Abstract

Summarized here is the work completed by Team 8: Atlas Lift, for the fall 2008 segment of the senior design project at Calvin College. This analysis includes a project proposal and feasibility study of Team 8’s design for a chemical dumping machine.

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

The design of the machine is built around a list of project objectives including machine functionality and design norms. The functionality of the machine acts as a basis for designing a machine that will meet all physical requirements such as lifting capacity and cycle time. The design norms focus on the user (Vertellus) and the interactions between them and the design team. It is imperative that the team’s objectives clearly focus on meeting the user’s needs and that clear communication between the two parties is continually present.

The design, as proposed below, meets all functionality requirements such as moderately fast cycle times, 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 will also fall within the provided budget.

With all physical and financial requirements met, this proposed project is feasible and will proceed into its second phase of manufacturing and assembly during the spring semester.
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1 INTRODUCTION

1.1 Team Description

Mark Beckman is a senior at Calvin College studying engineering 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 aspires to work at Herman Miller after his graduation in the spring of ’09. In his free time Mark likes to sail, and in winter enjoys to snow ski.

Jonathan Brock is a senior engineering student with a concentration in Mechanical Engineering. He has lived in the Grand Rapids area his whole life, graduating from Unity Christian High School. 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 enjoys water sports during the summer and skiing and snowboarding during the winter.

Erik Van Kampen is a senior engineering student 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 a senior engineering student in the Mechanical Engineering concentration. He hails from Willard/Celeryville, OH where he attended Willard High School and spent his summers working on the family vegetable farm. Last summer he was an intern at Rapid-Line Inc. in Grand Rapids, MI. Tyler enjoys a variety of activities and sports including hunting, basketball, tennis, and golf.
1.2 Project Statement

This project includes designing and fabricating a device for use by Vertellus Specialties Inc. (Zeeland Chemical) that will lift and pour the contents of cylindrical fiber barrels into numerous types of chemical reactors. The barrels, which currently are manually lifted by two employees, range from 100-200 lbs. in weight. The reactor ports, i.e. where the chemicals are poured into, are located approximately 40” above ground level and approximately 24” behind the edge of the reactor (forward of where one can stand). The current process of manual lifting is physically strenuous and a safety hazard for the employees.
2 PROJECT OBJECTIVES

2.1 Design Functionality

The functionality of the machine is dictated by numerous elements such as the scope of the project, how fast the lifter must operate, the reliability of the machine, the safety of the operators, and the cost.

2.1.1 Project Scope
The main objective of this project is to develop a machine that can efficiently load the contents of the barrels into various reactors. The simplicity of the device is something that is being constantly kept in mind. Whatever linkages, hinges, bearings, drive train end up on the final product, the simpler their 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 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-semester visits to Vertellus, it was decided that the device be mainly designed for one particular task – the pouring into an in-ground reactor (and not the dryers). This new direction narrowed the necessary capabilities of the device. There are two sets of reactors, located in two buildings, which the machine will be able to pour into. These two reactor sets do not have identical dimensions and will require extra designing as far as pouring location goes. Also, because all the reactors are located on the second floor on their respective buildings, the machine will be transported via fork-lift from one building to another as necessary. The machine will therefore require some measure of transport security, i.e. some way to secure the machine to a pallet.

2.1.2 Performance
The machine must be able to lift and pour quickly and with as little effort as possible for the operator. Originally, speed of operation was a high priority in the decision making. Also, resulting from the new direction previously mentioned, a shift in focus was made away from speed towards cost savings and safety. The dryers are loaded much more frequently than the reactors and because the dryers have been essentially dropped from the project scope, the frequency of use the machine will be seeing has also dropped. With less usage, the time savings incurred by a quick machine will also be less, hence the shift in design priorities. Late in the semester, priorities again shifted. With the economic downturn, cost savings became even more of a priority. More focus was placed on the possibility of acquiring used parts from an obsolete machine currently in Vertellus’ possession which will be discussed in more depth later.

