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# *Validation of Cadmium ($C_d$) Removal from Wastewater by using Different Adsorption Isotherms*

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## *Abstract*

*One of the worldwide environmental issues is water contamination by toxic heavy metals such as lead ($P_b$), zinc ($Z_n$), copper ($C_u$), arsenic ($A_s$), cadmium ($C_d$), chromium ($C_r$), nickel ($N_i$) and mercury ($H_g$). These heavy metals are most commonly found in industrial wastes, and it has potential impacts on the ecosystem and human health. In order to remove these heavy metals from synthetic water, an economically effective adsorbent is required. Data required for the study is extracted from a senior P.G. student with topic "Removal of Cadmium From Pharmaceutical Industry by Using Adsorption Technique". This study gives insight on one of the heavy metal removal technique i.e. Adsorption, using various adsorption isotherms such as Langmuir, Freundlich, Temkin, Thomas, Banghams adsorption isotherm equations which were derived from the basic empirical equations, and used for calculation and analysis of the data extracted from a dissertation report. This study highlights the best fit isotherm for the given set of data for one of the heavy metal Cadmium wherein the Bangham's Isotherm with 0.9487 value of coefficient of correlation, followed by Freundlich Isotherm with 0.9237 and Temkin Isotherm at 0.853.*

***Keywords:*** *Adsorption, Heavy metals, Biosorption, Isotherm, Wastewater*

## INTRODUCTION

Water is considered a part of society, the use of one person can impact other people as the wastewater treatment is a cycle, so the discharge of one user can become the supply to other. To a good water management it is necessary to understand the nature and the constituents of the wastewater to design and operate an efficient collection, treatment, reuse facilities and regulations, which drives the treatment of the wastewater by the knowledge of harmful components to living beings and the environment. Wastewater is generated after the use of fresh water in a variety of application and usually involves leaching, flushing, or washing away waste products and nutrients added to the water during these applications. A more detailed definition for wastewater is "Used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff / storm water, and any sewer inflow or sewer infiltration".

Wastewater treatment is a process used to remove contaminants from wastewater and convert it into an effluent that can be returned to the water cycle. Once returned to the water cycle, the effluent creates an acceptable impact on the environment or is reused for various purposes (called water reclamation). The treatment process takes place in a wastewater treatment plant. There are several kinds of wastewater which are treated at the appropriate type of wastewater treatment plant. For domestic wastewater (also called municipal wastewater or sewage), the treatment plant is called a sewage treatment plant. For industrial wastewater, treatment either takes place in a separate industrial wastewater treatment plant, or in a sewage treatment plant (usually after some form of pre-treatment). Further types of wastewater treatment plants include agricultural wastewater treatment plants and leachate treatment plants.

Industrial wastewater is generated as a consequence of industrial activities. There is a wide range of types of industrial wastewater (e.g. from processes, cleaning and cooling), with different types of pollutants. Industrial wastewater, if not properly treated before discharge, can contain toxic compounds and compounds that are difficult to break down, and have a pH far from neutral, etc. Depending on the contamination it presents, the processes necessary to treat it correctly vary. Most industrial processes use water in one way or another. Once used, the water has to be managed before being disposed of, regardless of whether it is returned to the natural environment or into the sewage network. Industrial wastewater can be managed until the discharge limits set by the local regulations are met, or it can be reused.

Adsorption process was first introduced by C.W.Scheele in 1773 for the treatment of gasses and was subsequently used for liquid waste treatment by Lowitz in 1785 (Kraemer,1930). Sorption of solids particularly on activated carbon has become a widely used process for the treatment of water and wastewater. Processes of adsorption have many applications for the treatment of industrial and municipal wastewater. Activated carbon has become widely used as an adsorbent and in general has a great capacity for the adsorption of organics.

Adsorption process is applied in wastewater treatment in two ways; one is tertiary treatment and the second is physical-chemical treatment. If the adsorption process is applied after the biological treatment to remove the residual organics remained in the effluent, it is called as "tertiary treatment". Otherwise, if adsorption applied only after physical or chemical treatment, then it is referred as physical-chemical treatment". Generally, adsorption is used to remove the color, phenols, detergents, cresols, and other toxic or non-biodegradable organics.

## RESEARCH METHODOLOGY

To assess the reliability of treatment, one must consider several aspects of treatment. First, what is the probability that the adsorbent used will be able to remove heavy metals and second, if the adsorbent is of good quality then which method should be used for adsorption and which adsorption isotherm will be the best fit for further analysis? Addressing these issues with respect to treatment method reliability requires a methodical evaluation. The study required ample data which was collected from a Dissertation Report of one of the senior P.G. student named Narendra R. Margade with topic as “Removal of Cadmium from Pharmaceutical Industry by Using Adsorption Technique”. An extensive study was conducted to select a method for removal of heavy metal. Adsorption Methodology was selected which is performed with the help Adsorption Isotherms.

## BIOSORBENT USED IN THE STUDY

There are various materials that can be used as adsorbents. The list of adsorbents that were used in this projects work is given as follows:

1. Bark of Teak Tree (BTT)
2. Bark of FicusreligiosaTree (BFT)

The bioadsorbate materials used for the study such as BTT, BFT were obtained from local area. Materials were washed thoroughly with deionized water, to remove dust and water soluble impurities and sundried until it become crisp. The dried biosorbents are powdered and further washed with distilled water till the washing of free of colour and turbidity. Then biosorbents is dried sieved from 850 micron sieve. The resulting powdered fractions are preserved in air tight glass bottles for used as an adsorbent and labeled it as BTT and BFT. The adsorbate has been used without any treatment.

## ADSORPTION ISOTHERMS

There are various type of Adsorption Isotherms depending on the number of parameter. Some of them are as follows:

### Langmuir Isotherm

Langmuir adsorption which was primarily designed to describe gas-solid phase adsorption is also used to quantify and contrast the adsorptive capacity of various adsorbents. The Langmuir equation can be written in the following linear form:

$$\frac{C_e}{q_e} = \frac{1}{q_m K_L} + \frac{C_e}{q_m}$$

Where, is concentration of adsorbate at equilibrium (mg g−1).

