Executive Summary

Dyes are a major pollutant of water bodies. This is not only because of their possible toxic, carcinogenic nature, but also the coloration dyes causes may have adverse effects on the ecosystem. At present, 200,000 tons of dyes used in textile plants make their way into effluents every year. This figure represents 10%-50% of the dyes used in the dying process. Much of this problem is due to inefficiencies in the dyeing process, but is also attributed to the difficulty in treating these effluents, as coloration can occur, even at low concentration of dye.

Hence, the process to reducing this problem, takes dyes dissolved in wastewater plant effluents and adsorbs them onto a surface. Currently, the team is considering two choices for the overall process. The first involves contacting dyes, the adsorbate, with an adsorbent in a slurry, to be adsorbed. The slurry is then filtered to remove the carbon, thus removing the dye from the effluent stream. The second involves a packed bed of the adsorbent. The effluent will flow through this packed bed, and after the adsorbent becomes saturated with dye, it is replaced with fresh adsorbent and the process is restarted. To increase the efficiency of the packed bed system, three or more packed beds may be used in a carousel. One of them is used to remove the bulk of the dye until the adsorbent is saturated, the second adsorbs lower concentrations, and the third lays in wait to replace the second as the low concentration adsorbing packed bed. Each bed functions as stage of adsorption until it reaches equilibrium with the dyes, reaching saturation. The first packed bed is cleaned and refilled with adsorbent when not in use and joins the end of the queue. With both choices, a process to recycle the adsorbent is being considered. In this process, the spent adsorbent is sent to a desorption process and then recycled back into the adsorber. The effluent is then sent to further treatment processes before being released into the environment, for pH adjustment, to remove any trace contaminant that may exist from the adsorbent, and physio-chemical treatment.

Currently, the team is considering using factory-made activated carbon, with alternatives of charcoal made from bagasse and fibrous hydrolyzed polyacrylonitrile. The dyes used in the study are Alizarin and Naphthol Green B. These two, particularly Alizarin, were chosen for their historically abundant use in the textile industry.

Our goal is to reduce the amount of dye in the effluent stream to levels where coloration is not evident. This will be quantified by making sure the absorbance reading is within 20% of a zero absorbance reading, calibrated from a spectrophotometer. In addition, the overall process will be optimized to reach a moderate to minimal daily cost.
Being stewards, additional design specifications have been made to eliminate or reduce the amount of pollution the implementation of the process may cause. This includes, but is not limited to, desorption of the adsorbents like activated carbon using environmentally friendly processes such as contacting with supercritical carbon dioxide as one of the alternative.
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1 Introduction

The senior design project is aimed at designing a process to remove dyes from textile wastewater effluent. Dyes are colored substances that have affinity to the substrate to which it is applied. Dyes are used in dyeing, textile, cosmetics, food, and paper industries. Dyes after been used in these listed industries can be hazardous to the environment if not properly disposed of. Reasons being that dyes usually are colored and thus have the ability to color surface water. Dyes also have complex aromatic molecular structure which make them difficult to biodegrade. Also dyes have the ability to reflect/absorb sunlight entering water and that can harm the growth of living organism. Dyes in wastewater undergo biological and chemical changes and therefore use up the dissolved oxygen and that is bad for aquatic life.

Designing a process to remove the dyes in wastewater stream would thus be needed to create an environment free of dyes and conducive for biological and aquatic life. Plants already exit to remove and treat the other constituents of a textile wastewater effluent stream.

Chemical and physical treatment method for dyes in effluent includes adsorption, coagulation, precipitation, filtration, membrane separation and oxidation. However, adsorption process is the most efficient method and it also provides alternative treatment. This alternative treatment can be less expensive if the adsorbent used is cheap. Therefore the treatment method that would be used for this design is adsorption.

Team 2, Transformers, is comprised of four chemical engineering students. The design topic chosen was a result of our calling as Christians to be good stewards of the earth. The mandate of having dominion over the land and taking care of it. The team wanted to do something that consciously seeks to take care of our land and thus the team decided on transforming textile effluent by removing the dyes.

---

2 Problem statement

Treatment of wastewater is a huge issue in textile industry. Conventional dyes in textile effluents often require expensive procedures in order to reach a satisfactory level of treatment. This is mainly due to the diverse composition of the effluent streams.

The team is therefore looking at designing and optimizing an adsorption column for textile industry effluent stream. Our design would be receiving textile effluent from a textile industry, passing it through an adsorption column where the dyes contained in the effluent are adsorbed using adsorbents. The design does not seek to purify the water to the point that it would be good for consumption.
3 Project Management

3.1 Team Organization

![Team Organization Chart]

**Figure 1: Team organization chart**

3.1.1 Team Members

The team consists of four seniors in engineering with chemical concentration. The team is collectively known as “The Transformers”. The task assigned to each team member is primarily what the individual is going to be leading and carrying out. Due to the nature of our project, each assigned task is not independent on the other, therefore there is going to be collaboration on some assigned task. For task that require the entire group, the task would be headed by the primarily assigned person for that task.
Jeffrey Fiam-Coblavie is a senior chemical engineering concentration student from Ghana. Jeffrey recently interned with BCSI Seattle, where he worked with dyes used in a vitro fertilization device. Given his recent experience working in a lab, Jeffrey has been assigned the task of data collection and testing. Later in the spring, he will be working alongside Rick and Nneka on the optimization of the process. At Calvin, Jeffrey is the vice president of the Friday Night Soccer Club and enjoys playing soccer.

Richard Mels is a senior chemical engineering concentration student from Tinley Park, Illinois. He recently interned at PacMoore this past summer and also has experience in carpentry work. Rick acquired valuable experience from both of these places, as a result he is tasked with choosing adsorbent, leading initial design of the adsorption column, building the pilot plant, and creating the simulated wastewater stream. Later in the semester, he would work alongside Jeffrey and Nneka in the optimization process. After graduation, Rick plans to get a job in a chemical engineering related field.

Diane Umufasha is a senior chemical engineering student from Grand Rapids, Michigan. She has held many jobs and leadership positions. She was the National Society of Black Engineers Calvin Chapter president for the 2011-2012 academic year. In this position, she was tasked with helping students network to obtain jobs and internships. She has also done lots of research for class projects. She is tasked with researching and acquisition of needed chemicals. She would also work alongside Jeffrey in the testing of the dyes.
Nneka Usifoh is a senior Chemical engineering concentration student from Nigeria. For the past summer, she worked as a process control intern with Nigeria Liquefied Natural Gas where she learned about optimization and general process in the production of Liquefied Natural Gas. As a result she is in charge of the optimization process. She is also in charge of team communications, budgeting, business plan, organization and planning. After graduation, she plans to get a job in a chemical/petrochemical engineering related field.

3.1.2 Advisors

Dr. J Aubrey Sykes is the faculty assigned to the team. He has a PhD in Chemical Engineering from the University of Maryland and was a PE in Texas. Dr. Sykes mainly aids the team by giving professional advice on how to organize the implementation of the project and talks through the design ideas the team has in order to discover and iron out any wrinkles that the team may not foresee.

He is also the person to whom our project proposal, reports, feasibility studies and other documents are submitted. He communicates back to us with feedback based on the items submitted.

3.1.3 Meeting Times

The team standard meeting time is Monday, Wednesday and Friday from 3:30pm -4:30pm weekly and the regular senior design class time on Monday, Wednesday and Friday at 2:30pm-3:20pm with occasional weekends if need be. The team meets with our team advisor every Monday at 10:30 am. The meeting location is at the Engineering building, Team 2 workspace.

Team files can be found on the team website, listed in the URL below:
http://www.calvin.edu/academic/engineering/2013-14-team2/Reports.html

3.2 Schedule

Table 1: Table showing major task for completion of project below shows the work break down the team anticipates completing. This is to give an estimate of our intended current status of the project. If followed properly, the project would be ready by end of April because the work break down allocates maximum time to be spent on each task which would not necessarily be the case.
Table 1: Table showing major task for completion of project

<table>
<thead>
<tr>
<th>Task</th>
<th>Maximum Time Allotted (hrs.)</th>
<th>Expected Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build Pilot Plant</td>
<td>7.5</td>
<td>2/14/2014</td>
</tr>
<tr>
<td>Data Collection from Pilot Plant</td>
<td>7.0</td>
<td>2/27/2014</td>
</tr>
<tr>
<td>Optimization of Plant</td>
<td>7.0</td>
<td>4/20/2014</td>
</tr>
<tr>
<td>Unisim Plant Design</td>
<td>8.0</td>
<td>4/27/2014</td>
</tr>
</tbody>
</table>

The team anticipates building a pilot plant by mid-February, optimizing and scaling up by ending April 2014. To meet this goal, the team plan to follow a detailed work structure to have all the details the team would need to build the plant ready. Requirements for the pilot plant are making and testing the defined waste water stream, purchasing necessary materials and making modifications if necessary.

By Interim (Mid-January), the team would have all the materials need purchased which are the dyes, testing strips, filters and activated carbon. Alongside all the materials been present, the waste water stream would be made and tested. This would take about three days depending on the method used in testing the ions.

