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Application of PCS fibres to multiple zone flame measurements in industrial power burners

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The author presents the results of his seven years' research on application of fibre optic technology in monitoring, protection and start-up systems for industrial burners. A brief description of the phenomena under investigation as well as theoretical assumptions are given. The design of a measuring device and some examples of results obtained with the use of this device are presented.

1. Introduction

An adjustment of Polish law to European Community code provoked big changes in standards specifying permitted levels of pollution emitted during a combustion process. These changes substantially affected the Polish power industry, which was obliged to modify the whole combustion process. In most of the cases, the so-called stage combustion process provided in new designs of low-emission burners was applied. The principle of operation of such a burner consists in burning the fuel (pulverised coal in most cases) in consecutive zones (stages) of the flame. In the primary one, there is deficiency of oxygen resulting in a decrease of flame temperature that causes thermal NO_x emission drop. In the consecutive zones the combustion process is being completed, *i.e.*, oxidation of CO to CO_2 takes place, by the appropriate additional air supply via the so-called OFA nozzles [1]. In burners, installed in the industrial power boilers, velocities are so high that the turbulent flow appears even at their outlets. On the one hand, it accounts for better homogeneity of the fuel-air mixture, which means better combustion; yet, on the other hand, it causes significant difficulties in evaluation of combustion quality [2]. Even if an industrial system is equipped with a fast fume-gas analyser, which is usually located in chimney collector, the measurements are averaged and delayed so that they are not suitable for evaluation of combustion quality in the individual burner. Considering the fact that there are usually many burners installed in a single industrial power boiler, the problem of designing systems for evaluation of combustion quality becomes very important [3].

2. Formulation of the problem

In the low-emission combustion process three basic zones can be distinguished [1]. In the first one (initial combustion), the coal carbonisation takes place, where the volatile parts conditioning the stable ignition are liberated. The duration of stay of a particle in the zone is 100–200 ms. The second stage of combustion (main combustion) takes place in substoichiometric conditions, creating a reducing atmosphere. The duration of stay of a particle in the zone is 0.8–2.0 s. In the third stage of combustion (final combustion), an additional air is provided in order to complete the oxidation above the stoichiometry ratio. Problems concerning the design of systems for flame monitoring in an industrial low-emission burner can be divided into two categories: 1) harsh operation conditions – dustiness, high temperature, vibration, 2) selection of parameters to be measured.

In industrial conditions, in principle, we deal with turbulent flames only. An exact description of mass and heat transport as well as of mixture stream momentum is, especially in the case of turbulent flow, very complicated and useless for practical application. Nevertheless, an assumption can be made [2] that although the instantaneous values of turbulent flame parameters are not constant in time, still they fluctuate around their mean values. This assumption formed the basis for investigation of influence of the zone of combustion, the kind of fuel and the amount of air on change of radiation intensity resulting from the burning of pulverised coal and fuel-oil in OP650 boiler. A hypothesis was taken that radiation intensity as well as its changes (flicker), for a given type of object, are values characteristic of the kind of fuel and the zone of combustion. The change in conditions of combustion (amount of primary or secondary air) results in variation of the above mentioned values in an unequivocal way. They can be therefore utilised for the monitoring and quality evaluation of combustion process.

3. Design of measurement device

Considering the emission spectrum ranges of particular fuels (Fig. 1) and small distances (several meters) of optical signal transmission, the PCS (Plastic Clad Silica) fibre was selected as a transmission medium, and modified silicon diode (Fig. 2) was selected as a photodetector. A block diagram of the device is shown in Fig. 3. Because the probe is placed inside the burning chamber, where the temperature rises above 400 °C and there is a high level of dustiness, the cooling by clean air was provided. It also acts as a cleaning medium for the optical system.

The analysis of coupling systems of the volume sources of light with optic fibres [4] as well as simulations made by "Fluent" program, let us select such a design of the probe that assures uninterrupted operation in dusty environment and the head temperature not exceeding 100 °C at the cooling/cleaning air pressure of 0.02–0.3 MPa. The temperature limitation is caused mainly by the maximum temperature admitted by the fibre. Figure 4 shows the schematic design of the probe. The spherical sector made of quartz covering optical head of the probe is an additional protection from hot particles.

The measuring device consists of 7 channels intended for:

– investigation of ignition point – two optical channels of low aperture, with acceptance angle of 6°,

