A LIFE CYCLE ANALYSIS OF GAC REACTIVATION

Thomas E. Chestnutt, David Mazyck, David P. Cooper, Dong-Uk Lee, Lynn V. McIndoo, Angela Lindner
Department of Environmental Engineering Sciences
University of Florida, 220 Black Hall Gainesville, Florida 32611

Introduction

Life cycle analysis (LCA) is a tool that allows one to assess the economic and environmental costs associated with a product or a process in each phase of the product's life. Several studies outlining and defining the steps of an LCA have been reported. An LCA theoretically chronicles the life of a product from "cradle to grave." Typically, boundaries are set to limit the breadth of material considered and to focus on the main issues of concern. The three components of an LCA are the inventory analysis, impact analysis, and the improvement analysis. The inventory analysis component is comprised of two subsets: scoping and data collection. Impact analysis is a method used to evaluate environmental issues that may arise from the processes under consideration (e.g. global warming, acid rain, etc.). Suggestions for the improvement of the process, in regards to the environmental impacts found in the impact analysis step, are detailed in improvement analysis (1-3).

This study is based largely upon data taken from Cincinnati Water Works (CWW), a large drinking water treatment facility with on-site GAC reactivation. CWW has an inflow range of 107 to 136 MGD, requiring 12 filter beds, each containing 60,000 lbs of GAC, for an total of 7.2 million pounds of GAC. The facility is recognized as the largest municipal GAC potable water treatment system (4). This paper is comprised of two parts, the first of which compared three reactivation protocols: conventional reactivation, steam curing, and steam-pyrolysis reactivation. Using the most desirable reactivation protocol determined from part 1, a comparison was made between a facility that uses virgin carbon exclusively (scenario 1) and one with an on-site reactivation plant (scenario 2). Together, these two parts serve to elucidate the environmental and economic impacts associated with each reactivation protocol, as well as GAC usage with or without reactivation.

Methods

Scope of Study. The first step in the LCA process is to define the scope of the project by creating a material and energy flow diagram (1). These diagrams begin from a macroscopic view of the system (level 1), which places boundaries on the project scope. Level 1 diagrams for scenario 1 and 2 are depicted in Figures 1a and 1b, respectively.