The team anticipates that due to unforeseeable issues which may arise, it may be unable to meet all the deadlines it has mapped out. For this reason, the team wrote a dynamic work schedule using Microsoft Project, with allowances for unknowns. The team periodically revises it, using the time allocated for the unknowns when need be. The team accepts that some deadlines are immovable and as such works outside it’s originally planned meeting times towards fulfilling our duties concerning such tasks. The URL below links to the work breakdown schedule found on the team website.

http://www.calvin.edu/academic/engineering/2013-14-team2/Reports.html
3.3 Budget

The main costs of the budget are concerned with building the pilot plant. Table 2 highlights the main material cost. The numbers provided are only current estimates and are subject to change.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Vendor/Source</th>
<th>Purchasing Official</th>
<th>Status</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alizarin Dye</td>
<td>100 g</td>
<td>Calvin Chemistry Department</td>
<td>Rich Huisman</td>
<td>Pending</td>
<td>$ -</td>
</tr>
<tr>
<td>Naphthol Green B Dye</td>
<td>25 g</td>
<td>Sigma Aldrich</td>
<td>Rich Huisman</td>
<td>Arrived</td>
<td>$ 21.50</td>
</tr>
<tr>
<td>Test strips</td>
<td>7</td>
<td>Hach</td>
<td>Bob Dekraker</td>
<td>Yet to be ordered</td>
<td>$ 250.00</td>
</tr>
<tr>
<td>Indicator</td>
<td>1</td>
<td>Digi-Key</td>
<td>Rich Huisman</td>
<td>Arrived</td>
<td>$ 50.00</td>
</tr>
<tr>
<td>Microbe-Lift - Carbon Pellets Activated carbon pellets</td>
<td>55 lb.</td>
<td>123ponds</td>
<td>Bob Dekraker</td>
<td>Yet to be ordered</td>
<td>$ 281.25</td>
</tr>
<tr>
<td>E.S.V. Granular Activated Carbon</td>
<td>5 lb.</td>
<td>Amazon</td>
<td>Bob Dekraker</td>
<td>Yet to be ordered</td>
<td>$ 67.45</td>
</tr>
<tr>
<td>1-1/2 in Sch 40 PVC-pipes</td>
<td>20 ft.</td>
<td>Home Depot</td>
<td>Bob Dekraker</td>
<td>Yet to be ordered</td>
<td>$ 4.18</td>
</tr>
<tr>
<td>Plastic tubes</td>
<td>5 ft.</td>
<td>Home Depot</td>
<td>Bob Dekraker</td>
<td>Yet to be ordered</td>
<td>$ 10.00</td>
</tr>
<tr>
<td>50 Mesh</td>
<td>1</td>
<td>Alibaba</td>
<td>Bob Dekraker</td>
<td>Yet to be ordered</td>
<td>$ 100.00</td>
</tr>
<tr>
<td>misc. Chemicals</td>
<td>N/A</td>
<td>Calvin Chemistry Department</td>
<td>Rich Huisman</td>
<td>Arrived</td>
<td>$ -</td>
</tr>
<tr>
<td>Buckets</td>
<td>4</td>
<td>Calvin Engineering Department</td>
<td>Bob Dekraker</td>
<td>Arrived</td>
<td>$ -</td>
</tr>
<tr>
<td>Disposal Tanks</td>
<td>2</td>
<td>Calvin Engineering Department</td>
<td>Bob Dekraker</td>
<td>Yet to be ordered</td>
<td>$ -</td>
</tr>
<tr>
<td>Printing</td>
<td>TBD</td>
<td>Calvin College</td>
<td>Nneka Usifoh</td>
<td>Pending report completion</td>
<td>$ -</td>
</tr>
<tr>
<td>Design Contingency/Allowances</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>$ 94.79</td>
</tr>
</tbody>
</table>

The team has projected a budget need of $850 which is currently being reviewed by the class advisor for approval.

3.4 Method of Approach

The team decided to split the project into three main stages.

Stage one is the research stage. Background research is done on the textile industry, the impact of pollution of wastewater streams by dyes, constituents of wastewater streams and the EPA standards of pollution by textile plants among other things. After completion of background research, the team researched ideal dyes, the adsorbent to use and possible alternatives and the methods to use in order to
increase adsorption capacity. Tests such as batch tests to determine the amount of the adsorbents adsorb. The research provides the basis for the rest of the project.

Stage two is the pilot plant design. This involves designing and making a wastewater stream, building a pilot plant based on the design alternatives to determine which alternative is the best, optimizing the best alternative and collection of unknown variables needed for scale up. Before the pilot plant is built, there would be testing of the dyes in the wastewater effluent using spectrophotometer and colorimeter. The adsorption capacity and the rate of adsorption of the activated carbon would be tested. The effect of initial pH, temperature and contact time would also be tested. The optimum conditions for the dye removals would then be determined which would be used in the pilot plant.

Upon completion of stage two, the design is scaled up to industrial proportions in order to determine the actual efficiency and cost of designing such a plant. This will represent the final design and will be a cumulative result of all the previous two stages.
4 Requirements

There are several requirements to be met for a feasibly design. The major requirement is that the wastewater stream is decolorized. To establish how much the color is reduced, the team plans on using a spectrophotometer to analyze absorbance reading from the samples collected from the pilot plant. An assay will be made to determine the absorbance reading of the wastewater stream without dye (this will be the 0 concentration reading), and the samples collected from the pilot plant. The lower limit set for the samples to pass the discoloration goal the team have set is within 20% of the absorbance at the 0 concentration reading.

Another requirement is the wastewater stream is as close to reality as possible. To do this, the team modelled our wastewater stream after the effluent of a textile factory in Romania\(^2\). The composition excluded the amount of dye used. The team decided to use a wide range of dye concentrations to account for the fact that in reality the concentration of dyes used varies.

Furthermore, the process will require some optimization, such as the amount and concentration of dye used, in order to accurately determine the best design for a given process. In terms of the individual components, the team must determine many requirements, but not enough information has been gathered. For instance, the team knows that in the reactor, the team must specify a temperature and pressure that will allow absorption to occur. Also, the team knows that some designs will be more efficient than others, but have not yet determined which ones because the team hasn’t done any tests yet.

Design Norms
The design norms incorporated into our senior design projects are care, justice, stewardship, and trust.

Our design is looking at designing a process for the removal of dyes from textile effluents. Dyes are colored substance that have the ability to color surface water at low concentration. Dyes also have the ability to reflect/absorb light which affects the growth of organisms.

As Christians we are called to have dominion over the earth and all that is in it. Part of having dominion over the earth is caring for the environment and living things on the earth. As a result of our calling, the team decided to be stewards by assisting in the cleanup and prevention of industrial waste. Also the team wants the design to be trusted for the purpose it was created for and to be a true representation of real world. This means that the design should be reliable and dependable in its ability to reduce the concentration of the dyes to a reliable level. The design shows justice in the laws that prevent big corporate companies from polluting are not well enforced and the companies are sometimes unable to reduce the dye concentration to the acceptable levels. The water sources of the indigenous populations are therefore polluted. Our design will help alleviate these worries. In this way the design also shows caring because it allows the indigenous people to use the water for their activities.

The impact of our design on the physical world is that it would motivate other companies that utilize dyes to do the same. That is, to utilize the designed process to remove dyes before they are sent for further treatment. It is highly recommended for the dyes to be removed before sent to the waste treatment plant. The reason being that most of these
plants carry out generalize cleaning of the wastewater and can miss the removal of dyes to an environmentally safe level. Culturally, the design can be utilized in other countries irrespective of whether they are developed or a developing country, to increase environmental concern for themselves. For developing countries where the laws and regulations concerning disposal of industrial waste into water bodies are lenient, having this process and carrying it out would be a great way to keeping the water bodies clean without many worries.

The planning and design of the project is focused on acting on our calling as Christians to use the resources available and take care of our environment. We prioritize care for the environment not only because we are called to but the fact that we also live in this land and have a love for our land. We plan with the idea of what positive impact our decision would have on our land and also affect other aspect of things living in it. We decided to make the project as close to reality as possible to ensure that our responsibilities as stewards are fully met.
6 Research

6.1 Wastewater stream contents

Our research showed that wastewater streams had the following constituents highlighted in Table 3.

Table 3: Components of the wastewater stream used

<table>
<thead>
<tr>
<th>Date</th>
<th>pH</th>
<th>NO$_3$ mg/L</th>
<th>TSS mg/L</th>
<th>Chlorides mg/L</th>
<th>COD mgO$_2$/L</th>
<th>H$_2$S mg/L</th>
<th>NH$_4$ mg/L</th>
<th>NO$_2$ mg/L</th>
<th>Fixed Residue mg/L</th>
<th>BOD$_3$ mgO$_2$/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-07</td>
<td>10.7</td>
<td>8</td>
<td>344</td>
<td>104</td>
<td>3836</td>
<td>-</td>
<td>33.3</td>
<td>1.28</td>
<td>1046</td>
<td>195</td>
</tr>
<tr>
<td>24-07</td>
<td>6.3</td>
<td>3.7</td>
<td>72</td>
<td>48</td>
<td>258</td>
<td>0.8</td>
<td>0.48</td>
<td>0.08</td>
<td>548</td>
<td>70</td>
</tr>
<tr>
<td>25-07</td>
<td>8.3</td>
<td>6.2</td>
<td>956</td>
<td>141</td>
<td>1185</td>
<td>1.3</td>
<td>11.5</td>
<td>0.92</td>
<td>184</td>
<td>300</td>
</tr>
<tr>
<td>26-07</td>
<td>8.05</td>
<td>6.04</td>
<td>147</td>
<td>-</td>
<td>1907.6</td>
<td>-</td>
<td>14.31</td>
<td>0.9</td>
<td>1600</td>
<td>-</td>
</tr>
<tr>
<td>28-07</td>
<td>6.5</td>
<td>4.7</td>
<td>820</td>
<td>386</td>
<td>5443</td>
<td>0.8</td>
<td>14.29</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>29-07</td>
<td>8.0</td>
<td>8.3</td>
<td>534</td>
<td>601</td>
<td>920</td>
<td>3.3</td>
<td>9.9</td>
<td>0.96</td>
<td>836</td>
<td>140</td>
</tr>
<tr>
<td>30-07</td>
<td>8.0</td>
<td>7.4</td>
<td>500</td>
<td>139</td>
<td>860</td>
<td>1.6</td>
<td>14.33</td>
<td>0.89</td>
<td>4400</td>
<td>155</td>
</tr>
<tr>
<td>01-08</td>
<td>8.6</td>
<td>4.1</td>
<td>623</td>
<td>100</td>
<td>853</td>
<td>1.9</td>
<td>16.5</td>
<td>1.32</td>
<td>717</td>
<td>-</td>
</tr>
<tr>
<td>average</td>
<td>8.06</td>
<td>6.06</td>
<td>499.4</td>
<td>213.2</td>
<td>1907.8</td>
<td>1.62</td>
<td>14.34</td>
<td>0.91</td>
<td>2016</td>
<td>170</td>
</tr>
</tbody>
</table>

