Abstract

This project was suggested by Randy Elenbaas, a Chemical Engineer at Vertellus Specialties Inc. The goal of this project was to build a machine that lifts and dumps the chemical contents of a fiber drum into a variety of chemical reactors; the machine was to be efficiently operated by one person.

The design of the machine was built around the goals of improving efficiency, maintaining a safe working environment, and keeping the cost of the machine low. Team ATLASLIFT also wanted to be good stewards of the materials and money given and wanted to communicate with Vertellus in an honest and trustworthy manner.

The machine meets all functionality requirements such as the necessary cycle time, accurate positioning of the barrels over the reactor, robust construction to handle industrial conditions, and safety requirements such as being explosion proof. The overall cost of the project also falls within the provided budget.
# Table of Contents

1 INTRODUCTION ................................................................................................................. 1  
1.1 Team Description ............................................................................................................. 1  
1.2 Project Statement ............................................................................................................. 2  

2 PROJECT OBJECTIVES ...................................................................................................... 3  
2.1 Functionality .................................................................................................................... 3  
2.1.1 Project Scope .................................................................................................................. 3  
2.1.2 Performance .................................................................................................................. 4  
2.1.3 Reliability ..................................................................................................................... 4  
2.1.4 Safety .......................................................................................................................... 4  
2.1.5 Costs ........................................................................................................................... 4  

3 MACHINE DESIGN .............................................................................................................. 5  
3.1 Machine Design Summary ............................................................................................... 5  
3.1.1 Frame ............................................................................................................................ 5  
3.1.2 Mobility ....................................................................................................................... 7  
3.1.3 Salvaged Machine ......................................................................................................... 8  
3.1.4 Barrel Security .............................................................................................................. 9  
3.1.5 Driving Mechanisms ..................................................................................................... 9  
3.1.6 Stress Analysis ............................................................................................................. 11  
3.1.7 Wiring ......................................................................................................................... 13  

4 MATERIAL PROPERTIES ..................................................................................................... 14  
4.1 Powder Flow Characteristics .......................................................................................... 14  
4.2 Factors that Affect Powder Flowability .......................................................................... 14  
4.2.1 Particle Size and Shape ............................................................................................... 14  
4.2.2 Moisture Content ......................................................................................................... 14  
4.2.3 Temperature ............................................................................................................... 14  
4.2.4 External Surface .......................................................................................................... 14  
4.3 Material Flow Research ................................................................................................. 15  
4.3.1 Material Properties ...................................................................................................... 15  
4.3.2 Angle of Repose .......................................................................................................... 15  
4.3.3 Caking & Clumping ..................................................................................................... 15  
4.3.4 Rate of Discharge ....................................................................................................... 15
1 INTRODUCTION

1.1 Team Description
Mark Beckman is a Calvin College engineer with a concentration in Mechanical Engineering. He is from Holland, MI and graduated from Holland Christian. Mark has interned at Herman Miller in new product development for the past 3 years and has accepted a position at Herman Miller. In his free time Mark likes to sail, and in winter enjoys to snow ski.

Jonathan Brock is an engineer with a concentration in Mechanical Engineering. He has lived in the Grand Rapids area his whole life, graduating from Unity Christian High School in Hudsonville, MI. Jon has had two engineering internships, first with Moore & Bruggink Consulting Engineers during the summer of ’07 and then at Progressive Technologies Inc. in ’08. Jon is a Product Engineer at Vanerum Stelter. Jon enjoys water sports during the summer and skiing and snowboarding during the winter.

Erik Van Kampen is an engineer in the Chemical Engineering concentration. He grew up in Elmhurst, IL where he attended Timothy Christian High School. He spent the summer of ’08 living and working as an intern in Germany, where he developed active pharmaceutical ingredients at Boehringer Ingelheim. Erik is also a member of Calvin’s Cross Country and Track teams.

Tyler Wiers is an engineer in the Mechanical Engineering concentration. He is from Willard/Celeryville, OH where he attended Willard High School and spent his summers working on the family vegetable farm. Last summer he interned at Rapid-Line Inc. in Grand Rapids, MI. Tyler will be returning to Ohio to work for Wiers Farm Inc. Tyler enjoys a variety of activities and sports including hunting, basketball, tennis, and golf.
1.2 Project Statement

This project covers the design and fabrication of a device for use by Vertellus Specialties Inc. that lifts and pours the contents of cylindrical fiber barrels into chemical reactors. The barrels, which were manually lifted by two employees, can weigh in excess of 200 lbs. The reactor ports, i.e. where the chemicals are poured into, are located approximately 42” above ground level and approximately 24” behind the edge of the reactor (forward of where one can stand). The current process of manual lifting the barrels is physically strenuous and a potential safety hazard for the employees. Having a machine to accomplish the task allows operators to avoid injury from strenuous activity and to be more efficient with their time.
2 PROJECT OBJECTIVES

2.1 Functionality
The functionality of the machine was dictated by numerous elements such as the scope of the project, the necessary performance and reliability, the safety of operators, and overall project cost.

