RECENT CONTRIBUTIONS TO PHYSICS
AL-FARABI KAZAKH NATIONAL UNIVERSITY

RECENT CONTRIBUTIONS TO PHYSICS

№1 (68)

Алматы
«Қазақ университеті»
2019
25.11.1999 ж. Қазақстан Республикасының Мәдениет, ақпарат және қоғамдық келісім министрлігінде тіркелген
Куәлік №956-Ж.

Журнал жылына 4 рет жарыққа шығады

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Currently, air pollution is a huge environmental problem. The participation of energy companies in environmental pollution by fuel combustion products and solid waste is significant. Above all, power plants operating on solid fuel are one of the main sources of air, water and soil pollution. Until recently, during coal combustion process the most part of attention has been paid to protecting the environment from solid pollutants, such as ash. Very little attention has been paid to the gas products of combustion reactions, especially to NOₓ and SO₂.

Mainly NO and NO₂ of nitrogen oxides are found in the atmosphere. NO is an unstable component that oxidizes to NO₂ during 0.5-3 to 100 hours. The toxicity of NO₂ is 7 times higher than the toxicity of NO. Nitrogen oxides are most dangerous as an active ingredient in the formation of photochemical smog. Currently nitrogen oxides are recognized as the most toxic atmospheric pollutants, and their maximum permissible concentration is 6 times less than for sulfur dioxide. It is believed that emissions of nitrogen oxides generated during combustion contribute to the oxidation of precipitation, photochemical air pollution and depletion of the ozone layer.

In this regard, many studies are aimed at the development of technologies for environmentally friendly combustion, which provide harmful dust and gas emissions at the level of international standards.

One of the ways to reduce the concentration of nitrogen oxides NOₓ is the stepwise combustion of a powdered coal mixture, in particular the "Over Fire Air" technology. The idea of this method is based on the fact that the main volume of air is supplied to powdered coal burners, and the rest of the air is supplied further along the height of the torch through special nozzles.

The article presents the study results of the Over Fire Air technology influence on the aerodynamic characteristics of the combustion chamber of the BKZ-160 boiler.

**Key words:** energy, combustion, nitrogen oxide, injector, combustion chamber, aerodynamics.
Recent Contributions to Physics. №1 (68). 2019

Askarova A.S. et al.

**Abstract**

Energy is one of the leading industries of many industrialized countries. These countries have switched to the innovative development of this industry, they have changed the system of view on its role and place in the modern and future society radically. The new system of view is reflected in the Smart Grid concept – the smart energy system, which should be the basis of the national energy and

**Keywords:** energy, generation, nitrogen oxide, injector, furnace, aerodynamics.
innovation development policy of any country and should be taken into account in the development of the domestic energy.

Efficient energy use is a prerequisite for economic and social development, as well as improving the ecology.

In the "Kazakhstan-2050 Strategy" N.A. Nazarbayev noted that: "Kazakhstan is one of the key elements of global energy security...".

Worldwide, the use of renewable energy resources (the share of solar and wind energy in the total energy consumption of the Republic of Kazakhstan is about 0.02%) is an integral part of measures to solve environmental problems.

However, solar and wind energy production is relatively expensive compared to traditional sources.

The country’s coal power plants generate more than 80% of energy. Therefore, “in the future, coal will have been playing a significant role in the country's energy sector” [1-4].

Energy is one of the leading industries in many industrialized countries, including Kazakhstan. It should be noted that more than 80% of all energy produced in the world is produced by combustion of organic fuel (Figure 1) [5]. In Kazakhstan, about 70% of electricity is generated from coal, 14.6% from hydro resources, 10.6% from gas and 4.9% from oil.

The main part of electricity in Kazakhstan is generated by 37 thermal power plants operating on coal from Ekibastuz, Maikubinsk, Turgai and Karaganda basins.

Production of electricity by burning solid fuel (coal) for our country is the traditional and most developed way due to the presence of hard coal huge reserves. Therefore, in spite of the beginning of the search process for Kazakhstan of alternative, more environmentally friendly ways of obtaining energy, for a long time the power plants operating on solid fuels will have been being the basis of energy production and energy security of the country. The quality and quantity of gas emissions and waste of thermal power plants is greatly influenced by the type of used fuel [6-9].

