Hexane Extraction System Design

A system to extract oil from *Chlorella vulgaris* algae cells using the chemical solvent, hexane
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**Purpose**

This document is intended to serve to educate future readers regarding the design of the system for the extraction of oil from *Chlorella vulgaris* algae cells. Provided in this document are narratives of the concept design, engineering calculations, and equipment specifications for the system. Also included are custom part detail drawings, assembly drawings, and bills of materials for the system. These documents should allow for the manufacture and purchase of necessary parts and the assembly of the entire system.

**1. Design Objectives**

Since it was decided that a chemical extraction scheme would be used, the following objectives were considered in the design of the extraction system:

- Maximize the oil yield from the extraction process
- Minimize hexane losses
- Reduce energy required to boil and condense the hexane
- Adequate equipment life
- Avoid risk of hexane ignition

**2. Concept Design**

**Why Hexane Extraction**

The vegetable oil that you use to cook your food is most likely extracted using a common chemical solvent, hexane. Most large scale operations for harvesting seed oils use hexane, or a similar chemical solvent, which dissolves the oil from seeds. The percentage of oil recovered from oil-bearing seeds far exceeds any other method, offering yields exceeding 90%.

The primary basis for the selection of hexane extraction for this design project was that the testing phase of the project showed no promising mechanical processes that could extract oil from the algae cells. Hence, hexane extraction was chosen as default, coupled with a belt-drying process to prepare the algae for use in the hexane extractor.

**2.1 Laboratory Scale Extraction**

The figure at right shows a Soxhlet extractor, a glass laboratory device commonly used for extraction processes, and the device that the authors used to test the effectiveness of chemical solvents for algal oil extraction.

Algae, contained in filter paper, is inserted into the *Algae Reservoir*. Liquid hexane is then added to the reservoir, where it dissolves a portion of the oil from the algae cells. When the liquid hexane reaches a certain level in the *Algae Reservoir*, a siphon is created, and the hexane, along with the oil it has dissolved, drains to the bulb, labeled *Hexane/Oil Reservoir*.

Since only a fraction of the algal oil is dissolved in one such cycle of immersion in hexane, the hexane must be cycled back through. A hotplate is used to heat the *Hexane/Oil Reservoir*. This causes the hexane to boil (hexane boils at ~156 °F at atmospheric pressure).

The vaporized hexane travels along the path indicated by the dashed line in the figure. It travels to the condenser tube, which is enclosed by a bath of cooling water, which cools the hexane vapor to the point of condensation.

![Figure 1 Diagram of laboratory scale Soxhlet extractor.](image)
This condensed hexane drains back to the *Algae Reservoir*, where it dissolves more oil, and the process repeats. When enough oil has been recovered, which is determined primarily on the color of the hexane when it drains from the *Algae Reservoir*, the cycle is terminated.

### 2.2 Extraction System Design

It was decided that the Soxhlet hexane extraction from laboratory experiments would be scaled up to accommodate a larger volume of algae. Also, the problem of hexane recovery must be addressed by the scaled-up system. This problem is addressed by rerouting the flow of condensed into the *Hexane Reservoir*, after the extraction is complete.

### 2.3 Schematic Process Overview

Like the Soxhlet process, the system will process a small batch of algae at a once. Figure 2, at left, shows the schematic cycle of the hexane extraction system. A batch of dried algae, referred to as the *mill*, will be placed inside the *Extraction Chamber* and the system will be evacuated to a partial vacuum in order to lower the boiling point of the hexane.

After evacuation, the system is sealed and the hexane is introduced to the *Extraction Chamber*. The hexane will fill the *Extraction Chamber* until it reaches a certain level, after which a siphon is created causing a mixture of hexane and oil (called *miscella*) to drain to the *Miscella Tank*. It must be cycled through the *Extraction Chamber* a number of times in order to extract a large proportion of the oil present in the algae.

Here, the hexane will be boiled, by running a hot fluid through a shell around it, so that it rises to the condenser chamber. There a cold fluid running through tubes will condense the hexane so that it drains to the *Hexane Reservoir* and back to the *Extraction Chamber*. When the oil has been extracted, the hexane must be separated from the algae and the oil and returned to the *Hexane Reservoir*. This will be accomplished by heating the *Miscella Tank* and *Extraction Chamber* and routing the hexane condensate back to the *Hexane Reservoir*.
2.4 Addressing Design Objectives
2.4.1 Safety Precautions
Because hexane is both corrosive and flammable, care must be taken to avoid the corrosion of system components and exposing it to open flame or electricity. Consequently, it was decided that all system components that contact hexane must be made of stainless steel. Also, pumping hexane is avoided, as this would entail the risk of sparks igniting the hexane. Furthermore, a flame arrestor will be employed at the outlet of the vacuum pump (which will not contact hexane under proper operating conditions), to prevent flashback.

2.4.2 Sizing Components
The team chose to size the system to process algae from a 2000 gallon solution, which grows to maturity in 3-4 days. From this, it has been calculated that approximately 2 gallons of dried algae may be separated, which the hexane extraction system must process. It was decided that, since the dried algae must be ground into a powder form for processing, the volume of the algae to be processed would increase, which would affect the design of the Extraction Chamber. A Mathcad worksheet for sizing of the system components is shown in Appendix I.

2.4.3 Material Selection
Hexane (chemical formula, C₆H₁₄) is hydrocarbon with a 6-carbon backbone. At room temperature, hexane is a colorless liquid, with a boiling point temperature of approximately 155°F. It is chemically stable, although it fosters corrosion in many materials, and it has flammability similar to gasoline, according to the Material Data Safety Sheet for hexane, shown in Appendix G. Because of its corrosiveness, it was determined that stainless steel would be required for all parts of the extraction system contacting hexane, in order to give long component life. Hexane’s flammability is another concern that must be addressed in the design. According to the MSDS sheet, hexane has a risk of ignition when its concentration by volume in air is between 1.15% and 7.5%. Of course, open flame or electric sparks are required for ignition within this flammability regime, and outside this regime, there is no explosion hazard. Because of the risk of explosion, electric elements will be isolated from hexane exposure.
3. System Component Design
This section describes the operation and design features of each of the extraction system’s components. A SolidWorks model of the entire extraction system is shown in Figure 3, below. All major components of the system are labeled in the figure and the subsequent sections describe the design of those major components. SolidWorks models of each of the system’s components are shown to aid in understanding the final design.

Figure 3 SolidWorks model of entire hexane extraction system.
3.1 Hexane Reservoir
The Hexane Reservoir acts as the starting point of the extraction system. Within the reservoir, hexane is initially stored prior to initiating the extraction process. As the system begins to run, hexane will exit the reservoir through a pipe located at the bottom of the stainless steel bucket, labeled within Figure 4, at right. To ensure that all liquid hexane drains though the reservoir without residual hexane accumulation, a conical bottom has been designed to channel the hexane into the drainage pipe, as shown in Figure 5, below. This exploded view shows more a more detailed view of the tank itself, minus the tubing and fittings that connect to it.

The Hexane Reservoir also acts as the finishing point to the extraction system. As hexane is condensed through the hexane condenser, liquid hexane is formed and will flow through a pipe leading to the top of the Hexane Reservoir. As the flow is initiated, hexane can immediately begin the process described above. However, upon complete extraction of the algae oil, a valve located within the drainage pipe of the Hexane Reservoir will be closed causing the hexane within the system to accumulate within the Hexane Reservoir and bringing the system back to the original state.

It is important to be able to open the Hexane Reservoir to add and remove hexane, but the tank must not leak during the system operation, since the system operates at a partial vacuum. It is necessary to keep this vacuum in order to maintain optimal heating system operation, as well as to minimize hexane losses. For this reason an o-ring is installed in the mounting flange of the tank, so that when the lid is secured, an airtight seal is formed. This prevents the release of hexane and the loss of system vacuum.
3.2 Extraction Chamber

The Extraction Chamber, as its name implies, is where the oil extraction takes place. Liquid hexane enters the Extraction Chamber from the Hexane Reservoir, as shown in Figure 6, at right. As hexane begins to accumulate within the Extraction Chamber, the cellular walls of the algae will begin to break down, allowing the lipids within the algae to release. The resulting mixture of hexane and oil is termed miscella. Once the miscella has reached a critical height within the chamber, a siphon will be initiated, allowing the miscella to drain into the miscella chamber. In order to ensure that the algae within the chamber is not released with the miscella, a straining bucket has been included within the design, which will keep the algae from exiting the tank. This strainer has a bottom constructed of a 1 micron, stainless steel mesh.