6.2 Adsorbent

6.2.1 Choice of Adsorbent

Based on the time allotted the team decided to limit the scope of adsorbent to activated carbon based on its high adsorption capacity, high surface area and micro porous structure. The team will consider the three forms of activated carbon to test which one is ideal for each design. The three activated carbons includes; powder activated carbon, granular activated carbon, and impregnated carbon (silver loaded activated carbon). The form of activated carbon used will depend on the system design used.

If a fixed bed column design is used, the form of activated carbon to be used will be granular activated carbon. This is to allow the water to flow through the column with less resistance. Powdered activated carbon would cause too much resistance of water flow through it, creating a large pressure drop. Granule size is based on a pressure drop down the column, since the smaller the adsorbent is, the more difficult it is for the water to flow through. Smaller granules generally have a higher rate of adsorption, so granule size chosen will be based on a balance between pressure drop calculations and the rate of adsorption to be gained experimentally.

If a slurry design is used, the form of activated carbon to be used with be either powdered or granular because the activated carbon is fluidized in the water due to agitation or an upward flow through a column. Powdered activated carbon has a faster rate of adsorption and requires less agitation to keep it fluidized in the water. However, it settles much slower than granular carbon and requires a filter to separate the carbon from the water. The minimum fluidization velocity of powdered activated carbon in...
water is also too low to use an upward flowing fluidized bed. Granular activated carbon has a slightly slower rate of adsorption and settles faster than powdered carbon. Because it settles faster than powdered carbon, granular carbon requires more agitation to keep it fluidized in water. Though by using granular carbon, a filter wouldn’t be needed, as it is easily separated from the wastewater by settling out. The decision between granular or powdered activated carbon will be based on a cost analysis including: the cost of a filter, the difference in cost of agitation, and the cost in size difference of the adsorption column, based on adsorption rate.

Each form of activated carbon has a selection of different kinds available. The selection options include: what material the activated carbon comes from, pore size, whether its acid washed or not, granule size, and pH stability. The material the activated carbon comes from can have an effect on its affinity for certain chemicals and its rate of adsorption. The material can also affect the cost, which can vary depending on the cost of the raw material and its availability in the area it is created. Pore size also has an effect on the carbon’s affinity for certain chemicals and its rate of adsorption, as well as the amount of adsorbate it can adsorb. Because dyes are generally large molecules, a large pore size would be needed to adsorb it. Pore size can depend on the material it comes from and the way it is created. Acid washed activated carbon can give it a higher affinity for certain chemicals. PH stability is important for wastewater with a pH other than 7 and systems that don’t have a separate pH stability process after adsorption. Which specific activated product the team use, for the adsorption of dyes, will be based on experimental data, for the rate of adsorption and the amount of dye it can adsorb.

6.2.2 Mathematical Model for Adsorption

Modeling the rate of adsorption, the saturation of the adsorbents, and the outlet composition change will depend on the adsorption process used. Over time, in a fixed bed adsorption column, the activated carbon begins to approach saturation, and the concentration of the dyes in the exiting wastewater stream increases, as illustrated in Figure 2. The time it takes for the adsorbate, leaving the adsorption column, to reach a certain concentration is called the breakthrough time.
Figure 2: Idealized Breakthrough curve of a fixed bed adsorber

For a fixed bed design, breakthrough time can be modeled using the Wheeler-Jonas equation:

$$t_b = \frac{W_e W}{C_0 Q} - \frac{W_e \rho_B}{k_v C_0} ln \left[ \frac{C_0 - C_x}{C_x} \right]$$

*Equation 1*

Where

- $t_b = \text{time to reach the breakthrough fraction } b = C_x/C_0 \text{ (min)}$
- $C_0 = \text{bed inlet concentration (g/cm}^3\text{)}$
- $C_x = \text{chosen breakthrough concentration (g/cm}^3\text{)}$
- $W = \text{weight of the carbon bed (g}_{\text{carbon}}\text{)}$
- $W_e = \text{equilibrium adsorption capacity for the carbon for a given dye (g/}_{\text{carbon}}\text{)}$
- $Q = \text{volumetric flow rate (cm}^3/\text{min)}$
- $k_v = \text{overall adsorption rate coefficient (min}^{-1}\text{)}$

Each of these variables, except for parameters $W_e$ and $k_v$, can be measured or specified. $W_e$ and $k_v$ must be determined to model the breakthrough time and can either be estimated by extrapolating from

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existing measurements, with a reference adsorbent or determined experimentally. Because dyes are generally difficult to remove from water and have slow rates of adsorption, the team will determine $W_e$ and $k_v$ experimentally for a more accurate breakthrough time.

For the slurry design, the adsorber can be designed around Equation 2,

$$\frac{c_F - c_{out}}{t_{res}} = k_L a (c_{out} - c^*)$$

Equation 2

Where

$c_F$ = Feed concentration of dye
$c_{out}$ = outlet concentration of dye
$t_{res}$ = vessel residence time
$k_L$ = external liquid phase mass transfer coefficient
$a$ = external surface area of adsorbent per volume of liquid
$c^*$ = equilibrium concentration with the adsorbent loading

The design of the slurry systems are focused around the vessel residence time, rather than the breakthrough time. The vessel residence time is the time the liquid must be in contact or in a slurry with the adsorbent to get to the desired outlet concentration. The slurry is designed around the vessel residence time because all the activated carbon in each tank is at the same level of saturation according to an ideal model of a CSTR. In our slurry adsorption design, there is a continuous feed of fresh activated carbon, proportional to the wastewater feed, and equal to a continuous outlet stream with spent activated carbon to be separated out.

The amount of activated carbon required for dye removal, and the average time the carbon should stay in the tank, due to it approaching saturation, will be determined from a modified version of Equation 1. This amount of time is called the space time of the activated carbon in the tank, and must be calculated differently than the breakthrough time because in a CSTR, the slurry is equally mixed. This means that some of the carbon in the outlet stream is close to equilibrium with the liquid, while some is nearly fresh activated carbon and has just entered the tank. Therefore, Equation 1 must be modified to use space time. The exact equation and its parameters will be determined from experimental data in the spring semester.
6.2.3 Alternatives to Activated Carbon

General requirement for adsorbents are that they must have a high thermal stability, high abrasion resistance and a small pore diameter. As such, alternatives to activated carbon include silica gels, synthetic polymers and zeolites, both of which are mainly used in gas phase adsorption. For the adsorption of dyes, activated carbon is deemed the best adsorbate and is the most widely used.

6.3 Waste/Used Dye Disposal

The dye can be disposed of by heating spent activated carbon to high temperatures. This will be considered if the team determines that desorption of the activated carbon is not in the scope of our project.

6.4 Desorption

The current alternatives to disposing the dyes the team used are regeneration and reactivation of the activated carbon.

6.4.1 Regeneration

Regeneration is the removal the dye from the pores of the activated carbon without destroying them.

1.1.1.1 Methods

Techniques for regeneration include:

1. **Pyrolysis**
   
   Research has shown that chemical adsorbed may not completely eliminated. However, recovery of initial adsorbent properties is limited and unlikely. There was enough literature to suggest that this is a highly undesirable for our purposes and so will not be considered.

2. **Gasification**
   
   This involves cleaning out pores of the activated using a gas. The effect of gasification is depends on both the adsorbent and the sample gasifying agent. Due to possibility of leaks and health and safety reasons, the team decided that evaluating this method would be outside our scope.

3. **Pyrolysis-Gasification**
   
   This is a method in which the adsorbent is first pyrolyzed and then gasified. If pyrolysis is not a viable option because the dye is destroyed, this would not be a viable option. For reasons similar to those above, the team decided not to consider this alternative.

4. **Chemical and solvent regeneration**
This involved the use of a chemical or solvent with a higher affinity to the dye than activated carbon. Typical solvents used are acetone, methanol and ethanol. This is simplest method of regeneration. The solvent type will have to be optimized to achieve regeneration level that are satisfactory.

5. Ultrasound Regeneration of Granular Activated Carbon

This involves the selection of a frequency to remove the dye from the pores of the carbon. Jae-Lim Lim, Mitsumasa Okada et al. performed ultrasound desorption using trichloroethylene (TCE). Figure 3 shows the experimental setup used.\(^4\)

\[ \text{Figure 3: Setup of Equipment used for Ultrasound Regeneration} \]

The percent desorption heavily depended on the amount present in the liquid phase. This can be seen in Figure 4.