$K_L$ is Langmuir constant related to adsorption capacity (mg g−1), which can be correlated with the variation of the suitable area and porosity of the adsorbent which implies that large surface area and pore volume will result in higher adsorption capacity.

### Freundlich Isotherm

This isotherm gives an expression which defines the surface heterogeneity and the exponential distribution of active sites and their energies. The linear form of the Freundlich isotherm is as follows

$$\log q_e = \log K_F + \frac{1}{n} \log C_e$$

Where, $K_F$ is adsorption capacity (L/mg) and $\frac{1}{n}$ is adsorption intensity; it also indicates the relative distribution of the energy and the heterogeneity of the adsorbate sites.

### Temkin Isotherm

Temkin isotherm model takes into account the effects of indirect adsorbate/adsorbate interactions on the adsorption process. The linear form of Temkin isotherm model is given by the following:

$$q_e = \frac{Rt}{b}\ln K_T + \frac{RT}{b}\ln C_e$$

Where, $b$ is Temkin constant which is related to the heat of sorption (Jmol−1) and$KT$ is Temkin isotherm constant (Lg−1).

**Thomas Isotherm**

The Thomas model (Thomas, 1944) is one of the most general and widely used to describe the dynamic behavior of the bio sorption process in fixed bed column. The expression by Thomas for an adsorption column is given by the following equation.

$$\frac{C_e}{C_i} = \frac{1}{(1 + \exp(\frac{k_{th}}{Q})(q_e m - C_i V_{eff})}$$

$$\ln\left(\frac{C_i}{C_e} - 1\right) = \frac{K_{Th} q_e m}{Q} - \frac{K_{Th} C_i}{Q} V_{eff}$$

The kinetic coefficient Kth and adsorption capacity of column can be detemine from the plot of $\ln(CiCe-1)$ against t at a given flow rate

Where,

$Veff$ = Volume of the effluent (ml)

Q = volumetric flow rate (ml/min),

m = mass of sorbent (gm)

**Bangham's Isotherm**

Adsorption kinetic models correlate the adsorbate uptake rate with bulk concentration of the adsorbate. Bangham's equation was used to evaluate whether the adsorption is pore-diffusion controlled.

$$\log\left\{\left[\frac{C_o}{C_o - qM}\right]\right\} = \log\left(\frac{K_o M}{2.30V}\right) + \alpha logt$$

Where,

$Co$ is initial concentration

V is volume of the solution

M is weight of the adsorbent

$qm$ is amount of adsorbate retained at time 't'

$\alpha$, $Ko$ are constants

**OBSERVATIONS**

Affinity separation owes its power as a purification method to specific biological interactions. The underlying concept of affinity separation is simple: a feed is contacted with a solid phase that has a high affinity for the solute of interest. After the solid phase has been saturated it is washed to remove non-specifically adsorbed contaminants. The solute is collected after disrupting the specific interactions. A large number of affinity systems have been developed for a wide variety of separations Affinity separations are generally operated in a batch mode and fixed bed mode.

For calculation of constants, a graph is prepared of the straight-line nature by plotting it between $1/ce$ Vs $1/qe$ for Langmuir isotherm, log ($c_e$) Vs log ($q_e$) for Freundlich isotherm, log ($c_e$) Vs $qe$ for Temkin isotherm, log ($ci/ce$-1) Vs time for Thomas isotherm and log t vs log {log [$C_o$-/($C_o$- $qm$)]} for Bangham's Isotherm. The set of data extracted from the thesis for which the systems were equilibrated with different adsorbent doses, bed heights and flow rate is tabulated in tables 3.1 to 3.10. This data is tabulated by using batch experiment and column study.

***Table 3.1: Adsorption Isotherms for BTT***

| Sr.no. | Adsorbent Dose (mg) | Ce (mg/lit) | Qe (mg/mg) | 1/Ce | 1/qe | log Ce | log qe |
|---|---|---|---|---|---|---|---|
| 1 | 20 | 7.42 | 0.129 | 0.135 | 7.782 | 0.643 | -0.553 |
| 2 | 40 | 4.82 | 0.129 | 0.207 | 7.766 | 0.602 | -0.62 |
| 3 | 60 | 3.32 | 0.111 | 0.301 | 9.022 | 0.559 | -0.672 |
| 4 | 80 | 2.65 | 0.092 | 0.377 | 10.884 | 0.52 | -0.777 |
| 5 | 100 | 1.15 | 0.089 | 0.87 | 11.299 | 0.473 | -0.852 |
| 6 | 120 | 0.93 | 0.076 | 1.075 | 13.23 | 0.401 | -0.904 |
| 7 | 140 | 0.88 | 0.065 | 1.136 | 15.35 | 0.31 | -0.974 |
| 8 | 160 | 0.57 | 0.059 | 1.754 | 17.003 | 0.179 | -1.071 |
| 9 | 180 | 0.59 | 0.052 | 1.695 | 19.067 | -0.009 | -1.142 |
| 10 | 200 | 0.68 | 0.047 | 1.471 | 21.436 | -0.143 | -1.209 |

***Table 3.2: Adsorption isotherm for BFT***

| Sr.no. | Adsorbent Dose (mg) | Ce (mg/lit) | Qe (mg/mg) | 1/Ce | 1/qe | log Ce | log qe |
|---|---|---|---|---|---|---|---|
| 1 | 20 | 7.92 | 0.104 | 0.126 | 9.615 | 0.643 | -0.553 |
| 2 | 40 | 6.73 | 0.117 | 0.149 | 8.547 | 0.602 | -0.62 |
| 3 | 60 | 4.66 | 0.102 | 0.215 | 9.803 | 0.559 | -0.672 |
| 4 | 80 | 3.84 | 0.086 | 0.260 | 11.678 | 0.52 | -0.777 |
| 5 | 100 | 1.08 | 0.084 | 0.926 | 11.976 | 0.473 | -0.852 |
| 6 | 120 | 0.72 | 0.071 | 1.389 | 14.002 | 0.401 | -0.904 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | 140 | 0.68 | 0.062 | 1.471 | 16.241 | 0.31 | -0.974 |
| 8 | 160 | 0.64 | 0.056 | 1.563 | 17.917 | 0.179 | -1.071 |
| 9 | 180 | 0.65 | 0.05 | 1.538 | 20.202 | -0.009 | -1.142 |
| 10 | 200 | 0.64 | 0.044 | 1.563 | 22.675 | -0.143 | -1.209 |

