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Determining Economic Feasibility: A Cost Analysis of an Adsorption Based Wastewater Treatment Plant

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Abstract

This paper presents a three way cost comparison between three different methods of wastewater treatment: a conventional activated sludge plant, an adsorption based plant and a surcharge based system. We assumed plant capacity of 1 million gallons per day and wastewater composition of 2% phenolic compound, BOD5 of 1370 mg/L and TSS of 1400 mg/L. Capital, construction, non-construction, operational and maintenance costs for all three systems were calculated, and their costs discounted over a period of ten years to find the Net Present Value in first quarter 2016 USD. The discount rate used was 8% as that was the average weighted average cost of capital for wastewater treatment firms across the United States. NPV was determined to be positive $31,000,000 for an adsorption based plant assuming 100% efficiencies, negative $14,600,000 for a conventional activated sludge plant, and negative $9,100,000 for a surcharge system. There is potential for significant revenue generation in the resource recovery stage of an adsorption process, where up to $6,200,000 worth of steam can be generated when the adsorbent is burned off. Therefore, this study shows that an adsorption based wastewater treatment plant can be economically and financially feasible.

Acknowledgements

Firstly, I'd like to thank Professor Mark Snyder and Professor Srinivas Rangarajan for providing me the opportunity to work on this research project and for their faith in my abilities. I'm also very grateful to my advisor Professor Alberto Lamadrid and Professor Vince Munley for their time and efforts in providing much needed feedback and guidance throughout this project. Finally, I'd also like to acknowledge my friends and family for all their support as well.

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1. Introduction

1.1: Motivations and Overview

The term “Energy-Water Nexus,” describes a concept of interdependence and linkage between water and energy systems in today’s society. Both energy and water have become cornerstones to the development and functioning of a modern economy, and demands for both inputs will increase significantly in the future in the face of growing populations, economies and changes in consumption and lifestyle patterns (“Water and Energy”, 2014). However, despite both being crucial inputs to modern society, energy and water policies still consists of trade offs, as policies designed to increase efficiency in one area, may create additional demand or negatively harm the other (Hussey & Pittock, 2012).

In the United States, one tangible example of energy-water nexus manifests in the wastewater treatment sector. Within a city or municipality, wastewater treatment is often the largest consumer of energy, and nationally, represents 0.1 - 0.3% of total energy consumption (Stillwell, Hoppock & Weber, 2010). On the other side, the energy sector is the second biggest consumer of water after the agriculture industry, and will also drive 85% of the expected increased consumption of water by 2030 (Carter, 2013). A 2014 Senate Committee on Energy and Natural Resources noted that all forms of energy generation require water and that the use of water also requires energy, thus making the energy-water nexus a foundation of the economy and essential to the economic and international security of the U.S (“Addressing Energy-Water”, 2015).

As energy and water needs increase in the future and apply even more pressure to dwindling natural resources, better coordination between these two areas is needed. One area of potential improvement can be found in wastewater treatment systems. Currently, conventional treatment methods which although effective, hold a great deal of inefficiencies. Their processes are not only energy intensive but are also financially draining.

In recent years, a technique called an *adsorption based process* has shown potential as an alternative wastewater treatment system. On a technical level, much research has been done highlighting the feasibility and effectiveness of this process on a scientific and chemical level (Qu, et al., 2009; “Feasibility Study”, 1982) . However, if this treatment process is to be the modern day solution to the modern day problem, we also need to understand how an adsorption based process compares to the status quo/conventional treatment methods from an economic standpoint.

1.2 Objectives

The purpose of this study is to conduct three way (three systems) cost analysis and comparison of a hypothetical 1- million gallon wastewater treatment plant. The three systems being compared are 1) An adsorption based process, 2) A conventional treatment plant utilising conventional activated sludge technology, and 3) A surcharge based treatment system. Capital, construction, non-construction and operational costs were calculated and the cash flows discounted over a time period of 10 years to calculate the NPV, and then used as the comparison figure.

2. Literature Review

This literature review is divided into four sections that summarise the main findings from relevant studies already conducted. Together, they work combine to provide context and a more comprehensive overview on the three treatment systems.

2.1 Overview on Wastewater Treatment Systems

Conventional Activated Sludge Systems:

The most common form of wastewater treatment and wastewater treatment plants in today's society is conventional activated sludge (CAS). After wastewater is passed through primary treatment to remove solids and other physical matter, it's passed into an aeration tank for secondary treatment. In this tank, air/oxygen is pumped in and let to set so to allow bacteria to break down the organic matter. From this process, two by products- water and sludge are created. The sludge is usually further treated and disposed of by compositing or used as a fertilizer, whilst the water can be further disinfected and disposed of depending on its ultimate end use ("How Wastewater Treatment", 1998).

