

Pavel NOSKIEVIČ, Pavel KOLAT

University of Mining and Metallurgy, Ostrava, Czech Republik

COMBUSTION RESEARCH IN CZECH „CLEAN COAL TECHNOLOGY” PROGRAM

Summary. Turbulent transfer phenomena in boilers have been shown to obtain more details about „controlled combustion process” ensuring reduction of solid and gaseous emission. From the results thus gained for more than 20 years of applied combustion research it is possible to evaluate the suitability of the designed output of the power plant unit with a minimum of harmful emissions when burning low grade Czech coal.

BADANIA SPALANIA W RAMACH CZEŚKIEGO PROGRAMU „CZYSTE TECHNOLOGIE WĘGLOWE”

Streszczenie. Przedstawiono zjawiska transportu turbulentnego w kotłach. Zjawiska te pozwalają uzyskać więcej szczegółów na temat kontroli procesu spalania zapewniającego redukcję emisji stałych i gazowych zanieczyszczeń. Wyniki prowadzonych od 20 lat badań pozwalają na właściwe projektowanie palników i palenisk kotłowych przy minimalnej emisji substancji szkodliwych, również podczas spalania węgli o niskiej jakości.

VERBRENNUNGSUNTERSUCHUNGEN IM TSCHECHISCHEN PROGRAMM „SAUBERE KOHLETECHNOLOGIEN”

Zusammenfassung. Die Probleme der Bestimmung von turbulenten Austauschgrößen in den Kesseln wurden dargestellt. Mehr als 20-jährige Untersuchungen geben genauere Daten über die „kontrollierte Verbrennung”, die eine Bewertung der Brennkammer – und Brennerkonstruktionen vom Gesichtspunkt der Erniedrigung der Schadstoffemissionen ermöglicht, sogar bei der Verbrennung von Ballastkohlen.

For decades, when the Czech economy was concentrated in the development of mining, heavy industry and chemical engineering, the natural environmental balance has been disrupted. Now that air, water and soil pollution levels are monitored regularly, the results force us to reconsider our previous approaches to the problem, which often neglected the need for systematic reductions of pollutant emissions at their source. Industrial plants are often unaware that simple adjustment of the combustion process can reduce emissions.

Measurement of combustion aerodynamics in furnace of high output boilers is part of complex research known as the Czech „Clean Coal Technology” program. Here we are also testing results from three-dimensional mathematical and isothermal models. The results are used for simple reconstruction of burners without additional financial requirements. Complex approach to these problems could lead to an increase in the capture of pollutants such as NO_x (including N_2O), SO_2 , HF, HCl, heavy metals and hydrocarbons.

OBJECTIVES OF MEASUREMENT

Measurement and analysis of combustion process concerns:

- optimization of combustion
- readjustment of burners to secure „controlled combustion”

Evaluation of aerodynamic properties during combustion requires the measurement of velocity, temperature and pressure fields and the collection of gaseous and solid samples. This is done in a few chosen furnace levels (see Fig. 1).

Deeper analysis of transfer phenomena requires the measurement of pressure and temperature fluctuation against time, which is necessary to establish turbulent transfer values.

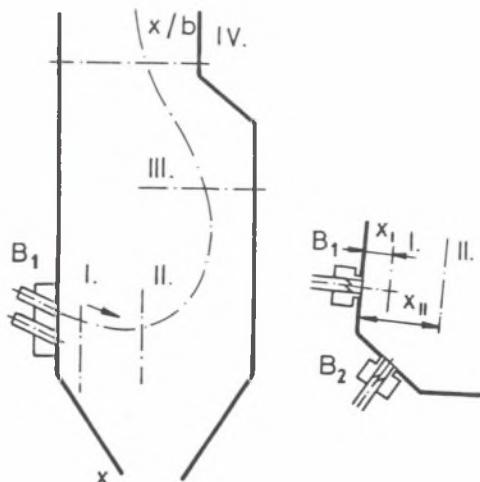


Fig. 1. Determination of the combustion path in the furnace

Rys. 1. Wyznaczenie drogi spalania w palenisku

COMBUSTION QUALITY AND TURBULENT TRANSFER PHENOMENA.

