ABSTRACT

Industries are obligated to maintain pollutant level below specified threshold when discharging effluent into water bodies. Some of the commonly used waste water treatment techniques to remove pollutants from waste water are adsorption, precipitation-coagulation, and liquid-liquid extraction. The removal in these processes involve chemical reaction and mass transfer. These are carried out in equipment wherein the solution containing the pollutants flows under terrestrial gravity. Low rate of reaction due to poor micro-mixing, low values of mass transfer rates due to high diffusional resistance result in equipment of large size to provide more residence time for removal to meet the regulatory standards. The aim of this work is to implement Process Intensification strategy though use of equipment operating under high gravity to increase process efficiency within reduce the equipment size and bring about reduction in capital and operating cost. In these equipment, the liquid flows under centrifugal acceleration hundreds of times the terrestrial gravity by rotating the equipment about its axis. Three different design of high gravity equipment has been studied, namely Rotating Packed Bed, Rotating Zigzag contactor and rotating spiral contactor. The liquid flows through the void space in the packing in the former and over a spiral baffle as thin film in the latter. In Rotating zigzag contactor, the liquid flows zigzag's its way across a series of rotating baffles, splashing and flowing as film/rivulets on their surface and flowing as rivulets and drops in the space between the baffles. The objective of the experimental studies has been to determine whether the conventional contactor can be replaced by this high gravity equipment towards obtaining higher removal efficiency.

Chemical species such as fluoride and phenol have a detrimental effect on humans as well as on aquatic life and animals. Fluoride removal has been studied by adsorption with powdered activated carbon, and precipitation-coagulation technique based on Nalgonda method using lime and alum.

Phenol has been studied by liquid-liquid extraction using Aliquat 336 as the extractant with kerosene as the solvent.

Removal of Fluoride by Adsorption

Solution flowing under terrestrial gravity through adsorbent packed in a fixed bed is the conventional equipment in industrial practise of this process. Investigators noted that the mass transfer rates can be improved by ~2.5 times by rotating packed bed adsorber. However, the limitations of liquid mal-distribution in the rotating adsorbent bed among others limited further improvement in mass transfer rates. In this experimental investigation, the effectiveness of slurry contact adsorption in rotating contactors for the continuous removal of fluoride was studied. Powdered activated charcoal was dispersed into the solution and pumped through the high gravity contactors. This approach can avoid the disadvantages of high pressure drop associated with fine adsorbents, high diffusion resistance with granular adsorbents in fixed bed adsorption. In the rotating contactors, the percentage removal increased with rotational speed and slurry concentration. The percentage removal decreased with increase of feed flow rate though the amount of fluoride removed increased. The percentage utilization of adsorbent capacity for fluoride in the contactors is higher at large adsorbate dosage and low feed concentration. The rotating spiral contactor is the most efficient among the rotating contactors for removal of fluoride by this technique. Use of high gravity makes the process more efficient compared to the conventional contactors, like continuous stirred tanks and fixed bed. The mass transfer rates in slurry adsorption in rotating contactors is much faster than in rotating packed bed adsorber. The reported values of the overall volumetric mass transfer coefficient in this study serve as a useful reference for designing this contactor.

Removal of Fluoride by Precipitation-coagulation

Alum serves as the source of aluminium ions that initiate coagulation, while calcium hydroxide supplies calcium ions responsible for fluoride removal through precipitation as calcium fluoride. The overall process is governed by both chemical reaction and mass transfer phenomena. The chemistry of this system is influenced by the pH and concentration dependent speciation of aluminium and

fluoride ions. In industrial practice, the process is typically carried out in two stages using continuous stirred tank reactors.

Experiments were carried out by simultaneously introducing saturated lime solution, alum and fluoride solution into the same reactor. The rotating spiral reactor exhibited the highest removal efficiency among the three high gravity equipment studied. The percentage removal in this reactor closely approached the maximum value obtained in batch studies within a radial distance of 0.08 m of the equipment and estimated residence time (flow rate = 1.0 L/min) of about a second at the optimal pH 7.0 (alum concentration = 7 gm/L). The performance of the high gravity reactors compared to traditional reactors (continuous stirred tank reactor and fixed bed) due to efficient micromixing and higher values of mass transfer coefficient in the former.

Removal of Phenol by liquid-liquid extraction

The present work focuses on intensifying liquid–liquid extraction by employing advanced rotating contactors such as rotating packed bed, rotating zigzag contactor, and rotating spiral contactor operating under centrifugal force. Phenol removal from aqueous solution was investigated using Aliquat-336 dissolved in kerosene, with decanol as a phase modifier. A wide range of operating parameters was examined, including rotational speed (300–1100 rpm), aqueous and organic phase flow rates (0.5–1.5 L/min and 0.5–1.25 L/min, respectively), feed concentration (25–200 mg/L), and extractant concentration (0.25–1.5 vol%). The results demonstrated that phenol extraction efficiency increased with rotational speed, feed concentration, extractant dosage, and solvent phase flow rate, but decreased with aqueous flow rate. Among the contactors studied, the rotating spiral contactor exhibited superior performance, achieving up to 78.8% phenol removal and higher overall volumetric mass transfer coefficient ($K_{oc}a$) than RZC, RPB, and conventional contactors such as fixed beds and stirred tank reactors.

Keywords: Defluoridation, Phenol, Alum, Lime, Aliquat 336, rotating packed bed, rotating zigzag bed, rotating spiral contactor.