The effectiveness of CAS systems is highlighted in its widespread use despite it being a very energy intensive process (Leu, et al., 2009). Traditionally, wastewater has been seen as a "waste," with governments adopting a simple "treat and dump" mentality to dispose of wastewater in the cleanest and most effective manner without regard to resource recovery. Therefore although the energy content in wastewater is 9-10 times greater than what is used to treat it (Yan et al., 2017), the CAS approach results in a lot of that energy being lost as heat or in the sludge. Attempts have been made to recover that energy through further treatment of the sludge to harvest the energy in the form of natural gas (methane), but a study by Wan et al (2016) found that energy efficiency was only 35% in a wastewater plant in Singapore, and 31% of another in China.

Adsorption Based Systems:

The increasing scarcity and demands on natural resources has shifted wastewater trends to focus on resource recovery and reuse which is what an adsorption based process can potentially provide.

An adsorption based wastewater treatment system works similar to how a brita filter functions. In a brita filter, the filter adsorbs any pollutants and the resulting effluent is clean water, when it's saturated, one throws the filter away and replaces it with a new one. In an adsorption based treatment system, wastewater is pumped through a tank containing an adsorbent (the filter). In this tank, pollutants stick onto the surface of the adsorbent, so when saturated, clean water is produced (which can then be further disinfected based on end user requirements). At this point, instead of throwing away the filter like you would with a brita, one can either burn off the adsorbent, thus creating heat, water and carbon dioxide, thus allowing for energy recovery.

Currently, adsorption technology is employed in certain situations to treat specific industrial wastewater discharges, but there is potential for it to be used in a wider variety of wastewater discharges. Overall, the ultimate effectiveness and efficiency will depend on the exact composition of wastewater, as well as the exact adsorbent chosen as not all are the same.

Industrial Surcharge:

The 1972 Clean Water Act is the legal mandate that establishes guidelines and regulations industrial entities must comply with in regards to industrial wastewater treatment. An industrial user has two main choices, they can either treat it themselves (or outsource the problem to a private firm) so it complies with regulations, and then discharge it into nature. Or pay a surcharge (fee) to the local government, which then allows the user to discharge the wastewater into a public sewage system, and into a Publicly Owned Treatment Works (POTW), that is also usually a CAS system plant. For some, the scale of operations may not be enough to justify the cost of running an onsite treatment facility, so will choose instead to go through the latter.

The surcharge imposed by a local government for an industrial user to discharge their wastewater into a POTW can depend. However, the surcharge is usually a function of pollutant strength and flow, with both factors positively correlated. Therefore, whether an industrial user ultimately chooses to treat the waste themselves or send it to a POTW can vary and depends on the exact chemical composition of the wastewater they're producing.

There are a few publicly available statistics on what choices firms choose in wastewater disposal. In a survey conducted by the wastewater focused news company Industrial Waterworld (2011), 55% out of 90 respondents reported they managed their own on site treatment facilities and 12% discharged to the sewer system (surcharge). Survey also found that out of the 55% that had onsite facilities, half of them utilised a CAS system. In addition, those who utilised the surcharge reported average annual costs of USD $600,000 for average annual flows of 760,000 gallons.

2.2 Overview of Similar Economic and Cost Analysis

The second category consists of economic/costs studies already conducted on wastewater treatment systems. Although there is an abundance of research on wastewater treatment in general, there is a lack of literature that pertains specifically to the economics of adsorption based wastewater treatment.

Andrade, Oliveria, et al's 2018 study of adsorption of pharmaceuticals from water and wastewater provides a brief cost estimate, stating that the cost of adsorption based pharmaceutical wastewater treatment processes can range between USD $10- $200 per million liters (approx USD $38- $750 per 1 million gallon)[1] depending on the adsorbent, whilst similar processes such as reverse osmosis, ion exchange or electrodialysis can cost US $450 per million liters (approx $1700 million per 1 million gallon), thus suggesting potential cost savings. In Rashed's paper on Adsorption Technique for Removal of Organic Pollutants (2012)[2], Rashed states adsorption based treatment has an advantage over modern alternatives also being pushed as it has a simple design and can involve low investment in terms of both initial cost and land required. Instead, the major focus nowadays seems to be on finding a low cost adsorbent that can also effectively adsorb pollutants.

Indeed, efforts to find further economic analysis of adsorption processes in wastewater treatment have come up dry (no pun intended). Gupta and Babu's 2008 economic feasibility study attempts to combine scientific/technical feasibility studies with unit level costs. In their paper, the adsorption capacities of different materials in CR(VI) wastewater and the costs of producing/creating 1kg of the different materials are compared. But the majority of the published research seems to focus on finding and testing the effectiveness of known "low cost" adsorbents on different pollutants (Gisi et al., 2016).

