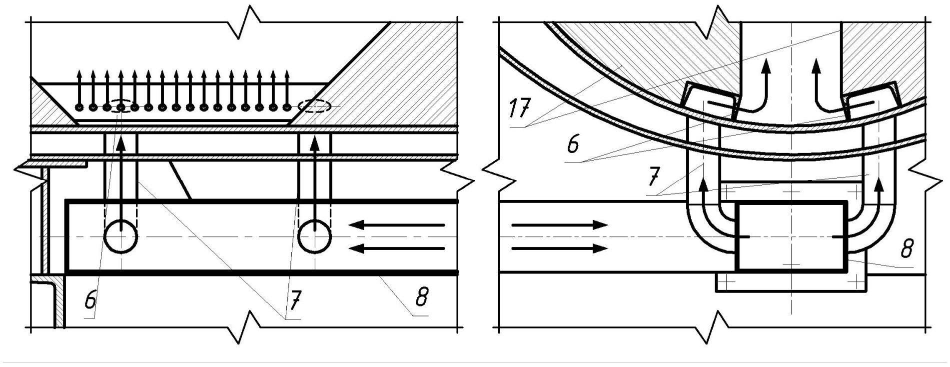


Figure 1. Experimental boiler diagram.



a) b)

Figure 2. Air distribution grill system and primary air supply diagram: a) longitudinal section; b) cross section.

The boiler comprises a cylindrical body 1 with a fire tube 2 which is connected by a network of short 3 and long heating tubes 4 to a smoke stack 5 where flue gases are removed from a boiler and released to a smoking pipe (not shown). In the bottom part of a fire tube there is an air distribution grill 6 consisting of two channels punched on the sides (fig.2). Primary air is supplied to the grill by a network of pipes 7 from a collector 8 which is connected to a forced-draught fan (not shown in the figure). In the top part of a boiler there is a network of pipes 9 for secondary air supplying which is connected by a collector 10 to a secondary air fan (not shown). In the same top part there is a branch pipe 12 for granule feeding into a boiler furnace which is connected to a granule feeding system (not shown). The exit end of pipes 9 leading to the furnace is covered by a channel 11, blanked at the ends and punched on its flange, faced to the longitudinal axis of a boiler. Turning type smoke boxes 13 and 14 are positioned on the end and back walls of the boiler. In the top part of a boiler cylindrical body 1 there is a branch pipe 15 for the removal of water heated in a boiler. An inlet branch 16 is in the bottom part of a boiler from the side of the back smoke box. The boiler furnace has chamotte incasing which bounds the combustion zone and provides stable ignition.

The boiler operates in the following way. Through an inlet branch 16 the boiler space is filled with water which, heating up, flows out through a branch pipe 15. Biofuel is fed through a branch pipe 12 to a fire tube 2 where it is transformed into a fluidized condition by means of blast air supplied under a fuel bed through punched channels 6. Flue gases flow to a smoke stack 5 and a smoking pipe through short 3 and long 4 heating tubes. At the same time water in the boiler body 1 heats up. While moving flue gases rotate by 180 degrees in a back smoke box 14 for more complete flue gas heat recovery. These gases are collected in a front smoke box 13 before they reach a smoke stack 5. Air supplied for combustion of granules is divided into two flows: primary air is supplied through a collector 8 and a network of pipes 7 under channels 6, through the perforations in the walls where this air is supplied under a fuel bed and changes it into a fluidized condition. Secondary air is supplied through a collector 10 and a network of pipes 9 under the channel 11 by the perforations, where it passes through its flange to a fire tube and is used for afterburning of volatile matters. The portion of secondary air flow is also supplied into a branch pipe 12, through which fresh granules are fed into the boiler. This air is also used for afterburning of volatile matters, and also protects a granule feeding system from penetration of flame and hot gases and prevents ignition of granules before their feeding into a boiler.

Measurements of pressure drop in a bed were taken by a differential micromanometer Testo-525 which allowed to take measurements every 50 mcs. A primary detector was placed under the air-distribution grill. It was a needle with a diameter of a needle orifice of 0.5 mm and a length of 60 mm. The micromanometer was connected to the primary detector by a silicone tube with the inside diameter of 4 mm and length of 200 mm.

