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# INVESTIGATION OF VOLATILE ORGANIC COMPOUNDS (VOCs) EMISSION BEYOND THE TERRITORY OF OIL TERMINALS DURING DIFFERENT SEASONS

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**Abstract.** The present paper deals with an important environmental issue: air pollution with volatile organic compounds (VOCs) in oil terminals. In attempt to determine the dependence of VOCs concentration in the air on the wind speed and oil loading intensity analyses were carried out during shorter time intervals, when the fluctuations of ambient temperature are minimal (1–3) °C. VOCs concentrations were analysed by gas chromatography method in different chosen observation posts during different seasons. A complex analysis of experimental study and impact of meteorological conditions on the air pollution was performed taking into account the oil loading intensity in oil terminals and the types of loaded oil products. A new indicator was introduced for the analysis of the obtained results – a loading indicator that characterizes the amount and type of handled products as well as the number and type of operations carried out in the terminal. The dependence of the change of VOCs concentration on the loading indicator has been determined.

**Keywords:** volatile organic compounds (VOCs), VOCs emission, oil terminal, loading indicator, air pollution, vaporization.

## 1. Introduction

The intensification and development of industrial processes reveals the negative effects of human activity to the nature: amounts of pollutants are increasing, industrial waste is accumulating, the balance of natural processes is broken and the natural resources are consumed thoughtlessly. Polluted air has adverse effects on human health (Baltrėnas and Zagorskis 2010; Barregard *et al.* 2009). Such hydrocarbons as benzene, toluene and xylene contained in VOCs are toxic, carcinogenic and harmful to humans (Ohura 2006; Srivastava and Joseph 2006; Kerbachi 2006). Those pollutants also cause the formation of greenhouse effect, as in the sunlight VOCs react with nitric oxides contained in the atmosphere, thus causing the increase of the amount of ozone (Chiang *et al.* 2007; Monks *et al.* 2009; Seco *et al.* 2007; Murphy and Allen 2005).

Air pollution has increased during the last decades especially due to intense development of energy, industry and transport. Most air pollutants may remain in the ambient air for quite a long period of time, and the air masses carry them far away from the sources of origin (Paulauskiene *et al.* 2008; Charles and Weschler 2007). At the moment environmental pollution studies and implementation of state-of-the-art environmental technologies are becoming a priority issue not only in Lithuania, but all around the world (Rauckyte *et al*. 2010). The allocations from the budget of the State of Lithuania for the environment protection have increased by more than 8 times lately – from 148.507 million LTL (in 2004) to 1.265 billion LTL (in 2008).

The pollution of the lower atmospheric boundary layer with VOCs is especially recorded in those regions of the western Lithuania, wherein the oil processing industry and oil production fields are developed, and where there is a concentration of oil and oil products' terminals. The problems of atmosphere pollution with VOCs become even more relevant, when oil processing and distribution terminals are close to or adjacent to the residential areas (Lin and Sree 2004; Park and Chah 2002). Research on the concentration of VOCs is very relevant to Klaipėda city, as the oil terminals adjoin the recreational areas and other companies of the seaport (Lashkova *et al.* 2007).

VOCs emission increased more than 3 times in Lithuania lately – from 5.952 thousand tons (in 1998) to 18.817 thousand tons (in 2008), and air pollution with VOCs in Klaipėda increased from 0.564 thousand tons (in 1998) to 3.007 thousand tons (in 2008), i.e. more than 5 times (Department of Statistics under the Government of the Republic of Lithuania). Thus, a special attention should be given to the solution of environmental problems in Klaipėda city and the seaport. As the meteorological conditions are very complicated in this coastal region, complex scientific research is necessary for the evaluation of pollution of air with VOCs.

Legal acts regulating the limitation of air pollution by companies are adopted and updated in Lithuania. They provide for the measures that are more of an economic nature, for example, oil products excise tax, pollution charge and fines for violation of environmental regulations. If the procedures for the assessment of the effect of a planned economic activity on the environment are validated, the country would have actual air pollution prevention measures. Such environmental prevention measures would make those companies that pollute air, give thorough attention to the issue and search for technological solutions for the reduction of VOCs emission to the lower atmospheric boundary layer.

Vaporization of VOCs from oil terminal zones and technological equipment depends on the product handling operations, type of handled product, meteorological conditions, etc. (Paulauskienė *et al.* 2009; Laskova *et al.* 2007; Doroševas *et al.* 2003).

A research on vaporization of VOCs from oil and oil products should be carried out not only from the environmental, but also economic point of view, as companies incur quite significant quantitative and qualitative losses due to VOCs vaporization (the quality of oil and oil products degenerates) (Paulauskienė *et al.* 2008; Sudintas 2008).

