Granulated Activated Carbon Filter Mathematical Model and Simulations

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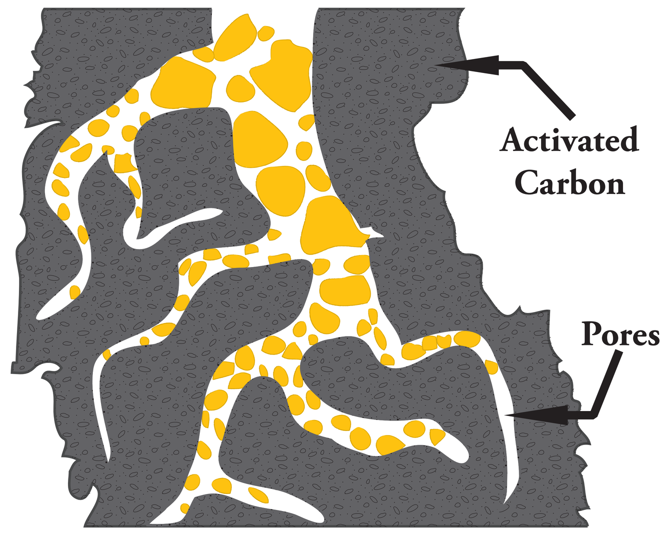
Abstract

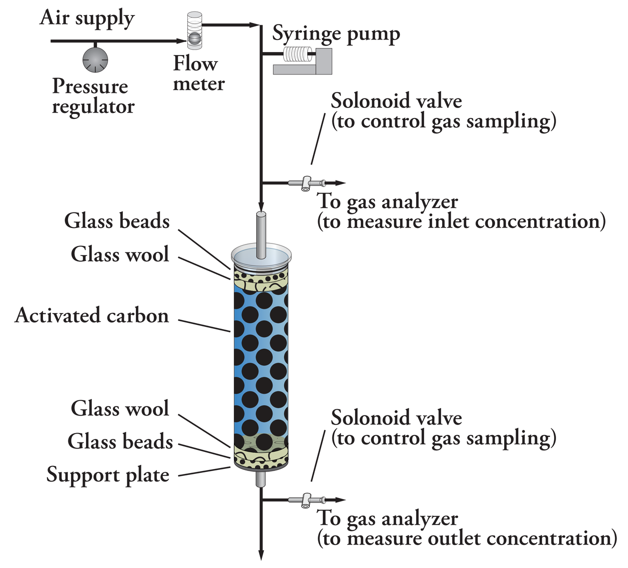
The purpose of this project was to study the dynamic behavior of the GAC filter in hopes that the results of this study would help engineers to design more efficient filters. Dr. Moe, of the LSU Civil and Environmental Engineering Department, researched how different loading ratios and time intervals affected the ability of the GAC filter to stabilize the contaminant loading. In this project, mathematical models were developed to coincide with Dr. Moe's experimental results.

Background

Granular Activated Carbon (GAC)

The carbon based material is converted to activated carbon by thermal decomposition in a furnace using a controlled atmosphere and heat. It is a low-volume, high-surface area material caused by macro and micro-porosity. The high surface area traps contaminants that come in contact with the activated carbon.

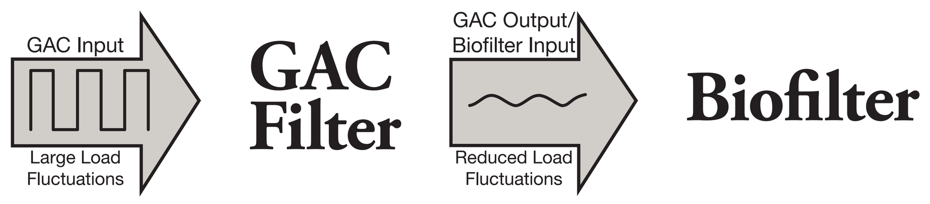




The GAC filter passively controls and regulates the flow of pollutants. The submicroscopic pores trap pollutants through a process called adsorption. As non-contaminated liquid or air flows through the filter, the granulated carbon releases stored pollutants.

