

Possibilities of using a Portable Continuous Concentrator for Detection and Identification of Explosives

Z. Večeřa, P. Mikuška, J. Kellner, J. Navrátil, A. Langerová

Abstract—The submitted paper deals with the problems of trapping and enriching the gases and aerosols of the substances to be determined in the ambient atmosphere. Further, the paper is focused on the working principle of the miniaturized portable continuous concentrator we have designed and the possibilities of its application in air sampling and accumulation of organic and inorganic substances with which the air is contaminated. The stress is laid on trapping vapours and aerosols of solid substances with the comparatively low vapour tension such as explosive compounds.

Keywords—Detectors of explosives, portable continuous concentrator, misuse of explosive, terrorism.

I. INTRODUCTION

THE threat of terrorist bomb attacks has become the starting point for searching effective methods to detect explosives. It is not an easy task, namely with regard to both the properties of explosives and bigger sophistication and perfidy of attacks. Current trends of the development of analytical methods for the detection of explosives result from the detection of explosive vapours in the ambient air and the analysis of their particles on surfaces. Unfortunately, explosives cannot be considered to be too volatile substances. These are usually substances with great molecular weight (often more than 150) and the pressure of their saturated vapours is very low. The saturated vapour pressure represents a maximum concentration of an explosive in the air for a given temperature. However, in fact, measured concentrations are up to six times lower. For instance, at 25°C, micrograms of dinitrotoluene (DNT), nanograms of trinitrotoluene (TNT) and only picograms of hexogene (RDX) are present in 1 gram of the air. These concentrations are really low; therefore, a suitable method for the detection of such substances must be highly sensitive, selective and reliable. It is possible to conclude that terrorist

attacks in which conventional explosives are used have still been relevant. At the same time, the development of new methods for their fast detection and clear identification is also very important.

II. VIEW OF THE PROBLEMS

Environmental pollution, namely in the atmosphere, raised concern about new methods to determine air pollutants of both organic and inorganic origin. With regard to a relatively low immission concentration of pollutants the enrichment techniques became an integral part of the trace analysis.

In conventional procedures, inorganic compounds are pre-concentrated by absorption in “impingers” or are collected on special filters. The pre-concentration in “impingers” is not suitable for concentrations lower than ppb. The use of filters is limited by their adsorption capacities; however, the losses of volatile substances which occur in the course of stage of sucking are their main problem.

Currently, it can be found out that inorganic gaseous pollutants are trapped in the denuders which are also suitable for separating gaseous pollutants in the gaseous phase from those which occur in the atmosphere in the condensed phase. It has been proved repeatedly [3]-[5] that the reliability of results acquired by denuders of different shapes is much better than the reliability of results acquired by the abovementioned traditional techniques. The dry denuder is the oldest type of diffusion denuder, the walls of which are provided with a suitable sorbent. The denuder [6] with oxalic acid as a sorbent was mentioned as the first one. This denuder was developed for determining ammonia in the ambient air. Unfortunately, the preparation of the sorbent covering the internal wall of the denuder tube as well as the extraction of the adsorbed compound was experimentally demanding.

Thermodenuders have also been used for enriching the samples of inorganic trace pollutants in the air [7]-[10]. This type of denuders also uses dry sorbents which adsorb pollutants; however, as opposed to conventional dry denuders, the trapped pollutants are desorbed thermally at increased temperatures. Measurements using thermodenuders can be automated; however, they usually show unsatisfactory selectivity [8]- [10]. This is their principal disadvantage. It is true, in general, that enrichment techniques for volatile organic compounds (VOCs) in gaseous media are based on the sorption on solid materials. From the viewpoint of the degree of enrichment the adsorption is much more effective than the

Z. Večeřa is with the Institute of Analytical Chemistry, Academy of Science of the Czech Republic, v. v. i., Veveří 97, 602 00 Brno, Czech Republic (e-mail: vecera@uiach.cz).

P. Mikuška is with the Institute of Analytical Chemistry, Academy of Science of the Czech Republic, v. v. i., Veveří 97, 602 00 Brno, Czech Republic (e-mail: mikuska@uiach.cz).

J. Kellner is with Civil Protection Department, University of Defence, Kounicova 65, 662 10 Brno, Czech Republic (e-mail: josef.kellner@unob.cz).

J. Navrátil is with Civil Protection Department, University of Defence, Kounicova 65, 662 10 Brno, Czech Republic (e-mail: josef.navratil@unob.cz).

