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Various Intensification Methods for Adsorption - A Review on Studies and Investigations

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ABSTRACT

Adsorption is used for removal of pollutants and waste gases from liquid and gases effluent. Use of waste material for adsorption preparation makes this method more attractive. Regeneration of this adsorbent is very important aspect of the application of adsorption for various applications. Intensification of the adsorption bed includes reducing cycle time for pressure swing (PSA) and temperature swing (TSA) adsorption increasing thermal conductivity of the bed, optimizing various operating parameters. Regeneration of bed is an important aspect in adsorption desorption cycle as the low thermal conductivity of adsorbent is responsible for extended cycle time. To increase the conductivity, conducting materials in the form of composite fins can be uses. This review aims to study of different intensification technique for adsorption desorption process.

Keywords: *PSA; TSA; Regeneration; Intensification; Conductivity.*

1.0 Introduction

Adsorption is a surface mass transfer process in which there is a sorption of the molecules takes place form bulk fluid to the surface of the solid. Activated carbon, silica gel, alumina, cellulose, zeolite are the commonly employed adsorbent in chemical industries. Some of the adsorbents used as a desiccants, catalysts, some are used for the gas isolation, liquid purification, prevention of contamination or for respiratory purposes protecting. In addition, in many solid state situations, adsorption phenomena play a critical role. Adsorption mainly categorizes in two types, Physical adsorption which is due to van der walls forces of attraction between the solid adsorbent and adsorbed molecule and Chemical adsorption in which the strong chemical bonds between adsorbed and adsorbent are present. Desorption is a process in which a adsorbed material is released from a surface over which absorption is happened. It is a reverse process of absorption also called as regeneration method. It is necessary to do regeneration in order to make the process cost efficient and environmental protective. Bed recycling is important to reduce process cost. The adsorbent used in process should be a more surface area. Activated carbon is used commonly only because of its strong bonds with hydrocarbons and large surface energy. The Absorption-desorption cycle mainly having two technologies called as pressure swing adsorption (PSA) and temperature swing adsorption (TSA). The pressure swing adsorption is generally used for gas separation in which the pressurization and depressurization process is carried out this method is widely used in the industries. On the other hand the temperature swing adsorption is a two bed cyclic process in which one bed used for adsorption of gases and other for regeneration until the cycle completion. The main problem with this process is the low thermal conductivities of the adsorbents due to which there is low heat transfer within the bed. Also the heating and cooling time required for the bed is more which directly effects on the cycle time. This review aims to study on various intensification methods for adsorption desorption cycle through which we can increase the heat transfer coefficient within bed which will reduce the cycle time.

2.0 Process Intensification

Process intensification is defined as a method to reduce cost, space and efforts for unit operation or process. For the set of target operations the process intensification is done by integration of functions and the unit operations [1]. According to C.

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Ramshaw, process intensification is an action for making dramatic reduction in the size of a chemical plants.

In another words, Intensification is a modern technique aims to shrinks the size of chemical plants and increase the efficiency of the plants [2]. An investigation on recent developments in process intensification in terms of sector and unit operation was carried out by Reay et al., [3]. According to them, the serious attraction on the process intensification was in 1970 which was basically from the chemical sector. For improvement of heat transfer and mass transfer there investigation approaches are basically towards historical aspects like the rotating operation of different equipment enhances the heat transfer within an equipment. Also they studied the process intensification of rotating equipment's like rotating boilers, rotating heat pipe, different types of separator and reactors etc. Their investigation helps to improve the process intensification techniques and develop the cost effective equipment. To develop a more sustainable chemical process, process intensification is considered as a most promising progress path. Selen Cremaschie explained various definitions of process intensification in there literature like any development in chemical engineering were leads to considerably smaller, cleaner, secure and most energy efficient technology [4].

The Adsorption-desorption operation is widely used in the waste water treatment and gas separation units due to simplicity of equipment and inexpensive fabrication. On the other hand, there is limitation in this operation like low thermal conductivity of adsorbent. More heating and cooling time is responsible for the extend in cycle time. To overcome this type of problems the intensification is needed which will gives good efficiency.

3.0 Pressure Swing Adsorption (PSA)

A PSA cycle comprises of two operations: Adsorption: performed at high pressure; and Desorption: performed at low pressure. H_2 purging in processing plants, air partition, CH_4 refinement, gas drying are some applications of pressure swing adsorption. Rajendran et al., designed and optimized pressure swing adsorption cycles for pre-combustion CO_2 capture [5]. Objective of their investigation was to plan an assortment of PSA measures with low energy utilization for pre-combustion CO_2 capture inside an IGCC power plant. The adsorbent material utilized was an initiated carbon called TDA AMS-19. The full scale PSA reproductions included tackling mass, force and energy balances to get the weight, temperature and concentration profiles for gases. The exhibition pointers, to be specific, virtue and recovery for CO_2 were determined after the cycle arrived at the cyclic consistent state by them. Simultaneously, they carried out an unconstrained multi objective optimization to expand the CO_2 virtue and recovery for six PSA cycle arrangements. Another investigation was carried on modeling and optimization of pressure swing adsorption unit by Aspen plus ® and Design expert ® by Sutradhar et al., [6]. The main aim of their investigation was to calculate the production of N_2 from air separation unit (ASU). With the help of Aspen plus ® they simulated the whole cycle and then optimized results with the help of Design expert ®. For the thermodynamic properties they used Ideal and Peng-Robinson models to get best equilibrium as the components namely nitrogen (N_2) and oxygen (O_2).