2.1.3 Reliability
The machine will be operated 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. During one visit to Vertellus, the pouring process was observed and it was noted that, with each barrel poured, a fine powder dust flew upwards, filling the local air before later settling. The design must account for the long term effects of this dusty environment and
components must be chosen that can handle or combat the dust. Components will also need to be easily accessible if something were to break; keeping maintenance time to a minimum is always a goal. One undesirable yet semi-typical problem with most hydraulic systems is hose and fitting leaks. Typically not a huge problem for most applications, hose leaks are in this case a big concern. Due to the necessary, close proximity to open reactors, any and all hydraulic leaks have the potential to leak into the reactors. This is an unacceptable situation as extensive time (money), effort (money), and wasted Vertellus product (more money) would be results of this type of leak. The design will incorporate measures that protect against hydraulic fluid leaks.

2.1.4 Safety
Because this machine will be operated by an employee, likely standing up close the machine, there is the potential hazard of getting something caught, pinched, or stuck in the machine. The design will minimize the risk to employees by protecting against the pinch-points commonly found with this type of mechanism. As mentioned before, the machine will be transported between buildings. The transporting of the machine needs to also be safe and secure to prevent employee injury as well as the integrity of the machine (emphasis of course on the employees).

2.1.5 Costs
As with any design, the goal is to minimize costs while meeting all physical constraints, requirements, and safety issues. Vertellus has graciously granted $5,000 towards designing and manufacturing a machine to complete the pouring task as stated in section 2.1.1.

2.2 Design Norms
The purpose of the design norms as listed below is to guide the development of this project to a successful completion. Following these requirements and considerations is imperative to ensure that appropriate requirements, constraints, and rules are met. In doing so, respect can be shown for the individuals using the machine and those responsible for the funding.

2.2.1 Stewardship
The machine design must be mindful of the calling to be good stewards of God’s kingdom. To obey this calling, a machine has been designed that will benefit Vertellus in numerous ways. The first is through improved worker efficiency. Using mechanical power to lift and pour the drums will allow for a quicker task completion. Second, a reduction in the amount of dust that escapes during the pouring process. Reducing the dust will have a twofold effect: more product will be produced and the area will stay cleaner and therefore safer for employees and equipment. Third, because the machine will keep the employees from lifting the drums, the strain and risk of injury that is inherent in the task will be removed.
2.2.2 Caring
Because this machine will be operated by and in close proximity to humans, care for the employees is a top design priority. This machine will have several moving parts that move quickly and with significant power, so many protective measures will be put in place to prevent possible pinch and impact points.

2.2.3 Transparency
For this project, transparency has taken two forms. First, to design a product that can be easily understood and operated. Vertellus Specialties Inc. is expecting a machine that can be used for many years to come. In order to make this a reality, this design must be simple and easy to understand for the sake of operation and routine maintenance and repair. Second, as proven over the years, parts get donated to senior design projects from outside sources for any one of numerous reasons. When a project is built for the intended use or benefit of an underprivileged audience/customer there is no real sense of private profit generated from the project. However, with the intended user being a private company with a focus on profit, any potential donator will have the circumstances and goals of this project clearly explained so as not to create any conflicts of interest or misunderstandings.

2.2.4 Trust
Vertellus Specialties Inc. is financing this project, and therefore as with any customer relationship, expects a functional, reliable piece of equipment that they can depend on. In order to fulfill this, thorough research must be conducted on this project to come up with the best possible option for them. This “best” option will consist of using only quality parts, materials and controls to build the machine and perform the task in a safe and effective manner.