As was the case with the Hexane Reservoir, the Extraction Chamber has a bottom with a conical shape, to allow the miscella to drain properly. Also, an o-ring is installed in the mounting flange of the chamber, so that when the lid is secured, an airtight seal is formed. This prevents the release of hexane and the loss of system vacuum.
3.3 Miscella Tank
Within the extraction system, the Miscella Tank is used to initially accumulate the miscella (the mixture of oil and hexane) which has been siphoned from the extraction tank. Once the siphon within the extraction tank has been activated drawing the miscella into the Miscella Tank, the tank will be heated via a water bath. This is made possible by the fact that the system will operate under a vacuum, so the boiling point temperature of the hexane will be much reduced. A more thorough discussion of the heating system can be found in Section 4. Upon reaching the necessary boiling temperature, the liquid hexane within the miscella mixture will encounter a phase change, turning into vapor.

Upon vaporization, the hexane will be free to exit the Miscella Tank though piping located on the side of the tank. The hexane vapor will flow upwards to the condenser, in order to be condensed so that the extraction cycle may be repeated. The inlets and outlets of the Miscella Tank are shown in Figure 8, at right. Also shown in the figure is the oil drainage valve. This valve allows for the release of the accumulated oil once the extraction process has been completed. Oil will be removed once all of the hexane has been recovered to the Hexane Reservoir and the vacuum has been relieved. Similar to the other two tanks, the Miscella Tank has a conical bottom, shown in Figure 9, below, which allows the oil to drain properly from the tank.

Also, an o-ring is installed in the mounting flange of the tank, so that when the lid is secured, an airtight seal is formed. This prevents the release of hexane and the loss of system vacuum.
4. Heating System Design

### Table 1 Saturation point pressures and temperatures for hexane.

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#### 4.1 Vacuum Selection

The hexane system requires the hexane to be simultaneously boiled and condensed, continuously. The boiling temperature of hexane at standard atmospheric pressure is approximately 156°F. Although this is lower than that of water, this would still lead to a significant energy requirement. However, if the pressure of the hexane were lowered, the boiling temperature would also lower. By lowering the boiling point, the energy required for the boiling process can be significantly reduced. Table 1, at left, shows various saturation points for hexane. It can be seen that at one atmosphere (14.7 psia), the hexane must be heated to 156° in order to boil. However, if the pressure is closer to 2.5-3 psia, which is achievable by reasonably priced vacuum pumps, then the hexane must only be heated to between 70 and 80 F to boil.

#### 4.1.1 Energy Reduction

To reduce the energy requirements for boiling the hexane, a vacuum pump that can achieve a suitable vacuum was required. Prior to selecting a specific pump, it had to be calculated how much the pressure in the system could vary at different points in its operation.

#### 4.1.2 Ultimate Vacuum

Because the system would be evacuated prior to opening the Hexane Reservoir, any air that was trapped therein would increase the pressure of the system when the Hexane Reservoir was exposed to vacuum. A Mathcad sheet was used to determine how much the system pressure would rise when this occurred. This sheet is shown in Appendix J, and calculates the final system pressure given several different volumes of hexane used in the system. Table 2, above right, shows the summary of this calculation sheet. The values are based on an initial vacuum pressure of 2.5 psia, which can be achieved by a reasonably priced vacuum pump. Based on this data, a vacuum pump should be chosen that can achieve a vacuum close to 2.5 psia. Pumps are given a rating for the ultimate vacuum that they can achieve (vacuum pressure given a long evacuation time), and is reported in inches of Mercury (in Hg). A 2.5 psia system pressure corresponds to a 25” Hg ultimate vacuum level. This is a reasonable goal for a pump selection, since there is a steep price increase for pumps that can achieve vacuums upwards of 25” Hg.

#### 4.1.3 Pump Flow Rate and Evacuation Time

Another consideration in pump selection should be pump flow rate. The flow rate that a pump can produce is rated in cfm (cubic feet per minute), although the flow rate of a specific pump will decrease with increasing vacuum. Pump flow rates are typically reported at atmospheric pressure, which is the maximum flow rate possible from the pump. The flow rate itself does not matter to the system design, but it is desired to keep the evacuation time as low as possible. The evacuation time for a pump between two pressures is given by:

\[
\tau_{\text{evacuation}} = \left( \frac{V}{Q} \right) \ln \left( \frac{P_0}{P_f} \right)
\]

Where \( V \) is the evacuation time, \( P_0 \) is the initial pressure (atmospheric), \( P_f \) is the final pressure. This relationship is only valid for a constant flow rate, \( Q \). However, an average flow rate can be used with reasonable accuracy. The vacuum pump calculation sheet in Appendix J shows the calculation an adequate pump flow rate. To achieve an evacuation time of 5 minutes, it was found that the average flow rate would need to be approximately 0.36 cfm.
The vacuum pump chosen should be an oil-less design, in order to eliminate the contamination, and also to avoid the risk of conflagration. The final pump that was selected was a 1/8 hp, oil-less, rocking piston pump with an ultimate pressure of 25” Hg and a rated flow rate of 1 cfm. This would adequate for the 0.36 cfm average for a 5 minute evacuation time, and since this specification is only one of operator convenience, it is not entirely necessary. The selected vacuum pump is shown in the Bill of Materials in Appendix A, and is also shown in Figure 10, at left. The model shows the vacuum pump and the shut-off valve that is used to seal the system once a vacuum has been achieved.

4.2 Hot Water Heating
The heating system is shown in the SolidWorks screenshots in, Figure 11. Both the Miscella Tank and the Extraction Chamber are enshrouded in a polyethylene bucket, which is filled with hot water to heat each tank.

The hot water is supplied by an on-demand, electric hot water heater, which is mounted to the framework of the system. It is capable of providing hot water at flow rates between 0.75 – 3 gpm. Garden hoses run between each water bucket for the supply and return of water. Both supply hoses are connected to the outlet of the hot water heater by a garden hose wye fitting. The wye fitting has shut-off valves for each line. The same wye fitting with shut-off valves is used at the inlet of the hot water heater. The shut-off wye fittings allow the flow of water to be directed exclusively to one of the water buckets. The water can be routed to the Miscella Tank water bath during extraction and during the hexane recovery stage, the water can be routed to each of the tanks sequentially.
4.3 Hexane Condenser

When the hexane is boiled in the Miscella Tank, it rises through tubing to the condenser, where it must be condensed to be used for another oil-dissolution cycle. The laboratory Soxhlet extractor uses a glass tube condenser (refer to Figure 1 in Section 2). In that condenser, the hexane vapor is contained within a vertical, glass tube, which itself is encased in a larger tube with cooling water flowing between the two tubes. Although this provides adequate cooling, this glass tube is open to the atmosphere, which allows significant hexane losses. In the lab, hexane losses are acceptable, and the safety risk is minimized by running the Soxhlet condenser under a fume hood to expel the potentially flammable gases. However, the hexane extraction system that this group is designing must not leak hexane. Hexane is not especially inexpensive, so hexane losses need to be minimized by keeping the condenser closed to the atmosphere. Of course, the vacuum operation of the system would negate any open-type condenser, since the vacuum would be impossible to maintain.

Because the condenser must be able to maintain and withstand vacuum exposure, any glass condenser would be unacceptable, since the stresses induced by the differential pressure across the glass walls would cause them to fracture. It is therefore a requirement that the condenser be constructed of metal, preferably one that offers corrosion resistance. Although water cooling is used in the laboratory, cold water temperatures are not typically below 50° F, at least in the summer, which is when the extraction system would see most of its use. Because of this, it was proposed to use a thermoelectric cooler to provide the cooling.

