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РЕСПУБЛИКИ КАЗАХСТАН
Казахский национальный университет
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3D MODELING OF COMBUSTION THERMOCHEMICAL ACTIVATED FUEL

Abstract. This article presents the results of numerical research of plasma thermochemical processes of preparing solid fuels for combustion in combustion chambers. During the numerical experiments have been applied the newest information technology and method of 3-D computer modeling of heat and mass transfer in the furnace space. Received the basic laws of convective heat and mass transfer in turbulent flows in the presence of chemical reactions using modern numerical methods, giving a complete description of the complex processes occurring in a real combustion chamber. Research of three-dimensional temperature and concentration fields has allowed establishing laws of the development of the combustion process in the entire volume of the object under study. Satisfactory agreement is obtained estimates with known results of natural experiments. Authors of article for the first time investigate influence of plasma thermochemical treatment of pulverized coal flows on the main characteristics of the physicochemical processes of solid fuel combustion. It has been established that the method of thermochemical activation of pulverized coal flows makes it possible to significantly optimize the process of burning low-grade high-ash Kazakhstan coal in the combustion chambers of the thermal power plants of Kazakhstan, significantly reduce emissions of harmful substances into the environment and create a way to obtain "clean" energy on energy facilities.

Key words. Heat and mass transfer, combustion, solid fuel, plasma activation, aerodynamic flow, concentration and temperature field, emissions of harmful substances.

Introduction

Studies of heat and mass transfer in high-temperature and chemically reacting environments are important at creation of new physical and chemical technologies, at design of aviation and rocket technics, by development new furnaces, gas turbines and internal combustion engines. In the conditions of depletion of natural energy resources and environmental pollution, the development of technological processes with the rational use of energy fuel and the solution of environmental problems are urgent and most important tasks for many thermophysical studies in this direction.

Heat and mass transfer processes in the presence of physical-chemical transformations and combustion are non-stationary, strongly non-isothermal with constant changes in the physical and chemical state of the environment, which greatly complicates them both experimental and theoretical study. Such flows are described by a complex system of non-autonomous nonlinear partial differential equations, in which the essential turbulence, multiphase nature of the medium, and source terms associated with the chemical kinetics of the processes occurring must be taken into account [1-5].

The main methods of study of such processes, particularly in the areas of real geometry are methods of numerical simulation and holding on to them through computational experiments adequately reflect the real physical processes, occurring in combustion chambers. Progress in the development of computational models, in the creation of effective computational algorithms and problem-oriented software packages allows us to solve many problems that have a huge practical application for various industries, especially for energy [6-11].

In this article is carried out of heat and mass transfer processes occurring in the areas of real geometry (combustion chamber), with the burning of energy fuel in them. The basic patterns and features of the formation of the aerodynamics of flow, velocity, temperature and concentration fields are established and the effect of plasma thermochemical treatment of pulverized coal on the main characteristics of the combustion process is shown.

This research builds on the achievements of modern thermal physics, on the use of new numerical methods for 3-D modeling, on the construction of efficient computational algorithms and new computational models, which make it possible to more accurately describe the actual physical and chemical processes occurring during at burning of power fuel in the combustion chambers of existing energy facilities [12-15].

Statement of the problem of burning thermochemically activated torch in the combustion chamber of an energy boiler

Thermochemical preparation of pulverized coal for combustion is implemented in accordance with the following mechanism. Aero mixture is fed through the dust pipe to the burner. According to the traditional scheme, the air mixture is fed into the "cold" hot fire chamber (T about 350K), then it heats up and ignites. If the burner is equipped with a plasma torch, then the air mixture is heated by the plasma torch in the volume of the burner to the exit to the furnace. In this case, volatile coal is emitted and the coke residue is gasified. Gasification and volatile products begin to oxidize with oxygen of the primary air of the air mixture, which leads to additional heating of the reaction air of the air mixture. At the same time, carbon of the fuel is gasified to CO, and not to CO_2, due to the existing coefficient of excess air in the air mixture (0.3-0.5 of the stoichiometric ratio) [13].

