

The development of ion mobility technology

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Abstract. Increased terrorist threat in recent years makes it especially important to improve the custom equipment including the development of ion mobility spectrometers for reliable, real-time and sensitive identification of illicit substances. The paper summarizes different approaches used in recent developments in the last years: statistical analysis, sampling automation and construction materials study.

1. Introduction

The border service interdicts illegal substances to be crossed the border [1-3]. The main problem in typical inspection area and border service is time-consuming inspection procedure of people, luggage, and parcels. The essential search purpose is to recognize explosive components that are the most harmful from illicit substances. Although the inspection is selective, even one incident of explosives on board can lead to a fatal crash. One of the most widely distributed technic for the detailed security inspection of passengers and cargo is the Ion Mobility Spectrometry (IMS). This method is capable of detecting volatile and semi-volatile illicit substances in a wide range of concentrations from ppq to ppm for custom service needs. The customs inspector assembles the illicit components from the surface of passenger's hands and luggage using a napkin, then he puts the napkin to the IMS system. The procedure may last for tens of seconds that is why selective inspection is used. However, two problems of inspection method do exist. Firstly, it is a long duration of probing. Secondly, it is expensive consumables because of high requirements to clearance. Solutions of the problems can be sampling, transport, and analysis of samples an automation, fast cleaning and multiple reuses of the collecting particles surface. In a case of close contact with explosive compounds, trace amounts of explosives stay on the skin surface for several hundred touchings even after washing. The suggested method includes following procedures:

- investigation of push mechanics;
- statistical analysis of fingerprint characteristics (figure 1);
- study of fingerprints traces allocation.

The system is used for analysis is fingerprint and documents which is described in previous papers [4,5]. The gas flow chart of fingerprint and documents system is presented in figure. 2-3. The ion mobility spectrometer [6-8] operates with substance in 3 seconds. The ideal probe preparations should include fast heating up to specified temperature and fast freezing of one object within the period of time range from ms to s.

The peculiarity of operation with fingerprint substances consists of sweat and fatty traces heating regime. The regime causes an increase of its evaporation time and limits heat temperature. The fingerprint should be heated in a mode that allows avoiding formation of soot smoke. In addition, the



regime of heating could be divided into stages for separation of substances by their boiling temperature.

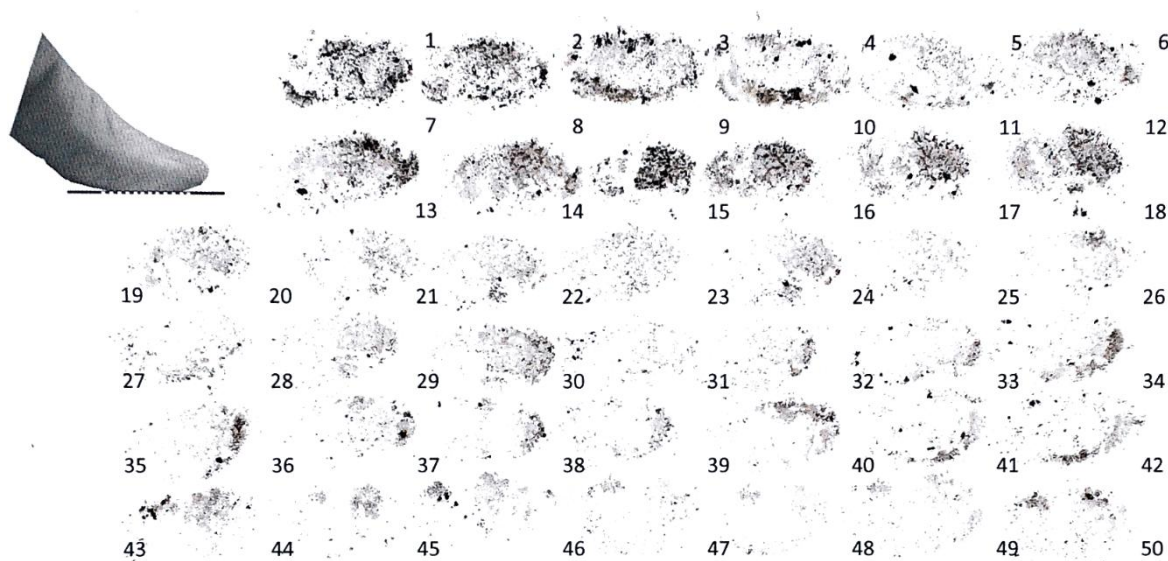


Figure 1. Statistical analysis of fingerprint characteristics.