4.3.1 Thermoelectric Device Operation

A thermoelectric element is a solid-state device which operates on the thermoelectric effect, which is actually the combination of several different effects. The thermoelectric effect describes the ability of a voltage to produce a temperature difference at the junction of two dissimilar metals. Thermoelectric devices are typically small, measuring only a few inches square and under ¼ inch thick. They contain many of these junctions between metals, called thermoelectric elements. They are most commonly used to cool electronics. A typical thermoelectric device is shown in the Figure 12, at right.

Thermoelectric elements produce a hot side and a cold side. On the cold side, heat energy is drawn in from the object to be cooled and on the hot side heat energy is expelled. Figure 13, at left, shows a schematic of a thermoelectric device and its general operation; the thermoelectric elements can be seen sandwiched between two thermally conductive plates.

4.3.2 Cooling Blocks

Although thermoelectric elements are quite small, they offer very high cooling rates. The ones that this system uses provide a heat transfer rate of approximately 225 W. Because of this high cooling vs. space efficiency, only a few number of thermoelectric devices are required for condensing the hexane. The hexane must flow through passages in a metal block that is cooled by the thermoelectric devices. The hexane cannot contact the thermoelectric device directly, as there is a risk of explosion if the hexane comes in contact with the electrical connectors. The hexane will be flow through an aluminum block with passages cut through it. The original design for the condenser was one using stainless steel construction, however, due to the high costs of materials and machining, it was decided to use
aluminum for the first prototype. Figure 14, above, shows the overall design of the condenser, with cooling blocks attached. The *Hexane Condenser Block* is attached to the cold side of the thermoelectric device, so that heat energy is removed from it. The *Water Cooling Block* is attached to the hot side of the thermoelectric device and acts as a heat-sink. Water flows through this block and removes the heat that the device transfers and emits. This offers a significant increase in improvement over an air-cooled hot side.

### 4.3.3 Hexane Condenser Block

The number of passes that will be made in the *Hexane Condenser Block* is limited by the minimum bending radius of the tubing that will be used to create the 180 degree turns. Since 3/8” tubing will be used to create these turns, the centerline bend radius of 15/16” is the distance the passages must be offset from each other. This means that the cooling block that was designed will have three passes. A diagram of the hexane cooling block in the system is shown in Figure 15, at left. Hexane enters the condenser block and flows through the passages, where it is condensed. The condensed hexane drains through the vertical passage, labeled *Condensate Passage*, and flows to the *Hexane Reservoir*. Any hexane vapor that is not condensed flows through the *Recirculation Tube*, so that it can be recycled through the condenser.

### 4.3.4 Water Cooling Block

A SolidWorks model of the *Water Cooling Block* is shown in Figure 16, at left. Water flows in through flexible plastic tubing and makes seven passes through the cooling block. This dense array of water passes will allow a high rate of heat transfer, which will keep the hot-side of the condenser cooler. Doing so will allow the cold side to be even colder.
5. Tubing, Valves, & Fittings

Each tube that hexane comes in contact with must be of stainless steel construction, to ensure acceptable component life. Additionally, since the system is under vacuum during operation, all tube fittings must be able to hold a vacuum. Although copper sweat fittings are the industry standard for HVAC applications, it is not possible to solder stainless steel pipes together, due to its high melting point. The most effective type of seal for stainless steel would be a welded fitting, but these are expensive and time consuming.

Another option, and the one that was settled upon, was compression fittings. Compression fittings are typically flare fittings, which involve deforming the end of the tube so that it forms an airtight seal with the fitting around it. However, a less expensive option and one that does not require specialized flaring equipment, is Swagelok fittings. Swagelok fittings (named for the company that produces them) operate by deforming two ferrules which slip around the tube, forming an airtight seal.

6. Framing

Without a sturdy frame to which the components may be mounted, the system is merely a pile of parts. It was decided that aluminum t-slot framing would be used for the substructure of the extraction system. It is easily constructed and reconfigurable, which will be important when constructing the system and connecting all of the components with the tubing routes. 80/20 is one of the leading manufacturers of t-slot framing systems, and it is their parts that the system has specified. A full list of these parts can be found on the Bill of Materials, in Appendix A.
7. Final Design Documentation
In order to allow future groups to pick up where the current group left off, detailed part drawings, assembly drawings, and parts lists for each component of the system have been produced. The following sections are aimed to provide a guide for the design documentation and aid in the assembly of components of the system, and the system as a whole.

7.1 Bill of Materials
The Bill of Materials for the entire system is listed in Appendix A. This details all items that must be purchased or acquired in order to assemble hexane extraction system. The leftmost column on the Bill of Materials is a BOM Item Number. This identifies each material or piece of equipment. Custom parts that require a stock material will reference the BOM Item Number of the stock required. Each item on the Bill of Materials contains:

- Description of the item
- Manufacturer and manufacturer part number, if available
- Vendor and vendor part number
- Price
- Quantity required

7.2 Custom Parts List
There are many parts in the system that must be manufactured or modified. These parts are detailed in the Custom Parts List, found in Appendix B. Each custom part is assigned a number, beginning with 100. Each custom part drawing is listed in Appendix C.

7.3 Vendor Parts List
Each piece of equipment on the Bill of Materials that does not require modification is assigned a vendor part number. The Vendor Parts List of all such parts is found in Appendix D. The vendor part numbers begin at 200, in order to distinguish them from the custom parts. Vendor parts do not have part drawings, although many can be obtained from the vendor if required.

7.4 Assembly Drawings and Parts Lists
Assembly drawings serve as the instructions for assembling the entire system. They are assigned numbers beginning with 300, in order to distinguish them from the custom parts and vendor parts. A list of all of the assemblies is provided in Appendix E. Each assembly is accompanied by an Assembly Parts List, which lists all of the parts and subassemblies that are required to construct that assembly. Each Assembly Drawing and accompanying Assembly Drawing Parts List is shown in Appendix F.

The upper-level assembly drawing, System Assembly, is used to assemble the entire system. It references the other assembly drawings, which, in turn, reference sub-assembly drawings and part drawings. In this manner, the assemblies can be built separately and added to the upper-level system assembly.
## Bill of Materials

**Algae Oil Extraction Capstone Project**

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<td>Hot Water Bath Bucket</td>
<td>15 Gallon Natural Closed Head Drum, 16&quot; Dia x 22.5/8&quot;H</td>
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<td>Garden Hose Male-Female Fitting Brass Outlet w/ 1/2&quot; Shut-Off Valves</td>
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<td>Garden Hose</td>
<td>Heavy Duty Garden Hose 5/8&quot; ID, 100' length</td>
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<td>16</td>
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<td>17</td>
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<td>18</td>
<td>Bottom</td>
<td>10.75&quot; OD x 1&quot; Th Disk</td>
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<td></td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>25</td>
<td>Bottom</td>
<td>8&quot; OD SS x 1.7&quot; Th, 304L Disk</td>
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<td>26</td>
<td>Mounting Tabs</td>
<td>Aluminum 6061, 12&quot; x 1.5 x 1/2&quot;</td>
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<td>27</td>
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<tr>
<td>28</td>
<td>Lid Bolts</td>
<td>2&quot;/20 X 1&quot; L, Zinc Plated, SHCS, Pack of 25</td>
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<td>Mounting Tab Bolts</td>
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<td>Labor - Extraction Chamber</td>
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<td>Labor - Miscella Tank</td>
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<td>32</td>
<td>Labor - Hexane Reservoir</td>
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<td>34</td>
<td>3/4&quot; Inch Tube</td>
<td>Steel Tubing, 0.035&quot; Wall Thickness</td>
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<td>35</td>
<td>1/2&quot; Inch Tube</td>
<td>Steel Tubing, 0.038&quot; Wall Thickness</td>
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<td>36</td>
<td>1/2&quot; Inch Bender</td>
<td>3/8&quot; Tube Bender</td>
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<td>38</td>
<td>Tee</td>
<td>7/16&quot; SS Tee</td>
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<td>Male Adapter</td>
<td>1/4&quot; Male NPT x 1/2&quot; Female Swagelok Adapter</td>
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<td>3/8&quot; SS Ball Valve w/ Female Acrylic Fittings, 1/2&quot; Tube Size</td>
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<td>Framing Profile</td>
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<td>End Fastener</td>
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<td>T-Nut Bolt</td>
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Total Cost: $6,362.61
## Appendix B: Custom Parts List

