P a r t 4

COMPLEX TECHNOLOGIES OF ENVIRONMENTAL POLLUTION FROM THERMAL POWER PLANTS

4.5. Analytics

4.5.2. Complex environmental technologies introduction in power industry of the Russian Federation

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ABSTRACT

The survey contains information on technologies which can be applied to reduce harmful environmental impact of TPPs in complex. Recent activities of power companies in this field are analyzed as well as their plans in the future. An opinion on the necessity of creating the incentives and beneficial conditions for introduction of complex technologies in the framework of state decisions relating to transition of industries to the best available technologies is expressed.

ABOUT COMPLEX TECHNOLOGIES

The division of environmental technologies into narrowly targeted (eg., ash collection, desulphurization, nitrogen removal, etc.) and complex ones in this MPEI Information system is of a conditional character. For example, the section "Complex technologies" includes the results of introduction of a system to convert a small portion of sulfur dioxides, contained in flue gases from Ekibastuzsky coal combustion, into sulfur trioxide, leading not only to reduction of SO_x emissions, but also to raising the ESP performance due to improvement of electrical properties of the ash. This technology could be successfully introduced in the subsection "ash collection" of the section "Air protection". NO_x reduction methods are inextricably linked with the possible appearance of excessive amount of CO and benz(a)pyrene in flue gases, and wet limestone FGD systems provide additional capture of ash in scrubbers; thus they can be referred to complex technologies. Complex character of environmental technologies can be interpreted as improvement of one or several ecological characteristics of the plant and simultaneous growth of its efficiency.

In connection with that natural gas combustion leads to formation of harmful substances, the main part of which are nitrogen oxides (CO and benz(a)pyrene represent minor amounts of pollutants), at coal-fired TPPs almost every variation of combustion technology leads to a change in the whole complex both technical, economic and ecological parameters of the boiler operation. At TPPs some minor amounts of residual oil are still combusted as well (about 1 % in the fuel mix of the Unified Energy System of Russia). In the power industry there are no power plants left burning residual oil. Residual oil is used mainly at coal-fired TPPs to maintain stable combustion of coal with low volatile content and at gas-fired TPPs to cover winter peak loads at a lack of gas. In [1, 2] a technology of oil-and-water emulsion combustion, which is prepared in MPEI-CHPP-23 cavitator is described. This provides NO_x reduction in addition to those $DeNO_x$ operation measures as well as reduction of CO and benz(a)pyrene. Together with that the increased water content up to 20…30 % results in improving the reliability of oil combustion. It is important to underline that the emulsion may be prepared with oily wastes which leads to reduction of waste discharges. From late 1970s in Russia, Baltic states and CIS countries successful industrial tests relating to combustion of water-and-oil emulsion in power boilers were conducted. There are well-known positive results on combustion of water-and-oil emulsions not only in high capacity boilers but in mid- and small-scale capacity boilers accompanied by an effect of even increase in boiler efficiency. This technology is most likely to be implemented at municipal and industrial oil-fired boiler-houses, which number in Russia is still considerable.

The following technologies at coal-fired TPPs may be referred to complex ones:

- atmospheric fluidized-bed boilers, circulating fluidized-bed boilers and pressurized fluidized-bed boilers;
- gasification of solid fuel;
- combustion of solid fuel in melt;
- boilers with cyclone pre-furnaces.

As for technological issues of these technologies, please, refer to Section 1.5 of this Informational System.

VIR-technology and coal combustion in circular furnaces are of the same type of technologies. Since they are not presented in Section 1.5 of the Informational System, below is brief information relating to them.

According to [3] VIR-technology is a low-cost measure with a change in traditional gas dynamics in the furnace (namely arrangement of whirling motion of gases in the furnace bottom). To achieve this, lower cold blast is arranged through the mouth of the boiler throat; the burners are inclined downward. As a result, two combustion zones appear (i.e., a kind of two-stage combustion): low-temperature vortex at the furnace bottom, including the boiler throat, and traditional direct-flow, located above the burners. In this case coarse dust is supplied to the boiler.

Construction of the circular furnace provides an effective use of a whirl motion of flue gases which is characteristic for tangential furnaces where in the central part of the furnace a slow-stream zone is formed. Construction of the circular furnace is an open octahedral prismatic chamber. Inside the chamber an octahedral central insert is installed throughout its height, equipped with gas-proof panels. Streamline burners with control system are installed on each outside wall in several tiers (depending on the boiler capacity); they are directed at a tangent to the inside insert. Such location of the burners provides a whirling motion of the flame in the circular furnace without its intensive impingement to the walls of inside and outside chambers. Such gas dynamics and increased thermal perception of screens of the circular furnace makes it possible to achieve comparatively low temperature of gases in the center of the flame (below 1200°C), and this eliminates a possibility of active slagging of screens, provides stable ignition, low level of NO_x emissions and effective burning of the fuel.

