University of Idaho Capstone Design

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May 15, 2015

Dr. Brian He
Professor
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University of Idaho
875 Perimeter Drive MS 0904
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Dear Dr. Brian He,

This is a final report on the project of upgrading the department's bio-diesel reactor. This report details the design as it progressed from its initiation in August 2014 to its completion in May 2015. Our primarily focus ended up being a sealed lid, proposed control scheme, proposed heating scheme, proposed mixing scheme, and proposed system configuration. As you know the lid is in the middle of a fairly complicated fabrication process that needs to be completed by skilled laborers. A comprehensive drawing package and detailed manufacturing plan for all remaining fabrication/assembly steps is included in this report.

If you have any questions with interpreting this report or require other materials feel free to contact myself or any other members of the team. Other long-term resource associated with this project are our projects poster (given to Keegan for display in JML) and our capstone wiki page (accessed via http://mindworks.shoutwiki.com/wiki/Main_Page).

Sincerely,

Gene Staggs & Team Liquid Gold

Enclosure: **Final Report: Pilot Bio-diesel Reactor**

Liquid Gold

Pilot Bio-diesel Reactor

Final Report

Andrew Engel (ME), Brain Hanson (BAE), Connor Saxe (ME), Gene Staggs (BAE)
5-9-2015

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Executive Summary

The team Liquid Gold has been working on renovating the Department of Biological and Agricultural Engineering's bio-diesel reactor. The client approached us with long list of specific needs. Most can be summed up into one of three categories: safety, budget, efficiency, and current technology. The design team worked with client representatives to break these categories into systems that we could address as design problems. This was also necessary to create an order of priority.

The team settled on breaking the project in or order of importance into 4 major design areas. These are Reaction Containment, Heating, Fluid Movement, and Technology / Controls. This covered all the needs categories with budget setting the background. Budget created one of the most interesting features of the project. The team essentially created two working designs for the first semester. One a low budget base model, and the second an optimum fully realized model. The one priority above budget however was safety. Methanol containment was priority due to toxicity and flammability. The second semester used the majority of the budget on manufacture of a lid for this reason.

In our deliverables we created a concept model to show what was possible on the project and give a budget scope for fully realizing client needs. The lid itself creates the first fundamental step in full methanol containment with a strong adaptive super structure. The greatest benefit of our design is the bolt on, modular aspect. As the other systems evolve the containment lid will support their designs.

Background

The department of Biological and Agricultural Engineering has operated the current reactor for several years. They currently use it to produce large batches of bio-diesel 2-3 times per year. The batches are approximately 300 gallons and normally use waste cooking oil from the university as a feed oil. The reactor like all equipment ages and as technology improves can be optimized with new innovations.

The current reactor has very simple operation. The first step is loading the large vessel with feel oil. This is normally done by rolling up oil storage tanks and filling the vessel with and external pump and hose. They fill a smaller secondary tank with the catalyst and mix it with the second reagent methanol. The methanol is measured by volume measurements in the tank, and the catalyst is weighed by scale and dumped in from a bucket by the operator. A mounted pump then pushes the methanol and catalyst into the main vessel. The reaction is agitated, while the vessel is heated by large electric bands placed on the outside of the vessel. After several hours the reactor they stop agitation and test the fluid and if necessary run a secondary reaction.

This process currently works. The design team actually worked with the department for one batch, but there are a flaws. The first is the labor intensity. One batch done this way puts a large drain on staff time. The second would be worker contact with hazardous chemicals. All workers were wearing proper protective equipment, but anytime exposure is cut the operator will be at less risk. The last is the current reactor has no instrumentation. All measurements are done by hand and any problems must be witnessed by the operator. Some of the expected benefits for the department would be a safer work environment with less exposure and automated alarms, quicker reactions, better metering, and less time drain on staff hours.

Problem Definition

Problem Statement:
The objective of this team will be to design and fabricate a state of the art pilot scale biodiesel reactor to address challenges for industrial partners. This system will handle reagents such as methanol and liquid sodium methylate.

System Needs:
- Reduce methanol exposure levels
- Create stable heating system
- Follow explosion safety guidelines
- Introduce instrumentation and controls
- Maintain or improve agitation

Project Goals:
- Provide a stainless steel containment lid for the reactor
- Incorporate sonication for agitation
- Provide stable automated heating
- Include enclosure venting and methanol condensing
- Add instrumentation and create electronic controls platform

Design Specifications:
- No materials used will react with the chemical process
- The design shall be cleanable without disassembly
- The design shall prevent methanol escape from the enclosure
- The design shall follow explosion safety guidelines
- The design shall not allow reactor to exceed 3 psig

System Design

Conceptual Design & Development

To better understand the concept design presented this section will cover some of the background research and the origin of ideas the team pursued. In the beginning we were haunted by low budget. We had to design a system and with the funds available, and implement as much as possible. One option outside of the budget was to repurpose currently owned equipment. One team looked and created and itemized list of possible salvage options while another actually learned how to make the reaction take place. The salvage mission did not turn up anything that could significantly cut cost. The bench top production experiments lead to some of the most productive idea generation for the design.

