NMR & MW Techniques for Detection of Explosive and Illicit Materials

Review paper

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Abstract—**The detection of explosives and illicit substances is a very important problem nowadays. Especially, improvised explosive devices (IEDs) manufactured from homemade explosive materials has become an issue of growing importance. In this work, recent developments in the field of time domain (TD) NMR and microwave/sub-THz detection of liquid substances are reviewed. It has been shown that both TD NMR and MW dielectric spectroscopy are potentially very effective techniques to detect content of concealed liquids.**

Keywords—detection of explosives & illicit substances; NMR detection; microwave detection; dielectric spectroscopy

The detection of explosives and illicit substances is a very important issue of modern society [1-4]. There are remains of explosives after the wars and local conflicts as well as the explosives, which are used by terrorists around the world. Especially a problem of so-called improvised explosive devices (IEDs), manufactured from homemade explosive materials, has a growing importance. In the aviation and public security, there is a problem of non-invasive detection of the explosives in the baggage, suits, cars, and others.

Available detection techniques can be divided on the two large group of bulk and trace explosive detection methods. Although some trace detection techniques have proven their highest effectiveness (such as dogs, ion mobility / mass / Raman / terahertz spectrometry, etc.), their solely use is unlikely to resolve an issue of the reliable explosive detection in the most of practical situations. It should be noted that in spite of the availability of various detectors, there is no currently a commercial solution for “bulk” explosive detection, which is suitable for deployment in airport checkpoint, mass-transport exits, parcel scanners, mine detection devices, etc. There are a number of problems to be resolved, such as increasing of the sensitivity & selectivity of various detection techniques, shortening the detection time, decreasing the scanner cost, etc. It is obvious that an efficient device should combine a few methods, including at least one bulk detection technique to increase reliability of the explosive detection. For that reason, all bulk detection methods, especially X-ray/neutron/gamma/THz detection techniques and NMR/NQR detection, are extensively studied nowadays.

Minimum false alarms will be given by the techniques, which are directed to detect not the metal, or plastic enclose or fuses but the explosive itself. In other words, they should provide the chemical-specific identification of explosive. Such selectivity is provided by spectroscopic techniques. Fortunately, only a few explosive types are commonly used in spite of the fact that there are hundreds of mine types and a lot of explosives materials [2, 5].

Among various spectroscopic techniques nuclear quadrupole resonance (NQR) and low-field nuclear magnetic resonance (NMR) are considered as very promising bulk explosives detection methods, based on the chemical identification of content. However, NQR technique cannot be applied in the case of liquid substances. Instead, they can be successfully detected by NMR technique. Taking into account restriction on application of high magnetic fields to scan the luggage and people, only low-field NMR (with frequencies below of few MHz) can be applied. First successful applications of NMR method for detection of liquid explosives was demonstrated as early as in 90th years of XX century [6-8]. Most of researchers consider so-called time-domain NMR as a prospective technique for such applications. In the time-domain NMR (TD-NMR), the spectroscopic information (i.e. resonance frequencies) of the scanned material is neglected. It is NMR in moderate or low magnetic field (≤1T) which is based on measurements of spin-lattice and spin-spin relaxation parameters (T1 and T2) of the proton nuclei. Specialized NMR analyzers of the liquid content of bottles have been demonstrated by Quantum Magnetics [6-8], Bruker Inc. [9] and T2 Biosystems [10, 11]. It should be noted that in principle the time-domain NMR can be done in as low magnetic field as Earth’s field NMR. Recent progress in experimental techniques allows wider range of applications of Earth’s magnetic field NMR [12]. In very recent works, an application of this technique for the liquid identification in

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plastic bottles and metal cans have been demonstrated (see [13] and [14], respectively).

In many studies, the conclusion has been made that the TD-NMR is an effective non-invasive, non-contact method to detect content of concealed liquids. Analysis of literature, as well as our recent studies (see Refs. [15, 16]), however, shows that for reliable discrimination between a large number of liquids, the scanning device has to involve some additional parameters. They could be NMR ones (not only T2 and T1 relaxation times probed by standard TD-NMR, but also the proton density, diffusion constant [15-17], etc.). Another approach is to use techniques, which are totally different from NMR, e.g. dielectric spectroscopy which can measure the dielectric constant and the loss tangent of liquids in the broad range of frequencies up to a few THz [18]. From this point of view, the microwave (MW, frequency range 1-100 GHz) or sub-THz spectroscopy looks very promising to be combined with the time-domain NMR in a single detection device for reliable identification of liquids.

In this respect, over past few years THz and sub-THz technologies have attracted an essential attention of researchers (see, e.g. [19-21]). The main interest was initially concentrated on the broadband spectroscopic techniques because spectral signatures of various explosives were expected to provide a new and very powerful technique for standoff (distant) detection of explosive, chemical or biological warfare agents and other threat materials. Despite of enthusiasm and very high expectation of the first years of exploration, currently only a few realization of THz technology as model setups to demonstrate feasibility of this technology are known. A real-time in-the-field identification for security applications meets several technical challenges, such a very limited penetration depth, limited bandwidth due to attenuation in ambient conditions, noise floor /scattering losses, etc [19]. For that reason, most of successful applications have been demonstrated with respect to the THz imaging systems, which are aimed to detect hidden objects under wear [20, 21]. However, there is a very simple and powerful way to exploit the MW and sub-THz technique in the liquid verification devices, such as a dielectric spectroscopy. This techniques provide the values of ε' and ε'' dielectric constants (or relative permittivity) in the range (or at least at some properly chosen characteristic) frequencies. Furthermore, this technique could be applied in combination with time-domain NMR to obtain better discrimination between benign and threat liquids especially for the case of very large group of liquids (i.e. in the situation that usually met in air-check points). The dielectric function of liquids in the frequency range from nearly 1 GHz up to one THz may serve as a fingerprint signature of a specific liquid at a given temperature. Fortunately, the differences in reflectance values for the most of pure liquids (excepting water and hydrogen peroxide) are relatively high [18].

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