***Table 3.3: Thomas Model Parameters for BTT 10 cm bed height***

| **Sr.no.** | **Time (min)** | **2 ml/min** | **4 ml/min** | **6 ml/min** | **8 ml/min** | **10 ml/min** |
|---|---|---|---|---|---|---|
| | | **BTT (Ce/Ci)** | **BTT (Ce/Ci)** | **BTT (Ce/Ci)** | **BTT (Ce/Ci)** | **BTT (Ce/Ci)** |
| 1 | 10 | 0 | 0 | 0 | 0 | 0 |
| 2 | 20 | 0 | -0.426 | 0.473 | 0.296 | 0 |
| 3 | 30 | -0.623 | -0.635 | 0.643 | 0.581 | 0.491 |
| 4 | 40 | -0.648 | -0.698 | 0.711 | 0.659 | 0.599 |
| 5 | 50 | -0.696 | -0.726 | 0.742 | 0.714 | 0.697 |
| 6 | 60 | -0.814 | -0.811 | 0.821 | 0.799 | 0.753 |
| 7 | 70 | -0.818 | -0.819 | 0.822 | 0.808 | 0.776 |
| 8 | 80 | -0.814 | -0.84 | 0.855 | 0.827 | 0.8 |
| 9 | 90 | -0.864 | -0.869 | 0.856 | 0.831 | 0.816 |
| 10 | 100 | -0.898 | -0.892 | 0.916 | 0.882 | 0.831 |
| 11 | 110 | -0.921 | -0.923 | 0.93 | 0.891 | 0.864 |
| 12 | 120 | -0.934 | -0.936 | 0.937 | 0.902 | 0.877 |
| 13 | 130 | -0.93 | -0.936 | 0.944 | 0.904 | 0.884 |
| 14 | 140 | -0.94 | -0.943 | 0.94 | 0.907 | 0.892 |
| 15 | 150 | -0.936 | -0.944 | 0.943 | 0.909 | 0.898 |
| 16 | 160 | -0.94 | -0.938 | 0.945 | 0.909 | 0.903 |
| 17 | 170 | -0.94 | -0.943 | 0.943 | 0.906 | 0.899 |
| 18 | 180 | -0.936 | -0.944 | 0.942 | 0.905 | 0.893 |

***Table 3.4: Thomas Model Parameters for BFT 10 cm bed height***

| Sr.no. | Time (min) | 2 ml/min BFT (Ce/Ci) mg/lit | 4 ml/min BFT (Ce/Ci) mg/lit | 6 ml/min FT (Ce/Ci) mg/lit | 8 ml/min BFT (Ce/Ci) mg/lit | 10 BFT (Ce/Ci) mg/lit |
|---|---|---|---|---|---|---|
| 1 | 10 | 0 | 0 | 0 | 0 | 0 |
| 2 | 20 | 0 | -0.456 | 0.512 | 0.353 | 0 |
| 3 | 30 | -0.624 | -0.661 | 0.662 | 0.562 | 0.512 |
| 4 | 40 | -0.722 | -0.763 | 0.769 | 0.632 | 0.599 |
| 5 | 50 | -0.781 | -0.796 | 0.814 | 0.742 | 0.722 |
| 6 | 60 | -0.813 | -0.812 | 0.822 | 0.81 | 0.773 |
| 7 | 70 | -0.825 | -0.83 | 0.84 | 0.818 | 0.8 |
| 8 | 80 | -0.848 | -0.856 | 0.848 | 0.821 | 0.821 |
| 9 | 90 | -0.878 | -0.878 | 0.861 | 0.836 | 0.835 |
| 10 | 100 | -0.936 | -0.94 | 0.916 | 0.905 | 0.898 |
| 11 | 110 | -0.94 | -0.946 | 0.957 | 0.905 | 0.902 |
| 12 | 120 | -0.938 | -0.951 | 0.956 | 0.92 | 0.902 |
| 13 | 130 | -0.942 | -0.95 | 0.955 | 0.923 | 0.911 |
| 14 | 140 | -0.943 | | | 0.913 | 0.917 |
| 15 | 150 | -0.938 | | | | |

***Table 3.5: Thomas Model Parameters for BTT 15 cm bed height***

| Sr.no. | Time (min) | 2 ml/min | 4 ml/min | 6 ml/min | 8 ml/min | 10 ml/min |
|---|---|---|---|---|---|---|
| | | BTT (Ce/Ci) mg/lit | BTT (Ce/Ci) mg/lit | BTT (Ce/Ci) mg/lit | BTT (Ce/Ci) mg/lit | BTT (Ce/Ci) mg/lit |
| 1 | 10 | 0 | 0 | 0 | 0 | 0 |
| 2 | 20 | 0 | -0.467 | 0.515 | 0.337 | 0 |
| 3 | 30 | -0.664 | -0.676 | 0.684 | 0.622 | 0.532 |
| 4 | 40 | -0.69 | -0.74 | 0.752 | 0.7 | 0.64 |
| 5 | 50 | -0.787 | -0.767 | 0.783 | 0.755 | 0.738 |
| 6 | 60 | -0.861 | -0.858 | 0.869 | 0.846 | 0.8 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7 | 70 | -0.865 | -0.867 | 0.869 | 0.855 | 0.824 |
| 8 | 80 | -0.861 | -0.887 | 0.902 | 0.874 | 0.848 |
| 9 | 90 | -0.912 | -0.916 | 0.903 | 0.878 | 0.863 |
| 10 | 100 | -0.946 | -0.99 | 0.964 | 0.929 | 0.878 |
| 11 | 110 | -0.968 | -0.97 | 0.978 | 0.938 | 0.912 |
| 12 | 120 | -0.982 | -0.983 | 0.981 | 0.949 | 0.925 |
| 13 | 130 | -0.978 | -0.983 | 0.991 | 0.952 | 0.931 |
| 14 | 140 | -0.988 | -0.991 | 0.988 | 0.955 | 0.939 |
| 15 | 150 | -0.983 | -0.992 | 0.991 | 0.957 | 0.946 |
| 16 | 160 | -0.988 | -0.986 | 0.992 | 0.956 | 0.95 |
| 17 | 170 | -0.988 | -0.991 | 0.991 | 0.953 | 0.946 |
| 18 | 180 | -0.983 | -0.992 | 0.99 | 0.953 | 0.941 |