As a result, the output of plasma-fuel system (PFS) a high-temperature (about 1300K) reactive flow of carbon-containing particles and gaseous products of the plasma thermochemical preparation aero mixture. In this case, regardless of the quality of the original product, we get highly reactive two-component fuel. When mixed with secondary air in the combustion chamber, it is intensely ignited and burns steadily without fuel oil or gas, traditionally used to ignite and stabilize the combustion of low-grade pulverized coal [14-15].

To carry out computational experiments, the combustion chamber of the BKZ-420 boiler of the Almaty Thermal Power Plant-2 has been chosen [16-17]. The BKZ-420 steam boiler with a 420 t/h steam capacity is equipped with six rotary pulverized coal burners located in two levels with three burners on the front wall of the boiler (Fig. 1 a).

At computer simulation, the method of control volumes which is applied to numerically solve differential equations describing heat and mass transfer in the combustion chamber, and is described in detail in the following papers [18-21].

For this, the combustion chamber of the boiler under study is divided into small control volumes, the number of which depends on the geometry of the combustion chamber, its dimensions, and the location of the burner and plasma devices. For the BKZ-420 boiler, the calculated area is – 261008 control volumes (72x139x126) (Fig. 1 b).

When conducting computational experiments for the boiler BKZ-420 were investigated two modes of operation of the combustion chamber: 1) traditional combustion (burner works with standard pulverized coal burners); 2) the plasma torch is installed and operates on a pulverized coal flow in three burners: two extreme burners of the lower tier and a central burner of the upper tier [22-29].

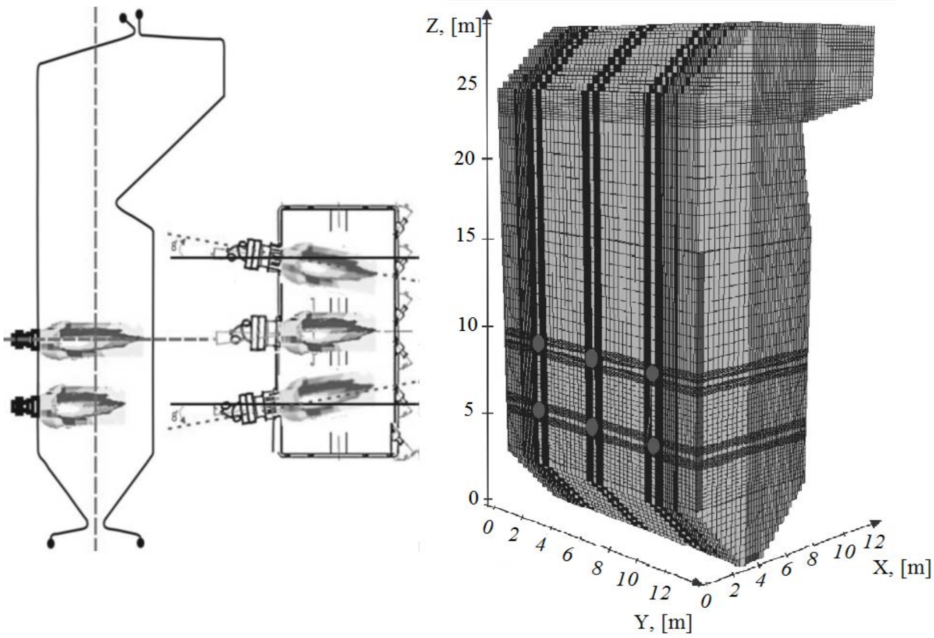


Fig. 1. General view of the combustion chamber of the boiler BKZ-420: configuration of torches (on left); breakdown into control volumes (on right)

The results of computational experiments

Below are the results of 3D computer simulation of the study of the influence of thermochemical activation of pulverized coal flows on the combustion process of a pulverized coal flame in the combustion chamber of the BKZ-420 boiler.