*The aim of the investigation* is to evaluate the effect of meteorological conditions and product loading indicator on the change of VOCs concentration in lower atmospheric boundary layer during different seasons in the territories adjacent to the oil terminals.

## 2. Methodology

SC "Klaipėdos nafta" and JSC "Krovinių terminalas" oil terminals are investigation object of the present paper. These terminals are analogous to the terminals of other countries according to its technical and technological characteristics. Thus, the scheme offered for the research planning, the methodology used for the study, and analysis of the results of the experiment can be used for the same research in other oil terminals.

### 2.1. Sampling area

Disposition of observation posts around oil terminals territory is provided in Fig. 1.

Observation posts are set out in the open field to eliminate effect of nearby objects (buildings, forest, etc.) on the outcome of the investigation.

In addition, to compare the results obtained from different observation posts, they are set at equal distances from the source of pollution:

- point 1 – Melnragė settlement (next to the tank park of the light oil products of SC "Klaipėdos nafta");
- point 2 – Smiltynė recreational zone;
- point 3 – trestles (next to the trestle of the light oil products of SC "Klaipėda petroleum").

Also, observation posts were chosen taking into account the disposition of the residential areas and the prevailing meteorological conditions.

### 2.2. Sampling of VOCs

At each observation post, air samples were taken at a height of 1.5 m from the ground surface into Teflon bags with a speed of 1 liter/min.

At one observation post, at least 3 air samples are taken, from which an average arithmetic value is obtained afterwards. Each result is a mean value of 9 measurements.

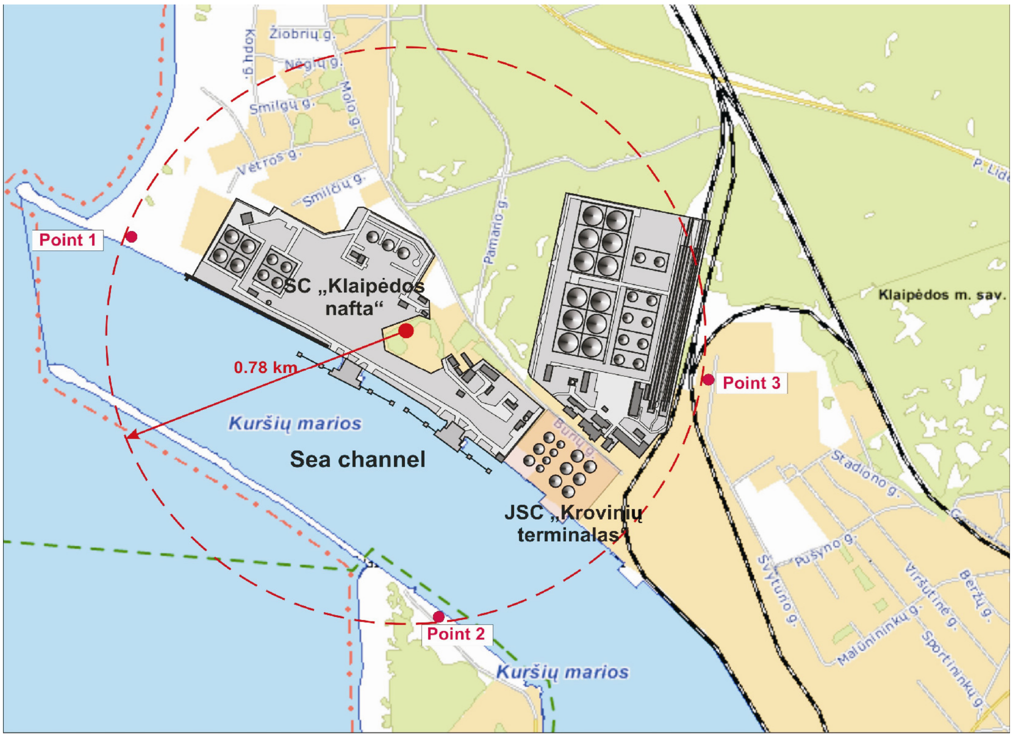


**Fig. 1.** Location of observation posts around oil terminals (at points 1–3)

Meteorological data was taken from meteorological station near oil terminals.

### 2.3. Analytical procedure for the VOCs extraction, apparatus and reagents

Analysis of VOCs concentration was made in Klaipėda University, Environmental Research Laboratory, using SHIMADZU GC-2010 gas chromatograph equipped with flame ionization detector (FID).

A silicon capillary column, 0.5 m long with internal diameter of 0.52 mm was used for the quantitative analysis of VOCs concentration. Temperature mode: evaporator – 125 °C; column – 125 °C; detector – 150 °C. Gas rate: helium – 30 ml/min, air – 400 ml/min, hydrogen – 40 ml/min.; volume of the sample – 1 $cm^3$.

