

Austrian Journal of Technical and Natural Sciences

**Nº 3–4 2016
March–April**



«East West» Association for Advanced Studies and Higher Education GmbH

**Vienna
2016**

Austrian Journal of Technical and Natural Sciences

Scientific journal

№ 3–4 2016 (March–April)

ISSN 2310-5607

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Homepage:	www.ew-a.org

Austrian Journal of Technical and Natural Sciences is an international, German/English/Russian language, peer-reviewed journal. It is published bimonthly with circulation of 1000 copies.

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Typeset in Berling by Ziegler Buchdruckerei, Linz, Austria.

Printed by «East West» Association for Advanced Studies and Higher Education GmbH, Vienna, Austria on acid-free paper.

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CFD simulation of production of NO_x in coal-fired furnaces

Abstract: Computational fluid dynamics (CFD) has been accepted as a powerful and effective tool for control and analysis of coal-fired utility boilers. Since coal burning in a utility boilers is a very complex process that comprises high-temperature reacting turbulent flow, particles transport and radiative heat transfer a reliable numerical simulation models of coal combustion requires high accuracy and careful interpretation of its numerical results.

Keywords: Computational fluid dynamics, Furnace, Combustion, Heat and mass transfer.

The object of this study was to improve an engineering tool by which combustion behavior of low-grade coals in coal-fired utilities boilers can be predicted. Computational fluid dynamics code FLOREAN was used to predict performance of full scale pulverized-coal utility and introduce additional models to simulate boilers of various types and pollutant emissions formation in combustion process, to provide and validated the model parameters required for the simulations. The main motivation of the numerical combustion research is its use for design and development of the combustion chamber modifications and other important parameters needed for the effective boiler performance.

Computational Fluid Dynamics is a powerful tool increasingly used for the solution of flow and combustion related scientific and engineering problems. The applications of CFD tools have a broad variety: combustion, heat and power generation, turbo machinery, aerospace and auto industry, chemical engineering etc. In the field of combustion CFD is being widely used for the optimization of pulverized coal-fired industrial furnaces. The modern combustion systems of power generation must satisfy the number of demands. They are high degree of solid fuel burnt out with a minimum of excess air, lower

slagging in the combustion furnace, operation with easily removed friable ash deposits, low NO_x emissions due to combustion process modifications, acceptance of coal quality variations without significant reduction of combustion efficiency and boiler plant availability etc. Additionally there is requirements for the combustion systems to be in agreement with CO₂ sequestration.

In the last years emissions regulations throughout the world are driving the need to modernize combustion equipment to reduce NO_x and other pollutant emissions from power and steam generating plants. As environmental regulations on industrial emissions have increased, the focus of coal research has shifted more and more to understanding and reducing harmful pollutants such as nitrogen oxides.

Common methods of reducing NO_x emissions during coal combustion include different primary and post-combustion measures. The objective of these methods is to assure that nitrogen is emitted as N₂ rather than NO_x. For example, staged combustion has achieved moderate success in reducing the amount of volatile nitrogen that is converted to NO_x. However, because the nitrogen in the char is released by heterogeneous oxidation, staged combustion methods have little effect on NO_x

formed from nitrogen in the char. Low-NO_x burners reduce NO_x emissions by creating locally fuel-rich regions with sufficient residence time and appropriate temperatures in which volatile nitrogen is converted to N₂ rather than NO_x. Low-NO_x burners have the potential to significantly reduce NO_x emissions from coal combustion facilities and are currently the most economically favorable alternative.

This study also sought to enhance the industrial usefulness of the applied CFD tool. It is expected that with these additional features, the CFD complex FLOREAN will be very useful in improving combustion process of low-grade coals in different boilers of industrial enterprises. A three dimensional computational fluid dynamics code was used to analyze the performance of different boilers with pulverized coal combustion at different operation modes. The main objective of this study was to show a number of possibilities of the applied three-dimensional furnace modeling as an effective method for design, optimization and problem solving in power plant operation. Consequently, the FLOREAN — code was used to predict thermal and hydrodynamic aspects of airflue gases mixing in the near wall region and in inside of the combustion furnace. In the case of OFA technology study it was demonstrated that effective mixing between flue gases and over fire air is of essential importance for CO reburying and NO_x reduction.