Several important things were gained from both events. Though the salvage failed in saving significant cost it did make the team to come to a realization that the entire reactor would not be built in this capstone year. This forced us to focus on an idea that would innovate and dominate our concept. We decided on a modular focus. We would create a base system capable of upgrades and easy in line additions for future teams. The bench top study gave rise to the entire process order our design would follow and ideas for controls and metering. Part of that process was separating the heating of the oil and the methanol, something done on the bench top but not in the current system. After this we quickly divided the most important systems into categories of Fluids, Heating, Controls, and Containment. The process was to divide design each portion semi-independently and integrate.

Fluids System

The objective of this system was to tie together all the other systems in an efficient and cost effective way. This system was designed to follow the flow chart seen in Figure 1. It proposed having an independent tank for each reagent. This would provide two distinct

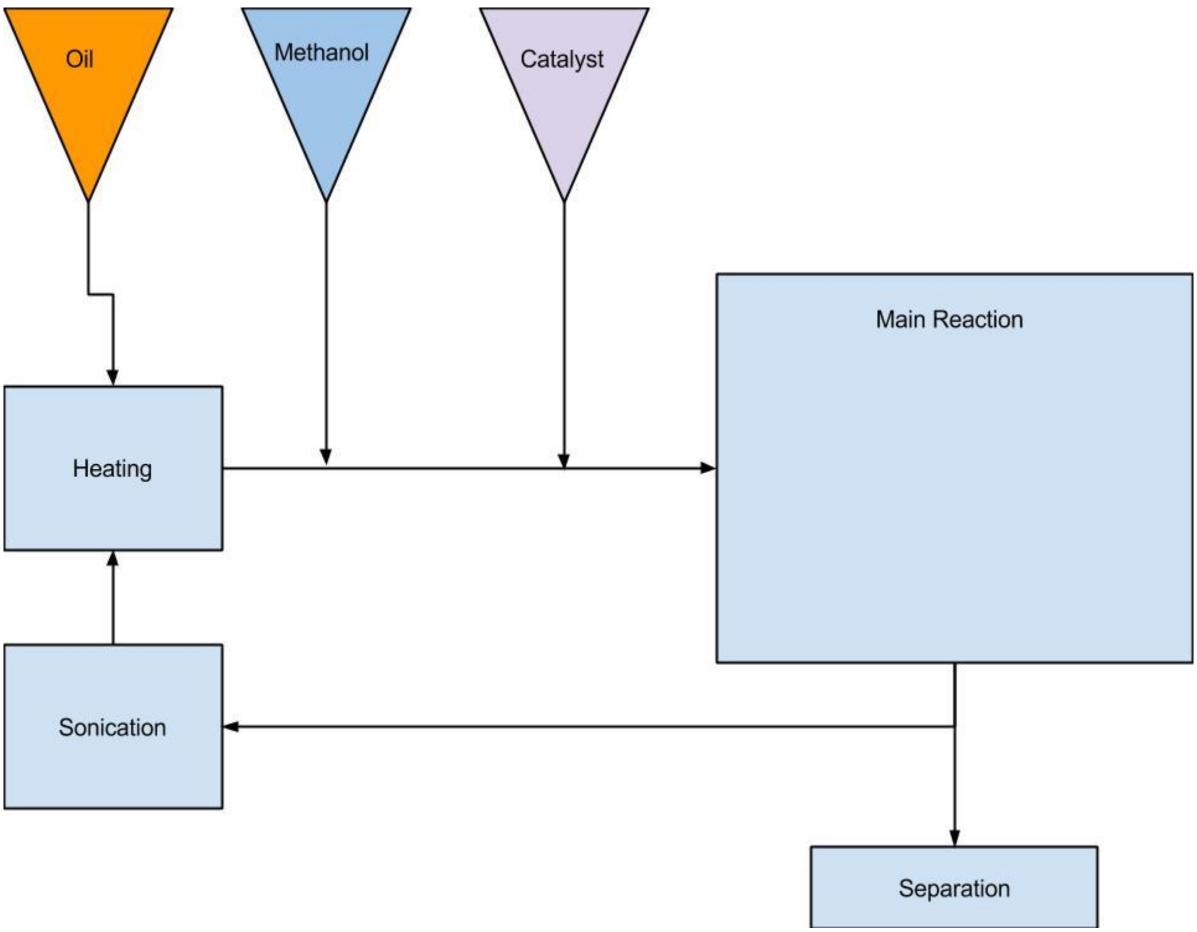

Figure 1: Flow chart demonstrating basic systems and flow path of the proposed design.

beneficial design features. The first is creating a buffer between bulk storage and the reaction process. This lowers risk of expensive contamination to bulk tanks. It also provides an easy avenue for establishing instrumentation and metering controls.

After the bench top example the designer of this system was able to calculate minimum size tanks for the maximum batch size the reactor vessel could handle. These sizes are based on canola and are as follows: Feed Oil 300 gal, Methanol 80 gal, Liquid Catalyst 15 gal, and for a Solid Catalyst 2 gal. Two materials were suggested the first a compatible plastic and the second stainless steel. The design engineer was also in charge of doing the structural analysis of the platform and tank mounts. Oil weight was the most significant with a full tank setting at 930kg.

