EU countries experience analysis in using various fume gas treatment systems from acid gases removing for WTE Plants

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Abstract. The existing method of selecting the structure of a Waste to energy plant (WTE plant) for thermal utilization of MSW in the Russian Federation is often not applicable to real objects, which leads to the need for each project to search for new methods, select the criteria for choosing the best technology. Conducting a comparative analysis of various structural schemes WTE plant, common in the EU and Japan, will help to identify their main advantages and disadvantages, determine the scope of application.

This article describes the statistical indicators of the fume gas treatment system (FGT) from acid gases, which can be applied at the stage of feasibility study, development of basic engineering. When building a WTE plant in urban conditions and striving to minimize the gross emissions of acid gases into the atmosphere, a wet FGT cleaning system can be recommended, which will provide low emissions of HF, HCl, and SOx. The system with a wet reactor will reduce the gross emissions of harmful substances during the construction of WTE plant with high-capacity, and in this case it is justified.

When building WTE plant with medium-capacity (up to 350 thousand tons of MSW per year), it may be recommended to use a semi-dry and dry FGT, while the highest preference should be given to the technology with a semi-dry reactor as the most promising.

Keywords. Thermal power plant on municipal solid waste (WTE plant), thermal treatment of municipal waste; engineering in thermal energy field.

1. Introduction

The use of municipal solid waste (MSW) as a resource for obtaining secondary raw materials and energy has long been an attractive option for commercial structures and local authorities in many countries (unfortunately, except Russia). Thermal neutralization helps to reduce the disposal of unsorted MSW in landfills, allows to process waste that cannot be effectively used for obtaining secondary raw materials or recovery by biological treatment.

The method of selecting the structure of Waste to energy plant (WTE plant), given in [1], is often not applicable to real objects, which leads to the need for each project to search for new methods, select the criteria for choosing the best technology.

Creating a methodology and defining criteria for evaluating various technologies for thermal processing of MSW, comparing elements that are part of the technological scheme is an urgent task in
the context of the development of the industry. As noted earlier, Russia currently has only a few large WTE plant, which means that it is impossible to analyze the impact of elements of the structure of WTE plant only on the basis of domestic experience in operating such installations. Conducting a comparative analysis of various structural schemes of WTE plant, common in the EU and Japan, will help to identify their main advantages and disadvantages, determine the scope of application. The purpose of the work carried out by the authors is to develop a General methodology for selecting the structure of a WTE plant and substantiate the choice of each of its elements separately, which meets the requirements of legislation and the conditions of the customer. This article describes the statistical indicators of the flue gas treatment system (FGT) from acid gases, which can be applied at the stage of feasibility study, development of basic engineering.

2. The main elements of FGT treatment system for WTE plant
Depending on the structure of the WTE plant, the flue gas treatment process may include various methods of primary and secondary removal of harmful substances, each of which performs the function of removing a specific substance or group of pollutants. In General, a list of the main pollutants in FG and treatment technologies is given in table 1.

| №  | Name of the substance | Technology of gas treatment                                      |
|----|-----------------------|-----------------------------------------------------------------|
| 1  | Solid particles       | Bag filters, electric filters, cyclones                         |
| 2  | Nitrogen oxides (NOx) | Primary reduction methods, SNCR and SCR                         |
| 3  | Acid gases (SOx, HCl, HF) | Wet (WS), semi-dry (Semi WS) or dry (DSI) systems               |
| 4  | Heavy metals          | Primary methods, direct injection of activated carbon, the removal of solid particles |
| 5  | Dioxins and furans    | Primary reduction methods, activated carbon injection, SCR, particulate removal |

3. Method for determining the best fume gas treatment system
The authors propose a method for selecting a flue gas treatment system technology based on an assessment of statistical data on reducing the concentration of harmful substances at existing enterprises. The authors analyzed the results of an experiment to collect statistical data on WTE plant, conducted in the EU in 2016. The experiment involved 204 enterprises for thermal neutralization of MSW of different productivity, built in different years and having different gas treatment schemes [2]. Emission control was performed for continuously monitored indicators with a half-hour time resolution throughout the year. For each controlled parameter, a series of 17,520 hourly mean values of pollutant concentrations was collected. Based on the data on emissions, the maximum average daily concentrations of pollutants in FG, the average annual concentrations, and the average reagent costs per ton of waste disposed of were determined.

