Improvement of combustion efficiency and air pollution

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1. SYNOPSIS

Experimental research of combustion process efficiency in fixed grate furnace of small district heating boilers and gas fired steam generation unit, Emission level.

2. ABSTRACT

Energy economy in Latvia has a hard time now. Therefore, Investigation of possibilities of en energy efficiency improvement in industrial plants and district heating systems has acquire vital imortance and any energy saving is closely associated with environmental protection. The results of a pasive experiment investigating nitrogen oxide, carbon monooxide and suophur dioxide in exhaust gases from boilers and economyzers are provided for an analyses of coal combution process efficiency in fixed grate furnace of small district heating boilers (heat load less than 1.0 MW). It allows one to find the possibilities for energy saving and air pollution reduction. Similar experimental results are obtained investigating steam biolers units (steam generation capacity up to 20 tons per hour). In this case, a combustion process of natural gas is different from periodical coal combustion process and changes of emission amounts are smooth.

3. INTRODUCTION

The power engineering issues examined in this paper are concerned boiler houses of industrial) and district heating enterprises. Such objects are mot often found in Latvia and equipment installed in those stands for 80...90% of total number (Blumberga and Veidenbergs 1992).

A general situation in Latvia is described with declining of industrial production, that in its turn caused a decreasing of heat load in power engineering enterprised. A similar tendency can be seen in the enterprises concerned district heating because of fuel price approaching the level of world prices on energy resources. Also chronic lack of resources in the budgets of municipalities forces to move to reduces temperature regimes for heating and periodical tap water supply - not more than twice a week. There are towns ehere tap water supply is stopped at all. That situation is caused by operating of heat generators in regimes of partial load (even up to 3 % of nominal capacity) with low efficiency of combustion process.

Power engineers of Latvia Republic industrial and district heating enterprises have inherited the bjects with partial or no process automatization in cases of small heat generators. Problems concerned metering of fuel consumption are poorly sold, there is no accounting of the heat supplied to consumers as well as received.

Mutual settling of accounts is based on projected heat loads, in many cases even without an outside temperature correction. In such conditions heat generators are operated manually, with large amounts of excess air and inefficient use of fuel.

Another issue concerned operation or heat generators is air pollution by flue gas CO, Nox and SO_2 emmisions in cases of burning fuel that content sulphur. The policy of Latvia Environmental Committee is that tax must be paid for permitted emission amcunts, and 10 times higher penalty charge must be paid in case of violation of these amounts.

Emission levels are determined according to method worked out in former U.S.S.R. The results obtained by using that method are different from those determined by metering in boiler rooms. We should mention, that such a measurements are accomplished only in recent years and in limited numer of boiler rooms. That can be explained by lack of the technical equipment that is necessary for flue gas analysis in Latvia.