Figure 4: Desorption of trichloroethylene at 20 kHz and 20W

There was also a weight loss experienced, dependent on the particle size. This can be seen in Figure 5.

Figure 5: Shows the effect of particle size on weight loss for desorption of trichloroethylene at 20 kHz and 20W

6. Wet Oxidative Regeneration (WOR)

In this method, the activated carbon is subjected to certain partial pressures of oxygen in order to remove the dye from the pores of the carbon. Figure 6 shows the experimental setup used.
Al-Degs et al. have reported that adsorption of dyes was of a chemical nature, specifically acid-base. This strong adsorption mechanism requires thermal oxidation to adequately regenerate these dyes. R.V. Shende and V.V. Mahajani et al, who used the dyes, chemiactive brilliant blue R and cibacron turquoise blue G, reported that after subjecting granular activated carbon to WOR in a temperature of 200°C and an oxygen partial pressure of 0.6 MPa, a 12% weight loss was observed. After four cycles, a weight loss of about 40% was observed. The equilibrium adsorption dropped by 5%. Figure 7 and Figure 8 highlight the effect of repeated cycles on percent equilibrium adsorption regenerated.

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Figure 6: Shows an example of the setup used in wet oxidative regeneration.5

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Figure 7: Percent Regeneration of spent granular activated carbon for the experiments performed by R.V. Shende and V.V. Mahajani

Figure 8: Percent regeneration of spent powdered carbon for the experiments performed by R.V. Shende and V.V. Mahajani

The percent weight drop and loss of surface area suggest the rate of adsorption and the pressure drop parameters will change when the regenerated carbons are used. This will have to be accounted for if used in our process.
6.4.2 Reactivation

Generally, reactivation is the destruction of the adsorbate at the active site rather than removing it. This is achieved by subjected the activated carbon to elevated temperatures. This restores the surface area and pore volume of the activated carbon. The method of reactivation is identical to the process of making the activated carbon. Care must be taken to ensure that the reactivation process does not exhaust the activated carbon.

7 Task Specifications

7.1 Making and Defining Wastewater

Textile wastewater effluent stream differs within each industrial category due to the varied textile process and the range of chemicals used. As a result of inconsistency in the textile wastewater effluent, the team decided upon making a simulated wastewater stream close to a typical textile wastewater stream. To do this, the wastewater stream was modelled after the effluent of a textile factory in Romania\(^6\). The BOD and COD test were carried out using DO probe.

7.2 Testing Activated Carbon/Sorbent

To determine which activated carbon has the highest rate of adsorption of the dyes, all three different types of carbons would be tested under the same operating conditions. There are several factors that affect the adsorption of dyes by activated carbon. These factors include; PH of the dye, concentration of the dye, temperature of the surroundings and the time it takes the waste to flow through the activated carbon. All these factors will be considered while testing the activated carbons and the one that has a higher adsorption rate under this conditions will be used as our sorbent.

7.3 Design Pilot Plant

The pilot plant would be modelled using Excel. The operating conditions for the Excel base case would be the optimum conditions determined from the test carried out. The components and design of the pilot plant would vary depending on the alternative chosen. The alternatives considered are the fixed bed column and slurry.

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7.3.1 Fixed Bed Design
In the fixed bed design, the components that would be designed is the adsorption column. It would be designed with an inlet for the wastewater effluent and an outlet for the treated effluent to flow out. It would be designed in such a way that the wastewater effluent flowing in is stopped when the binding capacity of the column has been reached. The binding capacity of the column would be determined based on the size and weight of the activated carbon, the flow rate of the effluent stream and other conditions of the process.

To accurately design the column, a test column breakthrough curve for the wastewater effluent and the activated carbon would be determined as seen in Figure 2. The breakthrough curve would be calculated using Equation 1. The design would account for mass transfer kinetics which controls the cycle time for the adsorption process. The control time relates the amount of adsorbent to the amount of materials needed. Fast kinetic means a sharp breakthrough curve whereas slow kinetic implies distended breakthrough curve.

Additionally, the design is assumed to be non-isothermal. Therefore, there would be test at different temperature conditions. Heat effects would also be accounted for the design for seasonal changes. The dimensions of the column would also be calculated.

7.3.2 Slurry recycle Design
The slurry recycle comprises of two continuous stirred tank reactor, settling tank, an agitator, cooling jacket, baffle, motor, and inlet feed and outlet product. The operating conditions for the slurry recycle would be the determine conditions derived from the testing. The mathematical model for this design is explained in section 5.2.2. The basic process of the operation of the slurry recycle design is given in details in section 8.2. The parameters that would be considered in the design are reactor size, reactor volume and residence time.

7.4 Build Pilot Plant
The pilot plant is anticipated to be built in the middle of February. The pilot plant will be built using inexpensive materials where possible, in order not to waste resources. The team believes this is in line with our call to be stewards. Resources available for building the pilot plant include parts in the maintenance room of the science building.
The team anticipates that in order to obtain appropriate data to collect for the scale up design, the team will have to construct meticulously and ensure that maintenance of the pilot plant is up to date. This means that the team will have to check periodically for leaks, cracks and any anomaly not indicated in our design and repair or account for this in our data. The team plan to have a detailed checklist of requirements the team deem necessary in order to begin data collection.

7.5 Pilot Plant Data Collection
Data collection will begin as soon as the pilot plant has been built. The team plans to perform enough experiments to construct a normal distribution for constants the team hopes to determine. This will mean a minimum of thirty experiments. These experiments will be conducted by a single member of the team in order to collect the data in the shortest possible amount of time. Along with the checklist of requirements, each data collection sheet will have to be approved by another member of the team in order for it to be added.

7.6 Optimize Pilot Plant
Certain physical parameters for a fixed bed design would be optimized such as the binding capacity. The variables that would be studied to optimize the binding capacity are temperature, viscosity of the fluid, velocity/flow rate of the fluid and time it takes to reach the binding capacity/saturation point of the adsorbent.

For the slurry recycle, parameters such as retention time, slurry recycle ratio, slurry waste ratio, slurry concentration in the settling tank would be studied in order to maximize the design.

Alongside the different variables to be studied for the optimization, cost would also be studied. The team works with an allocated budget and so the pilot plant to be built will need to be considered with respect to the budget.
8 Wastewater Treatment Plant Process

The wastewater treatment plant goes through three stages before its purified. Figure 9 below shows the overall process. Our team will focus on optimizing the adsorption unit.

![Figure 9: Stages of wastewater treatment](image)

As seen in Figure 9, the effluent enter the primary unit, adsorption, filled with activated carbon. The dyes are adsorbed by the activated carbon, the adsorption process and the design used are explained in the design alternative section, which causes an increase in PH and COD. The wastewater then goes to the secondary unit, PH adjustment. In this stage the PH is reduced to meet the EPA standards. This is achieved by first, identify the parameters — the pollutants or impurities — that are in the wastewater. Once the pollutants are identified, the starting and the ending pH values, along with a specific treatment procedure are determined; then the appropriate chemicals best suited for treatment is chosen. After the PH adjustment the wastewater goes to the tertiary unit where the physiochemical and biological treatment is done to purify the wastewater. The scope of our design only focus on primary unit, adsorption, and hopefully in the future another team will continue the process to purification of the wastewater.
9 Design Alternatives

There are currently four design alternatives considered for our project.

9.1 Packed Bed sorption column

9.1.1 Single Packed Bed
The first is a packed bed adsorption column filled with solid pellets of activated carbon seen in Figure 10.

![Figure 10: Shows the packed bed process](image)

The textile plant effluent will flow through the packed bed of pellets into which the dye will be adsorbed. The main issue with this design is as more dye is adsorbed into the activated carbon, it becomes saturated and no longer adsorbs any more dye. After a while, as the activated carbon becomes saturated, the concentration of dye in the wastewater will begin to increase unless the spent activated carbon is replaced. This involves stopping the adsorption column, emptying the spent activated carbon, and refilling with new activated carbon. Because the adsorption column is stopped, a large tank must be built to hold all the effluent which is still flowing from the textile plant. Depending on how quickly the activated carbon becomes saturated, and how long it takes to empty and refill the column with activated carbon, the adsorption column may need to be designed for a larger effluent flow rate than what the textile plant produces. This larger flow rate is the effluent produced by the textile plant plus draining the effluent in the storage tank from when the adsorbent was stopped to change out activated carbon.
9.1.2 Carousel method of activated carbon rotation

The second is a “carousel” rotation of adsorption columns consisting of three or more packed bed adsorption columns where the effluent is run through two of the columns. This design is to eliminate the need to stop the effluent flow, also eliminating the need for the storage tank. The first column adsorbs the bulk of the dyes and the second column gets the concentration of the dyes to lower levels. Once the initial column becomes saturated with dye, the system is rotated so the second column becomes the first column to remove the bulk of the dyes and the third unused column then replaces the second column to get a lower concentration of dye in the effluent while the first column with the saturated activated carbon is emptied and refilled with fresh activated carbon. The three columns go in a rotation for keeping fresh activated carbon at the end of the adsorption process.

9.2 Slurry with activated carbon filtered and disposed off

A third alternative is adsorption of dyes into a powdered activated carbon in a slurry of activated carbon and effluent, seen in Figure 11.

