Development of unauthorized airborne emission source identification procedure

L O Shtripling¹, V V Bazhenov¹ and N S Varakina¹, N P Kupriyanova²

¹Omsk State Technical University, 11, Mira ave., Omsk, 644050, Russia
²Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing in Omsk Region, Omsk, Russia

e-mail: losht59@mail.ru

Abstract. The paper presents the procedure for searching sources of unauthorized airborne emissions. To make reasonable regulation decisions on airborne pollutant emissions and to ensure the environmental safety of population, the procedure provides for the determination of a pollutant mass emission value from the source being the cause of high pollution level and the search of a previously unrecognized contamination source in a specified area. To determine the true value of mass emission from the source, the minimum of the mean-root-square mismatch criterion between the computed and measured pollutant concentration in the given location is used.

1. Introduction

High pollution level is one of the most important environmental problems in cities with developed industries. To estimate the atmospheric contamination level, monitoring systems comprising of priority pollutants stationary sites are arranged in the cities. However, the capability of such stations is limited. All we can know is the pollutants concentration reading at the site of the observational station. To make the atmospheric contamination level estimates and forecasts more accurate, the systems of monitoring include mathematical models of pollutants transfer to determine pollutant concentration in any location under specified meteorological conditions [1, 2].

At the same time, an important task in decision making in the field of ecological safety is to determine the sources of unauthorized emissions. This task can be solved in two ways: improvement of instrumental base for the network of monitoring and development of mathematical models for measuring different source contribution to the overall level of atmospheric contamination. Using lidar systems for control and detection of contamination source [3], wireless sensors [4, 5] and portable laboratories in monitoring networks possesses one significant drawback, which is a high cost of implementation. In addition, the capability for lidar systems of control in case of ground level concentration determination is restricted by dense industrial development.

Numerical simulation of atmospheric contamination processes is widely used in the search for contamination sources. For instance, the Gauss and the Lagrange model algorithms are applied in works [2, 7] to determine contamination sources. However, the emission source identification in this case is limited to determination of its contribution to the overall level of contamination. But the options for producing extreme high levels of air pollution from a previously unknown emission source or from an unauthorized mode operation source are not considered. A more reliable method of positive matrix factorization (PMF) is used in papers [8, 9] for pollution source detection. This method is used with success to solve local problems such as defining the cause-effect relationships of urban pollution.
and to analyze global problems, for instance, reasons for black carbon pollution in the northern hemisphere [10]. A significant drawback of the PMF method is that it can be used solely for the analysis of pollution by solid substances such as carbon, PM 2.5, PM10 and other solid particles, while most emissions of industrial enterprises include gaseous impurities. Thus, the problem of source detection of unauthorized atmospheric pollution by gaseous and solid substances is vital in case of insufficient information about its location and operation parameters in particular.

2. Task description
The purpose of the study is to develop the pollution source identification procedure for unauthorized airborne pollutant emission detection and localization of the source. The following steps are essential in achieving this objective. The first step is to develop the detection procedure for pollutant mass emission from the source resulted in unauthorized atmospheric contamination. The next step is to develop an algorithm for search and location of a previously unknown pollution source. The final step is to develop software for decision-making in the field of ecological safety.

3. Theoretical Basis
This work assumes that most elevated air pollution episodes are primarily related to familiar pollution sources operation under unauthorized modes. In this case, it is necessary to prove that a particular source or group of sources have exceeded the enforceable emission standards to take informed decisions on compliance measures or source operation constraints.

Pollutant concentration measured at the observational station \( C_{ss} \) can be represented as follows:

\[
C_{ss} = \sum_{i=1}^{n} C_i (x, y, z = 2),
\]

where \( C_i \) is the substance concentration from the \( i \)-th pollution source at the observation point above ground level of 2 meters, \( \mu g/m^3 \).

To calculate the concentration \( C_i \), any mathematical model can be used. For instance, the Gauss model determines the pollutant concentration of a single point source at the assigned area from the formula:

\[
C_i = \frac{Q \cdot K \cdot V}{2 \cdot \pi \cdot u_s \cdot \sigma_x \cdot \sigma_z} \cdot \exp \left( -0.5 \cdot \frac{y^2}{\sigma_y^2} \right),
\]

where \( Q \) is the substance emission, \( g/s \); \( K \) is the conversion factor being equal to \( 10^6 \); \( V \) is vertical dispersion conditions; \( \sigma_x, \sigma_z \) are standard deviations of horizontal and vertical dispersion, \( m \); \( u_s \) is the wind velocity of the effective source height, \( m/s \).

The use of the Gauss model and its derivatives to determine pollutant concentration is broadly examined, for example in [1], and it is outside the scope of this paper.