GAC Filter Used with Biofilters

Biofiltration uses microorganisms to remove VOC's (volatile organic compounds) from contaminated air. During periods of increased contaminant loading, the microorganisms can undergo shock; during periods of little or no loading, the microorganisms can undergo starvation conditions. Both of these situations can reduce the efficiency of the biofilter. Using GAC filters in conjunction with biofilters will alleviate the adverse effects during periods of contaminant overloading and also during periods of starvation caused by operational shutdown when no contaminants would be supplied to the biofilter.



A GAC filter is able to stabilize loads passively due to its ability to both adsorb contaminants during periods of increased loading and desorb previously adsorbed contaminants during periods of reduced loading. The GAC filter will initially adsorb practically all contaminants until it has reached a quasi-steady state breakthrough. It then begins to have an output in correlation with its input and it also acts to attenuate changes in the contaminant loading.

Governing Equations

Liquid Mass Balance Equation:

$$-\frac{\partial}{\partial \bar{z}}\bar{C}_i(\bar{z},T)=\frac{1}{(1+D_{g_t})}\frac{\partial}{\partial T}\bar{C}_i(\bar{z},T)+3S_{t_i}[\bar{C}_i(\bar{z},T)]-\bar{C}_{p,i}(\bar{r}=1,\bar{z},T)$$

Intraparticle Phase Mass Balance Equation:

$$\frac{1}{\bar{r}^2}\frac{\partial}{\partial \bar{r}}[\bar{r}^2[Ed_{s,i}+D_iEd_{p,i}]\frac{\partial \bar{Y}_i(\bar{r},\bar{z},T)}{\partial \bar{r}}+(Ed_{p,i}-D_iEd_{p,i})\frac{\partial}{\partial \bar{r}}\bar{C}_{p,i}(\bar{r},\bar{z},T)]]$$

$$=\frac{D_{g_t}}{(1+D_{g_t})}\frac{\partial \bar{Y}_i}{\partial T}(\bar{r},\bar{z},T)$$

System Equilibrium Equation:

$$\bar{C}_{p,i}(\bar{r},\bar{z},T)=\frac{q_i(\bar{r},\bar{z},T)}{\sum_{k=1}^{m}q_k(\bar{r},\bar{z},T)}\left[\frac{\sum_{k=1}^{m}n_kq_k(\bar{r},\bar{z},T)}{n_iK_i}\right]^{n_i}$$

The unknown functions are:

$\bar{C}_i(\bar{z}, T)$: Adsorbate concentration in bulk phase,

$\bar{C}_{p,i}(\bar{r}, \bar{z}, T)$: Adsorbate concentration in adsorbent pores,

$\bar{Y}_i(\bar{r}, \bar{z}, T)$: Total adsorbent phase conentration,

where $\bar{r}$, $\bar{z}$ and T are the radial, axial, and time coodinates, respectively.

