Removal of phenol from Effluent in Fixed Bed: A Review

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Abstract— Phenol removal from wastewater is very widely studied area of research. The practical approach for phenol removal by adsorption involves study of batch adsorption and more importantly the fixed bed operation. In the present study, various aspects of fixed bed adsorption for phenol have been discussed. The review of research carried out on this topic is presented. The phenol removal in fixed bed has been carried out by using adsorbents, biosorbents, aerobic and anaerobic biological mechanisms. In most of the investigations fixed bed adsorption was found to be satisfactory in terms of removal efficiency and time. The nature of break through curve was justified by using various models. The experimental data was in agreement with model results. In most of the cases, the equilibrium capacity increased with increase in influent concentration, bed height and decreased with increase in flow rate.

Keywords— Adsorption, saturation time, isotherms, kinetics, flow rate, concentration , removal efficiency.

I.INTRODUCTION

Industrial effluent is major source of effluent disposed to river, land other reservoirs. One of the major pollutant of great environmental concern is phenol. Wastewater from other industries such as paper and pulp, resin manufacturing, tanning, textile, plastic, rubber, pharmaceutical and petroleum also contain different types of phenols. Phenolic compounds are harmful to organisms even at low concentrations and many have been classified as hazardous pollutants because of their potential harm to human health. Various methods used for phenol removal from wastewater includes abiotic and non–biological processes such as adsorption, photodecomposition, volatilization, coupling to soil humus and thermal degradation. Removal of phenol by adsorption is very effective treatment method. Use of fixed bed for phenol removal offers many advantages such as flexibility, adoptability and high removal efficiency. In the present study, the work done in this field is summerized.The studies and research carried out includes isotherm, kinetic, breakthrough curve studies. The batch data was used for isotherm and kinetic studies. Attempts have also been done to use the batch data to predict fixed bed parameters. Various models were used to justify the nature of breakthrough curve by various researchers.

II.PHENOL REMOVAL IN FIXED BED

Studies for the removal of aqueous phenol from activated carbon prepared from sugarcane bagasse in a fixed bed adsorption column were carried out by Karunarathnea and Amarasinghe[1]. They prepared adsorbent from fine bagasse pith collected from a leading local sugar manufacturing factory in Sri Lanka .This bagasse was washed and dried in an oven under the temperature of 700C for 24h. Preparation of activated carbon(AC) was done by heating a bagasse sample at 600^0C for 1 hour in a muffle furnace in the absence of air. AC particles between 1-2 mm in size were used for all the experiments. They conducted column experiments using a glass tube of 3 cm diameter and 55 cm height. They conducted the experiments varying the weight of activated carbon using initial solution concentration of 20mg/l. There are many parameters involve in evaluation of performance of fixed bed column such as solution initial concentration, flow rate, amount of adsorbent used and particle size of the adsorbent. The results show that the increases of adsorbent dose in column enhance the adsorbent capacity of the bed. Further percentage of length of the unused bed to its original bed height decreases with the increases of amount of adsorbent used. Anisuzzaman et.al.investigated phenol adsorption in activated carbon packed bed column with emphasis on dynamic simulation[2]. Their many study was aimed at the dynamic simulation of phenol adsorption within the packed bed column filled with activated carbon derived from dates' stones. The parameters such as column length, inlet liquid flow rate, initial phenol concentration of feed liquid and characteristics of activated carbon were investigated based on dynamic simulation using Aspen Adsorption V7.1. However, based on the simulation, they concluded that the adsorption column is not feasible for conventional water treatment plant. A review on removal of phenol from wastewater in packed bed and fluidized bed columns was done by Girish and Murty[3].. Their study provided an bird eye view of the packed and fluidized bed columns used for treatment of wastewater containing phenol and also on the different operational conditions and their performance. They concluded that to enhance the performance of the reactors for phenol adsorption, there is an indispensable requirement of novel efforts to be done in the reactor design.Gayatri and Ahmaruzzaman studied adsorption technique for the removal of phenolic compounds from wastewater using low-cost natural adsorbents[4]. Though activated carbon is an effective adsorbent, its widespread used is restricted due to its high cost and substantial lost during regeneration. Their study indicated that the adsorption for phenol in a fixed bed a efficient method for phenol removal The data obtained during investigation is in agreement with the models available to relate the break through time and break through curve for adsorption. Ekpete et.al used fluted pumpkin and commercial activated carbon for fixed bed adsorption of chlorophenol[5].They compared the removal efficiency of chlorophenol by fluted pumpkin stem waste to a commercial activated carbon. The fixed bed experiment were carried out to study flow rate (2-4ml/min), initial concentration (100-200mg/l) and bed height (3-9cm). Column bed capacity and exhaustion time increased with increasing bed height. With increase in the flow rate the bed capacity decreased. They observed that the column performed well for lowest flow rate of 2 ml/min. It was also observed that the increase in flow rate decreased the breakthrough time, exhaustion time and uptake capacity of chlorophenol due to insufficient residence time of the chlorophenol in the column. Li et.al. developed a mathematical model for multicomponent competitive adsorption process, to describe the mass transfer kinetics in a fixed-bed adsorber packed with activated carbon fibers (ACFs)[6]. They analyzed the effects of competitive adsorption equilibrium constants, axial dispersion, external mass transfer, and intraparticle diffusion resistances on the breakthrough curves for weakly-adsorbed and strongly-adsorbed components. It was observed, during the analysis that the effects of intrafiber and external mass transfer resistances on the breakthrough curves can be neglected for a fixed-bed adsorber packed with ACFs. The axial dispersion was confirmed to be the main parameter that controls the adsorption kinetics.

