A study of the Effect of the Weight of a Fixed-Bed Adsorption Column for Removal of Ferrous Iron (Fe^{2+}) in Groundwater using Activated Carbon

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Abstract

The study involves the simulation of a fixed-bed adsorption column with COMSOL Multiphysics software. The bed of the Adsorption column was filled with only activated carbon to absorb the ferrous Iron. The equilibrium and dynamic model equations of the Langmuir adsorption isotherm and fixed-bed adsorption column were used and inputted into the COMSOL Multiphysics software. Line graphs and 2D surface plots were generated from the software after the simulation. Simulated result showed that increase in the weight of the bed could increase the bed performance and indicated that about 28 days' operative performance of the bed could be achieved for a bed weight of 1500kg and particle size of 0.001m.

Key words: *Weight, Fixed-Bed, Adsorption column, Ferrous Iron, Groundwater, Activated Carbon*

1. Introduction

The human life cannot do without clean water in our daily life and its importance is very obvious following the growing population of people and advances in modern technology. As a result, there is need for the availability of improved facilities that will bring clean water.

Ground water or water sourced from the ground which is our focus comes with high concentrations of iron which must be reduced to an acceptable level for the purpose of drinking. Nassar et al.,2003 states that " the development of red blood cells required a little amount of iron present in water and high concentrations of iron in drinking water poses challenging health problems and also causing environmental degradation and this drawback makes the removal of iron in water a vital step in every water purification unit."

Babu and Gupta, 2005 explained that "In chemical process industries, adsorption technology plays a vital role in the separation of valuable materials from process streams and also has application in chemical purification science where fixed-bed adsorption separation techniques require the continuous interaction of a fluid phase and a packed bed of adsorbents in which the transport of a solute component occurs naturally from a liquid or gaseous phase onto the surface of an adsorbent as a result of a difference in concentration between the two phases of interest. In the treatment of groundwater to produce drinking water, the principle of adsorption is utilized in the removal of heavy metal constituents like iron. This method of separation could be batch-wise, or easily set-up as continuous flow process in packed beds, which is relatively simple in design and scale up". Adsorption had been known to be an effective separation process for the removal of heavy metal fractions like those of iron and mercury from polluted water sources.

"In adsorption science, very important features like the adsorbent capacity and its operating life span play a key role in ensuring the effective operation of the column. In addition, a basic knowledge on adsorption dynamics and modelling are required Kaczmark et al., 1997." The important question to be answered in this study is, of what effect is the amount of adsorbent on the fixed-bed column performance in a quest to establish the actual time for bed regeneration and replacement. This work focuses on the performance analysis of a fixed-bed adsorption unit filled with activated carbon for a down flow configuration. This work focuses on "A study of the effect of the Weight of A Fixed-Bed Adsorption Column For Removal Of Ferrous Iron (Fe^{2+}) In Groundwater Using Activated Carbon".

2. Methodology

2.1 Materials

Figure 1 shows the "fixed-bed column" considered.

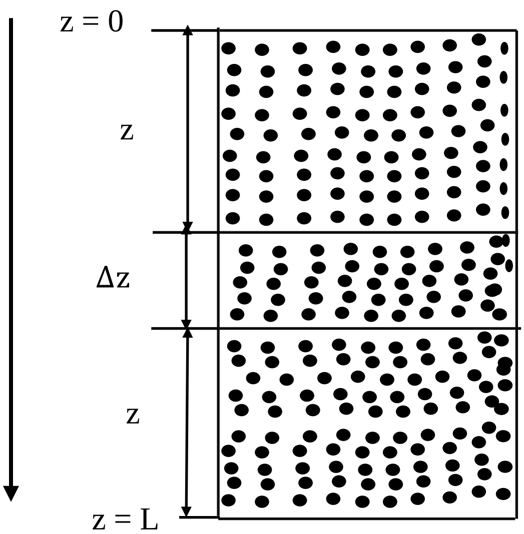


Figure 1: Differential element of fixed-bed adsorption column

In this study, "we considered the transport of material and energy through the adsorbent pellet to enable us study the distribution of material and energy within the pellet at different locations along length of the bed of adsorbent. The governing dynamic equations for the transport of material and energy through the fixed-bed was also considered for both transport in the axial direction by convection and in the radial direction by diffusion in a cylindrical coordinate system. The research methodology adopted to conduct this study was extensively established in the COMSOL Multiphysics software in simulating the adsorption bed.