Calibration was carried out using n-hexane, and the calibration curve is made up of five different concentration points, each of which is obtained by repeating the analysis of at least 10 times and calculating the average mean.

### 2.4. Calculation method used for determination of product loading intensity (loading indicator) in oil terminals

For analysing VOCs concentration, it is necessary to assess the intensity of oil and oil product loading operations in the terminals. The latter indicator is one of the most important factors determining the values of VOCs concentration and it may be measured in the observation posts.

The criterion offered by us, i.e. loading indicator, was calculated using the annual cargo handling capacity and inventory data of the terminals of SC "Klaipėda petroleum" and JSC "Loading terminal" situated in Klaipėda seaport.

The scheme for calculation of loading indicator is provided in Table 1.

It is known that the loading capacity of SC "Klaipėda petroleum" is 9 million tons per year, and the loading capacity of JSC "Loading terminal" is 3 million tons per year, which makes 82% and 18%, respectively. VOCs emission is expressed as percentage in each terminal zone.

According to the inventory data provided by SC "Klaipėda petroleum", it was determined that the biggest amounts of pollutants was emitted in jetty I – 44.96%. About 28.60% of the total amount of pollutants is emitted while loading light oil products in the railway trestle. 5.54% of VOCs is emitted into the ambient air while loading heavy oil products in the jetty II. The least amount of pollutants is emitted in the trestle II – 3.46%.

The loading indicator of JSC "Loading terminal" was calculated analogically.

### 2.5. Statistical analysis

In attempt to compare and summarise the results of VOCs concentration analysis beyond the territories of oil terminals during different seasons, we performed statistical data processing using software package *Statgraphic Plus*.

We applied *Kruskal-Wallis Test* reliability method in our tests. This test enables to establish significant differences of more than two independent groups.

## 3. Principal component analysis

VOCs concentrations beyond the territory of oil terminals during different seasons were analysed, when a new oil terminal of 3 million tons annual loading capacity, i.e. JSC "Loading terminal", started its activity in Klaipėda port (Table 2).

### 3.1. Temporal variation of VOCs

Meteorological elements have a significant impact on air quality in cities and industrial centres. Weak wind and air temperature inversions provide good conditions to accumulate air pollutants in lower atmospheric boundary layer.

Among the meteorological elements that affect the vaporization and dispersion of oil products are: air temperature, wind speed and direction, atmospheric pressure and relative humidity (Wise and Comrie 2005). It should be noted that vaporization of VOCs becomes more intensive with the rise of air temperature and wind speed. Those two parameters taken together affect the concentrations of VOCs in the air by 1–60% (Cetin and Odabasi 2003; Srivastava and Joseph 2006).

With increasing temperature the oil products evaporate more intensively, and these changes are most noticeable in summer. The highest monthly average air temperature is reached in July (16.7 °C) and the lowest – in January (–5.1 °C)

The average wind speed in Klaipėda was 4.7 m/s (1996–2006). The highest average wind speed is reached in autumn and winter, respectively, 5.6 and 5.0 m/s. The lowest average wind speed is reached in spring and summer, respectively, 4.2 and 4.0 m/s.

**Table 1.** Loading indicator (%) calculation scheme

| SC „Klaipėda petroleum“ | | | | | | JSC „Loading terminal“ | | |
|---|---|---|---|---|---|---|---|---|
| 100% | | | | | | 100% | | |
| I jetty (LOP) | II jetty (HOP) | I railway trestle (LOP) | | II railway trestle (HOP) | | III jetty | III railway trestle | |
| | | 1 track | 2 track | 1 track | 2 track | | 1 track | 2 track |
| 54.83 | 6.75 | 34.21 | | 4.21 | | 61.58 | 38.42 | |
| 82% | | | | | | 18% | | |
| 44.96 | 5.54 | 14.03 | 14.03 | 1.73 | 1.73 | 11.08 | 3.46 | 3.46 |

Note: LOP – light oil products, HOP – heavy oil products.

