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Recent progress in development of high performance polymeric membranes and materials for metal plating wastewater treatment: A review

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A B S T R A C T

Development of advanced technologies for metal plating wastewater treatment constitutes one of the major fields of research, primarily driven by the progressive environmental regulations issued to address the concerns. The emergence of various membrane-based processes and the satisfactory trial and field tests have created new avenues for minimization of the negative impacts caused by the uncontrolled discharge of metal plating waste streams. On the other hand, the progress in the polymer science and engineering provides opportunities for development of membrane materials with advanced functionalities and superior characteristics that can effectively be employed for design and fabrication of high performance membranes. The present review provides an overview on the specifications of metal plating wastewater streams and the significance of the treatment by presenting possible strategies that can be employed for heavy metal removal. Special attention is paid to nickel, chromium and zinc due to their high impacts and detrimental effects. In addition, a comprehensive review is provided on the recent advances in development of high performance polymeric materials for diverse membrane-based processes including reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), complexation–ultrafiltration (CUF), microfiltration (MF), polymer inclusion membranes (PIMs), electro-membranes (EMs), hybrid processes, liquid membranes, emulsion liquid membranes (ELMs) and membrane-based solvent extraction by highlighting the role of molecular design and architecture and other featured characteristics in the process performance and efficiency.

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1. Introduction

If we look around, we can identify plenty of objects made from diverse materials. Many of these objects are coated with another material(s). Examples range from simple parts such as bathroom fittings, chairs and tables to more sophisticated and complicated ones such as those used in machineries or airplane parts. The coating can often play the role of protection, such as against corrosion, or intended for improving the essential properties such as mechanical or chemical stability. Coating is sometimes used with the purpose of beautifying objects.

Metal plating is one of the most widely used techniques for coating of various parts. In this process, the surface is coated through deposition of certain metals. This is typically carried out in the presence of an electrical field and accordingly the process is known as "*electroplating*". "*Electroless plating*", on the other hand, is an auto-catalytic chemical reduction process which does not require electric current for deposition. Deposition occurs in an aqueous solution encompassing metal ions, reducing agents, catalysts and other additives to promote the reaction. This technique is often used to prevent corrosion and wear. Electroless plating has several advantages over electroplating. In addition to being free from flux-density and power supply issues, it can provide even and uniform deposits on all surface areas of the work piece regardless of the configuration or geometry. Moreover, it can be used for plating non-conductive surfaces by using a proper pre-plate catalyst.

Regardless of the type of the process used for plating, a typical metal plating process often involves deposition of specific metals onto the surface of the pre-washed substances followed by rinsing in a bank of counter-current rinse baths. The concentration of the metal ions increase over time due to the repeated recirculation of the rinsing liquid. This consequently results in reduced efficacy of the rinsing process. Therefore, it is often required to replace the rinsing liquid that has reached its maximum contamination level with a fresh solution. Due to the considerable amounts of liquid waste generated, this requires special attentions and considerations for handling and proper management in order to minimize the environmental risks. In fact, metal plating is recognized as one of the major sources of liquid waste effluents among the diverse industries due to the involvement of water in the various steps of the process. According to the Singapore Public Utilities Board, about 31,900 m^3/day of potable water was used by the metal products sector in Singapore in year 2000 [1]. It should be noted that metal plating factories, many of which operating in small scales, are largely concerned about the costs associated to the waste handling and disposal. For instance, the typical daily water consumption of a small enterprise with less than 100 employees can be as high as 1000 m^3 just in the rinsing step [2]. As a result, these factories have always been looking for feasible and affordable technologies that can offer the best solution in terms of efficiency and economy. In addition, there have been growing interests for technologies that can enable reclamation of metal ions as well as recovery and reuse of water from plating waste streams. This is particularly important in the countries with limited water resources and located in dried regions.

In response to the ever increasing demands for the treatment and management of the wastewaters generated in metal plating industry, various technologies have been developed and practiced over the years. Technologies based on chemical neutralization and precipitation, flotation, adsorption, ion exchange, solvent extraction, cementation, evaporation and electrochemical processes have been examined and presented their merits and limitations during the trials and field operations. For instance, chemical precipitation and coagulation–flocculation processes have extensively been used for the treatment of metal plating wastewater (MPWW) streams and despite their effectiveness have been suffering from excessive chemicals consumption, coproduction of sludge and inappropriateness for direct reuse of heavy metals. Careful considerations reveal that majority of the available technologies have been designed for effective removal of specific metal ions without considerations for global treatment of effluents that typically contain various metals ions all together or in certain combinations. Besides, it is evident that recovery and reuse of water has not been taken into account as an important consideration in the design and development of these processes. This has driven an increasing attention, particularly in recent years, to the research and development of membrane based technologies for the treatment of MPWW streams. Membrane technology is recognized to overcome or considerably minimize the limitations of the established technologies. Small footprint, high efficiency, low energy consumption, economy of scale, ease of operation and maintenance, minimum supervision and modularized design are among the advantageous features of membrane systems making them competitive compared to the established technologies for the treatment of various industrial wastewater streams [3]. The emergence of membrane technology with its special characteristics has created vast opportunities for the treatment of various wastewater streams. Furthermore, evolution of engineered polymers and those with advanced functionalities in conjunction with the advancements in the membrane design and fabrication skills provide new avenues for development of high performance polymeric membranes for targeted applications [4–9]. It must be pointed out that the progresses made over the past decades in the membrane science and technology have enabled the extensive penetration of membranes for diverse applications [10–21]. Scientists believe that many more opportunities avail for the membranes in years to come.

Despite the numerous research and experimental works carried out on the application of polymeric membranes for metal plating