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Temperature Inversions in the Atmosphere
using Different Analyzers**

**Egor Iasenko
PhD Candidate
National Research University ITMO
Russia**

**Vladimir Chelibanov
PhD Candidate
National Research University ITMO
Russia**

**Alexander Marugin
PhD Candidate
JSC OPTEC
Russia**

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Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL:
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Monitoring of Ozone Ground Concentration at Temperature Inversions in the Atmosphere using Different Analyzers

**Egor Iasenko
Vladimir Chelibanov
Alexander Marugin**

Abstract

The tropospheric ozone is one of the most dangerous pollutants, capable to arise in the contaminated atmosphere of any city. To date the monitoring of the ozone content in the air is carried out using the analyzer that is based on a method of ultraviolet (UV) photometry. Some time ago, this analyzer has been given a category Federal equivalent method (FEM), as the Federal reference method (the FRM) uses ethylene chemiluminescence reaction with ozone. There are a number of works that indicate that in a contaminated atmosphere UV photometry analyzer cannot issue the exact value of the concentration of the ozone. At the same time, the use of FRM is too complicated and a dangerous method of monitoring the ozone in the air. Relatively recently the ozone analyzer based on solid-state heterogeneous chemiluminescence was developed in our laboratory. Based on the results of the real monitoring of ozone ground concentration at the temperature inversions in the atmosphere of Saint-Petersburg, this paper shows the results of the comparative studies of two types of ozone analyzers: UV-photometry (Model 49i) and solid-state heterogeneous chemiluminescence (Model 3-02P-A). In addition, the laboratory comparison of the FEM analyzer and FRM (Bendix Model 8002) with Model 3-02P-A was done. The obtained experimental data demonstrates the significant influence of atmospheric air components on the measurement of ozone concentration by UV-photometry method. So, the presence of ozone in the contaminated atmosphere could be correctly identified by using the method of heterogeneous or homogenous chemiluminescence only.

Keywords: Air pollution, Chemiluminescence, Ozone, Temperature inversions, UV-photometry.

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Introduction

It is known that in the troposphere during the formation of temperature inversions appears barrier preventing vertical transfer of air masses. Furthermore, accumulation of active contaminants can occur in industrial cities in the air which is below the inversion layer. The situation can worsen in case of high solar activity when “secondary” toxic air pollutants are being formed. Tropospheric ozone is also formed by photochemical reactions in the lower atmosphere under sunlight in the presence of nitrogen oxides, volatile organic compounds (VOC), and others. The list of requirements to the air purity (Clean Air Act) determines its quality standards in terms of O_3 content and prescribes to the state and local authorities to carry out the permanent monitoring of the ozone in the ambient atmosphere. Also the ozone monitoring is relevant for the observed temperature inversion, when possible accumulation of large amounts of air pollutants.

On the territories where the non-conformity with air quality standards is revealed the respective management decisions shall be taken purposing to reduce the ozone concentrations to admissible values of its concentrations in the air. Such measures, as a rule, include rather expensive activities like reduction in emissions of hydrocarbons and NO_x . This is because the experimentally revealed non-conformities require costly measures to monitor these emissions. This can initiate the imposition of penalties on the responsible for the breach of environmental legislation. Therefore, it is very important to obtain accurate values of the ozone concentration.

By now, two methods for the measurement of ozone concentration in atmospheric air are actively used. The first is the Federal Reference Method (FRM) based on the selective chemiluminescent reaction of ozone with ethylene in the gas phase (gas-phase titration). This method was mostly used on the territory of the USA in the 1970-s and further down to the 1980-s. It is known that water vapor [1-3] was used as impurity of atmospheric air that could affect the readings of the instrument and this impurity was subjected to the examination. The influence of water vapor concentration was revealed. The additional output signal observed on the channel of O_3 concentration measurement made up the value of 3-4% per each 10,000 ppm of water vapor in air [1,4]. Later, in order to reduce operating costs and increase the safety level while carrying out the monitoring of ozone the gas-phase chemiluminescent method was substituted practically everywhere in the USA with the Federal Equivalent Method (FEM), ultraviolet (UV) photometry.

The UV-photometry uses the intensive band of ozone molecule absorption in UV emission which maximum coincides with the well-marked emission line of mercury vapors under low pressure at 253.7 nm. Measurements carried out using the low-pressure mercury lamp as radiation source and the optical cell of short length allowed providing the O_3 sensitivity of the analyzer on the level of ppb units. As experience shows the significant part of the instrument measurement error is pre-determined by uncertainty of the absorption cross-section at the mercury line of 253.7 nm. Industrial prototypes of instruments-analyzers based on UV photometry measure the UV radiation transmission through the gas cell, containing

ozone, and compare the intensity of the light flux at the outlet from this cell with the intensity of light flux at the outlet from the similar gas cell but without O_3 . The measurement of light transmission through the cell with ozone and without it should be considered as a more correct procedure, but this requires the obligatory presence of all impurities of atmospheric air excluding ozone. However, this is the task, difficult to implement in practice, as a selective catalytic absorbent of ozone used in so-called scrubbers is applied for the selective extraction of O_3 from the gas mixture. Many other atmospheric contaminants (undetectable by analyzer) being often capable to absorb, by themselves, the radiation at the wave length 253.7 nm, or being capable to be absorbed in scrubbers. This circumstance can drastically affect the accuracy and selectivity of the ozone analysis being carried out in contaminated atmospheric air by the UV-photometry method.

Researches carried out in the laboratory, allowed detecting the air pollutants capable to interfere with the results of analysis obtained by UV-photometry method. Hydrocarbons and secondary atmospheric products of reactions, [2, 5-9], mercury vapors, [3, 10], SO_2 , water vapor [3, 4, 11-13], NO_2 , dust [14] could be subsumed under such impurities. When it is referred to the error of the UV-photometry method the attention is usually and mostly paid to the efficiency of the ozone scrubber operation and to the influence of water vapors. We shall not discuss the particular design features of different scrubbers but just note that all of them to a greater or lesser extent have disadvantages in respect to the sorption selectivity of different types of pollutants in the air. The effect of the water vapor interference in the measurements of O_3 by UV-photometry method is rather complicated. Moreover, both the water vapor concentration value can interfere with the results of the analysis and the first time derivative of the analysis can do so as well.

