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LIMIT CONDITIONS FOR MINIMIZATION OF NO_x PRODUCTION IN FURNACES

Summary. By reducing combustion air amount a decrease of nitrogen oxide emission concentration in combustion products can be obtained. By this reduction, however, conditions for incomplete combustion occur manifested by carbon monoxide production. Such limit condition can be detected by measurement and conditions of optimum boiler operation can be defined.

WARUNKI GRANICZNE DLA MINIMALIZACJI POWSTAWANIA NO_x W PALENISKACH

Streszczenie. Obniżenie ilości tlenków azotu w spalinach można uzyskać poprzez zmniejszenie ilości powietrza do spalania. Mogą jednak wówczas wystąpić warunki do niezupełnego spalania prowadzące do zwiększonej produkcji CO. Poziom graniczny oraz optymalne warunki eksploatacji mogą być określone pomiarowo.

DIE GRENZBEDINGUNGEN FÜR DIE MINDERUNG DER NO_x BILDUNG IN FEUERUNGEN

Zusammenfassung. Die Abnahme der Verbrennungsluftmenge führt zur Abminderung des NO_x – Gehaltes in Rauchgasen. Die Unterschreitung eines Grenzwertes des Luftüberschusses gibt die Zunahme der CO– Bildung, was zur Verschlechterung des Kesselwirkungsgrades führt. Ein wichtiges Problem ist die Ermittlung der Grenzbedingungen für beide Prozesse. Die Arbeit enthält die Ergebnisse der Messungen, die in verschiedenen Kesseln durchgeführt worden sind um die Grenzbedingungen zu ermitteln. Es ist zu bemerken, daß jeder Kessel seine eigenen Grenzbedingungen hat und deren Ermittlung die Optimierung des Verbrennungsprozesses vom Standpunkt der Emissionsminderung ohne der Wirkingsgradverschlechterung ermöglicht.

1. INTRODUCTION

Nitrogen oxides occurring at fuel combustion in furnaces are produced by three different mechanisms described in detail by relevant literature [1]. According to them the nitrogen oxides are classified as thermal, fuel and prompt nitrogen oxides. A basic importance have the two former types and their genesis is describes as follows:

$$C_{NO}^{T} = K_1 \cdot \exp(-K_2/T) \cdot C_{N_2} \cdot C_{O_2} \cdot t \qquad (1)$$

Thus the genesis of thermal nitrogen oxides in expressed as predominant in combustion process, it is characterized by an exponential dependence on temperature while the influence of oxygen concentration is less pronouced. The correlation mentioned below, however, shows a more pronouced dependence on oxygen concentration in the combustion zone with less dependence on temperature by fuel NO:

$$C_{NO}^{P} = 7 \cdot 10^{-5} \cdot C_{NO_{max}}^{P} C_{O_2}^{2} \cdot (T_{max} - 1025)^{0,33} \qquad (2)$$

In the above–mentioned equations (1) and (2):

K – thermokinetic constants characterized by fuel type,
C – component concentration,
T – burning temperature,
t – reaction time, then by
$C_{NO_{max}}^{P}$ – NO concentration in combustion products is designated at 100% conversion of fuel nitrogen into NO and
T_{max} – maximum temperature in the combustion zone. [1, 2].

For minimization of nitrogen oxide production in furance the above–mentioned dependencies bring two basic reqirements: a reduction of burning temperature and reduction of oxygen concentration in furnace. These requirements should be understood as a reduction of local temperature peaks and oxygen concentration maximums and a realisation of such reduction measures used to be achieved by well–known technical solution with gradual burning air input, or eventually by gradual fuel input into the furance. In addiction to these basic measures minimizing directly the production of combustion caused nitrogen oxides there is a solution enabling a reduction of produced nitrogen oxides with carbon monoxide as adequate reducing agent.