A. Langerová is with Language Training Center, University of Defence, Kounicova 44, 662 10 Brno, Czech Republic (e-mail: alena.langerova@unob.cz)

absorption process as stated in literature [11]-[13]. The adsorption procedure is used for the concentration increase of organic compounds in the air in trace concentrations in the range from units of ppt up to tens of ppb (v / v). However, high values of the adsorption distribution constant complicate the liberation of analyte. Other problems are caused by variable contents of water vapours in the air [14], [15].

In the analysis performed by this method the sorbent, after sampling, is stored and transported to the laboratory to be analyzed where the analyte is analyzed using gas chromatography or the combination of gas chromatography and mass spectrometry after thermal desorption or extraction. This comparatively simple procedure is improper for the determination of thermolabile organic compounds (e.g. organic compounds which contain sulphur in their molecules or biogenic substances such as terpenes). In these compounds it has been discovered that monoterpenes adsorbed on a sorbent can undergo catalytic reactions, e.g. they can react with ozone in the course of ambient air sampling, which subsequently leads to the diminishing of analyte concentration due to the formation of reaction products of oxidation [16].

Activated carbon, Tenax or various compounds of silicon were used for the determination of VOCs in the atmosphere using dry denuders [18]-[20]. After taking samples of organic compounds these were usually thermally desorbed or extracted using a suitable solvent and analyzed. The discontinuity of determination is a common methodological disadvantage of all the abovementioned procedures. That means that only the integrated information values of the analyte contents in the atmosphere were received in a given time interval. Only a few methods allowing the continuous enrichment of a sample by a pollutant and on-line analysis have been described. The joint condensation of organic trace analytes with solvent vapours [21] or absorption of gases and vapours in the water film in the absorption liquid is characteristic of them. Admittedly, some methods have been published, but they have not been realized in practice yet [22]. The diffusion scrubber (DS) contains a semipermeable membrane in the denuder which separates the liquid and the gaseous phases. This determination has been developed by Dasgupta [23]. He was the first who realized the continuous method of enrichment and the on-line analysis of gaseous pollutants in practice. In the diffusion scrubber the running absorption liquid is separated from the air by a semipermeable microporous membrane in the reverse-flow arrangement. The diffusion scrubber was used for continuous, fully automated measurements of concentration of water-soluble inorganic gases [24]-[28]. Unfortunately, the porous material restricts the use with regard to time in case of long-term analyses when membrane pores clog.

III. PRACTICAL PART

Wet denuders where the absorption liquid is in the direct contact with the analyzed air provide much more effective enrichment of gaseous samples than the diffusion scrubber (DS) and do not allow the clogging of membrane pores [29].

The aerosol enrichment unit (AEU) [33] is an enrichment device we have proposed (Fig.1) with the direct contact of the absorption liquid and the analyzed air. This device works on the principle of equilibrium accumulation of pollutants from the gaseous phase using polydisperse aerosol. The polluted air is sucked through a tube in which stainless steel capillaries supplying absorption liquid are positioned. The sorption liquid is dispersed in the form of aerosol using air ejection. The polydisperse aerosol forms a pencil beam which condenses in the next part of the AEU due to the quasiadiabatic expansion and the collision with an inclined barrier. The sampling procedure enables automatic measuring.

IV. MINIATURIZED AEU AND ITS APPLICATION IN THE ENRICHMENT OF GASEOUS SAMPLES OF EXPLOSIVES

Within the Defence Research Project entitled PRINCIP the *Portable Continuous Aerosol Concentrator* (PCAC) was developed in the first year of the work on the project. It is based on the miniaturization of the *Aerodisperse Enrichment Unit* (AEU). The PCAC consists of the aerosol concentrator and the air pump. Further, it includes electronic components and microfluidic elements which allow changing the volume of liquid entering the PCAC, components and elements using which incoming air volume is controlled and electronic components using which the time of operation can be adjusted. The PCAC also contains the energy source (Ni-Cd accumulator) and the electronics intended for accumulator charging from the network. All the abovementioned components are integrated in an easily portable box.