The parameters of unauthorized emission source are determined as follows:

1. Pollutant concentrations \( (C_i) \) caused by emission of each \( i \)-th pollution source at the observation point are determined from the formula (2). The calculation takes into account meteorological conditions (wind direction and velocity, ambient temperature, etc.). It is assumed that \( Q \) is the quantity of the authorized substance emission from the source.

2. The criterion for expediency of pollution source accounting is determined:

\[
0.4 \cdot \max(C_i) = C_{bc} \quad (3)
\]

The determination of the true quantity of mass emission is performed among multiple pollution sources satisfying the condition:

\[
C_i \geq C_{bc} \quad (4)
\]

This allows reducing further calculations and taking into account emission sources that contribute to pollution at the specified point, the contribution being not less than 80 %. The parameter \( G \) is determined for the remaining sources:

\[
G = \sum_{j=1}^{n} C_j \quad (5)
\]
For the pollution sources satisfying the condition (4), the functional $J$ is calculated from the formula:

$$J = \sum_{k=1}^{n} \left( \left( C_{ss}^k - C^k \right) - C^k \right)^2,$$

where $C^k$ is the total computed pollutant concentration from all pollution sources at the $k$-th observation point, $\mu g/m^3$; $C_{ss}^k$ is the measured substance concentration at the $k$-th point.

Subsequently, varying the value $Q$ in the formula (2), we minimize the functional $J$, for instance, by applying the search method of global extremum. As the true values $Q$ for pollution sources we take the values with minimum functional $J$ being attained.

If the following condition is fulfilled for the $i$-th pollution source:

$$Q_i > Q_i^{\text{norm}},$$

where $Q_i^{\text{norm}}$ is the mass emission of the $i$-th source under its normal operation condition, this source is admitted to produce an unauthorized emission, and it is necessary to take additional regulatory measures towards this source.

It is obvious that calculation of mass emission by the formulas above brings to a misleading result if the unauthorized emission is conducted by previously unrecognized contamination source. In such a case the value $Q$ exceeds manifold $Q_i^{\text{norm}}$. In this instance it is essential to identify the possible location of the pollution source to take decisions on elimination of contamination.

To solve this problem we use the data on measured concentrations ($C_{ss}^k$) at a minimum three ground points as well as the value of pollutant concentration $C^k$ defined by the formula (2). The search area is divided into equal-area rectangles with the sides of 500 m. For each rectangle the possible parameters of virtual atmospheric contamination source such as height, mass emission and other parameters are determined. With these parameters the particular source may become a cause of the unauthorized pollution and under specified meteorological conditions produce the concentration:

$$C_n^k + C^k \approx C_{ss}^k,$$

where $C_n^k$ is the concentration produced by the virtual contamination source.

Provided that such source parameters are detected and the concentration measured at three points differs from the computed one within 25 per cent, such rectangle defines the most probable site for the unauthorized pollution source. If the deviation of computational concentration from the measured one is within 25-35 per cent, the rectangle determines the possible site for the pollution source.

Subsequent to the computational results, a map of the possible site for the pollution source is generated to continue ground location search and take measures on pollution elimination.

### 4. Experimental Results

The procedure considered above is software-implemented. This software was used to determine the previously unspecified hydrocarbon emission source in April, 2017 in the city of Omsk, Russia. An excess of pollution standard was recorded on April, 22 by the stationary site in the industrial area of the city. The search data for the unauthorized emission are shown in figure 1.
Table 1 shows the calculation data for one of the rectangles in the area of the most probable location of the pollution source.

**Table 1. Concentration of ethyl benzene at computational points**

| Rectangle position | Measuring point | Concentrations, µg/m³ | | | |
|---------------------|-----------------|------------------------|-------|-------|-------|
| Vertical | Horizontal | | C_n[k], µg/m³ | C_ss[k] | |Δ|, % | Q, g/s |
| 7 | 8 | 1 | 0.013 | 0.016 | 18.75 | 3.9 |
| | | 2 | 0.01 | 0.013 | 23.07 | 3.9 |
| | | 3 | 0.009 | 0.008 | 11.11 | 3.9 |

Table 1 and figure 1 represent data on the source of atmospheric contamination, with ethyl benzene not being previously accounted there.

5. Conclusions
The developed procedure to determine an unauthorized emission source allows one to define accurately the source location and its mass emission. The technique was approved in the city of Omsk, Russia, when ethyl benzene atmospheric contamination source was detected. The developed software
allows detecting the source of atmospheric contamination with the previously unaccounted emission of the pollutant (ethyl benzene). However, for further improvement of the presented procedure, it is necessary to conduct additional analyses aimed at defining optimum location for pollutant concentration points and optimizing the algorithm for the search of the pollution source location.

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