Air staging or two-stage combustion, is generally described as the introduction of over fire air into the boiler or furnace. Staging the air in the burner (internal air staging) is generally one of the design features of low NO_x burners. Furnace over fire air (OFA) technology requires the introduction of combustion air to be separated into primary and secondary flow sections to achieve complete burnout and to encourage the formation of N₂ rather than NO_x. The Over fire Air (OFA) process involves diverting a portion of the combustion air from the primary zone and channeling it through a number of ports above the top row of burners. This creates two zones, an oxygen lean primary zone and a second oxidizing burnout zone where the combustion is completed. Primary air (70–90%) is mixed with the fuel producing a relatively low temperature; oxygen deficient, fuel-rich zone and therefore moderate amounts of fuel NO_x are formed. The secondary (10–30%) of the combustion air is injected above the combustion zone through a special wind-box with air introducing ports and/or nozzles, mounted above the burners. Combustion is completed at this increased flame volume. Hence, the relatively low-temperature secondary-stage limits the

production of thermal NO_x. The location of the injection ports and mixing of overfire air are critical to maintain efficient combustion. Retrofitting overfire air on an existing boiler involves waterwall tube modifications to create the ports for the secondary air nozzles and the addition of ducts, dampers and the wind-box. For standard OFA systems the injection velocity through the ports is typically similar to that through the burners as the air is taken at the windbox or secondary air pressure. OFA has the advantage of needing no additional power consumption as the FD fan supplies the over fire air. Due to the higher air velocities, reduced residence times are required before the injection of the over fire air, to allow complete burnout of the coal particles.

A number of numerical experiments have been carried out with the aim to study influence of different technologies on formation of harmful emissions and furnace performance. First way is Over Fire Air technology. Over fire air (OFA) has been used for a long time on many coal fired boilers to achieve NO_x reductions in addition to Low NO_x Burners alone. OFA is a very cost effective way for reductions between 20 and 40% of the uncontrolled NO_x emission.

The Over Fire air is injected by jet injectors at different planes at upper levels in the furnace chambers. The arrangement of the jets is similar to the burners arrangement. Mixture of the air and coal powder is injected in down furnace part.

The mixture then flows up and burns, while it transfers some of the combustion heat to the walls containing the water pipes. A fraction of 10% and 20% of the total combustion air is diverted from the burners and injected through the OFA in the upper part of furnace. Use of over-fire air can lead to reduction of NO emissions up to 28% in comparison with operation without OFA, while boiler thermal efficiency decrease to 0,17% due to increased losses by with unburned carbon and carbon monoxide corresponds up to efficiency loss. Velocity fields in vector shape for the level of OFA location for studied boiler is given on Figure 1.

Figure 2 shows temperature distribution via furnaces height for studied cases. Points are correspondent to experimental data (Fig.2) for furnace PK39 operation without OFA [2; 1]. Large differences in calculated and experimental values of temperature are observed in the region of ignition and extinguishing. Apparently, it could be due to the increased heat radiation which is set because of the supposition about complete combustion of carbon and in neglect by endothermic restitution of CO₂ in coke resulting in increase of temperature.