Thus it was taken into consideration that in case of agglomerate formation in a bed, statistical characteristics of a random process of pressure fluctuations in a bed of burning biopellets would change uninterruptedly, as the amount and size of agglomerates in a bed would increase continuously. In order to detect the beginning of the defluidization process, the whole observation period for the combustion process in a bed was divided into intervals of 60 seconds, and statistical characteristics of a random process of pressure fluctuations in a bed for each interval were analyzed and the obtained values of statistical characteristics of a random process were compared. The interval duration was 60 seconds and it was conditioned by the results presented in the following papers: [2], [5], [6] within one minute there were no measurable changes of pressure drop values in a bed.

Pressure drop values obtained in the present study were statistically processed for every single interval and the following values were obtained:

1) Statistical expectation of a random process (mean pressure drop in a bed in the observation time (P_m):

$$P_m = \Sigma P_i/N; \tag{1}$$

2) Mean square deviation of pressure fluctuations:

$$\sigma = [\Sigma (P_i - P_m)^2/N]^{1/2}; \tag{2}$$

3) Dimensionless amplitude of pressure fluctuations:

$$\delta = \sigma/P_{m.} \tag{3}$$

According to the obtained data the following curves were plotted: mean value of pressure drop in a bed vs. gas flow rate; dimensionless amplitude of pressure fluctuations vs. gas flow rate; dimensionless amplitude of pressure fluctuations variation vs. observation period. These measurements were taken during the boiler operation at the workload equal to 50, 75 and 100% of the nominal. The workload was controlled by the variation in fuel flow rate with simultaneous increase (decrease) in air supply for combustion. In order to prove the absence of slag formation, in addition to pressure drop measurements in a bed, the samples of materials were taken out of the furnace every 40 and 90 minutes for the comparative fractional analysis by the standard technique, and then the combustible content of each fraction was determined.

The diagnostics of defluidization processes was carried out by certain methods. By means of dual link contact thermometer Center-306 the temperature of flue gases was measured continuously every 1.7 second on the assumption that the combustion process ceased and the temperature of exhaust gases dropped [7]. We also measured the concentration of reaction product in flue gases right outside the boiler every 15 seconds by means of gas-analyzer DAG-510. At the same time O_2 and CO concentrations were determined as long as CO concentration sharply increased in flue gases due to defluidization (fig. 3).

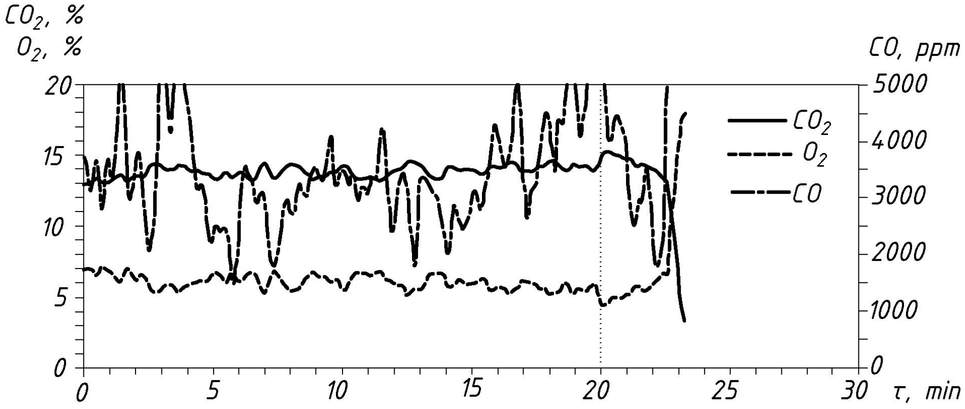


Figure 3. O_2, CO_2 and CO concentration behavior in exhaust gases during fluidized bed combustion of olive husk. Dashed line indicates defluidization [7].

Results and Discussion

As fig. 4 shows, the fluidization of burning straw pellets starts with the air flow rate equal to 0.35-0.6 kg/s (this zone of bed transition from fixed condition to fluidized is shown by hatching in figs. 5, 6 and 7).

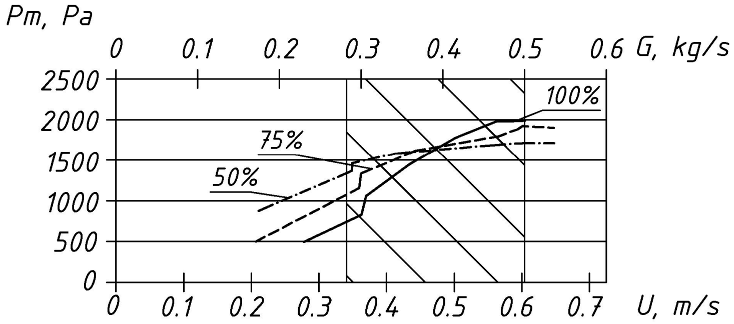


Figure 4. Pressure drop in a bed vs. air flow rate.