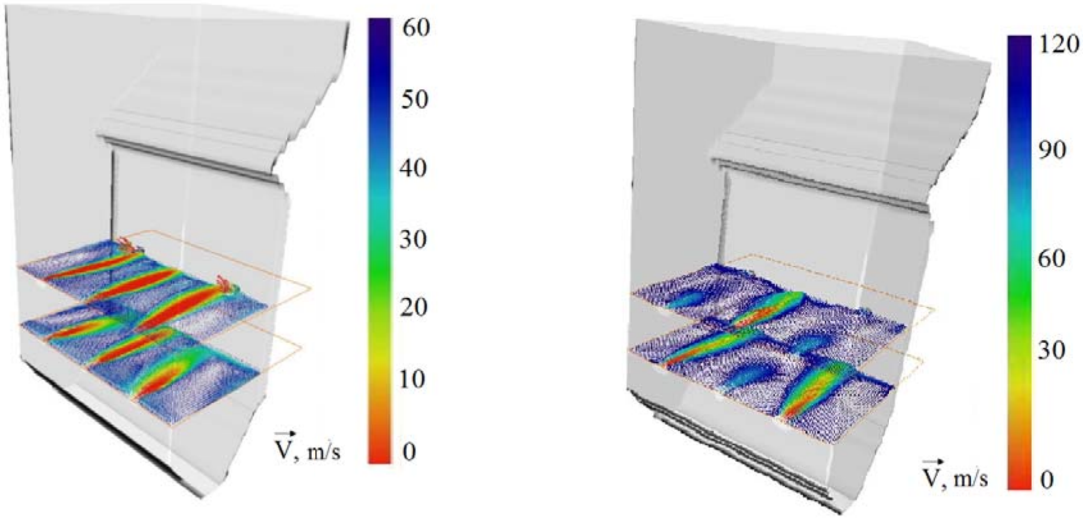
The aerodynamics of the flow (distribution of the full velocity vector), temperature and concentration fields of nitrogen oxides NO over the entire combustion space of the combustion chamber were obtained for the traditional combustion of fuel and for the case when the plasma torch in the three burners affects the pulverized coal.

Figure 2 shows the aerodynamics of the flow and the distribution of the full velocity vector in the belt region of the burners of the combustion chamber. Analysis of the figure shows that the thermochemical activation of the pulverized coal flow has a significant impact on the flow field on the propagation of the reacting jet in the furnace volume, mixing processes in the jet, on the size and shape of the flame. This can be explained by the fact that, under the action of plasma activation of pulverized jets, turbulization of flows is intensified, and this in turn leads to acceleration of mass and heat exchange associated with increased mixture formation, additional heating of the air mixture and intensification of the burning process.

Figure 3 illustrates the temperature field in the sectional plane of the burners of the lower tier of the combustion chamber of the boiler BKZ-420. Compared with the combustion of a conventional pulverized coal stream, the average temperature in this area in the case of using thermochemically activated streams increases and is 1530°C without activation, and 1640°C for 3 activated streams.