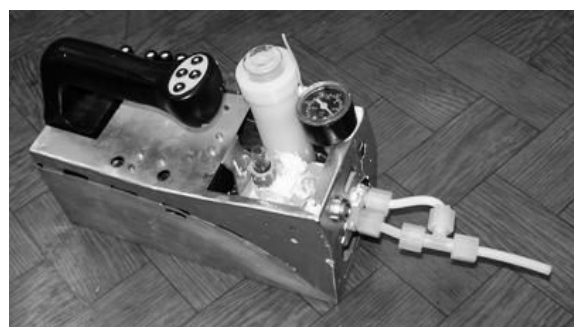


Fig. 1 Portable continuous aerosol concentrator operating on the principle of double flow Aerosol Enrichment Unit – AEU

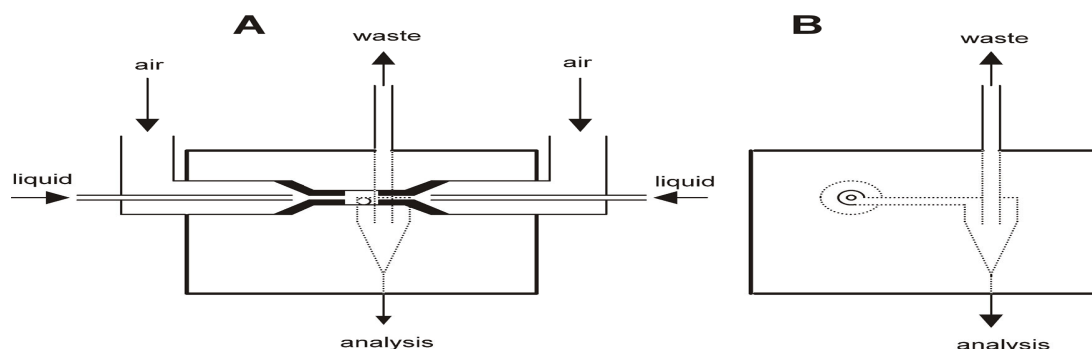


Fig. 2 Proposed design of the double-flow Aerosol Enrichment Unit – AEU
(A) Front view; (B) Side view.

The overall design is original. Available literature does not mention any device which would operate on the principle of aerosol concentrator and which would be intended for continuous increase of concentration of gases, vapours and aerosols in a liquid for the purpose of determining the concentration of gases, vapours and on aerosols absorbed compounds in the atmosphere. The PCAC was reliable and showed correct reliability performance during all exercise tests even with different kinds of liquids.

Practical application of the PCAC enables air sampling and the accumulation of organic as well as inorganic substances with which the air is polluted. The PCAC can be used for determining not only explosives, volatile and medium volatile organic substances, but also solid substances with a relatively low vapour tension. It appears from this that the PCAC can be used by the Fire Rescue Brigade, the CR Police and the Army of the Czech Republic.

The chemiluminescence detector was used for detecting trace concentrations of explosives. The achieved detection limit for nitrogen dioxide was 0.01 ppb (v / v). The calibration graph was linear up to the concentration of 400 ppb (volume). No significant interference from other gaseous pollutants incident in usual concentrations in the atmosphere was observed.

V. CONCLUSION

The threat of terrorist bomb attacks has started searching for effective methods to detect explosives. Current trends of the development of analytical methods for the detection of explosives result from the detection of explosive vapours in the ambient air and the analysis of their particles on surfaces. Unfortunately, explosives cannot be considered too volatile substances; therefore, a suitable method for the detection of such substances must be highly sensitive, selective and reliable. Further, the study is focused on the working principle of the designed miniaturized portable continuous concentrator and the possibilities of its application in air sampling and accumulation of organic and inorganic substances with which

the air is contaminated. Further, it has been proved that the miniaturized AEU is a simple and mechanically resistant device and thus suitable for the field of application developed, i.e. the trapping and enrichment of explosive vapours and aerosols.

ACKNOWLEDGMENT

This paper was realized on the basis of the Defence Research Project, Ministry of Defence of the Czech Republic (Grant No. 0901 8 7150 R / 1).