The coal of Kazakhstan is cheap energy fuel, the reserves of which will be enough for many hundreds of years. At the same time, its low sulfur content and low nitrogen content (not more than one percent) should be noted. However, at the same time, the coal of Kazakhstan, being a good energy fuel in its reactivity, has one big drawback – high ash content. The ash content of coal supplied from individual Kazakhstani fields to thermal power plants sometimes exceeds 70%. In compliance with the law in the UK it is – 22%, in the USA – 9%, in Germany – 8%.

The presence of ash in the fuel affects on its quality negatively, since ash reduces the amount of heat per unit mass of fuel. The smallest solid particles of ash are captured by the flow of flue gases and are carried away from the burner, forming fly ash, which pollutes and sometimes floods the convective heating surface.

During combustion of all types of fossil fuels, one of the most harmful products of combustion are NOx oxides, which damage both the environment and human health.

Thus, one of the actual tasks in the development of new and operation of existing combustion devices
is to reduce the concentration of carbon and nitrogen oxides during the combustion products.

Reducing NOx emissions from fuel combustion at TPPs plays an important role in reducing the total level of nitrogen oxides NOx emitted into the atmosphere. When using methods to reduce NOx in calculating the amount of NO2, it should not be used the traditional percentage of NO2 of the total amount of NOx (10%), as this leads to very significant errors in the calculations.

One of the ways to reduce the concentration of nitrogen oxides NOx is the stepwise combustion of a powdered coal mixture, in particular the "Over Fire Air" technology. The idea of this method is based on the fact that the main volume of air is supplied to powdered coal burners, and the rest of the air is supplied further along the height of the torch through special nozzles [10-15].

Mathematical model describing the process of heat and mass transfer during combustion of coal dust in the combustion chamber of the boiler BKZ-160 on Almaty thermal power plant

Many experimental and analytical studies are conducted under simplified conditions that differ from the actual conditions of the combustion process. For example, many of them are conducted under the conditions of burning large particles when they are burned in a large excess of air. Some researchers assumed that the temperature of the medium during the combustion process would not change, and the combustion would proceed in one of the extreme regimes: kinetic or diffuse. Such simplification of the combustion process misrepresents its essence and does not allow to determine the aerodynamics and heat transfer occurring in a real combustion chamber.

During the combustion of solid fuel in a powdered state, turbulent processes of heat and mass transfer of reacting components and products of their interaction occur in the combustion chamber. Equations based on the laws of mass and momentum conservation describe such processes. For reacting streams in which heat transfer processes and chemical reactions occur, it is necessary to solve the energy conservation equation and add the mixture components conservation equation or the mixture fractions conservation equation and their changes additionally. Turbulence is described by transport equations for turbulent characteristics.

The system of basic equations of the mathematical model used in this project to describe the processes of turbulent heat and mass transfer during the combustion of solid fuel in a powdered state (powdered coal flame) [15-20]:

a) The mass conservation equation, or the continuity equation:

$$\frac{\partial \rho}{\partial t} = - \frac{\partial}{\partial x_i} (\rho u_i) ,$$  \hspace{1cm} (1)

b) The law of conservation of momentum:

$$\frac{\partial}{\partial t} (\rho u_i) = - \frac{\partial}{\partial x_j} (\rho u_i u_j) +$$

$$+ \frac{\partial}{\partial x_j} (\tau_{ij} - \rho f_i) - \frac{\partial}{\partial x_j} \rho,$$  \hspace{1cm} (2)

Here $f_i$ is bulk forces, $\tau_{ij}$ is viscous stress tensor.

Turbulent flows are characterized by velocity pulsations that contribute to the mixing of transported characteristics, such as impulse, energy, and component concentration, and also cause fluctuations in these characteristics. Since the pulsations can be small in scale, but have a high frequency, directly calculating them is a very difficult task in practical technical calculations. Instead, the instantaneous (exact) determining equations can be averaged by the time, represented as an average over an ensemble, which leads to modified systems of equations that need less costs to solve.

However, the modified equations contain additional unknown variables. Therefore, additional turbulence models are necessary for their determination.

