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Approaches to Regulation of Odours in the Ambient Air at the Territory of the Russian Federation Based on Olfactometric Odour Measurements Relating to Industrial Emissions

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Abstract—This work presents results of odour concentration measurements performed by an olfactometric method in respect to industrial emissions, which are the source of offensive odour substances released into atmosphere. Moreover, this work also includes the measured odour concentrations at major sources of a wastewater treatment plant, as well as at heat and power plants. Related measurements were performed in the course of technological operations regarding fuel oil discharge and steam cleaning of railroad tank cars. Finally, this work introduces several approaches to further development of the odour regulation system in Russia. These approaches are based both on the foreign experience and the national sanitary regulation system regarding pollutant substances in ambient air of inhabited territories.
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Appearance of offensive odour in the air is immediately fixed by man, causing discomfort and irritation. An individual substance having its own scent, its reflexive impact on a person is taken into account when setting maximum permissible concentration (MPC) of the compound. However, in many cases the odour is not formed by a separate matter but by a complex mixture of substances, and it is often impossible to identify specific odouring compounds, most of which are unidentified and have no MPC. Moreover, even those odouring compounds being in a mixture for which the standard MPC is regulated, often present in such small quantities that air quality control doesn't show any MPC excess, despite the presence of a distinct odour.

If the odour is not formed by an individual matter, but by a mixture of odour substances of unknown composition, the developed countries do not control emissions of individual odour substances, but the odour in the whole. Measures to control odour include the most diverse activities, including population surveys, analysis from the public complaints, inspections, etc. However, the complete quantitative assessment of the odour in the air or industrial emissions is provided only by the olfactometric method and subsequent modeling of odour emissions into the atmosphere. Olfactometry is a method of measuring the odour according to its impacts on a human being, the human nose serves as a odour detector. The human sense of odour is rather acute, since the threshold of

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human odour perception in many cases is far below the sensitivity of detectors used in existing methods. Odour concentrations in the emissions obtained at olfactometric studies are used to calculate the emissions of odour, olfaction modeling in the atmosphere and establishing standards for the odour in the air.

In Russia no attention was paid to the problems of odour emissions from industrial plants up to the now. However, an increasing number of complaints from people on odour tired of living in uncomfortable conditions, forced the public authorities to take decisive action. In particular, in the near future a system of control and regulation of odours is expected to be introduced in Russia. At the same time the most advanced enterprises with sources of odourous emissions have already understood the importance of this problem and the need for quantitative research on odour emission sources belonging to the enterprise.

A device for measuring the concentration of odour by means of a human nose is called olfactometer. In olfactometer the odourous material is diluted with clean air in various proportions and, consequently, in different concentrations is served to the members of the expert group, who must choose the only answer: "Yes, it odours" or "No, no odour". Odour measurements obtained by olfactometer allow to obtain its concentration in units of odour in a cubic meter of air (OU m^{-3}), where one unit of odour (OU) is the concentration of odour that is odoured by more than 50% of experts. The obtained concentrations in the emissions are used to calculate the emissions of odour modeling the scent emissions in the atmosphere and establishing standards for the odour in the air.

This study presents the results of olfactometric analysis of odour emissions at several Russian enterprises carried out by the Research Institute of Air Protection (St. Petersburg, Russia), where the olfactometric Laboratory was organized in 2008. The research was caused by a large number of public complaints on the odour, while the environmental authorities failed to detect the excess of air quality standards in residential areas adjoined to enterprises on the substances which are included into the control standards schedule for maximum permissible emissions.