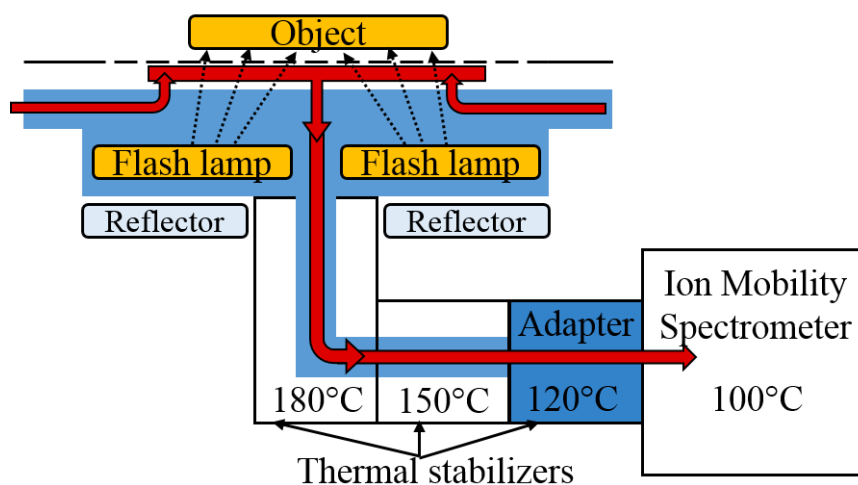


Figure 2. The gas flows chart of fingerprint and documents system.

The development of analytical instrument should involve material engineering and cleaning technology. The gas channels transporting probe are made of tubes from different materials such as Teflon F-4, 2. Glass and silanized borosilicate glass, 3. Stainless steel 12X18H9T / SilcoSteel, 4. Quartz glass.

The transport channel should be cleaned for next probe after probe's shift. The chemical composition of analyzed substances are acids. As a result metal and other materials could react with the probe. In that case, passivation is used for the avoidance of probe contact with metal. One of the passivation methods is a silanization.

Every detail in the analytical system is cleaned and annealed for a long time up to hours and days. Then the detail is set to the device. A new experience is received after the start of mass instruments' production. Statistics results start to show a worsening of quality baseline spectrum after a long storage of devices up to 2 weeks or more (Fig. 4). The reasons are the lack of initial treatment and the processes of accumulation of "pollutant" elements in the spectrometry cell.