### Custom Parts List

Algae Oil Extraction Capstone Project

<table>
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<tr>
<th>Part No.</th>
<th>Part Title</th>
<th>Fabricator</th>
<th>Price/Unit</th>
<th>Total Qty</th>
<th>Unit</th>
<th>Price</th>
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Total Cost $1,978.93
Appendix C: Custom Parts Drawings

Title:

**Body, Hexane Reservoir**

Use BOM Item No. 22

Material: Stainless Steel, 304

Finish: None

Application: Do not scale drawing

Dimensions are in inches. Tolerances:
- Fractional:
- Angular: Machined to
- Bend ± Two place decimal
- Three place decimal

Interpret geometric tolerancing per:

UNLESS OTHERWISE SPECIFIED:

<table>
<thead>
<tr>
<th>NAME</th>
<th>DATE</th>
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<tr>
<td>WAS</td>
<td>4/5/10</td>
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Title: Algae Oil Extraction Group

Scale: 1:4

Sheet 1 of 1
USE BOM ITEM NO. 15

BODY, EXTRACTION CHAMBER

STAINLESS STEEL 304

DIMENSIONS ARE IN INCHES

TOLERANCES:
- FRACTIONAL
- ANGULAR: MACH
- BEND: THREE PLACE DECIMAL
- TIGHT PLACE DECIMAL

UNLESS OTHERWISE SPECIFIED:
- SCALE 1:8
- WEIGHT:
THEORETICAL VERTEX

(\phi 8.000) \phi 0.840

7.59°

(\phi 7.500)

0.500

(1.000)

Algae Oil Extraction Group

TITLE:

BOTTOM, RESERVOIR/MISCELLANEOUS TANK

SIZE DWG. NO. REV
A 103

SCALE: 1:4 WEIGHT:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:

FRACTIONAL ±
ANGULAR: MACH ±
TWO PLACE DECIMAL ±
THREE Places DECIMAL ±

TOLERANCING PER:

INTERPRET GEOMETRIC

MATERIAL:
STAINLESS STEEL, 304

APPLICATION

NEXT ASSY USED ON FINISH

USE BOM ITEM NO. 25

NONE

CHECKED

ENG APPR.

MFG APPR.

Q.A.

COMMENTS:

DO NOT SCALE DRAWING

DRAWN WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

WAS 4/5/10

Q.A.

MFG APPR.
Theoritical Vertex

(Ø 10.750)

Ø 10.420

5.48°

Ø .840

.500

(1.000)

Algae Oil Extraction Group

Title:

Bottom, Extraction Chamber

Use BOM Item No. 18

Material: Stainless Steel, 304

Tolerancing Per: Interpreted Geometric

Dimensions are in inches

Tolerances:
- Fractional ±
- Angular: Machined ±
- Bend ±
- Two Place Decimal ±
- Three Place Decimal ±

 Comments:

Size: A

Drawn: Was 4/5/10

Checked

Eng. Approv.

Mfg. Approv.

Q.A.

Rev.

Sheet 1 of 1
Algae Oil Extraction Group

TITLE: LID, EXTRACTION CHAMBER

SIZE: A

DRAWN: WAS 4/5/10
CHECKED: Q.A.
ENG APPR.: MFG APPR.

MATERIAL: STAINLESS STEEL, 304

INTERPRET GEOMETRIC TOLERANCING PER:

DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTIONAL ±
ANGULAR: MACH ², BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

TOLERANCING PER:

UNLESS OTHERWISE SPECIFIED:

NOTES:

USE BOM ITEM NO. 16

NEXT ASSY USED ON

FINISH

APPLICATION

NONE

DO NOT SCALE DRAWING

(φ 13.920)

φ 12.500

90.00° 90.00°
90.00° 90.00°

.250 X 4

.500
Appendix C: Custom Parts Drawings

 SECTION A-A

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL:
ANGULAR: MACH\#2 BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL:
STAINLESS STEEL 304

USE BOM ITEM NO. 17

Algae Oil Extraction Group

LID MOUNTING FLANGE
EXTRACTION CHAMBER

NAME DATE
DRAWN WAS 4/7/10
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

SIZE DWG. NO. REV
A 108 -

SCALE: 1:4 WEIG HT: SHEET 1 OF 1

EXTRACTION CHAMBER

6X 1/4-20 UNC THRU ALL

10.750)
(13.920)

.210+.010 - .000

.100

(11.909)

.100

(5.00)

(5.00)

90.00°

90.00°

90.00°

90.00°

45.00°

45.00°

45.00°

45.00°

A

A

12.500

(11.909)

11.489+.000 -.005

11.400
Algae Oil Extraction

STRAINER BODY

DIMENSIONS ARE IN INCHES
TOLERANCES:
  FRACTIONAL ±
  ANGULAR: MACH ±
  TWO PLACE DECIMAL ±
  THREE PLACE DECIMAL ±

MATERIAL: STAINLESS STEEL 304

PROHIBITED. REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

WELD ENTIRE LENGTH

R4.937

(.063)

11.750

USE BOM ITEM NO. 21

DO NOT SCALE DRAWING

APPLICATION

FINISH

NEXT ASSY

USED ON

NAME

DATE

DRAWN

WAS

4/19/10
Algae Oil Extraction

2 FT LENGTH

DIMENSIONS ARE IN INCHES
TOlERANCES:
FRACTIONAL ±
ANGULAR: MACH ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL
ALUMINUM 6061

QUALITY ASSURANCE

USER BOM ITEM NO. 45

PROHIBITED.

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### Algae Oil Extraction

**Aluminum Profile, 3 FT LENGTH**

<table>
<thead>
<tr>
<th>NAME</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAWN</td>
<td>4/20/10</td>
</tr>
</tbody>
</table>

**Tolerances:**
- Fractional: ±
- Angular: Mach ±
- Bend ±
- Two Place Decimal: ±
- Three Place Decimal: ±

**Use BOM Item No. 45**

**Comments:**

**Dimensions are in inches**

**Material:**

**Finish:**

**Application:**

**Comments:**

**Proprietary and Confidential**

The information contained in this drawing is the sole property of [insert company name here]. Any reproduction in part or as a whole without the written permission of [insert company name here] is prohibited.

**Quantities**

<table>
<thead>
<tr>
<th>Q.A.</th>
<th>Comments</th>
</tr>
</thead>
</table>

**Appended C: Custom Parts Drawings**
### Algae Oil Extraction

**ALUMINUM PROFILE, 5 FT LENGTH**

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<tr>
<th>MATERIAL</th>
<th>Finish</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DIMENSIONS ARE IN INCHES**

- **TOLERANCES**
  - **FRACTIONAL**: ±
  - **ANGULAR**: MACH ±
  - **BEND**: ±
  - **TWO PLACE DECIMAL**: ±
  - **THREE PLACE DECIMAL**: ±

**USE BOM ITEM NO. 45**

<table>
<thead>
<tr>
<th>NEXT ASY</th>
<th>USED ON</th>
<th>APPLICATION</th>
<th>DO NOT SCALE DRAWING</th>
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</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**COMMENTS:**

- **PROPRIETARY AND CONFIDENTIAL**
  - THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF [INSERT COMPANY NAME HERE]. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF [INSERT COMPANY NAME HERE] IS PROHIBITED.
## Vendor Parts List