OLFACTOMETRIC STUDY OF ODOUR EMISSIONS FROM THE WASTEWATER TREATMENT PLANT

Waste water treatment plants receiving sewage disposal resulting from human activity as well as essential attributes of large industrial cities. Such enterprises usually built at some distance from the city as, being powerful sources of emissions of odourous substances, affect the population. However, the active construction of cottage settlements near the cities, as well as the expansion of the residential area of the cities themselves lead to an increasing number of people living in close proximity to such enterprises. Correspondingly that each year the number of public complaints on the odour increases. It should be said that environmental authorities are doing any actions. All the above mentioned enterprises conduct an inventory of pollutant emissions and set standards of maximum permissible emissions, which are controlled in accordance with the approved schedule. Besides, residential areas around such enterprises are usually periodically measured on odourous substances in the air, which, as a rule, do not confirm the existence of any excess of air quality standards.

The situation when unpleasant odour is felt in surroundings of an enterprise, while the concentration of controlled substances in the air is significantly below normal values, is fairly typical. It is associated primarily with the fact that the composition of odourous emissions in a given production process is usually much more complicate than is reflected in the relevant inventory and valuation documents. As it has already been mentioned, the odour causes a set of various substances, many of which may be present in trace quantity. Therefore, to solve the odour problem through the provision of such mixtures of individual substances and their valuation in most cases is extremely time-consuming and impractical process. So, in the case of a complex mixture of odourous substances with inability of identification of specific compounds the only way to assess the impact of odours on a human being is to study the odour emission. The emissions of enterprises of waste water treatment containing a mixture of macro and trace quantities of a variety of substances formed during the decomposition of biological materials present just a complex system, and the odours caused by decomposing sewage are impossible to correlate with any specific individual odourous substances.

The results of olfactometric research of odour emissions produced by a plant of household, industrial and surface waste water treatment in one of industrial cities are considered below. The plant is located at a distance of 8 km from St. Petersburg city limits. There are some summer cottages and two small villages in the vicinity of the latter. Based on organoleptic evaluation, performed during the field survey of the territory surounding the plant, six sources with the most strong odour were assigned. These sources include a receiving chamber, grills, sand trap, primary sedimentation tanks, aeration tanks and sludge thickeners. At least five sam-

Table 1. The concentration and emission strength of odorous emissions from sources of wastewater treatment plants

Emission source	Concentration, OU m^{-3}	Emission power, OU s^{-1} 10^{-3}
Screening plant frame, receiving chamber	4903	55.65
Screening plant frame, screening plant	7220	3.99
Uncovered structures, primary sedimentation tank	202	11.99
Uncovered structures, sand trap	34	1.79
Uncovered structures, aeration tank	25	8.23
Uncovered structures, sludge thickener	25	0.28

ples were taken at each of the selected sources. Average olfactometric results of sample analysis, as well as the calculated values of intensity of emission of odours are presented in Table 1.

The highest concentration of odour is observed during the initial processing of the coming wastewater. While cleaning, the odour concentration decreases. Despite the fact that the maximum concentration is found in the emissions at the filter screen, where the primary mechanical separation of the major water contaminants (a stationary source, where emissions enter the atmosphere through a ventilating pipe) takes place, the odour emission efficiency is less than that from other sources characterized by lower concentrations of odour. This is due to the fact that other sources are nonorganized and are the large areas of open water.

Calculation of the dispersion of the odour emissions of the studied enterprises in accordance with "Method of calculating the concentration of harmful substances in emissions of enterprises" [1] shows that its emissions can create very high concentrations of odour within inhabited territories (Table 2). The maximum calculated concentration of odour in the summer cottage area, directly adjacent to the plant reaches 136 OU m^{-3}, and the concentration of odour on the border of the neighboring villages can reach 40–90 OU m^{-3}. In developed countries the standard of odour in rural areas with low density of population varies from 5 to 15 OU m^{-3} [2–6]. Table 1 shows that obtained concentration of odour is in large excess over the normative values of other countries.

Calculation of odour dispersion received from different sources shows that the receiving chamber makes the main source of the air pollution (about 50%). The contribution of other sources is much lower and ranges from 5% to 12%. Accordingly, one of the important findings of this study is to identify the main source of emissions of odour, where activities to reduce emissions of odourous substances are more reasonable. Significant reduction of the odour emissions of such source will largely solve the problem of odour, even in the absence of any activities on other sources.

