Ensuring the Environmental Safety of Coal-fired Power Plants for the Flue Gases Purification

N Samarskaya¹, E Lysova¹, O Paramonova¹, N Yudina¹
¹Department of Environmental Engineering, Don State Technical University, 344022, Sotsialisticheskaya str. 162, Rostov-on-Don, Russian Federation

E-mail: Nat-samars@yandex.ru, katerina.lysova0803@gmail.com, paramonova_oh@mail.ru, udi-natasha@yandex.ru

Abstract. The article is devoted to solving of the pressing issue – provision of ecological safety of urban areas in flue gas purification of coal power plants and boiler houses. Use of the method for evaluating and selecting the maximum ecological efficiency and energy intensity value of purification of exhaust gases of thermal power plants and boiler houses of municipal services within the known physical and energetic approach allowed to obtain the parametric dependence of ecological efficiency and energy intensity value and determine the optimum parameters of hydrodynamic cleaning process with further designing of a new technical solution.

On the basis of the simulation process and cleaning systems a new device of hydrodynamical (wet) cleaning the flue gases via control parameters significantly affecting the ecological efficiency and energy intensity value of the cleaning process was worked out. Moreover, control of parameters is carried out at the design of flue gases cleaning system, which allows to significantly optimize the choice of ways and means of reducing air pollution in urban territories. The obtained simulation results can be used to develop new or improve existing devices of hydrodynamic flue gases purification.

1. Introduction

Global research conducted in the field of development of coal power show that, in general, with the growth in demand for electricity after the improvement of the quality of life demand for all energy sources will continue to grow, including coal as the cheapest and most affordable fuel [1-5]. Despite the decline in the role of coal plants compared to other types of energy such countries as China, India, Russia, Australia, South Africa, Indonesia, South Korea still belong to the countries with the largest volume of electricity and carbon heat production [6-11]. In the structure of the world electricity production share of coal power plants is about 40% (Figure 1).

At the same time, in these countries there is a steady trend towards a reduction of volumes of pollutant emissions into the air basin by burning coal fuel at the power plants. This trend is especially evident in South Korea and China [12-13]. However, for most major metropolitan areas coal power plants and boiler houses still occupy a leading position in contribution to the pollution of atmosphere. In the process of coal fuel combustion particulates of ash and soot, sulfur oxides, carbon, nitrogen, heavy metals, halides (fluoride, chloride, etc.), volatile organic compounds (VOC’s), dioxins, furans and other pollutants get into the air [14-16].
To ensure ecological safety in the urban environment, in this case various methods and means of purification of waste gases from toxic components are used.

![Figure 1. Structure of the world electric power production.](image)

Currently there is a huge amount of flue gases purification technologies, i.e. sets of options "approach-method-type" for implementation of the purification process and there is a problem to select the best by ways of efficiency way and means to reduce pollution of air, environmental purification efficiency calculation of which is often not justified, and is focused on ready-made construction solutions. Therefore, the problem of correct choice of the number of known or development of new constructive elements and working characteristics of the process and system to reduce air pollution becomes very pressing.

2. Materials and methods

Among the known and conventionally used methods for purification of flue gases of thermal power plants and boiler houses for the development of new constructive solution authors have selected hydrodynamic method as one of the most widespread and having a sufficiently high ecological efficiency [17]. Study of physical essence of the process of hydrodynamic flue gases purification allowed to carry out mathematical description of resulting parameters – ecological efficiency and energy intensity value [18].

Physical and energetic approach [19-21] used by the authors based on the theory of stability of dispersed systems, has allowed to systematize the property settings, energy parameters and stability of the pollutants formed during the thermal power plants and boilers operation [22]. Use of the method for evaluating and selecting a maximum energy efficient and ecologically efficient means of purification of exhaust gases of thermal power plants and boilers of municipal economy within the physical and power approach allowed to define the optimum parameters of hydrodynamic purification process with further designing of new technical solution.

3. Results of the study

In our opinion, the obtained parametric dependences of ecological efficiency and energy intensity value are complementary and characterize the process of reducing the air basin most fully. It is important that management of parameters is possible to carry out at the design stage of the system of flue gases purification. This allows to optimize the choice of ways and means of reducing of air pollution in urban areas. It is necessary to select as controlled ones those functionally independent parameters the variation of which entails simultaneous increase of values of ecological efficiency and energy intensity value (Table 1).
Table 1. Directions of improvement of flue gases purification with hydroirrigation.