In the zone of transition from a fixed to fluidized bed at first we could observe even decrease of a root-mean-square deviation of pressure fluctuations σ, and then we evidenced that σ started to increase with the complete fluidization of a bed (fig. 5).

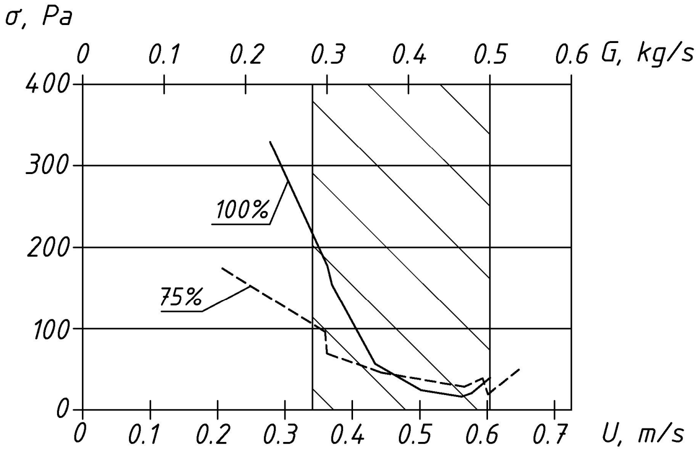


Figure 5. Root-mean-square deviation vs. air flow rate.

It sharply contrasted with the change of δ with air flow rate (fig. 6). Transition of a bed of burning pellets into a fluidized condition was characterized by sharp drop of values of dimensionless amplitude of pressure fluctuations δ.

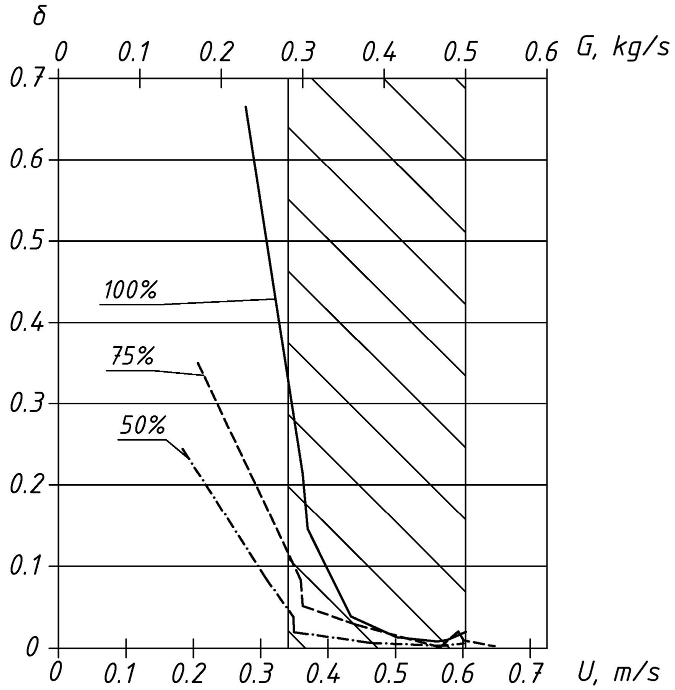


Figure 6. Dimensionless amplitude of pressure fluctuations vs. primary air flow rate at 50, 75 and 100% boiler workload of the nominal.

For that reason it was suggested to take the value of dimensionless amplitude of pressure fluctuations in a bed as a parameter which allowed to indicate the presence of agglomerates in a bed and to detect defluidization processes. If δ values did not exceed 0.1 it was possible to consider that the bed was in a fluidized condition and the process of defluidization did not occur. The variation in δ values in the course of the experiment indicated the absence of both agglomerates and defluidization of a bed (fig. 7).