Table 2. Maximum calculated concentrations of odour generated in a residential area by emissions of wastewater treatment plants

No.	Location	The concentration of odour , OU m^{-3}
1	Summer cottages	136
2	Village no. 1	90
3	Village no. 2	42

Table 3. The average value of odour concentration at discharge and storage of fuel oil and steam cleaning of railroad tank cars

Process operation	Average value of odour concentration, OU m^{-3}			
Number of enterprises	no. 1	no. 2	no. 3	no. 4
Oil discharge and steam cleaning	5965	2450	48609	4964 20170[a]
Receiving tank	37954	–	46729	–
Fuel oil tank	45931	–	–	–

[a] The measurements were carried out during summer.

OLFACTOMETRIC STUDY OF ODOUR EMISSIONS DURING THE UNLOADING OF RAILROAD TANK CARS WITH FUEL OIL

At some enterprises, such as heat and power plant (HPP) and boiler-houses that use liquid fuel, the unloading of railroad tank cars with fuel oil takes places rather regularly, and is often accompanied by complaints on odour from the public. Organoleptic observations of fuel oil discharge and steam cleaning of railroad tank cars show that the causes of odour are:

* trestle approach, where railroad tank cars are discharged and steam cleaned, with the release of steam along with the odourous substances through the neck tube, as well as through the overflow launder;

* intermediate storage tanks, where the heated oil is poured to from railroad tank cars with odouring substances released along with steam;

* fuel oil tanks where oil is pumped from intermediate storage tanks. The temperature of fuel oil in tanks being 50–80°C, the tank airspace is gradually saturated by odourous substances that evaporate and emit at tank breathing.

Four Russian enterprises (HPP and three boiler-houses) are chosen for sampling and olfactometric analysis of odour emission during unloading of fuel oil.

Average results of measurements of odour concentrations in (Table 3) show that the maximum concentrations of odour emissions during fuel oil discharge reach up to 38000–47000 OU m^{-3}. The concentration of odour at steam cleaning of railroad car tanks and fuel oil discharge at three enterprises (no. 1, 2 and 4) is within the range of 2400–6000 OU m^{-3}, i.e by an order of magnitude less than during the filling. The only exception of emissions was observed at enterprise no. 3, where the concentration of odour at steam cleaning is almost ten times higher than in the rest of boiler-houses, and even slightly higher than the concentration of the odour from the receiving tank. The enterprise no. 4 was sampled twice: in winter and in summer, while in summer the odour concentration during discharge exceeds the "winter" concentration about 4 times. Increasing concentration of odourous substances in emissions during summer can be explained by effect of higher temperatures evaporation, which is more intense. However, this significant increase in the concentration of odour in summer can hardly be explained only by the high air temperature. It should be noted that the procedure of fuel oil discharge and steam cleaning at all the studied HPP is almost identical and therefore, varying concentrations of odour emissions under the same weather conditions can not be explained by differences in technology. The only difference of the studied enterprises is manufacturing plants, where fuel comes from. Production technology of fuel oil at Russian enterprises is practically the same everywhere, but the quality and composition of arriving oil may vary significantly. Therefore, the most reasonable explanation for the differences in the concentrations of odour emissions during the above mentioned procedures is different composition and content of impurities in fuel oil. Unfortunately, the current specification on arriving fuel oil makes it impossible to evaluate preliminarily its odour emissions during the unloading. In general, according to the presented results, it can be concluded that the use of high-quality oil will allow to reduce several times the emissions of odourous substances during fuel oil discharge and steam cleaning of railroad tank cars without any costly and labor-consuming activities.