2.3 Overview of CAS System Costs and Surcharges

The third category is a review of literature on any costs incurred in the creation/running of a CAS system and of utilising a surcharge. For CAS capital and construction costs, the primary source was the 1980 EPA Report on Construction Costs for Municipal Wastewater Treatment Plants. For operational and maintenance (O&M), a different EPA Report on Operational and Maintenance Costs for Municipal Wastewater Facilities (1981) was used. Both the 1980 and 1981 reports detailed specific costs curves as a

[1] Using 1 litre = 3.78 gallons conversion rate
[2] Same conversion as above

function of flow rates for each different components/procedures (eg. capital costs of specific machinery, construction costs, etc). These cost curves derived from projected project costs from winning construction bids nationally for each specific process. For the construction costs report, the base dollar was in 1978 4th quarter dollars, whilst the O&M report was in 1981 1st quarter dollars.

For the surcharge, each local municipality sets its own surcharge cost equation with some variance. This was the surcharge set by the City of Bethlehem in Pennsylvania:

Surcharge = 0.00834 x Flow x {((Biochemical oxygen demand/BOD5 - 300) x BOD5 Cost) + ((Total suspended solids/TSS - 350) x TSS Cost) + ((ammonia nitrogen/NH3-N - 50) x NH3-N Cost)}

Where flow is in million gallons, BOD5, TSS and NH3-N is in milligrams per litre, and BOD5, TSS and NH3-N costs are ‘000 dollars per pound.

As it can be seen, the total cost of the surcharge is a component of flow, quantity of BOD5, the cost of treating BOD5, quantity of TSS, the cost of treating TSS, quantity of NH3-N and cost of treating NH3-N. As the City of Bethlehem did not provide this number, this paper uses figures published by the EPA region 4’s survey of costs of treatment instead (“Pretreatment program economics”, 2010).

In addition, the survey results by Industrial Wasteworld were also used as a benchmark to ensure the results from equation used above were not overly far off the mark.

2.4 General Overview of Similar Cost- Benefit Analysis:

Finally, a general search for similar cost- benefit analysis conducted for the wastewater industry was done to gain knowledge and understand the general outline, style and structure of a paper such as this. Ganai’s 2011 study on Cost- Benefit Analysis of Implementing Wastewater Treatment in Beer Breweries was particularly helpful.

3. Methodology

3.1 Methodology Overview

Assuming 1 million gallon capacity, the capital, construction, non-construction and operational costs were calculated to conduct a three way comparison between an activated sludge, surcharge and adsorption based systems. Then, using a period of 10 years, a discount rate of 8%, and an annual inflation rate of 1.87%, the NPV was calculated on excel. This discount rate was found by taking the average Weighted Average Cost of Capital of 11 water resource companies through data accumulated by the investment website finbox. The value for yearly inflation taken on May 8th, 2019, from the Federal Reserve of Economic Data's (FRED) 10 Year Breakeven Inflation Rate. The wastewater was also assumed to contain 2% phenol as the chemical composition.

3.2 Activated Sludge Methodology

Using the cost curves in EPA's Construction Cost's handbook, costs for specific components were found for one million gallon design flow. For capital costs, the costs for Preliminary Treatment, Influent Pumping, Primary Sedimentation , Conventional Activated Sludge, Effluent Chlorination, Effluent Outfall, Gravity Thickening , Aerobic Digestion, Drying Beds and Control/Lab Building were found in 1978 USD. Then, using the bureau of labor statistics CPI calculator, these values were converted into 2016 1st quarter USD. The 2016 1st quarter benchmark was chosen as some specific cost literature found used 2016 dollars, so this was chosen to aid comparison.

The same method was applied for construction costs, with costs for Mobilization, Sitework, Excavation, Electrical, Controls & Instrumentation, Yard Piping and Heating, Ventilation and Air Conditioning (HVAC) were found. Non- Construction costs consisting of Step I, Step II and Step III costs were also developed the same way. Finally, all three major components- capital, construction, non-construction, to find Total Project Costs.

Operational and Maintenance costs were then found using the cost curves for specific processes in the EPA's 1981 Operational and Maintenance (O&M) report. Costs for Administration, Total O&M (pumping and other energy costs), Sludge Handling and Staff/Labour were found in 1981 dollars and converted to 2016 1st quarter USD. One difference however was the cost curve for staff/labour provided the number of expected staff needed for a given design flow, rather than the total cost. Therefore, to find the total annual cost of labor, an additional step was needed. The number of expected labor (3 staff personnel for a 1 million gallon plant) was multiplied with the national average salary ($42,000) for a wastewater treatment plant operator that was found online on payscale.com.