| Parameter | Direction of change | Possible ways to change | Comment |
|-----------|---------------------|-------------------------|---------|
| Surface tension at the liquid-gas interface | reduce | 1. Increase pH for alkaline spray | + |
|          |                     | 2. Reduce pH for acidic spray |         |
| OH⁻ ion concentration | increase | Increase spray pH | + |
| Gas and spray interaction area | increase | Reduce the drop size with spray permanent consumption | + |
| Reactivity of gas pollutants | increase | Apply pre-oxidizing of gaseous pollutants with ozone | |
| Drop weight | increase | 1. Use liquid with a higher density as the core of the drop | + |
|          |                     | 2. Use a solid body as the core of the drop | + |
| Drop speed | increase | 1. Create a discharge corridor in front of the drop in the direction of its movement | - |
|          |                     | 2. Increase the dropweight with its volume and spray pressure unchanged | + |
| The flow rate with particles of pollutants | - | Organize satellite motion of particles of pollutants and spray drops | + |
| The number of drops colliding with pollutant particles | increase | 1. Increase spray tongue density with spray consumption unchanged | + |
|          |                     | 2. To increase the contact time of pollutant particles with a drop during their movement | + |
|          |                     | 3. Create local areas of high concentration of pollutants particles and drops in the active purification zone | + |
| Interaction time of gas molecules and spray drops | increase | 1. Reduce speed of gases in the active zone of interaction | |
|          |                     | 2. Apply satellite irrigation | |
| Volume of spray tongue active zone | increase | 1. Change the configuration of the tongue with the spray pressure unchanged | + |
|          |                     | 2. Increase the cross sectional area of the spray tongue by providing tangential component of drop velocity | + |

Simulation of directions for improving the purification of exhaust gases by water irrigation allowed us to develop a new device. The proposed device for hydrodynamic (wet) purification of hot flue gases (Figure 2) contains an inlet pipe 1 provided with a water sprinkler in the form of a collector 2 with centrifugal nozzles 3. The inlet pipe has a continuation in the form of a bubbler pipe 4, the lower part of which is made with perforated sections 5 and buried in the water of the precipitation chamber 6, equipped with several partitions in its upper part 7 and several partitions in its lower part 8, with a heat
exchanger in the form of a tubular coil 9, having an input 10 for cold water and outlet 11 for hot water. In the precipitation chamber filled with water, between each partition there are collectors 12 with nozzles 13 for spraying liquid with foam active substances added to the water collecting tank 14. Water enters the tank from the overflow window of the precipitation chamber with an adjustable gate through drain pipe 15. A water collection tank is connected to a screw pump 16, from which water under pressure enters through a pipe 17 to the collectors. The purified gas through the pipe 18 enters the duct 19 and is pumped out by the smoke exhauster 20 and fed through the duct 21 to the moisture separator 22 with a tangential inlet 23, and then through the duct 24 to the chimney 25. A device for wet purification of hot flue gases works as follows.

![Diagram of the device](image)

**Figure 2.** Device for hydrodynamic (wet) purification of hot flue gases.

Hot gases contaminated with ash particles pass through an inlet pipe, equipped with a water sprinkler in the form of a collector with centrifugal nozzles, into a bubbler pipe with perforated sections, buried in the water of the precipitation chamber, equipped with several partitions in its upper part and several partitions in its lower part, a heat exchanger in the form of a tubular coil having an inlet for cold water and an outlet for hot water. At the same time, the hot polluted air stream emerging through the perforated sections interacts with water and is directed through successively located partitions, and ash particles remain in the volume of water, which through the drain pipe enters the tank from the overflow window of the precipitation chamber. Foam substances are added to the tank and spray liquid is supplied to the collectors through nozzles. Passing through the partitions, the contaminated air stream is simultaneously irrigated by dispersed liquid from the nozzles. The water collection tank is connected to a screw pump, from which water under pressure enters through the pipeline to the collectors. The purified gas through the pipe enters the duct, is pumped out by a smoke exhauster and fed through the duct to a moisture separator with a tangential inlet, and then through the duct to the chimney.
4. Discussion and conclusions

Thus, our analysis of possible ways to change the parameters of ecological efficiency and energy intensity value allowed us to identify areas for improving the purification of exhaust gases by water irrigation. The obtained simulation results can be used in the development of new or improvement of existing devices for the hydrodynamic purification of flue gases. Those functionally independent parameters, the change of which entails a simultaneous increase in the values of ecological efficiency and energy intensity value indicator should be chosen as managed ones.