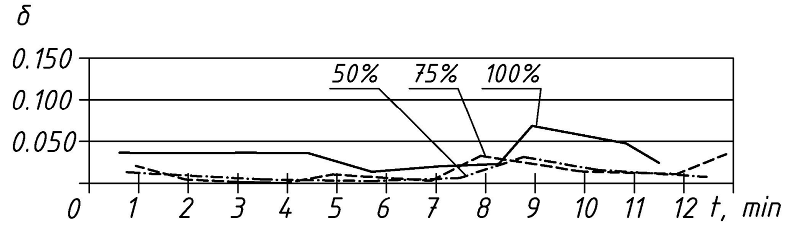
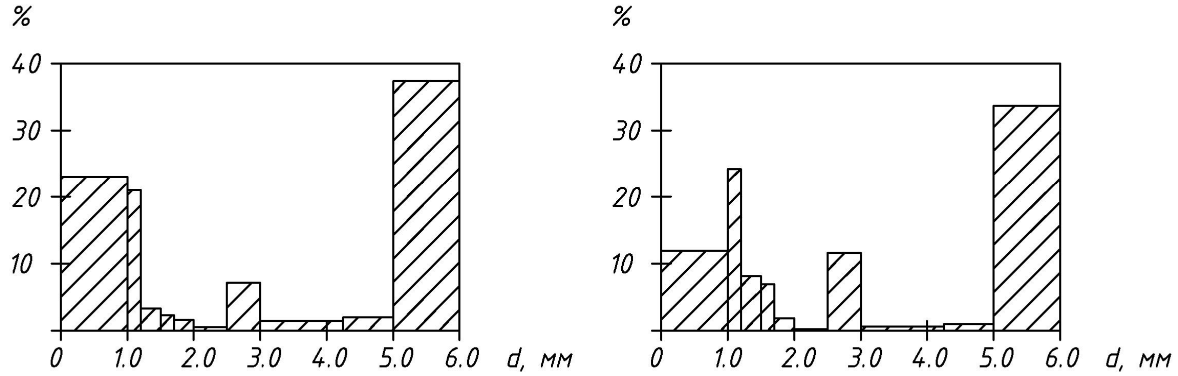


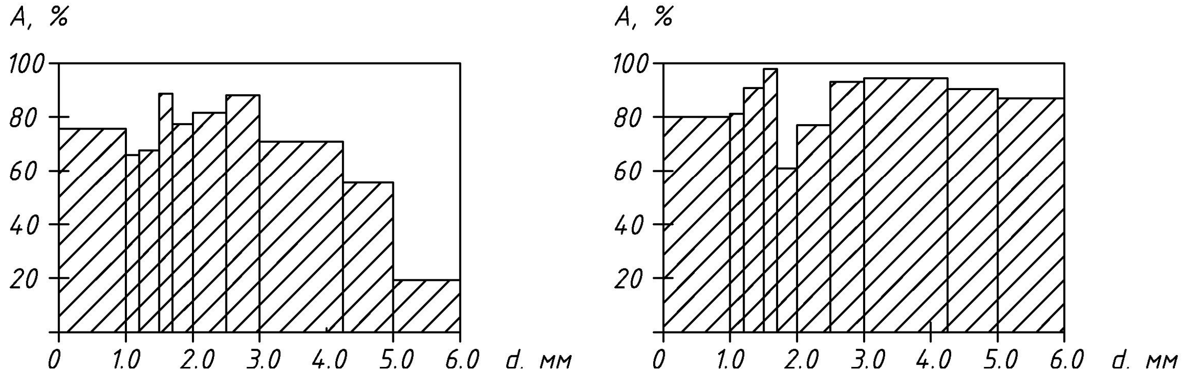
Figure 7. Dimensionless amplitude time variation.

It was proved by insignificant changes in the fractional composition in the course of the experiment: in 90 minutes after experiment beginning the fractional composition of a bed was simply the same as after 40 minutes (fig. 8).



a) b)

Figure 8. Fractional composition of a bed material:
a) after 40 minutes of experiment beginning; b) after 90 minutes of experiment beginning.

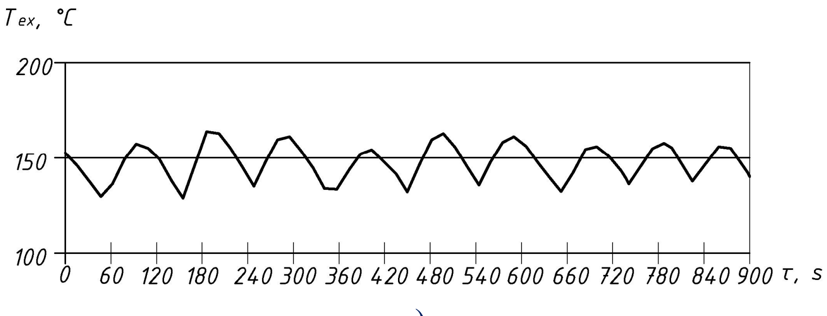


a) b)