The principle of control of combustion process with reduction of nitrogen oxides occurred together with results of operational tests has been described in detail in some studies [3, 4, 5]. The course process can be characterized in short as providing conditions enabling an accelerated fuel ingnition by application of adequate stoichiometry and aerodynamics of combustion. In regard to burners intensified burn–up of fuel at a sufficiently high temperature is connected with intense nitrogen oxide production. The choice of adequate air regime provides for creation of reducing atmosphere in the burner zone of furnance and thus a pronunced reduction of emission concentration of nitrogen oxides is achieved. A high efficiency of combustion is secured by an entire burn–up of combustible substances contained in the fuel, while by a reduction of burning temperature and oxygen concentration in furnace the combustion process is retarded and prolonged. By an inadequate solution of combustion process incomplete combustion occurs with its all infavourable economic and ecologic consequences. An adequate technical solution optimizing the course of combustion process within furnance must therefore fulfil requirements on complete fuel burn–up as well as minimum harmful substance emission. It is a logic conculsion that existing operational alternatives of application of primary measures for minimization of nitrogen oxide production are aimed on minimization of burning air volume. Less attention is however, devoted to air distribution. When the dependence of nitrogen oxide production on combusition air amount is evaluated the result is inequivocal: reduction of air amount means a reduction of nitrogen oxide emission.

But the problem is more complicated in view of risk of incomplete combustion of combustible fuel components. With regard to their burning velocity it is sufficient to devote attention to combustion of carbon and thus to the concentration of carbon monoxide in combustion products.

2. INVESTIGATION RESULTS

The current experiences with operation experiments investigating nitrogen oxide emission result into conculsion that when reducing combustion air amount it is at the same time necessary to follow up and maintain emission contents of carbon monoxide bellow their limit for achievement of below limit nitrogen oxide emission concentration. Therefore it is not sufficient to evaluate the combustion process quality in the furnace solely according to oxygen content of burning products behind the boiler. This fact is well–known from theoretical analysis on incomplete burning process. The results of operational measurements on various boiler types have indicated a great importance of furnance construction as a whole, including type of burners applied, their location, furnace geometry and its load, i.e. operational output.

The dependence of nitrogen oxide concentration on oxygen content in burning products behind the boiler was followed up in detail on a powder furnace of 200 MW block. In Fig. 1 measured courses within an output range from 160 MW up to nominal output are mentioned, the boiler was operated with three of four mills in various configurations. It was proved that the last

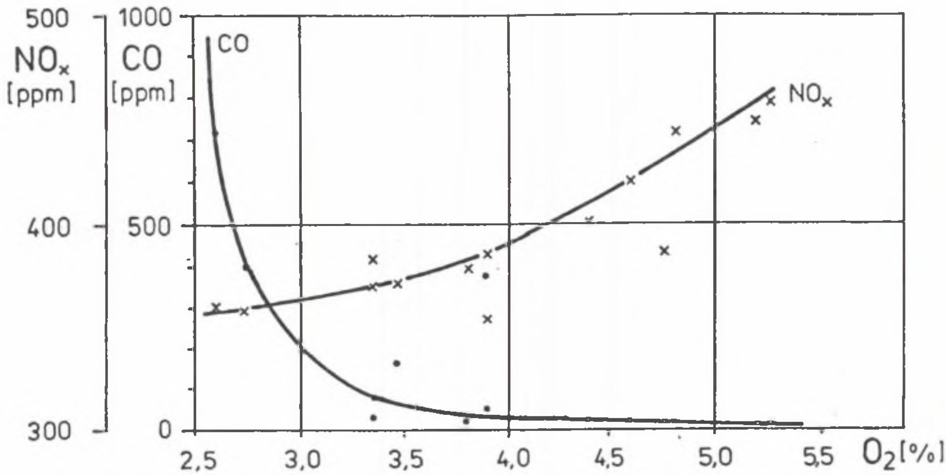

Fig. 1. Emission rates of nitrogen oxides and carbon monoxide for powder boiler of 200 MW_{el}

Rys. 1. Emisje tlenków azotu i tlenku węgla dla kotła pyłowego 200 MW_{el}

mentioned facts does not considerably affect the above–mentioned dependence. There is a pronounced decrease of nitrogen oxide content in combustion by oxygen content. In the exponent curve indicating the amount of carbon monoxide produced it is necessary to determine a limit value of oxygen content in compliance with valid emission limits and this below limit with some reserve must ba operationaly secured. The size of this reserve is given by attainably technical level and its importance is obvious because a reduction of 3,5% oxygen content even by 0,5% would increase carbon monoxide concentration approximately three times and a reduction by one percent already by two orders. Thus the lower limit of oxygen content, specified in regard to permitted carbon monoxide emission concentration, determines a minimum emission concentration of nitrogen oxides.