3.3 Adsorption Based Process

The methodology for finding the project costs and O&M costs for an adsorption based process is similar to that of the CAS system. For capital costs, after consulting with Professor Snyder and Professor Rangarajan, we removed several specific components found in CAS as they are not necessary for this treatment system. Cost information for the adsorbent and adsorption column were also provided through their technical calculations. Ultimately, the costs for Preliminary Treatment, Adsorbent, Adsorption Column, Effluent Outfall and Control/Lab Building were found and converted to 2016 first quarter USD.

Construction and non-construction costs were found the same was a for a CAS model with no changes made. All three major components- capital, construction, non-construction were then summed to calculate total project costs for an adsorption based process.

For O&M costs, we find the costs for Administration and Staff/Labor the exact same way as done for the CAS system. Total O&M was provided through Professor Snyder's and Professor Rangarajan's technical calculations. The calculation for resource recovery was done in several steps. First, the amount of phenol that would be adsorbed/day in grams was provided from Professor Rangarajan's technical calculations (1) .

$$7.57 \times 10^{7} \text{ grams.} \quad \textbf{(1)}$$

It was then converted to mols and multiplied by the heat combustion of phenol to produce the total amount of energy in kJ (2) to find the total energy produced by burning a 2% mixture of phenol adsorbed into the adsorbent in a day (3) .

$$(7.57 \times 10^{7} \text{ g phenol/day})*(1 \text{ mol phenol}/94.11\text{g phenol})*(3051 \text{ kJ/mol phenol}) \quad \textbf{(2)}$$

$$2.454 \times 10^{9} \text{ kJ/day} \quad \textbf{(3)}$$

Then, assuming pressure at 450 psig and temperature of 37.7 Celsius (100 fahrenheit) value was then divided by 1200kj to find how many lb's of steam could be produced each day (4)(5).

$$2454 \times 10^{9} \text{ kJ per day}/1200 \text{ kJ} \quad \textbf{(4)}$$

$$2.045 \times 10^{6} \text{ lb of steam} \quad \textbf{(5)}$$

Using Ulrich & Vasudevan's study on estimating engineering costs, we find the price of a lb of steam and converted it into 2016 USD via the Chemical Engineering Plant Cost

Index. The final price of a lb of steam in 2016 USD was found to be $0.0083. Afterwards, the value of the steam generated was found by multiplying (5) with the price of steam.

3.4 Surcharge

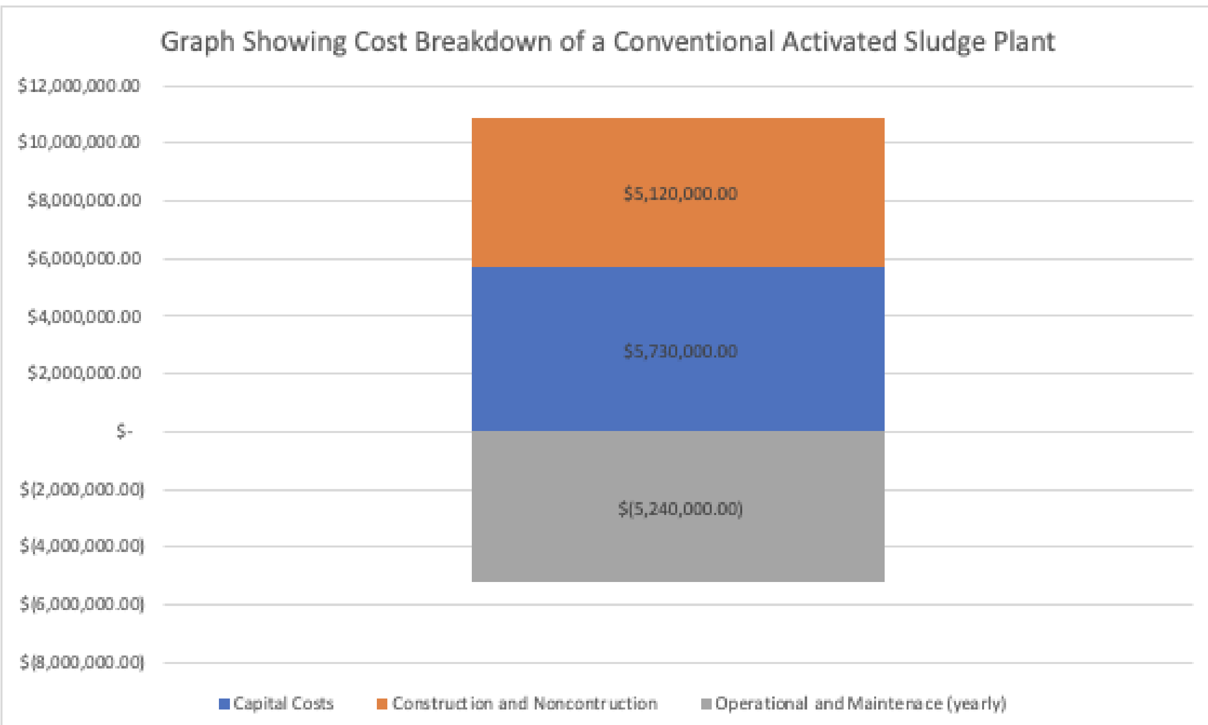
Using the equation and cost values outlined in the literature review, the surcharge for an industrial user of 2% phenolic wastewater, BOD of 1370mg/L, TSS of 1400 mg/L and NH3-N of 0 mg/L were calculated and adjusted for first quarter 2016 USD.