2.1.1 Project Scope
The main objective of the project was to develop a machine that can efficiently load the contents of the barrels into various reactors. Keeping the machine simple was continually a focus in the design process – the simpler the design the better. From an operator’s point of view, the less that is required from him or her – in terms of interaction with the device as well as initial training – the better. The reactors for which the ATLASLIFT was designed to serve can be seen in Figure 1.

![Figure 1: Reactors](image)

The initial project objectives were to pour into many types of reactors and dryers, with a focus on the dryers as they are more frequently used than the reactors. During a mid fall semester visit to Vertellus, the scope narrowed from pouring into reactors and dryers to only the reactors. This new direction narrowed the required capabilities of the device.

There are two sets of reactors, located in two buildings, which the machine will pour into. These two sets of reactors have similar dimensions, so a single pouring location will suffice. The reactors are located on the second floor of their respective buildings, which requires a means of transportation via fork-lift from one building to another as necessary. As a result, the machine
required some measure of transport security, i.e. some way to secure the machine to a pallet. To help accommodate this, wheels with brakes were included in the final design.

2.1.2 Performance
The machine must be able to lift and pour quickly and with as little effort as possible from the operator.

2.1.3 Reliability
The machine is intended for operation in an industrial setting, so it needs to be sturdy enough to handle rigorous use and a hazardous environment. The process of pouring powder chemicals is inherently dusty. Components were placed to facilitate easy maintenance; keeping maintenance time to a minimum is always a goal.

2.1.4 Safety
Because this machine will be operated by an employee standing near the machine, there is the potential hazard of getting something caught, pinched, or stuck in the machine. To prevent the operator from pinching his or her hands where the arm frame contacts the stopper bar, a piece of plexi-glass has been added which functions as a shield, blocking hands from being carelessly placed in the pinch point area.

Dust explosions were another concern addressed during the project. Dust from normal plant operation can, under the right circumstances, ignite and cause an explosion. To prevent these explosions, explosion proof electrical equipment was used. The electric motor and electrical housings are all UL listed under Class II Division 2 for combustible dusts.

Lastly, all sharp edges resulting from manufacturing processes were removed to prevent operators from cutting clothing or themselves.

2.1.5 Costs
One of the largest priorities of the ATLASILIFT was to minimize costs with no reduction in performance. Vertellus has graciously donated an obsolete machine to be used for scrap parts and promised to cover any costs they deem necessary.
3 MACHINE DESIGN

3.1 Machine Design Summary
The ATLASLIFT is a mobile chemical dumping machine. The frame is constructed of a tubular steel frame and is mounted to casters for easy mobility. The frame has two parts; the base and the tilting arm. Attached to the arm is a stainless steel chute that holds the barrels. The ATLASLIFT is driven by a hydraulic system. The hydraulic system is powered by an electric motor and is turned on and off with simple buttons. The motion of the ATLASLIFT is controlled by a bi-directional hydraulic control valve. An operator can push a lever and make the ATLASLIFT’s tilting arm go up, down, or shake.

3.1.1 Frame
The frame design for this machine is a very important element of the system. The frame geometry must move in such a way to pour the contents of the barrel directly into the reactor. There is room for a small amount of leeway in the dumping of the barrels because a funnel is placed in the reactor mouth during loading. During visits to Vertellus the team measured the reactors which the machine will serve (Figure 1). Using the measurements of the reactor, a 3D CAD model was constructed of the machine and reactor. The frame and tipping geometry were designed around the 3D CAD model of the reactor to validate that the machine would be tailored to the reactors at Vertellus. A 3D CAD model of the proposed frame design and the reactor can be seen in Figure 2.
The construction of the frame is simple and strong – constructed with 2”x 2” hollow tube steel. Steel was chosen as the desired material because it is affordable and strong. The decision matrix used to make this decision can be seen in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Steel</th>
<th>Aluminum</th>
<th>Stainless Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>10</td>
<td>10</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Weight</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Strength</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>6</td>
<td>6</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>285</strong></td>
<td>270</td>
<td>263</td>
<td></td>
</tr>
</tbody>
</table>

The 2”x 2” hollow tube steel was chosen because it is readily used and available by Vertellus. The 2”x 2” hollow tube steel was found, through Finite Element Analysis, to be sufficiently strong for this application. All of the power and drive components are mounted to a metal sheet on the base frame. These components are placed as far toward the back of the machine as possible. Having the extra weight towards the back it ensured that the center of gravity of the machine is within the footprint of the frame at all times throughout the arc of the arm. By keeping the center of gravity within the footprint of the frame ATLASLIFT is stable front to back and side to side. The swing arm is connected to the frame by a solid steel pivot bar and the hydraulic cylinder. The arm is also fabricated from 2” x 2” hollow tube steel. The chute attached to the arm was made from 10 gauge stainless steel. The chute in Figure 3 was graciously formed for ATLASLIFT by Genzink steel in Holland Michigan.