References

[1] Plakitkin Yu A and Plakitkina L S 2016 Overdue it is the second phase of restructuring of the coal industry? Coal (Moscow: Editorial Board of “Coal”) vol 6 pp 65-68
[2] Plakitkina L S 2013 Analysis and prospects of development of coal industry of the main countries of the world, CIS and Russia in the period up to 2030 (Moscow: Mining industry) p 416
[3] Gorkina T I 2017 The place and importance of the coal industry in the world energy Geography of world development (Moscow: Partnership of scientific publications) vol 2 pp 343-356
[4] Vosta M 2009 Global changes and new trends within the territorial structure of the oil, gas and coal industries Acta Oeconomica Pragensia (Prague: University of Economics). vol 17(1) pp 45-59
[5] Ivanov A S and Matveev I E 2015 World energy market: today and yesterday Russian foreign economic Bulletin (Moscow: All-Russian Academy of foreign trade of the Ministry of economic development of the Russian Federation) vol 4 pp 3-23
[6] Horbach J, Chen Q, Rennings K and Vögele S 2014 Do lead markets for clean coal technology follow market demand? A case study for China, Germany, and the US Environmental Innovation and Societal Transitions (Elsevier) Ed K Rennings vol 10 pp 42-58
[7] Liu B and Geman H 2017 World coal markets: Still weakly integrated and moving east Journal of Commodity Markets (Elsevier) Ed F Aasche, A Ogland and S Westgaard vol 5 pp 63-76
[8] Cronshaw I 2017 The Global Coal Market: Supplying the Major Fuel for Emerging Economies. Pacific Affairs (Pacific Affairs, a division of the University of British Columbia) Ed M C Thurber and R K Morse vol 90(1) pp 105-107
[9] Aydin G 2015 The Application of trend analysis for coal demand modeling Energy Sources, Part B: Economics, Planning, and Policy (Taylor & Francis Online) vol 10(2) pp 183-191
[10] Yanovski A B 2017 Key trends and development prospects of the Russian coal industry Coal (Moscow: Editorial office of the magazine “Coal”) vol 8 pp 10-14
[11] Sokolov A D and Takaishvili L N 2016 Trends of development of coal industry of the Eastern regions of Russia as a component of fuel and energy complex on a per-perspective The Bulletin of Irkutsk state technical University (Irkutsk: IRkutskiy national research technical University) vol 20 (11) pp 157-169
[12] Wu Y, Xiao X and Song Z 2017 Competitiveness analysis of coal industry in China: A diamond model study Resources Policy (Elsevier) Ed G A Campbell and D A Fleming-Munoz vol 52 pp 39-53
[13] Li J and Hu S 2017 History and future of the coal and coal chemical industry in China Resources, Conservation and Recycling (Elsevier) Ed M Xu vol 124 pp 13-24
[14] Bespalov V I and Lysova E P 2015 The analysis of ecological features of burning of organic types of fuel by the power supplying enterprises of municipal economy Collection of scientific papers SWorld (Ivanovo: Nauchny mir) vol 2 issue 1(38) pp 19-2458+24-
[15] Kotler V R and Belikov S E 2001 Industrial heating plants: combustion of fuels and protection of the atmosphere (St Petersburg: Energotech) p 272
[16] Paliwal S, Chandra H and Tripathi A 2013 Investigation and analysis of air pollution emitted from thermal power plants: a critical review IJMET (IAEME Publication) vol 4 issue 4 pp 2-37
[17] Bespalov V I, Samarskaya N S, Paramonova O N and Lysova E P 2014 Analysis of traditionally
used methods in the treatment of emissions enterprises fuel and energy complex *Scientific Review* (Moscow: Science of education) vol 9 issue 3 pp 921-924

[18] Lysova E, Paramonova O and Gurova O 2017 Simulation of the process and system of power plants exhaust gases purification during construction and re-construction of housing and utilities infrastructure of urban areas *MATEC Web of Conferences* (EDP Sciences) vol 129 p 05016

[19] Bespalov V I 1995 Physical-energy concept process descriptions and a systematic approach to the selection of highly effective and cost-efficient engineering systems of protection of air environment from emission of pollutants *News of the North Caucasian Scientific Center of Higher School. Natural Sciences* (Rostov-on-Don: Rostov state University) vol 9 pp 37-47

[20] Bespalov V I, Gurova O N, Paramonova O N and Lysova E P 2015 Development and Choice of an Evidence-based Technique of the Most Ecologically Effective and Energetically Economic Technologies of Cleaning of Toxic Components of the Departing and Exhaust Gases of Objects of an Urban Environment Assessment *BBRA* vol 12(2) pp 1459-1470

[21] Bespalov V I, Lysova E P, Paramonova O N et al 2014 Impact analysis and the development of a physical model of the process of air pollution for the enterprises of thermal power complex *Collection of scientific papers SWorld* (Odessa: KUPIENKO SV) vol 3 issue 1 pp 3-10

[22] Lysova E, Paramonova O, Samarskaya N, Gyrova O and Tsarevskaya I 2018 Application of physical and energetic approach to estimation and selection of atmospheric protection systems for energetic devices. *MATEC Web of Conferences* (EDP Sciences) vol 170 p 04013