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Investigation of discharged aerosol nanoparticles during chemical precipitation and spray pyrolysis for developing safety measures in the nano research laboratory

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ABSTRACT

Nowadays, the demands for the nanoparticles are increasing due to their tremendous applications in various fields. As a consequence, the discharge of nanoparticles into the atmosphere and environment is also increasing, posing a health threat and environmental damage in terms of pollution. Thus, an extensive research is essential to evaluate the discharge of these nanoparticles into the environment. Keeping this in mind, the present investigation aimed to analyze the discharge of aerosol nanoparticles that are synthesized in the laboratory via chemical precipitation and spray pyrolysis methods. The results indicated that the chemical precipitation method discharges a higher concentration of nanoparticles in the work site when compared to the spray pyrolysis method. The aerosol concentration also varied with the different steps involved during the synthesis of nanoparticles. The average particle's concentration in air for chemical precipitation and spray pyrolysis methods was around 1,037,476 and 883,421 particles/cm^3. In addition, the average total discharge of nanoparticles in the entire laboratory was also examined. A significant variation in the concentration of nanoparticles was noticed, during the processing of materials and the concentration of particles (14–723 nm) exceeding the daily allowed concentration to about 70–170 times was observed over a period of 6 months. Thus, the results of the present study will be very useful in developing safety measures and would help in organizing the rules for people working in nanotechnology laboratories to minimize the hazardous effects.

1. Introduction

Currently, nanoparticles are finding wide applications in daily uses, such as electronics (Jiang et al., 2015), Clinical (Sankaranarayanan et al., 2016), health care (Karunakaran et al., 2017), biocontrol (Rangaraj et al., 2014), protective clothing (Dhineshbabu et al., 2014), antioxidant (Karunakaran et al., 2016a) and biomedical (Yan et al., 2013) fields. Alumina nanoparticles are one of the widest used nanoparticles and have abundant importance. It is used as catalyst (Hossain et al., 2017), as an adsorbent for the removal of toxic dyes Orange G from the aqueous medium (Banerjee et al., 2017), also in improving thermal conductivity (Ha et al., 2017) and as tooth restoration material (Anusha Thampi et al., 2014). Nickel nanoparticles are also among the widely used nanoparticles and it has various applications, such as non-enzymatic glucose sensors (Ensafi et al., 2017), quercetin delivery carrier for curing cancer (MCF–7 cells) (Rameshthangam and Chitra, 2017), pollution depredating agent (Kamal et al., 2016) and dye-sensitized solar cells (Wu et al., 2016).

Numerous methods (physical, chemical and biological) are available for nanoparticles production, of which biological method is less promising, as its yield is less and the process needs to be optimized for effective nanoparticles production (Karunakaran et al., 2016b). However, for large scale production physical (spray pyrolysis) (Hafshejani et al., 2016; Li et al., 2016) and chemical precipitation methods are the found to be best and hence, are most widely used. As the demand of the nanoparticles is increasing every day, these methods and their routine usage has also increased in the research laboratory. As a result, the discharge of nanoparticles into the atmosphere and environment is also enhanced (Buzea et al., 2007).

In general, nano aerosols and nanoparticles, independent of their

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source are extremely undesirable in the vast majority of cases, because they pose a threat to people's health and inflict damage on the environment including different living species (Lewis et al., 1989; Karunakaran et al., 2013a, 2013b; Hossain et al., 2016; Zhou et al., 2016). Recently, several authors have repeatedly demonstrated the strong penetrating power, diffusive energy and high toxicity of nanoparticles, when inhaled by a living organism into the respiratory system (Noela et al., 2012; Yin et al., 2014). Hence, as far as the development of different production methods of nanomaterials is concerned, the development of precautionary measures to prevent the hazardous effects of such aerosols is also gaining equal importance.

It is worth noting that nanoparticles released into the atmosphere do not undergo a crystalline modification and are able to maintain their morphology, crystalline structure, forming aerosols with flat, needle and star-shaped particles. The peculiar qualities such as wide range in compositions, form and size of aerosol, leads to its release into the environment with high potential for reaction. Till date, there is a lack of physical and chemical informations on the nanoparticles discharge sources and further, there is no methodology available to rate the risk of nanoparticles towards human health and environment. Thus, research on this area, which can guarantee the safe working condition to personnel dealing with nanoparticles in the laboratory, is required in the current scenario (Godymchuk et al., 2012; Golovin et al., 2012).

In this study, the discharge of nanoparticles in different stages of alumina and nickel nanoparticles production, during chemical precipitation method and spray pyrolysis was analyzed. A comparison has been made between the concentration of nanoparticles that were discharged and the daily allowed concentration, to bring out the significance of the study. In addition, the average total discharge of nanoparticles throughout the laboratory was also examined using aerosol discharge analyzer.