The activated carbon is mixed into the effluent in a tank with good agitation to make the mixture of solids and liquids a slurry. The rate of adsorption depends on the concentration of dye, the level of saturation of the dye in the pores, as well as mixing. The agitation would allow a larger mass transfer of the dyes into the pores of the carbon due to a concentration of dye just outside the pores equal to that of the bulk. Once the dye has been adsorbed, the slurry leaves the tank and goes through a filter where the solid activated carbon is separated from the wastewater.

*Figure 11: Slurry without recycle*
The process may require multiple slurry stages. In this case, the effluent would be mixed into a slurry with activated carbon and separated again by filtration as with one stage. Then the wastewater from the first stage would go into another tank to be mixed into a slurry with new activated carbon and then separated again by filtration. This process can be completed as many times as needed with each stage obtaining a lower concentration of dye.

With multiple stages, the saturated activated carbon from the final stage could be filtered out and put into the stage before it. The stage before the one the activated carbon was filtered from will have a higher concentration of dye, and will therefore the activated carbon will have a higher equilibrium level of adsorption. The activated carbon would be filtered from that stage and put into the stage before it as well. This process would continue into the first stage where it is then filtered out and disposed of. By adding the carbon from last stage through the middle stages and into the first stage, the amount of activated carbon waste would be reduced. This is essentially a countercurrent adsorption process for the removal of dyes with activated carbon.

9.3 Slurry with activated carbon recycle

A fourth alternative is a slurry recycle process, where the effluent and a powdered activated carbon are in a slurry to adsorb the dyes just as previously described, but the activated carbon would be recycled back into the slurry, rather than disposed of. Figure 12 shows a schematic of the process with one slurry stage.
Figure 12: Slurry with recycle

The filtered out activated carbon goes through a desorption process before it is put back into the slurry. The desorption process requires testing and research to see if it is feasible. In the desorption process, the saturated activated carbon would be mixed with a solvent to reactivate and remove the dye from the activated carbon.
10 Design Decisions
To decide which design alternative for a dye removal process will be decided, based on the following design matrix with values determined from calculations, made from experimental data, to be found during the spring semester.

10.1 Decision Matrix

<table>
<thead>
<tr>
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<th>Cost</th>
<th>Ease of build</th>
<th>Outlet Conc.</th>
<th>Total</th>
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</thead>
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<td>10</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Single Packed Bed</td>
<td></td>
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<tr>
<td>Carousel of Packed Beds</td>
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<tr>
<td>Slurry with recycle</td>
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<tr>
<td>Slurry without recycle</td>
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</tbody>
</table>
11 Business Plan

Economic analysis for the feasibility of the overall process was developed with the guidance of the Engineering Business class.

11.1 Executive Summary

Transformer’s Dye Removal Systems, built around the textile industry, works to reduce dye release into the environment. The company designs custom dye removal systems for textile plants to remove dyes from their effluent in the most efficient and cost effective way. Dyes used in the textile industry are generally difficult to remove from wastewater and can cause coloration even at low concentrations. A custom process for the purpose of removing dyes must be added to the wastewater treatment processes which are operational enough to remove all other contaminants to environmentally acceptable levels.

Plants already exist that treat effluent, but they are generalized to clean all wastewater from an industrial sector and can miss the removal of dyes to an environmentally safe level. These wastewater treatment plants remove other contaminants to acceptable levels and are sufficient for most other industries wastewater treatment. However, dyes can be difficult to remove and would require further treatment to be removed. To apply further treatment to the entire industrial sectors wastewater is expensive, and largely unnecessary. There are companies which exist with predesigned systems for wastewater treatment, however, don’t specialize in dye removal.

Our strategy is to focus on the removal of dyes specifically so plants can save money by avoiding unnecessary use of materials and resources in trying to treat all components of textile wastewater together. This strategy is cost focused and is based on finding a niche in the market.

There are four key positions held by the four co-founders all of whom make up the board of directors. Nneka Usifoh is the head of the finance department. Richard Mels is the head of production and design. Jeffrey Fiam-Coblavie is the head of the testing and process technologies department. Diane Umufasha is the head of research and development.

Transformer’s Dye Removal Systems is requesting an initial loan of $500,000 with an additional $60,000 in initial invested capital; $15,000 invested by each board member. This will be used to purchase necessary office supplies, rent office space and space for research and development with pilot plant
components as well as storage for testing equipment, and for the necessary costs of travel to the customer.

11.2 Vision and Mission Statement

11.2.1 Mission Statement

The purpose of Transformer’s Dye Removal Systems is to design a process to remove dyes from industrial waste effluent streams, which makes the environment more eco-friendly, saving time and money to bring cleaner water to areas of which it was previously too expensive.

11.2.2 Vision Statement

To influence other companies to do the same, which eradicates the effect of dyes on the aquatic life, human population and the environment.

Transformer’s Dye Removal Systems seeks to create employment, make profit and to provide services that are needed. The desire to keep the environment free of industrial waste that happens every day is the driving force of the company.

Potential customers are companies that deal with dyes such as printing, dyeing and textile industry, and any company that works with dye on a daily basis. The company helps them save time and money.

Our product and service is to create and design processes to remove dye from wastewater effluent. The quality of our services is based on our calling as Christians to cater for the environment and since we live in this world and care about our lives and those who live in it, it is a 100% guaranteed excellent quality. The pricing of our service depends on certain factors such as how much effluent is discharged by the company daily.

11.2.3 Values and Principles on which the Business Stands:

The services provided by Transformer’s Dye Removal Systems is based on stewardship and trust. The company was founded on the grounds of care for the environment. The company seeks to ensure that the process designed can be trusted for the purpose it was created for and is a true representation of the real world.
11.3 Industry Profile and Overview

The large scale release of dyes into the environment has only recently become a major concern in treating wastewater. In the past wastewater treatment plants would do their best to remove the dyes. However, if the wastewater was still colored coming out of the treatment plant with their existing process, they would simply assume it was not worth removing. Today as environmental protection and awareness is a growing concern, the removal of dyes is essential. This is currently done by upgrading the entire primary treatment process of plants or pretreating the effluent from textile plants before sending it off the industrial treatment plant. This requires the use of a large amount of adsorbent to remove the dyes, which is expensive on a large scale.

The current methods of wastewater treatment to remove dyes provides three potential major customers. The first major customer is existing wastewater treatment plants. They would hire our company to analyze their current system and our company would design a new part for their process to allow them remove dyes more effectively and at a lower cost of adsorbent. The second major customer would be textile plant that are looking to reduce their cost from wastewater treatment plants by pretreating their wastewater for dye removal. The third major customer would be textile plants in developing countries that currently dump their wastewater directly to the environment without any treatment or contaminant removal. For this area, our company would focus specifically on cost and would design a contaminant removal system, that might not remove as much of the contaminants as the most effective system, but would be the most cost efficient based on their financial abilities.

Regulations for wastewater treatment generally differ from plant to plant. They differ based on the technology currently at the plant, the environmental sensitivity where the wastewater is dumped, and the types of contaminants in the wastewater. Because many dyes are difficult to remove using the typical processes of treatment plants, the regulations on dyes are typically somewhat lenient. They are lenient based on the dyes because even at low concentrations, they still can cause discoloration of the water, even though at those concentrations the dye itself might not cause any harm to the environment chemically. Regulations are becoming more restricted as environmental protection becomes a greater concern. Environmentalists have found that dyes in water effect living things in the water which depend on sunlight as the dyes absorb certain wavelengths of light that the living organisms may need.
Due to the growing awareness of protecting the environment, the need for system designs to remove dyes in wastewater is growing. According to Reportsnreports.com⁷, the water treatment market in the US is forecasted to grow 5.9 percent each year to create a $13 billion market in 2017. Globally the market is forecasted to grow 7.4 percent each year. With the growing concern, especially pertaining to dyes, there is a promising place in the market for our company.

A key restriction to entering this market is business reputation. Without a reputation of being known for success in this industry obtaining the first few contracts would be difficult. Without contracts from the start of the company, advertising the company to obtain a contract will be barrier since there is no history of our company’s success. A barrier in leaving this market will also be based on our contracts, since in our contracts, our company includes a certain amount of technical support and maintenance if needed after our designed systems are started up.

Building a reputation of being cost effective and successfully removing the amount of dyes as claimed is a key factor of success in this industry. If a system fails to work as the contracts claim, or ends up being too costly, our company will fail to fit into its niche as intended. Another key factor in success is that environmental protection continues to be concern for advertising and marketing purposes for our company. Based on the growing concern environment, and the forecasted growth of the wastewater industry, the outlook of our company for the future is good.

11.4 Business Strategy

11.4.1 Image

The overall image the company hopes to evoke is an organization that strives for environmental cleanliness by empowering and equipping other companies with the tools to do so. Transformer’s Dye Removal Systems believes that cleaning wastewater to acceptable emission standards, or even setting the standard, is the responsibility of all textile plants. The technology our company will provide will enable companies to reach this standard and attain it for the foreseeable future. This should enable them to operate day-to-day without much concern about the safety of their emissions.

11.4.2 Goals and Objectives

Our goal is to provide reliable and effective services to our customers. Paramount to the reliability of our products are highly detailed schematics developed from rigorous tests and a thorough maintenance regimes. This means that Transformer’s Dye Removal Systems will look to supply plans and schematics to the building of the customer’s pretreatment plants, supervise building of the plants and provide maintenance after the plant construction is completed.