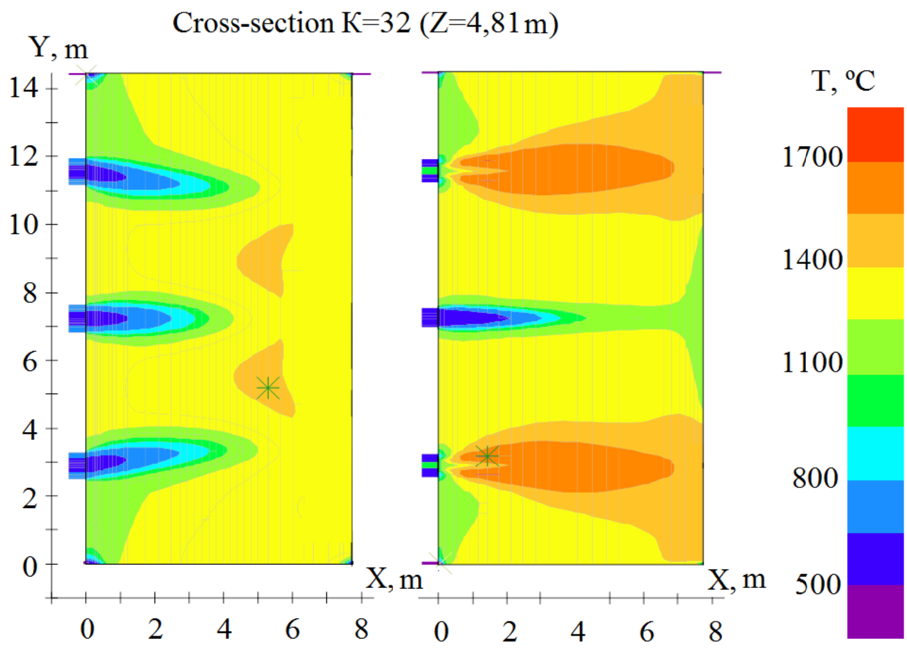
It can be concluded that the plasma activation of the aerosol leads to its rapid heating, ignition and stable heating. At the same time, there is a shift of the combustion front to the location of plasma activation systems of coal streams. The region of high temperatures with increasing number of plasma-activated flows is shifted to the center of symmetry of the furnace, while at the side surfaces a higher temperature level.

Figure 4 shows a comparative analysis of the distribution of the average temperature in the cross section over the height of the combustion chamber of the BKZ-420 boiler. When plasma processing of fuel is observed, the location of the core of the torch is shifted and the length of the zone of maximum temperatures increases. The increase in flame temperature during the burning of 3 activated streams occurs faster, and the temperature value differs to a greater extent in the burner belt. The minimum on the curves are related to the low temperature of the air mixture entering the combustion chamber through burners not equipped with plasma systems. In general, there is a lack of sharp temperature drops across the entire height of the combustion chamber, which indicates the stability of the combustion process.



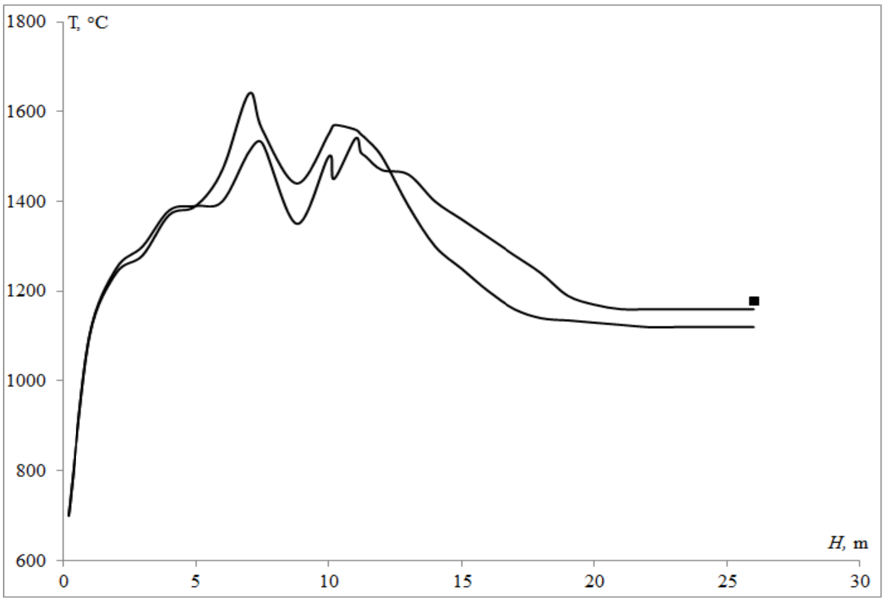
a) traditional fuel combustion (without PFS); b) 3 PFS;