The authors analyzed the results to determine the following performance indicators for each technology:
• Average annual emissions (distribution of installations by average annual emissions);
• Maximum daily and average daily emission values for facilities;
• Influence of gas cleaning system on reagent consumption;
• Prevalence of the technology.

The conclusions obtained in this paper can be used to determine the optimal structure of the FGT of WTE plant, in order to achieve a minimum negative impact on the environment.

4. Fume gas treatment from acid gases

4.1 Description of technologies for removing acid gases
As mentioned earlier, 3 different technologies are used to remove acidic gases:
• Dry gas cleaning (DSI);
• Semi-dry cleaning system (Semi WS);
• Wet gas cleaning (WS).

During dry cleaning of flue gases, gaseous acidic components (HF, HCl) are adsorbed by an alkaline chemical (sodium carbonate, lime, etc.), heavy metals, PCDD/f are removed using activated carbon injected into the system. For mixing, a dry reactor is used, which ensures a uniform distribution of the adsorbent in the flue gas flow and a sufficient reaction time. Due to the presence of reagents in dry form, the efficiency of the adsorbent reaction is quite low. To increase efficiency, adsorbent recirculation is used, the adsorbent consumption generally exceeds the stoichiometric ratio with a coefficient of about 2 [2], which leads to a large consumption of the reagent and, as a result, a large ash consumption on bag filters (BF). The system is characterized by the complexity of regulating the flow of reagent to maintain the set values of concentrations of pollutants.

The basic principle of the FGT technology by semi-dry method does not differ from the dry FGT technology, the main difference is that the reagent is dissolved in water to produce a liquid solution. The solution is sprayed in the flue gas stream at a temperature of 200-240°C, using nozzles in a semi-dry reactor. Spraying of the reagent leads to an increase in the contact area of the adsorbent with chemicals in the composition of the FG, when the water evaporates, the flue gases are cooled to a temperature of 130-180 °C. In the process of semi-dry cleaning, the bag filter ash containing a large amount of reagent is recirculated, the stoichiometric ratio is usually about 1.5 [2], and the formation of ash on BF is reduced. The efficiency of the system for removing harmful substances from flue gases is higher in comparison with dry.

There is a wide variety of elements and designs for wet flue gas cleaning systems. The main principle is intensive contact between flue gases and water. The flue gases come into contact with drops of the reagent solution, the polluting components are absorbed and removed with an aqueous solution. Typically, a two-stage FG treatment is used, in which the first stage flue gases pass through a scrubber, in which water is sprayed to remove HCl and HF, and in the second stage water with alkaline additives is sprayed to neutralize SOx. During operation of this system, lime does not enter the BF with ash, the volume of ash is reduced. The wet gas cleaning system is characterized by the highest efficiency and at the same time the greatest CAPEX. In a wet gas treatment system, waste water is formed that requires neutralization and additional treatment (high OPEX).

4.2 Gas concentration for different technologies

This Chapter presents the results of the analysis of the average annual and maximum daily concentrations of HCl, HF, SOx in the FG of the studied objects, and shows the maximum and minimum daily values of concentrations of pollutants.

In accordance with regulatory documents, the following indicators are normalized on the territory of the Russian Federation, reflecting acid gas emissions MAC, shown in table 2.

| Table 2. Maximum allowable concentration (MAC) of acid gas emissions |
|---------------------------------------------------------------|
| Technological indicator     | Unit of measurement | Concentration, mg/m3 |
| Sulfur dioxide (SOx)        | mg/m3               | 50                   |
| Hydrogen chloride (HCl)     | mg/m3               | 10                   |
| Hydrogen fluoride (HF)      | mg/m3               | 1                    |

Impact of the gas treatment system on HCl emissions

Analysis of data on average daily and average annual concentrations of HCl showed that the concentration of HCl in the flue gases of WTE plant depends on the gas treatment system used (see Fig. 1).