The key assumptions made during the study are:

I. The adsorption equilibrium relationship is non-linear as described by the Langmuir isotherm.

II. The adsorbent particles are spherical in shape and homogenous in size and density.
III. The adsorption column was operated under isothermal conditions".

2.2 The Adsorption Column Model Development

The model equations developed are shown elsewhere (Ali, 2021; Azizian, 2004; Forgler, 2012; Knepper, 1981; Mittal, 2006; Noureddine, 2016; Ruthven and Ching, 1989; Ruthven and Douglas, 1984; Seader and Earnest, 2010; Warren et al., 2001 ; Yousuo et al, March 2022; Yousuo et al., September 2022).

2.3 The use of Comsol Multiphysics Software

The derived equations in section 2.2 and the governing models "the adsorption isotherm model, the fixed bed model, the Particle model, the bed pressure drop equation and the energy balance model" were solved using the finite element method in COMSOL Multiphysics. The steps taken in solving the models using COMSOL Multiphysics software are shown elsewhere (Ali, 2021; Yousuo et al, March 2022; Yousuo et al., September 2022). "COMSOL Multiphysics is a cross-platform finite element analysis, solver and Multiphysics simulation software. It permits conventional physics-based user interfaces and the numerical solutions of coupled systems of partial differential equations (PDEs). COMSOL provides a unified workflow which shows the user how to carry out a COMSOL Multiphysics simulation".

2.4 Parameters used for the Simulation

The parameters used for the simulation are shown in Table 1 and Table 2. The use of the parameters for the simulation using the COMSOL Multiphysics is shown elsewhere (Ali, 2021; Yousuo et al, March 2022; Yousuo et al., September 2022).

Table 1: "Model parameters for the simulation" (Bautista et al., 2003).

Property	Value
Density of water	1000 kg/m^3
Molar mass of activated carbon	0.012 kg/mol
Molar mass of water	0.018 kg/mol
Porosity of adsorbent particle	0.3
Diameter of particle	0.001m
Thermal conductivity of column wall	50 W/(m.K)
Particle density	2100 kg/m^3

Table 2: "Model parameters for the simulation in the simulation environment.

Name	Expression	Value	Description
Rhop	2100[kg/m^3]	2100 kg/m³	Particle density
Qm	8.492[mg/g]/MFe	0.053175 mol/kg	Maximum equilibrium loading of adsorbent
K	0.234[L/mg]*MFe	37.37 m³/mol	Equilibrium Adsorption constant
Ep	0.3	0.3	porosity of particle
Eb	0.4	0.4	Porosity of Bed
Dp	0.001[m]	0.001 m	Diameter of particles
Rp	dp/2	5E−4 m	Radius of particle
rhoH2O	1000[kg/m^3]	1000 kg/m³	Density of water
visH2O	1.787E-3[Pa*s]	0.001787 Pa·s	Viscosity of water
Mfe	159.7[g/mol]	0.1597 kg/mol	Molar Mass of Iron
MH2O	18[g/mol]	0.018 kg/mol	Molar mass of water
MC	12[g/mol]	0.012 kg/mol	Molar mass of activated carbon

Name	Expression	Value	Description
mFein	7e-6[kg/L]	0.007 kg/m³	Inlet mass concentration of iron in water *
cFein	mFein/Mfe	0.043832 mol/m³	Inlet molar concentration of iron in water *
Tau	1.5[min]	90 s	Residence time *
Fl	(1 - eb)*Vr/tau	0.0079365 m³/s	Volumetric flow rate of water
Rr	0.5[m]	0.5 m	Radius of adsorption column
Ar	pi*Rr^2	0.7854 m²	Cross sectional area of adsorber
Vr	Ar*Lr	1.1905 m³	volume of adsorber
Lr	Wc/(Ar*rhob)	1.5158 m	Height of adsorption unit *
rhoH2Oin	rhoH2O*Fl*1[s]	7.9365 kg	Inlet mass density of water *
cH2Oin	rhoH2Oin/(MH2O*Vr)	370.37 mol/m³	inlet molar concentration of water
Vin	Fl/Ar	0.010105 m/s	Inlet velocity of water
Rhob	rhop*(1 - eb)	1260 kg/m³	Particle bed density
Wb	1500[kg]	1500 kg	Weight of adsorbent bed
Tin	298.15[K]	298.15 K	Inlet temperature of fluid *
Kw	50[W/(m*K)]	50 W/(m·K)	Thermal Conductivity of Column Wall *
Dx	0.5[cm]	0.005 m	Thickness of wall material *
Ts	295.18[K]	295.18 K	Temperature of the surrounding *

Note: The values of those parameters with asterisk (*) are assumed".