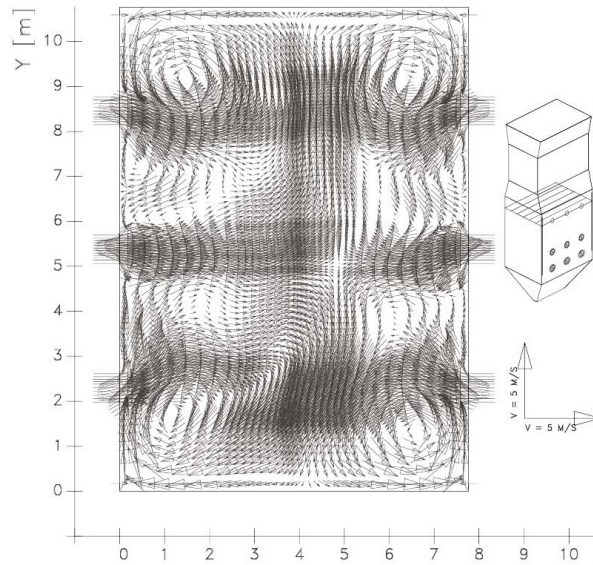
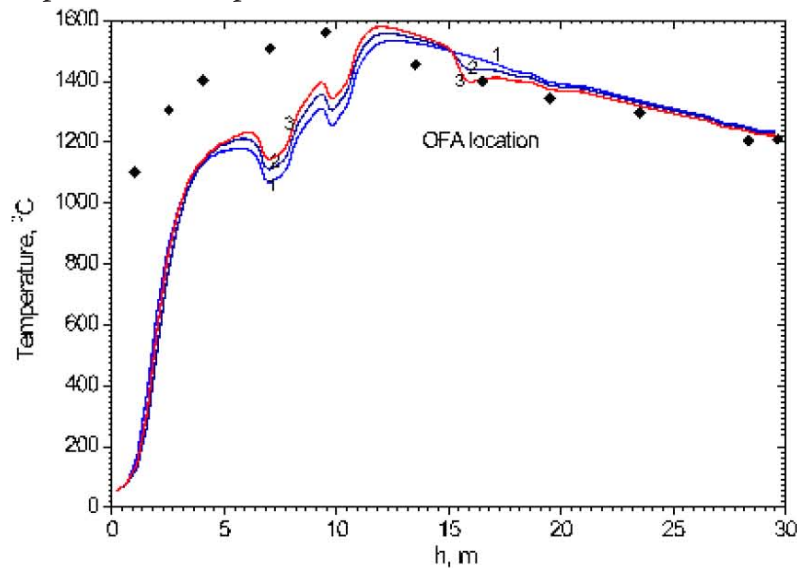


Figure 1. Velocity field

The influence of OFA on NOx formation in furnaces is shown on fig. 4. Use of over-fire air can lead to reduction of NO emissions up to 28% in comparison with

operation without OFA, while boiler thermal efficiency decreases up to 0,17% due to increased losses by with unburned carbon and carbon monoxide (Fig. 7).



1 – base; 2 – OFA-10%; 3 – OFA-20%; (* – experiment)

Figure 2. Influence of OFA on temperature distribution in the furnace of PK39-steam generator

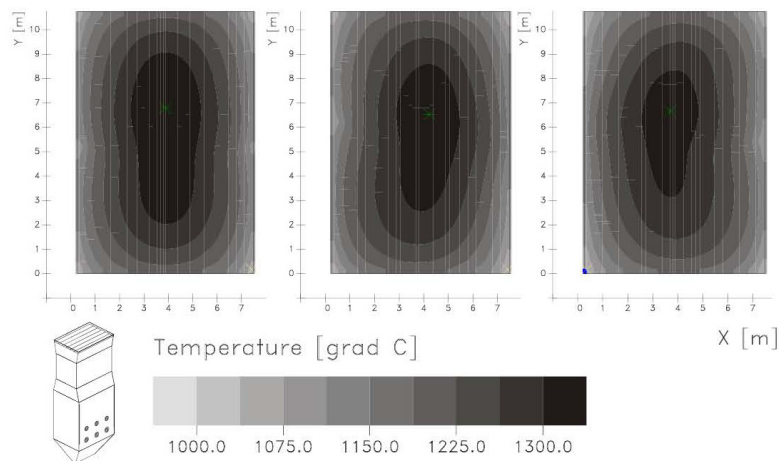


Figure 3. Influence of OFA on temperature at the furnace outlet of PK39-steam generator