2.3 Educational Opportunity

2.3.1 For the Team
This project is a great opportunity for the team to put its collective engineering education into practice for numerous reasons. Teams play a significant role in professional industry; working on a design team now is valuable experience and a good stepping stone into the professional world. Good experience will be gained in researching as the bulk of the time spent during the fall semester will be on researching viable power systems and existing designs. The designing experience that will go into creating a sound product will be invaluable as there are many facets to the design process, both expected and unforeseen. During the spring semester, construction of the device will also prove to be valuable as manufacturing designs and assembling techniques will shed light on where the design’s strengths and weaknesses are. Because the machine will be constructed in house at the Calvin College Engineering Building, initial construction issues will be immediately analyzed and resolved, something that isn’t so common in industry. Additional concerns for the project are that the machine is being built for a specific customer and a specific process. Communication skills between the team and client are key to designing a product that will meet all the needs and constraints posed by the customer.
2.3.2 For Others

Although the design is going to be used in a specific setting at Vertellus, there is still an opportunity for others to learn from this project. Using the team website and a web-accessible copy of the PPFS and final report, the general public, current, and potential engineering students will be able to learn about this project. Hopefully this will play a part in educating them in the basics of the power system, controls, and design process used here and that make up the engineering capstone course.
3 MACHINE DESIGN

3.1 Machine Design Summary
This design focuses on manufacturing a completely new product for Vertellus. A frame will be constructed to support the numerous components necessary to lift and tip the barrels. These major components include a rotary air motor, hydraulic pump, numerous safety and control valves, and a hydraulic cylinder to raise and lower the barrels.

3.1.1 Frame
The frame design for this machine is a very important element of this 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 inaccuracy in the dumping of the barrels as there is a funnel in the mouth of the reactor while loading. During visits to Vertellus the team took accurate measurements of the reactors for which the machine will be used. A picture of the reactors can be seen in Figure 1.

Using the measurements of the reactor, a 3D CAD model was constructed in Solid Works of the largest reactor. In the model, the funnel used during loading of the reactors was also modeled. The frame and tipping geometry were then designed around the 3D CAD model of the reactor to validate that the machine would be perfectly tailored to the reactors at Vertellus. A CAD model of the proposed frame design and the reactor can be seen in Figure 2.
The construction of the frame will be very simple and strong. The frame will be constructed with 2” tubular 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><strong>Price</strong></td>
<td>10</td>
<td>10</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td><strong>Strength</strong></td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td><strong>Corrosion Resistance</strong></td>
<td>6</td>
<td>6</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>285</td>
<td>270</td>
<td>263</td>
<td></td>
</tr>
</tbody>
</table>

The frame is designed into two sections. The base frame stays stationary and contains all of the driving mechanisms of the machine. A swinging arm will pivot around the top of the base frame and be raised to deliver the barrel contents into the reactor. The frame will be situated on four wheels, allowing for smooth and easy transportation of the machine.
3.1.2 Barrel Attachment

The fiber barrel will be attached to the frame by being placed in a cradle that is attached to the swing arm of the frame. The barrel cradle will be constructed of a curved piece of sheet metal that wraps around the sides of the barrel. The barrel will sit on a flat steel bottom. The top and front of the barrel will be exposed and in need of constraint so that the barrel will not fall out of the cradle while loading the reactor. There will be a bar put through the top of the cradle that the rim of the barrel will butt up against to hold the barrel from sliding out. To make sure that the barrel doesn’t slide out of the front of the cradle there will be a nylon strap that wraps around the front of the barrel. With a steel cradle, top bar, and nylon strap, the barrel will be properly attached to the machine leaving zero degrees of freedom for the barrel to dislodge from the machine. Another option being considered is shown below in Figure 3. Here, a metal chain and weldment hold the barrel in place. This option however does not allow the operator to adjust for the different heights of the barrels.

Figure 3. Barrel Attachment options.

3.1.3 Driving Mechanisms

There are many different possibilities of driving mechanisms that could have been chosen to run the machine. Some that were considered include hydraulic, pneumatic, human, air over oil, and a geared electric motor. The different choices were compared and evaluated in a design matrix. This matrix can be seen in Table 2.
Table 2: Power System Decision Table

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Hydraulic</th>
<th>Air over Oil</th>
<th>Electric Motor/Gearbox</th>
<th>Pneumatic</th>
<th>Human</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>10</td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Safety</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>7</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Functionality</td>
<td>8</td>
<td>10</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Speed</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Transportability</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>394</strong></td>
<td><strong>349</strong></td>
<td><strong>340</strong></td>
<td><strong>337</strong></td>
<td><strong>244</strong></td>
<td></td>
</tr>
</tbody>
</table>

From Table 2, a hydraulic system was chosen to drive the machine. The system will be a simple system, only incorporating one hydraulic actuator to give the machine the desired dumping action. There are a couple different choices for actuators as well; linear and rotary. Rotary applies a torque around the tipping axis to tip the barrel, while a linear applies a linear force to tip the barrel. The alternatives were evaluated in Table 3.