There are works that represent the results of actual measurements of ozone concentration in the air by different methods [8, 15-17]. Leston et al. [8] discovered the significant difference between the data of UV-photometric and chemiluminescent measurements of O_3 when the measurements took place in the city environment. Arshinov et al. [15] observed significant difference between UV-photometric and chemiluminescent methods of ozone measurement on board of the research ship. Authors explain this difference in the ozone measurements by interference of fine dispersed particles when using the UV-method. Dunlea et al. [17] compared methods of UV-photometry, differential optical absorption spectroscopy (DOAS) and Fourier transform infrared (FTIR) by measuring the O_3 concentration in two districts of the same city. The error of the ozone content between the methods was within the interval from +13% to -18% and the authors put this error down to incorrect calibration of O_3 UV-analyzers. The authors did not exclude the probable interference of non-measurable air impurities in the results of analysis. Without getting into discussions about other results of measurements we propose to refer to the detailed review of this topic made by Parrish and Fehsenfeld [18].

For accurate measurements of ground-level ozone in a polluted air, by JSC OPTEC analyzer was developed based on the method of solid-state

heterogeneous chemiluminescence. This paper presents the comparative study of field measurements of ground-level ozone in the urban environment under two ozone analyzers: Thermo Electron mod.49i (UV photometry) and JSC OPTEC mod. 302P-A (solid-state heterogeneous chemiluminescence). In addition, the laboratory comparison of FEM analyzer and FRM (Bendix Model 8002) with Model 3-02P-A was done.

Experiment and Discussion

The influence of impurities impeding the operation of ozone analyzers based on methods of UV-photometry, gas-phase and solid-state heterogeneous chemiluminescence were studied in conditions of laboratory and field experiments. Following analyzers were used as ozone measuring instruments:

- UV-photometry (Thermo Electron mod.49i);
- Gas-phase chemiluminescence (Bendix mod. 8002);
- Solid-state heterogeneous chemiluminescence (OPTEC, mod. 302P-A);

They all have optimal meteorological characteristics for the precise measurement of ozone in the air (Table 1).

Table 1. *Meteorological Characteristics O₃ Analyzers*

	Bendix (FRM)	49i (FEM)	OPTEC
Range	0-1 ppm	50-1000 ppb	0-500 ppb
Noise	1%	0.25 ppb	0.1 ppb
LDL	1.0 ppb	1.0 ppb	0.2 ppb
Zero drift 24hr	1%	<1 ppb	±0.5 ppb
Lag time	≤3 s	10-300 s	1 min

Solid-state Heterogeneous Chemiluminescent Analyzer OPTEC, mod.302P-A

The Optec JSC Model 3.02P-A Chemiluminescent O₃ analyzer is a gas comparator. The comparison is carried out between a reference gas mixture from a reference gas source (internal calibrator) and an analyzed gas sample. An internal pump is used to draw a gas sample into the chemiluminescent reactor for analysis. The basis of ozone concentration measurements in the analyzed airstream is the solid-state heterogeneous chemiluminescent method. The essence of this method consists in the luminescence accompanying the selective chemical interaction of O₃ molecules with the sensor that was developed to measure ozone in ambient air. As the sampled gas passes over the sensor, the ozone molecules interact with chemical substances, which are bound to the surface of the sensor resulting in the chemiluminescence, which is measured with a photomultiplier tube (Figure 1). The intensity of luminescence (near 560 nm) is linearly proportional to the concentration of O₃ in the analyzed gas. The measured signal is recorded internally and transformed to a digital display and can be transmitted via

analog outputs. The sensor is the plate of 25 mm in diameter and 1 mm thick and this is the main element of the reaction chamber in the gas analyzer. The sensor is coated with a special mixture consisting of 3,4,5-trihydroxybenzoic acid and Rhodamine 6G dye to provide chemiluminescent properties. The measurement process is schematically shown in Figure 2.

Figure 1. *Illustration of Chemiluminescent Process used in the Model 3.02P-A O₃ Analyzer*

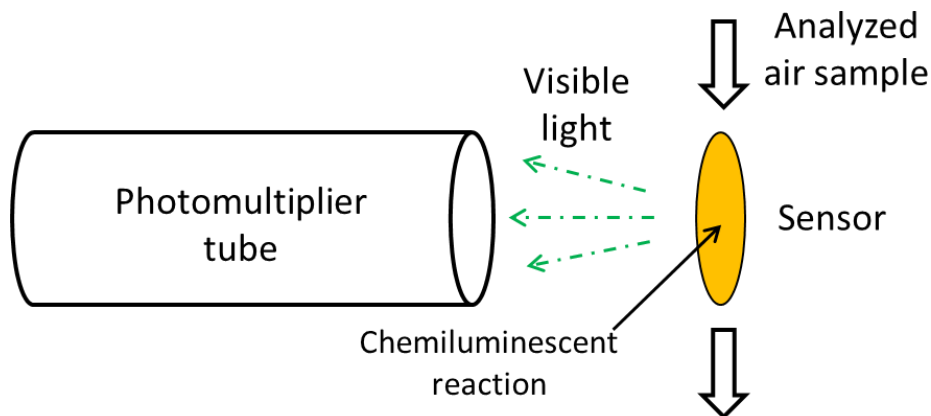
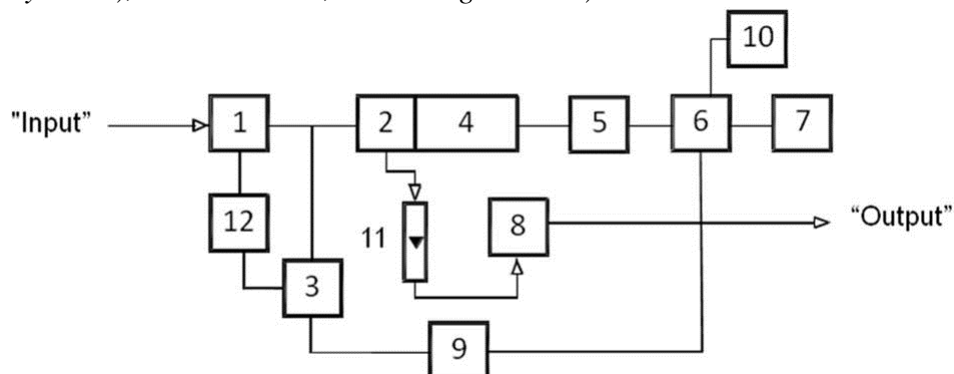


