ADSORPTION IN WASTE WATER USING ACTVATED CARBON: A Review

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ABSTRACT

Organic pollution is the term used when large quantities of organic compounds originate from domestic sewage, urban run-off, industrial effluents and agriculture wastewater. Sewage treatment plants and industry including food processing, pulp and paper making, agriculture and aquaculture [20]. The removal of nitrogenous compounds can be carried out by electrochemical, biological and adsorption methods [4]. Treated water use for Irrigation, toilet flushing, car washing, gardening, firefighting, etc. Adsorption is the simplest and low cost treatment technology based on the principle of attached growth process. A multimedia filter model was developed by G.I. sheet for treatment of domestic wastewater. Different packing media are used such as Activated carbon, sugarcane bagasse, sand and grass mulch [9]. It has been observed that 75-80 percent removal of COD and organic matter can be obtained by activated carbon [7]. Carbon adsorption is an extremely versatile technology. For many water treatment applications it has proved to be the least expensive treatment option.

Keywords- Introduction, Activated Carbon, Adsorption Isotherm

I.   INTRODUCTION

A. General

Carbon has been used as an adsorbent for centuries. Activated carbons ability to remove a large variety of compounds from contaminated waters has led to its increased use in the last thirty years. Recent changes in water discharge standards regarding toxic pollutants have placed additional emphasis on this technology [23]. Adsorption is a natural process by which molecules of a dissolved compound collect on and adhere to the surface of an adsorbent solid. Adsorption occurs when the attractive forces at the carbon surface overcome the attractive forces of the liquid. Adsorption is particularly effective in treating low concentration waste streams and in meeting stringent treatment levels. One of the major attributes of activated carbon treatment is its ability to remove a wide variety of toxic organic compounds to non-detectable levels (99.99%). Its suitability on a specific application will normally depend on costs as they relate to the amount of carbon consumed. [23]

B. ACIVATED CARBON

i) Vapor Phase Activated Carbon
General Carbon carries a complete line of activated carbon made from coal, coconut shell and wood for most vapor phase and air applications. These include impregnated carbons for specialty applications and high capacity non-impregnated carbon for H_2S control [1]. In addition, specialty medias are ideal for the treatment of many contaminants that activated carbon may struggle with. Orders of bulk activated carbon are also acceptable since   1958.

ii) Liquid Phase Activated Carbon
Like the vapor phase carbon, General Carbon's liquid phase activated carbon products are made from coal, coconut shell and wood for most liquid phase and water applications. These include acid washed activated

carbon for drinking water and food grade applications as well as products suitable for waste water remediation, decolorization applications, chemical and pharmaceutical purification. The stock of activated carbon for liquid phase applications are all manufactured in an NSF certified plant, meaning that they are approved for treatment of food grade applications.

II.   PREPARATION OF ACTIVATED CARBON

The medium for an activated carbon filter is typically petroleum coke, bituminous coal, lignite, wood products, coconut shell or peanut shell. The carbon medium is "activated" by subjecting it to stream (a gas like water, argon or nitrogen) and high temperature (800-1000°C) usually without oxygen. In some cases, the carbon may also undergo an acidic wash or be coated with a compound to enhance the removal of specific contaminants. The activation produces carbon with many pores and a high specific surface area. It is then crushed to produce a granular or pulverized carbon product.

Fig 1: Wood and Coal material

III.   ACIVATED CARBON ADSORPTION SYSTEMS

Fixed bed type: A fixed bed column is used commonly for contacting waste water with GAC. Fixed bed columns can be operated singly, in series or in parallel. Granular medium filters are commonly used upstream of the activated carbon contractors to remove the organics associated with the suspended solids present in secondary effluent. The water to be treated is applied to top of the column and withdrawn at bottom. The carbon is held in place with an under drain system at the bottom of column. Provision for backwashing and surface washing is often provided in waste water applications to limit the head loss build up due to the removal of particulate suspended solids within the carbon column.

The advantage of down flow design is that adsorption of organics and filtration of suspended solids is accomplished in a single step. Although up flow fixed bed reactors have been used, down flow beds are used more commonly to lessen the chance of accumulating particulate matter in the bottom of the bed, where the particulate matter would be difficult to remove by backwashing. If soluble particles are not maintained at a high level, more frequent regeneration of carbon may be required.
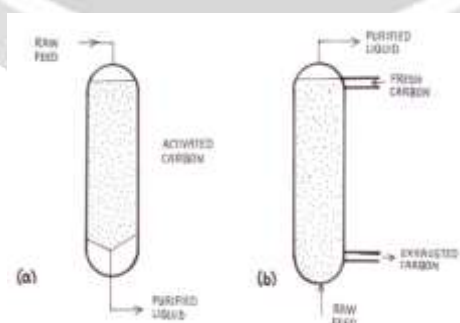