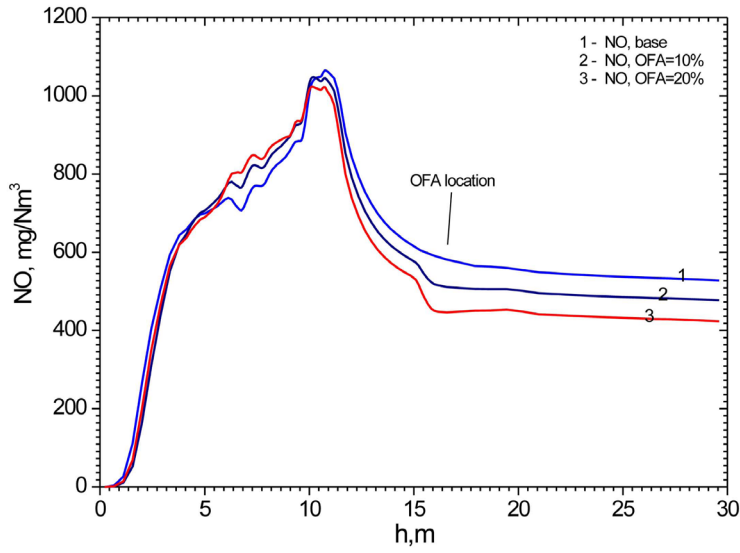


Figure 4. Influence of OFA on NO concentration in the furnace of PK39-steam generator

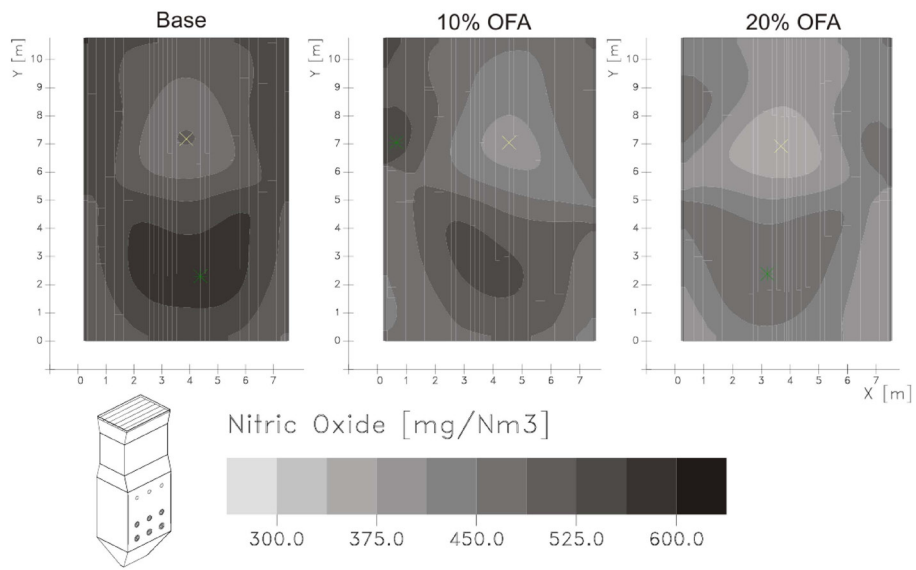


Figure 5. Influence of OFA on NO concentration at the furnace outlet of PK39-steam generator