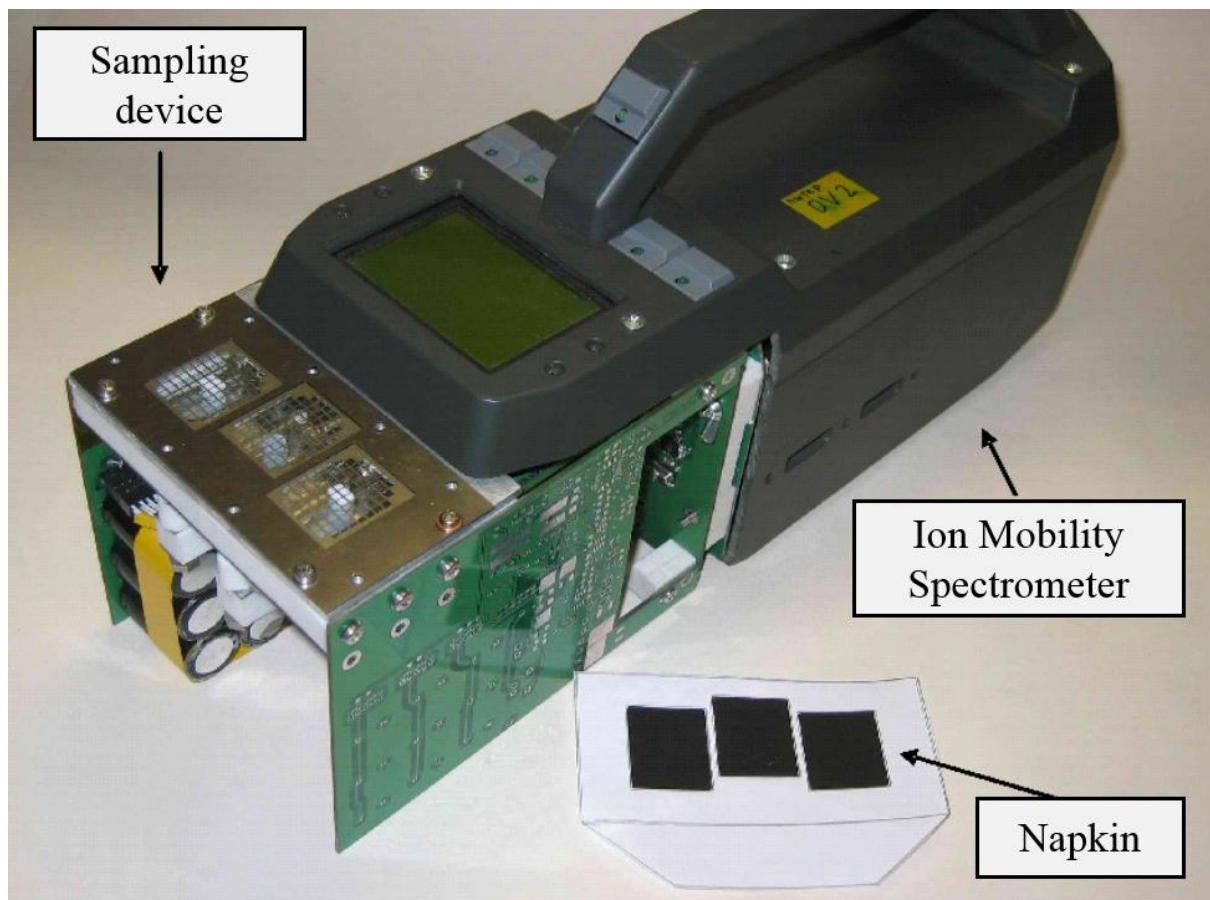


Figure 3. The sampling device is connected to ion mobility spectrometer. Adapted from Ref. [4] with permission.

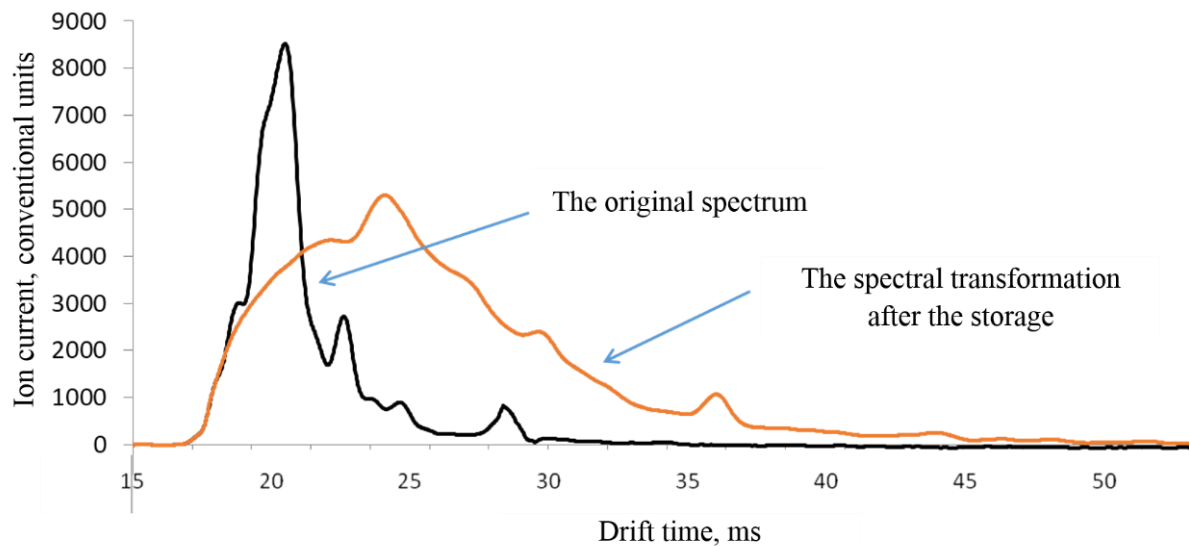


Figure 4. The spectrum before and after a week of storing the device.