Fig 2: Fixed Bed Type System

Expanded bed type: Expanded bed, moving bed and pulsed-bed carbon contactors have also been developed to overcome the problems associated with head loss build-up. In expanded bed system, the influent is introduced at the bottom of the column and the activated carbon is allowed to expand, much as a filter bed expands during backwash. When the adsorptive capacity of activated carbon is exhausted, the bottom portion of carbon is removed, and an equivalent amount of regenerated or virgin carbon is added to the top of the column. In such a

system, expanded-bed upflow contractors may have more carbon fines in the effluent than down flow contractors because bed expansion leads to the creation of fines as the carbon particles collide and abrade, and allows the fines to escape through passageways created by the expanded bed.
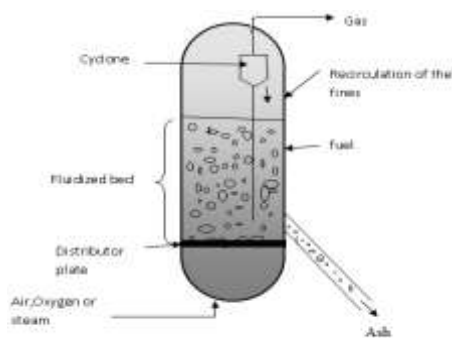

Fig 3: Expanded Bed Type System

Fluidized bed reactor type: A fluidized bed reactor (FBR) is a type of reactor device that can be used to carry out a variety of multiphase chemical reactions. In this type of reactor, a fluid (gas or liquid) is passed through a granular activated carbon at high enough velocities to suspend the solid and cause it to behave as though it were a fluid. This process, known as fluidization, imparts many important advantages to the FBR. As a result, the fluidized bed reactor is now used in many industrial applications.

The solid substrate (activated carbon) material in the fluidized bed reactor is typically supported by a porous plate, known as a distributor. The fluid is then forced through the distributor up through the activated carbon. At lower fluid velocities, the solids remain in place as the fluid passes through the voids in the material. This is known as a packed bed reactor. As the fluid velocity is increased, the reactor will reach a stage where the force of the fluid on the solids is enough to balance the weight of the solid material. This stage is known as incipient fluidization and occurs at this minimum fluidization velocity. Once this minimum velocity is surpassed, the contents of the reactor bed begin to expand and swirl around much like an agitated tank or boiling pot of water. The reactor is now a fluidized bed. Depending on the operating conditions and properties of solid phase various flow regimes can be observed in this reactor.
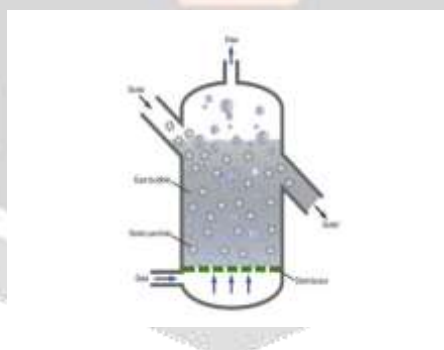

Fig 4: Fluidized Bed Reactor System

ADSORPTION ISOTHERM

The quantity of adsorbate that can be taken up by an adsorbent is a function of both the characteristics and concentration of adsorbate and the temperature. The characteristics of the adsorbate that are of importance include: solubility, molecular structure, molecular weight, polarity, and hydrocarbon saturation. Generally, the amount of material adsorbed is determined as a function of the concentration at a constant temperature, and the resulting function is called an adsorption isotherm. Adsorption isotherms are developed by exposing a given amount of adsorbate in a fixed volume of liquid to varying amounts of activated carbon. Typically more than ten containers are used, and the minimum time allowed for the samples to equilibrate where powdered activated carbon is used in seven days. If granular activated carbon is used, it is usually powdered to minimize adsorption times. At the end of the test period, the amount of absorbate remaining in solution is measured. The adsorbate phase concentration data computed using the equation, are then used to develop adsorption isotherms.

$$qe = [(C0 - Ce)/m] \, V$$

where, qe = adsorbent phase concentration after equilibrium, mg adsorbate/ g adsorbent

C0 = initial concentration of adsorbate, mg/L

Ce = final concentration of adsorbate after absorption has occurred, mg/L

V = volume of liquid in the reactor,

 L m = mass of adsorbent, g

Laboratory evaluation of the adsorption isotherm and the adsorption capacity is time consuming and may be affected by toxicity or the availability of the adsorbate. For such difficult cases, a model that can predict the adsorption capacity, making testing unnecessary, would be highly desirable. A number of such models have been proposed for the adsorption isotherm: the Freundlich isotherm equation; the Langmuir isotherm; BET-theory; the Hacskaylo and Levan equation; the Dubinin Raduskevish equation; and a modification of the DR equation developed by Stoeckli. Dubinin Raduskevish Equation

Among the existing predictive equations, the DR equation has been the most widely used to predict organic vapour adsorption onto activated carbon.

It has several advantages: a) there is a good data fit over a wide concentration range b) temperature is included as a parameter c) it is built around physical parameters d) it is easy to apply. Dubinin postulated that the amount of vapour adsorbed (W) by an activated carbon source, at a relative pressure (P/Ps), is a function of the thermodynamic potential (A), with A expressed as $A = RT \ln (Ps/P)$ where R is the universal gas constant, T is the absolute temperature, Ps is the saturated vapour pressure at temperature T, and P is the partial pressure of the adsorbate.