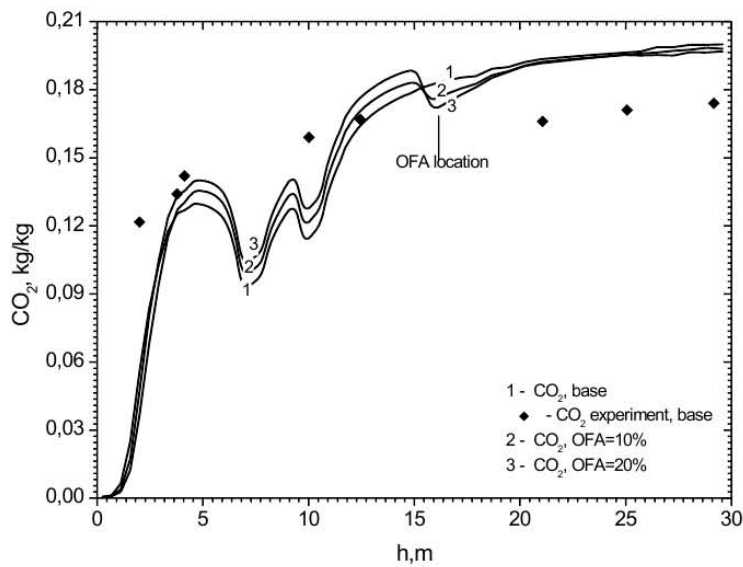


Figure 6. Influence of OFA on CO2 concentration at the furnace outlet of PK39-steam generator

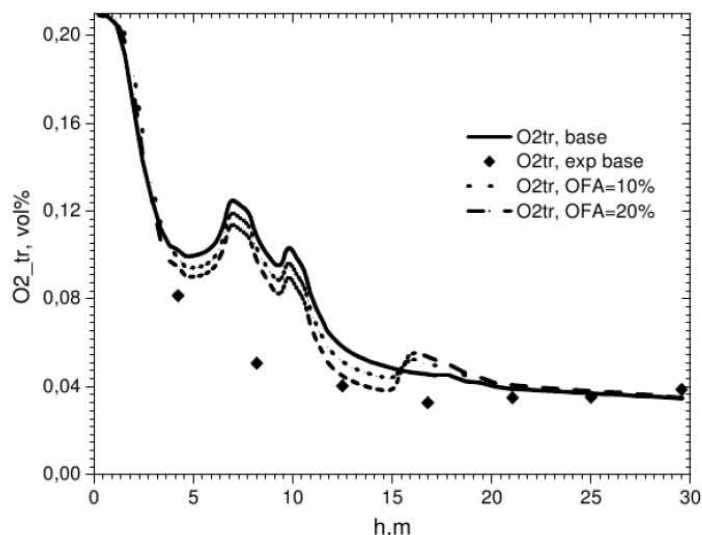


Figure 7. Influence of OFA on O₂ concentration at the furnace outlet of PK39-steam generator

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Autophase microwave-converter with multiple energy input

Abstract: The article considers the two-section TWT with an autophase output section model. It presents the results of numerical modelling of the back conversation in autophase TWT at the multiple microwaves energy input. It has been revealed that the efficiency of the back conversation can be considerably increased by the choice of optimal low of the static potential profile change.

Keywords: numerical modeling, autophase section, microwave power, electron bunch, converter.

The main mechanism of the autophase TWT work in the direct operation is described enough in the article [1]. The interaction mechanism in the autophase devices is the following: a bunch electron beam is gun in the interaction space, where the resistive coupling is

much more, for example ten times more, than in a bunch section. Given certain conditions electron bunches are taken by the running wave in its potential minimum and drift with speed that equals phase speed of the wave, saving their stability. Shifting the bunch in the breaking