Figure 2. *Schematic Illustration of the Model 3.02P-A O₃ Analyzer (1. Valve, 2. Chemiluminescent Reactor, 3. Calibrator, 4. Photomultiplier Tube, 5. Analog-to-digital Transformer, 6. Processor, 7. Digital Indicator, 8. Pump, 9. Calibrator Power Supply, 10. Control Buttons (Control Keyboard), 11. Rotameter, 12. Zero-gas Filter)*

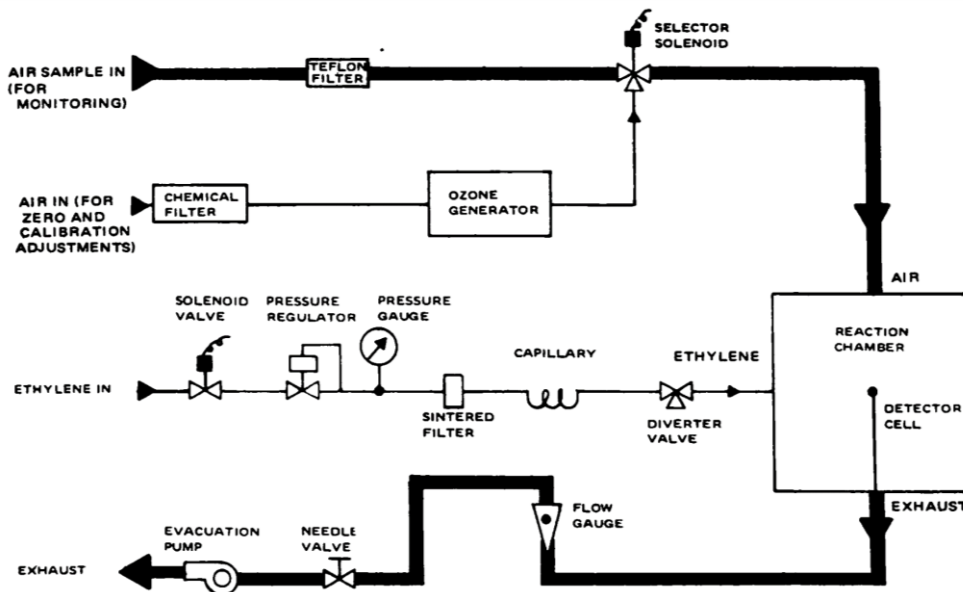


Gas-phase Chemiluminescence Analyzer Bendix mod.8002

The Bendix Ozone Monitor samples the ambient air, detects the presence of any ozone in the sample, and indicates the amount of ozone in the air on its front-panel meter (or on a chart recorder). An air pump in the unit constantly pulls in ambient air for sampling. The unit reacts quickly to changes in the air, providing an accurate reading within 10 seconds after a change occur in the intake sample. The basic operating principle is this: when ozone is mixed with ethylene gas, "chemiluminescence" occurs (gas phase titration). In the monitor, a controlled amount of ethylene gas is mixed with the samples of air pulled in by the air pump. If any O₃ is present

in the air sample, the chemiluminescence reaction occurs. A light-sensitive photomultiplier tube senses the light, and produces an output current which is amplified to drive the panel meter. Refer to Figure 3, which shows the flow paths for the air samples and the ethylene gas [19].

Figure 3. *Schematic Illustration of the Bendix Ozone Monitor Air Samples mod.8002*



The gas-phase chemiluminescence O_3 analyzer is also a gas comparator. For this reason, it also contains in its interior construction calibrator (ozone generator). It also has a Chemical filter, which is needed to create a zero gas (without ozone). Because the basis analyzer chemiluminescent reaction is selective, the chemical selectivity of the ozone filter (scrubber O_3) is not critical. It should be noted, although the FRM device and is accurate, it is difficult to use for monitoring the polluted air due to fire hazard and dimensions.

Thermo Electron mod.49i (UV-Photometry)

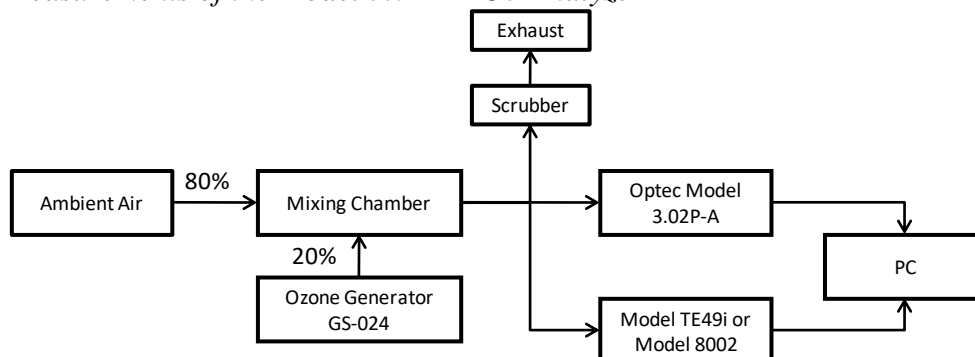
The Model 49i operates on the principle that ozone (O_3) molecules absorb UV light at a wavelength of 254 nm. The degree to which the UV light is absorbed is directly related to the ozone concentration as described by the Beer-Lambert Law [20]. This method is not selective, since polluted air has more compounds which are capable of absorbing the same wavelength of 254 nm. Moreover, as already mentioned all filters (scrubber) ozone in varying degrees, are not selective with respect to ozone.