Table 3: Actuator Options Decision Table

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Rotary Actuator</th>
<th>Linear Actuator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>10</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Safety</td>
<td>10</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Ease of Design</td>
<td>8</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Functionality</td>
<td>8</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Speed</td>
<td>5</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>329</strong></td>
<td><strong>332</strong></td>
<td></td>
</tr>
</tbody>
</table>

From this table it was chosen that a linear actuator would be best for the intended application. Another necessary decision made was that of what will power the hydraulic system. The hydraulic system could be powered by either an explosion proof electric or air motor. If an electric motor was chosen then the motor and all electronics would have to be explosion proof to comply with factory regulations at Vertellus, this adds a large amount of expense to the motor. An air motor doesn’t require any explosion proof electronics and it is powered by compressed air from the factory’s readily available plant air. The plant air is delivered at 100 psi and could be used to power an air motor. However, within the air motor selection, there are multiple options: reciprocating and rotating. Reciprocating air motors use pistons and cylinders to make a rotary output, while rotating air motors are more direct in making a rotating shaft output. These options were discussed and compared in Table 4.
Table 4: Motor Options Decision Table

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Explosion Proof Electric Motor</th>
<th>Reciprocating Air Motor</th>
<th>Rotating Vane Air Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>10</td>
<td>4</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Safety</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Functionality</td>
<td>8</td>
<td>10</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Speed</td>
<td>5</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>329</strong></td>
<td><strong>363</strong></td>
<td><strong>379</strong></td>
<td></td>
</tr>
</tbody>
</table>

After evaluation of the options, the air motor was chosen to drive the input shaft of the hydraulic pump. The pump will draw hydraulic oil from a tank and pump it through hydraulic lines to the 4-way manual directional valve. After passing through the directional valve the oil will go into the linear hydraulic cylinder to power it out or in. After going through the hydraulic cylinder the oil returns through the directional valve and back into the tank. There will be two other valves in the system that will be important to the operation of the machine. The two valves are a high pressure relief valve and an over center valve. The high pressure relief valve directs the oil back into the tank when the pressure in the hydraulic loop gets too high. The over center valve keeps the fluid from moving through the system as the barrel is over the center of the machine and dumping the chemicals into the reactor. Without an over center valve, gravity would pull down on the barrel and the arm would lower. A diagram of this system can be seen in Figure 4.

![Figure 4: Hydraulic Circuit](image-url)
3.1.4 Safety Features
Team eight is dedicated to designing and building a safe and reliable machine. Safety features of this machine include the selection of reliable, strong, a well regulated and easily controlled motion, a sturdy frame that will be capable of carrying all stress and strains, and a design that is easy to understand and operate. The use of the machine will drastically improve the safety to the loading operator of the chemical reactor. There will no longer be any lifting strain on the operator’s back. The machine will reduce the number of operators from two operators down to one.

3.1.5 Stress Analysis
A Finite Element Analysis will be performed for the machine frame in Solid Works. This analysis, along with other stress calculations will help to determine the best frame size and design. Through Finite Element Analysis, it will be determined where reinforcements will need to be made and where the machine is over designed. This will help the machine to be as light and strong as possible. Because it is a design objective to make the machine mobile, being as light as possible while still being able to handle the day to day loads is very important. These analyses will be used along with an appropriate safety factor to determine the right frame design.

3.1.6 Controls
A hydraulic system can be controlled by several different methods; the two applicable to this design are a 4-way valve controlled by an electric solenoid and a manual lever. Again, if an electrically powered method is chosen, then it must be explosion proof to comply with factory regulations. The different methods were compared and evaluated in Table 5.