***Table 3.6: Thomas Model Parameters for BFT 15 cm bed height***

| **Sr.no.** | **Time (min)** | **2 ml/min** | **4ml/min** | **6ml/min** | **8ml/min** | **10ml/min** |
|---|---|---|---|---|---|---|
| | | **BFT (Ce/Ci) mg/li** | **BFT (Ce/Ci) mg/lit** | **BFT (Ce/Ci) mg/lit** | **BFT (Ce/Ci) mg/lit** | **BFT (Ce/Ci) mg/lit** |
| 1 | 10 | 0 | 0 | 0 | 0 | 0 |
| 2 | 20 | 0 | -0.497 | 0.533 | 0.74 | 0 |
| 3 | 30 | -0.666 | -0.703 | 0.684 | 0.583 | 0.533 |
| 4 | 40 | -0.763 | -0.804 | 0.79 | 0.654 | 0.62 |
| 5 | 50 | -0.822 | -0.837 | 0.835 | 0.764 | 0.744 |
| 6 | 60 | -0.86 | -0.859 | 0.865 | 0.855 | 0.814 |
| 7 | 70 | -0.873 | -0.878 | 0.881 | 0.859 | 0.842 |
| 8 | 80 | -0.896 | -0.903 | 0.89 | 0.863 | 0.863 |
| 9 | 90 | -0.925 | -0.925 | 0.902 | 0.877 | 0.877 |
| 10 | 100 | -0.983 | -0.988 | 0.958 | 0.947 | 0.94 |
| 11 | 110 | -0.988 | -0.993 | 0.998 | 0.946 | 0.943 |
| 12 | 120 | -0.985 | -0.999 | 0.998 | 0.961 | 0.943 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 13 | 130 | -0.99 | -0.997 | 0.997 | 0.964 | 0.953 |
| 14 | 140 | -0.991 | | | 0.954 | 0.958 |
| 15 | 150 | - | | | | |

***Table 3.7: Second-Order Bangham's Pore Diffusion Model Parameters for BTT 10 cm bed height***

| Sr. no. | Log t | 2 ml/min | 4 ml/min | 6 ml/min | 8 ml/min | 10 ml/min |
|---|---|---|---|---|---|---|
| | | **BTT (Log(Log[Co/(Co-qm)]))** | **BTT (Log(Log[Co/(Co-qm)]))** | **BTT (Log(Log[Co/(Co-qm)]))** | **BTT (Log(Log[Co/(Co-qm)]))** | **BTT (Log(Log[Co/(Co-qm)]))** |
| 1 | 1 | | 0 | 0 | 0 | 0 |
| 2 | 1. | | -0.871 | -0.0814 | -1.02 | 0 |
| 3 | 1. | -0.627 | -0.61 | -0.599 | -0.682 | -0.794 |
| 4 | 1. | -0.592 | -0.522 | -0.504 | -0.578 | -0.658 |
| 5 | 1. | -0.525 | -0.482 | -0.458 | -0.5 | -0.524 |
| 6 | 1. | -0.339 | -0.345 | -0.326 | -0.365 | -0.44 |
| 7 | 1. | -0.333 | -0.33 | -325 | -0.35 | -0.403 |
| 8 | 1. | -0.34 | -0.292 | -0.262 | -0.316 | -0.363 |
| 9 | 1. | -0.243 | -0.233 | -0.261 | -0.309 | -0.336 |
| 10 | 2 | -0.167 | -0.183 | -0.121 | -0.205 | -0.309 |
| 11 | 2. | -0.109 | -0.104 | -0.082 | -0.184 | -0.243 |
| 12 | 2. | -0.069 | -0.065 | -0.062 | -0.159 | -0.216 |
| 13 | 2. | -0.081 | -0.064 | -0.039 | 0.152 | -0.201 |
| 14 | 2. | -0.05 | -0.05 | -0.05 | -0.145 | -0.183 |
| 15 | 2. | -0.065 | -0.037 | -0.04 | -0.14 | -0.167 |
| 16 | 2. | -0.05 | -0.056 | -0.035 | -0.141 | -0.156 |
| 17 | 2. | -0.05 | -0.04 | -0.04 | -0.149 | -0.167 |
| 18 | 2. | -0.065 | -0.044 | -0.043 | -0.15 | -0.179 |

*Table 3.8: Second-Order Bangham's Pore Diffusion Model Parameters for BFT 10 cm bed height*