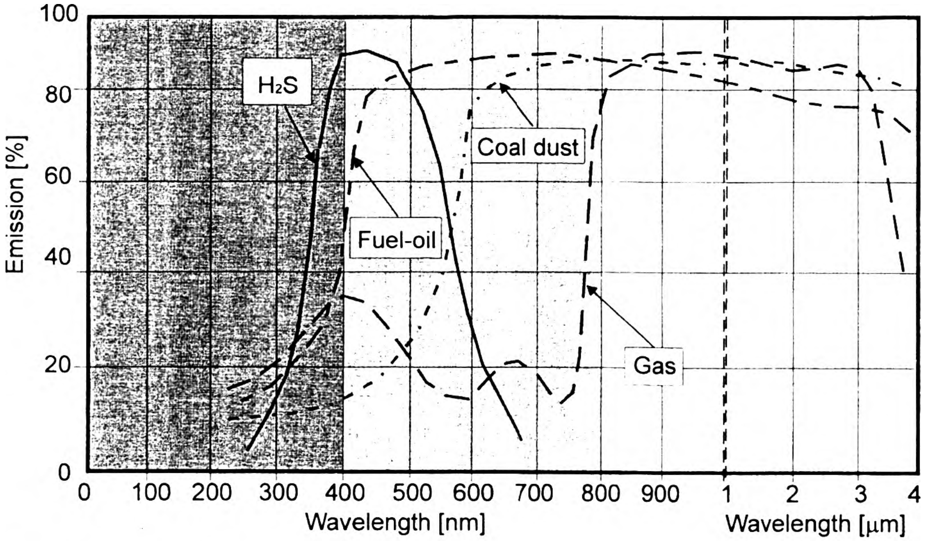

Fig. 1. Ranges of emission spectrum of fuels.

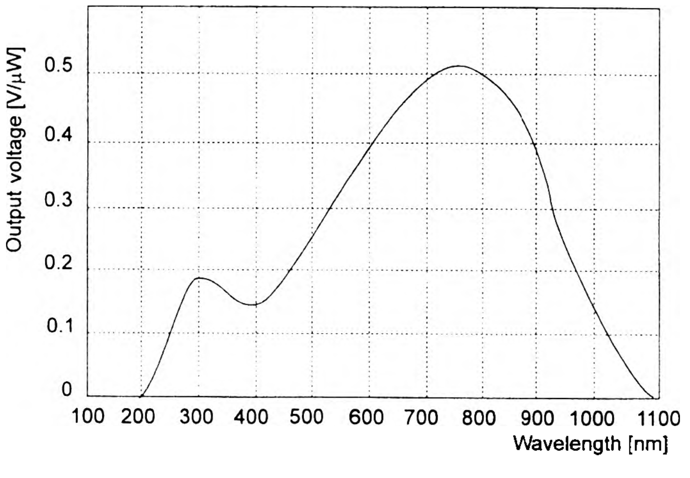

Fig. 2. Spectral characteristic of the modified silicon detector.

– investigation of flame front and first zone – one optical channel with acceptance angle of 12°,

– investigation of remaining zones as well as transitions between them – all with acceptance angles of 12°.

The way of installation of the probe in the power boiler is shown in Fig. 5. The numerical aperture of optical fibres was limited for the sake of selectivity of measurements. The acceptance angle being too wide caused an increased averaging, which meant a decrease of sensitivity to changes of input parameters of the burner. Initial measurements made on the real object let us determine the range of changes of

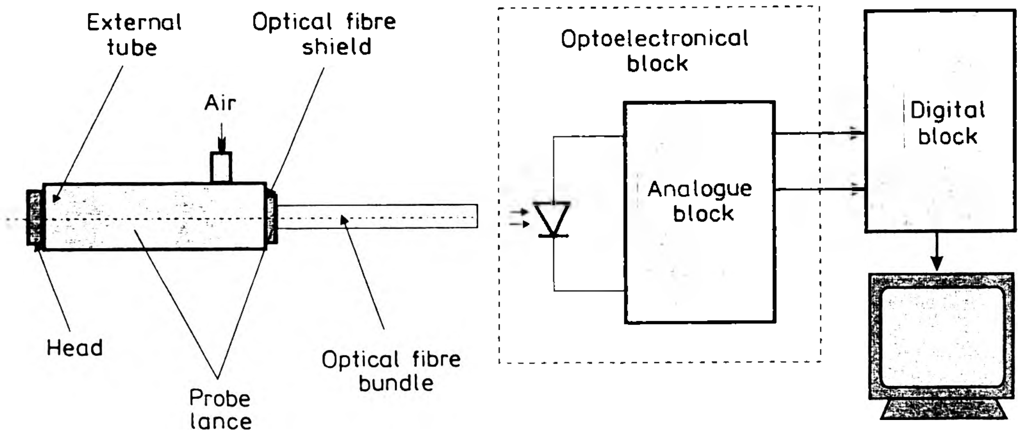

Fig. 3. Schematic diagram of optical fibre flame monitoring system.

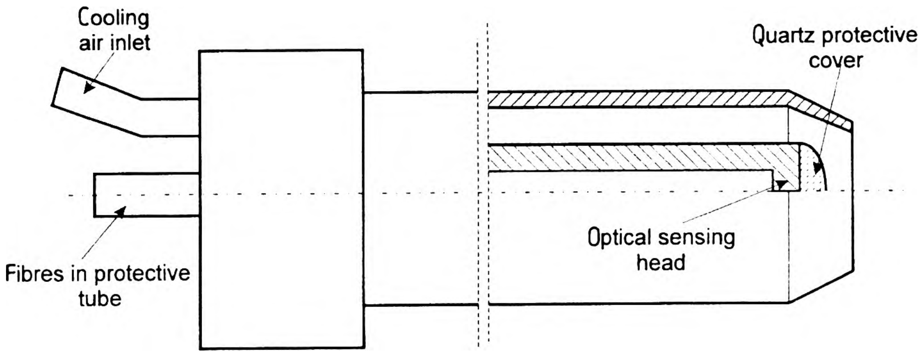

Fig. 4. Design of the probe.