HCl concentrations in the FG of installations equipped with dry and semi-dry gas cleaning systems are comparable to installations equipped with a wet gas cleaning system. The average annual concentration of HCl in FG after installations equipped with a semi-dry gas cleaning system is 13.3%
higher than for installations equipped with a dry gas cleaning system, the average maximum concentration is higher at and by 17.5%.

The maximum recorded concentrations of HCl in the FG of installations equipped with DSI and SemiWS differ slightly (2.6%) and are 19 mg/m³ and 18.5 mg/m³, respectively. The average value of maximum daily concentrations for installations with SemiWS is 1.13 MAC. The average value of maximum daily concentrations for installations with DSI is 0.96 MAC.

Analysis of statistical data shows that the lowest concentrations of HCl are achieved when using the wet gas cleaning system WS. The average maximum daily value of HCl concentration in FG is 5.0 mg/m³, the average average annual value of HCl concentration in FG is 1.8 mg/m³. The average maximum concentrations of HCL in FG when using WS are 93.1% less than for DSI and 127% less than for SemiWS. The maximum recorded concentrations of HCl in FG after installations equipped with WS are 16 mg/m³ which is 18.8% less than for DSI and 15.6% less than for SemiWS. The average maximum daily concentration of HCl in FG after installations with WS is 0.5 MAC.

Figure 2 shows a graph of the distribution of installations with different gas treatment systems by the maximum daily concentration of HCl in FG.

According to the results of the analysis, 33.7% of installations equipped with WS have peak concentrations for the pollutant less than 2 mg/m³, while 20.2% of installations have peak concentrations exceeding the MAC.

For 44.6% equipped with DSI, peak concentrations exceed the MAC. For 60.9% of SemiWS installations, peak concentrations exceed the MAC.

Figure 3 shows the distribution of installations with different gas treatment systems by average annual HCl emissions. According to the data analysis, 63.3% of installations with WS have average annual HCl concentrations of less than 2 mg/m³, while 100% of installations have average annual emissions of less than 8 mg/m³.
Among the studied objects with DSI, the concentration of HCl is 7.7% higher than the MAC on average for the year. Among the studied objects with SemiWS, the concentration of HCl in the average year is higher than the MAC by 4.3%.

The study [2] shows that thermal power plants at MSW equipped with a wet scrubber usually achieve lower concentrations (on average for the year below 2 mg/Nm3, the average daily maximum is 5 mg/Nm3) than facilities equipped with dry or semi-dry FG cleaning systems.

**Impact of the gas treatment system on HF emissions**

Analysis of data on average daily and average annual concentrations of HF showed that the concentration of HF in the flue gases of WTE plant depends on the gas treatment system used (see Fig. 4).

The highest levels of HF emissions are observed for installations equipped with a dry DS reactor. The average maximum concentration of HF for DSI is 0.49 mg / m3 which is 32.4% higher than for installations equipped with SemiWS and 113.6% higher than with installations with WS.

The maximum recorded daily concentrations of HF are 4.0 mg / m3, and the maximum average annual concentration is 3.0 mg / m3.

The average value of maximum daily concentrations for installations with DSI is 0.48 MAC.

Gas purification rates for SemiWS-equipped plants are slightly better than for DSI-equipped plants, with an average maximum daily concentration of HF of 0.37 mg / m3. The maximum recorded daily concentration of HF is 1.5 mg / m3, which is 61.3% higher than for installations with WS. The average value of maximum daily concentrations for installations with DSI is 0.36 MAC.

The best indicators of DH purification from HF are obtained when using systems with WS. According to statistics, the average maximum daily concentration of HF is 0.23 mg / m3, which is 61.3% less than for installations with SemiWS and 113.6% less than for installations with DSI. The maximum recorded daily concentration for systems equipped with WS is 1.0 mg / m3, the maximum average annual concentration is 0.4 mg / m3 which is 75% less than for systems with SemiWS and 650% less than for systems with DSI. The average value of maximum daily concentrations for installations with DSI is 0.22 MAC.

Figure 5 shows a graph of the distribution of installations with different gas treatment systems by the maximum daily concentration of HF in FG. According to the results of the analysis, 58.5% of installations equipped with...
WS have peak daily concentrations of HF less than 0.2 mg/m³, while 0% of installations have peak concentrations exceeding the MAC. Among installations equipped with DSI, 5.6% have maximum daily concentrations exceeding the MAC. Among installations equipped with SemiWS, 7.9% have maximum daily concentrations exceeding the MAC.