Figure 3: The Stainless Steel Chute
The chute was made from stainless steel because the chute comes in direct contact with chemicals and stainless does not oxidize or react with any chemicals like regular steel does, also stainless steel is easily cleaned and sanitized.

The new geometry of the frame helps the barrel achieve an optimal tilt angle of 38 degrees and a height of 46”. By achieving a tilt angle of 38 degrees the powder being dumped leaves the barrel and is transferred into the reactor very easily. Also by achieving a final lip height of 46” the ATLASILIFT is capable of pouring the barrel contents into any of the reactors at Vertellus. When the arm reaches its greatest angle the arm comes in contact with a stop, which does not allow the arm to go any farther. This stop prevents the shaft of the hydraulic cylinder from hitting the pivot bar.

When the new frame geometry was finalized a full-scale wooden model was taken to Vertellus to check for any clearance issues. There are many tight places ATLASILIFT has to fit in and there are many odd pipes that could possibly inhibit the operation of ATLASILIFT so this was a critical step to double check the 3D CAD model before fabrication. At the visit it was determined that there were no interference with the motion of ATLASILIFT and it would achieve the correct pouring height and angle required to pour into the reactors. With confirmation of correct geometry the finalized design was given approval for fabrication.

3.1.2 Mobility
The Frame was made mobile with the addition of the casters seen in Figure 4. A six inch caster was put at each corner of the machine. Two casters lock to keep the ATLASILIFT from moving during operation, and 2 casters swivel to make ATLASILIFT easy to turn.

The casters are six inches in diameter so ATLASILIFT can easily get over small obstacles common to the plant, such as cracks, stones, and screws. Each caster is rated by the manufacturer to be capable of supporting a 700 pound load. In total the casters are capable of supporting a 2800 pond load, this is sufficient to support the load of the loaded ATLASILIFT at 614 pounds. Hard phenolic plastic was chosen to be the wheel material to ensure that after long durations of sitting the large load of the machine would not deform the wheel making movement difficult.
3.1.3 Salvaged Machine

Vertellus Specialties donated an obsolete machine to the project. This machine was a valuable asset for salvaging parts. The machine was a barrel dumping machine that was purchased by Vertellus in the past to try to fulfill the same goals as this project has. The machine can be seen in Figure 5.

![Figure 5: Salvaged Machine](image)

The old machine was not a success; it was very inefficient and did not tilt to a sufficient angle, only 26 degrees. When in use the chemicals did not leave the chute, they had to be scraped off the chute and into the reactor. The machine had been rusting behind Vertellus for years but was now put to good use. Many parts were still operational and useful to ATLASLIFT, the motor, hydraulic pump, tank, electric system, electrical boxes, and conduit were salvaged and reused. When the machine was received the first step taken was making it operational. A new electrical plug was installed and access to 3-phase power was found in the building. When power was connected to the machine then it was tested. The current system was found to work but was not optimal. The power system was changed by adding a new 4 port 3 way hydraulic directional valve, removing an electric kill switch, and removing a hydraulic needle valve. The new power system was then tested on the old frame and was determined to be a success. This new system allowed the operator to power the chute up and down, and it could be rattled. With the power
system set the wiring and control boxes were carefully documented and disassembled, so this system could be reassembled on the new frame.

3.1.4 Barrel Security
The fiber barrel of chemicals sits in the chute that is attached to the swinging arm. The chute itself is constructed of a curved piece of stainless steel that wraps closely around the barrel. To secure the barrel in place, two clamps (Figure 6) on sliding rails can be slid to the exact barrel height – keeping the barrel in place.

![Figure 6: A Barrel Clamp](image)

3.1.5 Driving Mechanisms
The drive system for the ATLASILIFT machine includes a hydraulic pump that rests atop a tank of hydraulic fluid. The pump has a built in pressure release valve to safeguard against any high pressure problems. The pump is coupled to a 3-phase, 480 Volt explosion proof electric motor. High pressure hydraulic lines transfer hydraulic power through a 4-way, 3-position manual control valve with a tandem center to the hydraulic cylinder. All of these components are pictured in Figure 7.
The electric motor, pump, and cylinder used on the ATLASLIFT were salvaged from the machine donated by Vertellus Specialties Inc. The donated machine was driven to its upright position by pressing a “start” button and was lowered by twisting open a needle valve, this process was considered to be slow and did not offer operators much control over the machine. A schematic of the old system can be seen in Figure 8.