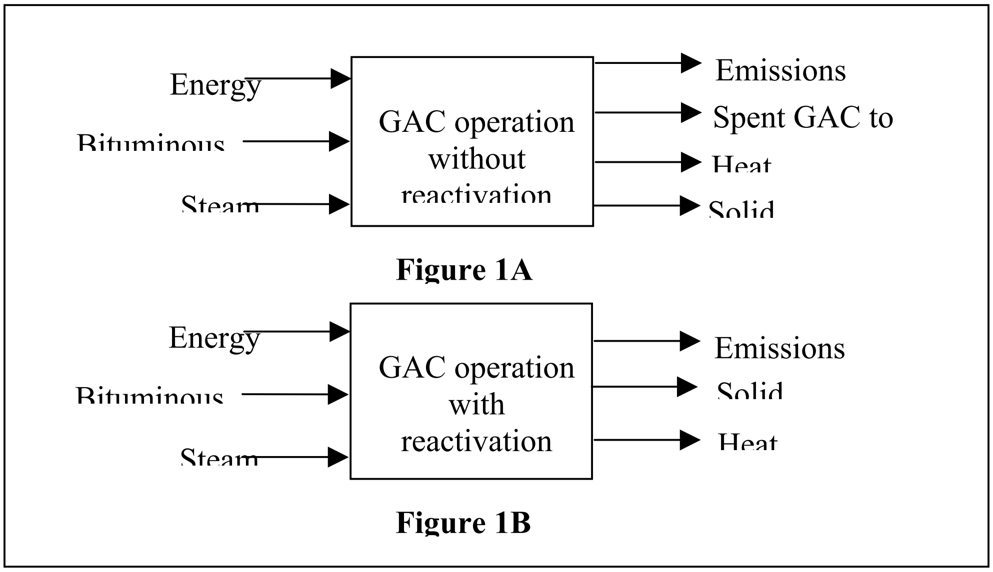


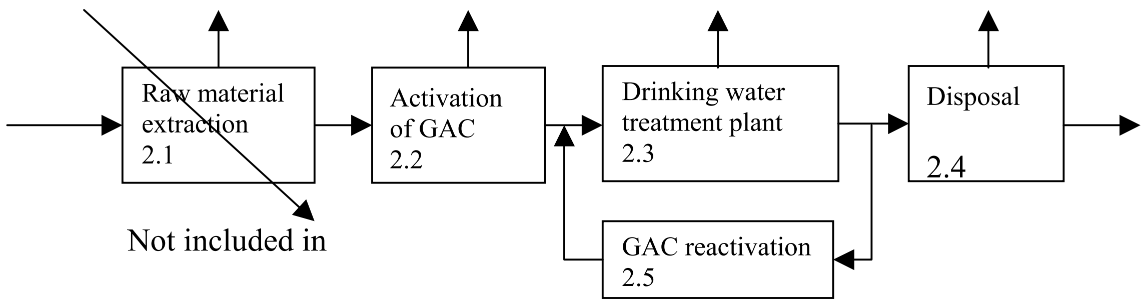
FIGURE 1. Level 1 diagrams for scenarios 1 and 2.

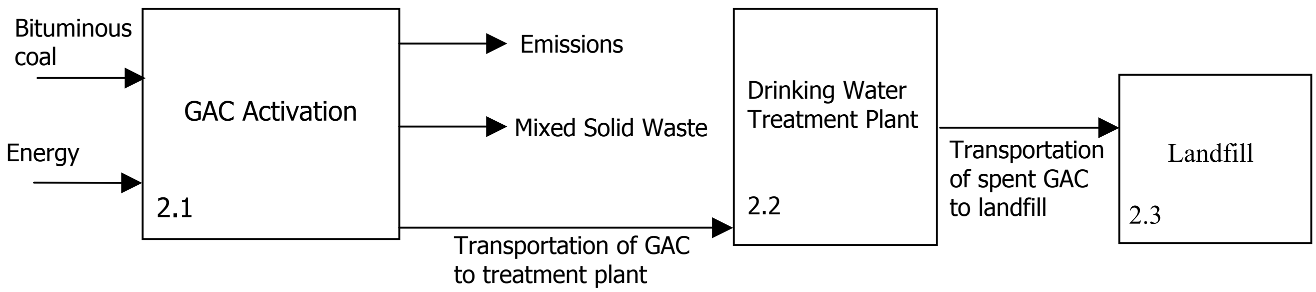
In order to further break the process down, level 2 diagrams are constructed. A generic level 2 diagram (Figure 2a) begins with the extraction of raw materials, includes their conversion to activated carbons, proceeds with their use in a treatment plant, and ends with their disposal. However, for this study, the extraction of raw materials was excluded due to time and data limitations. For scenario 1, the scope begins with GAC activation and ends with landfill disposal of spent GAC after a 2-year period (Figure 2b). The project scope for scenario 2 begins with GAC activation, includes a yearly reactivation process, and ends with the combustion of GAC to CO_2 (Figure 2c).

Comparison of the three reactivation protocols requires a separate level diagram (Figure 3) because it looks exclusively at the process of reactivation. Boundaries are placed on the process which begins with the introduction of spent GAC and ends with the reactivated product.

Project Assumptions

Certain assumptions were made to complete this study. The assumptions for the reactivation protocols were as follows: each carbon has the same water treatment performance in large scale; all spent GAC was reactivated every year; make-up carbon purchases included cost and impacts; and no environmental impacts associated with the construction of the reactivation plant were considered. The following three assumptions were made for GAC activation: the carbon has equal water treatment ability; the virgin GAC has a two-year life span; all spent carbon is landfilled; and there was no change in the price of carbon over a twenty-year period. Additionally, all emissions from the generation of electricity were excluded based on data limitations.