The development of the plans and schematics will be done with desired specifications from the textile company. This will be carried out by the research and development department. Once these plans and schematics are developed to our high quality standards, the company will outsource the building of the plants to a construction company but will be actively involved by placing onsite an engineering team from our offices to oversee the construction. Upon completion of the construction, the company will provide regular maintenance to ensure the reliability promised.

By primarily concerning itself with design and maintenance, the company hopes to reduce any capital costs it may otherwise incur in starting up. Transformer’s Dye Removal Systems will seek to maintain a small diverse team in order to reduce bureaucratic costs.

11.4.3 SWOT Analysis

The strengths of Transformer’s Dye Removal Systems will be the lost costs it will incur in designing these plants. This gives us the opportunity to make guarantee profits because our model is based heavily on utilizing intellectual knowledge to develop diagrams and less so on using capital assets to make products. Also, there is a guaranteed regular revenue stream from our maintenance services. This will cover and eventually pay back any costs incurred in acquiring equipment for testing plant equipment.

The main weakness is that there will be uncertainty in the quality of work done when construction is outsourced. It is our hope that provision of an onsite engineering team will mitigate this. Also our small team makes it difficult to deal with multiple clients.

Opportunities include taking advantage of the fact that Transformer’s Dye Removal Systems is the only company that deals specifically with dye removal and so our company will be highly knowledgeable, experienced and very cost effective in implementing our plan. These qualities give us the ability to reach out to companies facing difficulty in dye removal who may already have treatment plants.
The threat to the company is that there is a lot of money going into research to develop techniques to remove dyes from wastewater and there may eventually be a better solution than ours. Our company will have to keep up to date with new technology that comes out in the industry in the future to remain competitive.

11.4.4 Competitive Strategy
In tune with our vision of reliability, Transformer’s Dye Removal Systems aims to provide a rapid response maintenance team to all sites to ensure any possible problems are resolved. This team will comprise of maintenance offices and an engineer with detailed knowledge of the diagrams and schematics as well as the construction of the plant.

11.5 Company Products and Services

11.5.1 Service Components
Transformer’s Dye Removal Systems will be contracted to deliver quality services. These services include but are not limited to:

- Design the dye removal section of the plant
- Outsource the building
- Provide maintenance for the plant

11.5.2 Expected Product Performance
Our quality system will ensure that the following standards set out in our contract are met:

- Remove dyes (organic and inorganic) from wastewater streams
- Maintenance check by a Transformer’s Dye Removal Systems technician
- Needs to be shut down annually for activated carbon change or refill
- Works 24/7
- Filters need to be changed semiannually
- Recycle activated carbon every month

11.5.3 Customer Benefits
Our aim is to satisfy the customer and as such, our services will strive to alleviate burdens from our customer in the following ways:

- Reduce labor cost
• Save company time
• Save money that they have to pay other companies to do it every time they need to remove dyes

11.5.4 Warranties and Guarantees

The warranties and Guarantees offered to all customers, includes

• 24hr service with our technician for free
• Free checkup for their first plant
• 10% discount for their second plant
• 20% for a referrals
• Call center for questions or maintenance requests

11.5.5 Uniqueness

• Conduct pilot test for a perfect solution
• Services are limited to dye removal only from effluent
• Customize design process specific to individual company
• Carry out maintenance for the plant as needed

11.6 Marketing Strategy

The market strategy analyzes the target market, market size, market trends, advertising, and price. A brief description of the customer motivation to purchase the product is included. Distribution strategy is also outlined.

11.6.1 Target Market

Transformer’s Dye Removal Systems’ target market is the group of companies that uses dyes in there production, or wastewater treatment plants that work with wastewater effluent that contain dyes.

11.6.1.1 Problem

Almost every industrial dye process involves a solution of a dye in water. Transformer’s Dye Removal Systems will design a system that removes dyes from wastewater before they dispose the rest of wastewater into a water body or sent for further treatment.
11.6.1.2 Demographics

The Company’s services are not limited by gender, religion, race, status, or location. Transformer’s Dye Removal Systems recognizes the business opportunity of a company that could provide a system to remove organic and inorganic dyes from wastewater. With the impending need for a solution, the company believes that it would be beneficial to textile industries, printing companies, municipal, dye manufacturer, and any other company that uses dyes on daily bases. With growing regulations and incentives for companies to be environmentally friendly, there will be a large market with small corporations and institutions. Transformer’s Dye Removal Systems believes that the market for our product will be a profitable and rapidly growing industry, particularly with textile industries.

11.6.2 Customer Motivation to Buy

The primary aspect of Transformer’s Dye Removal Systems that separates it from other similar companies that may spring up to fill the market need is the company’s undertaking of producing a system that is safe, reliable, cost-effective, and an unbeatable warranty systems. Competitors will be unable to beat Transformer’s Dye Removal Systems’ friendly customer service, and pledge to help create an environmentally beneficial system. Transformer’s Dye Removal Systems desires to make a system that will help its customers save money and maintenance time and also eliminate the need for other methods of pre-treatment of dyes.

11.6.3 Market Size and Trends

According to BCC Research, the demand for waste and wastewater treatment products in the top 40 national markets was $47.7 billion in 2012¹. The U.S. market represent 33% of the total and the second largest is Europe followed by Asia. Middle eastern and African and the rest of Americas are 19% of the market value².

The global market for wastewater treatment is products is expected to reach $53 billion in 2013 and $59.2 billion in 2014. According to BCC Research the market to grow to nearly $96.3 billion by 2019, and register a five-year compound annual growth rate of 10.2% from 2014 to 2019.

11.6.4 Advertising and Promotion

Marketing of Transformer’s Dye Removal Systems’ services will be limited to industrial, or governmental institutions. In an age of growing environmentalism, Transformer’s Dye Removal Systems will seek out

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¹ http://www.bccresearch.com/market-research/environment/water-wastewater-treatment-markets-env008c.html
² http://www.bccresearch.com/market-research/membrane-and-separation-technology/MST032A.html
environmentally conscious bodies, i.e. governments, federal, state, or local, industrial facilities, in order to evaluate the potential for new customers.

Beginning with southern Alabama, and looking to expand into the national market, the Customer Relations Specialist will seek out new clientele and arrange to meet in order to determine which of the service offered by our company will best suit the needs of the customer.

The benefits listed above will be the key points of the marketing campaign for Transformer’s Dye Removal Systems. Our company will take a pronged approach to marketing. In this strategy, our company will attempt to win over interested customers by undercutting the price of our competitors in the wastewater treatment plants. The goal will be to track our competitor’s marketing strategies and advertise in similar locations, selling the comparative advantages of our service (price and safety). Given the current state of marketing in the wastewater treatment plants, the projections are that the bulk of this campaign will take place through the placement of internet advertisement.

For large scale projects, arrangements may be made to offer a better deal to the client, such as a discount on maintenance. Furthermore, because Transformer’s Dye Removal Systems relies so heavily on maintaining customer relations throughout the life of the service and beyond, referral discounts of 20% on the total bill for the remainder of the customer’s use of the products is offered. In order to determine how much of a discount a company is eligible for, variables such as the size of the company’s order and the number of referrals resulting in new customers will be taken into account.

11.6.5 Pricing

At start-up, a high up-front cost to cover equipment and other initial costs are expected, associated with the beginning of a business as mentioned in the business executive summary. As the company increases its customer base, Transformer’s Dye Removal Systems seeks to achieve an appropriate balance between high and low margin pricing. As a new business, having a low marginal cost will allow the building of market share and encourage new customers, as our company will seek to offer a less expensive alternative than our competitors. The downside to a low margin is that more units must be sold to turn the same profit. As a new business, offering too low of a margin would be risky, and therefore must be avoided. Our company plans to offer prices that will reflect the economic conditions at present.
11.6.6 Distribution Strategy

Since Transformer’s Dye Removal Systems provides a service, our service will be distributed in person. One or all the partners will go to the company that contracted us to deliver the plan and clarify any question that they might have.

11.7 Competitive Analysis

11.7.1 Existing Competitors

11.7.1.1 Aqua Chem, Inc.

Aqua Chem is a wastewater treatment company and manufacturer of aquasil products used for wastewater treatment from industrial and municipal waste that meet environmental demands. Aqua Chem is the leading industry on water quality analysis and data management.\(^\text{10}\)

Aqua Chem’s have been world leaders in water technology since 1929. The company has been in existence for a long time which is a plus because it signifies that the company has taken lots of risks and grown with both increasing technology and industrial companies. However, Aqua Chem carries out only general clean up on all wastewater from an industrial sector and can miss the removal of dyes to an environmentally safe level. They do not specialize in removing dyes from wastewater which is very critical and what Transformer’s Dye Removal Systems is particular about.

11.7.1.2 Schlumberger Water Services

Schlumberger Water Services offers engineered solutions to achieve sustainable water supplies. Schlumberger differentiate through technology by offering scalable solution to meet water solutions. However, they do not specialize on providing technology based on each specific industry as that can be costly and they do not design process that takes care of hazardous chemicals in water solution.

11.7.1.3 Aqueonics, Inc.

Aqueonics Inc. is a full service and wastewater consulting, design, engineering and construction company. The company developed a unique primary, secondary, and tertiary wastewater treatment process to provide high-quality effluent for advance requirements of regulatory agencies. Also they provide many services for different types of wastewater treatment whereas our company provides only services for companies that utilize dyes. They have facilities in 10 states and for over 25 years\(^\text{11}\).