The rest of the system was composed of piping and pumps. Each tank would be sealed and have a pipe from lid to base with a quick connection for filling, and pressure relief valves to allow two way flow. The methanol vapors pose a health risk and because of this, the pressure relief valve would be connected to the main vessel. The main vessel is open to atmosphere but vapor must travel through a condenser removing the methanol. The main pump controlling flow to the reactor was repurposed from inventory with a 2 inch inlet to a 1 inch outlet. The motor is 1hp 115/230v source. The team looked into different pipe sizes and quickly found 1 inch to be the most practical. Piping price goes up with size, but valve prices jump much more significantly. Sonication equipment is high end technology that has to be purchased through vendors, but is very easily to install anywhere in the recirculation piping system. The device on hand would not allow for needed flow rates. We sized the system to need a minimum of 1000W power with a 1 inch contact area probe. Depending on source price ranged from $2000 to $5000 dollars.

Heating System

The heating system was designed to decrease the time spent heating the feedstock fluid (Oil). The result of decreasing the heating time increased reaction potential causing the overall processing time of the biodiesel to decrease significantly. Another benefit will be increasing the overall quality of the biodiesel produced. The heating system was designed to heat the feedstock oil from room temperature (65°F) to 150°F in less than an hour. The heating system also had to fit the current utility connections located inside the facility as well as be a safe and lost cost. The total heating input required to for the reagents to reach temperature was 23 kWh. The input of our system was 27 kWh, thus allowing us to heat the fluid in less than one hour, satisfying the design criteria. Detailed calculations follow the main body report in the appendices.

Figure 2: Concept model of proposed electric heating system.

The heating system was also designed to allow for easy operation, cleaning, and effectiveness. The shell of the heat exchanger was designed using standard threaded pipe and standard fittings. We chose to use electric tankless water heater coils for the heating elements. These coils provide a compact heating supply that can be controlled relatively easily in order to promote safe stable heating. This control is necessary to not burn the oil while it is passed over it. The coils come with a standard screw fitting that allow them to be inserted into a standard sized pipe. The heating coils come manufactured for easy integration with standard electric connections and compatibility to most facility utilities. A concept model can be seen in Figure 2 on the left.

The system will also include instrumentation measuring temperature for safety and control with a three modes to be able to change the heating output to the oil. This heating adjustment control will be connected to the later mentioned process control system for overall integration. This heating system is able to provide the heating required for about $500. Compared to a second heating option that would utilize facility hot water supply, this system is much more cost effective. The heat exchanger required for the water heating system would cost $2500. This electric system design is a very effective system similar to those currently being integrated into modern households. The team believes this design should be investigated further as a heating system for future senior design project.

Sonication

One of the objective for the design was the addition of sonication. This was dependent on using currently available technology. The sonifier currently available is a Branson Digital Sonifier model 450. The factory recommended continuous flow adapter (EDP-100-146-171) will only support a maximum flow rate of 38L/hr. The current tank will produce about 1400L. We do not believe this sonifier will be appropriate for our design and will not include it.

Our suggestion is to design a smaller model to utilize current sonifier or purchase new sonication equipment. The current model has a total power output of 400W and similar sized systems from our research are running systems near 1000W.

Instrumentation & Controls System

The needs of this system were quite simple. The design engineer was tasked with providing a system and interface capable automation, and providing the operator precise real time feedback, and data logging. As an additional request we were to design a high and low budget version of the system. The current system makes use of different extension cords to power the reactor. One of the goals of this system is to gather all the wiring and route it through one panel box. The conduit would along the platform to the equipment increasing safety, reliability, and ease of operation. This panel would have manual industrial switches to all equipment, ground fault protection, and total power safety disconnect.

To assess what instrumentation was needed we broke the controls system down into different categories, Process, Safety, and Heating. Heating is held separately because of the different nature in its controls. Turning the heating system on is simple ladder logic, but element itself needs to have a PID controller. This system also has a level of inherent danger associated with it and needs an extra level of safety. We recommend wiring the elements with built in safety limits. This would create a safety net if the controls were to fail. It would be more expensive because for our design the heating system would essential have two different circuit branches. One for each mode of heating. To further safety we also wanted instrumentation to monitor each element’s temperature. The system was extensively modeled with computer software applications, and could be controlled with just an input and output feed. The extra instrumentation would just cut down time lag if there were a problem. Ideally the system would have 8 temperature sensor feeds 2 for control and 6 for safety.

On the process side of control we focused on ladder logic and what instrumentation we would need to make the system succeed. Fortunately the computer age has made electronic control elements relatively cheap. The solenoid valves for controls became this systems most expensive element. The methanol being a flammable substance requires the use of solid state relays for controls, and explosion proof solenoid valves made out of stainless steel. This hardware alone pushes the controls budget to near $1000. The team decided to meter the feed tanks with a load loss approach. It give the ability for the operator to know exact quantities in

Figure 3: Sample computer based controls system

each tank at real time and the system add specific amounts of reagents. There are several physical properties we could measure to accomplish this but it came down to volume or mass. We suggest load cells but with the excessive weight in excess of 900kg this type of sensor becomes very expensive. A cheaper alternative is ultrasonic distance sensors in the top of each tank lid. These sensors in combination with a controller, relays, and solenoid is all that is needed to run the system. Detailed logic tables are included in the appendices. The team is also providing 2 programs that establish proof of concept and demonstrate the process with manual and automated control modes. The screen of the computer graphical user interface can be seen in Figure 3 to the left.