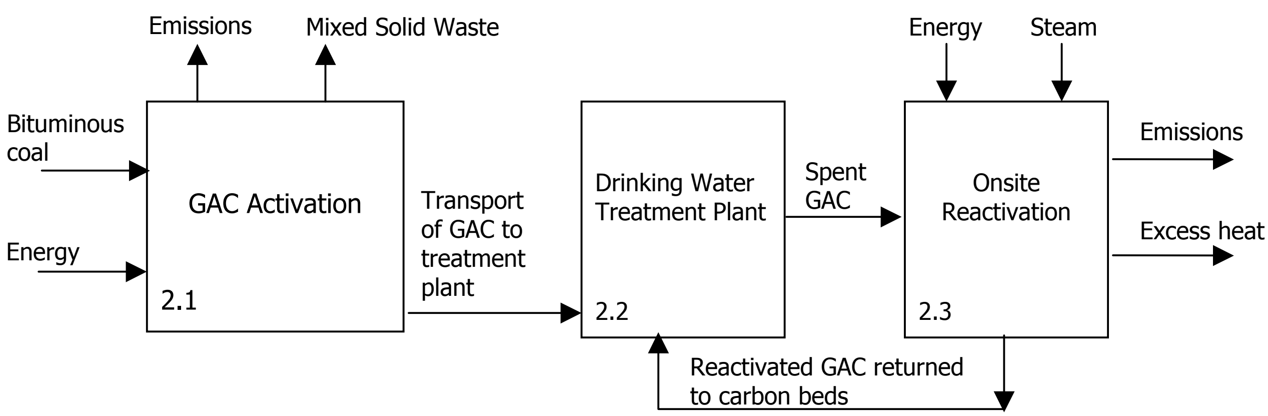


Figure 2c (Scenario 2)

FIGURE 2: Level 2 diagrams.

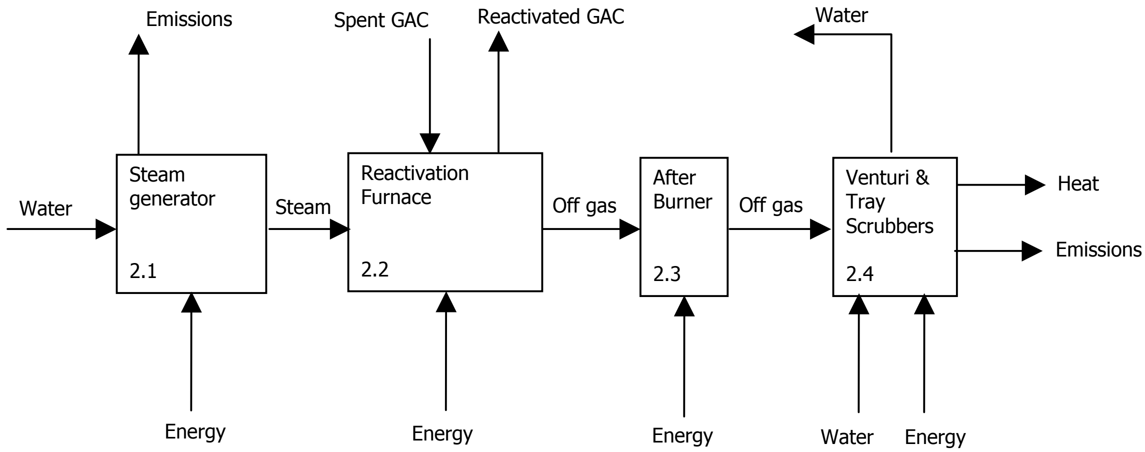


FIGURE 3: Level 2 diagram for reactivation protocols.

The comparison was made by use of a functional unit, which was defined as the surface area divided by the product of energy required and percent mass loss. The functional unit was chosen for the following reasons: surface area upon reactivation is a typical measure used to describe the quality of the reactivation and provides an estimate as to how the reactivated carbon will perform. Energy consumption for each reactivation protocol was used to calculate the relative amounts of energy that would be required. Mass loss was included in the functional unit, because it is a relative measure of the emissions that evolve from the process. The functional unit indirectly accounts for performance (surface area), and environmental costs (emissions and energy).

Reactivation Protocols

The conventional reactivation protocol utilizes a pyrolysis step followed by an oxidative step using steam. The time (15 minutes) and temperature (750°C) regimes used are the same for both steps. Two other thermal reactivation protocols; steam-curing and steam pyrolysis reactivation (SPR), were also investigated. The steam-curing protocol was developed by Mazyck and Cannon (5) as a response to the problems posed by calcium catalysis during reactivation (6). The protocol consists of oxidation for 1-hour at 375 °C in steam followed by pyrolysis in N_2. During the pyrolysis step, which lasts about one hour, the temperature is ramped from 375 to 850°C.

Reactivation Cost Analysis

Total cost of a reactivation protocol over a 20-year period is based upon capital costs for building construction, operation and maintenance (O&M) costs and the cost of the initial virgin carbon. Construction cost data are based on 1979 and 1980 studies of the CWW plant (7). These data were converted to current day values using the Bureau of Labor Statistics Inflation Calculator (8). A 6% interest rate was applied to the total capital costs of the GAC reactivation facility, and the value was amortized over a 20-year period. The financial data do not include labor costs required to operate the reactivation unit.

