Numerical modeling of the spread of harmful substances from gas stations

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Abstract. The spread and influence of harmful substances from gas filling stations (gas stations) on nearby buildings, taking into account the aerodynamics of wind flows, is not well investigated. Studying process of the spread of harmful substances in natural conditions causes certain difficulties. Being based on the results of theoretical and experimental studies obtained earlier, the authors performed a numerical modeling of the spread of pollutants emitted from gas stations. As well the authors analyzed influence of these pollutants on nearby buildings taking into account the flowing air flows. The results obtained from numerical modeling make it possible to assess the state of the environment at any point and at any distance from the gas station and allows us to predict the degree of influence of atmospheric air pollution on the environmental safety of residential buildings during the construction of gas stations. Using numerical simulation, it also seems possible to assess the effectiveness of the implementation of planned measures to reduce the negative impact of harmful substances from gas stations.

1. Introduction
A gas station is a facility of increased environmental hazard in the urban economy, even when using modern methods and technologies for the storage and dispensing of petroleum products [1, 2]. A gas station is a source of emissions of harmful substances into the environment, which negatively affect the nearby development and human activity (figure 1) [3, 4].

In this regard, the authors conducted theoretical studies [5-10] to assess the contribution to the pollution of the surface layer of the atmosphere with harmful substances during the construction and operation of gas stations. As the practice of gas stations operation shows, one of the determining climatic factors in the pollution of the surface layer of the atmosphere is the aerodynamics of wind flows from gas stations in the direction of the adjacent residential area, which was investigated by the authors using an experiment in an aerodynamic chamber [11]. To confirm the reliability of the results obtained during theoretical and experimental studies, a numerical modeling of the distribution of gas and air flows at the gas station was performed and an analysis of their influence on the development of the terrain on computers was given [12].

2. Research problem statement
Numerical modeling was performed using the software package ANSYS 18.2 (ANSYS, Inc.), using ANSYS CFX solver. The ANSYS CFX is based on an advanced algebraic multigrid adjoint solver.
ANSYS CFX solver uses a second-order sampling scheme to provide the most accurate results. [13, 14].

The process of spreading gasoline vapors from a gas station while interacting with wind flows and influence of these vapors on a nine-story residential building located at a distance of 50 m from the gas station is simulated.

In the process of modeling two urban-planning situations were considered for choosing the gas station construction site relative to the movement of the air flow in the absence of obstacles or if there are some. The barrier is made of densely located trees 17 m high with a through clearance below of 1.5 m high located at a distance of 25 m from the breathing tube.

During the modeling we considered the moment of filling an underground reservoir by a tanker (with a volume of 50 m³) for storing fuel - AI-92 gasoline - and the further distribution of gasoline vapor displaced from the reservoir through the breathing tube.

3. Research methodology
The model under study contains the following objects: a nine-story residential building, a gas station (operator’s room and 4 fuel dispensers with a canopy), a breathing tube from the fuel reservoir (figure 2), and a computational area that represents the boundary of atmospheric air monitoring (figure 3).
When creating the geometry of the computational area of the model, the overall dimensions of the objects were taken into account. The dimensions of the computational area itself are selected in such a way that its boundaries do not affect the computation results. For this, the characteristic size of the object (the largest of the sizes) was chosen - the height of a nine-story residential building. This condition is in accordance with the recommendations developed by the National Research Moscow State University of Civil Engineering and is proposed in [13].

To ensure accurate results in the areas around the buildings, the following details were additionally provided: a thickening area of the grid and a boundary layer near the buildings and near the lower boundary of the area - the surface of the earth; for this built-in ANSYS Meshing modules were used.

The boundary conditions of the model were described in the CFX-Pre preprocessor. Conditions at the entrance to the working area were set (figure. 3 (a)): the air flow at the speed of 3.3 m / s (based on the averaged climatic characteristics of the city of Voronezh [15]) moves parallel to the earth's surface to the gas station and residential building. Through the opening in the breathing tube, gasoline vapor is released vertically upward (figure. 3 (b)) with a concentration of 480 g / m ³ and speed of 1.33 m / s [11]. A mixture of gasoline vapor and air, flowing around an obstacle in its path, leaves the working area (figure. 3 (c)).