**Table 2.** VOCs concentration (mg/m³) in observation posts during different seasons

| Air sampling days \ Sampling points | WINTER | | | SPRING | | | SUMMER | | | AUTUMN | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| **1** | 2.38 | 1.51 | 1.64 | 0.86 | 0.97 | 1.01 | 1.41 | 1.27 | 1.73 | 1.49 | 1.51 | 1.43 |
| **2** | 1.75 | 1.59 | 1.39 | 1.03 | 0.98 | 1.03 | 1.51 | 1.84 | 1.98 | 1.53 | 1.53 | 1.60 |
| **3** | 1.41 | 1.48 | 1.54 | 0.77 | 0.76 | 0.91 | 1.32 | 1.44 | 1.64 | 1.40 | 1.65 | 1.59 |
| **4** | 1.43 | 1.44 | 1.36 | 1.02 | 1.05 | 1.15 | 1.48 | 1.45 | 1.81 | 0.70 | 0.63 | 0.58 |
| **5** | 2.49 | 2.21 | 3.12 | 1.16 | 1.32 | 1.31 | 1.23 | 1.27 | 1.26 | 0.90 | 0.97 | 0.98 |
| **6** | 1.77 | 2.49 | 1.93 | 0.99 | 1.06 | 1.16 | 1.50 | 1.66 | 1.47 | 1.04 | 1.04 | 1.03 |
| **7** | 1.69 | 1.74 | 1.82 | 1.02 | 0.93 | 0.98 | 1.63 | 1.69 | 1.45 | 1.02 | 1.05 | 1.10 |
| **8** | – | – | – | 0.83 | 1.09 | 1.07 | – | – | – | – | – | – |
| **9** | – | – | – | 0.71 | 1.02 | 0.86 | – | – | – | – | – | – |
| **10** | – | – | – | 0.77 | 0.83 | 1.00 | – | – | – | – | – | – |

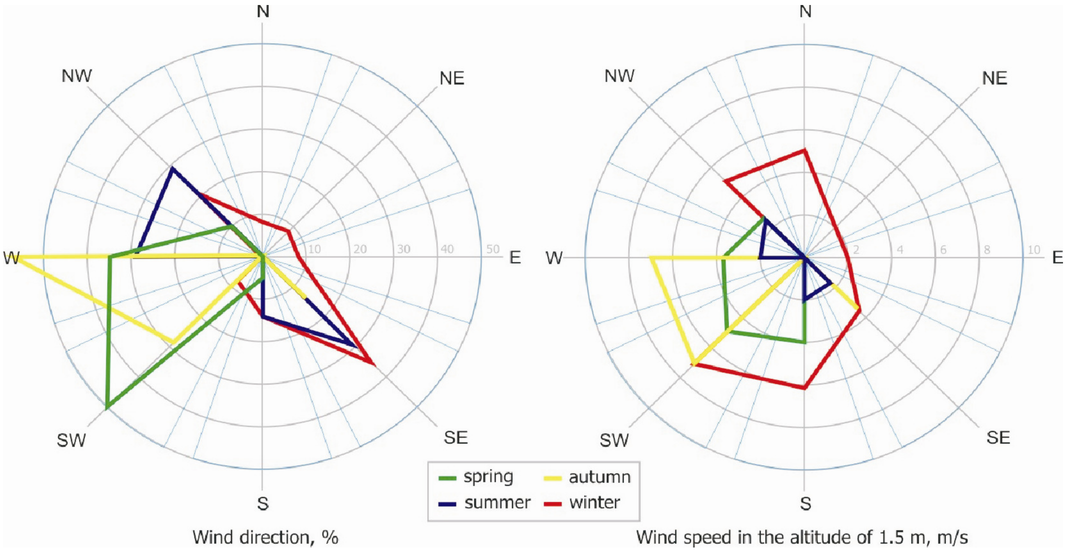


**Fig. 2.** Dominant wind speed and wind direction during air sampling

In order to determine the influence of wind speed on variation of VOCs concentration, a range of air sampling with ambient air temperature fluctuations of less than 3 °C was chosen.

The biggest wind speeds at 1.5 m height from the ground surface in the observation posts on analysis days were recorded in autumn – 2.40 m/s (Fig. 2). The wind speed was almost the same, i.e. up to 1.76 m/s, in winter and spring, and the lowest values of wind speed were recorded in summer, when the average wind speed was just 0.82 m/s.

Table 3 shows the prevailing meteorological elements and the values of loading indicator that were calculated according to the method shown in Table 1 during each season.

### 3.2. Spatial variation of VOCs

Amount of VOCs emission directly depends on the type of handling operations (loading or unloading), type of the loaded products (gasoline, jet fuel, diesel, fuel oil, etc.), height of the source of pollution and number of operations, i.e. the loading intensity (indicator). Distribution of VOCs depends on this indicator.

The intensity of the loading operations in oil terminals was the highest in summer – 56% (Table 3). The loading indicator during the analysing of VOCs concentration in spring and winter was lower and was up to 40%, meanwhile in autumn it was the lowest and up to 19%. Thus, we think that the change of VOCs concentration value in the lower atmospheric boundary layer depends not only on the intensity of loading operations in the oil terminals, but also on the meteorological conditions.