\(^{10}\)http://www.aqua-chem.com/content/history

\(^{11}\)http://gipcdev.blackbarn.net/sites/default/files/Aqueonics.pdf
However though, Aqueonics, specializes in multi-stage, aerobic/anaerobic-anoxic fixed film, trickling filtration process\(^\text{12}\). The filtration process has economic disadvantage due to cost and is not widely used to remove dyes. The Transformer’s Dye Removal Systems utilizes the adsorption process which is cheaper, easy and very economically favored. Thus it would be cheaper for our company to clean the dyes for Aqueonics, as our company is also specialized in dye removals, while they are not.

11.7.2 Potential Competitors: Companies that might enter the Market

Potential competitor that might enter the market would be existing wastewater treatment plants in Mississippi such as

1) Mississippi River Wastewater treatment plant, Jackson
2) Waterline for Diamondhead Wastewater treatment plant, Hancock
3) Clifton Williams Wastewater Treatment plant
4) Wright Smith Wastewater Treatment plant

11.7.2.1 Impact on the Business if they enter

The existing wastewater treatment plants would work with textile plant to develop pre-treatment specific for the textile industry. This would have a negative impact on our company due to the fact that our company is still new and those treatment plants have been in business for a long time. Also, those treatment plans are a bigger company and offer more services that our company. Our company is, however, not worried about the potential competitors because our company believes it would cost more for them to do that and they would rather hire a smaller company like ours that is skilled and also specialized to save time and money.

Also company’s would prefer to have a company that specializes on removing just dyes to work with that to work with a big company that only has a division that can do that.

11.8 Description of Management Team

The company is a joint venture of individuals with equal percent contribution. The management team is divided into four sections headed by each individual contributor.

\(^\text{12}\) http://www.environmental-expert.com/companies/aqueonics-inc-23578
11.8.1 Key Managers and Employees

11.8.1.1 Finance
The finance of the company is headed by Nneka Usifoh. She is an engineering student with a chemical concentration. She has previously worked at Makor Trading Company as a sales representative and assistant. As a result of work there, she has gained experience with budgeting, handling cash outflow and inflow, recording sales and deliveries. With this work experience, she is in charge of the finance department of the company where she works with the financial statements and also on marketing the services provided.

11.8.1.2 Production and Design
The production and Design of the company is headed by Richard Mels. Richard Mels is an engineering student with a chemical concentration. He has a lot of experience with carpentry and the skill he learnt from designing and making carpentry work he is bringing into the team. He is in charge of the design of the process that takes place in the adsorption column and if time permits the desorption column. He is also in charge of scaling up and optimization of the adsorption column.

11.8.1.3 Research and Development
The research and development of the company is headed by Diane Umufasha. Diane Umufasha is a senior, engineering student with a chemical concentration at Calvin College. In the course of the school year, the chemical engineering class has worked on lots of projects and design in teams. Of the numerous times and projects the class worked on, Diane always works on the research section of her team work. With the amount of time and experience she has had with Research, she is in charge of researching wastewater effluent streams and activated carbon for the design.

11.8.1.4 Testing and Process Technology
The testing and technology department is headed by Jeffrey Fiam-Coblavie. Jeffrey Fiam-Coblavie is a senior engineering student with a chemical concentration at Calvin College. Over the summer, Jeffrey worked for Blood Cell Storage Inc (BCSI). While working at BCSI, he gained experience in testing of dyes and medical devices. With the experience gained from his internship, Jeffrey is in charge of the testing of the activated carbon in the wastewater stream, and also the dyes. Also, Jeffrey will work alongside Richard in the optimization of the whole process.
11.8.2 Future Additions to Management

With the increase of the business, the four major divisions would be broken down further to have stand-alone divisions in marketing and sales, human resources and customer services. Also there would be more employees and spread-out division of labor. That is, there would be vice-presidents, project managers and directors added to the already existing sections of the company.

11.8.3 Partners

There are no board of Directors. The Company is a limited liability with equal ownership by the four co-founders of the business. Given the different skills and wide range of expertise of the four co-founders, there is sufficient experience to make decision that moves the company further.

11.9 Operations

11.9.1 Legal Form of Ownership

Transformer’s Dye Removal Systems will be a limited liability company. This allows the company to organize as the owners choose through a written agreement. This written agreement would provide details protecting the owners if the company fails by keeping the owners and the company’s credit separate. It would also make it easier for the company to be sold or for one partner to sell his share of the company as it would be specified in the written agreement. As a limited liability company, Transformer’s Dye Removal Systems will be taxed as a partnership rather than a corporation.

Each of the four co-founders will be partners of equal ownership and be the head of their own division. Authority for decisions is shared equally between the four partners and decisions are determined by a vote with a majority needed for a decision to be made. As the head of their own division, each partner is in charge of determining the size of the staff needed as well as the organization of their department.

Compensation will be given to employees for promoting and bringing work to the company. Bonuses will also be given according to the work an employee accomplishes. A 401k plan will be provided for all employees with benefits including health insurance, two weeks initial paid vacation and an additional day of vacation for every two years worked at the company.

The raw materials needed for our systems would not be a cost the company, but cost calculations would need to be performed for each custom design for the cost adsorbent required, and the initial capital cost of the system.
Transformer’s Dye Removal Systems will be located in southern Alabama, near the Mississippi River, as this is where the largest textile industry is located in the United States. This would reduce travel costs, and allow us to be a local company for many textile plants. The facility would be set up as an office building with a work area for the R&D department to perform their tests.

Figure 13: Transformer’s Dye Removal Systems Company Division

11.10 Financial Forecasts

11.10.1 Key Assumptions

The key assumptions made were that the company would require little capital to start up compared to revenue, the company would be able to reduce variable costs over the three year period, fixed costs would increase in the third year, and equipment purchases will have to be made in the second year.
11.10.1.1 Capital
The capital assumption ($560,000) is considered feasible because the most of the operations our company is concerned with are CAD designs and collection of data from pilot plants. Most other needs will be outsourced and this will form part of the variable costs.

11.10.1.2 Costs
Variable costs were assumed to fall with time because of the experience gained from daily operations and end of year reviews and optimizations.

11.10.2 Equipment
The equipment purchases made in the second year are used mainly for research and development to further the intellectual base and experience of the company.

11.10.3 Ratio Analysis
The financial forecast can be found in the business appendix. From Table 1Table 4, it can be seen that the company will become less focused on liquid assets. The Accounts Receivable shows that it will become more efficient at collecting accrued amounts owed. The fixed assets turnover ratio is constant over the first two year and drops in the third year. This shows that the company will become less efficient in using its assets to generate sales. Considering the company is privately owned, debt management is predicted to improve as seen in the decreasing figures of the debt ratio. Profitability overall will increase as seen in the increasing percentages of the Profit Margin on Sales, Basic Earning Power Ratio and the Return on Assets. The Market value is predicted to fall as seen by the Price/Cash Flow. This would make it difficult to attract investors but seeing as the company is in its infancy, this should not be an issue.

Table 4: Financial Ratios

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Ratio</td>
<td>211</td>
<td>4.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Accounts Receivable/days</td>
<td>14.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fixed Assets Turnover Ratio</td>
<td>14.6</td>
<td>7.4</td>
<td>8.4</td>
</tr>
<tr>
<td>Total Asset Turnover Ratio</td>
<td>4.4</td>
<td>4.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Debt Ratio</td>
<td>0.89</td>
<td>0.82</td>
<td>0.45</td>
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<tr>
<td>Profit Margin on Sales</td>
<td>-5.1%</td>
<td>6.2%</td>
<td>11.4%</td>
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<tr>
<td>Basic Earning Power Ratio</td>
<td>-38.0%</td>
<td>47.8%</td>
<td>61.7%</td>
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<tr>
<td>Return on Assets</td>
<td>-22.8%</td>
<td>28.7%</td>
<td>37.0%</td>
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<tr>
<td>Price/Cash Flow</td>
<td>0.23</td>
<td>0.25</td>
<td>0.10</td>
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</table>
11.11 Loan or Investment Proposal

11.11.1 Amount Requested

The capital requested to startup is about $60,000. The initial bank loan required is estimated to be at $500,000.

11.11.2 Purpose and Uses of Funds

The funds will be used to purchase capital equipment such as computers, licenses for CAD software and equipment used to build pilot plants to perform experiments to collect data to meet the specific plant needs of our customers.

11.11.3 Repayment

It is proposed that repayment should begin in the third year of operations when the company has a healthy bank balance. Despite the fact that all debt can be paid off at the start of the third year, a scheduled plan will be in place to reduce the debt to 20% of the initial cost in 5 years. The extra fund will be used for expansion purposes.

11.11.4 Timetable for Implementing Plan and Launching the Business

Transformer’s Dye Removal Systems hopes to launch in June 2014. Setup and location acquisition will take approximately one month. The company hopes acquire its first contract shortly after launch.
12 Conclusion

With the research resources at our disposal and initial calculations made, the team is confident that the project will be feasible. The feasibility of the report can be attributed to the fact that,

- there is a lot of data to support adsorption of dyes, especially using activated carbon
- there are many alternatives whose design, construction and scale up are within the time frame allotted
- there are mathematical models to predict the outcome of the adsorption process
- the materials needed for the project are available and within our budget

The team is well aware that it may encounter some difficulties ahead. The team, however, believe that most of the wrinkles have been ironed out in this report, and the team anticipates that the team will be able overcome any such difficulties by the due date in May. The team will work through the time remaining, in order to deliver an operating pilot plant or prototype of the best design, along with a pilot plant for a design alternative if time permits, a scaled up process design, and a Final Design report in May. After which, our team will present our findings and design during senior design night.
13 Acknowledgements

Professor Aubrey Sykes
Professor Sykes is the faculty advisor for team 2. He is always willing and ready to offer advice and give us helpful directions. He meets regularly with the team to discuss issues and progress of the project. He also provides helpful feedbacks on reports, presentation and documents.