In Table below presents ecological benefits of applying complex technologies as compared to traditional boilers without FGD and DeNOx systems.

Table. **Ecological effect of different complex technologies for coal-fired TPPs (in comparison with traditional combustion without FGD and DeNOx systems)**

Technology	Development phase in RF	Content of NO_x in flue gases; necessity of DeNOx	Content of SO_2 in flue gases; necessity of FGD	Conditions of ash precipitation	Suitability of slag and captured ash for utilization	Evaluation of probability of industrial introduction in RF
Fluidized bed boilers (atmospheric)	Introduced at Barnaul CHHP-3 (420 t/h boiler)	Low due to the absence of thermal NO_x; DeNOx is not needed	Can be reduced by 80 % in case limestone is injected in the furnace	Better conditions	Mixture of ash, calcium sulfate or sand. Can be utilized in road construction, etc.	No plans to introduce industrial boilers in RF
Circulating fluidized bed boilers	Construction of 330 MW unit at Novocherkasskaya SDPP is under way (commissioning is envisaged by the end 2015)	Up to 300 mg/m^3; DeNOx is not needed	Can be reduced by 90 % in case limestone is injected in the furnace	Better conditions	The same as above (for more details, please, refer to [4]). At Novocherkasskaya SDPP utilization of ash and slag isn't planned as yet	Depends on results of introduction at Novocherkasskaya SDPP
Fluidized bed boilers (pressurized)	R&D	Up to 200 mg/m^3; DeNOx is not needed	Can be reduced by 90…95 % in case limestone is injected in the furnace	Heavy conditions for high efficient precipitation in cyclones	Mixture of ash, calcium sulfate or sand. Can be utilized in road construction, etc.	No plans to introduce industrial boilers in RF
Gasification	R&D	Internal-cycle removal of HCN, NH_3 is needed	Internal-cycle removal of H_2S, COS, CS_2 is needed	Internal-cycle ash removal at high temperatures is needed	Additional R&D need to be held	Unlikely in the coming 5-10 years
Combustion of fuel in a melt	R&D; design of a demonstration installation at Nesvetay SDPP	100 mg/m^3; DeNOx is not needed	Reduction by 30%, in case limestone is injected in the melt up tp 90 %	Absent in the design; ash content in flue gases – 50 mg/m^3	Slag: (1) "heavy", metallic for use in metallurgy and (2) "light" for conventional use. Refusal from ash-and-slag disposal site is possible	Unlikely. In RF an idea to realize the technology appears from time to time since 1940s
Boilers with cyclone prefurnaces	R&D	240…300 mg/m^3; DeNOx is not needed	Reduction by 55% and up to 90% in case of 2-stage burning; no SO_2 removal is needed	16 mg/m^3	Additional R&D is needed	Unlikely in the coming 5-10 years
VIR-technology	Introduced at P-59 boiler of Ryazan SDPP and BKZ-75-35 of Komyenergo	Reduction by 40…50%; DeNOx is not needed	93 mg/m^3; no SO_2 removal is needed	Efficiency of electrostatic precipitators is increased	Conventional use	Unlikely because actual results obtained at Ryazan SDPP appeared to be lower than expected
Circular furnace boilers	Introduced at Novo-Irkutskaya CHP(820 t/h boiler)	400 mg/m^3; DeNOx is not needed	N.a.	N.a.	Conventional use	High probability. Positive operational history during more than 10 years.

INVESTMENT ACTIVITIES OF ENERGY COMPANIES IN THE FIELD OF IMPLEMENTATION OF COMPLEX ENVIRONMENTAL TECHNOLOGIES

In order to clarify the development phase of complex environmental technologies, the author studied activities of RF power companies, looked through their environmental reports for 2013 as well as related sections of their web-sites, investment and environmental programs, plans of activities. These power companies are: WGCs, TGCs, as well as DVEUK, KES, InterRAO. At the same time it should be noted that the content of the above materials is very poor or they are of declarative character; in many cases companies limit their information to a short document on ecological policy with well-known principles and directions of activities. In many cases certain plans are absent at all. Study of the above documents showed only some single plans of introduction of complex technologies.

About construction of power units with CFB boilers

Cherepetskaya SDPP. Originally it was planned to build two units of 225 MW with circulating fluidized bed boilers at Cherepetskaya SDPP. At the same power plant it was planned to test dry dust removal and desulphurization under NID-technology. However, finally, instead of CFB-boilers at Cherepetskaya SDPP it was decided to build conventional pulverized coal-fired boilers.