Laboratory Comparability Model 3.02 P-A with FEM and FRM

The performance of the Optec Model 3.02 P-A was evaluated in comparison with the Thermo Electron Model TE49i (FEM) ozone analyzer first and then in comparison with Bendix Model 8002 (FRM) ozone analyzer. This comparability test was performed according to the procedures

described in the 40 Code Federal Regulation (CFR) Part 53.32 and under the conditions set forth in 40 CFR Part 53, Subpart C, Table C-1. Figure 4 illustrates schematically the comparability test configuration.

Figure 4. *Illustration of Test Configuration for Comparability Measurements of the Model 3.02P-A O₃ Analyzer*



Comparability with FEM

The test with the Model TE49i analyzer was conducted for three days running since July 12, 2010. Figures 5-7 present comparisons of the readings from two analyzers for each day of the testing. The results of the comparability measurements between the Optec Model 3.02 P-A and the Model TE49i analyzer are summarized in Table 2.

Figure 5. *Results of the First Day of Comparability Test between the Optec Model 3.02 P-A and the Thermo Electron Model TE49i*

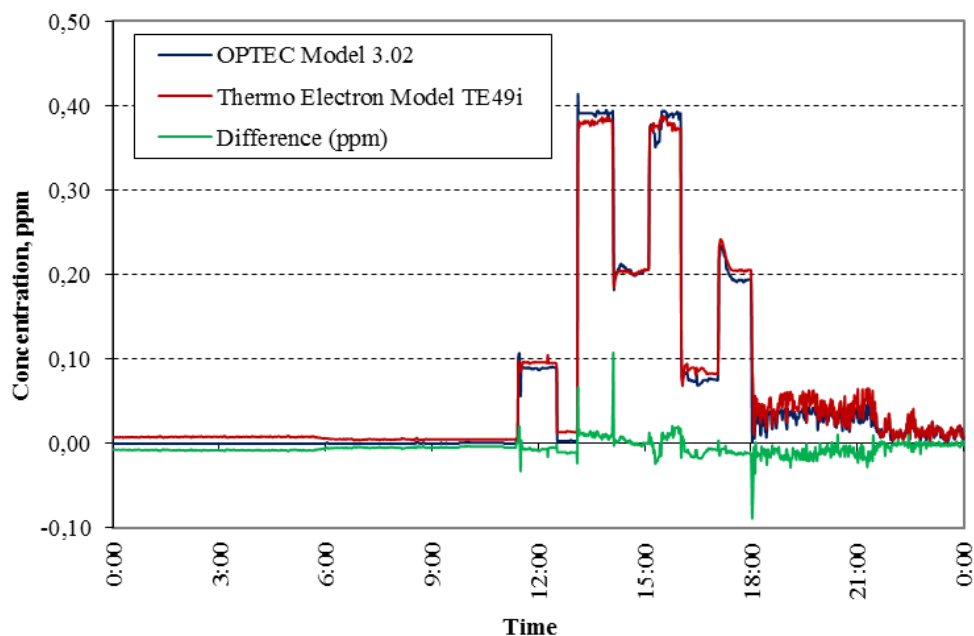


Figure 6. Results of the Second Day of Comparability Test between the Optec Model 3.02 and the Thermo Electron Model TE49i

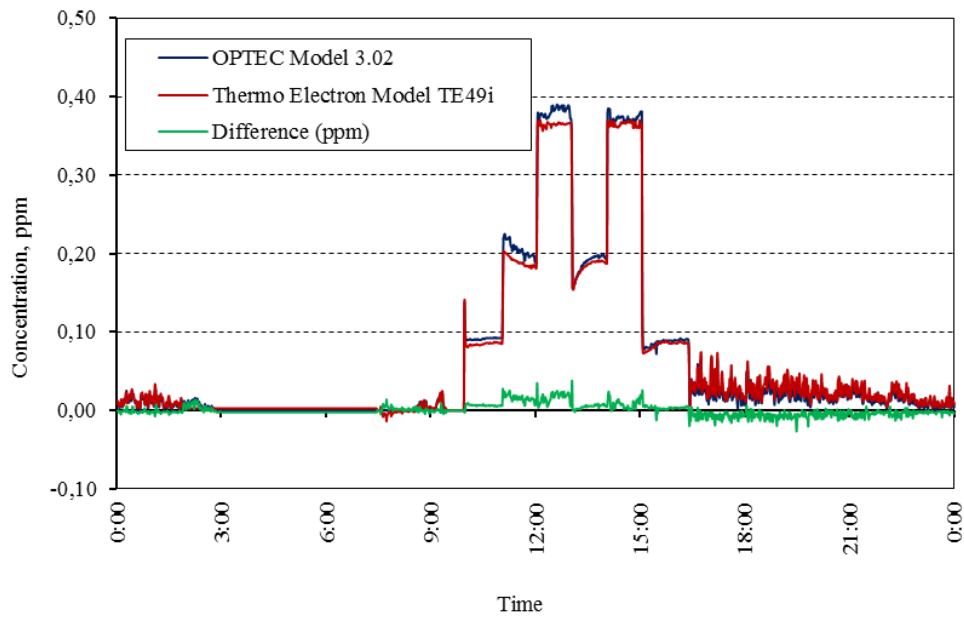


Figure 7. Results of the Third Day of Comparability Test between the Optec Model 3.02 and the Thermo Electron Model TE49i