The last portion of controls comes from the need of safety. This system would need more sensors and the goal is monitoring equipment and states within the system to protect the equipment and operator. We designed a list of sensors desired and a logic table for the programing listed in the appendices. One sensor in particular is very expensive. This is to detect methanol vapor concentration. Only a few companies produce these sensor with a guarantee on safety. The price is from $1200 to $2000 dollars. It is a very important sensor for employee safety. The STEL limit for methanol is 200ppm and only IR capable fire systems can detect its flame. To human vision methanol burns nearly invisible. Early detection devices of fumes is expensive but well worth the cost. The team has provide some recommendations for retailed sensors.

Methanol Condensing System

The team looked into several approaches. The requirements for this project was to have the system remain open to atmosphere, condense methanol and reintroduce it to the reaction. Only one solution really presented itself as matching all the criteria. We believe that to be a modified condensing column. We calculated the greatest volume of methanol gas escape to be during tank fill and heating. There are a few problems with this design. The first is it will not condense 100% of vapor and the second, to get it down to 200ppm emittance it has to be very cold. This causes a problem with room relative humidity and water condensing. This problem was never fully solved. One recommendation is to close of the tank from atmosphere once the reaction reaches a stable heat, the chamber should stabilize in pressure as well condense 100% of vapor. This also has some problems there is inherent risk of vessel damage from pressure or vacuum anytime the tank is sealed. The team recommends 2 fail safes. First, pressure relief valves at 2psi, and a two way rupture disc installed for 3psi.

Full System Summary

The full system will include all the previous items and will also include a containment lid set for manufacture this semester. The entire system will be integrated, able to run without the constant human interaction that is involved with the current biodiesel reactor. The most chemical interaction that the operator will have with the new system is during tank fill. Once the systems process feed tanks are filled the operator will have complete control of the system with a graphical user interface allowing them to operate the system in two modes, and potentially remotely. System safety was one of our greatest concerns included in the appendices a DFMEA. The system will be able to operate safely, generate stable heating, and will control the exposure to the operator. Proposed parts, modeling, and pricing will be included with deliverables in software format.

Figure 4: Proposed concept design full solid model.

Lid Design

Target Specifications

The tank lid was designed around the current reactor. The vessel dimensions are 55" in diameter with a 1.625" flange that wraps around the entire tank. The containment lid was designed to match the 55" diameter reactor. The lid was required to hold 250 lbs of force located in the center of the lid without defecting more than 1/16", and without causing yielding to the tank lid material. The 250 lb requirement was based around holding a person in the scenario they had to step onto the tank lid for servicing. The tank lid had to also withstand a 3 psi pressurization or vacuum of the tank while maintaining structural integrity. This requirement was based around a scenario where the tank venting malfunctioned causing a pressure to increase. The design will also include easy installation options, for pressure release valves and rupture disks to release before 3 psi is reached. The tank lid had to have ample viewing area for reaction observation and demonstrations. The design also had to include a dynamic lid that was able to open easily without having to remove the entire lid structure. The dynamic lid had to include an opening large enough to be able to change out different agitator attachments. The overall tank lid design could not reach a natural frequency during operation.

Implementation Choice

The use of stainless steel for this construction was chosen in order to prevent corrosion to the metal surfaces. This material was also picked because it does not react with the oil, catalyst, or methanol that will be used for the biodiesel manufacturing. Stainless steel will be used for all components on the tank enclosure to maintain the corrosive resistance of the entire system. The hinged access for this tank was added in order to give the operator the ability to access the tank without having to remove the entire tank lid. The hinged access will be completely sealed and have clamps to keep the shut during operation. The dynamic lid weighs 35 pounds and should be able to be opened by a single individual. This tank lid will have access for two forms of agitation. The first using the electric motor drive agitation. The second will be the hydraulic agitation. Both forms of agitation will be able to be used during operation while still keeping the system completely sealed. The viewport on this tank lid will be 9”X9”. This will allow for great observation capabilities during processing and for educational observation. The viewport will also be completely sealed. Pyrex glass is going to be used for the transparent viewing material. Dynamic lid clamps will be made using an all stainless steel construction. They will allow for adequate clamping for while still allowing the dynamic lid to open freely without the disassembly of clamps. A full pricing table can be found in the appendices and an image is represented below in Figure .