Many turbulence models used in computational practice are based on the concept of vortex (turbulent) viscosity. In contrast to molecular viscosity $\nu$, turbulent viscosity $\nu_t$ is determined by the state of turbulence and does not relate to the properties of the fluid. Turbulent viscosity can vary greatly from point to point in space depending on the type of flow. Sometimes, when calculating turbulent flows, $\nu_t$ is assumed to be constant. However, such a rough description of turbulence is permissible in those cases where the value of turbulent transfer is not significant or the use of more complex structures seems to be unjustified.

In this project, the standard k-ε model of turbulence is used to describe turbulence.
c) Energy equation:

\[
\frac{\partial}{\partial t}(\rho h) = \frac{\partial}{\partial x_i}(\rho u_i h) - \frac{\partial q_{\text{res}}^i}{\partial x_i} + \frac{\partial p}{\partial t} + u_i \frac{\partial p}{\partial x_i} + \tau_{ij} \frac{\partial u_j}{\partial x_i} + S_q,
\]

(3)

here \( h \) is enthalpy; \( q_{\text{res}}^i \) is energy flow density due to molecular heat transfer, \( S_q \) is energy source.

The source term \( S_q \) takes into account:
- heat flow due to convective exchange between particles and the gas phase \(- S_{h,p}\);
- the combustion heat, which takes into account the presence of solid particles of powdered coal fuel in the total flow of the mixture \(- S_{\text{abr}}\);
- heat due to radiation \(- S_{\text{tr}}\), the contribution of which, in the flame zone, is about 90% or more to the full heat transfer.

Therefore, we have: \( S_q = S_{\text{tr}} + S_{\text{abr}} + S_{h,p} \)

Heat exchange through radiation, as mentioned above, makes the maximum contribution during powdered coal fuel combustion in the combustion chambers of industrial boilers. In this regard, the simulation of radiant heat transfer in the study of heat and mass transfer in the combustion chambers is an important step in the calculation of heat exchange processes with physics and chemical transformations.

d) Conservation law for a substance component:

The concentrations of the mixture components in the element’s volume are recorded through the corresponding balance ratio, which takes into account the physics and chemical processes that influence on the concentration change of these substances.

In the element’s volume, the total mass is determined by the sum of the masses of all components involved in the chemical reaction of the coal particle combustion:

\[
m = \sum_n m_n .
\]

(4)

In general form the equation describing the concentration of the mixture components is written as follows:

\[
\frac{\partial}{\partial t}(\rho c_v^i) + \frac{\partial}{\partial x_i}(\rho u_i c_v^i) = - \frac{\partial}{\partial x_i}(\mu \frac{\partial c_v^i}{\partial x_i}) + \frac{\partial}{\partial x_i} \left[ \frac{\mu}{\sigma^i_{v,\text{eff}}} \frac{\partial c_v^i}{\partial x_i} \right] + S_{v}\,
\]

(5)

where \( S_{v} \) is source term, taking into account the contribution of chemical reactions to changes in the components concentration.

For multicomponent mixture, the source term is determined by the relation:

\[
S_{v} = \sum \omega_{n,r} ,
\]

(6)

where \( \omega_{n,r} \) is the speed of the chemical reaction, which is written as follows:

\[
\omega_{n,r} = \frac{\text{dc}_{AB}}{\text{dt}} = k(T)c_A c_B .
\]

The speed of the reaction depends on the temperature and concentrations of the substances A and B involved in the reaction (starting, intermediate, final products). The speed constant of the reaction \( k(T) \) is written as an exponential temperature dependence in the form of the Arrhenius law:

\[
k(T) = k_0 e^{-E/RT} ,
\]

(7)

where: \( k_0 \) is the constant, in the first approximation, is not dependent on temperature, \( E \) [kcal/mol] is activation energy, \( R=1.986 \) [kcal/mol·K] is universal gas constant.

Results of modeling the coal combustion process, using «Over Fire Air» technology

The combustion chamber of the BKZ-160 boiler (Figure 2a) has a design steam capacity of 160 t/h, at a pressure of 9.8 MPa and a superheat temperature of 540 °C. Thermal power of the combustion chamber is 124.4 MW. On the sides of the combustion chamber there are 4 blocks of straight-through slot burners, directed tangentially to the
central conventional circle. To study the influence of OFA, 3 modes were selected: 0%, 10% and 20% of the total air volume supplied through injectors in the upper part of the combustion chamber (Figure 2b) [21-26].