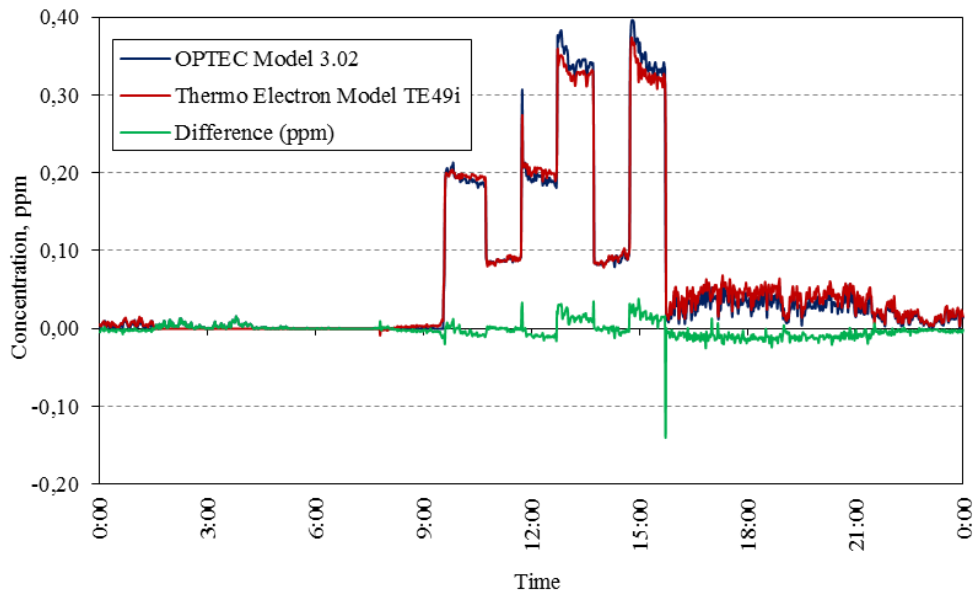


Table 2. *Summary of Comparability Test with Model TE49i (FEM) Analyzer*

Concentration Range, ppm	№	Date	Time	Concentration, ppm		Pass/Fail
				JSC OPTEC Model 3.02P-A	Thermo Electron Inc. Model TE49i	
Low 0.06-0.10	1	7/12/10	11:30-12:30	0.09	0.10	Pass
	2	7/12/10	16:02-17:01	0.08	0.09	Pass
	3	7/13/10	10:00-10:59	0.09	0.08	Pass
	4	7/13/10	15:04-16:03	0.09	0.08	Pass
	5	7/14/10	10:44-11:42	0.09	0.09	Pass
Med. 0.15 – 0.25	1	7/12/10	14:07-15:06	0.20	0.20	Pass
	2	7/12/10	17:05-17:59	0.20	0.21	Pass
	3	7/13/10	11:00-11:59	0.20	0.18	Pass
	4	7/13/10	13:03-14:02	0.19	0.18	Pass
	5	7/14/10	9:40-10:39	0.19	0.20	Pass
High 0.35 – 0.45	1	7/12/10	13:07-14:05	0.39	0.38	Pass
	2	7/12/10	15:08-16:00	0.38	0.38	Pass
	3	7/13/10	12:03-13:01	0.38	0.36	Pass
	4	7/13/10	14:03-15:02	0.37	0.36	Pass

Comparability with FRM

The test with the Bendix Model 8002 FRM ozone analyzer was performed for three days running since December 29, 2010 according to the same procedures and test conditions. Figures 8-10 present comparisons of the readings from two analyzers for each day of the testing. The results of the comparability measurements between the Optec Model 3.02 P-A and the Bendix Model 8002 are summarized in Table 3.

Figure 8. Results of the First Day of Comparability Test between the Optec Model 3.02 and the Bendix Model 8002

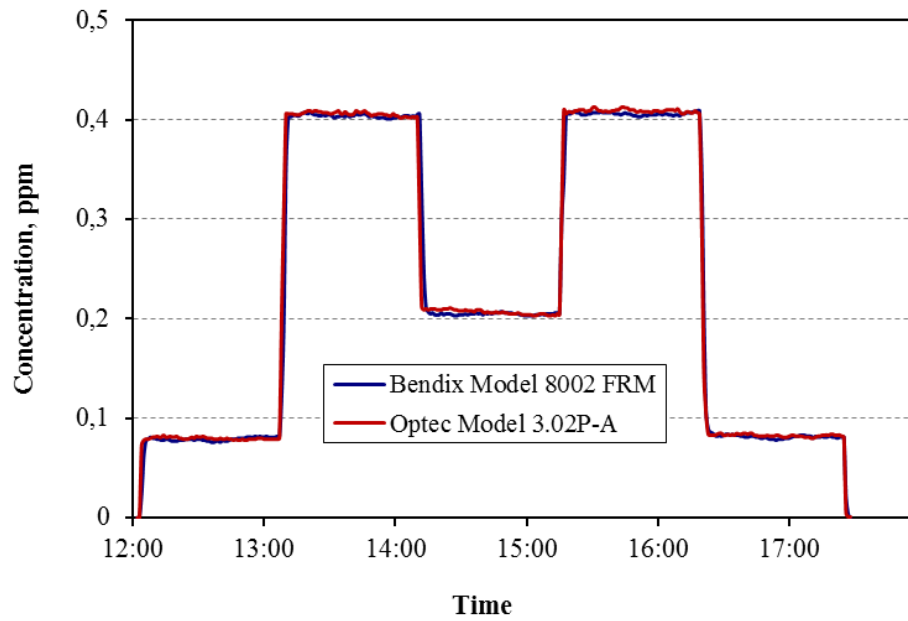


Figure 9. Results of the Second Day of Comparability Test between the Optec Model 3.02 and the Bendix Model 8002

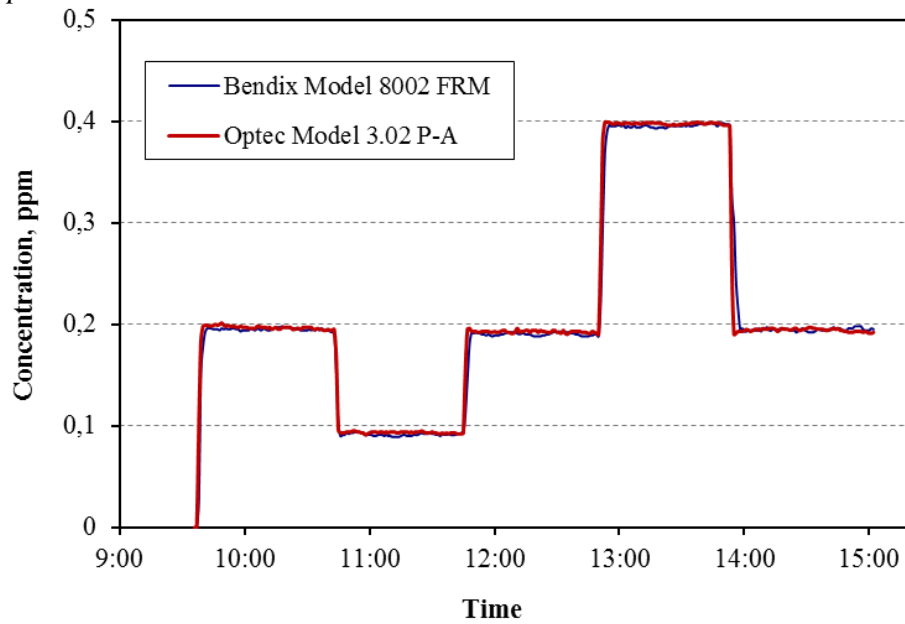


Figure 10. Results of the Third Day of Comparability Testing Test between the Optec Model 3.02 and the Bendix Model 8002