Contents

Section 1. Biology	3
<i>Jafarova Shafiga Maharram</i> Population — level impact of regional anthropogenic factors on birds.....	3
<i>Mamedov Chingiz Agamusa</i> Changes of brain serotonergic system activity in the brains of Persian (Kura) sturgeon fingerlings (<i>Acipenser persicus</i>) in ontogeny.....	6
<i>Mamedova Aybeniz Gara</i> Fauna of infusoria in Hovsan and Sahil water purification plants of Absheron peninsula	11
Section 2. Mathematics	16
<i>Borisovskiy Ivan Petrovich</i> Über einige Eigenschaften der Räume der Bootby-Wang-Zerlegung.....	16
<i>Drushinin Victor Vladimirovich</i> Single-degree of the sums of integers with stiping sings.....	18
Section 3. Materials Science	20
<i>Dosmukhamedov Nurlan Kalievich, Zholdasbai Erzhan Esenbaiuly</i> Optimization of the width and speed of molten zone in the conditions of purifying copper of impurities by zone melting	20
<i>Martirosyan Vilena Hakobovna, Sasuntsyan Marine Eduard</i> A morphological investigation of formation of iron monosilicide and slags produced at high- temperature synthesis of preliminarily mechano-activated burden	22
Section 4. Machinery construction	28
<i>Marchenko Andrii Petrovych, Ali Adel Hamzah, Omar Adel Hamzah</i> Parameter optimization of heat recovery steam generation for hyundai engine H25/33	28
<i>Vasenin Valery Ivanovich, Bogomyagkov Aleksey Vasilievich</i> Research of the filling of a casting mould with liquid metal through step gate	32
Section 5. Mechanics	35
<i>Karimov Kamolxon Abbasovitch, Akhmedov Azamat Xaitovitch, Habibullaeva Hudzhasta Nadzhibullaevna</i> Statement and the analytical decision of the problem about free fluctuations of constructions of the bearing two concentrated weights	35
Section 6. Food processing industry	38
<i>Mannanov Ulug'bek, Mamatov Sherzod, Shamsutdinov Bakhadir</i> Research and study mode vacuum infrared drying vegetables.....	38
Section 7. Agricultural sciences	42
<i>Badakhova Galina Khamzatovna, Verevkina Svetlana Ivanovna, Kravchenko Nelly Anatolievna</i> The dynamic of conditions of winter cereals autumn growth in Stavropol region against the background of region climate changes.....	42
<i>Nagiyev Polad Yusif, Asadova Naida Mail, Ibadova Sevda Mahyaddin, Agayev Amil Tofik</i> Compilation of map of soils salinization on basis of processing of space images and measures of struggle with salinization	45
Section 8. Technical sciences	51
<i>Turobjonov Sadridin Mahamaddinovich, Abdutalipova Nellya Mudarisovna, Nazirova Rano Agzamovna</i> Synthesis of new aminocarboxylic ampholytes with predetermined properties.....	51

<i>Akramova Rano Ramizitdinovna, Saidakbar Abdurahmonovich Abdurahimov</i> Stereospecies composition of triacylglycerols safflower oils derived from seeds cultivation in rainfad and irrigated lands	55
<i>Akramova Rano Ramizitdinovna</i> Research of unsaponifiable components of oils obtained from peeled and unpeeled safflower seeds	59
<i>Hafizov Qarib Kerim oglu</i> Overview of recent advances in technology, applied to persimmon fruit in order to preservetheir quality after harvest	61
<i>Jumaeva Dilnoza Jurayevna, Toirov Olimjon Zuvurovich</i> The obtainment of carbon adsorbents and their compositions for cleaning industrial wastewater	67
<i>Zatuchny Dmitry Aleksandrovich</i> Verwendung des verallgemeinerten ausgewogenen Verlustenbewertung für Flugsicherung des Flugschiffes	70
<i>Kustov Maksim Vladimirovich, Kalugin Vladimir Dmitrievich, Levterov Alexander Antonovich</i> Rain scavenging of a radioactive aerosol atmospheric precipitation.	73
<i>Madenov Berdimurat Dauletmuratovich, Namazov Shafoat Sattarovich, Seytnazarov Atanazar Reypnazarovich, Reymov Ahmed Mambetkarimovich, Beglov Boris Mihaylovich</i> Nitrogen-phosphate fertilizers based on ammonium nitrate melt and nodule phosphorite from Kara-Kalpakistan.	76
<i>Osipov Gennady Sergeevich</i> Multi-criteria analysis of systems at fuzzy criteria	82
<i>Rakhmanov Hoshim Erdanovich, Boynazarov Ilhom Maxmudovich, Fattaeva Dilafruz Abdumanonovna</i> The review of methods of identification of a personality on the basis of a man's iris	84
<i>Samadiy Murodjon Abdusalimzoda, Lutfullaev Sa'dulla Shukurovich, Mirzakulov Kholtura Chorievich</i> Physical and chemical characteristics of the insoluble rests in water and their influence on process deslurrying sylvinites of Tyubegatan	87
<i>Teshabayeva Elmira, Seydabdullayev Yakhyo, Ibodullayev Akhmadzhon</i> Influence research phosphate coating alkilolamids of fatty acids on formation of structure of the cross-linking grid and properties of composites.	92
<i>Kharatyan Armen Gerasim</i> Synthesis of reconfigurable manipulation mechanisms for generation of regulated controlled screw and revolute displacements	97
Section 9. Transport.	101
<i>Omarov Kazbek Altynsarovich, Shayahmetova Anar, Bulatov Nurzhan Kazhmuratovich, Bulatova Zhadyra Tolembaikyzy</i> Researches and calculation method of pneumatic vibrosupport of an car concrete mixers.	101
Section 10. Physics.	105
<i>Askarova Aliya, Saltanat Bolegenova, Valery Maximov, Shynar Ospanova, Symbat Bolegenova</i> CFD simulation of production of NO _x in coal-fired furnaces	105
<i>Vorotyntseva Irina, Martsenyuk Nataliya</i> Autophase microwave-convertoir with multiple energy input	109
Section 11. Chemistry.	112
<i>Allamuratov Makhmud Omarovich, Saidov Amin Halim-o`g`li, Mukhamedgaliev Bakhtier Abdukadirovich</i> Syntheses and possibility of the using phosphor containing polymers for decisions of the Aral crisis.	112