The location of the injectors applied to the “Over Fire Air” technology and the determination of the level where the secondary injected air mixes thoroughly (Figure 2b) are very important to create the conditions for the efficient combustion of coal powder.

Figures 3 and 4 show the results of computational experiments on the effect of OFA technology on the aerodynamics of flows in the combustion chamber of the BKZ-160 boiler. There is also comparison with the basic combustion mode of solid fuel, when there is no additional air supply (OFA = 0%).

![Injectors and OFA](image)

**Figure 2** – General view of the combustion chamber of the BKZ-160 boiler and its division on control volumes

![Distribution of velocity vectors](image)

**Figure 3** – The distribution of velocity vectors in the longitudinal section of the combustion chamber of the BKZ-160 boiler
Analysis of the figures shows that the use of OFA-injectors in the area above the combustion devices does not have a significant effect on the aerodynamic picture in longitudinal sections along the height of the combustion chamber (Figure 3), i.e. it does not violate the general combustion mode of powdered coal and removal of combustion products from the combustion chamber.

However, if we look at Figure 4, which shows the distribution of the velocity vector in the cross section of the installation of burners (Figure 4a) and in the cross section of the installation of OFA-injectors (Figure 4b), here we see that the supplying of an additional air amount through the OFA-injectors supports the vortex process of combustion. This affects favorably on the intensive mixing of the fuel and oxidizer, and, consequently, on the complete combustion of coal particles, which lead to a reduction in mechanical incandescence and in harmful dust and gas emissions, such as NOₓ.

**Conclusion**

The study conducted a comprehensive study on the creation of energy-saving and environmentally friendly technologies (Over Fire Air technology) in order to increase the efficiency of thermal power plants and minimize harmful dust-gas emissions into the atmosphere when high-ash Ekibastuz coal is burned in the combustion chambers of the BKZ-160 power boilers.

The “Over Fire Air” technology has been described and applied to optimize the combustion of coal dust in combustion chambers. The methods for its implementation in power boilers of thermal power plants have been developed. The experience of foreign experts in reducing harmful emissions into the atmosphere have been studied.

The analysis of the "Over Fire Air" technology and the methods of Kazakhstan's energy fuel combustion were carried out taking into account its peculiarities, as well as the design features of the combustion chambers of operating TPPs industrial boilers. The existing technology “Over Fire Air” has been adapted and supplemented to a specific low-grade Kazakhstan fuel having an ash content of ~ 40-50%.

Various systems of staged air supply were investigated: the systems of separate (SOFA) and dual “sharp” blast (CCOFA). The aerodynamics of the flue space was obtained (the aerodynamic picture of introducing additional air streams into the chamber according to the Over Fire Air method and the velocity distribution in the combustion chamber).
References