A manual control valve was chosen to be added to this system because it allowed for increased operator control of the machine such as the option to adjust speed with the built in flow control valve and the ability to shake and jostle the barrel in the upright position, as well as a quicker cycle time. Figure 9 shows the hydraulic diagram of the drive system on the ATLASLIFT machine.
Figure 9: Hydraulic Diagram for the Current System

An analysis of the hydraulic system and the loads it would experience was carried out and it was determined that the salvaged cylinder, pump, and motor were significantly oversized for use in ATLASLIFT. It was found that the maximum pressure in the system would be 200 psi; hydraulic systems usually run at an operating pressure of 1500 psi. An upside to the over construction of ATLASLIFT’s system was that it was not necessary for a component that was expected to be necessary. In a hydraulic system when the COG of the load goes over center a special valve called an over center valve is needed to hold the system stable. Usually operating a system that goes over center without an over center valve causes a vacuum to be pulled in the system, however the control valve was able to hold the machine in an over center configuration with ease.

3.1.6 Stress Analysis

Several Finite Element Analyses were performed on ATLASLIFT to determine if the frame would be strong enough to withstand the day to day stresses it would experience. In the FEA the feet of the frame were fixed and functional and proof loads were applied to the end of the chute arm in a worst case position. It was determined that the worst case loading condition ATLASLIFT would experience would be were the moment arm created by the extended chute arm would be the greatest. The tested Frame configuration with boundary conditions can be seen in Figure 10.
The functional load used in the analysis was 300 pounds to simulate a very heavy batch of chemicals as the average weight of the barrels are 200 pounds. A proof load of 1000 pounds was applied to the machine to make sure we designed for misuse. In a plant environment the ways the operators could misuse the machine are countless so it was important to see if ATLASLIFT could withstand large loads similar to what it would experience in misuse situations. It was found that the frame geometry could withstand the functional and proof loads with a sufficient safety factor. For the functional load the frame experiences max stresses around 1/10 of the tensile strength of the steel. The Results of the FEA can be seen in Figure 11.
The results of the proof loading also show that the ATLASLIFT was sufficiently strong. The ATLASLIFT only experiences maximum stresses of ½ the tensile strength of the frame. Having a safety factor of 2 is a sufficient safety factor for a large load the machine will hopefully never experience. A figure showing the stresses found in the proof case can be seen below.

![Figure 12: Proof Load](image)

Through the analysis of the functional and proof FEA it can be determined that the frame is sufficiently strong with a safety factor of 10.

3.1.7 Wiring

The electric system and controls used on the ATLASLIFT machine were salvaged from the machine donated by Vertellus Specialties Inc. In addition to the electric system, both cases for holding the electrical components were transferred to the new machine to ensure that the electrical system remained explosion proof. All wiring was run through new conduit between the two cases and the motor. The wiring of the ATLASLIFT machine was done by carefully diagramming and recording the exact wiring setup on the donated machine and replicating it on the new machine. The electrical wiring was done in reference to the requirements set forth by the UL Class II Division 2 codes for electrical equipment in hazardous locations. It is important to note that the wiring done by team ATLASLIFT was not inspected by a licensed electrician capable of determining if all codes and requirements were fully met. Also team ATLASLIFT was able to reference only the free, publicly available description of UL Class II Division 2 codes for hazardous locations and made it clear to its end receiver that all these things are the case.
4 MATERIAL PROPERTIES

4.1 Powder Flow Characteristics

It might be a little surprising at first, but fifty percent of all materials used in all of the major industries were at some point in time a powder. Because of this, extensive studies are done on the material properties, as well as the handling and packaging properties of powders. This is relevant to the project because the contents of the fiber drums that will be lifted and poured will be powder.

4.2 Factors that Affect Powder Flowability

4.2.1 Particle Size and Shape

According to Perry’s Chemical Engineering Handbook, “Particle size is one of the most common and controllable factors which affect the flowability of a given material”. As a general rule of thumb, the larger the material size the more easily it will flow. Shape is also a large factor in determining how well a powder will flow. Hard, round surfaces will be able to move better than flat or square shapes that are flexible. For this design, however, particle size and shape are controlled by the manufacturer of the raw materials that Vertellus acquires.

4.2.2 Moisture Content

The more moisture that a powder absorbs, the harder it is for the material to flow. Perry’s Handbook states that “Most materials can safely absorb moisture up to a certain point; further addition of moisture can cause significant flow problems”. This will not likely be a problem with the system because the chemicals spend very little time exposed to the atmosphere before being dumped immediately into the reactors. Zeeland is also not known for having persistently high humidity.

4.2.3 Temperature

The effect of temperature on the flowability of the powders was a big concern for the given conditions because the reactors are in a building where temperature can vary greatly between the various seasons in Michigan. However, after some research, it was found that the temperature only plays a large factor in chemicals whose physical properties may vary with the change in temperature. For example, powders that contain low melting-point components may get sticky at higher temperatures which would greatly affect the flowability. Vertellus has had no problems with any of their chemicals melting or getting sticky.