Ashtoukhy et.al. investigated removal of phenolic compounds by electrocoagulation using a fixed bed electrochemical reactor for petroleum waste.[7]. The investigation was carried out to study the removal of phenolic compounds in terms of various parameters in batch mode namely: pH, operating time, current density, initial phenol concentrations, addition of NaCl, temperature and the effect of phenol structure (effect of functional groups). Their study revealed that the optimum conditions for the removal of phenolic compounds were achieved at current density = 8.59 mA/cm2, pH = 7, NaCl concentration = 1 g/L and temperature of 25°C. EC of phenolic compounds using Al rasching rings connected together in the form of fixed bed sacrificial anode seems to be very efficient method from this research. The removal of 100% of phenol compound after 2 hrs was achieved for 3 mg/l phenol concentration of real refinery wastewater at the optimum conditions.Sorour et.al. studied application of adsorption packed-bed reactor model for phenol removal[8]. They conducted the experiments to determine the Langmuir equilibrium coefficients (α and Xm) and to determine the bulk sorbate solution concentration versus different adsorption column depths and different time as well. The model equations which are a combination of Particle Kinetics and Transport Kinetics were used to predicts the relations between sorbate concentration and flow rate as variables with column depth at any time. The granular active carbon[AquaSorbTM2000] and filtration anthracite [AMSI/AWWA 8100-96] was used as sorbents and phenol as sorbate through testing over a range of phenol concentrations (100-300 mg/l).The results of the model were in good agreement with the experimental data. The investigation on removal of phenol and lead from synthetic wastewater by adsorption onto granular activated carbon in fixed bed adsorbers was carried out by Sulaymon et.al.[9]. They used fixed bed adsorbers for removal of phenol and lead (II) onto granular activated carbon (GAC) in single and binary system. A general rate multi-component model which considers both external and internal mass transfer resistances as well as axial dispersion with non-liner multi-component isotherm, was utilized to predict the fixed bed breakthrough curves for dual-component system. The results showed that a general rate model was satisfactory for describing the adsorption process of the dynamic behavior of the GAC adsorber column. The research on fixed bed column studies for the sorption of para-nitrophenol from aqueous solutions using cross-linked starch based polymer was conducted by Sangeeta et.al.[10]. It was observed that the column experiments on cross-linked starch showed that the adsorption efficiency increased with increase in the influent concentration, bed height and decreased with increasing flow rate. Also the experimental data was well fitted with Yoon-Nelson model. It was concluded that the adsorbent prepared from the cross-linking of starch with HMDI was an effective adsorbent for the removal of para-nitrophenol (pNP) from waste water. maximum equilibrium capacity of 42.64 mg/g for pNP at 100 mg/L of influent concentration, bed height 7.5 cm and flow rate of 4 ml/min was observed. It was also seen that the equilibrium capacity increased with increase in influent concentration, bed height and decreased with increase in flow rate.Bakhshi et. al. used upflow anaerobic packed bed reactor (UAPB) for phenolremoval[11].The operating conditions were a hydraulic retention time (HRT) of 24 h under mesophilic (30±1°C) conditions. The operation was split into four phases. The concentration of phenol in phases 1, 2, 3 and 4 were 100, 400, 700 and 1000 mg/l, respectively..The reactor reached steady state conditions on the 8th day with a phenol removal efficiency and biogas production rate of 96.8 % and 1.42 l/d in phase 1.An increase of the initial phenol concentration in phase 2 resulted in a slight decrease in phenol removal efficiency. Phases 3 and 4 of startup followed the same trend. In phases 3 and 4, the phenol removal efficiencies at steady state conditions were 98.4 and 98%, respectively. A sudden decrease in biogas production was observed with stepwise increase of the phenol concentration, dynamic studies of nitro phenols sorption on perfil in a fixed-bed column were carried out by Yeneva et.al.