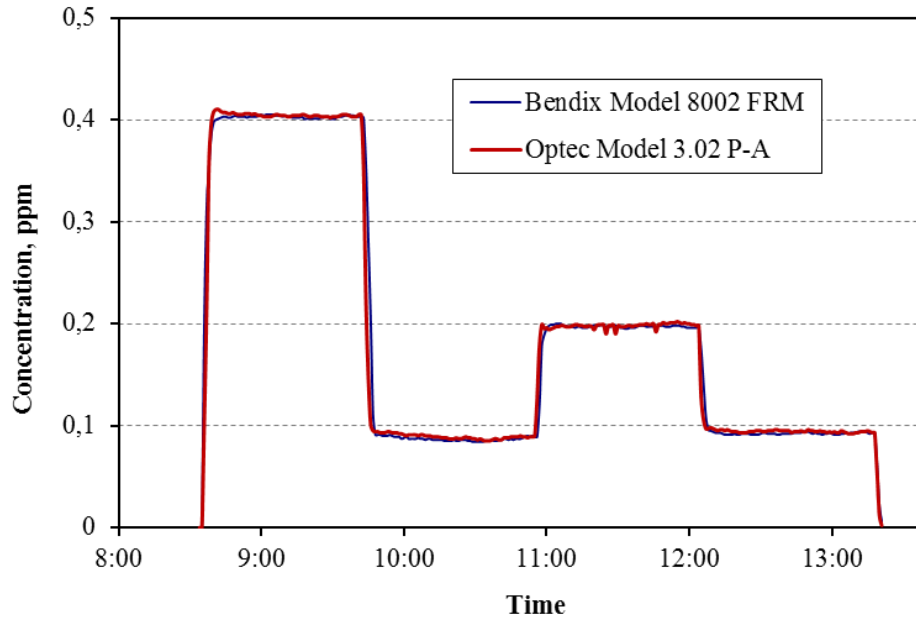


Table 3. Summary of Comparability Tests with Bendix Model 8002 (FRM) Analyzer

Concentration Range, ppm	№	Date	Time	Concentration, ppm		Pass/Fail
				JSC OPTEC Model 3.02P-A	Bendix Model 8002	
Low 0.06-0.10	1	12/29/10	12:06-13:05	0.079	0.080	Pass
	2	12/29/10	16:25-17:24	0.081	0.083	Pass
	3	12/30/10	10:47-11:45	0.091	0.093	Pass
	4	12/31/10	09:50-10:49	0.087	0.089	Pass
	5	12/31/10	12:11-13:10	0.092	0.094	Pass
Med. 0.15 – 0.25	1	12/29/10	14:15-15:14	0.205	0.207	Pass
	2	12/29/10	09:42-10:41	0.195	0.197	Pass
	3	12/30/10	11:49-12:48	0.190	0.193	Pass
	4	12/31/10	14:00-14:59	0.195	0.195	Pass
	5	12/31/10	11:00-11:59	0.197	0.198	Pass
High 0.35 – 0.45	1	12/29/10	13:11-14:10	0.404	0.406	Pass
	2	12/29/10	15:20-16:19	0.406	0.409	Pass
	3	12/30/10	12:56-13:53	0.395	0.398	Pass
	4	12/31/10	08:45-09:43	0.403	0.403	Pass

Comparison of Model 3.02 P-A with Model 49i in Real Urban Air under Conditions of Temperature Inversion

The goal of the experiments was to obtain and compare ozone values of two measurement methods (UV-photometry and solid-state heterogeneous chemiluminescence) under conditions of temperature inversion in the urban city. The stationary air monitoring station (JSC OPTEC), located on one of the busiest streets of the city of St. Petersburg has been used to obtain real data. The station equipment makes it possible to perform the monitoring of some air pollutants. In this case following substances were measured: NO₂, dust (PM 1.0) and of course the O₃ (UV-photometry and solid-state heterogeneous chemiluminescence). Figures obtained on March 28-29, 2016 are given below (Figures 11 and 12). During this time there was a temperature inversion in St. Petersburg (data from the open source of information <http://www.flymeteo.org/>) (Figure 13).

Figure 11. “Apparent” Increase in the Concentration of Ozone in Ground Level of Atmosphere that was observed during the Formation of Temperature Inversion on March 28-29, 2016. Influence of the Concentration of NO₂ on Readings of UV-Photometer, Model 49i

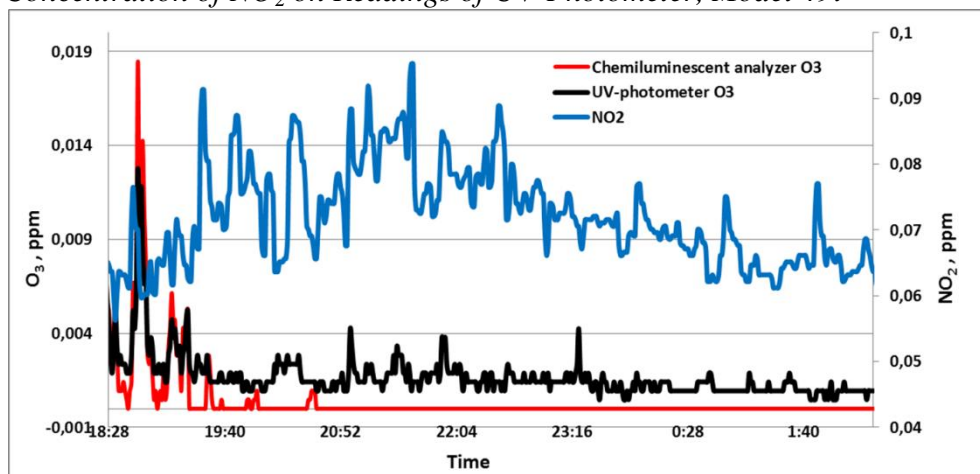


Figure 12. “Apparent” Increase in the Concentration of Ozone in Ground Level of Atmosphere that was observed during the Formation of Temperature Inversion on March 28-29, 2016. Influence of the Concentration of Fine Dispersed Dust Particles (PM1.0) on Readings of UV-Photometer, Model 49i