4.2.4 External Surface

The machine uses a chute in which to funnel the chemicals into the reactor. Stainless steel was chosen as the material for this part of the machine because the smooth surface allows the material to travel more easily into the reactor. It will also have no affect on the various chemicals that will be dumped and will be easy to clean. The stainless steel was ordered by Vertellus, and the operators and engineers are very familiar with its properties and uses.
4.3 Material Flow Research

4.3.1 Material Properties
In industry today there are many devices and tools as well as companies whose sole purpose is to test the various material properties of specific powders. It was decided not to pursue purchasing one of these machines or hiring an outside company for a few reasons. First, this data is normally acquired to optimize a large scale process to increase performance, profit, and quality. These processes include hoppers, storage bins, silos, mixers, and even conveyer belts. This project is much simpler and only involves pouring the powders with the help of gravity. Second, Vertellus uses a variety of chemicals which have different chemical properties. To do testing on all of the chemicals used would be expensive and would not be a good use of the financial resources provided.

4.3.2 Angle of Repose
To optimize the machine design, the angle of repose of the chemicals we would be dumping was of special concern. The angle of repose is the largest angle that a pile of granular material will remain at rest. It is directly related to particle size and shape. A chemical, Distearyl dimethylammonium methosulfate (DDAMS), which was given to team ATLASLIFT by Vertellus was used to test the angle of repose. It was discovered that the angle of repose for the base case was 45-46°. It was also noted that the material began to pour from the container at about 35°.

4.3.3 Caking & Clumping
An issue that came up when talking to advisors and machine operators was the issue of the chemicals caking and in some cases crystallizing in the fiber drums. One operator informed the team that sometimes incredibly large chunks form and that they have to pound the drums with hammers. This is one of the primary reasons for choosing a two way hydraulic valve, so that the operator can to some extent “shake” and has more control over the pouring motion. Because of this, ATLASLIFT was designed to be very stable to withstand the shaking and pounding.

4.3.4 Rate of Discharge
Another important issue the team tested is the cycle time of lifting and pouring an entire barrel. Although a fast cycle time is not crucial, it is desired to have a cycle time of around 30 seconds per barrel. This could be dramatically affected by the extent of caking or clumping. It is desired that the operator is able to control the pour rate so that a consistent, clean pour is made. This is very reasonable, and using the two way hydraulic valve the operator can lift, lower, or keep the chute at a constant angle.
5 FINANCIAL ANALYSIS

5.1 Construction Costs
The cost of the raw materials and components are shown in Table 2. This list of costs includes only purchases made for this project and does not include the cost of the parts donated by Vertellus Specialties Inc, the laser cutting and bending services provided free of charge by Genzink Steel, or the projected labor costs of the students and other people that assisted in the design and construction of the ATLASILIFT machine.

![Table 2: Purchased Material Cost](image)

Vertellus Specialties Inc originally provided a $5000 budget to team ATLASILIFT. After the economic downturn Vertellus requested that expenses be kept to a minimum wherever possible. Team ATLASILIFT kept expenses to a small fraction of the provided budget by adjusting the original design presented in the PPFS to incorporate parts from the obsolete machine donated by Vertellus Specialties Inc.

5.2 Projected Costs
The estimated material and component costs for the parts salvaged from the donated scrap machine are shown in Table 3.

![Table 3: Salvaged Parts Price](image)
The total material costs for the construction of the ATLAS-LIFT machine assuming that no parts are donated is shown in Table 4. The price more than doubles when the cost of donated parts are taken into consideration.

<table>
<thead>
<tr>
<th>Table 4: Total Material Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased Material</td>
</tr>
<tr>
<td>Donated Material</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

The projected total material cost is driven up by the oversized components donated by Vertellus Specialties Inc. Costs for most of the donated and purchased parts would be less if components more suitably sized for the operation were used for construction.
6 Conclusion

Designing and building the ATLAS|LIFT machine has provided the members of team ATLAS|LIFT with several valuable experiences. The benefit of working with an interdisciplinary team has provided each member of the team with a new learning experience. This has been a great chance for each member of the team to explore his own strengths and weaknesses as well as teach and learn from each of his teammates. Each team member also developed new communication skills. Team ATLAS|LIFT had to maintain close communication with companies like Vertellus Specialties Inc, a number of industrial consultants, and our professors. Finally, the importance of expertise was recognized. Team ATLAS|LIFT required important advice in a variety of fields from such experts as the metal shop manager, their team advisor, and the industrial consultants they brought in to address a variety of issues ranging from scheduling to detailed hydraulic advice.