4. Results

A breakdown of the different cost aspects for each system is presented, and a final comparison for the net present values is then shown.

4.1 Activated Sludge Systems

Graph 1: Graph Showing Cost Breakdown of a Conventional Activated Sludge Plant:



Capital costs total $5.73 million, construction and non construction total $5.12 million, and one year operational and maintenance costs (CF1) costs $5.24 million.

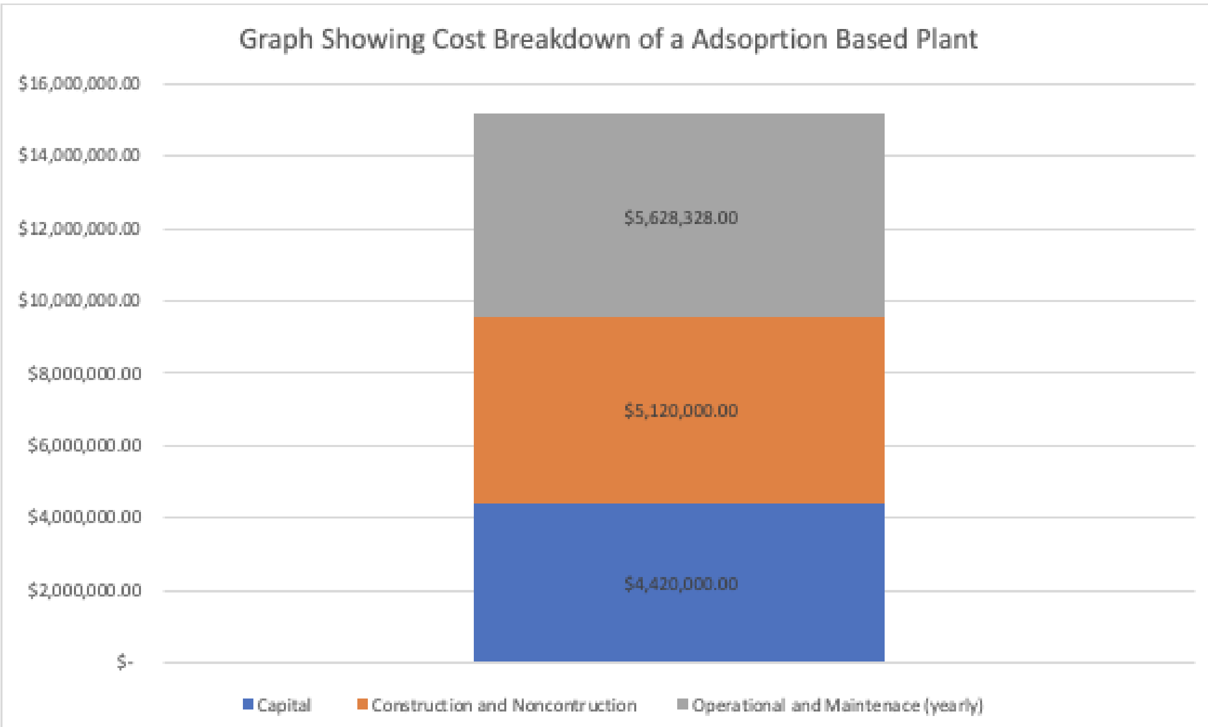
Table 1: Table showing Net Present Value of a Conventional Activated Sludge Plant:

Discount Rate	8%
System	CAS
NPV	**$ (14,642,757.00)**

Net Present Value for a Conventional Activated Sludge system amounts to -$14,642,757

4.2 Adsorption Based System

Graph 2: Graph Showing Cost Breakdown of an Adsorption Based Plant:



Capital costs total $4.42 million, construction and non construction total $5.12 million, and one year operational and maintenance costs (CF1) provide a positive revenue of $5.628 million.