Another instant is mentioned in Fig. 2. It concerns the same dependence investigated on a mazut boiler with nominal output 7 MW. The test was carried out at a 80% output. The nature of characteristics is identical as in the previous case, remarkable is the fact that at 8% oxygen in combustion products an above–limit amount of carbon monoxide is produced.

In this instance it is given by inadequate preparation of mazut fuel for combustion.

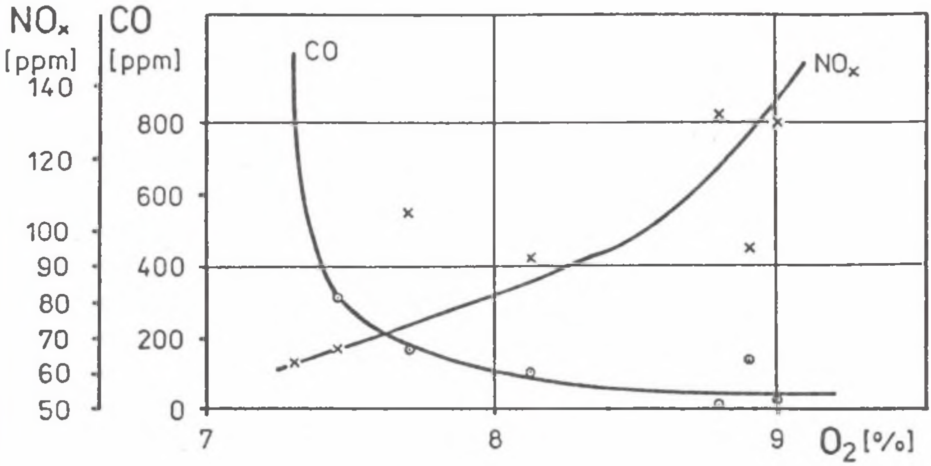

Fig. 2. Emission rates of nitrogen oxides and carbon monoxide depending on oxygen content for mazut boiler of 7 MW_t

Rys. 2. Emisje tlenków azotu i tlenku węgla w funkcji udziału tlenu w spalinach dla kotła mazutowego o mocy 7 MW_t

Interesting results have been obtained on gas boiler burning natural gas with nominal thermal output levels of the boiler and the correlations obtained are mentioned in Fig. 3.

The results indicate that for each output level a different correlation has been measured. In the Fig. 3 emission limit lines for carbon monoxide and nitrogen oxides are represented which respect referential 3% oxygen content in combustion products as well as the curve of minimum nitrogen oxide emission concentration values. The condition described is a consequence of inadequate conversion of orginally mazut boiler in which four mazut burners, located in two pairs one above another in the front wall were substituted by a pair of combined mazut–gas burners. In this conversion aerodynamics of furnace was not taken into consideration and it resulted into oncomplete mixture of fuel with combustion air. With decreasing output this inadequaty increases. The limiting factor of ecologically and economically acceptable operation of this boiler is permissible emission concentration of carbon monoxide and it is very difficult to control its operation.

Among basic primary measures for reduction of nitrogen oxide emissions a reduction of combustion air amount should be considered. However, for each furnace a limit operational condition exists which when exceeded means, that no complete burning can be provided. The result is a steep increase of content of another harm substance – carbon monoxide. Generally a reduction of boiler efficiency is connected with this condition and in case of solid fuel combustion the slagging of furnace walls is also increased.