Fig. 2. Vector field of full velocity in the area of the burner belt of the combustion chamber of the boiler BKZ-420



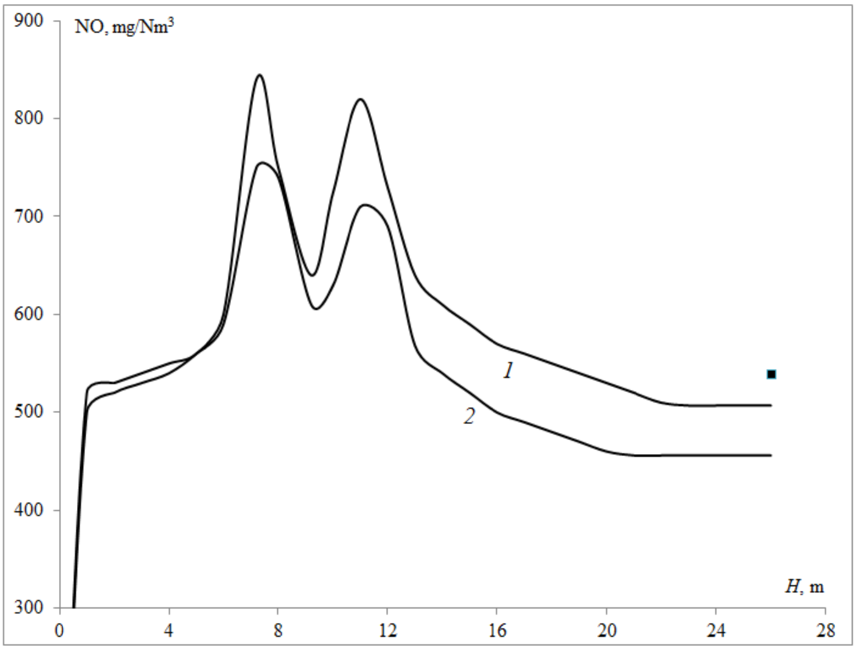
a) traditional fuel combustion (without PFS); b) 3 PFS;

Fig. 3. Temperature field in the section plane of the burners of the lower tier of the combustion chamber of the boiler BKZ-420



1 – traditional fuel combustion (without PFS); **2** – 3 PFS;
■ - experiment [30]

Fig. 4. Temperature distribution along the height of the combustion chamber of the boiler BKZ-420



1 – traditional fuel combustion (without PFS); **2** – 3 PFS;
■ - experiment [30]

Fig. 5. The distribution of the concentration of nitrogen oxides NO at the height of the combustion chamber of the boiler BKZ-420

Figure 5 shows the fields of concentrations of nitrogen oxides NO along the height of the combustion chambers of the boiler BKZ-420. As can be seen from Figure 5, the main NO gas formation occurs in the region of propagation of flows from the burners. Thus character of the distribution of curves in this area is ambiguous, which indicates the complex nature of the process of formation of nitrogen oxides in this area and the effect of plasma activation on the formation of these components. We see that the use of plasma torches leads to a decrease in the total concentration of NO from the furnace space and amounts to 507 mg/Nm^3 with traditional combustion, and with 3 thermochemically activated streams – 456 mg/Nm^3. This, in turn, indicates that the reduction of nitrogen oxides NO at the exit from the furnace space when using PFS increases the ecological and economic indicators of energy facilities.