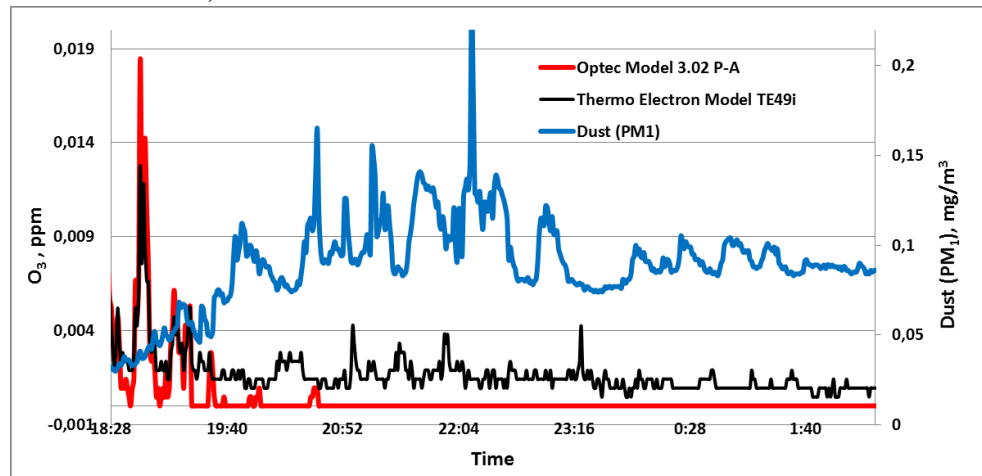
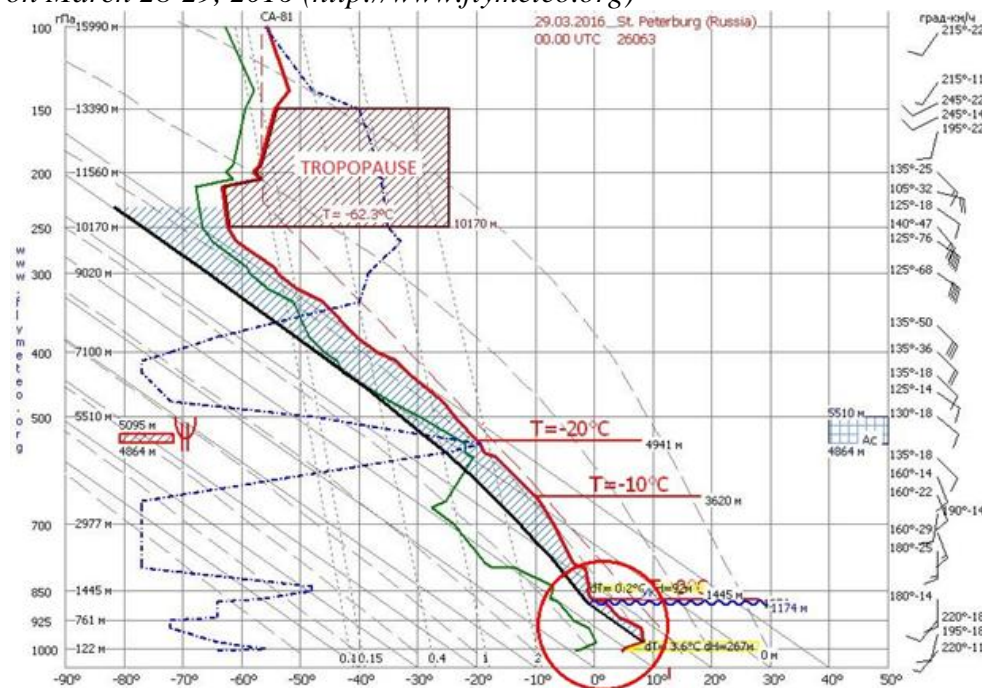


Figure 13. Temperature Inversion that was observed in Lower Troposphere on March 28-29, 2016 (<http://www.flymeteo.org>)



The tests fulfilled shown that during the temperature inversions the ozone analyzer - UV-photometer Mod.49i - can detect other contaminants, besides O_3 , that are accumulated in the ground level of atmosphere, including fine dispersed particles of the dust; the “apparent emergence” of O_3 as product of photochemical reaction being not consisted with the reality. This likely occurs because of the structural defects of the inlet filter of the instrument. The filter is not capable to remove non-measurable components and aerosol particles with the size less than 0.2 microns and has a poor

selectivity of ozone scrubber. It is quite likely that this is reason of positive interferences of ozone concentration values obtained on the optical UV-photometer in the morning and during the daytime.

Conclusions

The laboratory comparison of solid-state heterogeneous chemiluminescence analyzer OPTEC Model 3-02P-A with UV-photometry analyzer Thermo Electron mod.49i (FEM) and homogeneous chemiluminescence analyzer Bendix Model 8002 (FRM) was done successfully. It can be concluded that all three methods can be used to measure ozone in pure gases.

The comparison of Model 3.02 P-A with Model 49i in real urban air in Saint-Petersburg under conditions of temperature inversion also was done. The obtained experimental data demonstrates the significant influence of atmospheric air components (NO₂ and dust <0.2 microns) on the measurement of ozone concentration by the UV-photometry method. We assume that this is due to non-ideal particle filter and a poor selectivity of ozone scrubber. Who is able to absorb from the air in addition to ozone and other gases that absorb at the same wavelength of 254 nm.

