The influence of the wind regime on the methanol concentration change in the atmospheric air of the city residential area

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Abstract. The influence of the wind regime on the methanol concentration in the city residential area, which is released into the atmosphere as a result of the petrochemical enterprise, is analyzed. The initial data are the data obtained by the automatic atmospheric air control station (AAACS). There are the time series of the methanol concentration changes, the speed and angle of the wind direction for 3 years. The analysis of methanol concentration changes in the air of a settlement depending on the wind regime was carried out. It was revealed that the quality of atmospheric air in the residential area deteriorates with the north, east and south-west wind directions. Three-dimensional diagrams were built. They display the change in the methanol concentration in the atmospheric air depending on two parameters: wind direction and speed. It was found that at a wind speed of 1-2 m/s increase the air methanol concentration in the zone of population compact residence. The ways of methanol intake into the atmospheric air at dangerous wind directions have been determined. It has been established that an increase of the atmospheric air methanol concentration is due to the following reasons: the emission of a polluted gas mixture by a petrochemical enterprise, mechanical turbulence due to the high roughness of the underlying surface, the accumulation of pollutants over a reduced pressure area, in particular, over water bodies.

1. Introduction
Methanol is both an end product and a feedstock in the petrochemical industry [1]. In this regard, the presence of methyl alcohol in the air of the residential area of the city is a common situation [1-9].

The danger of the methanol presence in the air of settlements is due to the toxic effect, when it accumulates in the human body. In the air methanol is oxidized to form formaldehyde, a substance of hazard class 1 [10]. Methanol and its body metabolic products, formaldehyde and formic acid, are poisons that act on the nervous and vascular systems [11]. The negative effect of aldehyde during respiratory contact consists in an irritating effect on the upper respiratory tract, in which oncological tumors develop. The presence of both substances enhances the toxic effect on the human body [10]. The content of technogenic origin organic substances in the atmospheric air of the cities residential area is determined by the volume of emissions from industrial sources [4-5]. The concentration of these substances decreases with distance from the source as a result of diffusion in the surface layer of atmospheric air [9]. However, the continuity of the production process, and, as a consequence, the constant release of a contaminated gas cloud into the atmosphere, can significantly change the
methanol concentration in the air of the nearby settlement residential area and, in certain time periods, lead to an excess of standard indicators.

Meteorological conditions, such as the direction and speed of the wind, the amount and nature of precipitation, and temperature, have a significant effect on the methanol content in the air [6-7].

Thus, the dynamics of the methanol content in the urban area air is the result of the large number of factors action that change both qualitatively and quantitatively in fairly short periods of time.

Data from continuous monitoring of the atmosphere state can be the basis for analyzing the complex effect of several meteorological parameters on the methanol content. Due to the fact that the presence of methanol in the air is an indicator of a direct technogenic release from a petrochemical enterprise, it can be assumed that the defining meteorological parameter that affects the methanol content in the environment is the wind regime. Analysis of the influence of wind direction and speed on concentration changes of anthropogenic substances is of considerable interest for making decisions to minimize the effect of toxicants on the environment and humans [4; 9].

2. Materials and Methods
An enterprise with a petrochemical profile is located to the north of the residential zone of the population compact residence, at a distance of 1.9 km. The emission source is located in such a way that the azimuth is 342° (figure 1).

![Figure 1. Wind rose.](image)

The data were used for 3 years, obtained at the automated atmospheric air control station (AAACS) installed in the residential area of the city. Methanol concentrations in the city's atmospheric air are recorded by a Syntech Spectras chromatograph. Meteorological parameters (wind direction and speed) are determined by Vaisala Weather Station WXT530. Time series of methanol concentration hourly values in the residential area, angle of direction and wind speed for 3 years was formed (figure 2). The ordinal number of the record in the AAACS database was taken as the measurement number. The volume of measurements was more than 20,000 for each of the recorded parameters.

To identify the joint influence of the analyzed parameters on the toxicant content in the air, the method of constructing three-dimensional diagrams was used. The graphs were obtained based on the selection results from the original time series using filters. Situations of the wind regime were selected, when methanol was repeatedly recorded at AAACS, therefore the average concentration of the substance is indicated on the diagram.

3. Results
According to the wind rose (figure 1), an increase in methanol concentration in the urban area should be expected when the wind direction is S ─ SSE. To assess the wind directions at which an increase in the controlled substance concentration is observed, a diagram of the dependence "average concentration of methanol ─ wind direction" was built (figure 3).
Figure 2. Time series: I - methanol concentration in the atmospheric air of a residential part of the city, II - wind speed, III - wind angle.