| Sr. no. | Logt | 2 ml/min | 4 ml/min | 6 ml/min | 8 ml/min | 10 ml/min |
|---|---|---|---|---|---|---|
| | | BFT (Log(Log[Co/(Co-qm)])) | BFT (Log(Log[Co/(Co-qm)])) | BFT (Log(Log[Co/(Co-qm)])) | BFT (Log(Log[Co/(Co-qm)])) | BFT (Log(Log[Co/(Co-qm)])) |
| 1 | 1 | | 0 | 0 | 0 | 0 |
| 2 | 1.301 | | -0.835 | -0.768 | -0.955 | 0 |
| 3 | 1.477 | -0.625 | -0.575 | -0.573 | -0.705 | -0.768 |
| 4 | 1.602 | -0.488 | -0.425 | -0.416 | -0.614 | -0.658 |
| 5 | 1.699 | -0.395 | -0.371 | -0.339 | -0.457 | -0.487 |
| 6 | 1.778 | -0.341 | -0.343 | -0.324 | -0.314 | -0.409 |
| 7 | 1.845 | -0.39 | -0.309 | -0.292 | -0.333 | -0.363 |
| 8 | 1.903 | -0.275 | -0.26 | -0.275 | -0.326 | -0.326 |
| 9 | 1.954 | -0.214 | -0.214 | -0.251 | -0.3 | -0.301 |
| 10 | 2 | -0.064 | -0.05 | -0.121 | -0.15 | -0.167 |
| 11 | 2.041 | -0.05 | -0.032 | -0.011 | -0.151 | -0.159 |
| 12 | 2.079 | -0.059 | -0.011 | -0.008 | -0.111 | -0.159 |
| 13 | 2.114 | -0.043 | -0.015 | -0.005 | -0.103 | -0.135 |
| 14 | 2.146 | -0.04 | | | -0.131 | -0.12 |
| 15 | 2.176 | -0.057 | | | | |

*Table 3.9: Second-Order Bangham's Pore Diffusion Model Parameters for BTT 15 cm bed height*

| Sr.no. | Log t | 2 ml/min | 4 ml/min | 6 ml/min | 8 ml/min | 10 ml/min |
|---|---|---|---|---|---|---|
| | | BTT (Log(Log[Co/(Co-qm)])) | BTT (Log(Log[Co/(Co-qm)])) | BTT Log(Log[Co/(Co-qm)])) | BTT (Log(Log[Co/(Co-qm)])) | BTT (Log(Log[Co/(Co-qm)])) |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1.301 | 0 | -0.822 | -0.764 | -0.973 | 0 |
| 3 | 1.477 | -0.57 | -0.553 | -0.542 | -0.628 | -0.743 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | 1.602 | -0.535 | -0.461 | -0.442 | -0.52 | -0.603 |
| 5 | 1.699 | -0.385 | -0.418 | -0.392 | -0.437 | -0.463 |
| 6 | 1.778 | -0.249 | -0.257 | -0.234 | -0.279 | -0.363 |
| 7 | 1.845 | -0.242 | -0.238 | -0.233 | -0.261 | -0.322 |
| 8 | 1.903 | -0.25 | -0.194 | -0.157 | -0.22 | -0.277 |
| 9 | 1.954 | -0.134 | -0.121 | -0.156 | -0.214 | -0.0245 |
| 10 | 2 | -0.032 | -0.054 | 0.04 | -0.084 | -0.214 |
| 11 | 2.041 | 0.06 | 0.07 | 0.113 | -0.056 | -0.134 |
| 12 | 2.079 | 0.14 | 0.151 | 0.158 | -0.02 | -0.098 |
| 13 | 2.114 | 0.114 | 0.153 | 0.227 | -0.01 | -0.079 |
| 14 | 2.146 | 0.194 | 0.226 | 0.194 | 0.002 | -0.053 |
| 15 | 2.176 | 0.154 | 0.24 | 0.226 | 0.011 | -0.03 |
| 16 | 2.201 | 0.194 | 0.17 | 0.24 | 0.008 | -0.016 |
| 17 | 2.23 | 0.193 | 0.221 | 0.221 | -0.004 | -0.031 |
| 18 | 2.255 | 0.154 | 0.235 | 0.211 | -0.006 | -0.049 |

***Table 3.10: Second-Order Bangham's Pore Diffusion Model Parameters for BFT 15 cm bed height***

| Sr.no. | Log t | 2 ml/min | 4 ml/min | 6 ml/min | 8 ml/min | 10 ml/min |
|---|---|---|---|---|---|---|
| | | BFT (Log(Log[Co/(Co-qm)])) | BFT (Log(Log[Co/(Co-qm)])) | BFT (Log(Log[Co/(Co-qm)])) | BFT (Log(Log[Co/(Co-qm)])) | BFT (Log(Log[Co/(Co-qm)])) |
| 1 | 1 | | 0 | 0 | 0 | 0 |
| 2 | 1.301 | | -0.786 | -0.742 | -0.931 | 0 |
| 3 | 1.477 | -0.568 | -0.516 | -0.516 | -0.678 | -0.742 |
| 4 | 1.602 | -424 | -0.357 | -0.381 | -0.585 | -0.63 |
| 5 | 1.699 | -0.324 | -0.297 | -0.301 | -0.424 | -0.455 |
| 6 | 1.778 | -0.251 | -0.254 | -0.244 | -0.263 | -0.339 |
| 7 | 1.845 | -0.225 | -0.214 | -0.207 | -0.254 | -0.288 |
| 8 | 1.903 | -0.173 | -0.155 | -0.187 | -0.247 | -0.247 |
| 9 | 1.954 | -0.096 | -0.096 | -0.158 | -0.216 | -0.217 |
| 10 | 2 | 0.154 | 0.191 | 0.014 | -0.028 | -0.052 |
| 11 | 2.041 | 0.191 | 0.254 | 0.383 | -0.029 | -0.041 |
| 12 | 2.079 | 0.167 | 0.399 | 0.356 | 0.029 | -0.041 |
| 13 | 2.114 | 0.211 | 0.35 | 0.329 | 0.043 | -0.007 |
| 14 | 2.146 | 0.228 | | | -0.001 | 0.016 |
| 15 | 2.176 | 0.173 | | | | |

## RESULTS & DISCUSSION

The discharge of wastewater to the environment caused adverse conditions and this led to the development of intensive methods of wastewater treatment. Adsorption is the method used as a polishing technology after the biological wastewater treatment unit. And also as a complete treatment method in its wastewater after treatment using conventional and nonconventional adsorbents is highly dependent on pH, contact time, adsorbent dose, adsorbate concentration and adsorbent particle size. Change in the above parameters affects the adsorption process through dissociation of the functional group of the adsorbate and adsorbent.