3. DISCUSSION AND CONCLUSION

The effect of particle size is observed in Figure 2. It indicates that as the particle size increases the adsorption capacity of the bed decreases. Higher adsorption was found at smaller particle sizes; particle with 0.001 m was more in the adsorption capacity than 0.003m and 0.004m because the rate of adsorption in the column increases with decrease in particle size. Mehmet (2007) reported similar results during his studies on heavy metal adsorption by modified oak sawdust.

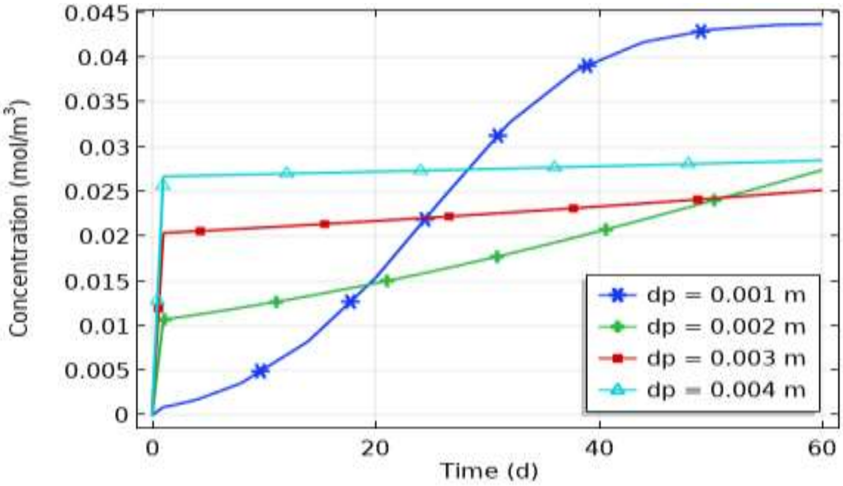
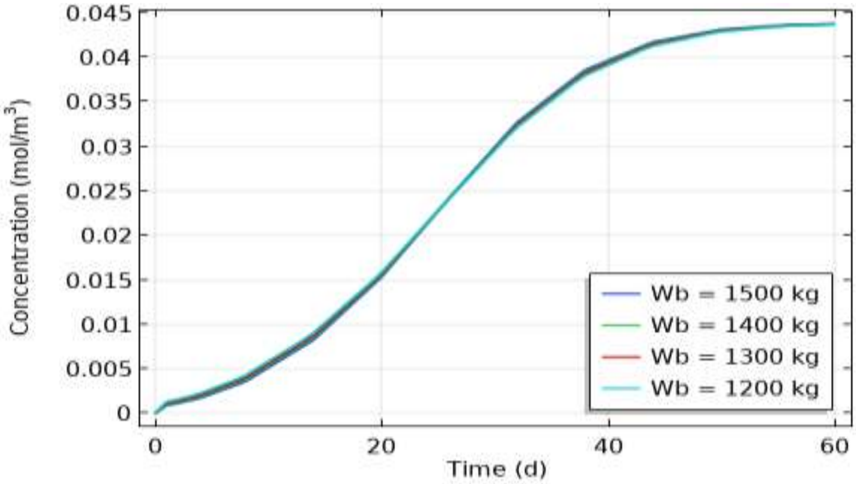


Figure 2: Breakthrough curve of ferrous iron concentration at the end of the bed.

Furthermore, the effect of the weight of the bed on the breakthrough curve can be seen in Figure 3. Simulated result for the variation of the weight of the packed particle established that increase in the weight of the bed could increase the bed performance time. This is as a result of wider surface of activated carbon, making more binding sites for adsorption.