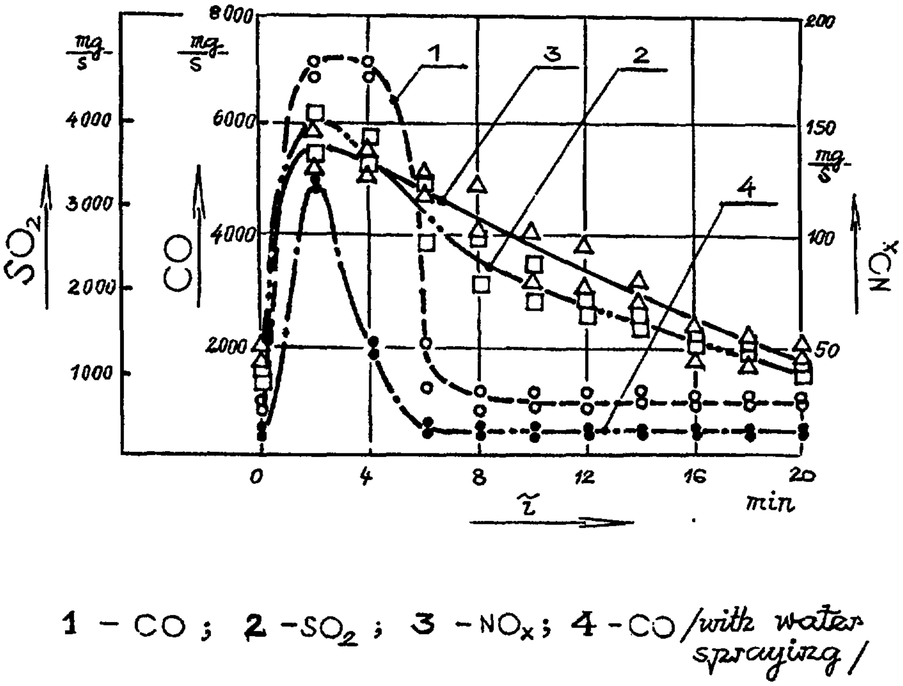

Figure 1. ***Channges of NO_x, CO, SO_2 content in cycle between fuel throwing***

Enumeration of examined problems allows to set the directions of investigation concerned heat generators that are of high priority, taking into account that situation in all mentioned aspects of small scale power engineering of Latvia can not be changed in the nearest years. It is diffivult to forecast, when it will possible to replace with new updated boilers installed in hundreds of boiler houses of Latvian enterprises and villages, and that have cast iron section fire-boxes with fuel combustion in bed on fixed grates, manual fuel feed and non-zonal air feeding under grates.

Those considerations forded us to start imestigation of operation of the mentioned boilers in order to clarify the perculiarities of combustion process in time period from one to another fuel feed, and focusing attention to reduction of taxic gas emissions and improvement of combustion efficiency and air pollution were carried out in all boiler houses of small town - Gulbene. Boiler houses were inspected and energy efficiency and air pollutants content in flue gases were checked (Blumberga and Veidenbergs. 1992a.).

3. RESEARCH APPROACH

Measurements of energy efficiency were accomplished using gas analysers MSI-200P and BACHARACH-300M, termocouples, thermometers, macrometers and other gauges.

Both steam generation units and district heating boilers are operating for technology and district heating needs with manual control and without high combustion efficiency regulation.

3.1 Boilers with fixed grate furnaces (fire -bow)

Research is carried out with small capacity steam generation units operated in boiler house of industrial plant ETMA (Madona). Two boilers cover heat load needed for technology and district heating needs of