**Algae Oil Extraction Capstone Project**

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Description</th>
<th>BOM Item No.</th>
<th>Manufacturer</th>
<th>Manufacturer Part No.</th>
<th>Vendor</th>
<th>Vendor Part No.</th>
<th>Price/Unit</th>
<th>Total Qty</th>
<th>Unit</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>GAST, 1/8 HP Oilless Piston Vacuum Pump</td>
<td>1</td>
<td>GAST</td>
<td>ROA-P251-AA</td>
<td>Grainger</td>
<td>52669</td>
<td>$302.00</td>
<td>1</td>
<td>EA</td>
<td>$302.00</td>
</tr>
<tr>
<td>201</td>
<td>Thermoelectric Element, 62mm X 62 mm, 24A Max, 15.2V Max</td>
<td>3</td>
<td>Custom Thermoelectric</td>
<td>12711-5M31-24CZ</td>
<td>Custom Thermoelectric</td>
<td>12711-5M31-24CZ</td>
<td>$45.50</td>
<td>2</td>
<td>EA</td>
<td>$91.00</td>
</tr>
<tr>
<td>202</td>
<td>Thermoelectric Element, 50mm X 50 mm, 12A Max, 15.2V Max</td>
<td>4</td>
<td>Custom Thermoelectric</td>
<td>12711-9M31-12CW</td>
<td>Custom Thermoelectric</td>
<td>12711-9M31-12CW</td>
<td>$34.50</td>
<td>2</td>
<td>EA</td>
<td>$69.00</td>
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<tr>
<td>203</td>
<td>Bosch PowerStar AE9.5 Point-of-Use Water Heater</td>
<td>6</td>
<td>Bosch</td>
<td>PowerStar AE9.5</td>
<td>-</td>
<td>amazon.com</td>
<td>$200.00</td>
<td>1</td>
<td>EA</td>
<td>$200.00</td>
</tr>
<tr>
<td>204</td>
<td>3/8&quot; OD Flexible Plastic Tubing - Cut to Fit</td>
<td>8</td>
<td>-</td>
<td>Park's Hardware</td>
<td>-</td>
<td>Park's Hardware</td>
<td>$0.87</td>
<td>10</td>
<td>FT</td>
<td>$8.70</td>
</tr>
<tr>
<td>205</td>
<td>Adapter, Thread Size 1/4 In, Barb Size 3/8 In</td>
<td>9</td>
<td>-</td>
<td>Grainger</td>
<td>JVRY1</td>
<td>$0.68</td>
<td>14</td>
<td>EA</td>
<td>$9.48</td>
<td></td>
</tr>
<tr>
<td>206</td>
<td>Steel Worm Drive Clamp, 7/32&quot; 5/8&quot; ID Range</td>
<td>10</td>
<td>-</td>
<td>McMaster</td>
<td>S388K14</td>
<td>$0.75</td>
<td>14</td>
<td>EA</td>
<td>$10.56</td>
<td></td>
</tr>
<tr>
<td>207</td>
<td>15 Gallon Natural Closed Head Drum, 16&quot; Dia x 22-3/4&quot;H</td>
<td>11</td>
<td>-</td>
<td>U.S. Plastic Corp.</td>
<td>74126</td>
<td>$33.90</td>
<td>2</td>
<td>EA</td>
<td>$67.80</td>
<td></td>
</tr>
<tr>
<td>208</td>
<td>Garden Hose Multi-Faucet Fitting Brass Outlet w/2 Shut-Off Valves</td>
<td>12</td>
<td>-</td>
<td>McMaster</td>
<td>7459711</td>
<td>$11.00</td>
<td>2</td>
<td>EA</td>
<td>$22.00</td>
<td></td>
</tr>
<tr>
<td>209</td>
<td>Heavy Duty Rubber Garden Hose 3/4&quot; ID, 5' Length</td>
<td>13</td>
<td>-</td>
<td>McMaster</td>
<td>7459712</td>
<td>$11.85</td>
<td>4</td>
<td>EA</td>
<td>$47.40</td>
<td></td>
</tr>
<tr>
<td>210</td>
<td>12 VDC Output, 100 Watts, 8.5 Amps</td>
<td>14</td>
<td>-</td>
<td>McMaster</td>
<td>7050K58</td>
<td>$205.56</td>
<td>1</td>
<td>EA</td>
<td>$205.56</td>
<td></td>
</tr>
<tr>
<td>211</td>
<td>ASA668A - 277 D-ring, FEP-Encapsulated Silicone, Shore A: 70</td>
<td>19</td>
<td>-</td>
<td>McMaster</td>
<td>9319K303</td>
<td>$12.53</td>
<td>1</td>
<td>EA</td>
<td>$12.53</td>
<td></td>
</tr>
<tr>
<td>213</td>
<td>1/4&quot;-20 X 1&quot; L, Zinc Plated, SHCS</td>
<td>28</td>
<td>-</td>
<td>McMaster</td>
<td>90128A247</td>
<td>$0.38</td>
<td>16</td>
<td>EA</td>
<td>$6.13</td>
<td></td>
</tr>
<tr>
<td>214</td>
<td>1/4&quot;-20 X 1&quot; L, Zinc Plated, SHCS W/Lock Washer</td>
<td>29</td>
<td>-</td>
<td>McMaster</td>
<td>94912A465</td>
<td>$1.78</td>
<td>6</td>
<td>EA</td>
<td>$10.68</td>
<td></td>
</tr>
<tr>
<td>215</td>
<td>1/2&quot; SS Tubing, 0.035&quot; Wall Thickness - Bend/Cut to Fit</td>
<td>34</td>
<td>-</td>
<td>Maine Valve &amp; Fitting Co.</td>
<td>OS-304L-TB-W-035</td>
<td>-</td>
<td>-</td>
<td>20</td>
<td>FT</td>
<td>$66.00</td>
</tr>
<tr>
<td>216</td>
<td>1/8&quot; SS Tubing, 0.028&quot; Wall Thickness - Bend/Cut to Fit</td>
<td>35</td>
<td>-</td>
<td>McMaster</td>
<td>8457K25</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>FT</td>
<td>$11.10</td>
</tr>
<tr>
<td>217</td>
<td>1/2&quot; SS Tee, Swagelok Adapter</td>
<td>38</td>
<td>Swagelok</td>
<td>316L-810-3</td>
<td>Swagelok</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>EA</td>
<td>$142.80</td>
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<tr>
<td>218</td>
<td>1/4&quot; Male NPT x 1/2&quot; Female Swagelok Adapter</td>
<td>39</td>
<td>Swagelok</td>
<td>55-B10-1-8</td>
<td>Maine Valve/Fitting</td>
<td>-</td>
<td>$15.80</td>
<td>3</td>
<td>EA</td>
<td>$47.40</td>
</tr>
<tr>
<td>219</td>
<td>1/4&quot; Male NPT x 3/8&quot; Female Swagelok Adapter</td>
<td>40</td>
<td>Swagelok</td>
<td>316L-600-1-4</td>
<td>Maine Valve/Fitting</td>
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<td>$10.50</td>
<td>4</td>
<td>EA</td>
<td>$42.00</td>
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<tr>
<td>220</td>
<td>1/2&quot; Male Pipe Weld x Female Swagelok Adapter</td>
<td>41</td>
<td>Swagelok</td>
<td>55-B10-1-BW</td>
<td>Maine Valve/Fitting</td>
<td>-</td>
<td>$15.90</td>
<td>8</td>
<td>EA</td>
<td>$127.20</td>
</tr>
<tr>
<td>221</td>
<td>3/16 SS Ball Valve w/Yor-Lok Fittings, 1/2&quot; Tube Size</td>
<td>44</td>
<td>-</td>
<td>McMaster</td>
<td>4537K23</td>
<td>$87.44</td>
<td>7</td>
<td>EA</td>
<td>$612.08</td>
<td></td>
</tr>
<tr>
<td>222</td>
<td>Joining Plate, L, 5 Hole</td>
<td>46</td>
<td>-</td>
<td>Parco Inc.com</td>
<td>4251</td>
<td>-</td>
<td>-</td>
<td>8</td>
<td>EA</td>
<td>$56.80</td>
</tr>
<tr>
<td>223</td>
<td>Joining Plate, Tee, 6 Hole</td>
<td>47</td>
<td>-</td>
<td>Parco Inc.com</td>
<td>4340</td>
<td>-</td>
<td>-</td>
<td>26</td>
<td>EA</td>
<td>$189.80</td>
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<tr>
<td>224</td>
<td>15 Series Inside Corner Bracket, 2 Hole</td>
<td>48</td>
<td>-</td>
<td>Parco Inc.com</td>
<td>4295</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>EA</td>
<td>$10.95</td>
</tr>
<tr>
<td>225</td>
<td>15 Series Single Economy T-Nut, (5/16-18)</td>
<td>49</td>
<td>-</td>
<td>Parco Inc.com</td>
<td>3278</td>
<td>-</td>
<td>0.27</td>
<td>3</td>
<td>EA</td>
<td>$0.81</td>
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<tr>
<td>226</td>
<td>15 Series Double Economy T-Nut, (5/16-18)</td>
<td>50</td>
<td>-</td>
<td>Parco Inc.com</td>
<td>3279</td>
<td>-</td>
<td>0.79</td>
<td>34</td>
<td>EA</td>
<td>$26.86</td>
</tr>
<tr>
<td>227</td>
<td>15 Series Triple Economy T-Nut, (5/16-18)</td>
<td>51</td>
<td>-</td>
<td>Parco Inc.com</td>
<td>3285</td>
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<td>1.35</td>
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<td>$45.90</td>
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<tr>
<td>228</td>
<td>15 Series Standard End Fastener</td>
<td>52</td>
<td>-</td>
<td>Parco Inc.com</td>
<td>3380</td>
<td>-</td>
<td>1.60</td>
<td>38</td>
<td>EA</td>
<td>$60.80</td>
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<tr>
<td>229</td>
<td>Button Head, Socket Cap Screw, 5/16-18 X 5/8&quot; L</td>
<td>53</td>
<td>-</td>
<td>McMaster</td>
<td>91255A5BD</td>
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<td>$0.20</td>
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<td>EA</td>
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**Total Cost** $2,526.17
## Appendix E: Assembly List