Novocherkasskaya SDPP modernization project. The modernization project of Novocherkasskaya SDPP is to build on a free power station site of a new unit №9 with capacity of 330 MW, installing an CFB-boiler. This will be the first in the country unit produced in Russia with application of CFB technology. The applied technology is an optimal solution in terms of existing environmental regulations and the relevant requirements of the applicable European emission standards. CFB boiler with steam output of 1000 t/h (steam parameters: 24,5MPa, 565°C) is the result of a joint production of JSC "M-Alliance" and Foster Wheeler. The project will increase the competitiveness of Novocherkasskaya SDPP in electricity and capacity market, raise the company profit by improving productivity and increased electricity supply, as well as enables to reconstruct the existing main power equipment.

An important disadvantage of the project on building the power unit №9 is implementation of technologically archaic, economically non-efficient and environmentally unacceptable wet system for ESP and bottom ash removal with the ash pond. Taking into account a deficit of construction raw materials in the regions it would be reasonable to design an economically effective and ecologically acceptable ash handling system for the whole power plant where ash and slag equipment of unit No. 9 would be a part of the new system. The launch of facility of the new system could comprise equipment of ash removal from unit No. 9 and silo for storing dry ash with a unit of processing of bottom and fly ash into commercial product. Under such an approach at refurbishment of old units of the plant the ash handling problem could be solved with the best acceptable technologies. Unfortunately, this hasn't happened. Construction works under the project are continuing according to the confirmed schedule, unit No. 9 is to be commissioned by the end of 2015. It is still possible to make amendments in the part of the project relating to ash handling at Novocherkasskaya SDPP

On implementation of new technologies and optimized fuel combustion in power boilers

Politechenergo ltd, being a developer of VIR-technology, announces of the plans to introduce it at some TPPs after it was tried at Ryazanskaya SDPP. And that's basically all that has been identified. There are no plans for the construction and development of supercritical units, combined cycle power plants (CCPP) with gasification of coal, carbon capture and storage of CO_2, and some others, bringing a comprehensive environmental effect. It should be also noted that technology implementation time specified in the table refers to the first years of the XXI century, and the majority of R&D projects, and design of pilot plants was actually stopped long ago. Such situation seems very unattractive in comparison with the situation abroad. By the beginning of XXI century a total number of fluidized bed boilers of all three types all over the world exceeded 600 with the overall capacity of more than 60000 $MW_{(th)}$. Another example: in 2014 German company RWE started realization of 450 MW project of combined cycle gas turbine installation with brown coal gasification and CO_2 capture and storage costing Euro 1,7 bln. In the former USSR the combined cycle technology was developed to the stage of designing; nevertheless, at the time being no plans to test such a technology on a demonstration installation in Russia were identified.

Under the existing conditions of economic management in the power sector it is not realistic to expect an initiative from power companies to promote complex nature protection technologies. Financial results, profitability will be the priority for them, and this system does not include substantial expenses for the large-scale environmental technologies. Their aims are limited by remedial actions taken to solve special-purpose technological problems at existing TPPs, narrow-targeted low-cost measures, satisfying current requirements from the state environmental supervision bodies and those requirements fixed in standards relating to permissible limits of emissions, water discharge and waste handling. Neither the normative system, nor ecological payments, which became quite usual in their financial balances, direct companies to take additional measures. Return of the environmental charges on new activities almost never practiced, and for the introduction of complex technologies much greater funding is required. The absence of state-of-the-art TPP technological design standards results in designing the majority of new coal-fired power plants as it was 30 years. That is of a special concern. For example, the fundamental TPP design document "Technological standards for thermal power plants design VNTP 81" were approved on October 8, 1981 by the USSR Ministry of Energy and since then has not been reviewed. In case of a real, not declared introduction in Russia of the best available environmental technologies arises the possibility of overcoming the technological gap in the energy sector.

POSSIBLE INCENTIVES

It's quite clear that complex technologies represent as a rule large-scale and high-cost projects and before an industrial introduction they should be tested on demonstrational installations. For realization of such kind of technologies a set of measures is needed to support pilot projects, creation of favorable conditions, incentives, etc. This can be done in the framework of introducing the system of the best available technologies, which was launched in Russia in 2014 [5, 6]. Measures for wide spreading the renewables accepted by the RF Ministry of Energy [7] can serve as an example. Proposals for such measures adapted to complex large-scale technologies are presented below. They include the following:

- working out and regularly updating the facilities of introducing complex technologies;
- providing the development and realization of measures for attracting non-budget investments to construct new and refurbish existing facilities, including the following legal measure (under Federal Law dated 26.03.2006 No.35-FZ "On the power sector") – providing subsidiary financing as a compensation of the cost of technological connection to electrical grids of sources classified as complex technologies.