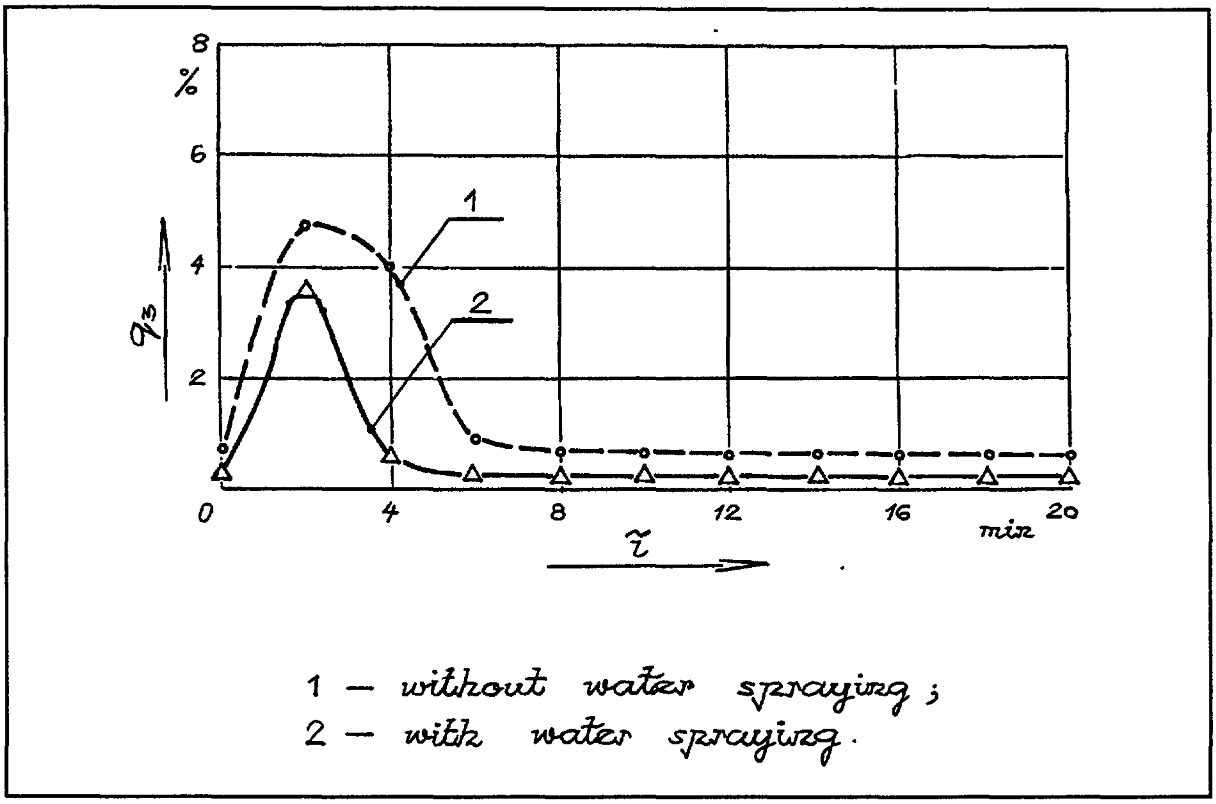

Figure 2. ***Changes of combustable heat losses in cycle between fuel throwing***

plant and residential house located nearly.

Technical data of steam generation units are following:

1. Type of boiler Minsk
2. Heat load up to 0, 4 MW
3. Steam pressure up to 0,17 MPa
4. Temperature of exhaust gases 220 ... 280'C

The fuel used in boilers during research was coal with heat content 19 MJ/kg, ash content 25,8 % and humidity content 20,3 %. Size of coal pieces were different - in range of 5 ... 100 mm.

Construction of furnace are foreseeing only one possibility to introduse air needing for combustion process - under fixed grate. It was implemented by fun and without regulation of air amount.

Combustion process an fixed grate has periodical character. One cycle of combustion is considered the time period between fuel feed. During experimental research fuel were burned with constant air consumption and flue gas flow.

The research data of variation of nitrogen oxides, sulphur dioxide and carbon manoaxide in one combustion cycle are presented in Figure1. Although an amount of excess air was high (2.7 ...4,5), after 2...4 min increasing of all emissions including carbon manoaxide was observed.

3. 2 Natural gas fired steam generation units.

An experimental investigation are carried out on steam generation with operated in the boiler house of Riga Milk Plant. The scheme of equipment, points of measurement and definalble parameters are showed in

