Part 4

COMPLEX TECHNOLOGIES OF REDUCTION OF ENVIRONMENTAL POLLUTION FROM THERMAL POWER PLANTS

4.4. Complex of reconstructive, operation and technological measures at natural gas and fuel oil burning

4.4.1. Complex reconstruction of TGMP-314C boilers at CHPP-23 of JSC "Mosenergo" for ensuring their environmental soundness, reliability and efficiency

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The article shows that an integrated approach to addressing environmental safety issues in combination with the measures for increasing the efficiency, reliability and resource-saving, provides a high efficiency at minimum cost.

Steam boilers of TGMP-314C type for T-250-240 units have been installed at CHPP-23 in 1970s…1980s of the last century. The main feature of the design of these gas-oil direct flow boilers of supercritical pressure was installation of four cyclone furnace extensions at the front and back walls of the furnace. As envisioned by MO CKTI designers, cyclone furnace extensions contribute to the intensification of the combustion process (fuel oil) due to intensive mixing with the air and presence of the carborundum coating on the inner surface of furnace extensions. However, experience of long-term operation has shown that the boilers of this modification have problems with reliability, and don't meet the modern requirements for emissions of harmful substances into the environment.

Initial concentrations of nitrogen oxides (without suppressing measures) in flue gases from the combustion of fuel oil comprise 800…1000 mg/m^3 (α=1,4), and at natural gas combustion they make 600…800 mg/ m^3, that is several times higher than the environmental normative (in accordance with the State Standard GOST R 50831-95).

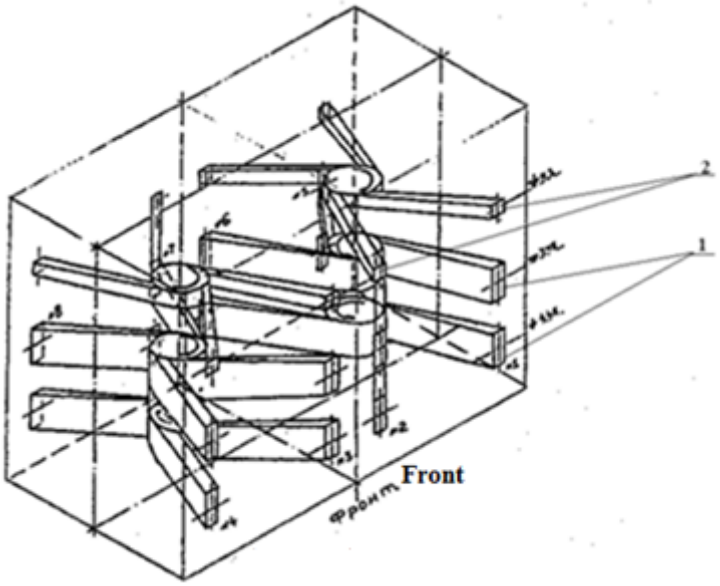
The core of addressing the problem of ecological purity of TGMP-314C boiler was a strategy, adopted by the JSC "Mosenergo", using primary methods: the regime-technological and reconstructive measures [1]. The challenge set while conducting the comprehensive reconstruction of TGMP-314C boilers at CHPP-23 was to lower emissions of nitrogen oxides to the normative values without increasing concentrations of benz(a)pyrene (BP) in flue gases, maintaining high reliability and efficiency of the boilers.