To determine the quality of combustion process it is necessary to measure the velocity, concentration and temperature field changes with time. Radiation pyrometers can be used to measure high temperatures (1200–1500°C); they are able to follow changes from just a few kHz. Pyrometers must be placed in water cooled probes (10 m – 30 ft length), because of the need to measure local temperatures in the flame. This universal probes are able to measure local temperatures of a flame by using an optical pyrometer or thermoelement, to collect solid and also to measure pressure and local velocity vectors.

Chemical energy in the fuel is turned into thermal energy during combustion. Conditions for mass transfer are assumed similar to those for heat transfer. This assumption is based on the close correlation of the Sherwood number for mass transfer and the Nusselt number for heat transfer.

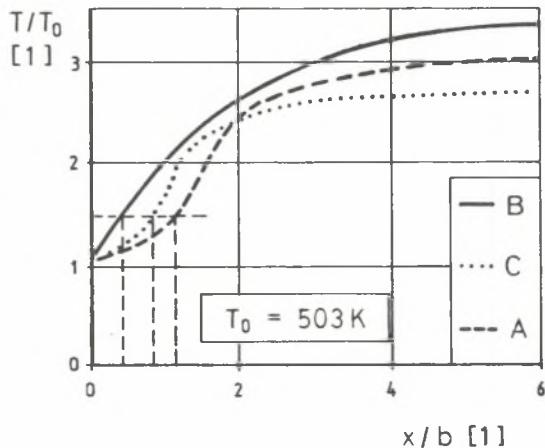


Fig. 2. Relative temperatures and ignition zone of burner:
A–200 MWe before readjustment, B–200 MWe after,
C–180 MWe before

Rys. 2. Względne temperatury i strefa spalania palnika

TEST RESULTS

Results of experiments are shown for 200 MWe Czech boiler for low grade brown coal before and after readjustment of burners. It is necessary to measure:

- temperature, velocity and mass flow fields, Fig. 2
- course of combustion of pulverized coal, Fig. 3
- solid and gaseous concentrations in flue gases
- fluctuation of temperatures and pressures
- turbulent transfer phenomena such as:

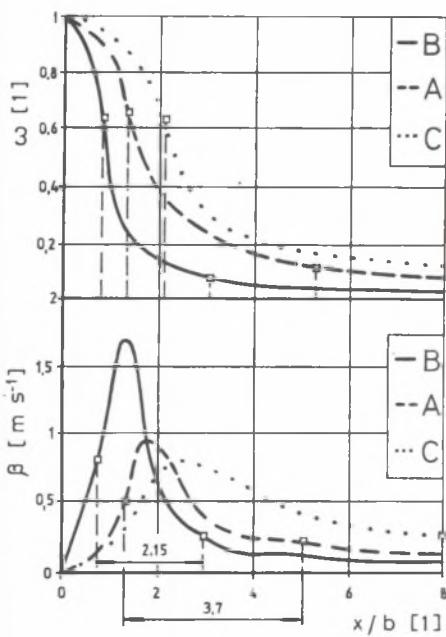


Fig. 3. Course of conversion of pulverized coal and mass transfer coefficient

Rys. 3. Przebieg konwersji pyłu węglowego i współczynnik wnikania masy

turbulent viscosity; Fig. 4 spectral and turbulent energy; Figs. 5,6 turbulent mass transfer in coal flame; Fig. 7

The following relations are generally applied for the zone with intensive combustion:

$$x/b = 3 \text{ to } 5 \quad Sh = f(Re_T \cdot Sc, x/b, y/0.5b) \quad (\text{see Fig. 8})$$

and for burn up zone:

$$x/b > 5 \quad Sh = f(Re_T \cdot Sc, Gr_D \cdot Sc, x/b)$$

CONCLUSION

Turbulent transfer phenomena in boilers have been shown to obtain more details about „controlled combustion processes” ensuring reduction of solid and gaseous emission, Fig. 10. From the results thus gained for more than 20 years of our applied combustion research it is possible to evaluate the suitability of design of the burner and the shape of the furnace to achieve the

