Technical possibilities of ash and sulphur oxides emission reduction at Russian coal-fired thermal power plants

To cite this article: P V Roslyakov and O E Kondratieva 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1061** 012035

Technical possibilities of ash and sulphur oxides emission reduction at Russian coal-fired thermal power plants

P V Roslyakov[1], O E Kondratieva[2]

[1]Department of Modeling and Design of Power Units, National Research University "MPEI", 14, Krasnokasarmennaya str., Moscow 111250, Russia
[2]Department of Engineering Ecology and Labor Protection, National Research University "MPEI", 14, Krasnokasarmennaya str., Moscow 111250, Russia

E-mail: RoslyakovPV@mpei.ru

Abstract. The issues of the introduction of the best available technologies (BAT) at Russian coal-fired thermal power plants in accordance with the recommendations of the current information and technical handbook ITS 38-2017 are considered. It is shown that the technological indicators of ITS 38-2017 on emissions of solid fuel ash and sulphur dioxide do not solve the problem of reducing the negative impact on the environment. The analysis of the properties of burnt coals and available technologies for sulphur dioxides and ash cleaning of flue gases was carried out in order to determine new technological indicators for emissions of solid fuel ash and sulphur dioxide and the best available technologies for updating ITS 38-2017. The analysis of existing technologies for ash cleaning and desulphurization of gases was carried out and recommendations were given for areas of their effective application to meet different quantitative levels of technological indicators of emissions. New technological emission indicators for updating ITS 38 are proposed and justified. Recommendations are given to expand the list of the best available technologies recommended for implementation at Russian thermal power plants.

1. Introduction

The transition in the Russian Federation to the best available technologies (BAT) and technological rationing of negative environmental impact were considered primarily as measures of industrial and environmental policy aimed at abandoning the use of outdated and inefficient technologies, increasing the environmental and resource efficiency of key sectors of the economy [1,2].

Thermal power plants (TIPs), along with other industrial productions, were included in the number of 39 fields of application of BAT by the order of the Government of the Russian Federation [3]. The Order of the Ministry of Natural Resources [4] defines a list of 300 enterprises that have the largest negative impact on the environment. Initially, this list included 44 thermal power plants, 36 of them coal-fired thermal power plants.

Solid fuel ash, sulphur dioxide SO_2, nitrogen oxides NO_X and carbon monoxide CO have been identified as marker pollutants, whose emissions according to the Legislation [2,5] are subject to control and accounting during the combustion of solid fuels. The main problem for coal-fired thermal power plants is emissions of ash and sulphur dioxide with flue gases. Technological emission indicators (TI) or specific emission standards into the atmosphere with flue gases of thermal power

plants have been established for these marker pollutants in various regulatory documents [6,7] depending on thermal power boilers and their commissioning dates (see Table 1).

Table 1. Technological indicators of emissions of pollutants during coal combustion (mg/m^3) [6-8].

Thermal power of installation, MV	Solid particles			SO_2		
	Directive 2010/75/EU	GOST 50831-95	ITS 38-2017	Directive 2010/75/EU	GOST 50831-95	ITS 38-2017
50-100	20	150-250	250-1200	400	1200-1400	1400-4000
100-199						
200-249				200-250	950-1050	
250-300					700	
> 300	10	50-150	200-1200	150-200	700	1200-4000

2. Tasks of research

It should be noted that the contents of solid fuel ash and sulphur dioxide SO_2 in fuel combustion products do not depend on the combustion conditions and are completely determined by the composition of the fuel itself - the content of ash and Sulphur per mass of fuel.

Therefore, the concentrations of ash (solid particles) and SO_2 in flue gases are calculated in terms of standard conditions (0 °C, 101.3 kPa, O_2 = 6%) [9]. The concentrations of these compounds for coals burned at Russian thermal power plants vary in fairly wide ranges: from 12720 to 81390 mg/m^3 for ash and from 620 to 7260 mg/m^3 for SO_2 (see Table 2).

The analysis of Tables 1 and 2 shows that the technological indicators of ash and sulphur dioxide emissions in ITS 38-2017 are set without taking into account the ash content and sulphur content of coals. Moreover, the TI for SO_2 emissions are set almost at the level of the calculated (actual generated) amounts for the most sulphurous coals, i.e. with a large margin. Higher values of SO_2 content than established in ITS 38-2017 [6] occur only when burning a very a very few coals with a parent sulphur content over 2%, such as Donetzkiy and Intinskiy coals.

In this regard, the determination of realistically achievable TI for emissions of solid fuel ash and sulphur dioxide and the best available technologies (BAT), that provide these TI, are very relevant and important for the real reduction of the negative impact of thermal power plants on the environment, primarily for the "dirtiest" coal-fired thermal power plants. As part of this work, a detailed analysis of the properties of the burned coals and the available serial technologies of sulphur and ash purification of flue gases was performed. At the same time, it was meant that the main objectives of the introduction of BAT at Russian enterprises are the modernization of production and increasing its efficiency [10].