Table. **Boiler reconstruction measures for harmful emissions reduction.**

№	Reconstruction measures	Boiler №5	Boiler №6	Boiler №7	Boiler №8
1	Replacement of cyclone boiler extensions	16 GMVP b(1)-40 Ekotop burners installed	16 GMVP b(1)-40 Ekotop burners installed	16 GMVIg (111)-50 TKZ-VTI burners installed	16 GMVIg (111)-50 TKZ-VTI burners installed
2	Reconstruction of low radiation section	Front and back walls of low radiation section 1 reconstructed	Front and back walls of low radiation section 1 reconstructed	Front and back walls of low radiation section 1 reconstructed	Front and back walls of low radiation section 1 reconstructed
3	Reconstruction of low pressure convective steam superheater	Heating surface of convective steam superheater-1 of low pressure reduced by 2600 m^2, steam by-pass of 1st stage of low pressure superheater installed	Heating surface of convective steam superheater-1 of low pressure reduced by 2600 m^2, steam by-pass of 1st stage of low pressure superheater installed	Heating surface of convective steam superheater-1 of low pressure reduced by 2600 m^2, steam by-pass of 1st stage of low pressure superheater installed	Heating surface of convective steam superheater-1 of low pressure reduced by 2600 m^2, steam by-pass of 1st stage of low pressure superheater installed
4	Reconstruction of water economizer	Surface of water economizer enlarged by 1560 m^2	Replaced with increase in the heating surface of water economizer	Surface of water economizer enlarged by 1560 m^2	Replaced with increase in the heating surface of water economizer
5	Reconstruction of regenerative air heater	Cold pack of regenerative air heater replaced with ball-and-stick	Cold pack of regenerative air heater replaced with ball-and-stick	Ball-and-stick pack of cold layer installed	Ball-and-stick pack of cold layer installed
6	Assembly of secondary forced draft overburner nozzles	8 overburner nozzles installed	8 overburner nozzles installed	8 overburner nozzles installed	8 overburner nozzles installed
7	Replacement gas recirculation fan	2 gas recirculation fans of GD-20 type installed	2 gas recirculation fans of GD20 type installed	2 gas recirculation ans of GD20 type installed	2 gas recirculation fans of GD20 type installed

The urgency of this objective of complex reconstruction is explained by experience in the application of regime-technological actions in JSC "Mosenergo" at TGMP-314 boilers having wall and bottom arrangement of burners. This experience indicates that the application of regime-technological measures (basically a combination of staged

fuel combustion with flue gas recirculation into the combustion zone) without reconstruction of burners it's possible to reach normalized values of NO_x concentrations when combusting natural gas, and (with some reservations) fuel oil. However, it raises a number of accompanying problems: increasing the concentration of benz(a)pyrene (almost proportional to C_{NOx} reduction), decline in reliability of boiler operation due to increased proportions of flue gas recirculation at loads close to nominal, leading to an increase in temperature of secondary steam, declined in operational reliability of furnace walls due to formation of aggressive gases at the wall zones of the furnace, boiler efficiency reduction due to the increase in temperature of flue gases, problems with draft and blast and limitations of boiler load, etc. Therefore, 1st stage of the program on complex reconstruction of TGMP-314C boilers (boilers № 5 and №6) provided replacement of cyclone burner extensions with wall direct-flow and swirl GMPV b(I)-40 Ekotop burners of tangential configuration with the arrangement of the two-vortex aerodynamic configuration in the combustion chamber (Fig.1).



Angles of setting the burners - 19°, 37°

Fig.1. A**rrangement of overburner nozzles with wall direct-flow and swirl GMPV b(I)-40 Ekotop burners:**
1) direct-flow and swirl burners (16 pcs), 2) overburner nozzles (8 pcs).

Dual-swirl aerodynamic configuration represents two swirls in each half of the furnace: swirl of the air-fuel mixture and swirl of the secondary air, rotating counter.

The second stage (boilers №7 and №8) of research program provided the replacement of cyclone furnace extensions with low toxic GMVI g (III) -50 TKZ-VTI burners (Fig.2). There have been reconstructed the front and back sides of low radiation sections-1 of all boilers, as well as the heating surfaces of convective steam superheater-1 of low pressure, water economizer and regenerative air heater. Measures on reconstruction of the heating surfaces of TGMP 314C boiler at CHPP-23 are presented in table. It should be noted that the index "C" in the boiler marking after replacing the cyclone furnace extensions with wall burners is conditional.

The table shows that the complex reconstruction of the boiler heating surfaces was aimed at prevention of negative impact of regime-technological $DeNO_x$ measures on the reliability and efficiency of boiler operation.

The studies conducted at TGMP-314C boilers had a complex character as well: there have been investigated the influence of reconstructive, regime and technological measures on emissions of nitrogen oxides, carbon monoxide and benz(a)pyrene in the working range of loads and modes, as well as a comprehensive study of the impact of these measures on reliability and efficiency of boiler operation, including the measurements of the heat flux density on screens of the combustion chamber, temperature regime of tubes of heating surfaces, investigation of the operation of the reconstructed boilers working on sliding pressure.