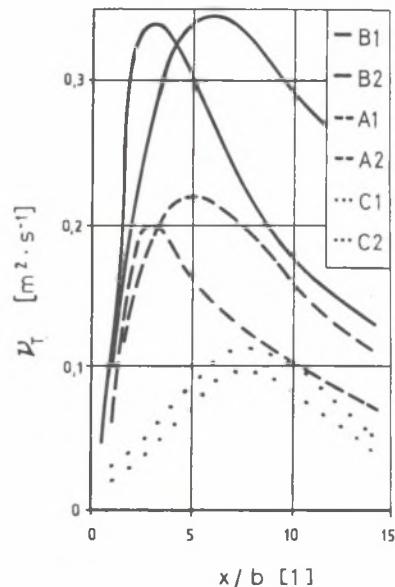


Fig. 4. Turbulent viscosity in furnace

Rys. 4. Lepkość wirowa w palenisku

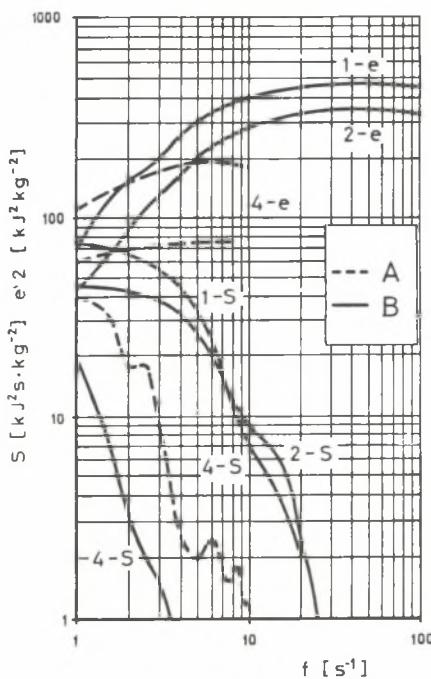


Fig. 5. Local spectral and turbulent energy

Rys. 5. Lokalna energia spektralna i turbulentna

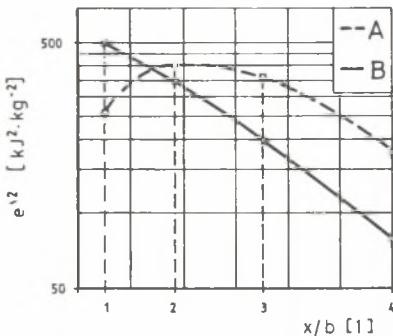


Fig. 6. Average turbulent energy in the flame

Rys. 6. Średnia energia turbulentna płomienia

designed output of the power plant unit with a minimum of harmful emission when burning low grade Czech coal.

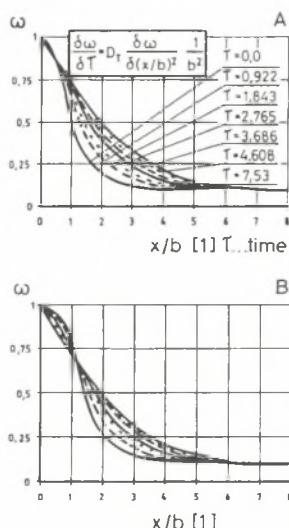


Fig. 7. Analyzer of turbulent mass transfer

Rys. 7. Analiza turbulentnej wymiany masy

NOTATION

b [m] width of burner, D_T [$\text{m}^2 \text{s}^{-1}$] turbulent diffusivity, e [kJ kg^{-1}] turbulent energy, f [s^{-1}] frequency, S [$\text{kJ}^2 \text{s kg}^{-2}$] spectral density of the turbulent energy, T [K] temperature,