Team ATLAS|LIFT feels that although a number of mistakes and errors were made and corrected, that this project was a success. The initial goals set by team ATLAS|LIFT were sufficiently accomplished. The final product has a tipping angle of approximately 38 degrees, the machine is easily mobile around a level floored room, costs were kept well under budget, the machine can accommodate a number of differently sized reactors, and a simple and efficient machine was built that will be able to withstand the rigors of everyday use. Team ATLAS|LIFT believes that the machine is true to its intended design in that it is a caring design that will be transparent to its operators and instill trust in its owners.
# Table of Appendices

Appendix A. Hydraulic Calculations ........................................................................................................................................... 20  
Appendix B. Fiber Drum Specifications ...................................................................................................................................... 22  
Appendix C. Reactor Dimensions ............................................................................................................................................... 23  
Appendix D. Bibliography ............................................................................................................................................................ 24  
Appendix E. Gantt Chart ............................................................................................................................................................... 25  
Appendix F. Bill of Materials ......................................................................................................................................................... 26  
Appendix G. Drawings ................................................................................................................................................................. 27
Appendix A

Hydraulic Calculations

\[ F_g = -330 \text{ [lbf]} \]
\[ x_g = 19.24 \text{ [in]} \]
\[ x_p = 14.31 \text{ [in]} \]
\[ \text{Angle} = 77 \text{ [deg]} \]
\[ \text{Bore} = 2.25 \text{ [in]} \]
\[ \text{Throw} = 22 \text{ [in]} \]
\[ \text{Pump Flowrate} = 3 \text{ [gal/min]} \]
\[ S_F = 1 \]
\[ F_g \cdot x_g - x_p \cdot F_p = 0 \]
\[ F_g + F_p + F_c = 0 \]

\[ F = \frac{F_c}{\sin (\text{Angle})} \]

\[ \text{Area Cylinder} = \pi \left( \frac{\text{Bore}}{2} \right)^2 \]

\[ \text{Pressure Hydraulic} = \frac{F}{\text{Area Cylinder}} \]

\[ \text{Volume Cylinder} = \text{Area Cylinder} \cdot \text{Throw} \]

\[ \text{Pump Flowrate} = \frac{\text{Volume Cylinder}}{\text{Time}} \cdot 0.2597 \cdot \frac{\text{gal/min}}{\text{in}^3/\text{sec}} \]

\[ \text{Time Cycle} = 2 \cdot \text{Time} \]

---

\[ \text{Angle}=77 \text{ [deg]} \]
\[ \text{Pump Flowrate}=3 \text{ [gal/min]} \]
\[ \text{Area Cylinder}=3.976 \text{ [in}^2] \]
\[ S_F=1 \]
\[ \text{Bore}=2.25 \text{ [in]} \]
\[ \text{Pressure Hydraulic}=199.7 \text{ [lb/in}^2] \]
\[ F=794 \text{ [lbf]} \]
\[ \text{Time}=7.573 \text{ [sec]} \]
\[ F_c=773.7 \text{ [lbf]} \]
\[ \text{Time Cycle}=15.15 \text{ [sec]} \]
\[ F_g=-330 \text{ [lbf]} \]
\[ \text{Volume Cylinder}=87.47 \text{ [in}^3] \]
\[ F_p=-443.7 \text{ [lbf]} \]
\[ x_g=19.24 \text{ [in]} \]
\[ x_p=14.31 \text{ [in]} \]

20
Free Body Diagram

\[ F_g = \text{The weight of the barrel and arm assembly} \]

\[ F_c = \text{The force exerted by the cylinder} \]

\[ F_p = \text{The Vertical force exerted by the pivot bar} \]

\[ F = \text{The total force exerted by the cylinder} \]

\[ x_g = \text{Distance from cylinder to the Center of Gravity} \]

\[ x_p = \text{Distance from cylinder to the pivot bar} \]

\[ \alpha = \text{Angle from the vertical to the cylinder} \]
Appendix B

Fiber Drum Specifications

Vertellus Specialties Inc. uses two different types of Fiber drums: a 30-gal and a slightly smaller 28-gal.

<table>
<thead>
<tr>
<th>Fiber drum type</th>
<th>Diameter</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in</td>
<td>cm</td>
</tr>
<tr>
<td>55-gal lever top</td>
<td>21</td>
<td>53.3</td>
</tr>
<tr>
<td>55-gal lever top</td>
<td>23½</td>
<td>59.7</td>
</tr>
<tr>
<td>55-gal lever top</td>
<td>22</td>
<td>55.9</td>
</tr>
<tr>
<td>41-gal lever top</td>
<td>20½</td>
<td>45.1</td>
</tr>
<tr>
<td>30-gal lever top</td>
<td>19</td>
<td>48.3</td>
</tr>
<tr>
<td>6.28-ft³ rectangular</td>
<td>17½*</td>
<td>44.8</td>
</tr>
<tr>
<td>55-gal liquid</td>
<td>22</td>
<td>55.9</td>
</tr>
<tr>
<td>30-gal liquid</td>
<td>19</td>
<td>48.3</td>
</tr>
<tr>
<td>55-gal fiber</td>
<td>20½</td>
<td>51.8</td>
</tr>
<tr>
<td>30-gal fiber</td>
<td>17½</td>
<td>44.1</td>
</tr>
</tbody>
</table>

*Side dimension, square.