The main results of studies relating to nitrogen oxides, obtained at the first stage of reconstruction (boilers № 5 and 6), are shown in Fig.3. From this figure follows that normalized values of NO_x concentrations of 125 mg/m^3 are achieved when combusting natural gas in combination with the staged combustion (β=16%) and recirculation of flue gases (r=11-12), i.e. in case one gas recirculation fan is operating. It's characteristic, that the initial NO_x concentration only but to installation of new burners (without secondary draft and recirculation) at a load close to the nominal one, was about 320 mg/m^3, which is significantly lower than at TGMP-314 boilers with wall swirl and bottom burners. Secondary blowing reduces the concentration of nitrogen oxides by 40% at a load close to the nominal, and operation of one gas recirculation fan at full load causes an additional reduction of almost two-fold. As a result, the level NO_x concentration at the rated load, and optimum excess air (α_{we}=1,09) made 95…100 mg/m^3 (hereinafter concentration of nitrogen oxides is converted to the standard excess air α=1,4). In case of unfavourable weather conditions, it is possible to reduce the concentration of nitrogen oxides to a level of 75…80 mg/m^3 by switching on the second gas recirculation fan.

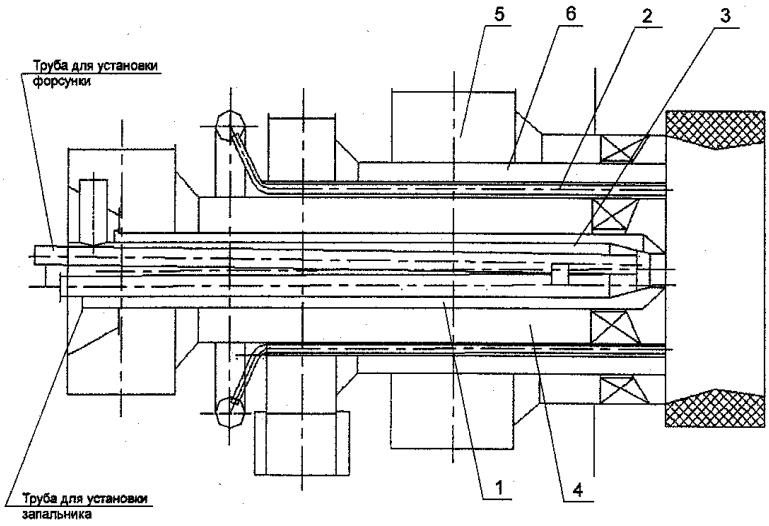


Fig.3. Cross-section of low toxic GMVI g(III)-50 TKZ-VTI burners

1- central gas supply - 30%
2- peripheral gas supply - 70%
3- central air supply - 18%
4- intermediate air supply - 32%
5- peripheral air supply - 50%
6- recirculation gas supply

Труба для установки форсунки - Pipe for installing the nozzles

Труба для установки запальника - Pipe for installing the igniter

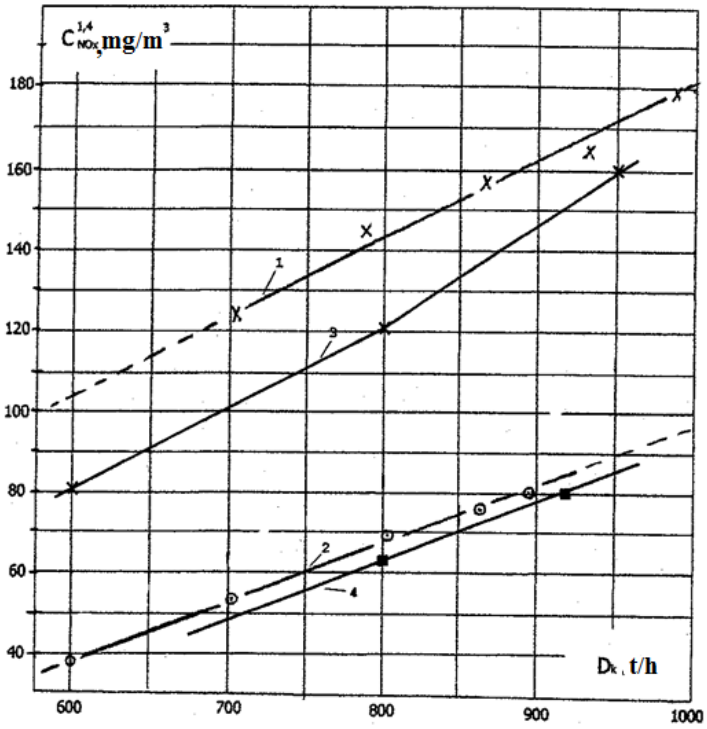


Fig.3. **The results of NOx concentration obtained after the first stage of reconstruction of boilers №№5,6:**
1- boiler №5, r=0 – gas recirculation fan is off, 2- boiler №5, r=12% -1 gas recirculation fan is on, 3- boiler №6, r=0 – gas recirculation fan is off, 4- boiler №6, r=12% -1 gas recirculation fan is on.