### Langmuir Isotherm

The data extracted from the thesis for Langmuir Isotherm was tabulated in the table 3.1 and 3.2 for different adsorbent doses and the graph was plotted between $1/c_e$ Vs $1/q_e$ as shown in Fig 4.1 and 4.2. These graphs were used to calculate the constants in the Langmuir equation by formatting an equation for straight line where x-axis is represented by $1/c_e$ and y-axis is represented by $1/q_e$ as shown in the below table. The coefficient of correlation is calculated for identifying the best fit adsorbent for this isotherm. The results indicate that Langmuir Isotherm is best fitted for BTT adsorbent with coefficient of correlation 0.8579.

***Table 4.1: Langmuir Isotherm constant for BTT and BFT***

| Adsorben | $R^2$ for | Equatio |
|---|---|---|
| BTT | 0.8579 | y = 7.1442x + 6.8392 |
| BFT | 0.7876 | y = 6.5129x + 8.2746 |

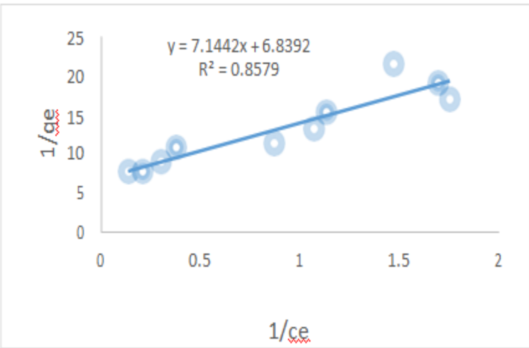



***Fig. 4.1: Langmuir Isotherm for BTT***

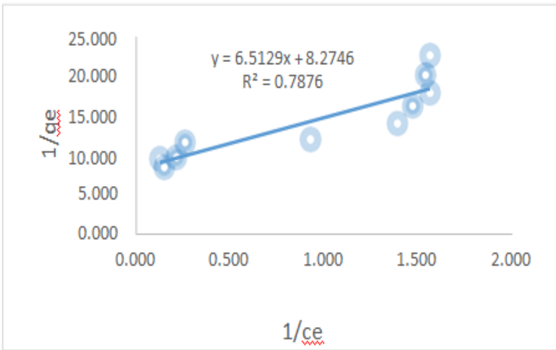



***Fig. 4.2: Langmuir Isotherm for BFT***

**Freundlich Isotherm**

The Freundlich isotherm graph was plotted between log (*ce*) Vs log (*qe*) as shown in Fig 4.3 and 4.4. The data extracted from the thesis for Langmuir Isotherm was tabulated in the table 3.1 and 3.2 for different adsorbent doses. These graphs were used to calculate the constants in the Freundlich equation by formatting an equation for straight line where x-axis is represented by log (*ce*) and y-axis is represented by log (*qe*) as shown in the below table. The coefficient of correlation is calculated for identifying the best fit adsorbent for this isotherm.

The results indicate that Freundlich Isotherm is best fitted for both BTT and BFT adsorbent with coefficient of correlation 0.9213.

**Temkin Isotherm**

The data extracted from the thesis for Temkin Isotherm was tabulated in the table 3.1 and 3.2 for different adsorbent doses and the graph was plotted between *qe* Vs log (*ce*) as shown in Fig 4.5 and 4.6. These graphs were used to calculate the constants in the Temkin equation by formatting an equation for straight line where x-axis is represented by *qe* and y-axis is represented by log (*ce*) as shown in the below table. The coefficient of correlation is calculated for identifying the best fit adsorbent for this isotherm. The results indicate that Temkin Isotherm is best fitted for BFT adsorbent with coefficient of correlation 0.8542.

***Table 4.2: Freundlich Isotherm constant for BTT and BFT***

| Adsorbent | $R^2$ for Freundlich | Equation |
|---|---|---|
| ***BTT*** | ***0.9213*** | y = 0.8051x |
| ***BFT*** | ***0.9213*** | y = 0.8051x |

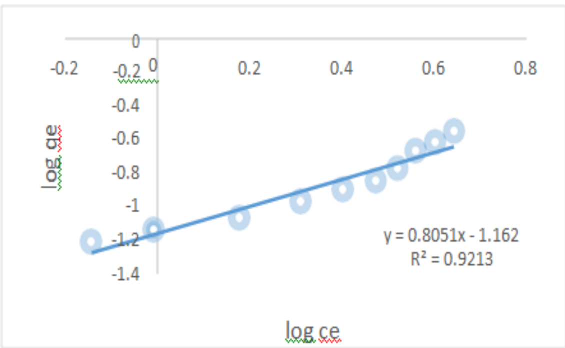



***Fig. 4.3: Freundlich Isotherm for BTT***

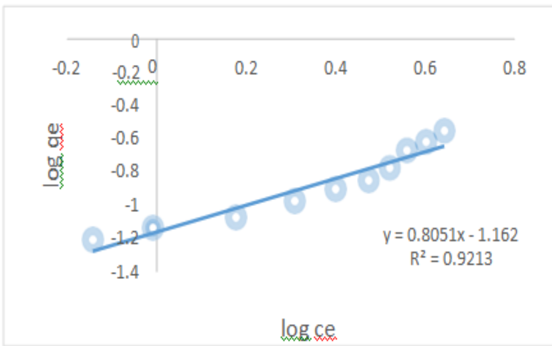



***Fig. 4.4: Freundlich Isotherm for BFT***

***Table 4.3: Temkin Isotherm constant for BTT and BFT***

| Adsorbent | $R^2$ for | Equation |
|---|---|---|
| BTT | 0.8284 | y = 8.0053x - 0.3262 |
| BFT | 0.8542 | y = 9.898x - 0.4146 |