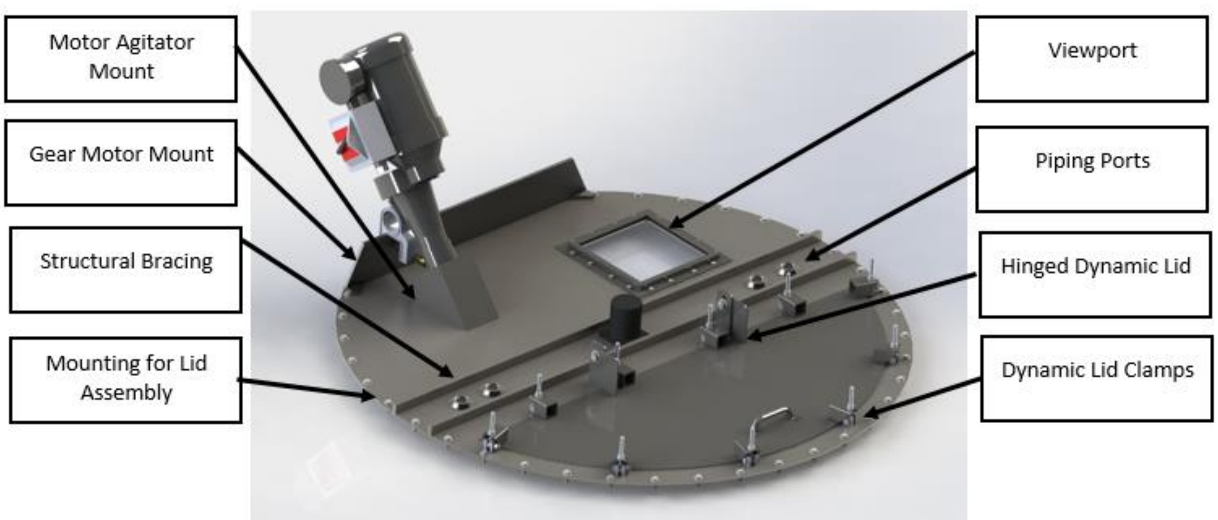

Figure 5: Containment lid solid model.

Manufacturing Overview

This manufacturing overview is a general outline on the manufacturing process of the tank lid. It will outline the processes used to manufacture the lid and the reasons they were used based on our design. A detail manufacturing plan will be attached with our report document and will be mention in further detail at the end of the report.

- *Main Tank Lid Sheet:*
    - Water Jet: The tank lid will be water jet cut from a single sheet of 304 stainless steel. Due to the water jet limitation the full tank lid will not be able to be cut from the sheet, instead it will have to be cut into two part that will be later welded together. In order to minimize the welding required, the tank lid will be cut into the two sections that will satisfy this requirement. The two tank lid piece separation location is shown below in figure 9 below.
    - Structural Members: Two 1/2-1” stainless steel flat bars will be welded along the center of the main tank lid sheet. The welding will have to be performed in an alternating stitch pattern in order to minimize the warping of the tank lid top due to the welding consequences.

  - <u>Hinges for Dynamic Lid:</u> The hinges for the dynamic lid will also have to be welded in place along the large opening of the tank lid. The hinges will be made from 3/8” stainless steel flat bar.
  - <u>Mounting Holes and Accessory Holes:</u> All the locations used for the mounting of the tank lid to the tank will be cut using the water jet to ensure equal spacing of the mounting holes which will be used as a template to drill the holes in the tank flange for mounting. The accessory holes will be also cut using the water jet to ensure location accuracy.
  - <u>Gasket:</u> For sealing the face between the tank lid and the tank flange a viton foam seal will be used. It comes in a roll form that is
- *Motor Driven Agitation Mount:*
  - <u>Water Jet:</u> The five flat plate pieces needed for the construction of the mount will be cut using the water jet from the leftover material from the .135” 4’ x 10’ stainless steel sheet. By using the water jet it will ensure accuracy as well as make the manufacturing process faster.
  - <u>Tank Lid Attachment:</u> The mount will first be welded together using the five water jetted pieces to create the mount. Then the solid mount will be welded above the shaft access hole located on the tank lid.
  - <u>Agitation Mount Seal:</u> The seal that will be used for the connection between the agitator and the mount will be cut from a solid piece of Buna-N gasket material. This will ensure an accurate fit of the seal.
- *Viewport:*
  - <u>Glass:</u> The glass portion of the viewport will be made out of Pyrex glass in order to have a durable, heat resistant, and chemically compatible, transparent material. The glass can be ordered to the exact size we need.
  - <u>Brace:</u> The brace will be made from the excess metal from the 4’ X 8’ sheet of stainless steel. The braces purpose is to be able to be bolted to the tank lid to provide compression on the gaskets and glass to make an air tight seal for the viewport.
  - <u>Gasket:</u> The gasket will be cut from a solid piece of Buna-N gasket material. This will ensure a perfect gasket fit for our application.
  - <u>Assembly:</u> The assembly will consist of four parts not including fasters. The first gasket will be placed around the opening of the view on the lid. Then the glass will be place on top of the first gasket. Next the second gasket will be placed on top of the glass. For the final part the brace will be placed on top of the previous items and secured with bolts. The reason two gaskets will be used for the viewport is to help minimize vibration that is exposed to the glass. The gaskets will act as a damper, keeping excess vibrations from cracking the glass of the viewport.
- *Dynamic Lid:*
  - <u>Water Jet:</u> This piece will be cut out from the 4’ x 8’ sheet of stainless steel with the main tank lid portion. No welding will be required for this piece since it is small enough to be cut from the sheet in one pass.
  - <u>Hinge:</u> The two hinges that will be used for opening and closing the lid will be made from 3/8” stainless steel flat bar. They will be welded to the dynamics

tank lid then connected to the main tank lid hinges with a bolt, nut, and washers.