At burning fuel oil the specified combination of regime measures also allows to reduce NO_x concentration in flue gases up to the normative -250 mg/m^3. Study haven't revealed any negative effect of regime measures on reliable operation of the boiler heating surfaces (№5 and №6) in the adjusting load range $(0,6–1,0)D_N$. Taking into account that the actual boiler load rarely exceeds 900 t/h, the necessary percentage of recirculation varies between 7 and 9%. This combined with measures on reconstruction of the convective steam superheater of low pressure (steam bypass beside the first stage of convective low pressure superheater and injections between stages of convective low pressure superheater after the bypass) almost removes the problems associated with the work of the secondary superheater. It was established that combustion of fuel oil hasn't excluded a risk of corrosion of hazardous H_2S concentrations. Therefore, at oil combustion one should not use for a long time the regimes with completely open nozzles of secondary blast and even one working gas recirculation fan at loads close to the nominal. Economic parameters of operation of the boilers were also saved on a high (design) level: gross efficiency of boilers at the rated load estimated as 93.45% and 93.52% when combusting natural gas with gas recirculation fan or without it, correspondingly. Thus, arrangement of direct-flow vortex burners, applied at the first stage of the complex reconstruction of TGMP-314C boilers in combination with the staged combustion and flue gas recirculation was quite satisfactory with regard to limitation of NO_x emissions at natural gas combustion.

The problem of reducing emissions resulted from gas and fuel oil combustion has been solved, to a large extent,

at the second stage of reconstruction of TGMP-314C boilers № 7 and №8, equipped with low-emission TKZ-VTI burners. With regard to its working process, the burner refers to the combined type, as it combines several principles (processes) which lead to decrease in the intensity of the NO_x generation during fuel combustion. TKZ BTU burner combines the processes of non-stoichiometric combustion, stage burning and screen injection of recirculation gases. Combination of these processes at the initial section of the flame produced two zones of fuel combustion: oxidation and reduction. Gas combustion occurs in the axial zone with local excess air of about 1,0 or a little bit higher. A reducing environment is formed in the peripheral area where excess air is substantially less than 1,0. In the peripheral zone the gas is firstly injected in the gas recirculation flow, and then mixed with the peripheral air flow. Mixing of two portions of the flame occurs at some distance from the edge of the burner after burning the main quantity of gas supplied to the central and middle parts of the burner. In addition to that, in the boiler furnace the use of a principle of staged fuel combustion by supplying part of air to the overburner nozzles is provided. At fuel oil burning the flame structure is different and more complex, but studies have shown that the effects of non-stoichiometric staged combustion adequately appear at oil combustion as well. Studies conducted at the boilers №7 and №8 at CHPP-23 showed that the approach used in designing a new burner, led to a sharp improvement of the environmental performance of boilers. Later on it will be shown that this appeared not only in terms of suppressing NO_x formation, but also with regard to the effectiveness of fuel combustion and significant reduction of benz(a)pyrene formation when burning natural gas and fuel oil.

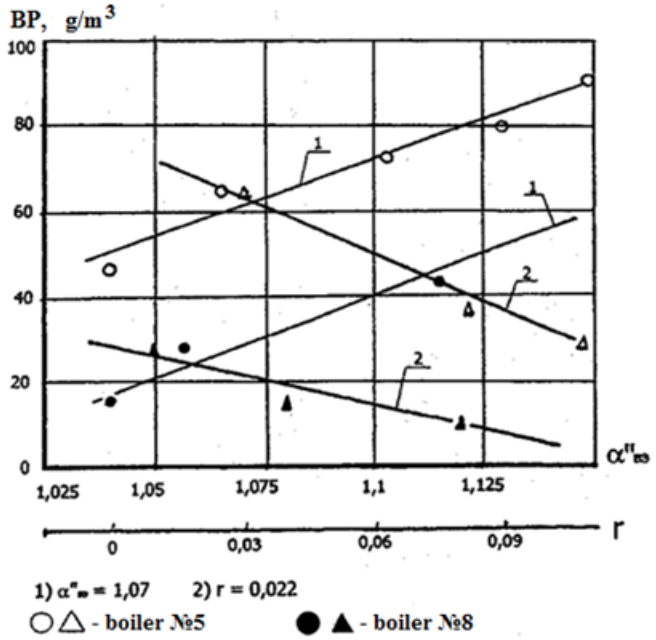


Fig.4. **The results obtained at the boilers №№5 and 8 and their effect on benz(a)pyrene emissions.**