<table>
<thead>
<tr>
<th>Table 5: Control Options Decision Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Price</td>
</tr>
<tr>
<td>Safety</td>
</tr>
<tr>
<td>Ease of Design</td>
</tr>
<tr>
<td>Functionality</td>
</tr>
<tr>
<td>Speed</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

From this table you can see that a manual controlled 4-way valve is the best option for this application. This valve will allow the operator to raise and lower the fiber drums in a simple and effective manner. A manual control will give the operator better control and feel for the machine. This valve will allow the machine to be powered up into a tipping position, and then power it back down into a loading position.
4 MACHINE SALVAGE

4.1 Machine Salvage Summary
Vertellus has a commercially available barrel dumping machine that would achieve many of the goals put forth by this project, however, this machine is not currently used. This machine is not used because it has some major design flaws. One of these design flaws is that its geometry does not allow it to pour accurately into the various reactor heights, and its weight and bulk made it difficult to move from site to site. The machine was also not sized correctly for the barrel sizes that are used at Vertellus. The hope is that some of these components can be incorporated into the design if they are still in good working condition. Some of the parts being considered are the explosion-proof motor, hydraulic pump, hydraulic cylinder, relief and check valves, hoses and fittings, and controls. There are major benefits that would be gained by using parts from this machine. Less time and money will be spent on ordering parts.

![Figure 5. Hercules Industries Barrel Dumper](image)

4.1.1 Driving Mechanisms
The machine that Vertellus currently has is very similar to the machine in Figure 5. This machine uses a linear hydraulic actuator to raise and lower the barrel. The cylinder is able to lift up to 750 lbs safely and efficiently. It also contains an explosion-proof motor which will run the hydraulic pump.
4.1.2 Controls
The device uses a push button starter that starts the electric motor which runs the hydraulic pump. A lever built into the hydraulic circuit allows the user to engage or disengage the flow to the cylinder. To control the speed of lifting, a needle valve is in place which acts as a fluid flow throttle. In order to power the lifter both up and down, a four-way valve would need to be installed. This would allow the reversal of flow direction into the cylinder so that it can be powered back in order to get beyond the dependence of gravity to bring the empty barrel back down.
5 MATERIAL PROPERTIES

5.1 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, there have been extensive studies 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 fibre drums that will be lifted and poured will be powder.

5.2 Factors that Affect Powder Flowability

5.2.1 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.

5.2.2 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 incredibly high humidity.

5.2.3 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.

5.2.4 External Surface
If the device uses some type of chute in which to funnel the chemicals into the reactor, a finish will have to be determined for the machine material. The degree of finish will have a large impact on how the powders flow. The smoother the surface the more easily the material can travel into the reactor.
5.3 Material Flow Research

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 in order 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 recourses given to us. A chemical frequently used by Vertellus, Distearyl dimethylammonium methosulfate (DDAMS), has been recently obtained and some basic experiments will be done with this chemical sample to help determine an appropriate machine tilt angle. Although Vertellus uses many different chemicals, the team contact at Vertellus said that all of the chemicals were very similar, and DDAMS would serve as a sufficient base case.
6 DESIGN CALCULATIONS

6.1 Free Body Force & Moment Analysis

In order to size and spec the components of the hydraulic system, calculations on the system were performed. Taking measurements from the geometry of the proposed frame design, a free body diagram of the loaded swing arm was made and can be seen in Figure 6.

![Free Body Diagram](image)

In this diagram the grounded revolute represents the top of the frame where the swing arm pivots. The beam represents the swing arm in a worst case scenario where the arm is fully extended. The mass of the barrel is applied to the end of the arm for a worst case scenario, and the hydraulic cylinder is applying a force at an 89 degree angle from ground; as is the worst case scenario for the proposed geometry. With this information, a moment and force balance were performed to determine the force the hydraulic cylinder would have to apply in order to keep the system in the free body diagram at equilibrium.

