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# Regeneration and Recovery in Adsorption- a Review

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**Abstract**

Adsorption is very promising method for removal of various pollutants from wastewater. Low cost of adsorbents, simplicity and high removal efficiency are few advantages of the method. In order to make this method more environment friendly and economical, regeneration of adsorbent is very important aspect. Many times it is also desirable to recover the solute from adsorbent. Thus the recovery of adsorbate and subsequent regeneration and reuse of adsorbent are important attributes of this process from economy and environmental point of view. In the current review, the summery of research carried out for recovery and regeneration of adsorbent is presented. It was found that various methods like solvent washing, chemical and electrochemical and thermal methods were used effectively for regeneration of adsorbents.

***Keywords:****adsorbent, adsorbate, reuse, regeneration, efficiency..*

## 1. Introduction

Treatment of wastewater by economical and effective method is very crucial in the era of development and technological advancements. Various organic and inorganic pollutants present in the effluent calls for specific and effective treatment technique. Adsorption by using low cost adsorbent is one such method. Adsorption has been used successfully by various investigators for removal of organic matter, phenol and heavy metals[1].Various adsorption techniques with high percentage removal are reported for removal of various metal ions from the wastewater. Low cost materials like leaf litter, flyash, rice husk and groundnut shell carbon have been used successfully for removal of organic and inorganic pollutants{2,3]. Also treatment of domestic effluent was carried out effectively with low cost adsorbents.[4]. The experiments carried out in batch and column mode were successful in terms of removal efficiency for heavy metal removal[5]. Removal of the pollutants like organic matter, phenol, dyes is very widely studied area of research[6,7,8,9]. The research on regeneration and recovery is the area of investigation which needs to be explored. The adsorbents like flyash can be regenerated chemical, thermal, solvant and biological methods[10].The reuse of adsorbent is required in order to make the process economical and environmental friendly. Various regeneration techniques like thermal, electrochemical, ultrasonic, chemical methods are reported for regeneration. The recovery of adsorbate is also reported by various investigators. The current review summarizes the research carried out for effective regeneration of the adsorbents. In many investigations successful recovery of solute was also reported. The need of recovery and regeneration depends on cost of solute and adsorbent and cost of recovery and also on the effect of the solute on the environment and weather it is to be disposal off in water reservoir or atmosphere.

## 2. Research for Regeneration, Recovery and Desorption

Shah et.al carried out investigation on thermal regeneration of adsorbents used for adsorbing volatile organic vapors[11]. They used activated carbon for acetone and methyl Ethyl Ketone (MEK) They carried out regeneration with dry air between 80 to $160^0$K. In case of MEK , it was observed that the regeneration efficiency increased with temperature. The increase in efficiency was about 13 percents.. For acetone, temperature change was not a factor. The regeneration was tried by using humid air. They found that the complete removal of adsorbate by humid air was not possible. It is necessary to have short drying phase at high temperature or long drying phase for low temperature. In both cases regeneration time increases. So short term steam injection was suggested by them.

Velu et.al reported regeneration of adsorbent used for spent oil [12]. The method with solvent washing, oxidative or reductive regeneration was used by them. For solvent washing a mixture of methanol and toluene was used. The adsorbent was treated at high temperature and in reductive method; the adsorbent was treated with hydrogen at 400-500 $^oC$. Solvent washing was very effective and advantageous from environmental point of view. The adsorbent such as supported Ni metal, adsorbs the sulfur compounds at elevated temperature. In some case reductive regeneration becomes necessary. In their review paper Rao et.al emphasized the need to gather more information on regeneration as they found that there is lack of information in this area [13].Quing-Zu et.al. investigated the regeneration of modified spent grain used for lead removal[14]. They used desorbing agents like HCl, $H_2SO_4$, $H_3PO_4$, NaOH, NaCl and ultrapure water in their research. They observed that hydrochloric acid was the most efficient desorbing agent with 86 percent efficiency. Water and sodium chloride were not effective in removing the adsorbed materials. They found that as the HCl concentration was increased initially, there was increase in efficiency up to certain concentration. During their investigation, it was also observed that, above certain concentration, the increase in HCl concentration may deteriorate the adsorbent. Desorption increases up to certain contact time, corresponding to equilibrium. An experimental and technical review on the steam regeneration of adsorbent was carried out by Shah et.al [15]. According to them the regeneration is very important from techo-economical viability point of view for the use of adsorption process. The method adopted for regeneration depends on cost and nature of adsorbent. They observed that familiarity and availability of steam generation units make this method common for regeneration. They concluded that the drying of steam was energy intensive. Also drying time was a concern. So research is required on this aspect of thermal regeneration.