### Assembly List

Algae Oil Extraction Capstone Project

<table>
<thead>
<tr>
<th>Assembly No.</th>
<th>Assembly Title</th>
<th>Fabricator</th>
<th>Total Qty</th>
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</thead>
<tbody>
<tr>
<td>300</td>
<td>SYSTEM ASSEMBLY</td>
<td>Crosby Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>301</td>
<td>FRAME ASSEMBLY</td>
<td>Crosby Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>302</td>
<td>HEXANE RESERVOIR ASSEMBLY</td>
<td>Advanced Manufacturing Center</td>
<td>1</td>
</tr>
<tr>
<td>303</td>
<td>MISCELLA TANK ASSEMBLY</td>
<td>Advanced Manufacturing Center</td>
<td>1</td>
</tr>
<tr>
<td>304</td>
<td>EXTRACTION CHAMBER ASSEMBLY</td>
<td>Advanced Manufacturing Center</td>
<td>1</td>
</tr>
<tr>
<td>305</td>
<td>HEATING SYSTEM ASSEMBLY</td>
<td>Crosby Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>306</td>
<td>CONDENSER ASSEMBLY</td>
<td>Crosby Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>307</td>
<td>HEXANE CONDENSER BLOCK ASSEMBLY</td>
<td>Crosby Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>308</td>
<td>WATER BLOCK ASSEMBLY</td>
<td>Crosby Laboratory</td>
<td>1</td>
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<tr>
<td>309</td>
<td>STRAINER BUCKET ASSEMBLY</td>
<td>Advanced Manufacturing Center</td>
<td>1</td>
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## Appendix F: Assembly Drawings & Assembly Parts Lists

### Assembly Drawing Parts List

<table>
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<th>Item No.</th>
<th>Description</th>
<th>Part No.</th>
<th>Manufacturer</th>
<th>Manufacturer Part No.</th>
<th>Vendor</th>
<th>Vendor Part No.</th>
<th>Price/Unit</th>
<th>Qty</th>
<th>Unit</th>
<th>Price</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>HEXANE RESERVOIR ASSEMBLY</td>
<td>302</td>
<td>Advanced Manufacturing Center</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$827.19</td>
<td>1</td>
<td>EA</td>
<td>$827.19</td>
</tr>
<tr>
<td>2</td>
<td>EXTRACTION CHAMBER ASSEMBLY</td>
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<td>Advanced Manufacturing Center</td>
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<td>-</td>
<td>-</td>
<td>$1,601.99</td>
<td>1</td>
<td>EA</td>
<td>$1,601.99</td>
</tr>
<tr>
<td>3</td>
<td>MISCELLA TANK ASSEMBLY</td>
<td>303</td>
<td>Advanced Manufacturing Center</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$843.09</td>
<td>1</td>
<td>EA</td>
<td>$843.09</td>
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<tr>
<td>4</td>
<td>CONDENSER ASSEMBLY</td>
<td>306</td>
<td>Crosby Laboratory</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$168.78</td>
<td>1</td>
<td>EA</td>
<td>$168.78</td>
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<tr>
<td>5</td>
<td>HEATING SYSTEM ASSEMBLY</td>
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<td>Crosby Laboratory</td>
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<td>-</td>
<td>$337.20</td>
<td>1</td>
<td>EA</td>
<td>$337.20</td>
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<tr>
<td>6</td>
<td>316 SS Ball Valve w/For-Lok Fittings, 1/2&quot; Tube Size</td>
<td>221</td>
<td>-</td>
<td>-</td>
<td>McMaster</td>
<td>4537K23</td>
<td>$87.44</td>
<td>7</td>
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<th>Qty</th>
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Total Cost $862.97
## Assembly Drawing Parts List

**Assembly Drawing Number:** HEXANE RESERVOIR ASSEMBLY

**Assembly Drawing Number:** 302

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<td>SS-810-1-8W</td>
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<th>Price/Unit</th>
<th>Qty</th>
<th>Unit</th>
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Total Cost: $843.09
DO NOT SCALE DRAWING

EXTRACTION CHAMBER ASSEMBLY

UNLESS OTHERWISE SPECIFIED:

WEIGHT:

REV'D WRC:

SIZE

SCALE: 1:3

Algae Oil Extraction

Q.A.

MFG APPR.

ENG APPR.

CHECKED

DRAWN

FINISH

MATERIAL

TOLERANCING PER:

INTERPRET GEOMETRIC

PROHIBITED.

THE INFORMATION CONTAINED IN THIS

DRAWING IS THE SOLE PROPERTY OF<INSERT COMPANY NAME HERE>.  ANY REPRODUCTION IN PART OR AS A WHOLE

WITHOUT THE WRITTEN PERMISSION OF

<INSERT COMPANY NAME HERE> IS PROHIBITED.

APPLICATION DIMENSIONS ARE IN INCHES

TOLERANCES:

FRACTIONAL

ANGULAR: MACH

THREE PLACE DECIMAL

TWO PLACE DECIMAL

USED ON

APPLICATION
### Assembly Drawing Parts List

#### Assembly Name: EXTRATION CHAMBER ASSEMBLY

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<th>Manufacturer Part No.</th>
<th>Vendor</th>
<th>Vendor Part No.</th>
<th>Price/Unit</th>
<th>Qty</th>
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**Total Cost** $1,601.99
### Assembly Drawing Parts List

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<th>Manufacturer Part No.</th>
<th>Vendor</th>
<th>Vendor Part No.</th>
<th>Price/Unit</th>
<th>Qty</th>
<th>Unit</th>
<th>Price</th>
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Total Cost: $337.20
## Assembly Drawing Parts List

**Assembly Name:** CONDENSER ASSEMBLY  
**Assembly Drawing Number:** 306

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<td>-</td>
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**Total Cost:** $168.78
# Assembly Drawing Parts List

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**Total Cost** $115.36
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<th>Qty</th>
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<td>2</td>
<td>Adapter, Thread Size 1/4 in, Barb Size 3/8 in</td>
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<td>-</td>
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**Total Cost** $33.04
Appendix F: Assembly Drawings & Assembly Parts Lists

Algae Oil Extraction

STRAINER BUCKET ASSEMBLY

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL -
Q.A. -
COMMENTS -

NEXT ASSEMBLY USED ON
FINISH NONE
APPLICATION DO NOT SCALE DRAWING

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE COMPANY NAME HERE. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF THE COMPANY NAME HERE IS PROHIBITED.
### Assembly Drawing Parts List

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Description</th>
<th>Part No.</th>
<th>Manufacturer</th>
<th>Manufacturer Part No.</th>
<th>Vendor</th>
<th>Vendor Part No.</th>
<th>Price/Unit</th>
<th>Qty</th>
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**Total Cost** $430.98
Material Safety Data Sheet
Hexanes MSDS

Section 1: Chemical Product and Company Identification

Product Name: Hexanes
Catalog Codes: SLH2335, SLH2032
CAS#: 110-54-3
RTECS: MN9275000
TSCA: TSCA 8(b) inventory: Hexane
Cl#: Not applicable.
Synonym:
Chemical Name: Hexane
Chemical Formula: C6-H14

Contact Information:
Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396
US Sales: 1-800-901-7247
International Sales: 1-281-441-4400
Order Online: ScienceLab.com
CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300
International CHEMTREC, call: 1-703-527-3887
For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

<table>
<thead>
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<th>Name</th>
<th>CAS #</th>
<th>% by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexanes</td>
<td>110-54-3</td>
<td>98.5-99.9</td>
</tr>
</tbody>
</table>

Toxicological Data on Ingredients: Hexane: ORAL (LD50): Acute: 25000 mg/kg [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of skin contact (permeator), of ingestion, of inhalation. Slightly hazardous in case of skin contact (irritant), of eye contact (irritant).

