Influence of gas stations on the ecology of the urban environment

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Abstract. The aggravation of the environmental situation in major cities of the Russian Federation has been observed in recent years. A significant contribution to the deterioration of the quality of the urban environment has a large number of vehicles and consequently the number of gas stations. They are generally concentrated within the city limits. As a result of the high level of competition of oil companies in the gas station market and the large consumption of liquid fuel oil by the urban population there is a point building of gas stations on free sites of urban development. The question of the need to improve the ecological safety of urban gas filling stations is acute and remains extremely relevant in our time. On the basis of the results of theoretical, numerical and experimental studies obtained by the authors, factors influencing spread of harmful substances from emission sources at gas stations have been identified, and their significance was established. The identified factors formed the basis of a multi-criteria analysis of the environmental impact of emissions from sources at gas filling stations. The authors have developed a methodology for assessing environmental safety of urban gas filling stations, which allows to assess the degree of impact of gas filling stations on the urban environment and to reduce their negative effect.

1 Introduction

Gas filling stations are an important part of urban economy and an integral element of the transport infrastructure of the city. The location of gas stations in a city is a kind of infill development within the vacant space, often without complying with the regulatory requirements for the orientation of the facilities relative to the prevailing wind direction and the minimum distance to the borders of land plots of public buildings or walls of residential buildings. Regulatory (technical, hygienic, etc.) documents determine different distances of sanitary zone from gas filling stations to residential buildings: from 25 to 100 m. Considering the given above, gas stations as urban economy facilities remain objects of increased environmental hazard even when taking into account modern technologies for storing oil products and strict adherence to the rules of construction and operation. Gas filling stations in a process of their operation appear to be a source of continuous release of harmful substances into the environment, which leads to an increase in the negative impact

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on residential building adjacent to the gas station, and adversely influences the quality of human life. [1-5]

Analytical review of domestic and foreign scientific researches and existing methods for determining spread of harmful substances from sources of air pollution located on the territory of gas filling stations, in the framework of the current approaches to ensuring ecological safety of urban gas filling stations showed that the known methods of ecological safety do not completely meet modern requirements. These methods are separate and are devoted to solving individual issues of the release and distribution of harmful substances from the transport infrastructure of the city in general and from gas filling stations in particular. [6-9]

The authors have set a task of developing methodology for assessing ecological safety of urban gas filling stations, which will include a list of measures that might improve the ecological safety of gas filling stations and reduce its negative impact on the environment. Therefore, theoretical studies on the distribution of harmful gaseous substances from emission sources at gas filling stations and their impact on the adjacent buildings were conducted. [10-12]

To confirm the reliability of theoretical studies of the distribution of harmful gaseous substances concentrations released at gas stations, as well as to study the influence of town planning and architectural planning factors on the movement of air flow around gas filling stations and the surrounding area, experimental studies in an aerodynamic chamber [13] and numerical studies on a computer with the program ANSYS were conducted [14].

2 Materials and Methods

The main harmful substances released from emission sources at gas filling stations during operation are gaseous substances. In the gaseous state, the particles of a mixture are bound by the interaction forces and move freely, occupying the entire volume provided to them. Having considered the movement of gas floccule in a jet of emission and the interaction of this jet with atmospheric air flows and after having applied the probability theory to determine the distance of a particle falling out of the air flow, we obtained a dependence that allows us to determine the concentration of gas hazardous substances in any coordinates of the plane and directions of propagation of harmful impurities from emission sources at gas filling stations [15, 16]:

$$C = C_{\max} \exp \left(-\frac{y^2 \cdot W_x^2}{2x^2 \cdot W'^2} \right), \quad (1)$$

Where $C_{\max}$ – maximum concentration of gaseous substances, mg/m³; W_x – rate of air-gas flow, m/s; W' – rate of flow pulsing, m/s; x – distance from the source of atmospheric pollution along the emission axis, m.

