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Control of Harmful Emissions Concentration into the Atmosphere of Megacities of Kazakhstan Republic

Aliya Askarova[1], Saltanat Bolegenova[1], Valeryi Maximov[2], Aidyn Bekmukhamet[3], Zarina Gabitova[3], Meruyert Beketayeva[3,*]

1Dr. of phys.-math. Sc., Professor of al-Farabi Kazakh national university, Almaty, Kazakhstan
2PhD, Lecturer of al-Farabi Kazakh national university, Almaty, Kazakhstan
3, corresponding author, PhD Student of al-Farabi Kazakh national university, Almaty, Kazakhstan*

Abstract

Solid fuel plays significant role in the development of civilization as the main fuel source. Use of low-grade (ash content ~ 40-45%) coal is partially offset environmental problems also affect human health when it is burned. As the main industrial corporations use coal, in particular low-grade high-ash content coal from Ekibastuz coal basin because of its cheap cost the atmosphere of megacities like Almaty is polluted by noxious volatile. In this study were developed a mathematical model of turbulent heat and mass transfer process occurring in the combustion chamber of SB-39 of Aksusskaya TPP for control the concentration of volatile and to recommend the optimize methods for burning process. Based on 3D computer modeling investigated formation of harmful dust and gas emissions during the combustion of low-grade coal and offered cost-effective methods of burning.

Keywords: air excess, coal, combustion, concentration, emission, environmental problems, low-grade, modeling, numerical simulation, process.

1. Main text

Currently in Kazakhstan, about 85% of electricity is generated by thermal power plants (TPP), which is the main fuel is coal. More than 80% of coal burned in these TPP is low grade ash content of about 50%. Burning

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of low-grade coal fraught with difficulties in their fire, growth of mechanical unburning, increase of harmful dust and gas emissions (ash, carbon oxides, vanadium pentoxide, nitrogen and sulfur oxides, hydrocarbons). Emissions from industrial plants of Kazakhstan in the atmosphere are more than three million tons per year, of which 85% are 43 large enterprises. In the emissions from various sources of Unified Energy System dominated solids - 35%, sulfur dioxide - 31%, carbon monoxide, 19%, nitrogen oxides - 14% [1, Shabanova L.V., 2013].

Nomenclature

SB-39	Steam Boiler
TPP	Thermal Power Plant
SNCR	Selective Non-Catalytic Reduction
MPC	Maximum Permissible Concentration
	Basic transport variable;
Γ_ϕ	Generalized exchange ratio;
S_ϕ	The source term in the transport equations;
ρ	Density, kg/m^3;
h	Enthalpy, J/kg;
σ_k, σ_ε	Empirical constants in the turbulence model;
T	Temperature , K;
μ_{turb}	Turbulent viscosity, $kg/m{\cdot}s$;
μ_{eff}	Effective viscosity, $kg/m{\cdot}s$;
p	Pressure, Pa;
ε	Dissipation rate of turbulent kinetic energy per unit mass, m^2/s^3;
k	Turbulence kinetic energy per unit mass, m^2/s^3;
C_β	Mass concentration, kg/kg;

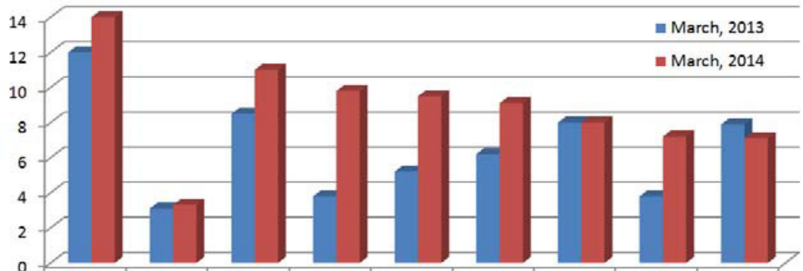
1. Study of pollutants of megacities

Condition of the air basin is the most important indicator of the ecological situation in the city. Air pollution in Almaty is an environmental problem that is complicated by climatic conditions. The city is located in the cavity, where often there is no wind, fog and ground inversions that inhibit dispersion of pollutants in space. In addition, an ill-conceived development of the city prevents the natural movement of air flow in the horizontal direction [2, Nurkeev S.S., etc., 2005]. According to long-term observations KAZHYDROMET, the main pollutants include dust (particulate matter), sulfur dioxide, carbon monoxide, nitrogen oxide and dioxide, phenol, formaldehyde.