***In spring*** VOCs concentration fluctuated from 0.81 mg/m³ to 1.26 mg/m³. The biggest VOCs concentration (1.32 mg/m³) was determined on the fifth analysing day, when the amount of loading works was not big – just 12%, but a slight wind of west-southwest direction was prevailing, the speed whereof was merely 2.46 m/s (Fig. 3).

**Table 3.** Summary of meteorological conditions and loading indicator

| Seasons | Air sampling days | Meteorological conditions | | | | | Loading indicator, % |
|---|---|---|---|---|---|---|---|
| | | Wind speed, m/s | Wind direction | Air temperature, °C | Relative air humidity, % | Atmospheric pressure, mm Hg | |
| WINTER | 1 | 0.82 | E, NE | 1.0 | 88 | 765 | 35.91 |
| | 2 | 1.64 | SE | 0.8 | 53 | 776 | 25.42 |
| | 3 | 2.87 | S, SW | 1.0 | 88 | 757 | 25.42 |
| | 4 | 2.05 | N, NW | 1.1 | 79 | 759 | 18.17 |
| | 5 | 2.05 | NW | 1.8 | 93 | 756 | 63.35 |
| | 6 | 0.82 | SE | 0.6 | 100 | 748 | 88.03 |
| | 7 | 2.05 | S, SE | 1.6 | 89 | 774 | 18.17 |
| SPRING | 1 | 0.82 | W, SW | 12.0 | 84 | 756 | 1.47 |
| | 2 | 1.23 | SW | 11.7 | 99 | 755 | 30.44 |
| | 3 | 2.87 | W, SW | 10.8 | 80 | 762 | 63.05 |
| | 4 | 2.67 | SW | 10.8 | 81 | 760 | 66.61 |
| | 5 | 2.46 | W, SW | 9.5 | 91 | 757 | 11.97 |
| | 6 | 1.23 | W | 10.9 | 80 | 758 | 28.23 |
| | 7 | 1.64 | S, SW | 10.5 | 68 | 754 | 58.32 |
| | 8 | 1.44 | W, NW | 10.3 | 87 | 752 | 23.2 |
| | 9 | 2.46 | SW | 10.0 | 86 | 750 | 80.35 |
| | 10 | 0.62 | W, NW | 9.9 | 84 | 753 | 31.47 |
| SUMMER | 1 | 0.82 | W, NW | 22.3 | 52 | 773 | 66.61 |
| | 2 | 0.82 | W, NW | 21.6 | 63 | 772 | 63.35 |
| | 3 | 1.23 | NW | 22.2 | 74 | 769 | 19.94 |
| | 4 | 0.82 | W | 23.4 | 70 | 768 | 74.58 |
| | 5 | 0.41 | SE | 22.0 | 53 | 767 | 28.23 |
| | 6 | 0.82 | S, SE | 23.6 | 51 | 765 | 61.88 |
| | 7 | 0.82 | S, SE | 25.0 | 55 | 761 | 74.58 |
| AUTUMN | 1 | 2.87 | W | 10.2 | 93 | 755 | 51.38 |
| | 2 | 2.87 | W, SW | 10.8 | 96 | 758 | 1.47 |
| | 3 | 4.93 | W, SW | 9.6 | 97 | 745 | 11.96 |
| | 4 | 2.87 | W | 8.8 | 93 | 754 | 6.20 |
| | 5 | 0.82 | EW | 9.4 | 98 | 757 | 17.73 |
| | 6 | 1.44 | SE | 8.2 | 98 | 762 | 6.20 |
| | 7 | 0.99 | W | 8.8 | 97 | 766 | 39.85 |

The loading operations were the most intensive on the 9th day of analysing (up to 80%), when two tankers were filled with gasoline and it was unloaded on three railway tracks at the same time. However, VOCs concentration was low and up to 1.02 mg/m$^3$. In order to determine the peculiarities of the change of concentration of pollutants in the lower atmospheric boundary layer, it is necessary to analyze the impact of meteorological conditions on the scope of pollution.

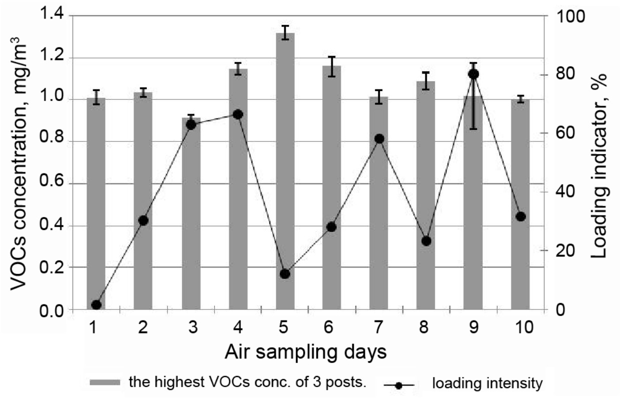


**Fig. 3.** Dispersion of VOCs concentration and loading indicator in spring

Wind speed and wind direction are the main meteorological elements determining the spread of pollutants. It was determined that the spread of the pollutants in the ambient air was increasing, when wind speed is lower than 2.0 m/s, and the spread of VOCs in the air is decreasing with bigger wind speeds. If wind speed is increasing, VOCs that are heavier than ambient air are carried away at bigger distances from the emission source, and they mix with a bigger amount of ambient air.