REFERENCES

- [1] J.C.G. Walkee, *Evolution of Atmosphere*, McMillan, New York, 1977.
- [2] F.S. Rowland, *The Science of Chromatography*, J. Chromatogr. Library (F. Brunner, Eds.), Vol.32, pgs. 461-476, Elsevier, Amsterdam, 1985.
- [3] I. Allegrini, F. De Santis, V. Di Palo, C. Perrino, and M. Possanzini, *Sci. Total Environ.*, 67, 1-16, 1987.
- [4] N.L. Eatough, S. McGregor, E.A. Lewis, D.J. Eatough, A.A. Huang, E.C. Ellis, *Atmos. Environ.*, 22, 1601-1618, 1988.
- [5] J.M. Dasch, S.H. Cadle, K.G. Kennedy, and P.A. Mulawa, *Atmos. Environ.*, 23, 2775-2782, 1989.
- [6] M. Ferm, *Atmos. Environ.*, 13, 1385-1393, 1979.
- [7] M.P. Keuken, A. Wayers-I Jpelaan, J.J. Mols, R.P. Otjes, and J. Slanina, *Atmos. Environ.*, 23, 2177-2185, 1989.
- [8] R. Niessner, and D. Klockow, *Intern. J. Environ. Anal. Chem.*, 8, 163-175, 1980.
- [9] J. Slanina, A. Van Lamoen-Doornebal, W.A. Lingerak, W. Melior, D. Klockow, and R. Niessner, *Intern. J. Environ. Anal. Chem.*, 9, 59-70, 1981.
- [10] J. Slanina, and C.A.M. Schoonebek, *Anal. Chem.*, 57, 1955-1960, 1985.
- [11] M.P. Ligocki, J.F. Pankow, *Anal. Chem.*, 57, 1138-1144, 1985.
- [12] A.B. Bandy, B.J. Tucker, and P.J. Maroulis, *Anal. Chem.*, 57, 1310-1314, 1985.
- [13] D.P.J. Lucero, *J. Chromatogr. Sci.*, 23, 293-303, 1985.
- [14] M. Termonia, and G. Alaerts, *J. Chromatogr.*, 328, 367-371, 1985.
- [15] D.J. Freed "Trace Organic Analysis: A New Frontier in Analytical Chemistry", (Hertz S., Chesler S. N., Eds.), Nat. Bur. Stand. Publ. No. 519, pp. 95, Washington DC, 1979.
- [16] A. Calogirou, B.R. Larsen, C. Brussol, M. Duane, and D. Kotzias, *Anal. Chem.*, 68, 1499-1506, 1996.
- [17] D. Helming, *Atmos. Environ.*, 31, 3635-3651, 1997.
- [18] G.P. Cobb, R.S. Braman, and K.M. Hua, *Anal. Chem.*, 58, 2213-2217, 1986.
- [19] U. Risse, E. Flammenkamp, A. Kettrup, *Fresenius J. Anal. Chem.*, 350, 454-460, 1994.
- [20] D.A. Lane, N.D. Johnson, S.C. Barton, G.H.S. Thomas, and W.H. Schroeder, *Environ. Sci. Technol.*, 22, 941-947, 1988.
- [21] J.C. Farmer, and G.A. Dawson, *J. Geophys. Res.*, 87, 4779-4785, 1984.

- [22] M. Kato, M. Yamada, S. Suzuki, *Anal. Chem.*, 56, 2529-2534, 1984.
- [23] P.K. Dasgupta, *Atmos. Environ.*, 18, 1593-1599, 1984.
- [24] P.K. Dasgupta, S. Dong, H. Hwang, H.C. Yang, and Z.Genfa, *Atmos. Environ.*, 22, 949-964, 1988.
- [25] P.F. Lindgren, and P.K. Dasgupta, *Anal. Chem.*, 61, 19-24, 1989.
- [26] T.E. Kleindienst, P.B. Shepson, C.N. Nero, R.R. Arnts, S.B. Tejada, G.I. Mackay, L.K. Mayne, H.I. Shiff, J.A. Lind, G.L. Kok, and A.L. Lazrus, *Atmos. Environ.*, 22, 1931-1939, 1988.
- [27] O. Fan, and P.K. Dasgupta, *Anal. Chem.*, 66, 551-556, 1994.
- [28] Z. Genfa, P.K. Dasgupta, and S. Dong, *Environ. Sci. Technol.*, 23, 1467-1474, 1989.
- [29] Z. Večeřa, P.K. Dasgupta, *Anal. Chem.*, 63, 2210-2216, 1991.
- [30] M.P. Keuken, C.A. Schoonebek, A. Van Wensveen-Louter, and J. Slanina, *Atmos. Environ.*, 22, 2541-2548, 1988.
- [31] G.P. Wyers, R.P. Otjes, J. Slanina, *Atmos. Environ.*, 27A, 2085-2090, 1993.
- [32] M.T. Oms, P.A.C. Jongejan, A.C. Veltkamp, G.P. Wyers, J. Slanina, *J. Intern. J. Environ. Anal. Chem.*, 62, 207-218, 1996.
- [33] Z. Večeřa, J. Janák, *Anal. Chem.*, 59, 1494-1498, 1987.