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available.
MUTAGENIC EFFECTS: Mutagenic for bacteria and/or yeast.
TERATOGENIC EFFECTS: Not available.
DEVELOPMENTAL TOXICITY: Not available.
The substance may be toxic to peripheral nervous system, skin, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures
Eye Contact:
Check for and remove any contact lenses. Immediately flush eyes with running water for at least 15 minutes, keeping eyelids open. Get medical attention if irritation occurs.

Skin Contact: Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention if symptoms appear.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if symptoms appear.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

| Flammability of the Product: Flammable. |
| Auto-Ignition Temperature: 225°C (437°F) |
| Flash Points: CLOSED CUP: -22.5°C (-8.5°F). (TAG) |
| Flammable Limits: LOWER: 1.15% UPPER: 7.5% |
| Products of Combustion: These products are carbon oxides (CO, CO2). |
| Fire Fighting Media and Instructions: Flammable liquid, insoluble in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray or fog. |
| Special Remarks on Fire Hazards: Extremely flammable liquid and vapor. Vapor may cause flash fire. |
| Special Remarks on Explosion Hazards: Not available. |

Section 6: Accidental Release Measures
Appendix G: Material Data Safety Sheet for Hexane

Small Spill: Absorb with an inert material and put the spilled material in an appropriate waste disposal.

Large Spill:
Flammable liquid, insoluble in water. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not get water inside container. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep locked up. Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/vapor/spray. Avoid contact with skin. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Keep away from incompatibles such as oxidizing agents.

Storage:
Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Safety glasses. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves (impervious).

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 500 (ppm) from OSHA (PEL) [United States] Inhalation
TWA: 1800 (mg/m3) from OSHA (PEL) [United States] Inhalation
TWA: 176 (mg/m3) from ACGIH (TLV) [United States] SKIN
TWA: 50 (ppm) from ACGIH (TLV) [United States] SKIN
TWA: 500 STEL: 1000 (ppm) from ACGIH (TLV) [United States] Inhalation
TWA: 1760 STEL: 3500 (mg/m3) from ACGIH (TLV) [United States] Inhalation
Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Gasoline-like or petroleum-like (Slight.)

Taste: Not available.

Molecular Weight: 86.18g/mole

Color: Clear Colorless.
Appendix G: Material Data Safety Sheet for Hexane

**pH (1% soln/water):** Not applicable.

**Boiling Point:** 68°C (154.4°F)

**Melting Point:** -95°C (-139°F)

**Critical Temperature:** Not available.

**Specific Gravity:** 0.66 (Water = 1)

**Vapor Pressure:** 17.3 kPa (@ 20°C)

**Vapor Density:** 2.97 (Air = 1)

**Volatile:** Not available.

**Odor Threshold:** 130 ppm

**Water/Oil Dist. Coeff.:** The product is more soluble in oil; log(oil/water) = 3.9

**Ionicity (in Water):** Not available.

**Dispersion Properties:** See solubility in water, diethyl ether, acetone.

**Solubility:**
- Soluble in diethyl ether, acetone.
- Insoluble in cold water, hot water.

### Section 10: Stability and Reactivity Data

**Stability:** The product is stable.

**Instability Temperature:** Not available.

**Conditions of Instability:** Heat, ignition sources, incompatibles.

**Incompatibility with various substances:** Reactive with oxidizing agents.

**Corrosivity:** Not available.

**Special Remarks on Reactivity:** Hexane can react vigorously with strong oxidizers (e.g. chlorine, bromine, fluorine)

**Special Remarks on Corrosivity:** Not available.

**Polymerization:** Will not occur.

### Section 11: Toxicological Information

**Routes of Entry:** Absorbed through skin. Dermal contact. Inhalation. Ingestion.

**Toxicity to Animals:**
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE.

Acute oral toxicity (LD50): 25000 mg/kg [Rat].
Acute toxicity of the gas (LC50): 48000 ppm 4 hours [Rat].

**Chronic Effects on Humans:**
MUTAGENIC EFFECTS: Mutagenic for bacteria and/or yeast.
May cause damage to the following organs: peripheral nervous system, skin, central nervous system (CNS).

**Other Toxic Effects on Humans:**
### Section 12: Ecological Information

**Ecotoxicity:** Not available.

**BOD5 and COD:** Not available.

**Products of Biodegradation:**
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

**Toxicity of the Products of Biodegradation:** The product itself and its products of degradation are not toxic.

**Special Remarks on the Products of Biodegradation:** Not available.

### Section 13: Disposal Considerations

**Waste Disposal:**
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

### Section 14: Transport Information

**DOT Classification:** CLASS 3: Flammable liquid.

**Identification:** Hexane UNNA: 1208 PG: II

**Special Provisions for Transport:** Not available.

### Section 15: Other Regulatory Information

**Federal and State Regulations:**
Connecticut hazardous material survey.: Hexanes
Illinois toxic substances disclosure to employee act: Hexanes
Illinois chemical safety act: Hexanes
New York release reporting list: Hexanes
Rhode Island RTK hazardous substances: Hexanes
Pennsylvania RTK: Hexanes
Florida: Hexanes
Minnesota: Hexanes
Massachusetts RTK: Hexanes
Massachusetts spill list: Hexanes
New Jersey: Hexanes
New Jersey spill list: Hexanes
Louisiana spill reporting: Hexanes
TSCA 8(b) inventory: Hexanes
SARA 313 toxic chemical notification and release reporting: Hexanes
CERCLA: Hazardous substances.: Hexanes: 5000 lbs. (2268 kg)

Other Regulations:
EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS B-2: Flammable liquid with a flash point lower than 37.8°C (100°F).
CLASS D-2B: Material causing other toxic effects (TOXIC).

DSCL (EEC):
R11- Highly flammable.
R20- Harmful by inhalation.
R38- Irritating to skin.
R51/53- Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
R62- Possible risk of impaired fertility.
R65- Harmful: may cause lung damage if swallowed.
R67- Vapors may cause drowsiness or dizziness.
S9- Keep container in a well-ventilated place.
S16- Keep away from sources of ignition - No smoking.
S29- Do not empty into drains.
S33- Take precautionary measures against static discharges.
S36/37- Wear suitable protective clothing and gloves.
S61- Avoid release to the environment. Refer to special instructions/Safety data sheets.
S62- If swallowed, do not induce vomiting; seek medical advice immediately and show this

HMIS (U.S.A.):

Health Hazard: 2
Fire Hazard: 3
Reactivity: 0
Personal Protection: g

National Fire Protection Association (U.S.A.):
## Appendix G: Material Data Safety Sheet for Hexane

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<th>Health: 1</th>
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<tr>
<td>Flammability: 3</td>
</tr>
<tr>
<td>Reactivity: 0</td>
</tr>
</tbody>
</table>

### Specific hazard:

#### Protective Equipment:
- Gloves (impervious).
- Lab coat.
- Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate.
- Safety glasses.

---

### Section 16: Other Information

**References:** Not available.

**Other Special Considerations:** Not available.

**Created:** 10/10/2005 08:19 PM

**Last Updated:** 11/06/2008 12:00 PM

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Appendix H: Algae Batch Size Calculation

The purpose of this sheet is to calculate the volume of algae to be processed in a single batch using the hexane extractor.