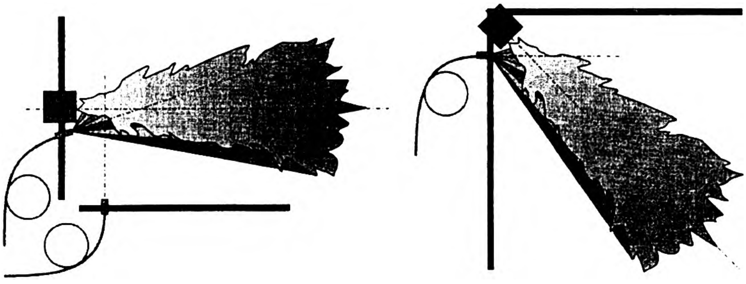

Fig. 5. Example of installation of optical fibre probes in boilers with wall and tangential burners.

ignition point caused by changes of input parameters (amount of primary or secondary air) of the burner within the control range. This allowed us to select acceptance angle of the first two optical fibres. By determining the initial combustion zone we were able to select acceptance angle of optical fibre for monitoring this zone.

Analogous angles were applied in remaining channels although there was a difference between areas of flame being monitored. However, as the area grows the distance increases, which results in certain compensation.

The measurement system developed is connected to an industrial data logging system whose acquisition period is 1 s. The device was therefore equipped with microprocessor for data pre-processing.

4. Measurement results

The design of the probe is versatile enough to allow flame measurements in both wall and tangential burners. It also enables the spatial scanning. The results of measurements made using the probe are shown in Figs. 6 – 18. Measurements were performed in normal conditions of operation of the boiler, *i.e.*, according to the

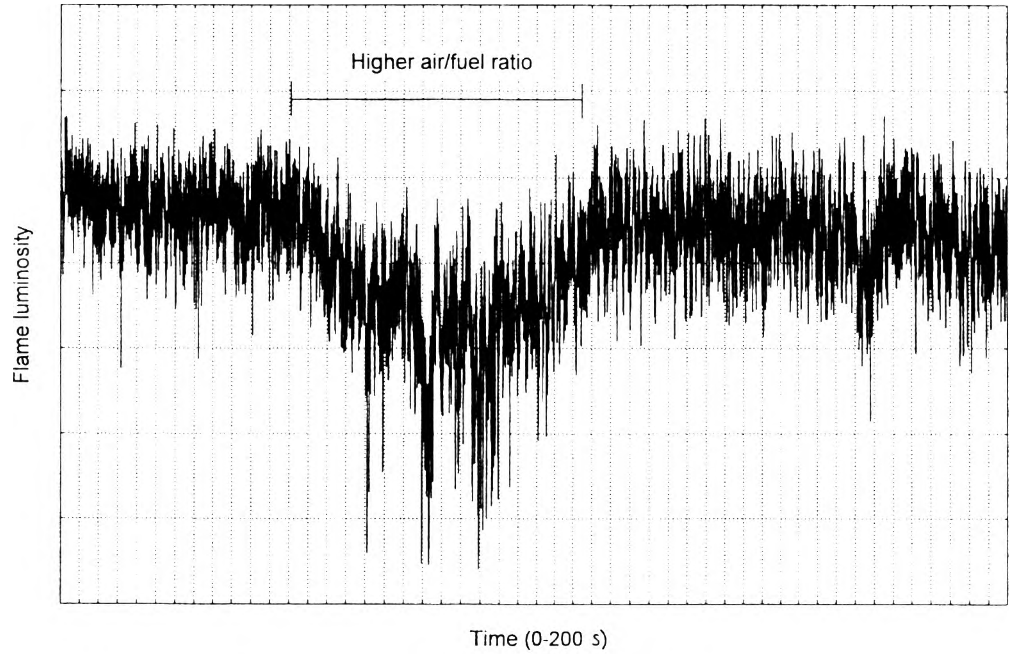

Fig. 6. Time series of flame intensity when air/fuel ratio was changed.

requirements of the General Load Dispatching Unit. Input values (amount of air and pulverised coal, additional fuel oil) were changed only in the burner being measured (one of 24) and only within the limits that did not affect an overall power performance of the unit (~200 MW). Therefore the changes were of relatively short duration (several minutes), and relatively narrow range (max. ±20% from standard adjustment of flap drives). The results of measurements presented as time series (Figs. 6 – 8), as well as frequency plots, both flat (Figs. 9 – 11) and 3D (Figs. 12 – 15) show significant variations of output caused by changes in input signals. In order to