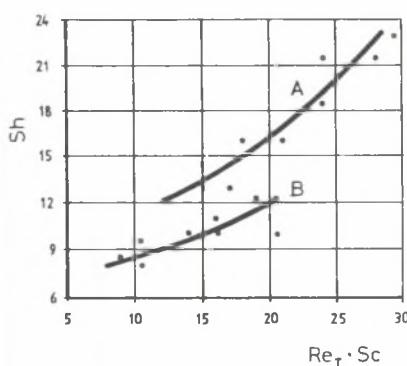


Fig. 8. Correlation of Sherwood number in the flame before and after readjustment

Rys. 8. Przebieg zmienności liczby Sherwooda w płomieniu przed i po regulacji

v_T [m²s⁻¹] turbulent viscosity, β [m s⁻¹] mass transfer coefficient, ω [kgkg⁻¹] relative concentration of fuel, x/b relative length of flame, $y/0.5b$ relative width of flame. Dimensionless groups: Sh Sherwood, Sc Schmidt, Re_T Reynolds turbulent, Gr_D Grashof for mass transfer.

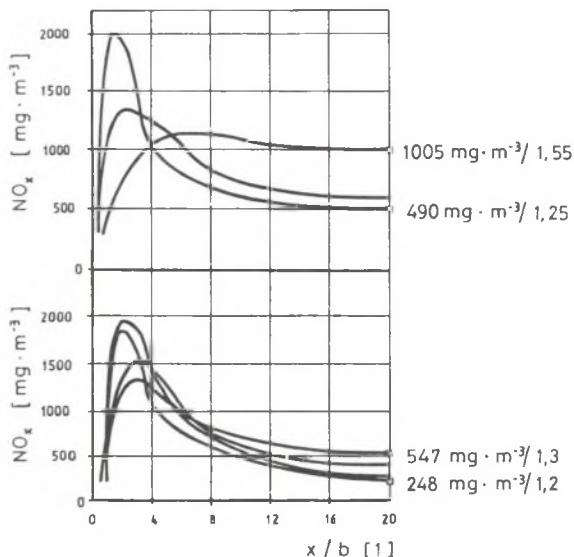


Fig. 9. Formation of NO_x emission in the flame before and after readjustment: NO_x emission/excess of air

Rys. 9. Emisja NO_x przed i po regulacji: Emisja NO_x /stos. nadmiaru powietrza

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Streszczenie

W pracy przedstawiono zjawiska transportu turbulentnego w kotłach. Pomiary aerodynamiki spalania w paleniskach kotłów wielkiej wydajności stanowią część badań prowadzonych w ramach czeskiego programu „Czyste technologie węglowe”. Testowane są również rezultaty uzyskane za pomocą trójwymiarowego modelu matematycznego i modeli izotermicznych.

Pomiary i analiza spalania dotyczą:

- optymalizacji spalania,
- regulacji palników do uzyskania „kontrolowanego spalania”.

Wymaga to zmierzenia pól prędkości i ciśnień wraz z ich fluktuacjami względem czasu oraz pobrania próbek gazowych i stałych składników spalin dla wybranych poziomów paleniska. Wykorzystywane są w tym celu pirometry radiacyjne pozwalające na pomiar temperatur rzędu 1200–1500°C oraz ich zmian o częstotliwości kilku kHz do ok. 10 m w głąb paleniska – rys. 1.

Wyniki badań przedstawiono na przykładzie kotła bloku 200 MW opalonego niskojakościowym węglem brunatnym, przed i po regulacji palników. Zmierzono:

- pola temperatury, prędkości i przepływów masowych – rys. 2,
- przebieg spalania pyłu węglowego – rys. 3,

- koncentracje gazowych i stałych składników spalin,
- fluktuacje temperatur i ciśnień,
- wielkości turbulentne: lepkość wirową – rys. 4, energię spektralną i turbulentną – rys. 5 i 6, turbulentną wymianę masy w płomieniu węglowym – rys. 7.

Badania tego rodzaju, prowadzone od ponad 20 lat, pozwalają uzyskać więcej szczegółów na temat kontroli procesu spalania zapewniającego redukcję stałych i gazowych zanieczyszczeń.