 By examining the adsorption of simple organic compounds, such as benzene, Dubinin concluded that the function was Gaussian.

This led to the classical expression of Dubinin and Radushkevich (the D-R equation):

 $$W = W0 * \exp (A/\beta E0)2$$

Where, W0 is the maximum amount adsorbed, E0 is the characteristic adsorption energy for a reference vapour on a specific adsorbent. The parameter β is called the affinity coefficient or similarity coefficient, and expresses the ratio of the characteristic free energies of adsorption for the test and reference vapours. Benzene is, by convention, used as the reference compound for carbonaceous materials, and is, by definition, given the value $\beta = 1$. Freundlich Isotherm

The Freundlich isotherm is used most commonly to describe the adsorption characteristics of the activated carbon used in water and waste water treatment. It was derived in 1912 and is defined as follows: x/m = KfCe1/n Where, x/m is the mass of adsorbate adsorbed per unit mass of adsorbent, mg adsorbate/ g activated carbon Kf = Freundlich capacity factor, (mg absorbate/ g activated carbon) Ce = equilibrium concentration of adsorbate in solution after adsorption, mg/L 1/n = Freundlich intensity parameter Langmuir Isotherm Langmuir adsorption isotherm is derived by assuming:

(1) a fixed number of accessible sites are available on the adsorption surface, all of which have the same energy, and

 (2) adsorption is reversible. Equilibrium is reached when the rate of adsorption of molecules on to the surface is same as the rate of desorption of molecules from the surface. The rate at which adsorption proceedes is proportional to the driving force, which is difference between the amount adsorbed at a particular concentration and the amount can be adsorbed at that concentration. At the equilibrium concentration, this difference is zero. Langmuir adsorption isotherm can be expressed as:

x/m =(abCe)/(1+bCe)

 x/m = mass of adsorbate adsorbed per unit mass of adsorbent, mg adsorbate/g activated carbon a, b = empirical constants Ce = equilibrium concentration of adsorbate in solution after adsorption, mg/L

Adsorption isotherm Initially, when a contaminated gas stream passes through a packed carbon bed, most of the contaminant, the adsorbate, is adsorbed in the vicinity of the inlet to the bed. The gas then passes on with little further adsorption taking place. Later, when the inlet part of the adsorbent becomes saturated, adsorption takes place deeper inside the bed. As more gas passes through and adsorption proceeds, the so-called mass transfer zone (MTZ) moves forward until the breakthrough point is reached. If the flow of gas is continued, the exit concentration from the bed will rise gradually until it reaches the level of the inlet concentration. At this point, the bed is fully saturated. The service life of the filter bed is regarded as the time when the exit concentration has reached an unacceptable level.

Adsorption kinetics

Several models to predict the breakthrough curves for physisorption of organic vapours have been proposed. Among these, the Wheeler-Jonas equation is the most widely used to estimate the breakthrough time of organic compounds on activated carbon. It has a simple form, with some parameters readily available from the literature or from carbon manufacturers, and it is known to yield good predictions for breakthrough times. It has recently been shown that the Wheeler-Jonas equation has a wider scope of application than just physisorption for a constant flow pattern. The Wheeler-Jonas equation takes the form where t_b = time to reach the breakthrough fraction b = C_x / C_0 (min) C_0 = bed inlet concentration (g/cm3) C_x = chosen breakthrough concentration (g/cm3) W = weight of the carbon bed (g carbon) We = equilibrium adsorption capacity of the carbon for a given vapour (g/g carbon) Q = volumetric flow rate (cm3/min) ρ_B = bulk density of the carbon bed (g carbon/cm3) kv = overall adsorption rate coefficient (min-1) To use this equation, two parameters, We and kv, must be determined. This can be done either experimentally or by extrapolation from measurements using a reference adsorbate. The first parameter We, the adsorption capacity, is usually calculated from an adsorption isotherm equation; the Dubinin-Radushkevich equation is often used in the case of organic vapour adsorption.

IV ADVANTAGES OF ACTIVATED CARBON IN TREATING WASTE WATER

1. Highly effective at removing non-polar organic chemicals from water.
2. Applicable to a wide variety of organic compounds   Very effective at removing colours from waste streams.
3.   Effective at removing low levels (ppb range) of inorganic pollutants.
4. Thermal regeneration of the carbon destroys the adsorbed waste solute.
5.   Very flexible system allows rapid start-up and shut down as needed. System can be designed so that it is portable, to be taken to waste sites.

V.   DISCUSSION

Activated carbon filtration is a commonly used technology based on the adsorption of contaminants onto the surface of a filter. This method is effective in removing certain organics (such as unwanted taste and odours, micro pollutants), chlorine, fluorine or radon from drinking water or wastewater. However, it is not effective for microbial contaminants, metals, nitrates and other inorganic contaminants. The adsorption efficiency depends on the nature of activated carbon used, the water composition, and operating parameters. There are many types of activated carbon filters that can be designed for household, community and industry requirements. Activated carbon filters are relatively easy to install but require energy and skilled labour and can have high costs due to regular replacement of the filter material

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