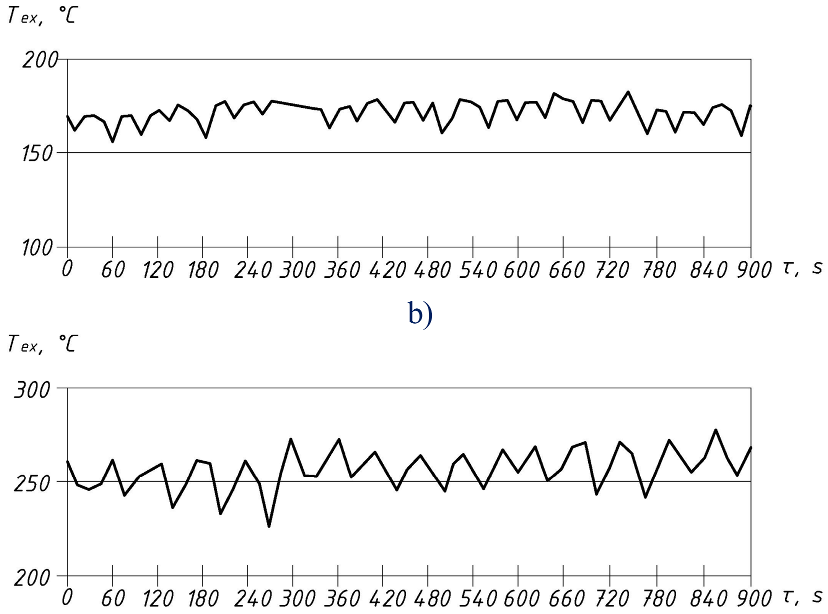
Figure 9. Ash content in a bed material: a) after 40 minutes of experiment beginning, b) after 90 minutes of experiment beginning.

Moreover, as it appears from fig. 9, with prolongation of experiment time, ash content of a large fraction sharply grows (in 1.5-4.0 times). I.e., even if small agglomerates are formed in a bed, combustion process of char does not stop that allows to assume very insignificant fuel loss due to mechanical incompleteness of combustion.

In the course of the experiments sharp temperature drop of flue gases was not evidenced (fig. 10 a, b, c) and sharp growth of oxygen concentration in flue gases outside a boiler which would indicate the defluidization and the end of combustion was not observed as well though sharp fluctuations of oxygen concentration, related to the fractional fuel supply, were perceived (fig. 11 a, b, c).



a)

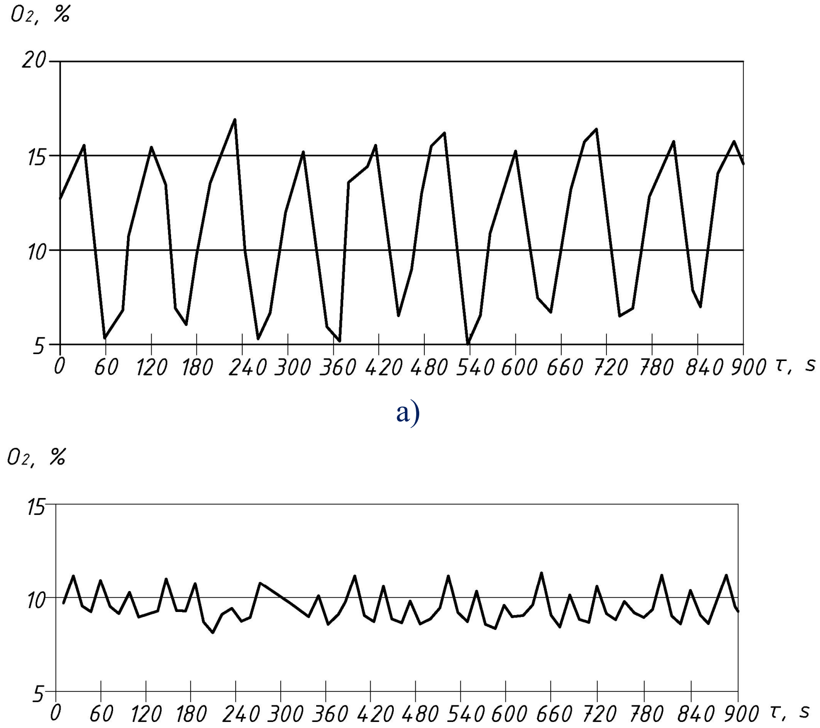


b)

c)