As a result of industrial tests conducted at boiler №7 it was found that at loadings close to nominal, only due to constructive solutions TKZ-VTI burner ensured a decrease in NO_x emissions to a level of 307 mg/m^3 in case of natural gas combustion and to 407 mg/m^3 at fuel oil combustion, which is about three times lower than in case the burners of TKZ, HF CKB-VTI, bottom ones and cyclone furnace extensions are set. There was carried out a series of experiments to find the optimal operation mode for low-emission TKZ-VTI burners in combination with the air supply to the overburner nozzles and flue gas recirculation. In case of natural gas burning, at loads close to nominal ($0,9D_{nom}$) and secondary blast in operation (β=32%), at flue gas recirculation r=6% and excess air in the performance mode α''_{we}=1,09, concentration of nitrogen oxides maintained at the level of 90…100 mg/m^3. In case of fuel oil burning at $D=0,9D_{nom}$, β=5%, r=0,17 and α''_{we}=1,09 concentration of nitrogen oxides was 200°mg/m^3, which is also significantly lower than the normative one. Thus, the use of TKZ-VTI burner in combination with staged combustion allows to reduce NO_x concentration up to the normative values at much lower part of recirculated flue gases, which alleviates the problem associated with reliability and efficiency of the boiler. This combined with the measures for complex reconstruction of boilers almost completely solved these problems and to maintained high reliability and efficiency operation of the boilers. But the most important result of using TKZ-VTI burners was non-increase in BP concentration in modes where technological methods aimed at NO_x suppression have been applied.

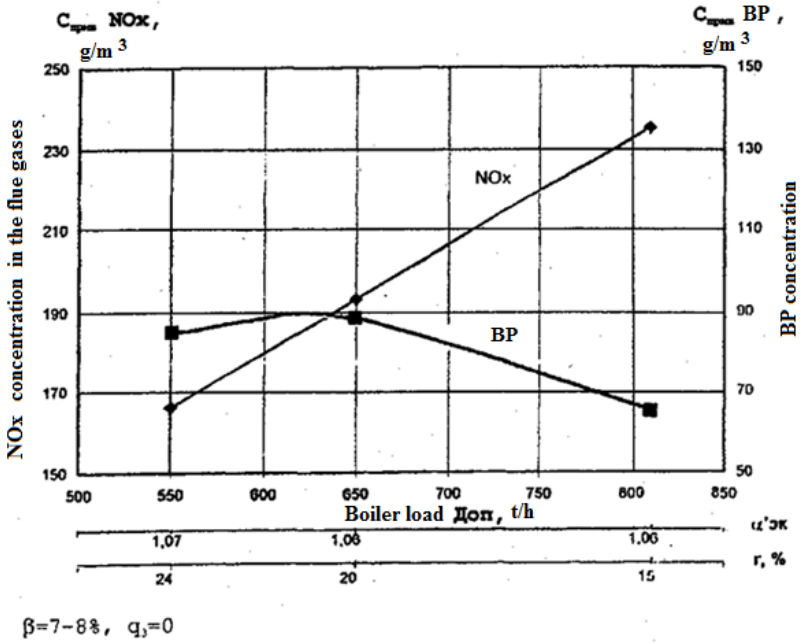


Fig. 5. **Influence of measures applied at TGMP-314C boiler on BP and NO_x emissions.**

From the data presented in Fig. 5 follows that the usual type of BP concentrations - excess air and BP concentrations - flue gas recirculation relationships has changed. Such types of BP concentration - excess air and BP concentration - flue gas recirculation relationships were observed in case of gas and fuel oil burning. Another unusual result was that the original BP concentration (without staged combustion and recirculation) at oil combustion was lower than at gas burning: 89 g/m^3 and 140 g/m^3, accordingly. The latter can be explained by the fact, that fuel oil used in our study had a moisture content of about 10% and was treated in the emulsifier. In studies [2, 3] the authors wrote about the positive influence of oil emulsifying on reduction of BP formation intensity. A similar result was obtained in this study. As for BP concentrations - excess air and BP concentrations - flue gas recirculation relationships, here, apparently, all is explained by the peculiarities of mixture formation and combustion process, implemented by low-emission burner. Here could be also noted that CO concentration in the flue gases in all the investigated regimes was significantly below the limit. Fig. 6 shows the comparative level of NO_x and BP concentrations in flue gases from TGMP-314 boilers. It is seen that the best environmental performance have the boilers, equipped with low-emission TKZ-VTI burners.