Results and Discussion

The steam curing protocol experienced a mass loss of 8.7%, the SPR protocol 8.0%, and the conventional protocol 9.1%. Steam curing produced a greater surface area, 693 m^2/g followed by SPR at 663 m^2/g and the conventional protocol at 644 m^2/g. The energy requirements for the steam curing reactivation, SPR, and conventional were 8.9, 2.73, and 2.73 KWh, respectively. These were calculated using data from lab-scale fluidized bed experiments and the following equation:

$$Energy\,(kwh) = m\,t\,C\,\Delta T$$

$$m = mass$$

$$C = Specific\ Heat\ (6)$$

$$\Delta T = change\ \ in\ \ temperature$$

$$t = time$$

The comparison of the three reactivation protocols was made using the functional unit equation:

$$Functional\,Unit = \frac{Surface\ Area}{Mass\ Loss \cdot Energy\ Input}$$

The functional unit value for SPR was 30.4 m^2/g-KWh, followed by the conventional protocol at 25.9 m^2/g-KWh and finally by the steam curing protocol at 9.0 m^2/g-KWh.

TABLE 1. Reactivation Experimental Data and Functional Unit

Protocols	**Surface Area** (m^2/g)	**Mass Loss** (%)	**Density** (g/mL)	**Energy** (kwh)	**Functional Unit** (m^2/g-kwh)
Steam Curing	693	8.7	0.500	8.9	9.0
SPR	663	8.0	0.500	2.73	30.4
Conventional	644	9.1	0.488	2.73	25.9

Purchase of the initial 7.2 million pounds of virgin carbon to fill the twelve filter beds costs \$3.96 million and does not change for the different protocols. Total costs associated with the construction of the reactivation facility are approximately \$1.76 million for a 6% interest rate over a 20-year period. Operation and maintenance costs present the biggest difference in cost between the three protocols. Energy use for the steam curing protocol results in nearly twice as much cost over the 20-year period. Reactivation costs for the three protocols are as follows:

conventional, 20¢/lb GAC reactivated; steam curing, 37¢/lb GAC reactivated; and steam pyrolysis, 19¢/lb GAC reactivated. From a purely economic point of view, steam pyrolysis is the best protocol for reactivation.

TABLE 2. Total Costs for Each Reactivation Protocol

	Conventional	Steam Curing	Steam Pyrolysis
Capital costs ($/20 yr)	1,764,068	1,764,068	1,764,068
Virgin GAC ($)	3,960,000	3,960,000	3,960,000
O&M ($/20 yr)	22,957,440	47,482,560	22,086,480
Total Cost ($/20 yr)	28,681,508	53,206,628	27,810,548
Cost ($/lb GAC)	**0.20**	**0.37**	**0.19**

The costs for scenario 1 over a 20-year period are summarized in Table 3. The most salient conclusion from this table is that the cost per mass of GAC used for scenario 1 is approximately 94¢. This price is considerably higher than that of reactivation, regardless of which protocol is employed.

TABLE 3. Total Costs for GAC Use Without Reactivation (Scenario 1)

	Cost ($/20 yr)
Purchase of virgin F-400 carbon	39,600,000
Transport of virgin carbon to treatment facility	23,807,896
Transport of spent carbon to landfill	2,506,094
Landfill disposal fee	1,881,235
Total	67,795,225
Cost ($/lb GAC)	**0.94**

Using the 20-year emission data collected**,** global warming and acid rain potentials were calculated (9). Potentials for ozone depletion and smog formation were also considered, but the processes considered did not emit constituents responsible for these impacts. A comparison of the global warming potential (GWP) and acid rain potential (ARP) for scenario1 and scenario 2 may be seen in Table 4. Higher potential values represent greater risk to the environment. The total solid waste generated from activation and reactivation over a twenty year period was calculated as 3.7 million and 171,000 yd^3, respectively; therefore, scenario 1 requires nearly 22 times more landfill volume than scenario 2.

TABLE 4. Global Warming and Acid Rain Pollution Potentials

	GWP	ARP
Activation	6.14 E+08	3.69 E+05
Reactivation	3.86 E+08	9.57 E+04

Acknowledgements
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