The largest VOCs concentration (1.32 mg/m$^3$) was recorded at 2.46 m/s wind speed, high relative humidity (91%) and atmospheric pressure lower than 760 mm Hg. All those factors determined the dispersion of pollutants in the ambient air.

***In summer*** VOCs concentration fluctuated from 1.27 to 1.98 mg/m$^3$ in three observation posts. Loading of light oil products was predominant during VOCs concentration analysing days in both oil terminals. The total average intensity of loading works was 56%, which is 1.4 time bigger compared to the analysis results obtained in spring.

In summer wind speed varied from 0.41 to 1.23 m/s (at 1.5 m height) and was by approximately 3 times lower than in spring. The lowest value of loading indicator was recorded on the third day of analysing (20%) (Fig. 4). At that moment VOCs concentration was as big as 1.64 mg/m$^3$,

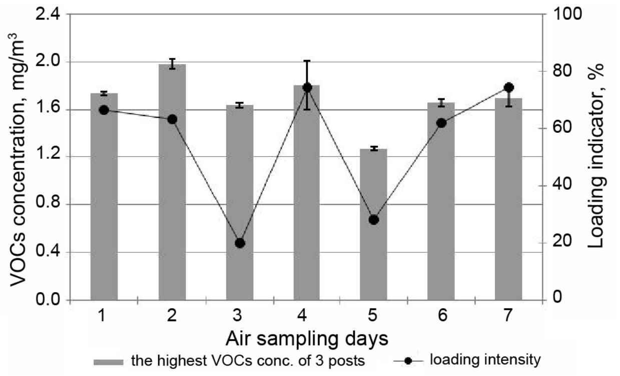


**Fig. 4.** Dispersion of VOCs concentration and loading indicator in summer

as the wind was quite weak (1.23 m/s). Intense loading operations were carried out in the oil terminals on the fourth and the seventh days of analysing (as big as 75%), and the VOCs concentration was maximum (1.81 mg/m$^3$ and 1.69 mg/m$^3$, respectively). A weak wind of 0.82 m/s was prevailing on the two analysing days.

Thus, the increase of VOCs concentration in summer was mostly determined by more intensive loading works of oil products in the presence of a weak wind. The average VOCs concentration varied from 1.44 to 1.62 mg/m$^3$ at three observation points and was by 65% bigger than in spring.

***In autumn*** VOCs concentration varied from 0.58 to 1.65 mg/m$^3$ in three observation posts.

The biggest VOCs concentration values were recorded in all the three observation posts during the first three analysing days of the period (Fig. 5). They varied from 1.40 to 1.65 mg/m$^3$. West wind 3.56 m/s (4.4 times bigger than in summer) was prevailing during the analysing period. The lowest VOCs concentration of 0.58 mg/m$^3$ was determined in the three observation posts on the fourth day of analysing, when the intensity of the loading operations was 6% in oil terminals.

On the first day of analysing, when the loading operations in the oil terminals were the most intensive (loading indicator – 51%), VOCs concentration was 1.51 mg/m$^3$ and by 31% lower than the biggest VOCs concentration value recorded in summer (1.98 mg/m$^3$, loading indicator 63%), and by 16% bigger than the biggest VOCs concentration value recorded in spring (1.32 mg/m$^3$, loading indicator 12%).

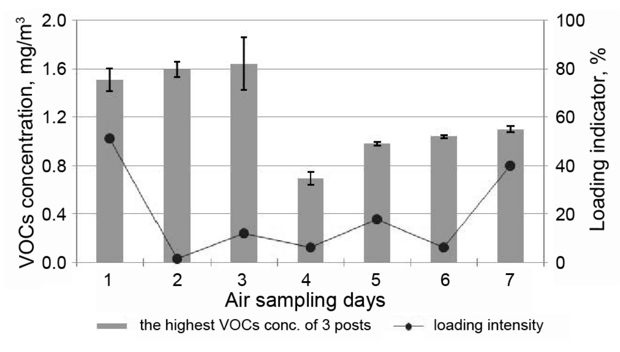


**Fig. 5.** Dispersion of VOCs concentration and loading indicator in autumn

When measuring VOCs concentration in autumn, west (57%), southwest (29%) and southeast (14%) winds were prevailing. The average speed of west and southwest wind was up to 2.56 m/s, and southeast – 1.44 m/s.