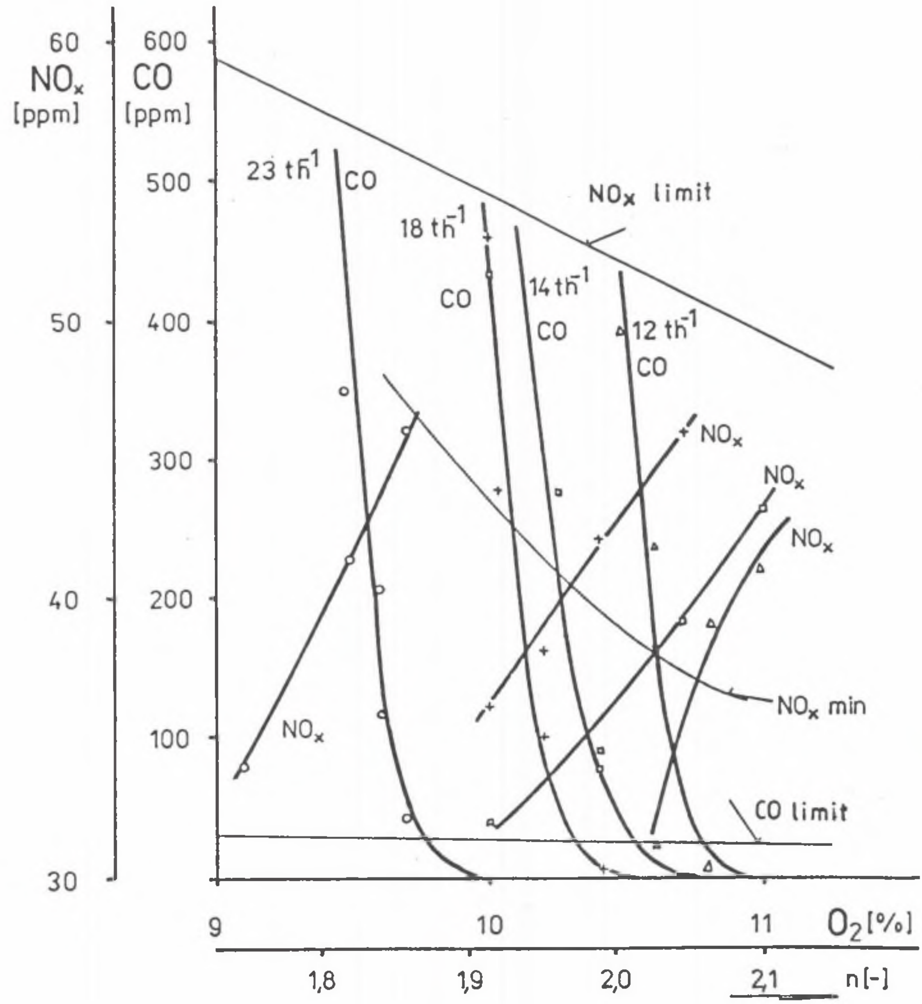

Fig. 3. Output dependence of carbon monoxide and nitrogen oxide emissions on air surplus for gas boiler of 20 MW_t

Rys. 3. Zależność emisji tlenku węgla i tlenku azotu od stosunku nadmiaru powietrza dla kotła gazowego o mocy 20 MW_t

It is possible to define a continuous operation at optimum conditions based on results of operation measurements. To secure and to safeguard it a continuous analysis of combustion products is necessary and according to analytic results the boiler shall be operated.

3. CONCLUSIONS

1. By reducing combustion air amount a decrease of nitrogen oxides concentration in flue gas can be obtained, but the reduction is connected with an increase of carbon monoxide production.
2. The results of measurements on various boilers have indicated a great importance of furnace construction, including type of burners, their location, furnace geometry and its load.
3. In the curve indicating the amount of CO production it is necessary to determine a limit value of oxygen content in compliance with emission limits.
4. It is possible to define a continuous operation at optimum conditions based on operational measurements.

NOMENCLATURE

C_{NO}^{T} – concentration of thermal NO in flue gas, %,
C_{NO}^{P} – concentration of fuel NO in flue gas, %,
C_{N_2} – concentration of nitrogen in flue gas, %,
C_{O_2} – concentration of oxygen in flue gas, %,
$C_{NO_{max}}^{P}$ – concentration of NO in flue gas, designated at 100% conversion of fuel nitrogen, %,
K_1, K_2 – thermokinetic constants,
t – reaction time, s,
T – burning temperature, K.

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Streszczenie

Zmniejszenie ilości powietrza do spalania pozwala osiągnąć obniżenie zawartości tlenków azotu w produktach spalania. Może jednak wówczas wystąpić niezupełne spalanie prowadzące do wzrostu zawartości tlenku węgla w spalinach. Istotne jest więc określenie granicznych warunków dla obu procesów. W pracy przedstawiono wyniki pomiarów opalanych różnymi paliwami kotłów o różnej wydajności, przeprowadzonych pod kątem określenia ww. warunków granicznych. Stwierdzono, że dla każdego kotła istnieją warunki graniczne silnego wzrostu zawartości CO w spalinach, zaś określenie ich pozwala na optymalizację procesu spalania z punktu widzenia zarówno emisji NO_x, jak i sprawności spalania.