3. Ash emission

To evaluate solid fuels from the point of view of atmospheric air pollution with fly ash and sulphur dioxide, the content of ash and sulphur in them are used, as well as the given contents of these components $A^{pr} = A^r/Qr^i$ and $S^{pr} = S^r/Qr^i$ (% · kg) /MJ, taking into account the influence of the lower heat of combustion of fuel Qr^i, MJ/kg.

During burning coal, the mineral part mainly passes into the fly ash contained in the flue gases. The remaining insignificant part is removed from the boiler furnace in the form of slag and is not released

into the atmosphere. According to the ash content in fuel (A^r, %), coals can be divided into low-ash (A^r <10%,), medium-ash ($10 \le A^r \le 20\%$) and high-ash ($A^r > 20\%$).

Table 2. Calculated concentrations of solid particles and sulphur dioxide formed during coal combustion at Russian thermal power plants.

Brand of coal	Ash content A^r, %	Estimated solid particles content, mg/m^3	Sulphur content S^r, %	Estimated SO_2 content, mg/m^3
Maikubinskiy	24,6	43640	0,5	1580
Pereyaslavskiy	10	18450	0,4	1350
Kharanorskiy	13,2	29150	0,3	1210
Irsha-Borodinskiy	7,4	12720	0,2	620
Nazarovskiy	7,9	15640	0,4	1290
Berezovskiy	4,7	7990	0,2	340
Bikinskiy	23,0	70800	0,3	1680
Artemovskiy	33,1	81390	0,3	1340
Erkovetzkiy	12,4	26970	0,3	1190
Kuznetzkiy	16,9	20110	0,4	910
Ekibastutzkiy	36,9	58020	0,7	2190
Intinskiy	28,8	46070	2,5	7260
Vorkutinskiy	29,4	41500	1,0	2550
Neryunginskiy	25,8	31870	0,3	680
Donetzkiy	34,8	59680	1,5	3950

Russia and the European Union (EU) currently have significantly different standards (technological indicators) for emissions of marker substances for thermal power plants [5,7,9]. The required reduction efficiency of solid fuel ash emissions to meet these standards are: 89 - 98% for ITS 38-2017, 98 - 99.5% for GOST R 50831-95 and more than 99.8% for the EU Directive. The fulfillment of the requirements of ITS 38-2017 is fully ensured by the installed old equipment - battery cyclones and wet scrubbers. This practically does not require modernization or replacement of existing ash collectors with more efficient ones and, of course, does not reduce the environmental impact from coal-fired thermal power plants. On the contrary, the requirements of GOST R 50831-95 [7] imply the use of more efficient equipment with an ash collection efficiency of at least 99%, and hence the introduction of modern equipment.

To assess the various achievable levels of ash emissions into the atmosphere at coal-fired thermal power plants, this paper considers the use of already mastered ash collection technologies (Table. 3), including those included in the list of recommended BAT in ITS 38-2017 [6].

The analysis of Table 3 shows that battery cyclones with a ash capture efficiency of no more than 92% can be used only when burning low-ash coals in the case of establishing a TI for ash emissions of no more than 700 mg/m^3. But they cannot be recommended for use with tougher TI.

Wet scrubbers with ash capture efficiency up to 97% also have limited use and can be used for burning low- and medium-ash coals. However, in general, they cannot provide ash emissions of less than 500 mg/m^3.

Various emulsifiers have a higher ash collection efficiency up to 98%. Their use in principle makes it possible to ensure a TI of ash emissions of less than 500 mg/m^3. Nevertheless, their use is impractical for the highest ash coals.

Table 3. Solid particle content in flue gases when using different ash collection technologies.

Brand of coal	Estimated solid particles content, mg/m^3	Ash content after ash collector, mg/m^3				
		Ash collection technologies (cleaning efficiency, %)				
		BC (92%)	WS (97%)	Em (98%)	EP (99,5%)	BF (99,8%)
Berezovskiy	7990	640	240	160	40	up 20 to 40
Irsha-Borodinskiy	12720	1020	380	255	65	
Nazarovskiy	15640	1250	470	315	80	
Pereyaslavskiy	22140	1770	665	445	115	
Erkovetzkiy	26970	2160	810	540	135	
Kharanorskiy	29150	2330	875	585	150	
Maikubinskiy	43640	3490	1310	875	220	
Bikinskiy	70800	5660	2125	1420	355	
Artemovskiy	81390	6510	2440	1630	410	
Kuznetzkiy	20110	1610	600	405	100	
Neryunginskiy	23990	1920	720	480	120	
Vorkutinskiy	41500	3320	1245	830	210	
Intinskiy	46070	3680	1385	920	230	
Ekibastutzkiy	58020	4640	1740	1160	290	
Donetzkiy	59680	4770	1790	1195	300	

Designations: BC - battery cyclone; WS - wet scrubber; Em - Emulsifier, EP – electrostatic precipitator; BF - bag filter

The most effective ash collectors are electrostatic precipitators (EP), bag filters (BF) and combined (two-stage) filters. The experience of their using at thermal power plants, including Russian ones, has shown a positive result.