The figure shows the spectrum of degradation:

- peaks of substances have bad resolution;
- there are new peaks of additional substances;
- the sensitivity decreases.

According to the figure, it can be resumed that initially clean parts of construction have a clean surface, but they may contain the scope of the "polluter" is diffused within. It evaporates slowly and steadily when heating starts. It tends to in the following processes:

Penetration of "pollutant" substances through porous materials. It includes:

- dissolving the solute in the surface layer of the material;
- diffusion of dissolved solute through the material as a result of the concentration gradient;
- the evaporation of the adsorbate from the space between assembled details;
- the rate and depth of penetration of the adsorbate are increased respectively through high concentration, temperature or pressure. Moreover, besides, these parameters affect crystal structure of the material.

Teflon is popular inert fluoroplastic which has "semi-crystalline" structures with both crystalline and amorphous domain structures. Various domain structures are determined by the chemical composition of the polymer and its production technology. Increased crystallinity reduces the intermolecular volume.

2. The deposition (adsorption) on the surface of materials with low porosity

The dense crystalline structure prevents penetration of the adsorbate and diffusion through the volume. Proper materials prevent adsorption on materials surfaces such as borosilicate glass, quartz glass, steel. The surface of the quartz glass has the low adsorptive capacity for various gasses and moistures.

Silanization method reduces surface adsorption by protective coating for metal and glass. The method is based on silanol group ($-\text{Si}-\text{OH}$). It is presented on the glass surface with the silanizing agent for chemically sewn hydrophobic siloxane film formation. This reaction eliminates of free chemical bonds.

An applicability comparison of various materials for inlet channel is held. The experiment consists of blowing through the investigated samples of TNT vapor under constant conditions (time, concentration, flow, temperature). The results showed (Fig. 5) that the use of Teflon tubes as the pipeline is highly undesirable due to effect described earlier.