6.2 Hydraulic System Calculations

From the proposed geometry, it was measured that the stroke of the hydraulic cylinder would need to be 15” to achieve the necessary tipping action. A 30% safety factor was applied to the stroke to allow for improved shear strength in the extended rod. For the calculations, a hydraulic cylinder with a bore of 1” was used, and an extension time of 5 seconds was assumed. From this data the maximum pressure in the fluid, fluid flow rate, and cycle time of the system were calculated.

6.3 Calculation Conclusion

It was found that the proposed system would need a pump capable of .8 GPM (gallons per minute), hoses capable of handling a maximum pressure of 1200 PSI, and a fully extended shaft capable of handling a 900 lbf load. A typical hydraulic pump can easily produce a .8 GPM flow rate as 3 GPM is the normal maximum flow rate. Also, a maximum pressure is acceptable for this
system as all hydraulic lines and fittings in the United States are capable of handling maximum pressures exceeding 2000 PSI. The system would complete a full cycle in 10 second which is an acceptable time for the machine to operate in. These calculations further show that this project is feasible. A standard hydraulic system of the proposed size can easily provide the needed forces, pressures, and flow rates while allowing for a large factor of safety.
7 FINANCIAL ANALYSIS

7.1 Prototype Cost Estimates

After making the design decisions about the frame design and hydraulic system components, a cost analysis of the prototype can be done. The cost of the raw materials and components were compiled and totaled. These can be seen in Table 6.

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary Vane Air Motor</td>
<td>1</td>
<td>$266.00</td>
<td>$266.00</td>
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<tr>
<td>Hydraulic Pump</td>
<td>1</td>
<td>$198.00</td>
<td>$198.00</td>
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<tr>
<td>Hydraulic Cylinder</td>
<td>1</td>
<td>$150.00</td>
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<tr>
<td>Hydraulic Control Valve</td>
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<tr>
<td>Pressure Relief Valve</td>
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<td>$57.00</td>
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<tr>
<td>Hydraulic Over Center Valve</td>
<td>1</td>
<td>$112.00</td>
<td>$112.00</td>
</tr>
<tr>
<td>Oil Reservoir</td>
<td>1</td>
<td>$75.00</td>
<td>$75.00</td>
</tr>
<tr>
<td>Hydraulic Hose [4 ft]</td>
<td>6</td>
<td>$8.00</td>
<td>$48.00</td>
</tr>
<tr>
<td>Steel [lb]</td>
<td>450</td>
<td>$2.84</td>
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</tr>
<tr>
<td>Shipping &amp; Handling</td>
<td></td>
<td></td>
<td>$500.00</td>
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<tr>
<td>Contingency</td>
<td></td>
<td>50.00%</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>$4,185.00</strong></td>
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Vertellus has set a maximum cost allowance of $5,000 that they will supply for the manufacturing of the machine. The preliminary component pricing in Table 6 shows that the project costs fall within the allowable amount even with a 50% contingency. This analysis shows that the project is financially feasible and the manufacturing of the prototype should come in under budget.
8 FEASIBILITY STUDY

8.1 Performance
Basic calculations have shown that it is possible to construct a machine that will perform to the specified requirements. Acceptable cycle times in the range of 10-20 seconds are possible to obtain with working pressures within feasible and safe ranges. The geometry required to pour the chemicals into the reactor accurately is also possible to obtain with the components chosen.

8.2 Reliability
The components chosen are industrial equipment by nature – and proven to withstand the potentially harsh environments that they could see at Vertellus. Dust is the main contributor to the harsh environment but should not pose too great a problem to require extra precautions or design considerations.

8.3 Safety
The greatest potential safety issue is a spark that ignites a dust explosion. The principal design meets the requirement of being explosion proof by operating on readily available compressed air to run the motor. Instead of using electric motors and controls, air-powered components will provide safe working conditions. The other requirement of being safe for users to operate in close proximity will also be met by designing a machine that minimizes and prevents pinch-points.