1. Maksimov V. Yu., Messerle V. E., Ustimenko A. B., et al. Numerical simulation of the coal combustion process initiated by a plasma source // Thermophysics and aeromechanics. – 2014. – Vol. 21, Is. 6. – P. 747-754.
2. Askarova A., Karpenko E.I., Messerle V.E., et al. Plasma enhancement of combustion of solid fuels // Journal of High Energy Chemistry. – 2006. – Vol. 40, Is. 2. – P. 111-118.
3. Messerle V. E., Ustimenko A.B., Gabitova Z. Kh., et al. Numerical simulation of pulverized coal combustion in a power boiler furnace // High temperature. – 2015. – Vol. 53, Is. 3. – P. 445-452.
4. Askarova A., Maximov V.Y., Bekmukhamet A., Beketayeva M.T., et al. Computational method for investigation of solid fuel combustion in combustion chambers of a heat power plant // High temperature. – 2015. – Vol. 5, Is. 5. – P. 751-757.
5. Bekmukhamet A., Maximov V.Yu., Ospanova Sh.S., et al. Numerical research of aerodynamic characteristics of combustion chamber BKZ-75 mining thermal power station // Procedia Engineering. – 2012. – Vol.42. – P. 1250-1259.
6. Askarova A., Ospanova Sh., Bolegenova Symbat, Ergalieva A., et al. 3D modeling of heat and mass transfer during combustion of solid fuel in BKZ-420-140-7c combustion chamber of Kazakhstan // Journal of Applied Fluid Mechanics. – 2016. – P. 699-709.
7. Ergalieva A., Ustimenko A.B., Messerle V.E., et al. Reduction of noxious substance emissions at the pulverized fuel combustion in the combustor of the BKZ-160 boiler of the Almaty heat electropower station using the “Overfire Air” technology // Thermophysics and aeromechanics. – 2016. – Vol. 23, Is. 1. – P. 125-134.
8. Askarova A., Gabitova Z., Bekmukhamet A., Beketayeva M., et al. Control of Harmful Emissions Concentration into the Atmosphere of Megacities of Kazakhstan Republic // International Conference on Future Information Engineering (FIE2014), IERI Procedia. – Beijing, PEOPLES R CHINA. – 2014. – P. 252-258.
9. Leithner K., Vockrodt S., Schiller A., et al. Firing technique measures for increased efficiency and minimization of toxic emissions in Kazakhstan coal firing // VDI, 19th German Conference on Flames, Germany, VDI Gesell Energietechn; Verein Deutsch Ing., Combustion And Incineration, VDI Berichte. – 1999. – Vol. 1492. – P. 93.
10. Müller H. Numerische Berechnung dreidimensionaler turbulenter Strömungen in Dampferzeugern mit Wärmeübergang und chemischen Reaktionen am Beispiel des SNCR-Verfahrens und der Kohleverbrennung // Fortschrift-Berichte VDI-Verlag. – 1992. – Vol. 6. – No. 268. – P. 158.
11. Leithner R. Energy Conversion Processes with CO2-Separation Not Reducing Efficiency. Handbook of Combustion. Wiley VCH Verlag GmbH & Co. – 2010.
12. Epple B., Leithner R., Linzer W., Walter H. Simulation von Kraftwerken und wärmetechnischen Anlagen. – Springer. – 2009. – 702 p.
13. Patanker S.V. Numerical Heat Transfer and Fluid Flow. – Hemisphere Publishing Corporation. – 1980. – 106 p.
14. Leschziner M.A. Practical Evaluation of three finite difference schemes for the Computation of Steady State Recirculation Flows // Computer Methods and Applied Mechanics an Engineering. – 1980. – Vol. 23. – P. 293-312.
15. Messerle V.E., Ustimenko A.B., Lavrichshev O.A. Comparative study of coal plasma gasification: Simulation and experiment // Fuel. – 2016. – Vol. 164. – P.172-179.
16. Karpenko E.I., Messerle V.E., Ustimenko A.B., et al. Mathematical modeling of the processes of solid fuel ignition and combustion at combustors of the power boilers // 7th International Fall Seminar on Propellants, Explosives and Pyrotechnics. – Xin. – 2007. – Vol. 7. – P. 672-683.
17. Buchmann M.A., Askarova A. Structure of the flame of fluidized-bed burners and combustion processes of high-ash coal // Gesell Energietechn, Combustion and incineration – eighteenth dutch-german conference on flames, VDI Berichte. – 1997. – Vol. 1313. – P. 241-244.
18. Askarova A.S., Karpenko E.I., Messerle V.E., Ustimenko A.B., et al. Plasma-supported coal combustion in boiler furnace // IEEE Transactions on Plasma Science. – 2007. – Vol. 35, Is. 6, PART 1. – P.1607-1616.
19. Leithner R., Ergalieva A., Nuymanova A., et al. Computational modeling of heat and mass transfer processes in combustion chamber at power plant of Kazakhstan // MATEC Web of Conferences, 2016. – P. 5.
20. Askarova A., Boranbayeva A., Bolegenova S., Berdikhan K., et al. Application of numerical methods for calculating the burning problems of coal-dust flame in real scale // International Journal of Applied Engineering Research. – 2016. – Vol. 11, Is. 8. – P. 5511-5515.
21. Askarova A., Bolegenova S., et al. Influence of boundary conditions to heat and mass transfer processes // Intern. Journal of Mechanics. – 2016. – Vol.10. – P. 320-325.
22. Gorokhovski M., Chtab-Desportes A., Voloshina I., et al. Stochastic simulation of the spray formation assisted by a high pressure // AIP Conference Proceedings. – Xian. – 2010. – P. 66-73.
23. Askarova A., Beketayeva M., Ospanova Sh., Gabitova Z.K., et al. Investigation of turbulence characteristics of burning process of the solid fuel in BKZ 420 combustion chamber // WSEAS Transactions on Heat and Mass Transfer. – 2014. – Vol. 9. – P. 39-50.
24. Bolegenova S.A., Gabitova Z.K., Ospanova Sh.S., et al. Numerical modeling of turbulence characteristics of burning process of the solid fuel in BKZ-420-140-7c combustion chamber // International Journal of Mechanics. – ISSN: 1998-4448. – 2014. – Vol. 8. – P. 112-122.
25. Nuymanova A., Mazhrenova N., Manathayev R., Berezovskaya I., et al. 3D modeling of heat and mass transfer processes during the combustion of liquid fuel // Bulgarian Chemical Communications. – 2016. – Special Is. E. – P. 229-235.
26. Safarik P., Maximov V., Beketayeva M., et al. Numerical Modeling of Pulverized Coal Combustion at Thermal Power Plant Boilers // Journal of thermal science. – 2015. – Vol. 24, Is. 3. – P. 275-282.
Numerical simulation of fuel combustion processes to reduce harmful dust and gas emissions using Over Fire Air