Figure 3:



Breakthrough curve of ferrous iron concentration at the end of the bed for different bed weights.

REFERENCES

Ali Timinidi. “Simulation of Equilibrium and Dynamic Behaviour of a Fixed-Bed Adsorption Column for Removal of Ferrous Iron (Fe^{2+}) in Groundwater Using Activated Carbon”. An approved thesis work for Master of Engineering in Chemical Engineering in the Department of Chemical Engineering, Niger Delta University, P.M.B 071 Yenagoa, Bayelsa State of Nigeria, 2021.

Azizian S. “Kinetic models of sorption: a theoretical analysis”. Journal of Colloid and Interface Science. 276, 47-52, 2004.

Babu, B.V and Gupta S. “Modeling and simulation of fixed-bed adsorption column. Effect of velocity variation, Department of Chemical Engineering Birla Institute of Technology & Science Pilani 333031 (Rajasthan) India” 51, 57, 2005.

Bautista, L.F., Martinez, M.and Aracil, J. “Adsorption of -Amylase in a Fixed-bed: Operating Efficiency and Kinetic Modeling”. *AIChE Journal* 49, 2631-2641, 2003.

Forgler, H. S. “Elements of Chemical Reaction Engineering”. Fourth Edition, 243-245, 2012.

Kaczmark, K., Mazzotti, M., Storti, G. and Morbidelli, M. “Modeling fixed-bed adsorption columns through orthogonal collocation on moving fine elements”. *Computers and chemical engineering* 71, 641-660, 1997.

Knepper, W. A. “Kirk-Othmer encyclopedia of chemical technology”. 13, New York, NY, Wiley Inter-science, 735-753, 1981.

Mehmet, E. A. “Heavy metal adsorption by modified oak sawdust: Thermodynamics and kinetic”. Journal Hazardous Materials 141, 77-85, 2007.

Mittal, A. “Adsorption kinetics of removal of a toxic dye, malachite green from waste water using hen feathers”. Journal of Hazard Matter B 133, 196-202, 2006.

Nassar, M. M., Ewida, K. T., Ebrahiem, E. E., Magdy, Y. H. and Mheaedi, M.H. “Fixed-bed adsorption for the removal of Iron and manganese onto palm fruit bunch and maize”. *Cob Adsorpt. Sci. Technl.* 21161, 324, 2003.

Noureddine, E. I., Mohammed, E., Abdellah, D., Abdellah, L. and Bahcine B. “Biosorption of Congo red in a fixed-bed column from aqueous solution using jujube shell: Experimental and mathematical modeling”. Journal *of Enviromental/Chemical Engineering*, 43845, 544-551, 2016.

Ruthven, D. M. and Ching, C. B. “Counter current and simulated counter-current adsorption separation processes”. Chemical Engineering Sciences 44, 1011-1038, 1989.

Ruthven, H. and Douglas, M. "Principles of Adsorption and Adsorption Processes", Seventh Edition, John Wiley and Sons Inc, New York, 115-161, 1984.

Seader, J. D. and Earnest J. H. "Separation Process Principles". John Willy and Sons, Houston, 342, 2010.

Warren, L. M., Julian, C. S. and Peter, H. "Unit Operations of Chemical Engineering", Sixth Edition, Mc Graw Hill, Texas, 49,67, 2001.

Yousuo Digieneni, Ali Timinidi and Gbonhinbor Jeffrey Randy. "A Study of the Behaviour of a Fixed-Bed Adsorption Column for Removal of Ferrous Iron (Fe^{2+}) in Groundwater using Activated Carbon". CEDTECH International Journal of Social Science & National Development. Volume 3, Number 1, http://www.cedtechjournals.org, ISSN: 2756-4525. Pg 21-44, March 2022.

Yousuo Digieneni, Gbonhinbor Jeffrey Randy and Ali Timinidi. "CFD Investigation of the Effect of Particle Size of A Fixed-Bed Adsorption Column for Removal of Ferrous Iron (Fe^{2+}) in Groundwater Using Activated Carbon". International Journal of Engineering and Modern Technology (IJEMT) E-ISSN 2504-8848 P-ISSN 2695-2149, Vol 8. No. 4, www.iiardjournals.org, DOI:10.56201/ijemt.v8.no4.pg1-11, September 2022.