8.4 Cost
As seen in section 7.1, the initial cost estimate with a 50% contingency balance still falls within the $5,000 budget as provided by Vertellus. Though not every single piece of hardware was incorporated into the initial financial estimate, (as it is essentially impossible to name every single fitting needed at this point in the design process), the 50% contingency should more than cover the small parts left unlisted.
9 CONCLUSION

After analyzing the different possible alternatives for a device that could pour a barrel into a variety of chemical reactors, a final design was reached. The design involves a device with adjustable pour heights that is powered by a hydraulic system using a linear ram. This design achieves all of the design requirements put forth by Vertellus and efficiently carries out its task. So, after analyzing the frame designs, powering techniques, finances, and fabrication techniques it is determined that this project is feasible.
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Appendix A

Hydraulic Calculations

\[
\text{Mass}_{\text{Barrel}} = 250 \text{ [lbf]}
\]
\[
\text{Length}_{\text{Cylinder, End}} = 29 \text{ [in]}
\]
\[
\text{Length}_{\text{Cylinder, Pivot}} = 8 \text{ [in]}
\]
\[
\text{Angle} = 89 \text{ [deg]}
\]
\[
\text{Bore} = 4 \text{ [in]}
\]
\[
\text{Throw}_{\text{effective}} = 15 \text{ [in]}
\]
\[
\text{Time} = 8 \text{ [sec]}
\]
\[
S_F = 0.3
\]
\[
\text{Pressure}_{\text{Hydraulic}} = \frac{P_y}{\text{Length}_{\text{Cylinder, Pivot}} \cdot \text{Mass}_{\text{Barrel}} - \text{Length}_{\text{Cylinder, End}}}
\]
\[
P = \frac{P_y}{\sin (\text{Angle})}
\]
\[
\text{Throw} = \text{Throw}_{\text{effective}} \cdot (1 + S_F)
\]
\[
\text{Area}_{\text{Cylinder}} = \pi \cdot \left( \frac{\text{Bore}}{2} \right)^2
\]
\[
\text{Pressure}_{\text{Hydraulic}} = \frac{P}{\text{Area}_{\text{Cylinder}}}
\]
\[
\text{Volume}_{\text{Cylinder}} = \text{Area}_{\text{Cylinder}} \cdot \text{Throw}
\]
\[
\text{Pump}_{\text{Flowrate}} = \frac{\text{Volume}_{\text{Cylinder}}}{\text{Time}} \cdot 0.2597 \frac{\text{gal/min}}{\text{in}^3/\text{sec}}
\]
\[
\text{Time}_{\text{cycle}} = 2 \cdot \text{Time}
\]

Angle=89 [deg]  Pump Flowrate=7.956 [gal/min]
Area_Cylinder=12.57 [in^2]  P_y=906.3 [lbf]
Bore=4 [in]  S_F=0.3
Length_Cylinder_End=29 [in]  Throw=19.5 [in]
Length_Cylinder_Pivot=8 [in]  Throw_effective=15 [in]
Mass_Barrel=250 [lbf]  Time=8 [sec]
P=906.4 [lbf]  Time_cycle=16 [sec]
Pressure_Hydraulic=72.13 [lbf/in^2]  Volume_Cylinder=245 [in]
Figure A1. How Pump Flow Decreases with Cycle Time.

Figure A2. How Pump Flow Increases with Increasing Bore Size.
Figure A3. How Bore Size Affects Working Pressure.

Figure A4. How Flow Rate Affects Working Pressure.
Appendix B

Fibre Drum Specifications

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<th>Fiber drum type</th>
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<th>Height</th>
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<tr>
<td></td>
<td>in</td>
<td>cm</td>
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<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>17¾*</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

<table>
<thead>
<tr>
<th>Project Objective</th>
<th>Duration</th>
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<td>PPFS Outline</td>
<td>16-20 Oct</td>
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<tr>
<td>Meet with Randy Elenbaas</td>
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<tr>
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<td>1-15 Nov</td>
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<tr>
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<td>26-30 Nov</td>
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<td>Dec 1-15</td>
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Gantt Chart details:
- Project Objectives Defined
- PPFS Outline
- Project Web-site
- Meet with Randy Elenbaas
- Research Power Options Design and Model Frame
- Make Preliminary Design Selection
- Draft PPFS
- Revised Updated Project Web-site
- PPFS