On the basis of the theory of turbulent jets and using the “moving source” model, when the coordinate system moves with the wind and at the same speed, there was obtained a dependence that allows us to calculate the concentration of harmful substances from the parameters of the source of air pollution:

$$C = C_{eco} + \frac{M}{2\pi L} e^{-(W_{\infty}/2A')(x-W_{\infty}\tau)} \cdot K_0 \left(\frac{W_{\infty}}{2A'} \sqrt{(x-W_{\infty}\tau)^2 + y^2} \right), \quad (2)$$

Where C_{eco} – background concentration of harmful substance, mg/ m³; y – distance from emission axis, m; M – mass emission of harmful substances, mg/s; L – volumetric

flow rate of gas-air mixture at the mouth of the source of air pollution, m^3/s ; A' – turbulent exchange coefficient m^2/s ; W_∞ – rate of air flow, m/s ; $K_0(\alpha)$ – Bessel function.

The situation of spread of gasoline vapour emitted through a breathing tube coming out of an underground reservoir was experimentally and numerically simulated, when the reservoir was filled with regular unleaded gasoline with a gasoline tank truck (50 m^3 of volume). The influence of gasoline vapours and the distribution of their concentrations near a residential nine-storey building located at a distance of 50 m from gas filling station facilities was considered. Several urban planning situations of the location of gas filling station facilities were simulated with respect to the movement of air flows in the absence of obstacles (trees, bushes) and if there are some.

The results of numerical studies on a computer are presented in graphic images of the movement of gas-air flows directly at gas filling stations and the adjacent territory, as well as areas where the maximum permissible concentration of petrol vapour is exceeded (Figure 1).

Fig. 1. Area of exceeding maximum permissible concentration of petrol vapours in the air when modeling on a computer parallel version of the location of the gas filling station without any barriers (side view).

In the result of the analysis of all city planning situations conducted on computer numerical modeling the following conclusion can be made:

- on parallel gas filling station layout substantial overrun of maximum concentration of petrol vapour limit of upper surface of apartment block is determined. Petrol vapour accumulation is determined from the windward part of building and from the zone of aerodynamic shadow on the windward side, that is connected with the decrease of gas-air flow speed in these areas.

- having changed the location of gas filling station regarding the air flow decrease of concentration of petrol vapour near residential building is noticed (on condition that maximum concentration limit isn't exceeded). It is explained by the fact that vortex region of the air flowing from the building in the premises of tank breather tube is superimposed on vortex region formed by oncoming flow of canopy of the fuel-dispensing unit and operating terminal, causing reverse air flow, holding petrol vapour back on the territory of gas filling station;

- when placing additional barriers between residential buildings and gas filling station from the wind ward of building by means of bushes and trees the concentration of petrol vapour is low, no maximum allowable concentration increase is determined. In some cases the zone of maximum allowable concentration is formed from wind ward side of the building. That once again proves the necessity of the complex decision of the problem of harmful substances distribution on the territory of gas filling station.

On the basis of analysis of scientific works dedicated to increase of ecological safety of gas filling station and decrease of their influence, as well as on the theoretical, numerical and experimental research the decomposition of factors, which influence on harmful

substances distribution from the source of emission from gas filling station, has been carried out. Their significance is determined. The variety of facts can be represented by six basic categories: nature-and-climatic (NC), city-planning (CP), architectural-and-planning (AP), technological (Tg), technical (T) and qualitative (Q).

The revealed factors serve the basis for multicriterion analysis of the influence of gas filling station emissions on environment that forms methodology of ecological safety assessment of city gas filling station.

For multicriterion analysis of factors the map of assessment was developed (Table), that contains the general system of criterion used for assessing the degree of influence of different factors on gas filling station ecological safety.

Table 1. Map of factors assessment influence on gas filling station ecological safety.