Bulfin et al., produced a high purity nitrogen from air by combining the pressure swing absorption with downstream redox chemical looping cycle [7]. Main aim of their investigation was to remove the oxygen traces and obtain a high purity nitrogen from air. To obtain an approximate energy demand they performed an energy balance in which the air was passed through PSA unit for the removal of CO_2, H_2O and H_2 traces. Then they increased a gas temperature to perform an oxidation and passed the gas to the packed bed. An investigation was carried out to obtain an adsorption equilibrium data of pure CO_2 and pure CH_4 on activated carbon with a different temperatures and pressure conditions by Grande et al., [4].

They also studied the breakthrough curve analysis for the same purpose. They first measured the surface area of activated carbon which is pretreated 423 k and vacuum for 10 hrs. by N_2 adsorption with the help of two manometric units namely Belsorp-max, and Belsorp-mini. In order to determine the break through curves they performed dynamic experiment on the fix bed unit. Mass controller, two temperature sensors, pressure regulator and continuous detection unit all were mounted on the fixed bed. As a result they obtained a deviations as high as 20% in the total loading which was obtained from the dynamic and static methods. Also the relative loading difference was as high as 25% of CO_2 and CH_4. They concluded that the high pressure multicomponent experimental data is very important for the design of PSA cycle for the gas separation. Selective literature on Intensification on Pressure swing Adsorption is tabulated in Table 1.

Table 1: Literature Study on Intensification of Pressure Swing Adsorption

Ref. No.	Author	Paper Title	Results
1	Sai GokulSubravetia, Kasturi NageshPaia, Ashwin Kumar Rajagopalanb, Nicholas StilesWilkinsa, Arvind Rajendrana,	Cycle design and optimization of pressure swing adsorption cycles for pre-combustion CO2 capture	10-step PSA cycle, reduced energy consumption of 95.7 kWhe/ton of CO2 caught at a low efficiency esteem (3.3 mol CO2/m3 adsorbent/s)
2	Pranta Sutradhar, Pritam Maity, Sayan Kar, Sourav Poddar	Modelling and Optimization of PSA (Pressure Swing Adsorption) Unit by using Aspen Plus® and Design Expert ®	A maximum flow rate of N2 is 87.2136 kg/h oxygen 140.608 kg/h and water vapor 107.62 kg/h obtained at T = 301.75 k, 312.34 k and 299.34 k.
3	B. Bulfin , L. Buttsworth, A. Lidor, A. Steinfeld	High-purity nitrogen production from air by pressure swing adsorption combined with SrFeO3 redox chemical looping	the energy demand of 14 kJ mol−1 N2 for a cut-off oxygen impurity of 3 × 10−6
4	Carlos A. Grande, Richard Blom, Andreas Moller, Jens Mollmer	High pressure separation of CH_4/CO_2 using activated carbon	The relative loading difference was as high as 25% of CO_2 and CH_4

4.0 Temperature Swing Adsorption

An investigation was carried out on thermal conductivities of AQSOA FAM-ZO2 packed bed adsorbers by Rouhani et al., [9]. The aim of their investigation was to study the effective thermal conductivity of packed bed absorbers. For calculating steady state thermal conductivity measurements of packed bed absorbers, they used a heat flow meter (HFM) apparatus. Askalany et al., investigated with the aim that to decrease the regeneration time of granular activated carbon by increasing the thermal conductivity of its[10]. For the same purpose they added the fillings of iron, copper and aluminum which all are having mass concentration within 10 to 30%. According to their investigation with the increase in mass concentrations of metallic additives the thermal conductivity should be increased. By the addition of 30% concentration of aluminum fillings they successfully decreases the cycle time by 50% In addition to that the specific cooling power increases by 100%.