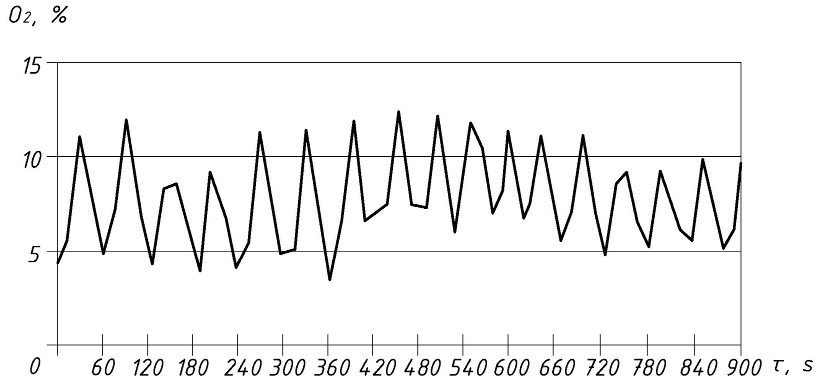
Figure 10. Temperature variation in exhaust gases outside the boiler: a) at 50% workload of the nominal; b) at 75% workload of the nominal; c) at the nominal workload.

Sharp growth of carbon oxide concentration in flue gases was not observed which could indicate the defluidization as well. Fluctuations of carbon oxide concentration (fig. 12) were caused by periodic fuel supply. In this case the decision on the proportions of primary to secondary air flow rate provided the minimal CO emissions into the atmosphere, meeting the requirements of the Russian standards.



a)

b)



c)

Figure 11. Variation in oxygen content in flue gases outside the boiler: a) at 50% workload of the nominal; b) at 75% workload of the nominal; c) at the nominal workload.

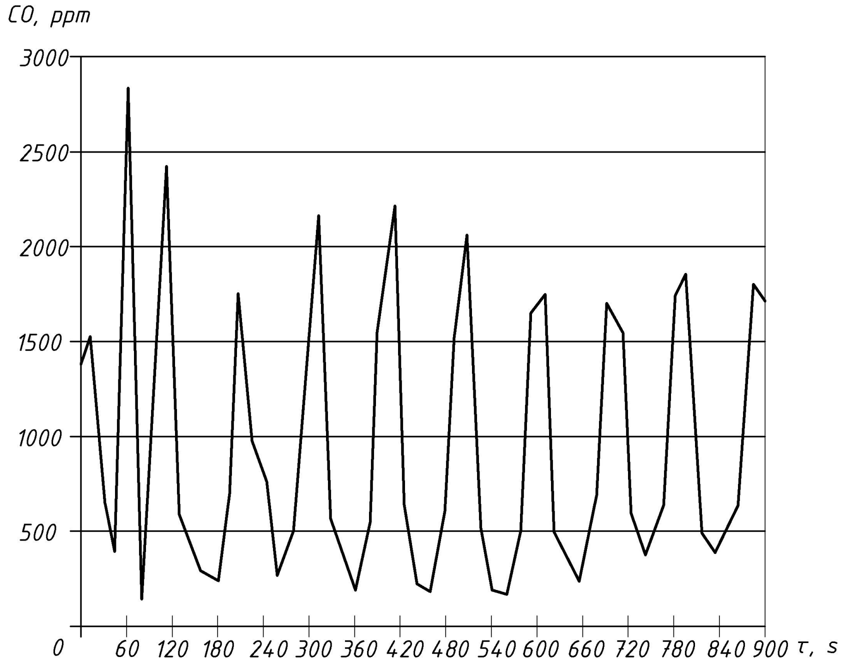


Figure 12. CO content in exhaust gases at the nominal workload.

Conclusion

Therefore, it is experimentally proved that the dimensionless amplitude of pressure fluctuations in a bed can be applied as a parameter of defluidization process and while it does not exceed 0.1 it is possible to consider that the bed remains in a fluidized condition and the process of defluidization does not occur.

Nomenclature

A	ash content
P	pressure
ρ	density
ε	porosity
δ	dimensionless amplitude
σ	mean square deviation
τ	time

Subscripts

b	bulk
ex	extended gases
i	current
m	mean

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