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Review

Catalytic ozonation for the treatment of synthetic and industrial effluents - Application of mesoporous materials: A review

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1. Introduction

The significant numbers of chemical and allied industries have come up in recent years leading to enormous generation of effluent containing refractory, toxic, carcinogenic and mutagenic organic compounds. These industries process various kinds of organic compounds as raw materials or intermediates to obtain desired products. The organic compounds include dyes, detergents, pharmaceuticals, personal care products, pesticides, carboxylic acids and aromatic compounds. Water is commonly used as solvent or reaction medium in these industries. The organic compounds find their ways in the effluent due to their low conversion efficiency. Most of the organic compounds present in the effluent are chemically stable and non-biodegradable. The disposal of such effluent in water bodies obstructs light penetration, thereby, reducing photosynthetic activity of aquatic life. It not only destructs the aesthetic nature but also disturbs the food chain of the water ecosystem (Gupta and Saleh, 2013; Gupta et al., 2011a).

The human exposure to these organic pollutants causes damages to nervous central system, blood system and primary organs like livers, lungs, kidneys etc. Some pharmaceutical compounds present in the effluent interfere endocrine systems causing birth defects and other developmental disorders (Huang et al., 2015; Medellin-Castillo et al., 2013). Therefore, the industrial waste streams must be treated to reduce contaminant concentrations to the acceptable limits, prescribed by regulatory authorities, before discharging into the environment. The treatment of industrial effluent is a major environmental challenge although efforts are being made throughout the world to find an effective treatment process.

Numerous conventional methods like adsorption, coagulation, flocculation, incineration, membrane separation, biological oxidation, etc are available to degrade organic pollutants present in the effluent. Sometimes coupling of these conventional methods is employed to enhance the degradation of organic pollutants. However, these methods have some limitations like less degradation efficiency, more power consumption and unsuitable for high toxicity level (Tisa et al., 2014). These conventional methods are also costly due to large space requirement and need high degradation time (Martinez et al., 2007). These limitations have encouraged scientific fraternity to develop more advanced procedures with the potential of completely degrading refractory organic compounds.

Advanced oxidation processes (AOPs) have received increasing attention in a recent few years due to their higher efficiencies in removing organic pollutants from the effluent. The AOPs involve the generation of hydroxyl radicals which have higher oxidizing potential than other oxidizing agents such as ozone, hydrogen peroxide etc. (Sharma et al., 2015). Among all the AOPs, Fenton/photo-Fenton processes, ozonation, wet air oxidation (WAO), electrocoagulation and photocatalytic oxidation are extensively used. In ozonation, ozone is utilized as an oxidizing agent to degrade refractory organic pollutants of the effluent. However, ozonation alone is not often adequate in completely removing organic pollutant as ozone is selective in attacking some organic compounds and sometimes it produces toxic intermediates (Shokri and Mahanpoor, 2017). Therefore, ozonation is carried out in the presence of catalyst, called as catalytic ozonation, in order to achieve higher efficiency for effluent treatment.

Many metal ions and metal oxides immobilized on catalytic supports have been used as catalysts in catalytic ozonation. The materials like activated carbon, alumina, silica, titania and ceria have been widely explored as catalyst supports and transition or noble metals have been impregnated as active sites on these catalyst supports to enhance their catalytic activity. The significant numbers of catalytic ozonation studies involving these catalysts are available in the literature. The mesoporous materials have also been appeared as very efficient catalyst supports because of their large surface area, uniform pore structure and high thermal stability. However, less numbers of catalytic ozonation studies are reported in the literature for catalytic ozonation involving mesoporous materials in spite of their unique physical properties. This review paper, therefore, emphasizes the application of mesoporous materials as catalysts or catalyst supports in catalytic ozonation studies. The paper presents graphical data on catalytic ozonation studies published in the last twelve years (2005–17). The data demands the utilization of mesoporous materials in catalytic ozonation in order to get high mineralization efficiency. The need for the application of catalytic ozonation for the treatment of real industrial effluent of hazardous chemical industries is also highlighted through data analysis. The present work is useful in making catalytic ozonation process cost attractive as cost analysis and reduction measures have been recommended.

2. Conventional effluent treatment methods

Adsorption is a physical method for the removal of pollutants which get adsorbed on the surface of the adsorbent. Materials with high surface area and fast adsorption kinetics are generally used as adsorbents. Adsorbents having high carbon content are utilized for the removal of organic and inorganic pollutants, whereas the adsorbents with inorganic base are employed to remove heavy metals (Gupta et al., 2009). The regeneration of the exhausted adsorbent and safe disposal of the concentrated pollutants are the major limitations of the adsorption. Activated carbon is widely used as an adsorbent to adsorb variety of pollutants such as dyes, phenols, acids, heavy metals and derivatives of biological compounds including bio-organisms (Asfaram et al., 2015; Gupta et al., 2011b, 2013; Malik, 2004; Monesar and Adhoum, 2002). However, due to high cost of activated carbon and difficulties associated with its preparation and regeneration, various low cost natural materials such as sugarcane bagasse, rice husk, coconut shell, fruit peels, etc. have emerged as alternative adsorbents (Ahmaruzzaman and Gupta, 2011; Angelis et al., 2017; Carvalho et al., 2011; Gupta and Suhas, 2009).

The cost towards the adsorbents has been minimized by utilizing the wastes from soya oil producing industries and thermal power plants for the removal of hazardous dyes (Gupta et al., 2012a; Mittal et al., 2009a, 2009b, 2010a, 2010b). The fertilizer waste has also been utilized to develop low cost carbonaceous adsorbent for the treatment of effluent containing metal ions, dyes and phenols (Gupta et al., 1998; Jain et al., 2003). Saleh and Gupta (2014) highlighted the use of waste rubber tire derived carbon as adsorbent for the removal of organic pollutants from aqueous solution. Biochar obtained by the pyrolysis of sludge of pulp and paper mill has also been used as an adsorbent in mineralizing pentacholorophenol from the industrial effluent (Devi and Saroha, 2015).

Biological methods (aerobic and anaerobic) for the treatment of effluent are environmental friendly and economical. However, microorganisms used in these methods require large residence time to degrade the organic compounds present in the effluent (Liotta et al., 2009). Biological treatment is also unsuitable for effluent containing toxic compounds restricting their applications only to non-toxic effluents. These limitations restrict their usage in industrial effluent treatment as most of the industrial effluent contains toxic compounds (Oller et al., 2011). Various membrane filtration processes are also used in lowering contaminant concentration in effluent below the prescribed discharge limits. Microfiltration and ultrafiltration membrane systems can remove