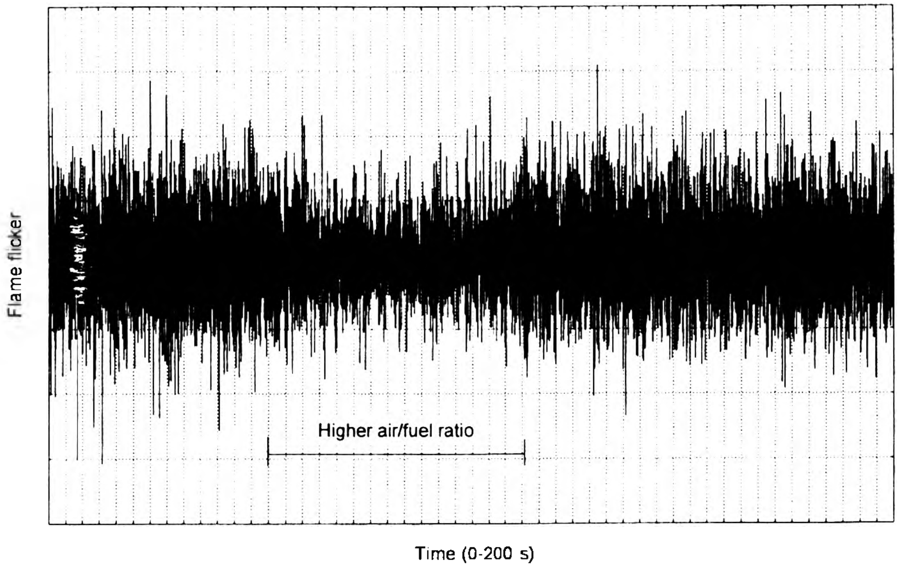

Fig. 7. Time series of flame pulsation when air/fuel ratio was changed.

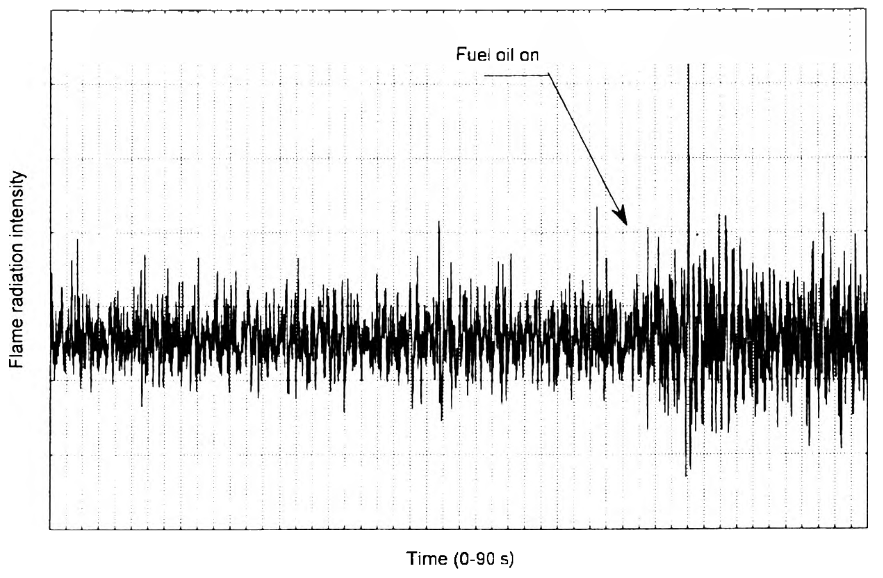

Fig. 8. Time series of flame intensity with additional fuel-oil.

compare suitability of chosen transformation FFT and wavelet spatial plots of the same flame conditions are shown (Figs. 12 and 16). As it can be seen, there is no significant difference. Figures 17 and 18 show mean amplitude and frequency distribution in time domain when additional fuel-oil was switched on. In both cases it produces significant changes in output signal. The results of research are

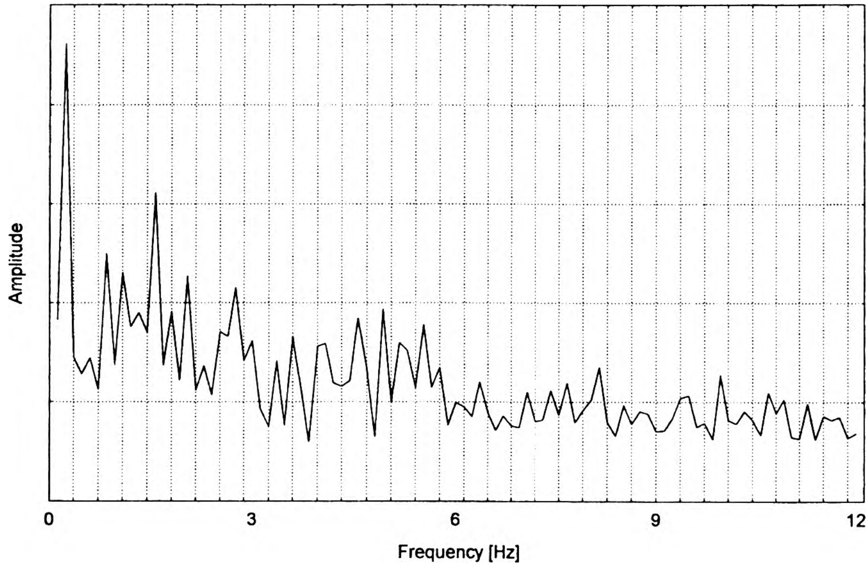

Fig. 9. FFT plot in nominal conditions.