Design Evaluation

The finite element analysis (FEA) was performed using SolidWorks software. Three different studies were performed using the software, stress, deflection, and natural frequency. The FEA were used for prototyping designs and used for a selecting a final design to implement.

The test was based around maintaining structural integrity when a pressure of 3 psi was built up in the tank, not having any yield of the material when 250 lbs was applied to the center, and not having more than a 1/16" of deflection when 250 lbs was applied to the tank lid. Along with establishing the boundary conditions used for the tests was also important. The boundary condition was established around the bolts holes for mounting to the tank flange. See appendix for image of boundary conditions and forces applied to model.

- Designs Tested:
  - Design 1: 0.1875" Stainless Steel Plate
  - Design 2: 0.135" Stainless Steel Plate
  - Design 3: 0.1875" Stainless Steel Plate with ¼"-1" Double Stainless Steel Flat Bar Bracing
  - Design 4: 0.135" Stainless Steel Plate with ¼"-1" Double Stainless Steel Flat Bar Bracing
  - Design 5: 0.135" Stainless Steel Plate with ¼"-1" Double Stainless Steel Flat Bar Bracing
  - Design 6: 0.135" Stainless Steel Plate with ½ "-1" Double Stainless Steel Flat Bar Bracing

The final design 6 was only design to pass all of our design criteria and was the chosen to be used for our manufactured product. The design also minimized metal costs while still passing the necessary design criteria.

Design Failure Mode Effects Analysis (DFMEA) was used to identify, quantify, and reduce the risk of our designs. The team performed a DFMEA of the tank lid system and identified 7 areas of potential failure. All of the areas we identified as potential problems are described in detail, in Appendix C. The two highest risk problems we faced when performing our DFMEA was warping of tank lid causing toxic chemicals to be released and ignition source being introduced into the tank causing an explosion. The tank lid warping can be compensated with a thicker seal material. The explosion of the tank can be mitigated by containing the flammable materials and eliminating any ignition sources near the reactor. For more information on the DFMEA please see Appendix C.

Future Work

Figure 4 is the solid model of the conceptual design. This is what this reactor could become. The largest hurdle would be cost. For completion with a new up scaled sonication unit it would a cost approximately $6000 dollars. We see possible implementation occur over the new few years with senior capstone design being a valuable tool to achieve this purpose. The sonication unit would not make a great project with little chance to design. With the idea of future capstone projects as an outlet will make our recommendations as a project base.

The first project we would advise doing is a condenser system. It is needed to complete the containment of the methanol vapors. The department already has access to a refrigeration unit and bare minimum condensing column could be constructed on the low for under two hundred dollars. To achieve better results and creativity our team would recommend $1000 budget. This design was one of the least developed by our team and in turn has the most potential for creativity from other capstone generations.

The next installment we believe to be the most beneficial to be completed the following year would be design and construction of a heating system. The reaction temperature is fundamental for decreasing batch process time. Depending on design this system can range from $1000 to $3000. We believe $2000 would still be an adequate budget for a team. Building utilities must be taken into account for this design, any modification can potential greatly increase budget.

The last installment would be instrumentation and controls this system would cost around $1500 to bring to completion using currently available tanks. There is great potential for design creativity here. There are countless instrumentation devices to pick from, and ways to program it. We recommend requesting a computer science, and electrical engineering major for this portion of the project. This expertise was lacking from our design team and would have been invaluable.

Manufacturing Plan

Due to the time constraints our team was unable to manufacture all the parts for the reactor lid. Since we were unable to produce all the parts we have put together a manufacturing plan for completing the remaining parts. Attached with this report will be detailed instructions on completing the viewport, agitator brace, dynamic lid hinges, and the full assembly of the tank lid. Along with the manufacturing plan a full drawing and solid model package will be included. The drawing package, solid models, and manufacturing plan should allow the client to finish the design and have a complete working tank enclosure. If any questions arise from these included items when manufacturing, the team will be available for any questions that will assist on completing the tank lid.

Appendix A: EES Model of Heating System

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EES Ver. 9.801: #2191: For use only by students and faculty in Mechanical Engineering, Univ. of Idaho, Moscow, Idaho

```
"Connor Saxe"
"Senior Design"
"Heat transfer for the heat exchanger"

"Fluid Properites - Canola Oil"
C_p=2.254*convert(kj/kg-k,j/kg-k)           "Heat capacity canola oil"
T[1]=converttemp(F,K,60)                    "Initial temperature of the oil"
T_ref=273.15[K]                             "Reference temperature"
rho=.914*convert(g/cm^3,kg/m^3)             "Density of canola oil"
nu=78.2*convert(mm^2/s,m^2/s)               "Kinematic viscosity of canola oil"

"Heat transfer"
D=.026645[m]                                "Diameter of the tube"
P=pi*D                                      "Perimeter of the tube"
L=18*convert(in,m)                          "Length of the tube"
v_dot=4.1667*convert(gpm,m^3/s)             "Volumetric flow rate of the oil"
m_dot=v_dot*rho                             "Mass flow rate of the oil"
q_conv=4500[W]                              "Flux from heating element"
q_prime_prime=q_conv/(P*L)                  "Flux per unit area"

"Temperature of oil after first element"
T[2]=T[1]+(q_prime_prime*P/(m_dot*C_p))*L

"Temperature of oil after second element"
T[3]=T[2]
T[4]=T[3]+(q_prime_prime*P/(m_dot*C_p))*L

"Temperature of oil after third element"
T[5]=T[4]
T[6]=T[5]+(q_prime_prime*P/(m_dot*C_p))*L

"Temperature of the oil after fourth element"
T[7]=T[6]
T[8]=T[7]+(q_prime_prime*P/(m_dot*C_p))*L

"Temperature of oil after fifth element"
T[9]=T[8]
T[10]=T[9]+(q_prime_prime*P/(m_dot*C_p))*L

"Temperature of oil after sixth element"
T[11]=T[10]
T[12]=T[11]+(q_prime_prime*P/(m_dot*C_p))*L

"Positions"
x[1..12]=[1,2,3,4,5,6,7,8,9,10,11,12]
```