According to the results of concentrations of odour emissions at the above mentioned enterprises, the power

Table 4. Calculation results of scattering odour emission of oil products at fuel oil unloading

Number of enterprises	Odour concentration in ambient air of residential area, OU m^{-3}	
	at maximal odour emission	at minimal odour emission
no. 1	4.6–6.2	2.2–5.4
no. 2	0.68	0.20
no. 3	31.4–35.5	7.0–7.8
no. 4	2.9–5.0	0.9–1.2

of odour emission (OU s^{-1}) was calculated based on simultaneous unloading of two (minimal emissions) or eight (highest emissions) of railroad tank cars. The dispersion of odour emissions within the enterprise surroundings was also calculated, in particular, on the border of the residential area [1]. The results are shown in Table. 4. Low concentrations of odour in a residential area around the enterprise no. 2 are due to a significant distance of the nearest building from the enterprise located in an industrial zone.

As for the enterprise no. 1 located near the city center, the impact of odour on the population according to the public complaints was additionally estimated. For this purpose, several isolines of calculated concentrations of odour in the air (1, 3, 5 and 10 OU m^{-3}) were studied, commonly used in developed countries as a threshold limit value. It was estimated that during the unloading of the maximum possible number of railroad tank cars the odour concentration 1 OU m^{-3} was achieved at a distance of approximately 1.2–1.5 km from the emission source, the concentration of odour 5 OU m^{-3} was achieved at a distance of 300–500 m. Comparison of concentration isolines 1 and 5 OU m^{-3} with the places where people live and note the odour of petroleum products, shows that the overwhelming majority of complaints come from the territory bounded by the isoline of the concentration of 1 OU m^{-3}, i.e. at this concentration people not only feel the odours of oil, but also begin to complain actively on the discomfort caused by such odour.

In general, according to the estimated dispersion of emissions, concentrations of petroleum odour generated in a residential area during the unloading of fuel oil is substantially lower than in the case of a wastewater treatment plant. However, it should be noted that the studied enterprises engaged in unloading fuel oil are located within a large industrial city and the concentrations given in Table 4 are formed in a heavily populated area, affecting a large number of people. Wastewater treatment plant, as already mentioned, is located outside the city, near two small villages and summer cottages and, respectively, far fewer people suffer from high levels of odour in the air.

Thus, the olfactometric studies of odour emissions performed at several Russian enterprises not only demonstrate the validity of public complaints on the odour but indicate possible solutions of this problem. At the same time, in the absence of regulatory framework in respect to odour, similar studies are of limited scope and do not allow environmental authorities to act upon enterprises and require any actions to reduce emissions of odourous substances.

APPROACHES TO REGULATION AND CONTROL OF EMISSIONS AND AMBIENT AIR

In most developed countries the control over the odour in the air has long been common practice. At early stage of implementing the odour regulation, some attempts were made to establish unified standard of odour for large areas or even the whole country, but further research showed inexpediency of such method. Currently, the odour regulation is carried out at the local level, with an established standard for a certain inhabited territory with a specific source of emissions of odourous substances. Accordingly, even within a certain region the odour standard is not a fixed quantity and is determined, according to the characteristics of specific areas (places of dense population, recreation areas, industrial areas, rural areas, etc.). In some countries, the value of odour standard depends on population density: the higher the density, the stricter the standard is. As an example, the current odour standards in New Zealand are given in Table 5 [4].

Table 5. Odour standards in New Zeland

Population density, men km^{-2}	Smell standard, OU m^{-3}
≥~2000 and/or schools, hospitals	2
~500	3
~125	4
~30	5
~10	6
separate house	7

In general, the odour standard in developed countries, based on the results of dispersion of odourous emissions is at the level of 2–15 OU m^{-3} [2–6].

In Russian Federation, despite the absence of the odour monitoring in the ambient air, the gradual understanding of the importance of the problem involves not only people, who do not want to live in uncomfortable conditions, but also the state environmental authorities.

Currently, the Research Institute of Air Protection in collaboration with A.N. Sysin Institute of Human Ecology and Environmental Hygiene (Moscow) are developing a procedure for regulation and control of odour in the air of residential areas, as well as emissions of odourous substances in the atmosphere [7–11]. Standards of odour in the air are supposed to be determined for certain relatively small areas in the vicinity of those enterprises, which industrial activity is accompanied by a large number of public complaints on odour. Maximum permissible emissions of odourous substances at such enterprises will be also established, i.e. the emission values, which, according to simulative calculations of dispersion of emissions, do not exceed the odour concentrations above the set standard.