In order to smooth competition conditions for energy producers with complex technologies and conventional technologies it should be envisaged:

- to establish and regularly update discount rates and periods when the discounts are valid; this discount is to be added to weighted price of electricity at the wholesale market in order to get the final price of electricity, produced using the complex technologies;
- to establish the duty of wholesale buyers to purchase electricity, produced with complex technologies;
- to realize measures to improve legislative regime of nat-

ural resources use for construction and operation of facilities with complex technologies;
- to use mechanisms of additional support of development of complex technologies;
- to work out a complex of normative and regulation measures to introduce a support to complex technologies, primarily additions to the power prices, those measures are to be incorporated into the mechanisms of functioning of wholesale and end markets of electricity (incl. regions that are not united with price zones of the wholesale market).

In the field of improving the infrastructural provisions of power production development applying complex technologies it should be envisaged to do the following:
- improve the efficiency of scientific provisions and technological support of complex technologies development;
- rationally use the potential of domestic industry;
- create and develop information environment for population;
- organize training of specialists and prepare normative and technical documentation for designing, construction and operation of generation facilities with complex technologies;
- provide assistance in creation the system to stimulate the production and sales of electricity produced with complex technologies;
- regional planning;
- initiative of business communities; wide discussions of power companies perspective programs to reach the targets of introduction of the best available technologies.

It is clear that the initiative to introduce complex technologies should come from the RF Ministry of Energy, it should be supported by scientific and academic community, financial and industrial groups and the most valuable technologies could make one of the Ministry's programs. US "Clean Coal Technologies Program" can serve as a prototype. It started in 1986 and was several times updated (the latest ones took place in 2006 and 2009). The initial target was to struggle against acid rains caused by NO_x and SO_2 emissions. The Program was financed by the US Government, state departments and private business. It comprised promising technologies which needed to be brought to commercial level. Initial cost constituted USD 3.7 bln (1.5 bln out of the sum came from the Federal Government fund). It is remarkable that private business exceeded expectations and invested USD 3.2 bln in the program realization. Over 55 power producers, 50 developers and 30 engineering and consulting companies participated in the first version of the program. The Program covered such directions as coal gasification and gas turbines, fuel cells, production of liquid fuel, CO_2 capture and storage. The latest 2009 version of the Program comprises 43 demonstrational installations.

It is clear that at the time being RF cannot afford such a large-scale program, nevertheless 3-4 most actual technologies with 100 % guaranteed positive ecological and economical effect from their introduction could find their places in one of the program of the Ministry of Energy.

On environmental level of TPPs with dry-bottome and slag-tap boilers

At the Russian TPPs dry-bottom boilers (DBBs) and slag-tap boilers (STBs) are implemented. In each case making a choice of a new boiler or reconstructing the existing one, it is completely necessary to clear out all of the environmental advantages and disadvantages of each of the technology. Such an analysis can consider in more details the ecological factors together with technical and economical indicators. Traditionally difference in NO_x content in flue gases is considered to be the key environmental aspect. And here some issues appear: what is an efficiency of a number of primary furnace measures to suppress NO_x formation (multi-stage coal combustion, special construction of burners, transportation of coal dust to the furnace with high concentration, flue gas recirculation into the furnace, etc.) while reliability of the boiler and its economic indicators are kept and whether $DeNO_x$ system is needed to reach normative permissible level of emissions. Introduction of a DeNOx system will lead to a substantial increase in capital and operational expenses and to more complicated operational conditions. But besides these differences something else is to be taken into account. STBs are equipped with hydraulic slag removal systems only (while abroad pneumatic and mechanic bottom ash removal systems are implemented at DBBs successfully operating for a long time). As a result of operation of wet removal systems it's necessity to build an ash-and-slag pond with all the environmental disadvantages. Pneumatic and mechanic bottom ash removal systems make it possible not only to increase the fuel utilization factor of the plant due to a guaranteed reduction of unburned carbon in the ash below normative index, but also to create conditions to utilize dry bottom ash with required consumer properties with low loss on ignition. In furnaces of DBBs and STBs there are different levels of benz(a)pyren and CO content. Different proportions of fly ash and slag generated in the furnace lead to different dust content in flue gases and cause some differences in ash precipitation conditions. The same appears because of different fineness of coal grinding, necessary for optimal combustion in DBBs and STBs. Because of different levels of unburned carbon in ash and slag removed from DBBs and STBs, they have different consumer properties for their utilization; in some cases it is reasonable to implement electromagnetic separation of the captured ash. According to opinion of specialists of Moscow Power Engineering Institute complete consideration of the above factors bring them to a conclusion that there are a lot of reasons for switching from STBs to DBBs. Technological and environmental aspects of combustion of certain coal ranks in some concrete STBs and DBBs are, particularly, described in articles of Section 4.3 of this Informational System.

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