Table 4 provides an analysis of the use of serial ash collection technologies and provides recommendations for their use to ensure different quantitative levels of TI. The conducted studies allow to reasonably propose the following recommendations for the establishment of new TI for ash emissions into the atmosphere.

The values of the TI for the ash emissions can be accepted for all boilers introduced before 31.12.2000: for low-ash coals - 500 mg/m^3; for medium-ash coals - 700 mg/m^3; for high-ash coals - 900 mg/m^3. At the same time, the estimated calculations showed that the difference in the costs of upgrading the ash collectors of boilers commissioned before 31.12.2000 to ensure the TI of ash emissions at the level of 500 and 900 mg/m^3 is not too large.

The following values of the TI for the ash emissions are accepted for all boilers commissioned since 1.01.2001 can be accepted: for low-ash coals - 150 mg/m^3; for medium-ash coals - 200 mg/m^3; for high-ash coals - 250 mg/m^3.

Due to the low efficiency of ash collection of battery cyclones that do not meet modern requirements for ash emissions into the atmosphere, they should be excluded from the list of recommended BAT. Wet scrubbers and emulsifiers can be recommended for limited use when burning low- and medium-ash coals (in accordance with the instructions in Table 4). The most effective BAT ash collection are electrostatic precipitator, as well as bag filters and combined filters already implemented at Russian thermal power plants.

4. Sulphurdioxide emission

The classification of Russian coals by the sulphur content in their composition are shown in Table 2. All coals were divided into low-sulphur with an estimated sulphur dioxide content in flue gases of no more than 1400 mg/m^3 and high-sulphur with a SO_2 content in flue gases of more than 1400 mg/m^3.

Table 4. Areas of application of various BAT ash removal to ensure different TI of ash emissions.

Type of ash collector (ash removal efficiency, %)	Technological indicator of solid particles emission, mg/m3		
	1200 (ITS 38-2017)	700	250 (GOST 50831-95)
Battery cyclone (92%)	Limited, only for low-ash coals	Very limited, only for low-ash coals	Cannot be recommended as a BAT
Wet scrubber (97%)	For low- and medium-ash coals	Limited, for low- and medium-ash coals	Very limited, for low-ash coals only
Emulsifier (98%)	For all coals	Limited for high-ash coals	For low-ash coals only
Electrostatic precipitator (99,5%)	For all coals without restrictions	For all coals without restrictions	For all coals
Bag filter (99,8%)	For all coals without restrictions	For all coals without restrictions	For all coals without restrictions
Combined filters (99,9%)	There is no need to apply to achieve the specified TI		For high-ash coals without restrictions

Comparison of the data given in Table 2 with the TI on emissions of sulphur dioxide in ITS 38-2017 (Table 1) indicates that for old boilers commissioned on 31.12.2000, flue gas desulphurization is not required in principle.Since the numerical values of the TI correspond to the actual emissions of sulphur dioxide on these boilers. More stringent SO_2 emission standards (at the level of 1200 – 1400 mg/m^3) apply only to new boilers commissioned on 1.01.2001. But even these TI do not exceed the actual emissions of sulphur dioxide when burning low-sulphur coals.

However, in order to meet the requirements of GOST 50831-95 for SO_2 emissions during the combustion of a number of coals, flue gas desulphurization with an efficiency of 10 to 40% will already be required. In turn, the implementation of the TA of the EU Directive when burning Russian coals will require gas desulphurization in the range from 40 to 95%. It requires the introduction of more efficient and, accordingly, more expensive gas desulphurization technologies.

Table 5 shows the sulphur dioxide concentrations during the combustion of various Russian coals both without desulphurization of gases, and in the case of the use of various known desulphurization technologies. It is obvious that when burning all low-sulphur coals the level of SO_2 emissions, even without desulphurization of exhaust gases, will be below 1400 mg/m^3. And for a number of low-sulphur coals SO_2 content in flue gases, even without their desulphurization, does not exceed 700 mg/m^3, established in GOST R 50831-95 as the emission limit.