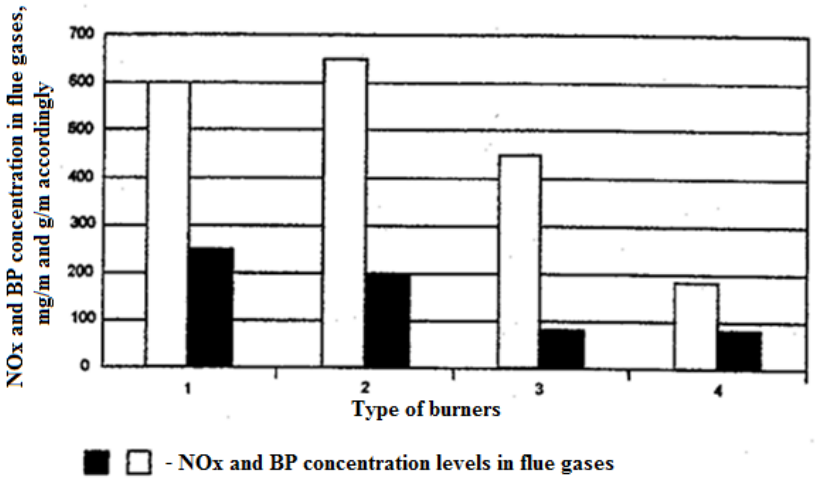


Fig.6. **Comparative level of NO_x and BP concentrations in flue gases from TGMP-314 boilers.**
1 - HF CKB-VTI burners; 2 - bottom burners; 3 – with cyclone furnace extensions; 4 – TKZ-VTI burners boiler №7

CONCLUSIONS

1. The results obtained at TGMP-314C №7 and 8 boilers (at the 2nd stage of the work), confirmed the correctness of the chosen concept to ensure environmental cleanliness, reliability and efficiency of boilers working on supercritical pressure, by the complex reconstruction of burners with the installation low-emission burners and reconstruction of a number of heating surfaces (low radiation section, convective steam superheater of low pressure, water economizer, gas recirculation fan), in combination with the technological regime methods of suppressing the formation of harmful substances.
2. Taking environmental measures at boilers of CHPP-23 JSC “Mosenergo” resulted in sharp reduction of emissions of harmful substances into the atmosphere. So, in flue

gases from boilers, working on supercritical pressure, NO_x concentration is five times or even more smaller, and the total mass emissions of nitrogen oxides in the atmosphere of the city, discharged with flue gases from power boilers in 2002 was 4.5 times lower compared to 1994 (the year before the reconstruction).

3. Considering the positive results achieved with regard to emissions of benz(a)pyrene, carbon oxides and other harmful substances, we can recognize that this is a rather significant contribution to improving the environmental situation of Moscow.

REFERENCES

1. **Горюнов И.Т.** Анализ, разработка и выбор оптимальных мероприятий по повышению экологической эффективности эксплуатации крупной энергосистемы. Дисс. канд. техн. наук. М. – 1998.
2. **Зройчиков Н.А., Дегтерев В.Н., Чернов С.Л. и др**. Глубокое снижение выбросов оксидов азота технологическими методами от котла ТГМ-96Б, работающего на природном газе // Вестник РАПЭ. –1997.- С.67-74.
3. **Зройчиков Н.А., Чернов С.Л.** Опыт эксплуатации дымососа рециркуляции газов (ДРГ-ГД-25S) с S-образными лопатками на котле ТГМП-314 // Известия АПЭ. –1998.-№1.- С.25-31
4. **Кормилицын В.И., Лысков М.Г., Румынский А.А.** Комплексная экосовместимая технология сжигания водомазутной эмульсии и природного газа./ Теплоэнергетика. – 1996. - № 9. – с. 13-17.
5. **Галас И.В., Морозов О.В., Усман Ю.М.** Влияние эмульгирования мазута на выбросы вредных веществ // Энергосбережение и водоподготовка, 2000, №3

Zroychikov N.A., Galas I.V., Lyskov M.G., Morozova E.A. Complex reconstruction of TGMP-314C boilers at CHPP-23 of JSC “Mosenergo” for ensuring their environmental soundness, reliability and efficiency // Thermal Engineering – 2006 – №5 – p.26–31.