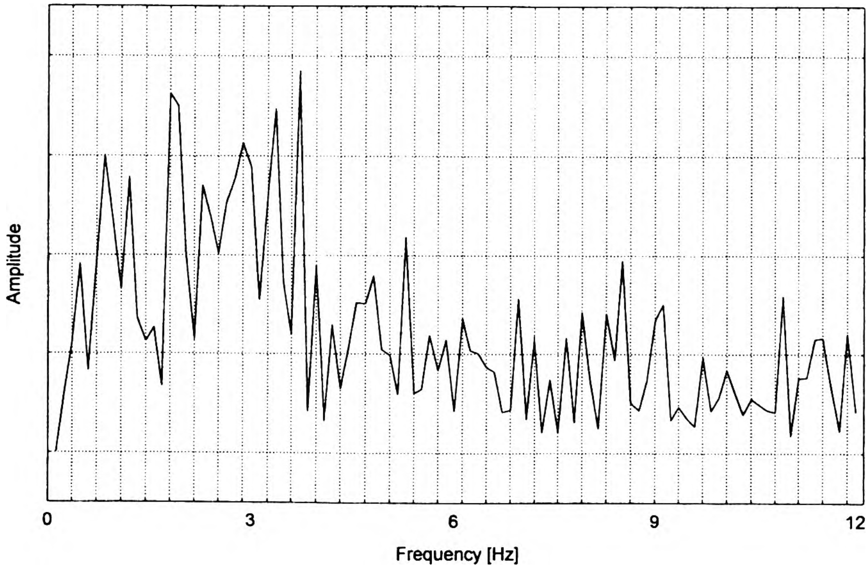

Fig. 10. FFT plot with additional fuel-oil.

presented here with the purpose of emphasising variations of output caused by input changes, on the one hand, and on the other, our aim is to select the most adequate method from the practical point of view. Another goal is the selection of the most sensitive flame zone. It has to be underlined that the sensitivity also depends on the fibre's acceptance angle, its core diameter and spectral characteristic of photodetec-

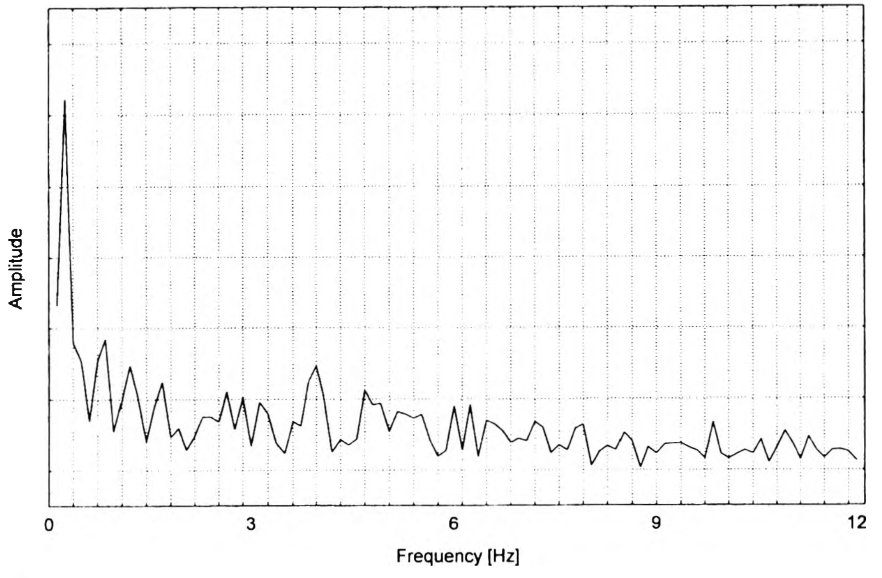

Fig. 11. FFT plot in conditions of air excess.