SOLUTION

Unit Settings: SI K kPa kJ mass deg

C_p = 2254 [J/kg-K]

D = 0.02665 [m] {0.08742 [ft]}

L = 0.4572 [m]

$\dot{m}$ = 0.2403 [kg/s]

ν = 0.0000782 [m^2/s]

P = 0.08371 [m]

q_{conv} = 4500 [W]

$q'_{,prime}$ = 117582 [j/m^2-s]

ρ = 914 [kg/m^3]

T_{ref} = 273.2 [K]

$\dot{v}$ = 0.0002629 [m^3/s] {4.167 [GPM]}

No unit problems were detected.

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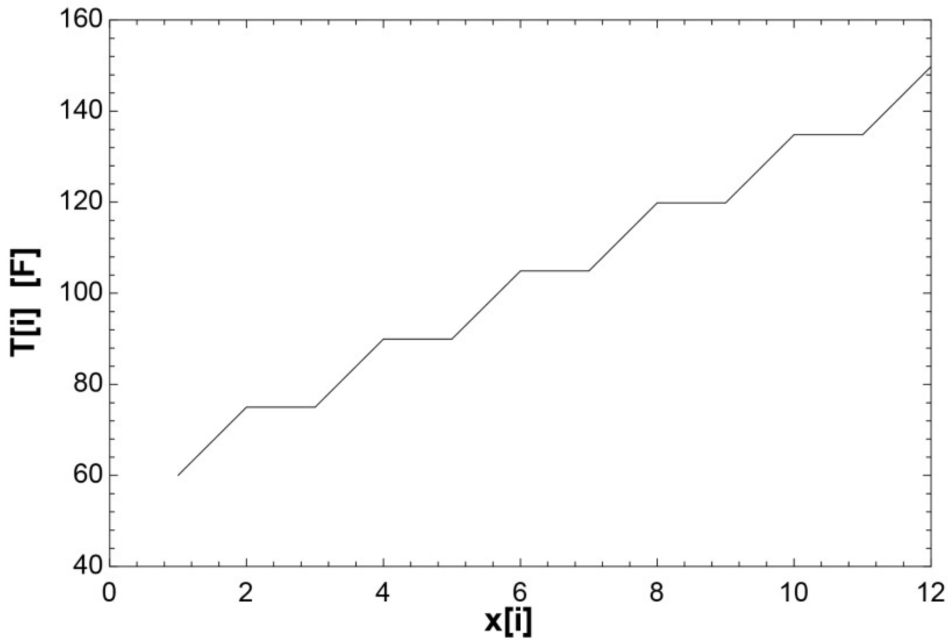
Arrays Table: Main

	x_i	T_i [K] {[F]}
1	1	288.7 {60}
2	2	297 {74.96}
3	3	297 {74.96}
4	4	305.3 {89.91}
5	5	305.3 {89.91}
6	6	313.6 {104.9}
7	7	313.6 {104.9}
8	8	321.9 {119.8}
9	9	321.9 {119.8}
10	10	330.3 {134.8}
11	11	330.3 {134.8}
12	12	338.6 {149.7}



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```
"Senior Design"
"Thermodynamic estimates of heating energy"

"!Mixture: Ratio of methanol to canola oil"
Mix_ratio=121.52/1072.75

"!Canola oil"
C_v=2.3855[kj/kg-k]                      "Specific heat"
T_1=converttemp(c,k,20)                  "Initial temperature of the oil"
T_2=converttemp(c,k,63)                  "Final temperature of the oil"
rho=.915[kg/L]                           "Desity of the oil"
V=200[gal]                               "Volume of oil"
M=rho*(V*convert(gal,L))                 "Mass of oil"

"Change in internal energy"
DELTA_U=C_v*(T_2-T_1)

"Energy need to heat oil"
Q=(DELTA_U*M)*convert(kJ,kWh)

"!Methanol"
f$='methanol'
P=1*convert(atm,psi)                     "Pressure of methanol"
T_1_m=converttemp(k,F,T_1)               "Initial temperature of the methanol"
T_2_m=converttemp(k,F,T_2)               "Final temperature of the methanol"
rho_m_1=density(f$,T=T_1_m,P=P)          "Density of the methanol"
V_m=Mix_ratio*V                          "Volume of methanol"
M_m=rho_m_1*(V_m*convert(gal,ft^3))      "Mass of methanol"
u_m_1=intenergy(f$,T=T_1_m,P=P)          "initial internal energy of the methanol"
u_m_2=intenergy(f$,T=T_2_m,P=P)          "Final internal energy of the methanol"