2. Materials and methods

Aluminum nitrate (Al_2NO_3), nickel nitrate ($NiNO_3$) and sodium hydroxide were procured from Roche chemicals, Russia. Alumina (Al_2O_3) nanoparticles were produced by the well-known chemical precipitation method (Kuznetsov et al., 2010) and its schematic representation of different stages of its production, collection of aerosol samples are shown in Fig. 1a. Aluminum nitrate and sodium hydroxide solutions were prepared in 10% concentration and poured into the reactor as shown in Fig. 1a. It was then subjected to homogenous mixing, until a light milky white precipitate was formed. pH 9.5 was maintained throughout the reaction. Once precipitation occurs, the solution was centrifuged at 4000 rpm for 30 min. The obtained precipitate was washed, until the pH reaches 7.0 followed by sonication of the obtained aluminum hydroxide. The disaggregated precipitate was dried in hot air oven at 40 °C for two hours. The obtained powder was subjected to milling, after which it was heated at 700 °C for 3 h in air. The obtained dried aluminum hydroxide powder was used for the experiments.

Nickel (Ni) nanoparticles were synthesized through spray pyrolysis (Lysov et al., 2010). The schematic representation of different stages of its production and collection of aerosol samples are shown in Fig. 1b. The precursor nickel nitrate solution was filled in the ultrasonic generator. When the ultrasonic generator was turned on, it generates small aerosol droplets, which were allowed to travel inside the silica reactor under flow rate of around 16 L/min (Fig. 1b). The flow rate was maintained by using two flask pumps. The silicon reactor was maintained at 1200 °C using tube furnace. Aerosols generator was allowed to operate till the solution gets ends up. After the complete generation of aerosol, the ultrasonic generator and the furnace were allowed to cool to room temperature. After about 10–15 h, the prepared nanopowders were obtained from the pyrolysis collection chamber. The obtained powder (nickel oxide) was exposed to hydrogen flow to reduce it from nickel oxide to nickel nanoparticle.

Fig. 1c shows a layout of the equipment used in the laboratory and the fundamental sectors and stages for nanopowders processing. Over the course of the testing and research, Al_2O_3 and Ni nanopowders were produced. The productivity of nanoparticles in the laboratory was 50 g per 24 h under non-stop operation condition. The prepared nanoparticles were characterized by (PSD) particle size distribution using dynamic light scattering technique (Nano Zetasizer, Malvern, USA) in which, 1.0 ml of nanoparticle dispersion was filled in a capillary cuvette (U-shape polystyrene) devoid of air bubbles operated at 25 °C, using He-Ne laser with a capacity of 4 mW under the wavelength of 633 nm. SEM (scanning electron microscopes) analysis was done by using SEM-VEGA3 TESCAN, Brno, Czech Republic. For observation, carbon film was used, which was mounted using carbon tape and a drop of nanoparticle suspension was added over it and further dried to observe under the microscope operated at 20 kV.

The discharge analysis of the aerosol (the concentration of particulate matter and size distribution of particles) was made with the help of scanning classifier for particle mobility SMPS 3936 (TSI Inc., USA) which is shown in Fig. 2. The apparatus consists of three main components: the electrostatic classifier model 3080 (Fig. 2a), which is responsible for determining aerosol particles by size with a high degree of accuracy and is outfitted with a differential mobility analyzer model 3081 Long DVA (Fig. 2b), and a condensation meter model 3775 (Fig. 2c), which enables the determination of the quantity of aerosol particles in prescribed volumes. Following the established methodology (Wiedensohler et al., 2012), the aerosol stream was released at a speed of 0.3 l per minute over 180 s. All the measurements were taken between the range of 14 and 723 nm.

In addition, the dispersed phase from the aerosol was selected for investigation using nanometric aerosol sampler 3089 (TSI Inc., USA). The charged particles were immediately settled on copper mesh with the help of sampler and used for microscopic analysis using transmission electron microscope (JEM-1400, Jeol, Japan).

An aerosol for analysis was chosen at every stage of nanopowder processing. The aerosol samples were taken from the air directly, during each stage of nanoparticles production from different work zone of the laboratory. The aerosol samples were collected from a distance of around 0.5 m from the potential emission sources and at a height lower than 1.5 m from the floor.

To determine the average daily concentration of aerosol particles in the laboratory working area, monitoring was carried out three times a day: morning (10:00– 11:00 h), afternoon (13:00–14:00 h) and evening (18:00–19:00 h), over a period of 6 months. From the gathered data, the average concentration was calculated for each 24 h period, and then the average was calculated.

3. Results and discussion

Al_2O_3 and Ni nanopowders were prepared by chemical precipitation and spray pyrolysis methods. Fig. 3 shows the PSD and SEM images of the synthesized nanoparticles. Fig. 3a and c represent the histogram of nanopowders. The average particle size of the nanoparticles was found to be around 140 nm for Al_2O_3 and 105 nm for Ni nanoparticles. SEM images (Fig. 3b and d) of Al_2O_3 and Ni nanopowders revealed the spherical shape and aggregating nature of the particles. In addition, SEM images matched exactly with the PSD results for the average particle size distribution.

Fig. 4a illustrates the average particles distribution during each step of Al_2O_3 nanoparticle synthesis. Variation in particles size distribution was observed in each step of synthesis. For example, PSD during chemical precipitation, sonication, drying, milling, heating and final collection was found to be 27 nm, 29 nm, 41 nm, 250 nm, 41 nm and 59 nm respectively.

Table 1 depicts the concentration of different aerosol discharge during the synthesis of Al_2O_3 nanoparticles. During each stage of alumina nanoparticle synthesis, different concentrations of aerosol