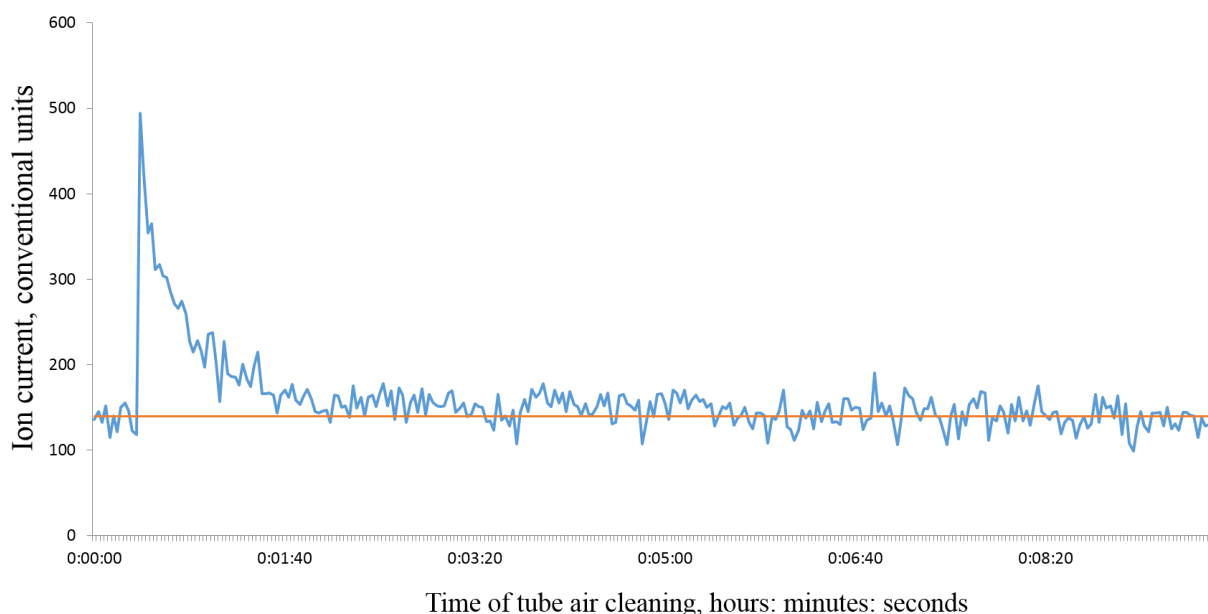


Figure 5. Signal amplitude of trinitrotoluene trace concentrations while cleaning process in the processed quartz tube sample (blow of clean air at a certain temperature) versus time of tube air cleaning.

In order to avoid contamination diffusion effect the following procedure is applied:

- using standard heat treatment. A sample of material is packed in foil. Contamination materials evaporate and condense immediately because of substances being of low volatile. This foil is analyzed on the spectrometer;
- using minimization of materials list up-to several components which are characterized by stable physicochemical characteristics from certain manufacturers.

Silanized glass at low (room) temperatures reduces a level of contamination, but at operating temperatures (about 100 degrees) the difference is irrelevant. A similar situation may be observed with tubes of steel with protective coatings. The quartz tubes are collected the least amount of contamination from components mentioned above. However, the quartz high melting point makes it difficult to manufacture tubes with special shape (bented). Glass tubes is an applicable option, with improved dynamics and sensitivity at low concentrations of the sample.

3. Conclusion

The complex solutions for acceleration and purity increase of IMS probing are discussed. The paper summarizes different approaches used in recent developments: sampling automation, adsorption fabric study, fast cleaning and multiple reuses of the collecting particles surface. Using of chemically inert materials and passivation of transport tube surface allows to solve the problem of contamination sorption. On the one, hand the best characteristics were demonstrated by quartz and silanized glass tubes having minimum TNT sorption. On the other hand, it is concluded that the using of Teflon tubes as the pipeline leads to undesirable growth of analyzed substances in material. Nowadays the methods of illicit substances' transportation systematically improves that is why the additional development of IMS methods is needed

Acknowledgements

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References

- [1] Eiceman G A, Karpas Z and Hill H 2013 *Ion Mobility Spectrometry (3rd ed.)* (Taylor & Francis Group) **406**(11) p 2493–2494
- [2] Borsdorf H, Mayer T, Zarejousheghani M and Eiceman G A 2011 *Appl. Spectrosc. Rev.* **46** 472-521
- [3] Sysoev A, Poteshin S, Chernyshev D, Karpov A, Tuzkov Y, Kyzmin V and Sysoev A 2014 *Eur. J. Mass Spectrom.* **20**(2) 185-192
- [4] Samotaev N, Vasilyev V, Malkin E, Gromov E, Belyakov V, Golovin A, Pershenkov V, Ivanov I, Shaltaeva Y and Matusko M 2015 *Proc. Eurosensors* **5** p 10-15
- [5] Vasilyev V, Pershenkov V, Belyakov V, Samotaev N, Golovin A, Malkin E, Gromov E, Ivanov I, Matusko M, Ivanova A, and Lipatov D 2015 *Proc. 3rd Int. Conf. Nanotechnologies and Biomedical Engineering (Chisinau)*(Springer: IFMBE Proceedings) **55** 515-519
- [6] Samotaev N, Pershenkov V, Belyakov V, Vasilyev V, Golovin A., Pershenkov V., Ivanov I, Shaltaeva Y and Matusko M 2015 *Procedia Engineering* **87** 436-439
- [7] Matsaev V, Gumerov M, Krasnobaev L, Pershenkov V, Belyakov V, Chistyakov A and Boudovitch V 2002 *International Journal for Ion Mobility Spectrometry* **5**(3) 112-114
- [8] Samotaev N, Golovin A, Vasilyev V, Malkin E, Gromov E, Shaltaeva Y, Mironov A and Lipatov D 2014 *Lecture Notes in Electrical Engineering* **268** 447-451