Figure 3. Average concentration of methanol depending on wind direction.
Judging by the distribution of the average methanol concentrations in the air of the residential area, increased methanol concentrations are recorded at ENE, SSW — WSW and the highest at NW — N wind directions (figure 3), which indicates the possibility of the additional factors influence on the distribution of methanol in the air.

To analyze the distribution of methanol concentrations recorded using AAACS, three-dimensional diagrams of their censored values from the wind regime in the ranges of $0 \ldots 0.5 \, \text{mg} / \text{m}^3$, $0.5 \ldots 5 \, \text{mg} / \text{m}^3$, $5 \ldots 10 \, \text{mg} / \text{m}^3$ of methanol were constructed.

![Figure 4. Isolines of the average methanol concentration on the plane (wind speed and angle) for the moments of methanol registration at AAACS in the following concentration: I - $0 \ldots 0.5 \, \text{mg} / \text{m}^3$, II - $0.5 \ldots 5 \, \text{mg} / \text{m}^3$, III - $5 \ldots 10 \, \text{mg} / \text{m}^3$.](image)

The data obtained show that at AAACS methanol in a concentration of $0 \ldots 0.5 \, \text{mg} / \text{m}^3$ is registered in the atmospheric air of the city under the following wind conditions: N wind direction (the angle changes $300 ^\circ \ldots 30 ^\circ$) and a speed of $0.4-2.5 \, \text{m} / \text{s}$; SW wind direction (angle varies $180 ^\circ \ldots 240 ^\circ$) at a speed of $0.3-3.5 \, \text{m} / \text{s}$. During the period of predominance of E winds, the toxicant is recorded in the air with less frequency.

When censoring the initial data (removing values less than $0.5 \, \text{mg} / \text{m}^3$ from the time series of concentrations) it was revealed that dangerous wind directions are NW (the angle changes $300 \ldots 360 ^\circ$) and SW (the angle changes $180 \ldots 240 ^\circ$) (figure 6) with a range of wind speed change of $0-2.5 \, \text{m} / \text{s}$.

High concentrations of methanol ($5 \ldots 10 \, \text{mg} / \text{m}^3$) are recorded at a wind speed of $0-1 \, \text{m} / \text{s}$ and $2-3 \, \text{m} / \text{s}$ (Figure 4). Moreover, during the period when low wind speed ($0-1 \, \text{m} / \text{s}$) prevails, the toxicant is present in the air regardless of the wind direction. At a wind speed of $2-3 \, \text{m} / \text{s}$, methanol is recorded at E (angle $80 \ldots 100 ^\circ$) and SW (angle $240 \ldots 270 ^\circ$) wind directions. Thus, the range of
wind speed changes at which the toxicant is registered at low concentrations is wider than for high concentrations.

4. Discussion

The increase in the methanol concentration in the atmospheric air of the city at the E and SW wind directions is unexpected. In the absence of transboundary transport, the danger of SW wind direction is most likely associated with the phenomenon of mechanical turbulence, the so-called “rotors” [11]. In the atmospheric air, rotors arise due to the increased roughness of the underlying surface, the presence of urban multi-storey buildings, tree planting, etc. [11]. They carry the polluted gas cloud upwind and contribute to its deposition downwind. Moreover, with an increase in wind speed, the speed of vortex formation increases. As a result, ventilation intensity decreases when air moves through city streets, and pollutants accumulate in the ground space on the south side of buildings or other obstacles. When the wind direction changes (periods S of the wind direction), the accumulated substances are transferred to the city quarters for the second time. However, the concentration of methanol is lower than in the N wind direction.

The transfer of pollutants in the E direction of the wind may be due to the relief of the surrounding residential area. To the east of the city there is a river and industrial reservoirs. Due to the difference in atmospheric pressure over land and water bodies, falling winds are formed blowing away from the city [12]. In addition, the wind speed increases during the transition from land to water by an average of 30% [12]. Thus, the accumulation of pollutants occurs in the air above the reservoir, which are transferred again to the residential area of the city at the E wind direction.

Figure 5. Scheme of the emission source and water bodies.

5. Conclusion

When constructing models for changing the concentration of toxicants in the atmospheric air, one should take into account not only the meteorological conditions and emission regimes of industrial enterprises, but also the relief of the underlying surface. At the same time, predictive models for different cities will differ significantly due to the characteristics of the adjacent landscape. The versatility of the model can be achieved through the introduction of parameters that reflect the topographic features of the area.

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