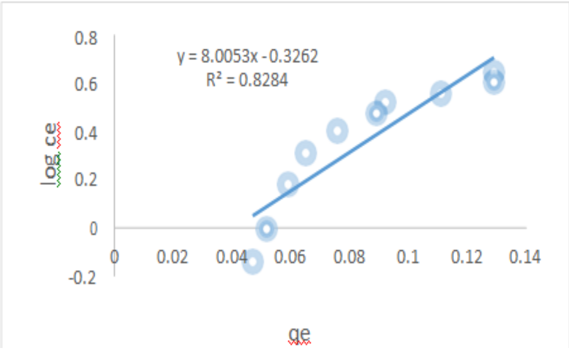



***Fig. 4.5: Temkin Isotherm for BTT***

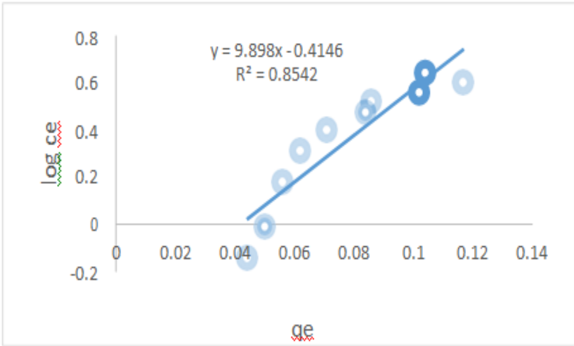



***Fig. 4.6: Temkin Isotherm for BFT***

**Thomas Isotherm**

The data extracted from the thesis for Thomas Isotherm was tabulated in the table 3.3 and 3.6 for different bed height and volumetric flow rate and the graph was plotted between log ($c_i/c_e$-1) Vs time as shown in Fig 4.7 to 4.10. These graphs were used to calculate the constants in the Thomas equation by formatting an equation for straight line where x-axis is represented by log ($c_i/c_e$-1) and y-axis is represented by time as shown in the below table. The coefficient of correlation is calculated for identifying the best fit adsorbent for this isotherm. As seen in the table, there was a good agreement between the experimental and parameters of the Thomas Isotherm in all tests except for the rate of flow of 2 ml/min. The best results were in bed height of about 15 cm and the flow rate of 10 ml/min because the correlation coefficient of this point was 0.705 at 50 mg/lit the initial concentration of Cd.

***Table 4.4: Thomas Models constant at different bed height and flow rate for BTT and BFT***

| Z cm | Adsorbent | F ml/min | $R^2$ for Thomas | Equation |
|---|---|---|---|---|
| 10 | BTT | 10 | 0.626 | y = 0.0042x + 0.3162 |
| 10 | BFT | 10 | 0.7032 | y = 0.0063x + 0.2127 |
| 15 | BTT | 10 | 0.6153 | y = 0.0044x + 0.3403 |
| 15 | BFT | 10 | 0.7052 | y = 0.0661x + 0.2206 |