Figure 6 shows the distribution of installations with different gas treatment systems by average annual HF emissions. According to the results of the data analysis, 74.2% of installations with WS have average annual concentrations of HF less than 0.2 mg/m³, while 100% of installations have average annual emissions of less than 0.6 mg/m³. Among the studied objects with DSI, the concentration of HF is 3.6% higher than the MAC on average for the year. Average annual HF emissions for installations with Semi WS are less than 0.8 mg/m³ in 100% of cases, which is slightly worse than for installations with WS.

The study [2] shows that thermal power plants on MSW equipped with a wet gas treatment system usually achieve lower emission levels (on average, less than 0.16 mg/Nm³ per year, the average daily maximum is 0.23 mg/Nm³) than facilities equipped with a dry or semi-dry GAS treatment system. At the same time, both installations with Semi WS and installations with DSI remove HF from the FG stream to a sufficient extent, the concentrations of HF at 90% of WTE plant do not exceed the MAC even in the form of peak daily values.

**Impact of the gas treatment system on SOx emissions**

Analysis of data on average daily and average annual concentrations of SOx showed that the concentration of SOx in the flue gases of WTE plant is unambiguously dependent on the gas treatment system used (see Fig. 7) for average annual and maximum concentrations.

The highest concentrations of SOx are observed in installations equipped with a semi-dry gas cleaning system. Average maximum daily concentrations are 33.2 mg/m³, which is 23.4% higher than for installations equipped with WS and 40.2% higher than for installations with DSI. The maximum recorded daily concentrations of SOx are 90.0 mg/m³ and the maximum average annual concentration is 40.0 mg/m³. The average value of maximum daily concentrations for installations with SemiWS is 0.66 MAC.

SOx concentrations after installations equipped with DSI are slightly lower than for SemiWS, the average maximum daily
concentration is 23.7 mg/m³. The maximum daily concentration is 90 mg/m³, which is comparable to statistical data for all types of gas treatment systems. The average value of maximum daily concentrations for installations with DSI is 0.47 MAC.

The best average annual values of SOx purification of FG are obtained when using systems with WS, according to statistical data, the average annual concentration is 7.1 mg/m³, which is 35% less than for installations with DSI and 73.6% less than for installations with SemiWS. The maximum daily concentration is 88.0 mg/m³, which is comparable to the results for all treatment systems. The average maximum concentration of SOx in FG is 26.9 mg/m³, which is 12% higher than for DSI. The average value of maximum daily concentrations for installations with WS is 0.53 MAC.

Figure 8 shows a graph of the distribution of installations with different gas treatment systems by the maximum daily concentration of SOx in FG.

According to the results of the analysis, 28.1% of installations equipped with DSI have peak concentrations for the pollutant less than 10 mg/m³, while 15.6% of installations have peak concentrations above the MAC, which is the best result according to the statistics provided.

Among installations equipped with SemiWS, the maximum daily concentration of SOx is 25.6% higher than the MAC. Among installations equipped with WS, the maximum daily concentration is 18.6% higher than the MAC.

Figure 9 shows the distribution of installations with different gas treatment systems by average annual SOx emissions.

According to the results of data analysis, 74.2% of installations with WS have average annual SOx concentrations of less than 10 mg/m³.

Among all the studied objects with various gas treatment systems, there are no objects with average annual emissions exceeding the MAC.

The study [2] shows that thermal power plants in MSW equipped with a dry gas treatment system usually achieve lower peak emission levels (on average, lower than 23.7 mg/Nm³ per year) than facilities equipped with a wet or semi-dry GAS treatment system. At the same time, the maximum emissions recorded during operation of all types of systems have almost the same indicators. The average annual concentration of SOx in flue gases for installations equipped with a wet gas cleaning system is 7.1 mg/m³, which is the best indicator among the technologies under consideration.
4.3 Influence of gas treatment system on reagent consumption

The results of statistical data analysis [2] showed that the flow rate of the alkaline reagent depends on the gas cleaning system used (see Fig. 10).