At the exit from the working area, a zero relative static pressure averaged over the entire output area is set. At all other boundaries, non-leakage conditions are set: the velocity component according to the exponent of hyperbolic decline curve to the boundary is zero, and there is no viscous friction. The process is permanent, isothermal (temperature 20ºС). There is no background concentration of gasoline vapor.

To solve the problem and obtain the necessary data in the ANSYS CFX program, we used three moment conservation equations, the mass conservation equation, and the equation for calculating the kinetic energy of turbulence and turbulence of vortex flow dispersion. In the simulation, the k-ε model of turbulence is adopted, without heat transfer. As a method for solving system of partial differential equations, a numerical method of finite elements is considered [14, 16].

4. Research results
To get calculation and visualization of the modeling processes module ANSYS CFX-Solver Manager was used. The results of the numerical studies conducted on computer are graphically depicted as gas-
air flow moving immediately at the gas station and at the adjacent territory as well as at the areas of maximum concentration limit increase of gasoline vapor.

Figure 4 (a, b) shows the fields of air flow speeds within the territory of gas station and the adjacent residential building when there are no obstacles between them. Clearly, the air flow near gas station and residential building is of complicated character. This may be explained by the fact that the atmospheric air pressure is lower from the leeward side of the residential building than that from the windward side, consequently, air shadow is observed behind the building. Reverse air flow is observed that leads to vortex of oval form, formed from the leeward side.

Figure 4. The fields of air flow speeds: a – without obstacles (side view); b - without obstacles (view from above); 1 – residential building; 2 – operator’s room; 3 – the fuel-dispensing unit with a canopy; 4 - breathing tube; 5 – trees.

Figure 5 (c, d) shows the fields of air flow speeds at the territory of the gas station and the adjacent residential building when there are obstacles between them. When obstacles are observed the character of air flow notably changes. In accordance with the theoretical basis of aerodynamics [17,18], when flowing around extra obstacles air flow loses part of its kinetic energy and substantially turbulizes, increasing the speed of air flow from the windward side and side wall of a building and before the obstacle. The air flow speed from the leeward side of the building and trees decreases. It is clear, that stagnant zone is observed behind the building, the air flow is hardly noticeable. Between the building and trees vertex movement is observed that is connected with the fact that the air flow having increased its speed when coming across an obstacle (creating underpressure behind the obstacle) meets the windward side of the building and is partially reversed.
Thus, different character of aerodynamics of air flows depending on presents or absents of obstacles between source of harmful substances and residential building exerts its influence on the spread of harmful substances in the environment and on the values of gasoline vapors concentration from the gas station in the same points (figure 6).

Figures 6 show the results of modeling of gasoline vapors spread at the territory of gas station depending on the observed obstacles. It makes it clear that the zones of increase of gasoline vapors maximum allowable concentration (MAC\textsubscript{m.a.}=5 mg/m\textsuperscript{3} [19]) occur under the given boundary conditions.

The presence of the barrier – trees – increases vortex area between the building and the trees and increases the air flow speed. Apparently, the vortex core where the speed of air flow is very low is shifted from the residential building, so the area of maximum allowable concentration increase is shifted from the building closer to the trees. The speed of wind from the leeward side of the building is approaching to zero (calm), the air flow through in the zone of aerodynamic shadow is absent due to which gasoline vapors are accumulated behind the building that leads to maximum allowable concentration increase (figure 6 (c)).

The obtained results of modeling revealed the necessity to observe the additional layouts of the gas station in respect to the residential buildings and to place additional barriers between gasoline station and the residential building to create vortex movements, that later contributed to determine the most favorable layouts of gasoline stations for dispersion of harmful substances [20,21].
Figure 6. Zones of maximum allowable concentration increase of gasoline vapors within the territory of gas station and the adjacent building: a – without obstacles (side view); b – without obstacles (view from above); c - the presents of trees (view from above).

5. Conclusion
Having analyzed the results of numerical modeling one may conclude that when locating gasoline station within urban development it is necessary to comprehensively take into consideration all the factors influencing the spread of harmful substances from gasoline station (the distance, layout decisions, observed obstacles, wind flow direction, roof form of the operator’s room and the canopy over the fuel-dispensing unit).

The use of computational modeling allows to evaluate the influence of harmful substances from the sources of air pollution from gasoline station at any point and at any distance and to make a prognosis of degree of their influence on the environmental safety of a city when gasoline station building to
prevent negative influence of gasoline station on the nearest residential building areas and human activity.

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