Professor Muyskens
Professor Muyskens is the chemistry chairperson. He provided the team with one of the dyes needed for this project.

Class Advisors
Professor David Wunder, Professor Ned Nielsen and Professor Steven Vanderleest are all assisting us through their lectures, presentations and guidelines on how to go about senior design.

Bob Dekraker
Bob Dekraker assists the team in placing order for materials and supplies needed for the project.

Rich Huisman
Rich Huisman assists us with the chemicals needed for this project. He is also going to be showing us how to use certain instruments like the ion chromatography and being safe in the lab. He is also assisting us in the disposal of certain wastes.

Bruce Klanderman
Bruce is the industrial consultant attached to our team. The team met with him on Monday November 11, to discuss our project and he provided us with feedbacks.

Kwesi O. Asare
Kwesi Asare was the team’s photographer.
14 Bibliography

Bible. Genesis 1:28


15 Appendix

15.1 Sample Textile Effluent and Compositions

<table>
<thead>
<tr>
<th>Values</th>
<th>pH</th>
<th>NO-3 (mg/L)</th>
<th>TSS (mg/L)</th>
<th>Chlorides (mg/L)</th>
<th>COD (mgO2/L)</th>
<th>H2S (mg/L)</th>
<th>NH4+ (mg/L)</th>
<th>NO-2 (mg/L)</th>
<th>Fixed Residue (mg/L)</th>
<th>BOC (mgO2/L)</th>
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<tr>
<td>min</td>
<td>7</td>
<td>1.6</td>
<td>135</td>
<td>40</td>
<td>825</td>
<td>7.6</td>
<td>5.06</td>
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<td>66</td>
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<tr>
<td>max</td>
<td>7.3</td>
<td>3.6</td>
<td>544</td>
<td>80</td>
<td>1369</td>
<td>9.6</td>
<td>14.6</td>
<td>2.2</td>
<td>610</td>
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<tr>
<td>Average (PG)</td>
<td>7.15</td>
<td>2.6</td>
<td>273</td>
<td>60</td>
<td>1097</td>
<td>8.6</td>
<td>9.93</td>
<td>1.6</td>
<td>358.6</td>
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15.2 Business Plan

15.2.1 Financial Statements

15.2.1.1 Income Statement

<table>
<thead>
<tr>
<th>Transformer’s Dye Removal Systems</th>
<th>Pro-Forma Statement of Income</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 1</td>
</tr>
<tr>
<td>Sales revenue</td>
<td>2,500,000</td>
</tr>
<tr>
<td>Variable Cost of Services</td>
<td>2,100,000</td>
</tr>
<tr>
<td>Fixed Cost of Services</td>
<td>250,000</td>
</tr>
<tr>
<td>Depreciation</td>
<td>28,580</td>
</tr>
<tr>
<td>Gross Margin</td>
<td>121,420</td>
</tr>
<tr>
<td>Variable Operating Costs</td>
<td>200,000</td>
</tr>
<tr>
<td>Fixed Operating Costs</td>
<td>70,000</td>
</tr>
<tr>
<td>Operating Income</td>
<td>(148,580)</td>
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<tr>
<td>Interest Expense</td>
<td>15,000</td>
</tr>
<tr>
<td>Income Before Tax</td>
<td>(163,580)</td>
</tr>
<tr>
<td>Income tax (40%)</td>
<td>(65,432)</td>
</tr>
<tr>
<td>Net Income After Tax</td>
<td>(98,148)</td>
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</table>
### 15.2.1.2 Balance Sheet

Transformers Dye Removal Systems

#### Balance Sheet

<table>
<thead>
<tr>
<th></th>
<th>December 31</th>
<th>December 31</th>
<th>December 31</th>
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<tbody>
<tr>
<td><strong>Assets</strong></td>
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<tr>
<td><strong>Current Assets</strong></td>
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<tr>
<td>Cash and Cash Equivalents</td>
<td>$260,432</td>
<td>$237,172</td>
<td>$620,352</td>
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<tr>
<td>Marketable Securities</td>
<td>$30,000</td>
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<td>Accounts Receivables</td>
<td>$100,000</td>
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<td><strong>Total Current Assets</strong></td>
<td>$390,432</td>
<td>$237,172</td>
<td>$620,352</td>
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<tr>
<td><strong>Total Property, Plant and Equipment</strong></td>
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<td>$500,000</td>
<td>$500,000</td>
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<tr>
<td>Less Accumulated Depreciation</td>
<td>$28,580</td>
<td>$91,850</td>
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<tr>
<td><strong>Net Property, Plant and Equipment</strong></td>
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<tr>
<td><strong>Liabilities and Shareholders' Equity</strong></td>
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<td></td>
</tr>
<tr>
<td><strong>Current Liabilities</strong>:</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Accounts Payable</td>
<td>$-</td>
<td>$-</td>
<td>$200,000</td>
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<td>Current Income Taxes Payable</td>
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<td>Other Current Liabilities</td>
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<td><strong>Long-Term Liabilities</strong></td>
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<td>Long-term Debt</td>
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<td>$457,000</td>
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<td><strong>Total Liabilities</strong></td>
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<td>$457,000</td>
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<tr>
<td><strong>Shareholders' Equity</strong></td>
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<td>Common Stock</td>
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<tr>
<td>Foreign Currency Transaction Adjustments</td>
<td>$-</td>
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<td>$472</td>
</tr>
<tr>
<td><strong>Total Shareholders' Equity</strong></td>
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<td><strong>Total Liabilities and Shareholders' Equity</strong></td>
<td>$561,852</td>
<td>$645,322</td>
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</table>
### Transformer's Dye Removal Systems

#### Pro-Forma Statement of Cash Flows

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning Cash Balance</td>
<td>-</td>
<td>290,432</td>
<td>267,172</td>
</tr>
<tr>
<td>Net Income After Tax</td>
<td>(98,148)</td>
<td>184,890</td>
<td>374,730</td>
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<tr>
<td>Depreciation expense</td>
<td>28,580</td>
<td>91,850</td>
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<tr>
<td>Invested Capital (Equity)</td>
<td>60,000</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Increase (decrease) in borrowed funds</td>
<td>500,000</td>
<td>-</td>
<td>(100,000)</td>
</tr>
<tr>
<td>Equipment Purchases</td>
<td>(200,000)</td>
<td>(300,000)</td>
<td>-</td>
</tr>
<tr>
<td>Ending Cash Balance</td>
<td>290,432</td>
<td>267,172</td>
<td>650,352</td>
</tr>
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</table>
### 15.2.2 Break Even Analysis

#### Transformer’s Dye Removal Systems

#### Break Even Analysis

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sales revenue</strong></td>
<td>2,500,000</td>
<td>3,000,000</td>
</tr>
<tr>
<td><strong>Less: Variable Costs:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Cost of Goods Sold</td>
<td>2,100,000</td>
<td>2,050,000</td>
</tr>
<tr>
<td>Variable Operating Costs</td>
<td>200,000</td>
<td>150,000</td>
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<tr>
<td><strong>Total Variable Costs</strong></td>
<td>2,300,000</td>
<td>2,200,000</td>
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<tr>
<td><strong>Contribution Margin</strong></td>
<td>200,000</td>
<td>800,000</td>
</tr>
<tr>
<td><strong>Less: Fixed Costs</strong></td>
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<tr>
<td>Fixed Cost of Goods Sold</td>
<td>250,000</td>
<td>300,000</td>
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<tr>
<td>Fixed Operating Costs</td>
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<td>70,000</td>
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<td>Depreciation</td>
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<td>91,850</td>
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<td>Interest Expense</td>
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<tr>
<td><strong>Total Fixed Costs</strong></td>
<td>363,580</td>
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<td><strong>Income Before Tax</strong></td>
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<td>308,150</td>
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<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Fixed Costs</strong></td>
<td>363,580</td>
<td>491,850</td>
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<tr>
<td><strong>Contribution Margin %</strong></td>
<td>8%</td>
<td>27%</td>
</tr>
<tr>
<td><strong>Break Even Sales Volume</strong></td>
<td>4,544,750</td>
<td>1,844,438</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equipment Purchases</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Purchases Year 1</td>
<td>200,000</td>
<td>28,580</td>
<td>48,980</td>
</tr>
<tr>
<td>Equipment Purchases Year 2</td>
<td>300,000</td>
<td>42,870</td>
<td>73,470</td>
</tr>
<tr>
<td>Equipment Purchases Year 3</td>
<td>-</td>
<td>91,850</td>
<td>108,450</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depreciation</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>28,580</td>
<td>91,850</td>
<td>108,450</td>
<td></td>
</tr>
</tbody>
</table>
### MACRS Rates (7-year recovery period)

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1429</td>
<td>0.2449</td>
<td>0.1749</td>
</tr>
</tbody>
</table>

### Interest Expense:

- **Annual interest rate on debt**: 6%

<table>
<thead>
<tr>
<th>Year</th>
<th>Average debt balance</th>
<th>Interest expense</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250,000</td>
<td>15,000</td>
</tr>
<tr>
<td>2</td>
<td>500,000</td>
<td>30,000</td>
</tr>
<tr>
<td>3</td>
<td>450,000</td>
<td>27,000</td>
</tr>
</tbody>
</table>