Table 2: Literature Study on Intensification of Temperature Swing Adsorption

Ref. No.	Author	Paper Titles	Result
1	Mina Rouhani, Wendell Huttema, Majid Bahrami.	Effective thermal conductivity of packed bed adsorbers: Part 1–Experimental study	From this experimental study the effective thermal conductivity of packed adsorber bed was calculated.
2	Ahmed A. Askalany, Stefan K. Henninger, Mohamed Ghazy, Bidyut B. Saha.	Effect of improving thermal conductivity of the adsorbent on performance of adsorption cooling system	As a result they obtained, the specific cooling power is increased accordingly with decreasing in cycle time
3	L. Jianga, R.Q. Wanga, A. Gonzalez-Diaza, A. Smallbonea, R.O. Lamidib, A.P. Roskilly.	Comparative analysis on temperature swing adsorption cycle for carbon capture by using internal heat/mass recovery	Highest energy efficiency of 4-step TSA cycle with recovery technologies.
4	Tore Eriksson, Yohannes Kiros.	Temperature swing adsorption device for oxygen-enriched air	As a result they obtained, 15L of oxygen could be produced at a concentration of 30% in the oxygen enriched air per kg zeolite and hour.
5	Bowen Liu, Yahui Lian, Shuangjun Li, Shuai Deng, Li Zhao, Bing Chen, Dahai Wang.	Experimental investigation on separation and energy-efficiency performance of temperature swing adsorption system for CO2 capture	Range of second law efficiency is between 3.24% and 9.23% with the max. Recovery rate 83.97% and the purity of 94.75.

During investigation they also conclude that the adsorption cooling system is one of the most important aspect in the field of renewable energy.

They found that the specific cooling power increased with decreasing cycle time. The specific cooling power increased from 0.015KW/Kg to about 0.027KW/Kg of activated carbon. By using aluminum filling specific cooling power could double. An investigation was carried out on performance of a 4-step temperature swing adsorption cycle is explored by recovery technology by Jiang et al., [11].

Main aim of their investigation was to analyze TSA cycle for CO2 capture by internal heat and mass recovery. By using the characteristics of activated carbon, theoretical performance of 4-step temperature swing adsorption cycles was first evaluated by them based on the carbon pump theory. According to their investigation there are 4 working processes for composing the 4-step TSA cycle. i.e. adsorption, preheating, desorption and precooling. An investigation was carried out on temperature swing adsorption device for oxygen enriched air by Eriksson et al., [12].

The main aim of their investigation was to produce oxygen enrich air from ambient air using temperature differences in the TSA. Temperature swing adsorption is usually used to clean gases from various impurities. According to their study, TSA device was small in scale. Research was carried out on post combustion CO2 Capture by Liu et al., [13]. Aim of their investigation was to analyze energy efficiency performance of TSA system for CO2 capture. They also conclude that TSA is one of the efficient methods for CO_2 adsorption. The adsorbent used in this was zeolite 13X-APG which is an alkali alumino-silicate adsorbent in the form of spherical beds. This was used in separation of H2O and CO2 from air. In adsorbent regeneration temperature swing adsorption can employ low and medium grade energy. They obtained, second law efficiency between 3.24% and 9.23% which has a maximum recovery rate of 83.97% with a purity of 94.75. Selective literature on Intensification on Temperature swing Adsorption is tabulated in Table 2.

5.0 Breakthrough Curves

A breakthrough curves are graphically represented between adsorbate concentration in the outlet effluent stream of an adsorber and the time. The effluent stream maybe contain either a mixture of air and adsorbate or liquid-adsorbate. The breakthrough curves is steeper when the flowrate of gas mixture is slower. A breakthrough curves generally represents the working life of an adsorbate. In the absorption bed conversion of effluent mixture to pure element takes place. The conversion will takes place within a definite zone which is called as mass transfer zone (MTZ), and the mass transfer of adsorbate to the surface of adsorbent is the main influencing factor by which the shape of the breakthrough curve gets influences [14].

Factors affecting on Breakthrough curve

Chowdhury et al., evaluated the design parameters for the study of kinetics of Cu(II) cations fixed bed column with the help of lignocellulose waste and breakthrough curve analysis has been done for the same purpose. [15]. In their investigation they perform the breakthrough curve analysis by considering the parameters like Influent concentration, Bed height and the Influent flowrate.

Influent Concentration.

To study the effect of influent concentration of breakthrough curve, initially they varied the concentration between 50, 70, and 100 mg/L with the bed height 4.5 cm and at 1.5 mg/L flowrate.

By performing this experiment, they observed that as the concentration varying from the 50 to 100mg\L the breakthrough curve gets steeper and the bed reached its break point quickly than the other two concentrations [15]. They also conclude that by keeping the lower concentration of effluent, longer contact time required to exhaust the bed which results in an overall decrease in mass transfer coefficient [15].

Bed height

To study the effect of bed height on the breakthrough curve, initially they considered the two heights of bed i.e.. 3 and 4.5 respectively with the initial concentration of 100mg/L and the flowrate of 1 mL/min [15]. By performing this experiment they observed that the bed with a higher height shows the less steep tendency. Also they noticed that the time required to reach the break point for higher height is more as compare to lower height. In addition to that of they concluded that the by increasing the height of bed we can treat the large volume of the influent.

6.0 Conclusions

In this review paper we have discussed about process Intensification and need of adsorption intensification. Also the various intensification methods on pressure and temperature swing absorption along with breakthrough curves and various factors which affect on the breakthrough curves are studied. In this review our main aim is to study methods to reduce the absorption desorption cycle time by increasing the heat transfer coefficient within the bed to make it ecofriendly and economically cheaper.

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