Quang et.al. carried out investigation in order to reduce the energy required for regeneration of adsorbent used for $CO_2$ capture [16]. They used impregnated silica for $CO_2$ capture as solid adsorbent. The silica was impregnated with various amines including 2-aminomethylpropanol (AMP), monoethanolamine (MEA), diethanolamine (DEA) and polyethyleneimine (PEI). They observed that the impregnated solid adsorbent was better than conventional MEA (30%) for $CO_2$ capture. The heat required for MEA impregnated adsorbent for regeneration was 47 % less than MEA process. They concluded that silica was promising solid support material for solid adsorbent. High-power electromagnetic field was used for adsorbent regeneration by Goncharenko et.al [17]. They used drying at reduced pressure for increasing adsorption because of reduction in moisture content of oil from transformers. Kwon and Jeon carried out investigation on previously adsorbed indium ions on phosphorylated sawdust for adsorption and desorption characteristics[18]. About 97 percent regeneration was possible with 0.5N hydrochloric acid. By using Ethylenediamine-tetraacetic acid and nitrilotriacetic acid 79 percent desorption efficiency was possible. For HCl , it was 74 percent They also observed that the desorption efficiency of recycled phosphorylated sawdust for indium ions can be kept at 85% through 4 cycles. Saito used a solar desiccant system using an adsorbent in an integrated desiccant/solar collector[19].This system used direct solar energy as a heat source for efficient regeneration of the adsorbent. The adsorbent was heated by solar radiation. In their study they used silica gel as adsorbent. Brown et. al. carried out electrochemical regeneration of the carbon based adsorbent loaded with crystal violet[20]. They carried investigation using a non-porous, electrically conducting carbon-based adsorbent at different conditions. They observed that large number of variables including charge passed, current density, treatment time, electrolyte type and concentration and the adsorbent bed thickness affected the efficiency of electrochemical regeneration. Various adsorption processes were discussed by Cavalcante Jr. They considered various aspects of the adsorption process such adsorbate concentrations, adsorbent regeneration methods, and modes of operation[21]. They discussed various regeneration techniques such as temperature and pressure swing method(TSA and PSA), inert purge and desorbent replacement. According to their discussion, TSA method has advantage of high adsorbent recovery with small temperature change but thermal aging of adsorbent, heat loss and slow cycle are few disadvantages of this method. Also they observed that rapid cycling was possible in PSA but low pressure requirement and low desorbate quality and high mechanical energy are concerns. Purge method operates at constant temperature and pressure but needs high purge volumes. Also they emphasized that displacement of desorbent has advantages such as avoiding thermal effects such as aging and cracking, the disadvantage being necessity of product separation and recovery.

Bhuvaneshwari et.al. investigated the regeneration of chitosan after heavy metal sorption[22]. They used dilute mineral acids and organic acids as eluents. By using sulphuric acid, 88 % of the chromium was recovered without any damage to the adsorbent. They also observed that the regenerated adsorbent was almost as efficient as the original new adsorbent. Yamamoto et.al. carried out research on the removal of moisture from air by adsorption and subsequent regeneration[23]. They used nonthermal plasma for possible replacement of the electric heater. They observed that water vapor desorption rate showed superior characteristics in term of energy efficiency. Hussain et.al. carried out investigation on regeneration of various graphite based adsorbent by electrochemical method. The regeneration was carried out in a simple electrochemical reactor[24]. The anodic oxidation of adsorbed species at the adsorbent surface was the operating principle. They investigated the formation of breakdown products during their electrochemical regeneration. They observed that fewer breakdown products were obtained for exfoliated graphite (EG) adsorbent. In their investigation for removal of lead from vanillin solution by modified cattail biomass, Lu and Liang also investigated the regeneration of adsorbents[25]. They found that the biomass was very easily regenerated by 0.1 N hydrochloric acid. Biosorptive removal of toxic metal ions from wastewater was done by Ferreira do et.al[26]. They carried out column recovery for metals using nitric acid of 0.1 M and hydrochloric acid of 0.1 M. They observed that the removal efficiency decreased by 10-13 percent from first to forth cycle. Banana Peel as bio-adsorbent was used for copper removal by Hossain et.al[27]. The desorption of copper up to 94 % was possible by 0.1 N sulphuric acid. They also observed the cycles can be repeated for 7 times with satisfactory results. They also tried solvents such as the tap water, distilled water, $CH_3COOH$ and NaOH. These solvents exhibited limited amount of desorption(less than 30%).Stability enhanced magnetic nanoparticles were used for rapid chromium removal from waster by Pang et.al[28]. They observed that the alkaline conditions suited the desorption. In their investigation, sodium hydroxide solution was used for regeneration. They observed there was not significant decrease in the adsorption capacity after successive regenerations. The drop in capacity of only 9 % was observed after 6 cycles.

## 3. Conclusions

Regeneration is very important aspect of the adsorption from economy and environmental point of view. The disposal of adsorbent is one of the problems associated with the adsorption processes. The regeneration can reduce the need of new adsorbent and also reduce the problem of disposal of used adsorbent. Various regeneration methods have been used with different degrees of success. These methods includes solvent washing, thermal, chemical and electrochemical regeneration. The recovery of many solutes was possible by using solvent washing. Use of nonthermal plasma instead of electric heater showed promising results in terms of energy efficiency. MEA impregnated silica was promising alternative in terms of adsorption and desorption efficiency for carbon dioxide. It can be concluded that regeneration, reuse of adsorbent and the recovery of solute are few important aspects of the adsorption which can render this wastewater treatment method more economy, value and importance.

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