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Review

Direct-reading methods for analysis of volatile organic compounds and nanoparticles in workplace air

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ABSTRACT

This review aims to characterize direct-reading methods for analysis of volatile organic compounds (VOCs) and nanoparticles (NPs) in workplace air, in terms of general operating principles, analytical parameters, advantages and limitations. Furthermore, we summarize recent studies using direct-reading methods to assess exposure to VOCs and NPs in workplace air, and comment on future applications and potential research interests within this field.

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1. Introduction

Workplace-air analysis is essential to characterize and to estimate exposure to certain chemical hazards [1]. This information is vital to control the safety of workers' occupational health, and to make decisions about risk and hazard assessment, public health, medical monitoring, and use of personal protective equipment. The production, the manufacture and the use of chemicals, materials, tools and machinery at sites of construction, mining, agricultural and industrial activities can cause serious health risks [2]. In some industrial activities, large quantities of chemical compounds, such as volatile organic compounds (VOCs), including carbonyl compounds [e.g., benzene, toluene, ethyl benzene, and xylenes (BTEX), styrene, naphthalene and chlorobenzene] are directly released into the working environment. Benzene has been used as an industrial solvent in paint and lacquers, adhesives, gasoline, dyes, insecticides, and plastics, as well as a chemical raw material in the synthesis of styrene, phenol, cyclohexane aniline, maleic anhydride, alkyl benzene, and chlorobenzene [3]. Toluene has been widely used in the petroleum industry and as a solvent in paints, aerosols, nail polish, adhesives, thinners, and resins [3]. Commercial xylene is a set of three isomers [ortho (o-), meta (m-), and para (p-)] found in petroleum and used in the production of polyethylene terephthalate (PET) and in the fabrication of paints, inks, and detergents. In turn, styrene is the precursor to polystyrene and several copolymers and is widely used in plastics and resin manufacture [3]. Several VOCs are mutagenic, neurotoxic, genotoxic and/or carcinogenic and can produce adverse effects in the short term and the long term [3].

In the recent years, the nanotechnology industry has been producing a plethora of nano-based products for ever-increasing consumer demand. Nanoparticles (NPs) are defined as particles with dimensions up to 100 nm. The most commonly produced particles in the nanotechnology industry are based on:

- carbon {e.g., carbon black, fullerenes, nanoclusters, dendrimers, quantum dots (QDs), carbon nanotubes (CNTs), nanohorns, nanowires, and nanorods [4]};
- metal and metal oxides (e.g., Ag, TiO_2, ZnO, Li_2TiO_3, CuO, and Ni); and,
- silicon (e.g., SiO_2).

Carbon black is used in the fabrication of car tires, coloring rubber, ink, leather, and antistatic textiles [5]. Fullerenes are applied in hydrogen storage, drug delivery, medical imaging, electronics devices, sensors and sensing devices [1,6]. CNTs have been used as multi-walled CNTs (MWCNTs) and single-walled CNTs (SWCNTs) for several applications, including electromagnetic shielding, field-emission materials, catalyst support, nanoelectronic devices, and electrical-energy storage [1,4,5]. Metal and metal-oxide NPs are used in environmental remediation, paints, sunscreen products, laundry detergents, textiles, cosmetics, plastics, catalytic processes, UV shielding, and oxygen sensors [1,4,5,7]. Silicon-based NPs are used in electronics and electronic devices, optics and optical devices, biosensing and bioimaging, and solar energy applications [7–9].

In contrast to VOCs, little information is available regarding the risks of NPs to occupational safety and health, so occupational exposure guidelines for such hazardous substances are required, and international organizations, such as the World Health Organization (WHO) and the International Labor Organization (ILO), US organizations, such as the Occupational Safety and Health Administration (OSHA), the National Institute of Occupational Safety and Health (NIOSH), and the Environmental Protection Agency (EPA), and European organizations, such as European Agency for Safety and Health at Work (EU-OSHA), are committed to establish guidelines and regulations on occupational exposure, as well as guidelines and standards on methods for air monitoring in working environments. In order to protect workers' health and environmental quality, measurement of VOCs and NPs is therefore essential for early identification of emergency situations and industrial processes. Thus, it becomes essential to use analytical approaches, such as direct-reading methods that provide a fast, real-time response [10]. Direct-reading methods can be applied to area, process and personal monitoring and they can be specific for a given compound or cover a wide range of compounds.

In this review, we discuss the direct-reading methods for workplace-air analysis of VOCs and NPs, as well as the general operating principles, the analytical parameters, the advantages and the limitations of such methods. Furthermore, we discuss the most recent studies on workplace-air monitoring of exposure to VOCs and NPs. We also report on future applications and potential research interests within this field.

2. Adverse effects of VOCs and NPs on human health

Due to the adverse effects of some chemical compounds on human health, threshold limit values (TLVs) were designed in order to protect workers against the exposure to hazardous substances. TLVs are the maximum concentrations of air contaminants to which an unprotected worker may be exposed during work activities, and they are usually defined by means of:

- a long-term exposure limit (LTEL) calculated as an 8-hour time-weighted average (TWA); and,
- a short-term exposure limit (STEL) that is the maximum allowable concentration over a shorter period of time (usually 10 or 15 min).

2.1. VOCs

According to the EPA, there is sufficient evidence from both human and animal studies to believe that some VOCs have carcinogenic and mutagenic effects on human health [11]. The exposure to these compounds can be through inhalation, ingestion, and skin contact [3], and the extent of the threat from exposure to these compounds is reflected in the list of harmful substances compiled by EPA [11], which contains several VOCs confirmed as carcinogens. For example, benzene is classified as a carcinogen by the EPA [12] and exposure to it at low concentrations in air may cause several symptoms, such as euphoria, headache, vertigo, eye irritation, nose and throat discomfort, allergic skin reaction, nausea, and dizziness [3]; on a long-term basis and subsequently at high concentrations, it may lead to cardiovascular and respiratory diseases, central nervous system damage, and toxic effects in liver and kidneys [3].

VOCs are acutely and chronically toxic at low concentrations, so symptoms may not become completely manifest for years. Several environmental agencies have set limits of exposure for VOCs; Table 1 shows the STELs and the TWAs for BTEX of three occupational health agencies (OSHA, NIOSH and EU-OSHA) [13–16].

2.2. NPs

NPs are defined as particles with size up to 100 nm and characterized by several physicochemical properties, such as number concentration, surface-area concentration, mass concentration, crystal structure, shape, particle-size distribution, chemical composition, surface charge, porosity, surface reactivity, and solubility