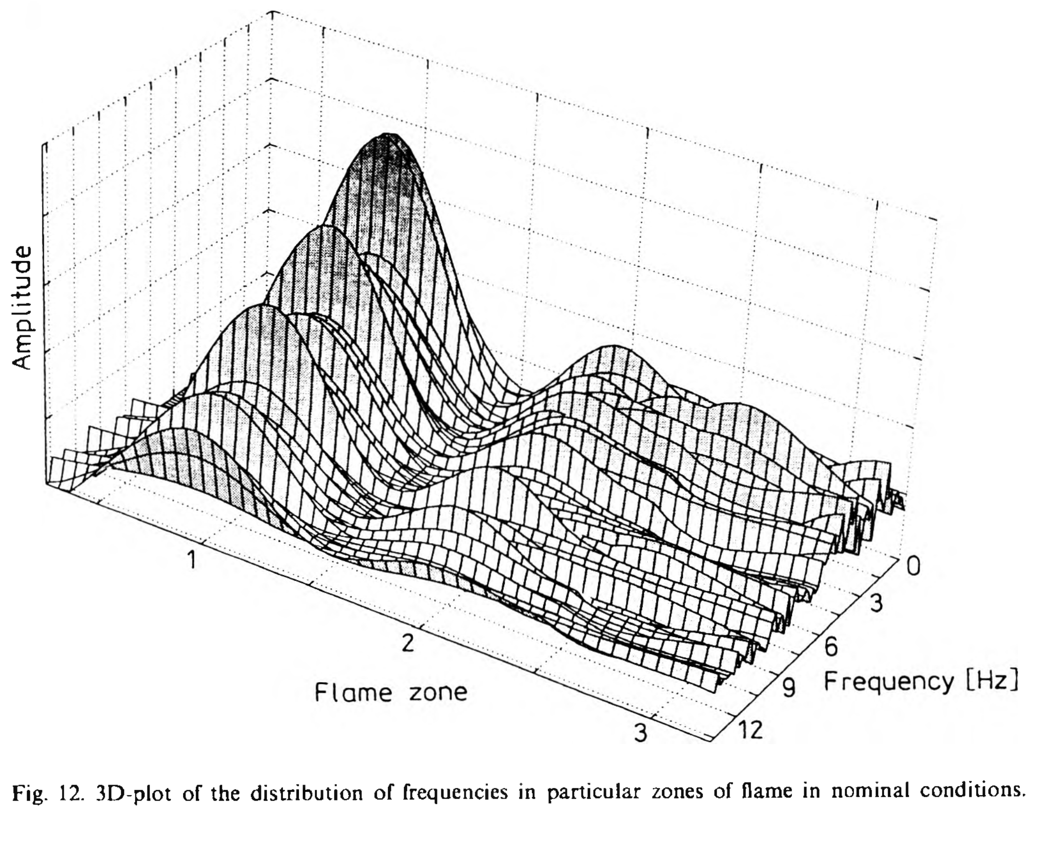

Fig. 12. 3D-plot of the distribution of frequencies in particular zones of flame in nominal conditions.

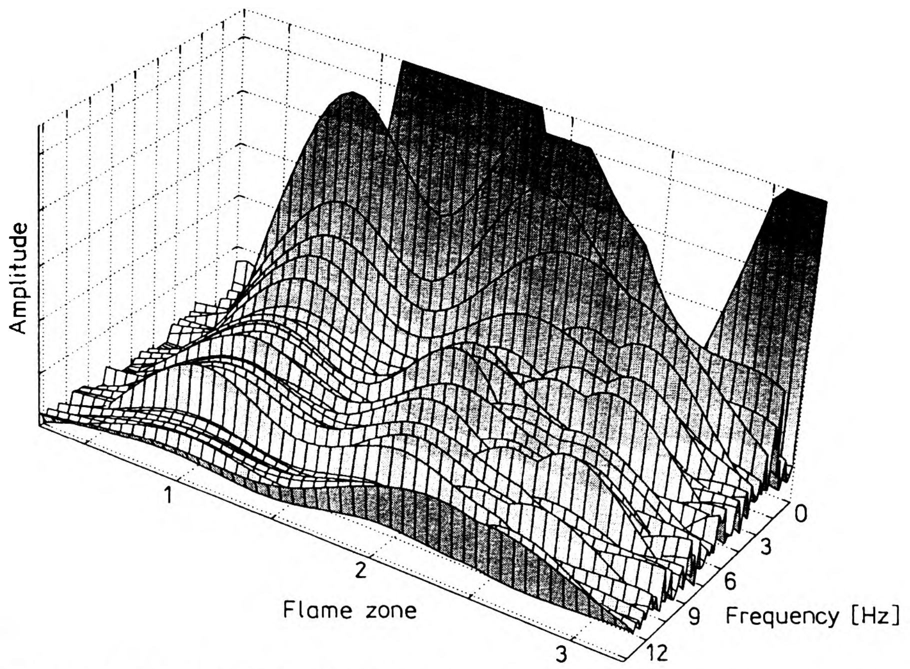

Fig. 13. 3D-plot of the distribution of frequencies in particular zones of flame with additional fuel-oil.

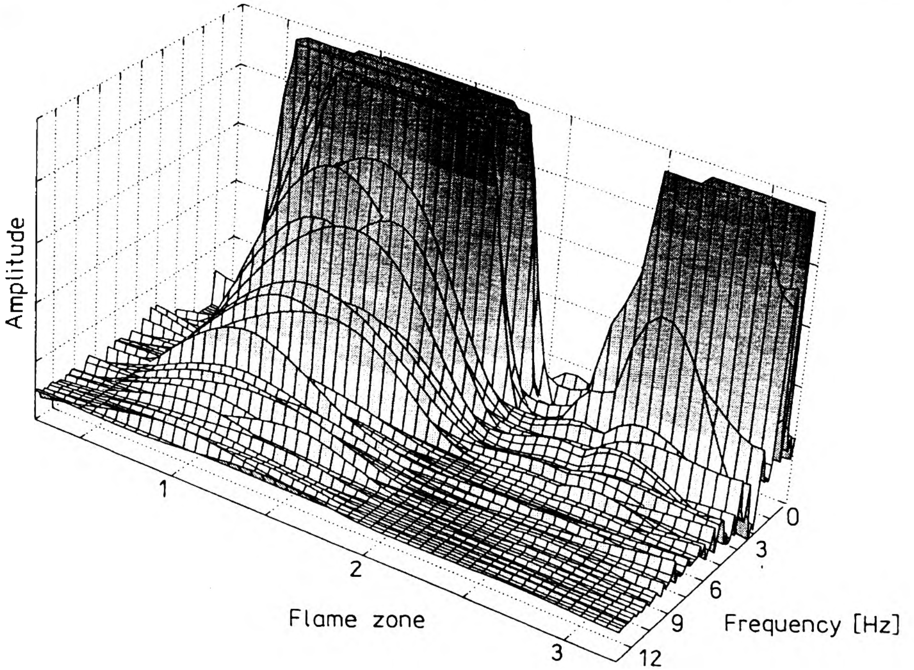

Fig. 14. 3D-plot of the distribution of frequencies in particular zones of flame in conditions of air deficiency.