Numerical Method

The orthogonal collocation method is applied to solve the above equations. This method uses Legendre polynomials as trial functions and the collocation points are taken as the roots of those polynomials. The spatial derivatives are expressed in matrix form in terms of the dependent variables evaluated at the collocation points. This process leads to a set of ordinary differential equations where the independent variable is the time T. To integrate these equations, the following MATLAB solver was used:

```
[T, Y] = ode15i (odefun, tspan, y0, yp0, options)
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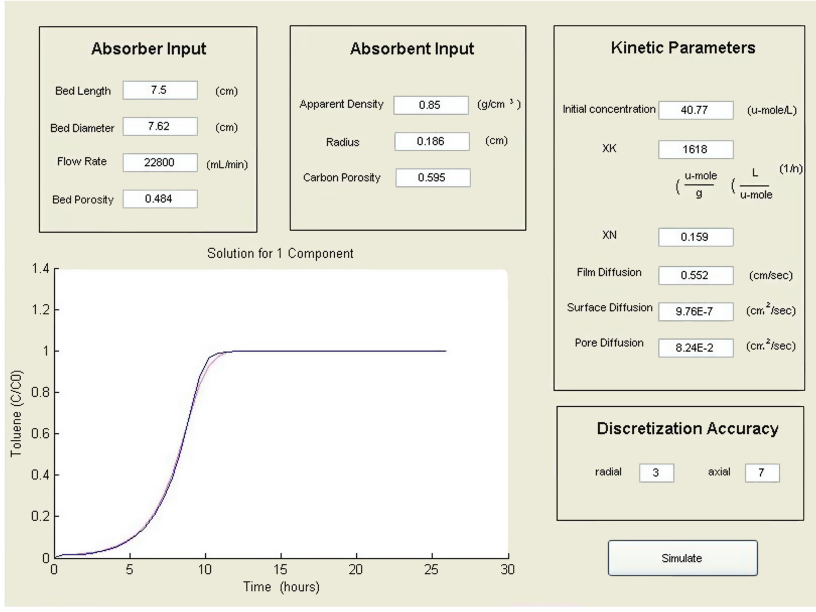
Model & Simulations

GAC User Interface

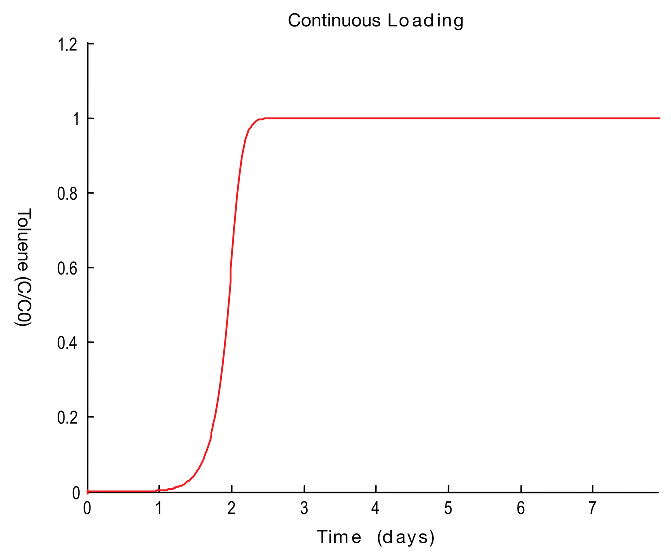
The basic GUI (Graphical User Interface) for the GAC filter simulation was made using MATLAB's built-in GUIDE system. The GUI presents the option to change the basic GAC filter properties and approximations.



The GAC Interface:

- Starts with a default test case, thus making variables and values easily identifiable for the user.
- Outputs the results directly within the interface.
- Allows selection of various input conditions, such as:
  - -Constant loading.
  - -Intermittent loading.
  - -Input according to a function.
  - -Input data imported from Excel.
- Allows for the exporting of data to Excel.

Simulated Loading Conditions

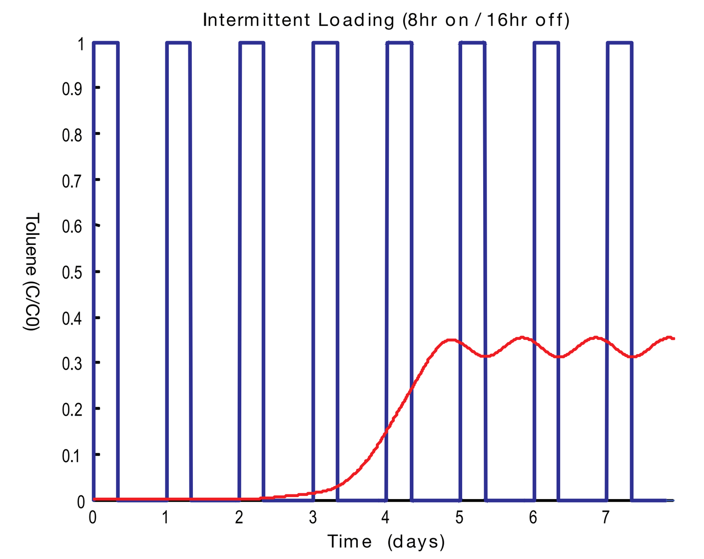


Continuous Loading

The model was used in a simulation with continuous input loading of the contaminant toluene. The filter reached breakthrough after approximately 1.5 days and saturation after two days.

Intermittent Loading

The model was used in a simulation with intermittent loading. In the simulation, the contaminant toluene was passed through the filter using a cycle of eight hours of continuous loading and sixteen hours of non-loading. The graph shows the output reaching a quasi-steady state after five days. Once in the quasi-steady state, the output fluctuates between two constant values.



Conclusion

The mathematical model that was developed closely matched Dr. Moe's experimental results. Results show that contaminants can be temporarily accumulated in a GAC filter during intervals when concentrations are high and then desorb within a short time interval when concentrations are low. Also, smaller cycle times and smaller loading ratios provide for a more constant load input to the biofilter.