It should be noted that in Russia the system of hygienic regulation of pollutants in ambient air in settlements based on MPC has been successfully functioning for several decades [12]. Based on [12] hygienic standards of individual odourous substances according to their reflex effects on humans have been established, as well as some mixtures of odourous substances in the dimension mg m^{-3}, for example, MPC for volatile flavors used in the manufacture of chewing gum and MPC for volatile mixture of fragrances and essential oils contained in the industrial emissions of perfumery and cosmetics industry. So, valuation of the odour in this already-established and well-working system would be quite natural. At the same time, applying the method of valuation of pollutants to the rationing of odour as a whole it should be taken into account that when assessing the reflex effects of contaminants the standard is set with the dimension mg m^{-3}, as in such cases a control sample with known concentrations of standardized materials is used. While determining the standard it is necessary to study the odour test odours selected directly on the source of emissions, as it is impossible to simulate complex mixture of emission substances in the laboratory. Since the qualitative and quantitative composition of the sample odour is unknown, the concentration of odour with the dimension of OU m^{-3} determined by the olfactometric method is the only quantitative characteristic. Accordingly, the odour standard has the same dimension.

Another difference is that the sanitary system of regulation of pollutants in Russia is based on an assessment of harmful effects of pollutants on human health or his future descendants. In most cases odour is formed by a complex mixture of odouriferous substances, where each agent individually may be present in small amounts and not endanger humans in terms of impact on health. Therefore, the presence of the odour in the air is not so hygienic, but the social factor making human life unhealthy.

Nevertheless, hygienic method of valuation of pollutants can also be used to determine the threshold concentration of odour, which under the particular circumstances (population density, the model results, places of complaints, etc.) is good to set the value standard for the odour of a certain area.

The introduction of odour valuations in the air into the environmental practices of the country requires monitoring of the established standards. According to the international experience, control, in most cases, should be conducted at sources of odourous emissions or on the basis of field investigations of odour.

Control at the source includes:

* sampling of odour emissions at the source of the controlled enterprise;

* olfactometric analysis of samples taken to determine the concentration of odourous emissions (OU m^{-3});

* calculation of odourous emissions (OU s^{-1});

* calculation of dispersion of odourous emissions in the vicinity of the enterprise.

In Russia, for calculating the dispersion of emissions "Technique to calculate the concentration of harmful substances in emissions of enterprises is used [1], which can also be used to calculate the dispersion of odourous emissions. When comparing the calculated maximum concentration of odour on the border of a residential area with the regulatory value, the compliance or non compliance with the odour standard is elicited. However, it should be noted that this method is quite time-consuming and expensive. It is used at the primary study of odourous emissions, and its results are applied to a draft of normative values of concentration of the odour in the ambient air for a particular locality. Repeated measurements of odourous emissions and the subsequent calculation of the dispersion are reasonable to be carried out during change of raw materials, production process, production modernization, evaluation of measures to reduce emissions of odour, etc., as well as according to prescription of inspection authorities.

In monitoring the standard odour during field studies the portable olfactometers can be used, which can measure the concentration of odours directly in the air of populated areas. In addition, field studies may include examination of the territory of the residential area adjacent to an enterprise by specially trained inspectors, evaluating odour by organoleptic method. The program of field studies is developed for each case individually, taking into account climatic and geographic conditions, surface topography, frequency of odourous emissions, odours, etc. The developed program must be tested in real conditions, odour concentrations measured in ambient air must be compared with the results of dispersion of odourous emissions from sources of odourous substances.

CONCLUSION

To reduce the social strain among the population living near sources of odours, a national system of regulation and control over odours is need. It can be based on a combination of Russian hygienic standardization of odourous substances and approving of the international experience of developed countries.

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