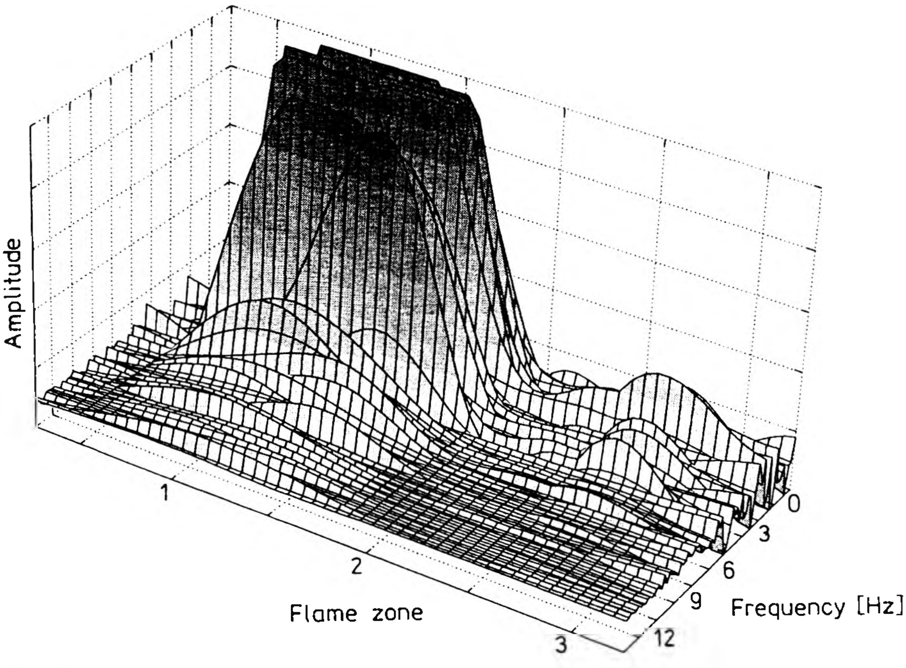

Fig. 15. 3D-plot of the distribution of frequencies in particular zones of flame in conditions of air excess.

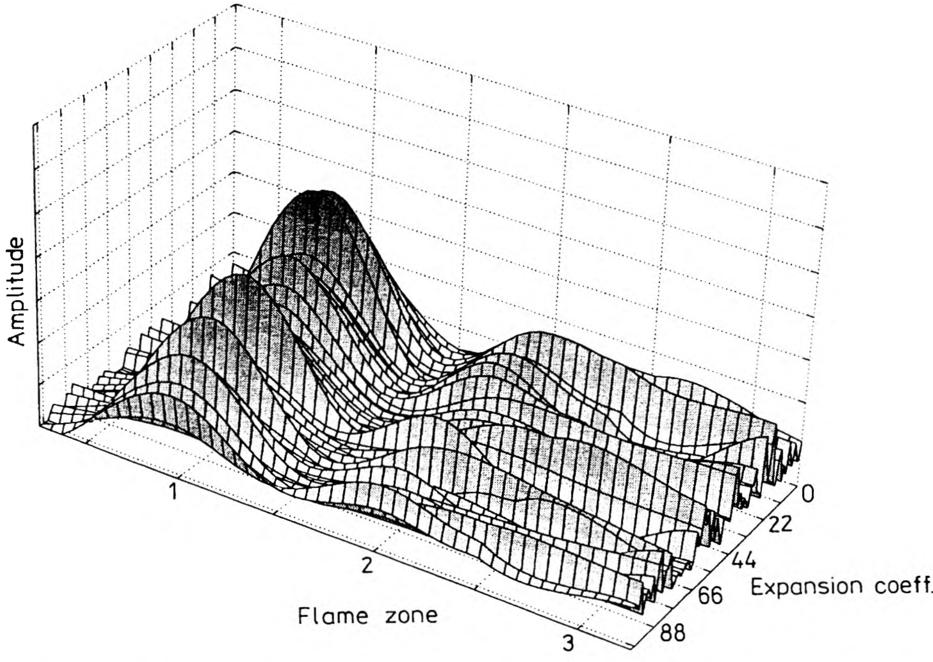

Fig. 16. 3D-plot of the wavelet distribution in particular zones of flame in nominal conditions.

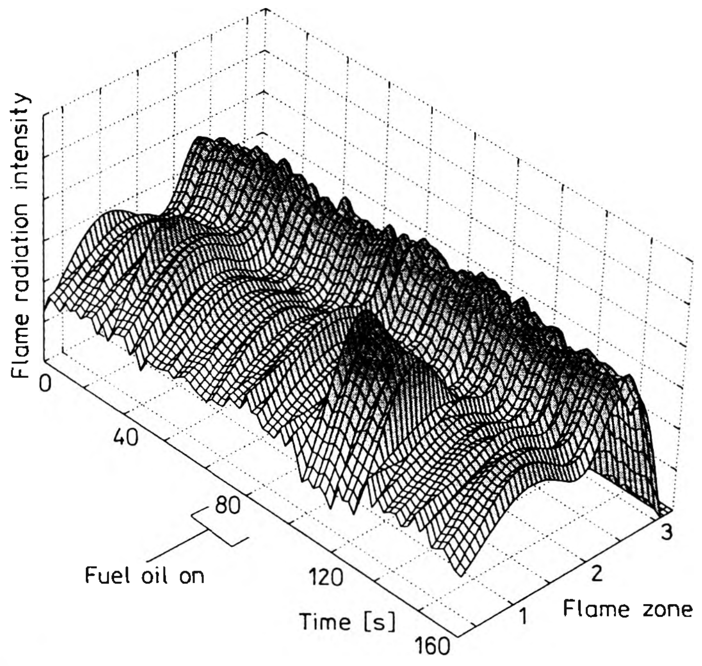

Fig. 17. 3D-plot of the mean amplitude in particular zones of flame with additional fuel-oil.