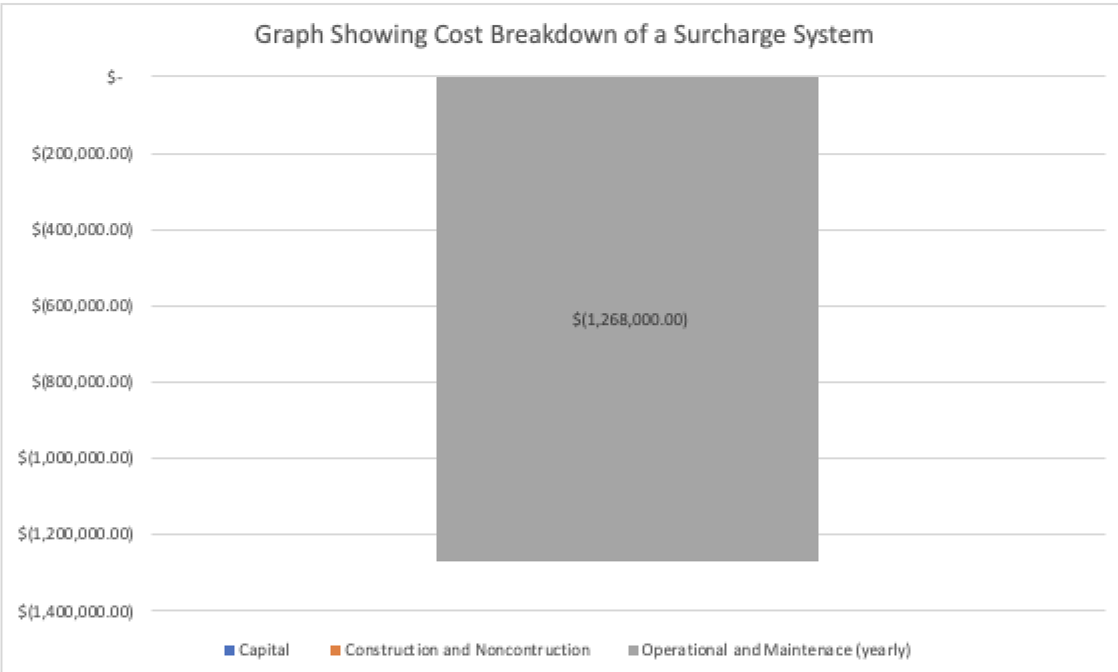
Table 2: Table showing Net Present Value of a Conventional Activated Sludge Plant:

Discount Rate	8%
System	Adsorption
NPV	**$31,028,914.00**

Net Present Value for an Adsorption Based system amounts to positive $31,028,914.

4.3 Surcharge System

Graph 3: Graph Showing Cost Breakdown of an Adsorption Based Plant:



As the surcharge system does not require any capital investments (and subsequently, construction and non construction costs), the only costs incurred are the yearly operational costs/fees of sending wastewater to a municipal plant. This O&M cost amounts to -$1,268,000 (CF1).

NPV:

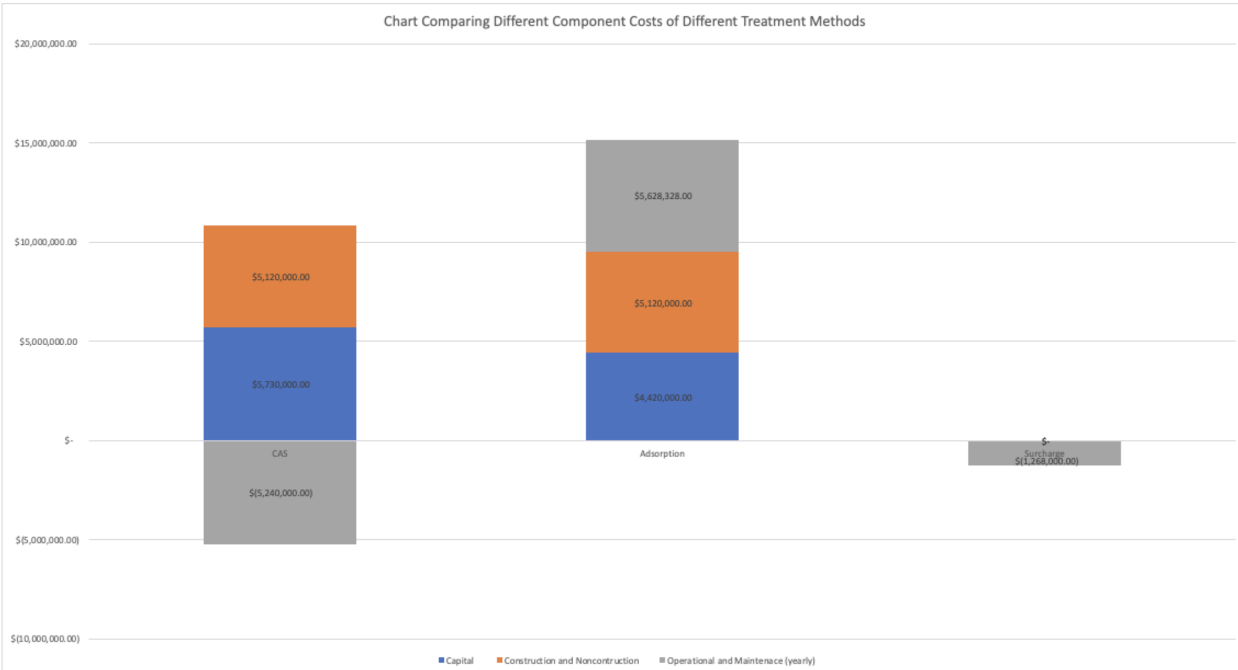
Table 3: Table showing Net Present Value of a Surcharge System:

Discount Rate	8%
System	Surcharge
NPV	**-$9,157,364.69**

Net Present Value for a Surcharge system amounts to -$9,157,364.

4.4 Comparison:

Graph 4: Graph Showing Cost Breakdown Comparison Between All Three Systems:



NPV:

Table 4: Table showing Net Present Value of a Surcharge System:

Treatment Method		NPV
CAS		-$14,642,757.00
Adsorption		$31,028,914.00
Surcharge		-$9,157,364.69

From the summary tables/graphs, it can be seen that the adsorption system provides the highest NPV. The surcharge system has the second highest and the activated sludge method the lowest. In terms of capital costs, the activated sludge method is the highest. For construction costs, both systems have the same value. Finally, the activated sludge method also has the highest operational and maintenance costs.

5. Conclusions and Further Work

This paper conducted a three way cost comparison between 1) a conventional activated sludge wastewater plant, 2) an adsorption based wastewater treatment plant, and 3) a surcharge system.

We can conclude that the adsorption based system is a viable and attractive choice. It has the highest NPV and the financial gain from the sale of steam generated more than offset the operational and maintenance costs of running such a plant.

This study is meant to be a first order feasibility study and although shows promise, can be refined further. When modelling the adsorption plant costs, we've assumed 100% efficiency in the phenol (resource) recovery and energy recovery (generation) process. Furthermore, the model for the activated sludge plant is a base model that assumes no resource recovery of any type. If an activated sludge plant, this assumption does not hold true. Therefore, next steps to refine the models should incorporate a more realistic efficiency level for an adsorption plant, and some level of resource recovery for an activated sludge plant.

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7. Appendix:

Supporting tables/graphs:

A: Conventional Activated Sludge Plant

Process	Conventional Activated Sludge
Total Capital Costs	$ 5,740,000.00
Total Construction Costs	$ 2,760,000.00
Total Non- Construction Costs	$ 2,360,000.00

Table showing total project costs of an activated sludge plant (1MG)

Discount Rate	8%				
Time Period	$ -	$ 1.00	2	3	4
Cash Flows	$ (10,860,000.00)	$ (524,000.00)	-$533,798.80	-$543,780.84	-$553,949.54
5	$ 6.00	$ 7.00	8	9	10
-$564,308.40	$ (574,860.96)	$ (585,610.86)	-$596,561.79	-$607,717.49	-$619,081.81
NPV	**-$14,652,7572**				

Table showing cash flows and NPV of an activated sludge plant (1MG)

Capital Costs:

Process:	Average Cost (1978 USD)	Cost 2016 (USD) Approx.
Preliminary Treatment	$ 64,000.00	$ 246,000.00
Influent Pumping	$ 131,000.00	$ 505,000.00
Primary Sedimentation	$ 120,000.00	$ 460,000.00
Conventional Activated Sludge	$ 519,000.00	$ 2,000,000.00
Effluent Chlorination	$ 63,000.00	$ 240,000.00
Effluent Outfall	$ 61,000.00	$ 235,000.00
Gravity Thickening	$ 69,000.00	$ 265,000.00
Aerobic Digestion	$ 199,000.00	$ 770,000.00
Drying Beds	$ 69,000.00	$ 265,000.00

Control/Lab Building	$ 193,000.00	$ 745,000.00
Total Capital Cost	**$ 1,488,000.00**	**$5,740,000.00**

Table showing capital cost breakdown of an activated sludge plant (1MG)

Construction Costs:

Process	Average Cost (1978 USD)	Cost 2016 (USD) Approx.
Mobilization	$ 63,000.00	$ 245,000.00
Sitework	$ 111,000.00	$ 430,000.00
Excavation	$ 133,000.00	$ 515,000.00
Electrical	$ 167,000.00	$ 645,000.00
Controls & Instrumentation	$ 78,000.00	$ 300,000.00
Yard Piping	$ 115,000.00	$ 445,000.00
HVAC	$ 48,000.00	$ 185,000.00
Total Construction Costs	**$ 715,000.00**	**$ 2,765,000.00**