Perry’s Chemical Engineers’ Handbook (21-37)
Appendix C

Reactor Dimensions
Appendix D

Bibliography


Appendix E

Gantt Chart
### Senior Design Expense Report

<table>
<thead>
<tr>
<th>Date</th>
<th>Purchaser</th>
<th>Store</th>
<th>Purpose</th>
<th>Price</th>
<th>Purchaser</th>
<th>Amount Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/11/2009</td>
<td>Vertellus</td>
<td>McMaster Carr</td>
<td>Casters</td>
<td>$176.76</td>
<td>Mark</td>
<td>$7.27</td>
</tr>
<tr>
<td>3/20/2009</td>
<td>Vertellus</td>
<td>Harbor Steel</td>
<td>Steel</td>
<td>$472.45</td>
<td>Tyler</td>
<td>$8.59</td>
</tr>
<tr>
<td>3/9/2009</td>
<td>Vertellus</td>
<td>All Phase Hydraulics</td>
<td>Valve, Fitting, Hoses</td>
<td>$270.02</td>
<td>Erik</td>
<td>$17.21</td>
</tr>
<tr>
<td>4/2/2009</td>
<td>Tyler</td>
<td>Menards</td>
<td>Frame Mock-up</td>
<td>$8.59</td>
<td>Jon</td>
<td>$72.52</td>
</tr>
<tr>
<td>4/22/2009</td>
<td>Erik</td>
<td>Menards</td>
<td>Reactor Mock-up</td>
<td>$7.65</td>
<td>Vertellus</td>
<td>$919.23</td>
</tr>
<tr>
<td>4/25/2009</td>
<td>Mark</td>
<td>Lowes</td>
<td>Conduit</td>
<td>$25.22</td>
<td>Budget</td>
<td>$105.59</td>
</tr>
<tr>
<td></td>
<td>Mark</td>
<td>Lowes</td>
<td>Conduit</td>
<td>(15.18)</td>
<td>Vertellus</td>
<td>$919.23</td>
</tr>
<tr>
<td></td>
<td>Mark</td>
<td>Lowes</td>
<td>Conduit</td>
<td>$0.92</td>
<td>Total</td>
<td>$1,024.82</td>
</tr>
<tr>
<td>4/29/2009</td>
<td>Jon</td>
<td>Lowes</td>
<td>Conduit</td>
<td>$42.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/2/2009</td>
<td>Jon</td>
<td>Tractor Supply Co.</td>
<td>Paint</td>
<td>$21.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/4/2009</td>
<td>Jon</td>
<td>Tractor Supply Co.</td>
<td>Paint</td>
<td>$74.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/4/2009</td>
<td>Jon</td>
<td>Lowes</td>
<td>Conduit</td>
<td>(25.10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/4/2009</td>
<td>Mark</td>
<td>Lowes</td>
<td>Conduit</td>
<td>(3.69)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/6/2009</td>
<td>Erik</td>
<td>Meijer</td>
<td>Spray-paint</td>
<td>$7.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/6/2009</td>
<td>Erik</td>
<td>Lowes</td>
<td>Bolts</td>
<td>$2.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/11/2009</td>
<td>Jon</td>
<td>Tractor Supply Co.</td>
<td>Paint</td>
<td>(52.97)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix G

Drawings
1: Base Legs
2: Cross Bars
3: Vertical Legs
4: Support Bars
5: Stop Bar Mounts
6: Stop Bar
7: Valve Mount
8: Caster Mounts

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL:
ANGULAR: MACH BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

Title: Base Weldment

DRAWN JMB 5/14/09
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Senior Design Team 8
Calvin College '08-'09

SCALE: 1:24 WEIGHT: SHEET 1 OF 1
### BASE LEGS

**Title:** BASE LEGS

**Material:** 2" SQUARE TUBE

**Finish:**

**Dimensions:**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.00</td>
<td></td>
</tr>
</tbody>
</table>

**Tolerances:**

- Fractional
- Angular: MACH, BEND
- Two Place Decimal
- Three Place Decimal

**Comments:**

**Drawn:** JMB 3/3/09

**Checked:**

**Eng Appr.:**

**Mfg Appr.:**

**Q.A.:**

**Comments:**

**Scale:** 1:8

**Weight:**

**Sheet:** 1 of 1
Cross Bars

2" SQUARE TUBE

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

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL:
FINISH:

DO NOT SCALE DRAWING

SCALE: 1:10 WEIGHT: TEAM8

NAME DATE DRAWN
JMB

CHECKED
ENG APPR.
MFG APPR.
Q.A.