References

1. V. Yu. Maksimov et al., Thermophysics and aeromechanics. 21, 747-754 (2014).
2. A. Askarova et al., J. of High Energy Chemistry. 40, 111-118 (2006).
3. V. E. Messerle et al., High temperature. 53, 445-452 (2015).
4. A. Askarova et al., High temperature. 5, 751-757 (2015).
5. A. Bekmukhamet et al., Procedia Engineering (2012), 1250–1259.
6. A. Askarova et al., J. of Applied Fluid Mechanics. 699-709 (2016).
7. A. Ergaliyeva et al., Thermophysics and aeromechanics. 23, 125-134 (2016).
8. A. Askarova et al., Inter. Conference on Future Information Engineering (FIE2014), IERI Procedia (Beijing, 2014), p. 252-258.
9. R. Leithner et al., VDI, 19th German Conference on Flames, Germany, VDI Gesell Energietechn; Verein Deutsch Ing., Combustion And Incineration, VDI Berichte (Germany, 1999), p. 93.
10. Müller H. Fortschritt-Berichte VDI-Verlag (1992), p. 158.
11. R. Leithner, Energy Conversion Processes with CO2-Separation Not Reducing Efficiency. Handbook of Combustion, (Wiley VCH Verlag GmbH & Co, 2010), 412 p.
12. B. Eppele et al., Simulation von Kraftwerken und wärmetechnischen Anlagen (Springer, 2009), 702 p. ISBN 3211296956.
13. S.V. Patankar, Numerical Heat Transfer and Fluid Flow, (Hemisphere Publishing Corporation, 1980), 106 p.
14. M.A. Leschziner, Computer Methods and Applied Mechanics an Engineering, 23, 293-312 (1980).
15. V.E. Messerle et al., Fuel, 164, 172-179 (2016).
16. E.I. Karpenko et al., 7th Inter. Fall Seminar on Propellants, Explosives and Pyrotechnics (Xian, 2007), p.672-683
17. M.A. Buchmann et al., Gesell Energietech, Combustion and incineration – eighteenth dutch-german conference on flames, VDI Berichte (1997), p.241-244.
18. A.S. Askarova et al., IEEE Transactions on Plasma Science (2007), p.1607-1616.
19. R. Leithner et al., MATEC Web of Conferences (2016). https://doi.org/10.1051/matecconf/20167606001.
20. A. Askarova et al., Inter. J. of Applied Engineering Research, 11, 5511-5515 (2016).
21. A. Askarova et al., Inter. J. of Mechanics, 10, 320-325 (2016).
22. M. Gorokhovski et al., AIP Conference Proceedings (Xian, 2010), p.66-73.
23. A. Askarova et al., WSEAS Transactions on Heat and Mass Transfer, 9, 39-50 (2014).
24. S.A. Bolegenova et al., Inter. J. of Mechanics, 8, 112-122 (2014).
25. A. Nuguymanova et al., Bulgarian Chemical Communications, 229-235 (2016).
26. P. Safarik et al., J. of thermal science, 24, 275-282 (2015).
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