***In winter*** VOCs concentration fluctuated from 1.39 to 3.12 mg/m$^3$ at all the three observation points. The total average intensity of loading operations in oil terminals was 39% and 1.4 time less than in summer, 2 times higher than in autumn, while it was practically the same from the loading indicator determined in spring. Comparing the test results obtained in winter with the results obtained during other seasons, VOCs concentrations were the highest in winter.

The intensity of loading operations in the oil terminals was the highest on the sixth day of analysing – as high as 88% (Fig. 6). The meteorological conditions were unfavourable for the dispersion of pollutants on that day: wind speed was under 0.82 m/s. With such an intensity of loading operations and unfavourable meteorological conditions, VOCs concentration in the ambient air was as high as 2.49 mg/m$^3$.

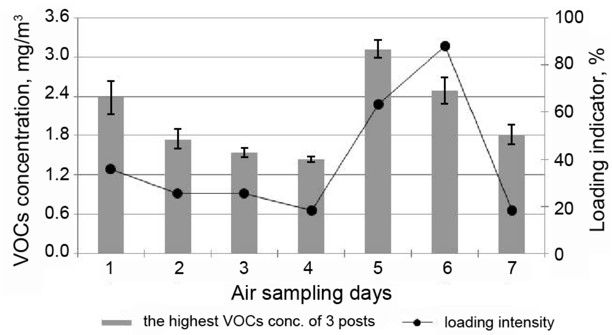


**Fig. 6.** Dispersion of VOCs concentration and loading indicator in winter

The lowest VOCs concentration value (1.44 mg/m$^3$) was recorded on the fourth day of analysing, when the intensity of loading operations in the oil terminals was the lowest (18%). The biggest VOCs concentration value at the three observation points (3.12 mg/m$^3$) was recorded on the sixth day of analysing; meanwhile, the intensity of loading works was 63% and northwest wind 2.05 m/s was blowing. In the latter case, the average VOCs concentration in the observation posts fluctuated slightly: from 1.60 to 1.74 mg/m$^3$.

Decreasing intensity of loading operations in the oil terminals from 62% to 25% had the main impact on the decreasing of VOCs concentration values during this season, and the effect of ambient air temperature, relative humidity and atmospheric pressure was minimal.

Thus, the VOCs concentration in lower atmospheric boundary layer depends on both the intensity of oil loading terminals, as well as the meteorological conditions – wind speed and ambient temperature, so the emission factors should be considered simultaneously.

It is known that the effect of ambient air temperature on VOCs concentration is as high as 48% (Cetin and Odabasi 2003). However, in our case, the summary of the results obtained during all the seasons reveals that air temperature does not have a predominant effect. The latter factor is important for the evaluation of the change of VOCs concentration in the lower atmospheric boundary layer only in such objects, where the intensity of loading intensity change from 0 to 100%.

It is stated in the scientific research works that the effect of wind speed on VOCs concentration in the lower atmospheric boundary layer fluctuates from 1 to 29% (Cetin and Odabasi 2003). The highest wind speed at 1.5 m height from the ground surface in the observation posts was 2.40 m/s on the average during analyses performed in autumn (Table 3). Wind speed was almost the same in winter and spring, and the average wind speed was 1.76 m/s. the lowest wind speed was recorded in summer – just 0.82 m/s on the average. Analysing the results of different seasons it was noted that VOCs concentration tended to decrease with the increase of wind speed. This tendency is revealed best in the results of the analyses performed in winter.

Using *Stratgraphic Plus* software package and *Kruskal-Wallis Test* method of reliability (95%), data analysis showed that the VOCs concentration depended on wind speed only when it was greater than 4 m/s (1.5 m above ground level – 1.64 m/s).

## 4. Conclusions

1. It is determined that the biggest VOCs concentrations may be recorded in winter and in summer – 3.12 mg/m$^3$ and 1.98 mg/m$^3$, respectively:
   - the increase of VOCs concentration in winter is related to the peculiarities of the produced fuel, i.e. more volatile fuel is produced during the cold season that allow to start the engine of a car easily in cold weather and to keep it running while on the way. The density of winter fuel is lower, so such a fuel vaporizes easier at lower temperatures;
   - the main reason of VOCs concentration increase in summer is higher air temperatures (up to 25 °C);
   - VOCs concentrations in spring and in autumn differ by up to 10%.
2. A new indicator – loading indicator – is offered for making complex evaluation of the effect of the intensity of loading operations in oil terminals and the kind of oil products loaded on VOCs emission. It is determined that there exists interdependence between the change of VOCs concentration and the loading indicator. Statistical data processing have revealed that the number and nature of loading operations (loading indicator) carried out in oil terminals determines VOCs concentration in the lower atmospheric boundary layer only in those cases, when the loading indicator is higher than 80% ($P < 0.05$).
3. After making an analysis of VOCs concentration investigation results obtained during different seasons and of the multifactor dispersion analysis with 95% reliability, it has been determined that the change of VOCs concentration in the lower atmospheric boundary layer depends on wind speed when it is higher than 4 m/s (at 10 m height, $P < 0.05$). The dependence of VOCs concentration on the atmospheric pressure and relative humidity is insignificant ($P > 0.05$).