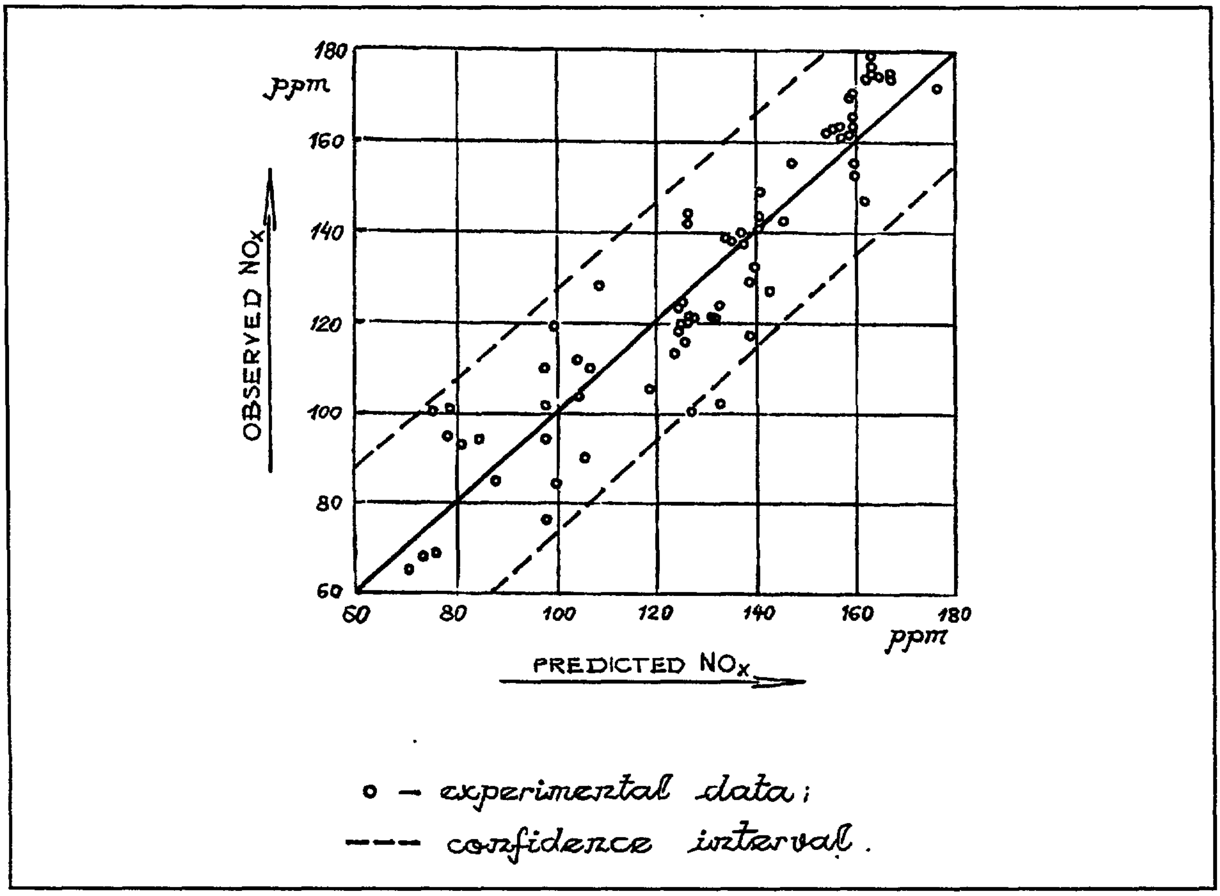

Figure 3. *Observed NO_x verses predicted values*

(Blumberga, Veidenbergs and Bazhbauers 1992).

In spite of the unanimous opinion of the authors concerning the sourdes and mechanisms of nitrogen oxide formation in the flames, the calculation of nitrogen oxides concentration under conditions of real furnace processes is very difficult. It can be explained by the multiple factors influencing the formation of NOx. Broadly speaking, these are: structure of furnace and burner creating various intensity of turbuence and mixing, methods of air supply and formation of the mixture (Gupta, Ramavajjala and Chomiak 1991), unit

Table 1. *Model calcuation results*

Variables	coefficient b	Standard error	t statistics	P value
const.	-201.6390	38.1240	-5.289	0.0000
x_1 = qv	0.5039	0.0323	15.586	0.0000
$x_2 = \lambda$	88.1270	24.1250	3.653	0.0005

load and air fuel ration (Hopkins, et al. 1991), cleanliness of the furnace surface and others. As can be seen, some factors are determined by the structure of a given unit, others depend on the mode of operation. Of course, the impact of the structure on the Nox output manifests itself in different ways in varios modes of operation, but the general tendency is clearly seen - variable factors are those that determine the unit operation mode, but NOx output is a dependent variable.

During a year time we have worked with vertical two-drum water-tube boilers with steam capacity 16 ...20 t/hour in order to determine NOx output with a goal to find an equation for calculation of NOx leverl. The contonts of fuel gas were determined using gas analyzer MSI-2000P and recalculated to air fuel ration = 1,17 , which corresponds to 3 % oxygen content in axhaust gases.