Conclusion

According to the research, the following conclusions can be formulated:

- Presents the results of 3-D computer modeling of heat and mass transfer processes during combustion of pulverized coal, which was pre-processed in the PFS.
- Research of three-dimensional temperature and concentration fields has allowed establishing the basic patterns of development of heat and mass transfer processes in the entire volume of the combustion chamber of power boilers. Satisfactory agreement of the calculated data with the results of field experiments was obtained.
- It has been established that the method of thermochemical activation of pulverized coal flows makes it possible to significantly optimize the process of burning low-grade high-ash coal in the combustion chambers of Kazakhstan's thermal power plants and significantly reduce emissions of harmful substances into the environment.

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АКТИВТЕНДІРІЛГЕН ТЕРМОХИМИЯЛЫҚ ОТЫННЫҢ ЖАНУЫН 3D МОДЕЛЬДЕУ

Аннотация. Мақалада жану камераларында қатты отынды жағуда плазма термохимиялық дайындау процестерін сандық зерттеу нәтижелері келтірілген. Сандық есептеу эксперименттерін жүргізу кезінде қазанның кеңістіктегі жылу және масса тасымалдау процестерінің ақпараттық технологиялары мен 3-D компьютерлік модельдері қолданылды. Нақты жану камерасында орын алатын турбулентті ағыстардағы конвективті жылу және массалық кешенді процестердің толық сипаттамасын беретін қазіргі заманғы сандық әдістермен химиялық реакциялардың қатысуымен алынды. Объектінің барлық көлеміндегі жану үдерісі үш өлшемді температура мен концентрация өрістерін зерттеуде даму моделін құруға мүмкіндік берді. Толық ауқымды эксперименттердің белгілі нәтижелерімен есептелген деректердің қанағаттанарлық сәйкестік алынды. Мақаланың авторлары қатты отын жануының физика-химиялық процестерінің негізгі сипаттамаларынада шаңтозаңды көмір ағынын плазмалық термохимиялық өңдеудің әсерін зерттеді. Көмір ағынының термохимиялық активтендіру әдісі Қазақстанның жылу электр станцияларының жану камераларында жанғыш күлді көмірді көму үдерісін едәуір оңтайландыруға мүмкіндік береді, қоршаған ортаға зиянды заттар шығарындыларын едәуір азайтады және энергетикалық қондырғыларда «таза» энергетикаға қол жеткізуге мүмкіндік береді.

Түйін сөздер. Жылулық массатасымалдау, жану, көмір, плазмалық белсендіру, ағын аэродинамикасы, тұтқындар және температуралық өрісі, залалды заттардың шығарылу

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3D МОДЕЛИРОВАНИЕ ГОРЕНИЯ ТЕРМОХИМИЧЕСКИ АКТИВИРОВАННОГО ТОПЛИВА

Аннотация. В данной статье представлены результаты численных исследований процессов плазменной термохимической подготовки твердых топлив к сжиганию в камерах сгорания. При проведении вычислительных экспериментов были применены новейшие информационные технология и метод 3-D компьютерного моделирования процессов тепломассопереноса в топочном пространстве. Получены основные закономерности конвективного тепломассопереноса в турбулентных течениях при наличии химических реакций с использованием современных численных методов, дающих полное описание сложных процессов, имеющих место в реальной топочной камере. Исследование трехмерных температурных и концентрационных полей позволило установить закономерности развития процесса горения во всем объеме исследуемого объекта. Получено удовлетворительное согласие расчетных данных с известными результатами натурных экспериментов. Авторами статьи впервые исследовано влияние плазменной термохимической обработки пылеугольных потоков на основные характеристики физико-химических процессов горения твердого топлива. Установлено, что метод термохимической активации пылеугольных потоков позволяет в значительной степени оптимизировать процесс сжигания низкосортных высокозольных казахстанских углей в топочных камерах ТЭС Казахстана, существенно снизить выбросы вредных веществ в окружающую среду и создать способ получения «чистой» энергии на энергетических объектах.

Ключевые слова. Тепломассоперенос, горение, твердое топливо, плазменная активация, аэродинамика течения, концентрационные и температурные поля, выбросы вредных веществ.

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