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## LAKIŲJŲ ORGANINIŲ JUNGINIŲ EMISIJOS TYRIMAS UŽ NAFTOS TERMINALŲ TERITORIJOS SKIRTINGAIS SEZONAIS

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Santrauka

Analizuojama svarbi aplinkosauginė problema – oro tarša lakiaisiais organiniais junginiais (LOJ) naftos terminaluose. Siekiant nustatyti LOJ koncentracijos ore priklausomumą nuo vėjo greičio, aplinkos drėgmės ir atmosferos slėgio, atlikti trumpesnės trukmės tyrimai, kai aplinkos temperatūros svyravimai yra minimalūs – 13 ºC. Pasirinktuose stebėjimo postuose dujų chromatografijos būdu nustatytos LOJ koncentracijos skirtingais sezonais. Atlikta kompleksiniai eksperimentiniai tyrimai ir meteorologinių sąlygų (oro temperatūros, aplinkos drėgmės, atmosferos slėgio, vėjo greičio ir krypties) įtakos oro taršai analizė, atsižvelgiant į naftos terminalų krovos intensyvumą ir kraunamų produktų rūšis. Analizuojant gautus duomenis įvestas naujas rodiklis – krovos indikatorius, apibūdinantis kraunamų produktų kiekį, rūšį, terminale atliekamų operacijų skaičių ir pobūdį. Nustatytas LOJ koncentracijos kitimo priklausomumas nuo krovos indikatoriaus. Statistiškai apdorojus rezultatus akivaizdu, kad naftos terminaluose krovos operacijų skaičius ir pobūdis (krovos indikatorius) lemia LOJ koncentraciją pažemės atmosferos sluoksnyje. Atlikus LOJ koncentracijos tyrimo skirtingais sezonais duomenų analizę ir daugiafaktorinę dispersinę analizę, 95 % patikimumu nustatyta, kad LOJ koncentracijos kitimas pažemės atmosferos sluoksnyje priklauso nuo vėjo greičio, kai vėjo stiprumas yra didesnis nei 4 m/s (10 m aukštyje, $P < 0{,}05$).

**Reikšminiai žodžiai:** lakieji organiniai junginiai (LOJ), LOJ emisija, naftos terminalas, krovos indikatorius, atmosferos tarša, garavimas.

## ИССЛЕДОВАНИЕ СЕЗОННЫХ ВЫБРОСОВ ЛЕГКОЛЕТУЧИХ ОРГАНИЧЕСКИХ СОЕДИНЕНИЙ ЗА ПРЕДЕЛАМИ НЕФТЕБАЗ

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Резюме

Исследована проблема испарения легколетучих органических соединений (ЛОС) на нефтебазе. Для того, чтобы установить зависимость концентрации ЛОС от скорости ветра, влажности воздуха и давления атмосферы было произведено исследование концентрации ЛОС в воздухе, во время которого изменение температуры не превышало 3 градусов. Методом газовой хроматографии были исследованы сезонные выбросы ЛОС в приземные слои атмосферы. Комплексно проанализированы полученные экспериментальные данные и метеорологические условия (температура и влажность воздуха, давление атмосферы, сила и направление ветра) с учетом производимых операций по перегрузке нефтепродуктов и их типа. Для более точного анализа полученных данных был сформулирован новый «индикатор погрузки», который характеризует количество и тип перегружаемых нефтепродуктов, количество и тип производимых технологических операций. В связи с этим была установлена зависимость концентрации ЛОС от индикатора погрузки. Статистический анализ данных показал, что количество производимых технологических операций на нефтебазах, а также их тип, влияют на изменение концентрации ЛОС. Анализ исследования сезонных выбросов ЛОС и многофакторный дисперсионный анализ данных с 95%-й точностью показали, что изменение концентрации ЛОС в приземных слоях атмосферы зависит от скорости ветра в том случае, если она превышает 4 м/с на высоте 10 м ($P < 0.05$).

**Ключевые слова:** легколетучие органические соединения (ЛОС), эмиссия ЛОС, нефтебаза, индикатор погрузки, загрязнение атмосферы, испарение.

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