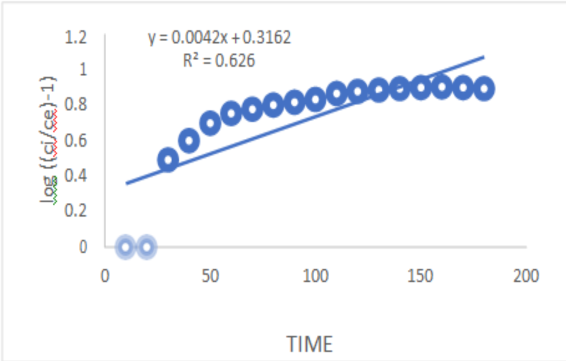



*Fig. 4.7: Thomas Model for BTT (Flow 10 ml/min, Height 10 cm)*

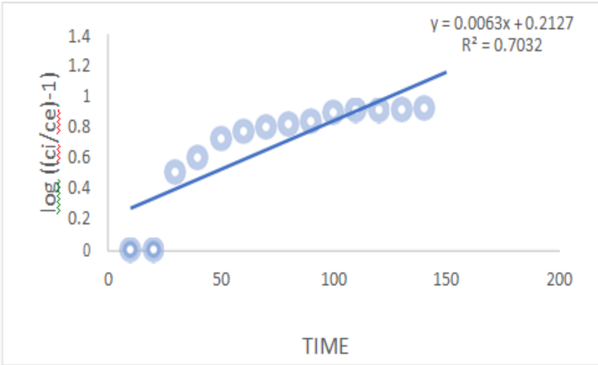



*Fig. 4.8: Thomas Model for BFT (Flow 10 ml/min, Height 10 cm)*

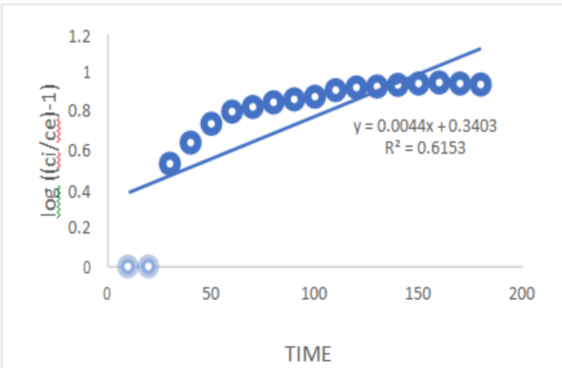



*Fig. 4.9: Thomas Model for BTT (Flow 10 ml/min, Height 15 cm)*

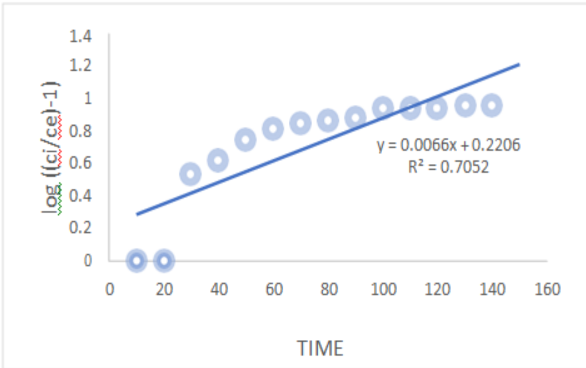


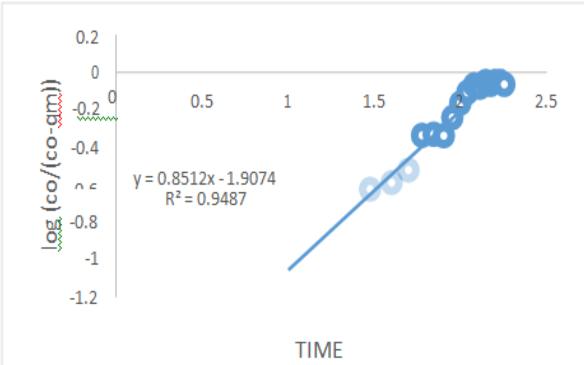

*Fig. 4.10: Thomas Model for BFT (Flow 10 ml/min, Height 15 cm)*

**Bangham's Isotherm**

The data extracted from the thesis for Bangham's Isotherm was tabulated in the table 3.7 and 3.10 for different bed height and volumetric flow rates and the graph was plotted between log t vs log {log [C_o-/(C_o- q_m)]} as shown in Fig 4.11 to 4.14. These graphs were used to calculate the constants in the Bangham's equation by formatting an equation for straight line where x-axis is represented by log t and y-axis is represented by log{log [C_o-/(C_o- q_m)]} as shown in the below table. The coefficient of correlation is calculated for identifying the best fit adsorbent for this isotherm. As seen in the table Bangham's model is best fitted for the rate of flow of 2 ml/min of the remaining other cases correlation coefficient is low indicating that adsorption is not pore diffusion controlled. The best results were in bed height of about 10 cm and the flow rate of 2 ml/min because the correlation coefficient of this point was 0.9487 at 50 mg/lit initial concentration of Cd.

***Table 4.5: Bangham's Models constant at different bed heights and flow rate for BTT and BFT***

| Z cm | Adsorbent | F | $R^2$ for | Equation |
|---|---|---|---|---|
| 10 | BTT | 2 | 0.9487 | y = 0.8512x - 1.9074 |
| 10 | BFT | 2 | 0.9383 | y = 0.8871x - 1.9272 |
| 15 | BTT | 2 | 0.9331 | y = 0.7528x - 1.4539 |
| 15 | BFT | 2 | 0.9396 | y = 1.2203x - 2.4013 |



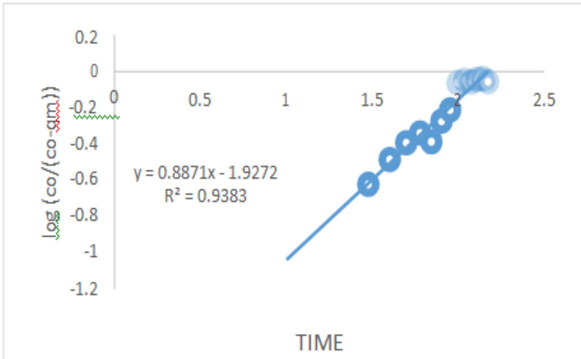
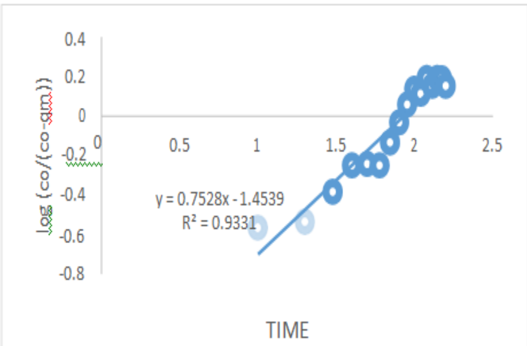




***Fig. 4.11: Bangham's Plot for BTT (Flow 2 ml/min, Height 10 cm)***

***Fig. 4.12: Bangham's Plot for BFT (Flow 2 ml/min, Height 10 cm)***



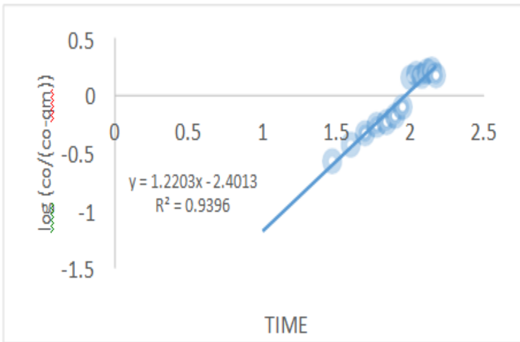




***Fig. 4.13: Bangham's Plot for BTT (Flow 2 ml/min, Height 15 cm)***

***Fig. 4.14: Bangham's Plot for BFT (Flow 2 ml/min, Height 15 cm)***

## CONCLUSION

**Based on the study following conclusions can be drawn:**

The laboratory data required for the study was successfully extracted from the Dissertation Report for heavy metal Cadmium and analyzed for the behavior of adsorption using five adsorption isotherms. The application of isotherms used in this study are:

- Langmuir Isotherm is used for defining the maximum uptake of adsorbent and affinity between adsorbent and adsorbate.

- Freundlich Isotherm is used to determine the adsorption capacity of adsorbents.

- Temkin Isotherm is used to determine the interaction between adsorbent and adsorbate.

- Thomas Isotherm is used to predict the breakthrough curves and determine the characteristics parameters of the column useful for process design using non linear regression.

- Bangham's Isotherm is used for determining the intra particle pore diffusion between the adsorbent and adsorbate.

- The highest value for coefficient of correlation is 0.9487 for Bangham's Isotherm at 10 cm bed height and 2 ml/min volumetric flow rate. It is followed by Freundlich isotherm with coefficient of correkation at 0.9237 although it fails at high concentration of adsorbate and is valid only upto a certain pressure. Langmuir Isotherm has failed to account the surface roughness of adsorbent retains a low $R2$ value. Temkin Isotherm is best fitted for $R2$ at 0.8532 but it can not be used for complex systems. Thomas Isotherms has lower coefficient of correlation which decreases with increase in flow rate and bed height.

- This study concludes that Bangham's Isotherm is the best for the series of data collected with $R2$ value of 0.9487 and implies that with increase in volumetric flow rate of adsorbate the efficiency of adsorption decreases

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