[12]. They investigated the adsorption of two substituted nitrophenols, namely 4-nitrophenol (4-NP) and 2,4-dinitrophenol (2,4-DNP), from aqueous solutions onto perfil in a fixed bed. They applied the theoretical solid diffusion control (SDC) model describing single solute adsorption in a fixed bed based on the Linear Driving Force (LDF) kinetic model to the investigated systems. They used Biot number as an indicator for the intraparticle diffusion. The Biot number was found to decrease with the increase of bed depth. This indicated that the film resistance was increased or the intraparticle diffusion resistance was decreased. Coated sand (CS) filter media was used to remove phenol and 4-nitrophenol from aqueous solutions in batch experiments by Obaidy [13]. They studied the influence of process variables represented by solution pH value, contact time, initial concentration and adsorbent dosage on removal efficiency of phenol and 4-nitrophenol.The adsorption of phenol from aqueous solution onto natural zeolite was studied using a fixed bed column by Ebrahim[14]. They carried out experiments to study the effect of influent concentration, flow rate, bed depth and temperature on the performance of the fixed bed. The study indicated that there was a good matching between experimental and predicted data in batch experiment by using surface diffusion method. It was also observed that The Homogeneous Surface Diffusion Model (HSDM) which includes film mass transfer and surface diffusion resistance provides a good description of the adsorption process. With increase in concentration the breakthrough curve became steeper, because of increase in the driving force. The investigation on adsorption of phenol, p-chlorophenol and mercuric ions from aqueous solution onto activated carbon in fixed bed columns was done by Mckay and Bino[15]. It was observed that the parameters like bed depth, solution flowrate and pollutant concentration affect the breakthrough curve and breakthrough time. The Depth Service Time was used to analyze the data. The experimental data agreed with the model. In case of modeling, insufficient models are available to describe and predict fixed-bed or column adsorption. Mathematical models proposed to describe batch adsorption in terms of isotherm and kinetic behavior can be used for study of fixed bed.The review done by Xu et al. indicates that the general rate models (and "general rate type" models) and (linear driving force) LDF model generally fit well with the experimental data for most cases, but they are relatively time-consuming[16].It was also found in the review that The Clark model was suitable to describe column adsorption obeying the Freundlich isotherm and do not show conspicuously better accuracy than the above models. A research on Biological degradation of chlorophenols in packed-bed bioreactors using mixed bacterial consortia was carried out by Zilouei and Guieysse[17]. For the continuous treatment of a mixture of 2-chlorophenol (2CP), 4-chlorophenol (4CP), 2,4-dichlorophenol (DCP) and 2,4,6-trichlorophenol (TCP), two packed-bed bioreactors filled with carriers of foamed glass beads were tested at 14 degree C and 23 degree C. The results presented in their study represented some of the highest chlorophenol volumetric removal rates reported, even in comparison to the rates achieved in well homogenized systems such as fluidized bed and air-lift reactors. The maximum removal upto 99 percent was achieved without let concentration less than 0.1 mg/l. **Nakhli et.al. investigated** biological removal of phenol from saline wastewater using a moving bed biofilm reactor containing acclimated mixed consortia[18].It was observed that the performance of reactor depends on parameters such as inlet phenol concentration(200–1200 mg/L),hydraulic retention time (8–24 h),inlet salt content(10–70 g/L),phenol shock loading, hydraulic shock loading and salt shock loading. It was also observed that the an aerobic moving bed biofilm reactor (MBBR) was able to remove up to 99% of phenol. They concluded that the MBBR system with high concentration of the active mixed biomass can play a prominent role in order to treat saline wastewaters containing phenol in industrial applications very efficiently.

III. CONCLUSION

The phenol removal by fixed bed operation is very promising method of treatment. The percentage removal of the order of 99 to 100 percent has been reported. The nature of breakthrough curve is affected by the parameters such as initial concentration, bed depth and flow rates. With initial concentration and bed depth, the equilibrium adsorption capacity increases and it decreases with flow rate. The nature of breakthrough curve was justified in most of the cases by using the available models. There is still scope for developing the model for the fixed bed as available models in few studies were not able to explain the fixed bed adsorption phenomenon completely in terms of breakthrough time, saturation time and retention time.

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