The pressure of generated steam, fuel consumption and depedence of excess air on technology steam consumption were obtained during experimental investigation. In case of manual control and regulation of the combustion process the air fuel ration changes in a wide range indepently on the fuel consumption. All the above said partially ecplans specific to this research.

4. RESULTS

4.1 Coal combustion process

The emissions of carbopn monoaxide create both heat losses because of incomplete combustion and higher air pollution level.

Results of calculation of incomplete combustion heat losses are presented in Figure 2 (curve i).

One of the reasons of carbon monoaxide content increasing could be explained by aerodinamic process. Improvement of mixing CO with oxigen was implemented by water injection into overbed space of furnace. Such a simple method gave possibility to reduce content of carbon manoaxide by 40 % (Figurel curve 4) and to increase boiler efficiency by i ...1,5 %. Reducing of imcomplete combustion heat losses is shown in Figure2 (curve 2).

4.2 Natural gas combustion and nox emissions

The results, that include 80observations, were analyzed using a method of the dispersion and regression analyzed (Afifi and Eisen 1982).

The results of observations of NOx emmissions present occurance of random processes which after their analysis determined to be stationary and ergodic. The search of mathematical relationship between the random dependent variable of NOx waste and randow independent factors is shown as multiple linear regression equation:

$$\bar{y} = b_o + b_1 X_1 + b_2 x_2 \qquad (1)$$

where:
- y - evulation of the NOx output, ppm;
- b_o - evulation of the free member of the equation;
- $b_{1,2}$ - evaluation of the equation coefficients;
- $x_1 = q_v$ - furnace heat load, kW/m^3;
- $x_2 = \lambda$ - air/fuel ration.

In the course of analysis also other multiple factor linear regression models were studied, that took into the condiseration the spending effekt of independent variables. However, later kthese were rejected as they gave no substantial improvement of correlation between the expected and the measured values of NOx.

In data processing 95 % confidence interval was accepted and the significance level is 0,05. The results of