High levels of air pollution recorded in 8 cities: Almaty, Uskemen, Kyzylorda, Chimkent, Karaganda, Temirtau, Taraz (Table 1) [3, Environmental situation on the territory of Kazakhstan in March , 2014].

Following information shows us the main pollutants and their maximize spread concentration in example of Almaty city. Daily course of *dust* concentration in winter months is more pronounced than in summer.

Table 1. Level of air pollution cities of Kazakhstan



	Almaty	Astana	Uskemen	Kyzylorda	Shymkent	Karaganda	Temirtau	D.Glubokoe	Taraz
March, 2013	12	3,1	8,5	3,8	5,2	6,2	8	3,8	7,9
March, 2014	14	3,3	11	9,8	9,5	9,1	8	7,2	7,1

Most dangerous concentration of CO in urban air is in the evening and night hours, when even daily averages on some days exceed the MPC several times. In summer months, the main sources of carbon monoxide (emission boilers and heating furnaces) are missing, so the observed concentrations below MPC (on average no more than 1.5-2.0 mg/m^3). *Nitrogen dioxide* concentrations exceed the MPC almost throughout the year, since the main source of income emissions - an internal combustion engine does not depend on the time of year. In the daily course of the highest concentrations observed in the afternoon and evening in winter. *Phenol and formaldehyde* in winter than in summer concentrations below and have a similar course with a minimum in the afternoon. Compared with the corresponding MPC summer and winter average values observed above. In the summer time concentrations of formaldehyde often exceeds the MPC several times, as high temperatures contribute to the processes of decomposition of organic matter, and that his main source of income in the atmosphere. Hydrometallurgical orographic conditions and location specific Almaty contribute to the accumulation of harmful emissions in the air basin, so no special measures to reduce harmful emissions in the environmental situation will not improve.

The problem of interaction of power system and the environment is very multilateral, is at the forefront of scientific thought and requires special attention [4, Askarova A.S., etc., 2013], [5, Askarova A.S., etc., 2012]. Considerable interest for energy in reducing anthropogenic impacts on the environment are researching and developing new and improving existing processes to improve low-grade solid fuels that reduce emissions of pollutants into the atmosphere and at the same time improving the basic indicators of energy complexes. Development of methods of mathematical modelling in research in heat and mass transfer processes with combustion flows has led to the emergence of various software packages-oriented, by which more or less successfully resolved fundamental problems as well as applied. Physical-mathematical and chemical models and computational experiments conducted to determine the aerodynamic, thermal characteristics and concentration fields of volatiles in the entire volume of the combustion chamber of the SB-39 of Aksu TPP. The results will develop a model to describe the process of selective non-catalytic reduction of nitrogen oxide in combustion environments on the basis of thermal DeNOX for Kazakhstan TPP. The most effective temperature range and most profitable initial values of defining parameters determined for the selective non-catalytic reduction (SNCR) of nitrogen oxides. "Clean" technology of Ekibastuz coal burning in combustion chamber of SB-39 of Aksu TPP developed with the use of selective non-catalytic reduction of nitrogen oxide emissions in the environment.

2. *Mathematical and physical formulation of study*

This environmental problem can be solved by the new information technologies and the modern software products of mathematical simulation of processes in reacting media. In this regard numerical experiment is becoming one of the most economical and convenient way for detailed analysis and understanding of complex physical and chemical phenomena taking place in the combustion chamber. Using the latest advances in information technology for modeling the processes in heat engineering and thermal power engineering was allowed to conduct analytical studies of the formation of harmful substances in the man-made gases on real TPP. A mathematical model of the problem is based on the laws of conservation of mass, momentum and energy. To describe the three-dimensional motion of reacting flows in the areas of real geometry used a system of differential equations [6, Lawn C.J., 1987]:

mass balance equation and the continuity equation:

$$\frac{\partial \rho}{\partial \tau} = -\frac{\partial}{\partial x_i}\left(\rho u_i\right) \tag{1}$$

law of conservation of momentum:

$$\frac{\partial}{\partial \tau}\left(\rho u_i\right) = -\frac{\partial}{\partial x_j}\left(\rho u_i u_j\right) + \frac{\partial}{\partial x_j}\left(\tau_{i,j}\right) - \frac{\partial p}{\partial x_j} + \rho f_i , \tag{2}$$

where f_i – body forces; $\tau_{i,j}$ – stress tensor,

energy equation:

$$\frac{\partial}{\partial \tau}\left(\rho h\right) = -\frac{\partial}{\partial x_i}\left(\rho u_i h\right) - \frac{\partial q_i^{res}}{\partial x_j} + \frac{\partial p}{\partial \tau} + u_i \frac{\partial p}{\partial x_i} + \tau_{ij}\frac{\partial u_j}{\partial x_i} + s_q , \tag{3}$$

where: h – enthalpy; S_q – a source of energy is taken into account due to the heat radiation, convective exchange between the particles and the gas phase and the heat of combustion.