Due to the fact that different objects use different alkaline reagents used in the acid gas removal system - the amount of the reagent is recalculated to the equivalent of quicklime according to the stoichiometric ratio.

As mentioned earlier, the stoichiometric ratio has different values for different gas cleaning systems. According to the data [2]-stoichiometric ratios for various gas cleaning systems are:
- DSI-2;
- SemiWS-1.5;
- WS-1.

Analysis of statistical data confirms that the consumption of reagents for removing acid gases of a wet gas treatment system is less than for systems with a dry reactor by 8.5% and a semi-dry reactor by 52.1%.

However, according to statistical data, the reagent consumption for a dry reactor system is lower than for systems with a semi-dry reactor, which does not correspond to theoretical data and is probably due to the different chemical composition of recycled MSW, differences in technical solutions used at WTE plant.

The maximum reagent consumption for installations with DSI and SemiWS is 27.3% higher than the maximum recorded consumption for installations with WS.

4.4 The Prevalence of technology

Technological schemes of gas cleaning are constantly being upgraded, the experience of operating gas cleaning systems has allowed manufacturers to offer more cost-effective solutions on the market, the analysis of the relationship between the year of commissioning of the facility and the gas cleaning system used has allowed us to determine the trend in the frequency of use of various schemes for removing acid gases. The relationship between the year of commissioning of the WTE plant and the gas treatment system used in the study group, shown in Fig. 11 shows that the wet gas cleaning system was used in 52.7% of cases at facilities built before 2000. For facilities built after 2006, 79.1% of facilities are equipped with dry and semi-dry gas cleaning systems.

The dependence obtained by analyzing the maximum daily concentrations of HCl, HF, SOx in FG WTE plant of various years of commissioning is shown in Fig.8 showed a tendency to increase the concentration of pollutants in flue gases for newly constructed facilities, which is well correlated with data on the reduction in the number of newly
commissioned facilities with a wet gas cleaning system and data on the performance of various gas cleaning systems.

The analysis of statistical data showed that the accumulated equipment suppliers experience in various technologies acid gas removal in the EU led to the fact that for newly constructed facilities less frequently offered system wet gas cleaning is likely to reduce SARAH and WALNUT, as well as in connection with the increasing development of technology dry and semi-dry scrubbing, which show good results for cleaning of FG acidic gases that the vast majority of installations do not exceed MAC.

Fig. 12 Maximum daily acid gases in DG TPP for MSW of different years of construction

5. Conclusion
As follows from the analysis of statistical data - all gas treatment systems used at modern WTE plants have, indicators for emissions of acid gases HCl, HF, SOx within the MAC. Among all the systems considered, there are modern WTE plants, whose emissions exceed the MAC, as indicated in the report [2]. The excess is often associated with abnormal operating modes of the enterprise. During the study of the material, some conclusions are made that can be used as criteria for choosing a system for cleaning FG from acid gases:

- WS wet reactor gas treatment systems have the best HCl and HF removal rates, as well as the best SOx removal rates on average for the year;
- FG purification rates from acid gases for dry and semi-dry reactor systems are comparable (HCl and SOx removal is better in dry reactor installations, HF removal is better in semi-dry reactor installations);
- The reagent consumption for systems with a wet reactor is lower than for other systems, while the reagent used in this technology does not pass to the ash waste of the WTE plant, it is removed by the wastewater treatment system, which reduces the amount of ash generated;
- At modern WTE plants, systems of dry and semi-dry cleaning of FG from acid gases are increasingly used, which is associated with good performance, low CAPEX and OPEX.

When building a WTE plant in urban conditions and striving to minimize the gross emissions of acid gases into the atmosphere, a wet reactor system can be recommended, which will provide low emissions of HF, HCl, and SOx. The system with a wet reactor will reduce the gross emissions of harmful substances during the construction of thermal power plants with high-capacity MSW, and in this case it is justified.

When building a WTE plant with medium-capacity (up to 350 thousand tons of MSW per year), it may be recommended to use a semi-dry and dry reactor, while the highest preference should be given to the technology with a semi-dry reactor as the most promising [3].
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