**Volume of Algae Solution (Water+Algae):**

\[ V_{\text{solution}} := 2000\text{gal} \]

**Concentration of Algae Solution (Algae by Volume):**

This assumes that the concentration of algae by volume is the same as that by mass, a reasonable assumption.

\[ C_{\text{algae}} := 0.001 \]

**Volume of Algae in Solution:**

\[ V_{\text{algae}} := V_{\text{solution}} \cdot C_{\text{algae}} = 2 \cdot \text{gal} \]

\[ V_{\text{algae}} = 7.571\text{L} \]
Appendix I: Tank Sizing Calculation

The purpose of this sheet is to determine the required heights of the various tanks in the system, based on their volumes and commercially available stainless steel pipe sizes.

Volume of Extraction Tank: \( V_E \) := 4.5gal  
Volume of Miscella Tank: \( V_M \) := 3gal  
Volume of Hexane Reservoir: \( V_R \) := 2gal

For 10 in. Nominal Diameter Pipe:

Actual Inner Diameter:
\( d_{10} := 10.42 \text{in} \)

\[ r_{10} := \frac{d_{10}}{2} \]

Extraction Tank Height:
\[ h_E := \frac{V_E}{\pi r_{10}^2} = 1.016 \text{ ft} \]

\[ h_E = 12.19 \text{ in} \]

For 8 in. Nominal Diameter Pipe:

Actual Inner Diameter:
\( d_{8} := 7.5 \text{in} \)

\[ r_{8} := \frac{d_{8}}{2} \]

Miscella Tank Height:
\[ h_M := \frac{V_M}{\pi r_{8}^2} = 1.307 \text{ ft} \]

\[ h_M = 15.686 \text{ in} \]

Hexane Reservoir Height
\[ h_R := \frac{V_R}{\pi r_{8}^2} \]

\[ h_R = 10.458 \text{ in} \]
The purpose of this sheet is to calculate the final operating pressure of the extraction system, given an initial vacuum level and the amount of air introduced to the system upon opening the hexane reservoir.

**Input initial pressure achieved by vacuum pump**
\[ P_{\text{vac1}} := 2.5 \text{psi} \]

**Air Properties**

\[
\begin{align*}
\text{Gas Constant} & \quad \text{Operating Temperature} \quad \text{Atmospheric Pressure} \\
R_{\text{air}} & = 287.058 \frac{\text{J}}{\text{kg} \cdot \text{K}} & T_{\text{air}} & = 294.261 \text{ K} & P_{\text{atm}} & = 14.696 \text{ psi}
\end{align*}
\]

Density function:
\[ \rho(p) := \frac{p}{R_{\text{air}} T_{\text{air}}} \]

**Dimensions of System Components**

**DESIGN FOR TANK VOLUMES OF: 4 Gal Extraction Tank, 2 Gal Hexane Reservoir, 3 Gal Miscella Tank**

**Extraction Chamber:**
- Tank Height: \( h_{\text{extr}} := 12 \text{in} \)
- Tank Diameter (inner): \( d_{\text{extr}} := 10.42 \text{in} \)
- Tank volume:
  \[ V_{\text{extraction}} := \pi \frac{d_{\text{extr}}^2}{4} h_{\text{extr}} = 4.43 \text{ gal} \]

**Hexane Reservoir:**
- Tank Height: \( h_{\text{res}} := 10.5 \text{ in} = 10.5 \cdot \text{in} \)
- Tank Diameter (inner): \( d_{\text{res}} := 7.5 \text{ in} \)
- Tank volume:
  \[ V_{\text{res}} := \pi \frac{d_{\text{res}}^2}{4} h_{\text{res}} = 2.008 \text{ gal} \]

**Miscella Tank:**
- Tank Height: \( h_{\text{mis}} := 16 \text{ in} = 16 \cdot \text{in} \)
- Tank Diameter (inner): \( d_{\text{mis}} := 7.5 \text{ in} \)
- Tank volume:
  \[ V_{\text{miscella}} := \pi \frac{d_{\text{mis}}^2}{4} h_{\text{mis}} = 3.06 \text{ gal} \]

**Tubing:**
- Total tubing length: \( l_{\text{tubing}} := 20 \text{ ft} \)
- Tubing diameter (inner): \( d_{\text{tube}} := .43 \text{ in} \)
- Tubing volume:
  \[ V_{\text{tubing}} := l_{\text{tubing}} \pi \frac{d_{\text{tube}}^2}{4} = 0.151 \text{ gal} \]

**Volume occupied by air when evacuation begins:**
\[ V_1 := V_{\text{extraction}} + V_{\text{tubing}} + V_{\text{miscella}} = 1.021 \text{ ft}^3 \]

**Mass of air in system at time of evacuation:**
\[ \rho_1 := \rho(p_{\text{vac1}}) = 0.013 \frac{\text{lbm}}{\text{ft}^3} \]
\[ m_1 := V_1 \rho_1 = 0.013 \text{ lbm} \]
Appendix J: Vacuum Pressure Calculation

Write functions necessary to compute the pressure after the hexane reservoir is opened

**Volume occupied by air after hexane reservoir opened**

\[ V_2(V_{\text{hexane}}) := V_1 + V_{\text{res}} - V_{\text{hexane}} \]

**Mass of air added when hexane reservoir is exposed to vacuum**

\[ \rho_{\text{atm}} := \rho(P_{\text{atm}}) = 0.075 \text{ lbm/ft}^3 \]

\[ m_{\text{add}}(V_{\text{hexane}}) := \rho_{\text{atm}}(V_{\text{res}} - V_{\text{hexane}}) \]

**Mass of air in system after hexane reservoir is exposed to vacuum**

\[ m_2(m_{\text{add}}) := m_1 + m_{\text{add}} \]

**Compute Pressure in Tank when Hexane Reservoir is opened to vacuum**

Use ideal gas law

\[ P \cdot V = m \cdot R \cdot T \]

**Calculate Final System Pressure**

Substitute the expressions above into the pressure expression:

\[ P_2(V_{\text{hexane}}) := \frac{[m_1 + \rho_{\text{atm}}(V_{\text{res}} - V_{\text{hexane}})] \cdot R_{\text{air}} \cdot T_{\text{air}}}{V_1 + V_{\text{res}} - V_{\text{hexane}}} \]

**Input volumes of hexane used in system**

<table>
<thead>
<tr>
<th>Volume of Hexane</th>
<th>Final System Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gallon</td>
<td>( P_{1_\text{gal}} := P_2(V_{\text{hex1}}) = 3.922 \text{ psi} )</td>
</tr>
<tr>
<td>1.25 Gallons</td>
<td>( P_{1.25_\text{gal}} := P_2(V_{\text{hex2}}) = 3.601 \text{ psi} )</td>
</tr>
<tr>
<td>1.5 Gallons</td>
<td>( P_{1.5_\text{gal}} := P_2(V_{\text{hex3}}) = 3.260 \text{ psi} )</td>
</tr>
<tr>
<td>1.75 Gallons</td>
<td>( P_{1.75_\text{gal}} := P_2(V_{\text{hex4}}) = 2.899 \text{ psi} )</td>
</tr>
<tr>
<td>2 Gallons</td>
<td>( P_{2_\text{gal}} := P_2(V_{\text{hex5}}) = 2.513 \text{ psi} )</td>
</tr>
</tbody>
</table>

**Flow rate Calculation**

Evacuation Volume:

\[ V_{\text{evac}} := V_1 = 1.021 \text{ ft}^3 \]

Initial Pressure, \( P_o \):

\[ P_o := P_{\text{atm}} = 14.696 \text{ psi} \]

Initial Pressure, \( P_1 \):

\[ P_1 := 2.5 \text{ psi} \]

Desired evacuation time:

\[ t_{\text{evac}} := 5 \text{ min} \]

Evacuation time expression for constant flow rate, \( Q \):

\[ t_{\text{evac}} = \left( \frac{V_{\text{evac}}}{Q} \right) \ln \left( \frac{P_o}{P_1} \right) \]

Required Flow Rate for given evacuation time:

\[ Q := \left( \frac{V_{\text{evac}}}{t_{\text{evac}}} \right) \ln \left( \frac{P_o}{P_1} \right) = 0.362 \text{ ft}^3/\text{min} \]