<i>Gaibnazarov Sunnatilla Bohodirjonovich</i>	
The prospects of the using secondary resource in development efficient bore solution	114
<i>Gulamova Iroda Botirjonovna, Mukhamediyev Mukhtarjan Ganiyevich</i>	
Synthesis of polymers on the basis of citric acid	117
<i>Khazratkulova Sevara Musinovna, Gulomova Iroda Botirjonovna</i>	
Synthesis of N-sabstuted acrylamides on the base natural oxiacids	120
<i>Inatova Maksuda, Alimova Dilnoza, Smanova Zulayxo</i>	
Immobilized reagents for determination of metal ions.	123
<i>Teshabayeva Elmira, Vapayev Murodjon, Akhmadzhon Ibadullayev</i>	
Modification of mineral fillers and their influence on properties of rubbers	125
<i>Islamova Saida Turg'unovna, Ubaydullayev Obid Kaxromon ug'li, Ibraximov Temur Tulqin ug'li</i>	
Identification of paints gas chromatography	129
<i>Eshmatatova Nodira Baxromovna, Akbarov Khamdam Ikromovich</i>	
Quantitive value of effectivity of nitrogen and phosphor-containing ingibitors by the results electrochemical and gravimetical investigations	132
<i>Ergashev Dilmurod Adiljonovich, Askarova Mamura Komilovna, Saiydiaxral Tuxtaev</i>	
Investigation of the mutual effect of the components in systems substantiating the process of obtaining a new defoliant	135
<i>Urinov Ulugbek Komiljonovich, Maksumova Oytura Sitdikovna, Abdumalikova Xusnora Bahodir kizi</i>	
About the reaction of urea with epichlorohydrin.	141
<i>Usmanova Xilola Umataliyevna, Jurayev Ilxom Ikromovich, Smanova Zulayxo Asanaliyevna</i>	
Corbtsionno-fluorimetric determination of lead ion polymer immobilized reagents and application in the analysis of natural waters.	145
<i>Khamdamova Shokhida Sherzodovna, Tuxtaev Saiydiaxral</i>	
Solubility in system calcium chlorate-diethanolamine-water.	147
<i>Khamraev Mukhamadi Shirinovich</i>	
From the history of development of classic colloid chemistry.	153