Table showing construction cost breakdown of an activated sludge plant (1MG)

Non-construction Costs

Non-construction Costs	Average Cost (1978 USD)	Cost 2016 (USD) Approx.
Step I	$ 51,000.00	$ 195,000.00
Step II	$ 122,000.00	$ 470,000.00
Step III	$ 440,000.00	$ 1,695,000.00
Total Non-construction Costs	**$ 613,000.00**	**$ 2,360,000.00**

Table showing non- construction cost breakdown of an activated sludge plant (1MG)

O&M

Process	Conventional Activated Sludge
Administration	-$30,000.00
Total O&M	-$305,000.00
Annual Sludge handling	-$60,000.00
Staff/Labour	-$126,000.00
Total O&M Costs (2016 USD)	**-$ 521,000.00**

Table showing operational and maintenance cost breakdown of an activated sludge plant (1MG)

B: Adsorption Based System

Total Project Costs:

Process	Adsorption Based Process
Total Capital Costs	$ 4,482,000.00
Total Construction Costs	$ 2,760,000.00
Total Non- Construction Costs	$ 2,360,000.00
Total Project Costs	**$9,602,000.00**

Table showing total project costs of an an adsorption based plant (1MG)

NPV:

Discount Rate	8%				
Time Period	0	1	2	3	4
Cash Flows	-$9,602,000.00	$5,628,328.00	$5,733,577.73	$5,840,795.64	$5,950,018.52
5	6	7	8	9	10
$6,061,283.86	$6,174,629.87	$6,290,095.45	$6,407,720.23	$6,527,544.60	$6,649,609.69
NPV	**$31,028,914.35**				

Table showing cash flows and NPV of an adsorption based plant (1MG)

Capital Costs:

Process:	Average Cost (1978 USD)	Cost 2016 (USD) Approx.
Preliminary Treatment	$ 64,000.00	$ 245,000.00
Adsorbent	NA	$ 929,000.00
Adsorption Column	NA	$ 2,328,000.00
Effluent Outfall	$ 61,000.00	$ 235,000.00
Control/Lab Building	$ 193,000.00	$ 745,000.00
Total Capital Cost	**$ 318,000.00**	**$4,482,000.00**

Table showing capital cost breakdown of an activated sludge plant (1MG)

Construction Costs

Process	Average Cost (1978 USD)	Cost 2016 (USD) Approx.
Mobilization	$ 63,000.00	$ 245,000.00
Sitework	$ 111,000.00	$ 430,000.00
Excavation	$ 133,000.00	$ 515,000.00
Electrical	$ 167,000.00	$ 645,000.00
Controls and Instrumentation	$ 78,000.00	$ 300,000.00
Yard Piping	$ 115,000.00	$ 445,000.00
HVAC	$ 48,000.00	$ 185,000.00
Total	**$ 715,000.00**	**$ 2,765,000.00**

Table showing construction cost breakdown of an adsorption based plant (1MG)

Non-construction Costs

Non-construction Costs	Average Cost (1978 USD)	Cost 2016 (USD) Approx.
Step I	$ 51,000.00	$ 195,000.00
Step II	$ 122,000.00	$ 470,000.00
Step III	$ 440,000.00	$ 1,695,000.00
Total Non-construction Costs	**$ 613,000.00**	**$ 2,360,000.00**

Table showing non- construction cost breakdown of an adsorption based plant (1MG)

O&M Costs

Process	Adsorption
Admin Cost Curve	-$30,000.00
Total O&M	-$400,000.00
Staff/Labour	-$137,000.00
Resource Recovery	$6,195,328.00
Total O&M Costs (2016 USD)	**$5,628,328.00**

Table showing operational and maintenance cost breakdown of an adsorption based plant (1MG)

C: Surcharge System

Discount Rate	8%				
Time Period	0	1	2	3	4
Cash Flows	$ -	-$1,268,508.30	-$1,292,229.41	-$1,316,394.10	-$1,341,010.66
5	6	7	8	9	10
-$1,366,087.56	-$1,391,633.40	-$1,417,656.95	-$1,444,167.13	-$1,471,173.06	-$1,498,683.99
NPV	**-$9,157,364.69**				

Table showing cash flows and NPV of an adsorption based plant (1MG)

O&M Costs:

Surcharge	
Constant	0.00834
Flow (in MG)	1
BOD5 (mg/l)	1370
Constant	300
BOD5 Cost (per '000 lb)	232
TSS (mg/l)	1400
Constant	350
TSS Cost (per '000 lb)	186
NH3-N (mg/l)	0
Constant	50
NH3-N Cost (per '000 lb)	561
Surcharge (per day)	**$ 3,465.19**
Total Cost (Year)	**$ 1,268,508**

Table showing surcharge breakdown and yearly operational and maintenance costs (1MG)