COMMENTS:
UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
FINISH

DO NOT SCALE DRAWING

NAME DATE

DRAWN JMB
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

TITLE:

VERTICAL LEGS

SIZE DWG. NO. REV

A TEAM8

SCALE: 1:8 WEIGHT:

SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL:
ANGULAR: MACH BEND
TWO PLACE DECIMAL:
THREE PLACE DECIMAL:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL:
FINISH:
DO NOT SCALE DRAWING:

NAME | DATE
-----|-----
JMB   |     

TITLE:
SUPPORT BARS

SIZE | DWG. NO. | TEAM8 | REV
-----|---------|------|-----
A     |         |      |     

SCALE: 1:8  WEIGHT:  SHEET 1 OF 1
**Title:** Valve Mount

**Material:** 3/16" Sheet Steel

**Finish:**

<table>
<thead>
<tr>
<th>UNLESS OTHERWISE SPECIFIED:</th>
<th>NAME</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIMENSIONS ARE IN INCHES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOLERANCES:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRACTIONAL:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANGULAR: MACH N BEND N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TWO PLACE DECIMAL:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>THREE PLACE DECIMAL:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Interpret Geometric Tolerancing Per:**

- FRACTIONAL
- ANGULAR: MACH N BEND N
- TWO PLACE DECIMAL
- THREE PLACE DECIMAL

**Comments:**

Senior Design Team 8  
Calvin College '08-'09

**Check:** JMB 5/14/09  

**Drawing Scale:** 1:5

**Weight:**

**Valve Mount**
1: Upper Chute Arm
2: Barrel Arm Cross Bar
3: Chute Pivot Bar
4: Upper Cylinder Mounting Arm
5: Lower Chute Arm
6: Chute
7: Chute Bottom

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH

DO NOT SCALE DRAWING

DRAWN: JMB 5/14/09
CHECKED: 
ENG APPR.:
MFG APPR.:
Q.A.:
COMMENTS:

Senior Design Team 8
Calvin College '08-'09

SCALE: 1:24 WEIGHT: SHEET 1 OF 1

Chute Weldment
**Title:** BARREL ARM CROSS BAR

**Material:** 2" SQUARE TUBE

**Finish:**

**Comments:**

---

**Dimensions are in inches.**

**Tolerances:**
- Fractional
- Angular: MACH BEND
- Two Place Decimal
- Three Place Decimal

**Interpret geometric tolerancing per:**

**Scale:** 1:8

**Weight:**

---

<table>
<thead>
<tr>
<th>UNLESS OTHERWISE SPECIFIED:</th>
<th>NAME</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIMENSIONS ARE IN INCHES</td>
<td>DRAWN</td>
<td>JMB</td>
</tr>
<tr>
<td>TOLERANCES:</td>
<td>CHECKED</td>
<td></td>
</tr>
<tr>
<td>FRACTIONAL:</td>
<td>ENG APPr.</td>
<td></td>
</tr>
<tr>
<td>ANGULAR: MACH BEND:</td>
<td>MFG APPr.</td>
<td></td>
</tr>
<tr>
<td>TWO PLACE DECIMAL:</td>
<td>Q.A.</td>
<td></td>
</tr>
<tr>
<td>THREE PLACE DECIMAL:</td>
<td>COMMENTS:</td>
<td></td>
</tr>
</tbody>
</table>

---

**Keep the drawing to scale.**

**Do not scale drawing.**
**Title:** Chute Pivot Bar

**Dimensions:**
- Diameter: 1.10" Steel Rod
- Length: 23.00"
UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
2" SQUARE TUBE
FINISH
DO NOT SCALE DRAWING

NAME DATE
DRAWN JMB
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

TITLE:
UPPER CYL.
MOUNTING ARM

SIZE DWG. NO. REV
A TEAM8
SCALE: 1:8 WEIGHT: SHEET 1 OF 1
CUSTOM CURVE FITTED TO CHUTE

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL
2" SQUARE TUBE
FINISH

DO NOT SCALE DRAWING

WEIGHT:
Lower Chute Arm

SCALE: 1:8  WEIGHT:  SHEET 1 OF 1

TITLE:
Lower Chute Arm

DRAWN  JMB
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

NAME  DATE
Chute Bottom Shown For Reference

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL: Stainless Steel
FINISH:

DO NOT SCALE DRAWING

DRAWN  JMB  3/3/09
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

SCALE: 1:20
WEIGHT:

A

SHEET 1 OF 1
Half octagon with side length 8.28"