Criterion of assessment	Factors N_k						Result
	N_{NC}	N_{CP}	N_{AP}	N_{Tg}	N_T	N_Q	
1	N_{NC1}	N_{CP1}	N_{AP1}	N_{Tg1}	N_{T1}	N_{Q1}	$L_1 = \sum N_{k1}$
2	N_{NC2}	N_{CP2}	N_{AP2}	N_{Tg2}	N_{T2}	N_{Q2}	$L_2 = \sum N_{k2}$
3	N_{NC3}	N_{CP3}	N_{AP3}	N_{Tg3}	N_{T3}	N_{Q3}	$L_3 = \sum N_{k3}$
4	N_{NC4}	N_{CP4}	N_{AP4}	N_{Tg4}	N_{T4}	N_{Q4}	$L_4 = \sum N_{k4}$
5	N_{NC5}				N_{T5}		$L_5 = \sum N_{k5}$
6	N_{NC6}						$L_6 = \sum N_{k6}$
Total	$K_1 = \sum N_{NCn}$	$K_2 = \sum N_{CPn}$	$K_3 = \sum N_{APn}$	$K_4 = \sum N_{Tgn}$	$K_5 = \sum N_{Tn}$	$K_6 = \sum N_{Qn}$	$K = \sum K_n = \sum L_k$
Index of gas filling station ecological safety (T – maximum possible number of points on all criteria)							$\Psi = \frac{K}{T} \cdot 100\%$

To compare different factors N_k , measured in scales varying in range and size, relative non-dimensional index K_i can be used. It represents the proximity degree of absolute index of factors N_k to maximum index T . Relative index is determined by the equation: $K_i = f(N_{min}, \dots, N_k, \dots, N_{max})$.

On the basis of the conducted research 27 significant indexes – criteria of assessment influencing distribution of harmful substances from gas filling station – have been presented. All possible variants of matching have been determined for every criterion. These are established on the results of analyses of regulatory technical and methodical documentation and scientific works dedicated to ecological safety of the objects of the city transport infrastructure. Every variant of factor matching the definite number of points is assigned. The quantity of points for every criterion (variant) depends on the degree of their influence on ecological safety of gas filling station.

Multicriterion analysis of factors results in determination of the index of assessment of ecological safety of gas filling station (Ψ). It can be applied to conduct complex evaluation of all factors' influence and characterize the degree of negative impact of gas filling stations (not only ones in operation, but also those being in project) on city environment, assessing possible harmful influence of their future exploitation.

In accordance with the determined index of ecological safety of gas filling station rating system of evaluation of ecological safety is presented. It can be used for safety class assignment: class A + (highly ecological) – $\Psi=91-100\%$; class A (ecological) – $\Psi=71-90\%$; class B (medium environmental friendliness) – $\Psi=51-70\%$; class C (hazardous) – $\Psi=21-50\%$; class D (highly hazardous) – $\Psi=0-20\%$.

The determined class of gas filling station ecological safety presents the hazard level of the object for urban milieu. In consideration with the results of the conducted assessment protection measures are worked out, contributing to improvement of ecological safety of city gas filling stations (Figure 2)

Fig. 2. Scheme of assessment methods realization of ecological safety of city gas filling stations on the basis of multicriterion factor analysis.

Three basic groups of measures are represented: constructive-and-technical, organizational-and-legal and city-planning. Profound success in preservation and enhancement of ecological safety can only be achieved by comprehensive use of all the above mentioned measures. According to the conducted research, city-planning measures are determined as the prior ones influencing the movement of gas-and-air flow from gas filling station and spread of harmful substances.

3 Conclusion

On the basis of the conducted research the methodology to increase the ecological safety of gas filling station has been presented. This methodology is established on multicriterion analysis of factors that influence the spread of harmful substances from emission sources to gas filling station. The application of the proposed methodology will allow: to monitor the state of the urban milieu in a context of the impact of sources of harmful emissions at gas filling stations; to assess the state of ecological safety of gas filling stations; to determine the need for environmental protection measures of constructive-technical, organizational, legal and city-planning nature in order to increase the ecological safety of gas filling stations.

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