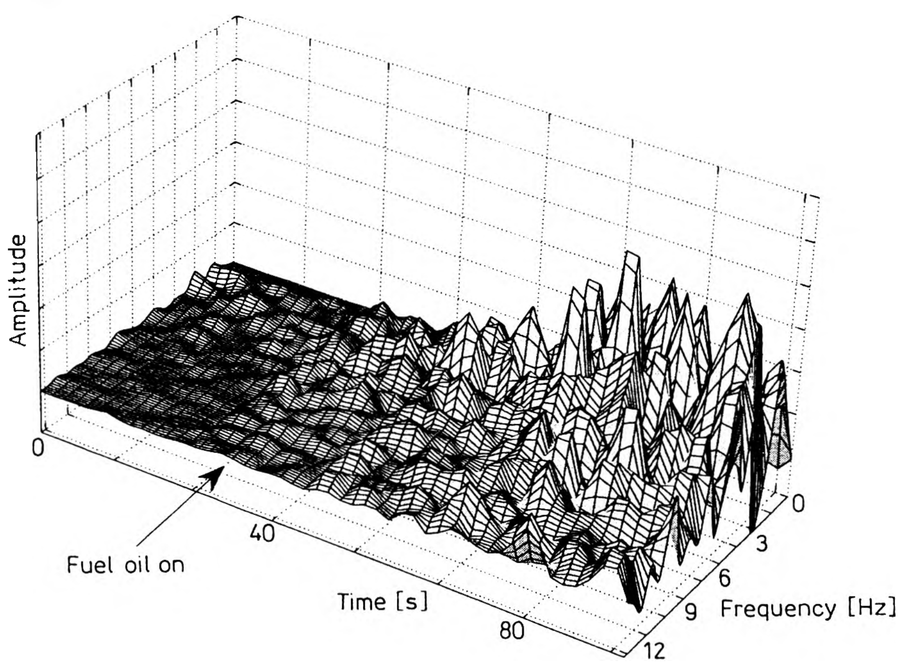

Fig. 18. 3D-plot of frequency distribution in time domain with additional fuel-oil.

tor. Widening the acceptance angle results in increased averaging, which means a decrease of sensitivity. The same applies to the fibre's core diameter and the photodetector. In our device, the wide-spectrum photodetector (Fig. 2) and the 200/400 μm PCS fibre are used. This configuration produces averaging of flame pulsation that results in shifting the signal (flame pulsation) spectrum towards the lower frequencies, as can be seen from the results presented, nevetheless it does not affect their practical suitability.

5. Conclusions

On the grounds of research a conclusion can be drawn that the intensity of flame radiation and flame pulsation (flicker) are variables that allow unequivocal evaluation of combustion process quality. This makes possible unequivocal distinction of pulverised coal flame from fuel-oil flame. First zone of the flame and the beginning of the second one, as well as the ignition point should be taken into consideration because of their high sensitivity to input parameters. Because of differences in performance of individual burners, each should be equipped with the flame monitoring system. For the practical reasons the design of the measurement system should be simplified basically by limitation of the number of optical channels. Considering that the performance of each particular burner is different, spatial scanning using the device discussed should be made before working out an industrial version. The research concentrates on replacement of PCS fibres by HCS fibres that can operate at temperature as high as 350 °C and on simplification of design of the probe.

Seven years of research carried out by the author on application of fibre optic technology in monitoring, protection and start-up systems for industrial boilers equipped with high and low NO_x emission burners, resulted in implementation of the monitoring system described here in industrial power boiler OP650. It has to be underlined that the solution discussed, unique in the world, was developed in co-operation of research teams from the Laboratory of Optical Fibre Technology of Maria Curie-Skłodowska University of Lublin directed by Jan Wójcik and from the Department of Electronics of the Technical University of Lublin directed by the author. Further works will be focused on development of probe integrated with the burner and multi-burner probe (for 2 or 4 burners).

References

[1] Wendt J., *NO_x formation and destruction, mechanism in pulverised coal,* [In] Proc. Int. Seminar *Fuel Utilization and Environment,* Prague 1991, pp. 119–128.
[2] Fristrom F. M., *Flame Structure and Process,* Oxford University Press, New York 1995.
[3] Wójcik W., Proc. SPIE **3189** (1997), 74.
[4] Krolopp W., Wójcik W., Kotyra A., Przyłucki S., Smolarz A., *The light source to optical fibre coupling* (in Polish), Sci. Bull. Łódź Technical University, Elektryka, No. 90, 1998 (in print).

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