The investigated object in this paper – combustion chamber of the boiler SB-39 block to 300 MW with steam capacity - 475 t/h. Boiler installed at the Aksu thermal power plant (Kazakhstan). The combustion chamber is equipped with 12 three-way vortex burners. Burners are arranged oppositely in two tiers to 6 burners each. Burners have two sizes, which allow for different rates of excess air in them: the lower tier α_r =1.4, the upper tier of α_r=0.9. Fuel is distributed evenly on the tiers. The composition of Ekibastuz coal used as raw material in most energy facilities: Wp – 7.0%, Ap – 40.9%, Sp – 0.8%, Cp – 41.1%, Hp – 2.8%, Op – 6.6%, Np –0.8%.

2. **Results of numerical simulation**

The results of computer simulations allow us to estimate the basic laws governing the formation of carbon dioxide in the vortex combustion chambers on the example of boiler SB-39. Fig.1 shows three dimensional distribution of the concentration of carbon dioxide in the region of the burners in a real combustor. It can be seen that the most rapid formation of carbon dioxide CO_2 occurs with increasing distance from the inlets, i.e.

in the collision of the jets of fuel and oxidizer from oppositely burners. Color scale allows determining the concentrations of CO_2 at any point in the combustion chamber and at the output of it.

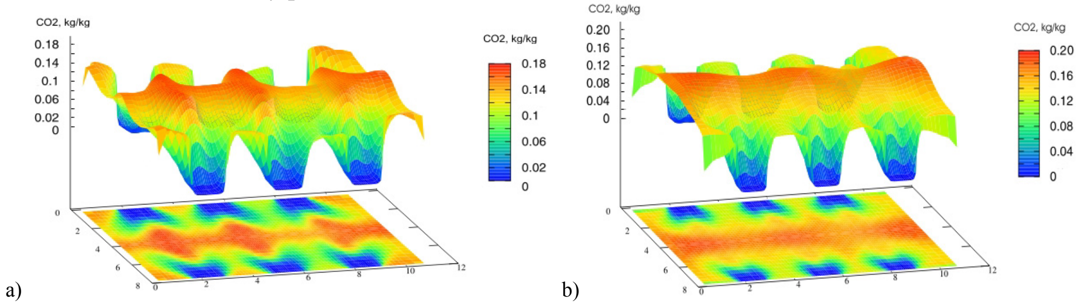


Fig. 1. 3D concentration distribution of CO_2 in the combustion chamber of the SB-39 in the field of burner (a) - lower level; (b) - the top-level

On the basis of the considered Mitchell and Tarbell kinetic model of NO formation in this work were carried out computational experiments to determine the regularities of formation and destruction of the main components (HCN, NH_3, and NO) in the volume of the combustion chamber of the boiler SB-39 of Aksu TPP. Numerical simulation results are presented in the form of three-dimensional concentration distributions of nitrogen-containing components in the different areas of the combustion chamber. The distribution pattern of the concentration of nitrogenous components involved in the formation of nitrogen oxides represented by Fig.2 (a, b, c) in the form of three-dimensional distributions of the concentrations of ammonia NH_3 (a), hydrocyanic acid HCN (b) and nitrogen oxide NO (c). As specific planes was chosen horizontal plane at the level of upper and lower tiers of burners of studied combustion chamber.