Due to all the above it can be concluded that ozone ground concentration at temperature inversion in the atmosphere could be correctly identified by using the method of chemiluminescence only. Since the method is based on selective reaction with ozone, even in the presence of other air pollutants.

References

- [1] Mayer, V.A., S.A. Arendt, S.J. Bailey, et al., eds. 2006. D 5149-02 Standard test method for ozone in the atmosphere: continuous measurement by ethylene chemiluminescence. In *Annual Book of ASTM Standards*. vol. 11.03, 430. West Conshohocken, PA: ASTM.
- [2] Kleindienst, T.E., E.E. Hudgens, D.F. Smith, F.F. McElroy, and J.J. Bufalini. 1993. Comparison of chemiluminescence and ultraviolet ozone monitor responses in the presence of humidity and photochemical pollutants. *J. Air Waste Manage. Assoc.* 43:213-22. DOI= doi:10.1080/1073161X.1993.10467128.
- [3] Leston, A., and W.M. Ollison. 1992. Estimated accuracy of ozone design values: Are they compromised by method interferences? In *Tropospheric Ozone: Nonattainment and Design Value Issues*, 451. Pittsburgh, PA: Air & Waste Management Association.
- [4] Hudgens, E.E., T.E. Kliendienst, F.F. McElroy, and W.M. Ollison. 1994. A study of interferences in ozone UV and chemiluminescence monitors. In *Measurement of Toxic and Related Air Pollutants*, 405-15. VIP-39. Pittsburgh, PA: Air & Waste Management Association.
- [5] Kleindienst, T.E., C.D. McIver, and W.M. Ollison. 1997. A study of interferences in ambient ozone monitors. VIP-74. *Proceedings A&WMA Symposium on Measurement of Toxic and Related Air Pollutants*, 215-25. Pittsburgh, PA: Air & Waste Management Association.

- [6] Huntzicker, J.A., and R.L. Johnson. 1979. Investigations of an ambient interference in the measurement of ozone by ultraviolet photometry. *Environ. Sci. Technol.* 13:1414. DOI= doi:10.1021/es60159a005.
- [7] Grosjean, D., and J. Harrison. 1985. Response of chemiluminescent NO_x analyzers and ultraviolet ozone analyzers to organic air pollutants. *Environ. Sci. Technol.* 19:862. DOI= doi:10.1021/es00139a016.
- [8] Leston, A.R., W.M. Ollison, C.W. Spicer, and J. Satola. 2005. Potential interference bias in ozone standard compliance monitoring. *J. Air Waste Manage. Assoc.* 55:1464-72. DOI= doi:10.1080/10473289.2005.10464749.
- [9] Zdanevitch, I. 2002. Study of ozone measurement interferences. Final report DRC-02-39246-AIRE-673-v2-Izd. Verneuil-en-Halatte, France: Institut National de L'Environnement Industriel et des Risques (INERIS).
- [10] Godet, Y. 1995. Evaluation of a UV absorption ozone analyzer. Report INERISLCSQA. Ref. 737/96 Environnement SA O3 41M and 740/95 Thermo- Environmental Instrument 49C. [As cited in Zdanevitch (2002).]
- [11] Meyer, C.P., C.M. Elsworth, and I.E. Galbally. 1991. Water vapor interference in the measurement of ozone in ambient air by ultraviolet absorption. *Rev. Sci. Instrum.* 62:223-28. DOI= doi:10.1063/1.1142311.
- [12] Maddy, J.A. 1998. A test that identifies ozone monitors prone to anomalous behavior while sampling hot and humid air. *Proceedings A&WMA 91st Annual Meeting*. Paper 98-MPB.02P. Pittsburgh, PA: Air & Waste Management Association.
- [13] Wilson, K. L., & Birks, J. W. 2006. Mechanism and elimination of a water vapor interference in the measurement of ozone by UV absorbance. *Environmental science & technology*. 40(20): 6361-6367. DOI= DOI: 10.1021/es052590c.
- [14] Belan, B.D. 2010. Ozone v troposphere. Tomsk: Izdatelstvo Instituta optiki atmosphere imeni V. E. Zueva SO RAN.
- [15] Arshinov, M. Y., Belan, B. D., Krasnov, O. A., Kovalevskii, V. K., Pirogov, V. A., Plotnikov, A. P., ... & Fofonov, A. V. (2002). Comparison of ultraviolet and chemiluminescent ozonometers. *ATMOSPHERIC AND OCEANIC OPTICS C/C OF OPTIKA ATMOSFERY I OKEANA*. 15(8): 656-658.
- [16] Williams, E. J., Fehsenfeld, F. C., Jobson, B. T., Kuster, W. C., Goldan, P. D., Stutz, J., & McClenny, W. A. 2006. Comparison of ultraviolet absorbance, chemiluminescence, and DOAS instruments for ambient ozone monitoring. *Environmental science & technology*. 40(18): 5755-5762. DOI= 10.1021/es0523542.
- [17] Dunlea, E. J., Herndon, S. C., Nelson, D. D., Volkamer, R. M., Lamb, B. K., Allwine, E. J., ... & Cardenas, B. 2006. Technical note: Evaluation of standard ultraviolet absorption ozone monitors in a polluted urban environment. *Atmospheric Chemistry and Physics*. 6(10): 3163-3180. DOI= doi:10.5194/acp-6-3163-2006.
- [18] Parrish, D. D., & Fehsenfeld, F. C. 2000. Methods for gas-phase measurements of ozone, ozone precursors and aerosol precursors. *Atmospheric Environment*. 34(12): 1921-1957. DOI= doi:10.1016/S1352-2310(99)00454-9.
- [19] Dueker R.L. 1974. Fully Proceduralized Instruction Manual for a Chemiluminescent Ozone Monitor. EPA-450/3-74-039: PP. 2-3.
- [20] Thermo Fisher Scientific Inc. 2011. Instruction Manual Mod. 49i UV Photometric O₃ Analyzer Part number 102434-00. PP. 2.