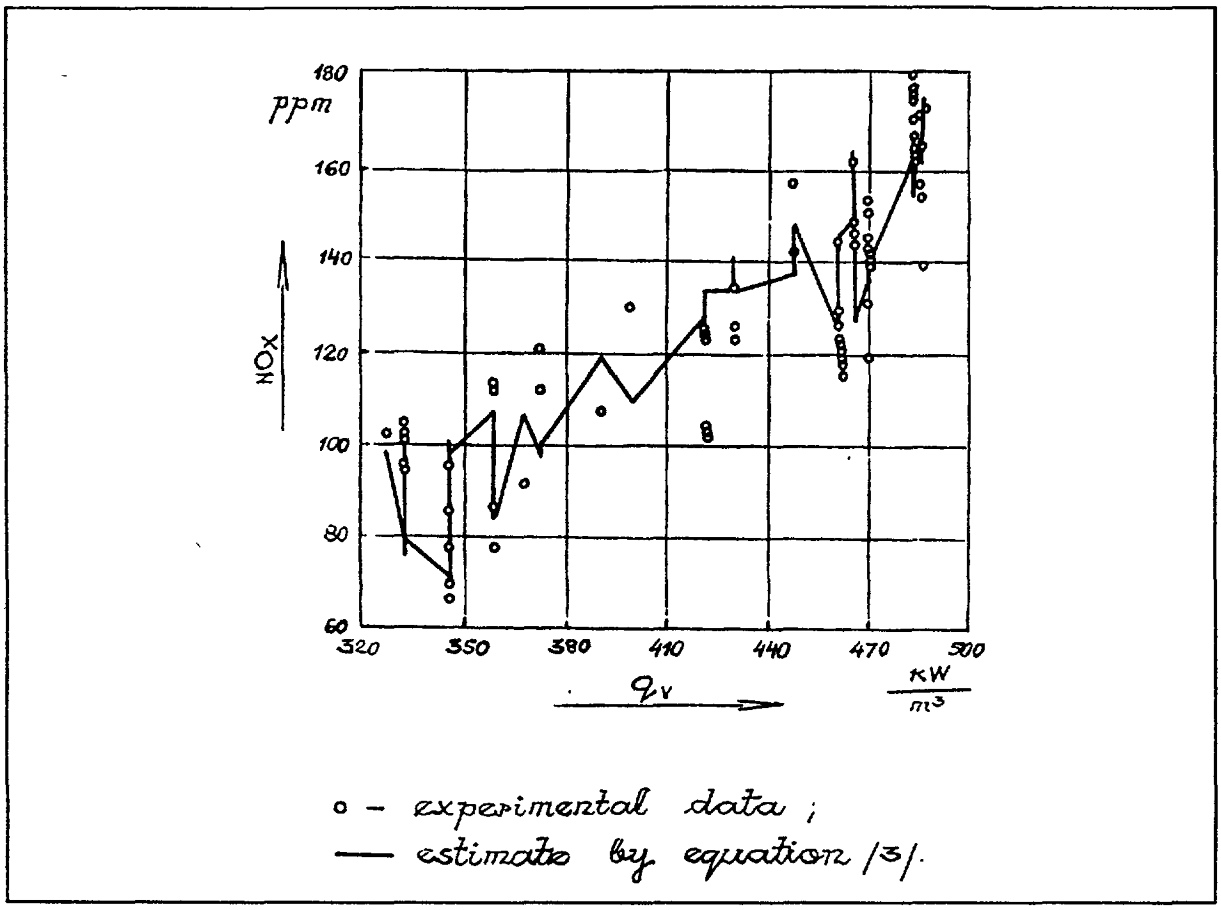

Figure 4. *Nitrogen oxide output verses furnace heat load*

regression equation coefficient calculation results (i), standard coefficient errors, t - statistics and their p values are reflected in the table.

R - SQ = 0.756
Furnare heat load:

$$q_v = \frac{B \cdot Q_L}{V} \quad , \quad \frac{kW}{m^3} \tag{2}$$

where: B - fuel comsumption, kg/s;
Q_L - low heatin value of fuel, kJ/kg;
V - volume of furnace, m^3.

As can be seen from comparision of p-values derived from t-statistics with the value level 0.05 all regression coefficients b is significant and the regression equation assumed to be as follows:

$$NO_x = -201{,}6 + 0{,}504q_v + 88{,}1\lambda \quad , \quad ppm(O_2 = 3\%) \tag{3}$$

Value of R-squared coefficient 0.756 proves that regression equation (3) explains 76 % of NOx presence detected in boiler output.