During high-sulphur coals burning actual SO_2 emissions will be slightly higher. But even for these coals, they usually do not exceed 3000 mg/m^3. The only exceptions are a few of the most high-sulphur coals (such as Donetzkiy, Intinskiy, Podmoskovniy, Kizelovskiy coals and several others with limited use), the SO_2 content in the combustion products of which is even higher (exceed 3000 mg/m^3).

It is necessary to choose more efficient technologies for desulphurization of gases with a desulphurization efficiency of at least 60% during using these coals at thermal power plants. For the rest of the coals, depending on the approved TI, desulphurization is not required or, if necessary, the simplest technologies can be used with an efficiency of up to 40%.

Recommended applications of known gas desulphurization technologies and restrictions on their use are presented in Table 6. The simplest and relatively inexpensive desulphurization technologies

can become the most widespread, taking into account the Russian specifics. There is currently no technical need for the introduction of wet desulphurization installations at Russian coal-fired thermal power plants with sulphur dioxide emissions predicted in the near future.

Table 5. SO_2 content in flue gases when using different desulphurization technologies.

Brand of coal	SO2 content after desulphurization, mg/m3 Desulphurization technologies (cleaning efficiency, %)				
	Semi - dry simplified E-SOx (40%)	Semi-dry with an absorber (60%)	Semi-dry NID (80%)	Wet scrubber with alkaline cycle (70%)	Wet desulphuri-zation (90%)
Berezovskiy	205	140	70	105	35
Irsha-Borodinskiy	375	250	125	190	65
Erkovetzkiy	715	480	240	360	120
Kharanorskiy	730	485	245	365	120
Nazarovskiy	775	520	260	390	130
Artemovskiy	805	535	270	405	135
Pereyaslavskiy	810	540	270	405	135
Maikubinskiy	950	630	320	475	160
Bikinskiy	1010	675	340	505	170
Neryunginskiy	265	180	90	135	45
Kuznetzkiy	540	360	180	270	90
Ekibastutzkiy	1315	880	440	660	220
Vorkutinskiy	1530	1020	510	765	255
Intinskiy	4360	2900	1450	2180	730
Donetzkiy	2370	1580	790	1185	395

As a result of the conducted research, the following recommendations were developed for the establishment of new TI for emissions of sulphur dioxide into the atmosphere. The TI for SO_2 emissions are set depending on the sulphur content of the fuel (see Table. 6) in the ranges: low-sulphur with $S^{pr} \leq 0.0315$ (% · kg)/MJ; high-sulphur with $S^{pr} > 0.0315$ (% · kg)/MJ.

Separation of SO_2 emissions technological indicators (TI) by thermal power, as well as by commissioning dates for boiler plants not equipped with flue gas desulphurization is not required.

The quantitative values of the TI for emissions of sulphur dioxide SO_2 for all boiler plants introduced before 31.12.2000 and not equipped with gas desulphurization can be taken, regardless of the thermal capacity, as follows: for low-sulphur coals - 1400 mg/m^3; for high-sulphur coals - 3000 mg/m^3. In this case, the TI for sulphur dioxide emissions will not be carried out only when burning the most high-sulphur coals, having limited use.

TI values for SO_2 emissions can be accepted for boiler plants equipped with desulphurization, regardless of thermal power boiler installations, as well as the timing of their commissioning: for low-sulphur coals - 700 mg/m^3; for high-sulphur coals - 1400 mg/m^3.

5. Conclusion

The tightening of technological emission indicators and the introduction of more efficient bats for this will undoubtedly require large financial costs. In order to determine new values of technological indicators emission from the point of view of economic feasibility and financial capabilities of energy companies, it is necessary to conduct additional research with a preliminary survey of thermal power plants.

Table 6. Areas of application of various desulphurization technologies to ensure different SO_2 emission standards.

Desulphurization technology (removal efficiency, %)	Technological indicator of SO2 emission, mg/m3		
	3000 (ITS 38-2017)	1400	700 (GOST 50831-95)
Semi - dry simplified E-SOx (40%)	For coals with sulphur content less than 0.05 (%·kg)/MJ	For coals with sulphur content less than 0,045 (%·kg)/MJ	Limited, for low-sulphur coals with reduced sulphur content less than 0.025 (%·kg)/MJ only
Semi-dry with an absorber (60%)	For all coals	For coals with sulphur content less than 0,05 (%·kg)/MJ	For coals with sulphur content less than 0,039 (%·kg)/MJ
Semi-dry NID (80%)	For all coals	For coals with sulphur content less than 0,058 (%·kg)/MJ	For coals with sulphur content less than 0,058 (%·kg)/MJ
Wet scrubber with alkaline cycle (70%)	For all coals	For coals with sulphur content less than 0,058 (%·kg)/MJ	For coals with sulphur content less than 0,045 (%·kg)/MJ
Wet desulphurization (90%)	For all coals	For all coals	For all coals

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