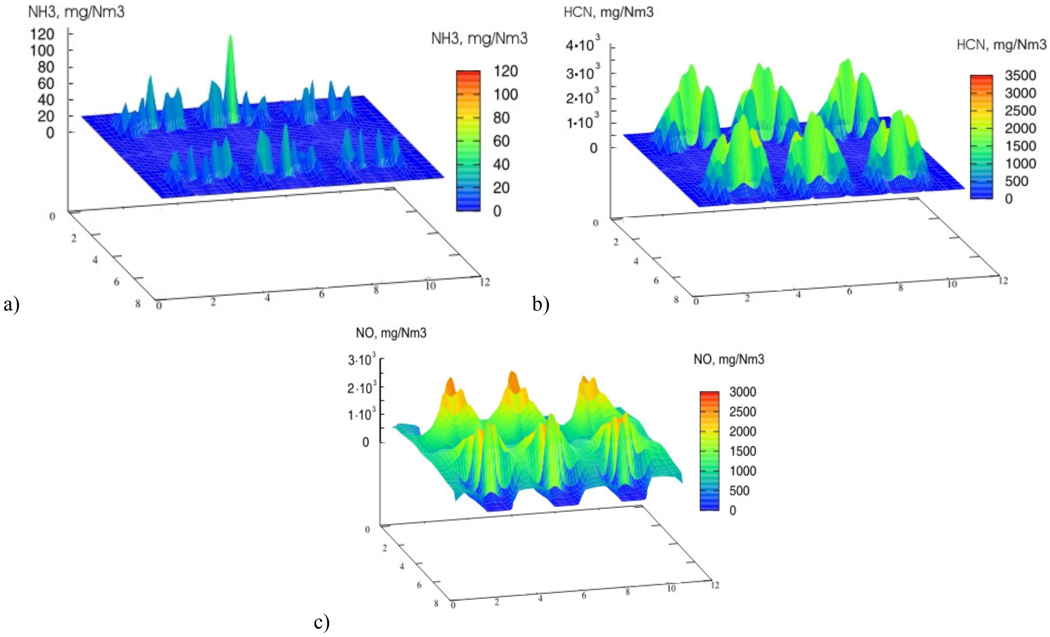


Fig. 2. Distribution of the concentration (a) - ammonia NH_3; (b) - HCN; (c) - NO nitrogen monoxide in the combustion chamber of the boiler SB-39 in the field of lower level of the burners

During combustion of coal nitrogen of fuel is distributed between the volatile and coke. The share of nitrogen oxides produced from coke is relatively small and is about 20%. Analysis of concentration distributions shows that the main zone of gas formation of nitrogen-containing components and directly NO area is the burners. Excess air ratio in the cell plays an important role in the mechanism of formation of NO_x. For all components, the relatively high level of their occurrence is observed at the root of the torch, i.e. in an area of burners and therefore of maximum concentration in the field of fuel and oxidant. As you move the gas mixture to the exit of the combustion chamber there is a decrease in their concentration. Figure 3 shows the distribution of the maximum, minimum and average values by cross section of the concentrations of nitrogen compounds (HCN, NH_3 and NO) at the outlet of combustion chamber of the boiler SB-39 Aksu TPP.

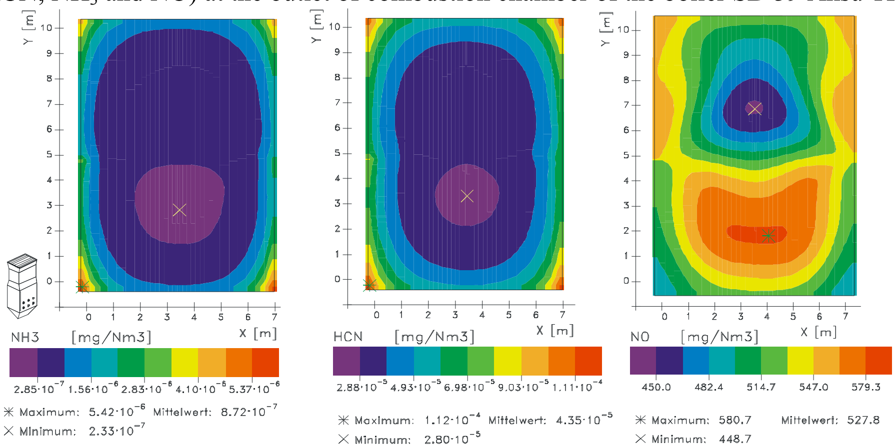


Fig. 3. Distribution of the concentration of nitrogen compounds at the outlet of combustion chamber of SB-39 of Aksu TPP

3. Conclusion.

Based on the methods of 3D computer modeling studied the complex process of heat and mass transfer occurring in the fields of real geometry (combustors TPP) during the burning of solid energy fuel. The main regularities and features of the formation of harmful dust and gas emissions of carbon oxides (CO and CO_2), nitrogen oxides NOx (NO and NO_2) and nitrogen compounds (HCN, and NH_3) mounted from the combustion of high-ash low-grade fuel (Ekibastuz coal) on the real energy object of the Republic of Kazakhstan (combustion chamber of the boiler SB-39 of Aksu TPP which will helps to improve the technological process also to find reliable parameters of combustion.

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