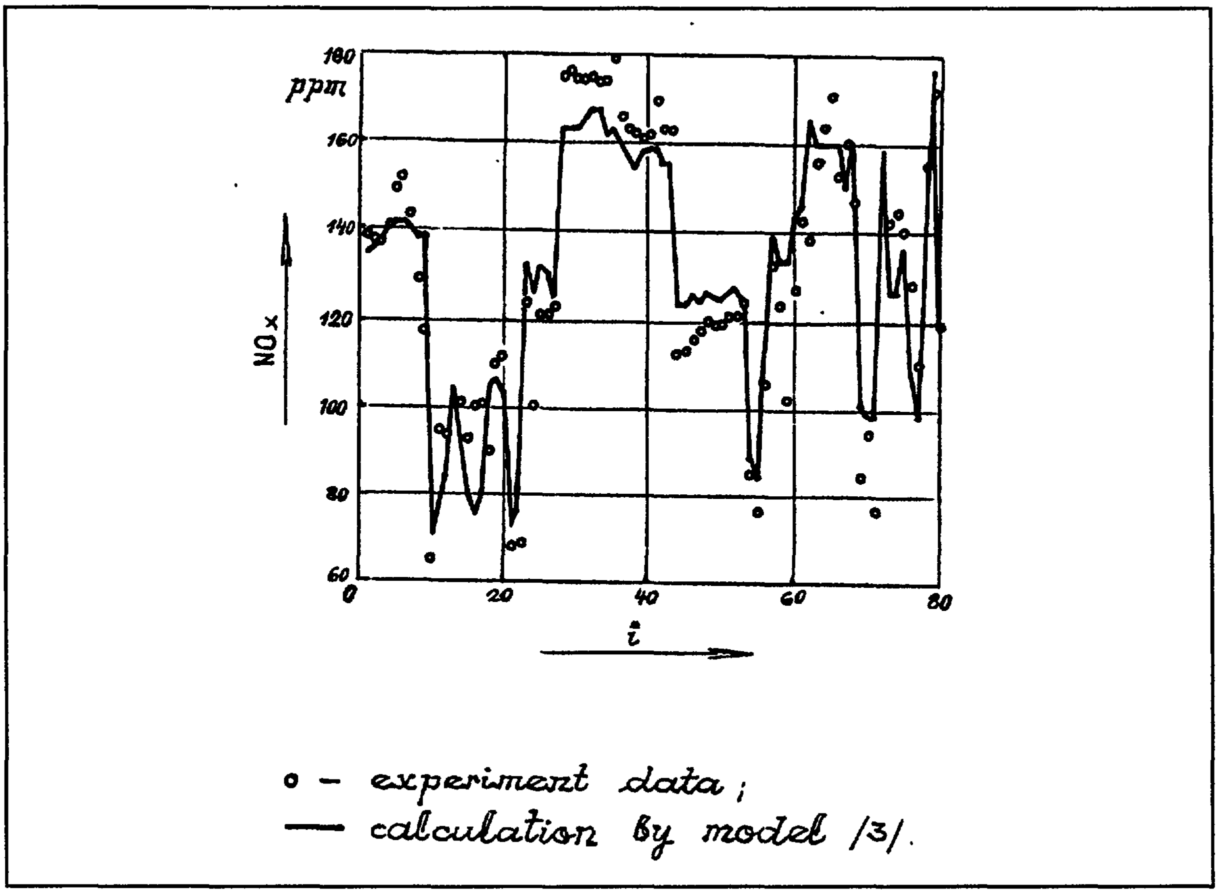

Figure 5. *Nitrogen oxide output*

A comparision of NOx output calculated by model (3) with the experimental data is seen on Figure 3.

Borders of confidence interval are also seen in the figure, corresponding to the confidence probability of 0,95. As is seen from Figure i the experimental results do not exceed the borders of the interval.

Dependence of nitrogen oxide output on the furnare heat load is shown on Figure4. In the course of the experiments the furnace heat load varied from 320 to 500 kW/m^3.

As seen from Figure 4 NOx output increased with the increase of fuel consumption. The change of fuel consumption, in its turn, was determined by the rate of changes of the boiler steam generation rate capacity. However, the correlation between steam generation rate and Nox output is not simple (Krizhanovsky 1990), as the combustion also exerts its influence. In boiler lacking the automatic load regulators a simple correlation between the steam generation rate and the fuel consumption is hard to determine. It is reflected by the fluctuations of the generated steam. In cases of manual regulation of the combustion process substantial changes of fuel air proportions were observed i.a. the air-to-fuel ratio changes in a wide range independently on the fuel consumption. All the above said partially explains the diversity of the experimental data on Figure 4.

Comparison of experimental NOx output values with the calculated ones according to model relating the dependent varibale to independent variables (Blumberga, Veidenbergs and Bazhbauers 1992) is given in Figure 5).

In the figure the ordinal number of definite chosen results is marked on the horizontal axis. As seen from the graph, the model gives a good description of the experimental data. This conclusion is in good agreement with the data in Figure 3 and the results of model analysis. It proves the correctness of the method used in the given paper and proves its suitability for analysis of NOx output result analysis for the boilers used in this research as well as for the investigation of other units.

CONCLUSION

1. Energy efficiency of fixed grate furnaces is low. It is possible to implement improvement of the energy efficiency of small boiler units and reduction emission level with low cost arrangements.

2. The evaluation of NOx formation is based on empirical regression model describing NOx output, which have been developed on the basis of statistical data processing of the industrial experiment on steam generators. The model can serve as a basis for numerical evaluation of NOx output and forecasting the NOx level in the case of purposeful variation of operating modes.

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