"Change of internal energy"
DELTA_U_Methanol=u_m_2-u_m_1

"Energy required to heat methanol"
Q_m=(DELTA_U_Methanol*M_m)
```

SOLUTION

Unit Settings: Eng F psia mass deg

C_v = 2.386 [kJ/kg-K]	ΔU = 102.6 [kJ/kg]
$\Delta U_{Methanol}$ = 48.98 [Btu/lb_m]	f$ = 'methanol'
M = 692.7 [kg]	Mix_{ratio} = 0.1133
M_m = 149.6 [lb_m]	P = 14.7 [psi]
Q = 19.74 [kWh] {67350 [Btu]}	Q_m = 7326 [Btu]
ρ = 0.915 [kg/L]	$\rho_{m,1}$ = 49.38 [lb_m/ft^3]
T_1 = 293.2 [K]	$T_{1,m}$ = 68 [F]
T_2 = 336.2 [K]	$T_{2,m}$ = 145.4 [F]
$u_{m,1}$ = -502.2 [Btu/lb_m]	$u_{m,2}$ = -453.2 [Btu/lb_m]
V = 200 [gal]	V_m = 22.66 [gal]

No unit problems were detected.

Appendix B: Logic Tables

Table 1:Alarm logic table

Input\/	Output>	Agitator	Pump	HExchanger	Trouble Alarm	Emergency Alarm
Amp Ag		0			1	
Amp P1			0		1	1
Reactor Temp H				0	1	1
HExchanger H				0	1	1
HExchanger L					1	
Reactor Pressure				0		1

Table 2: Process logic table

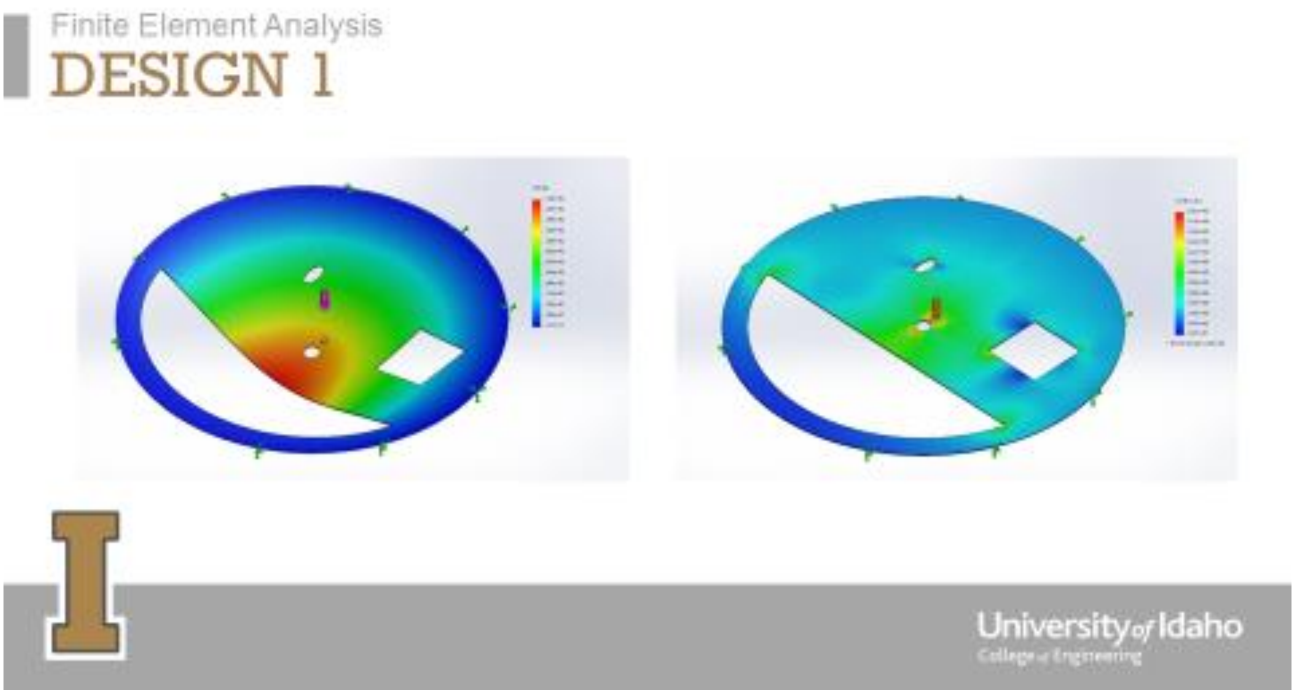
Test Reactor Logic Table Control										2015	
IN ∨		OUT--->	Set	Mode	Timer	Pump	Agitator	Valve1	Valve2	Valve3	Valve4
	Pin		B0	B1	B2	8	9	10	11	12	13
Button1	0		0	0		0					
Button2	1			0			0				
Button3	2		0					0			
Button4	3								0		
Button5	4									0	
Button6	5										0
Button7(start)	6					0		0			
Button8(stop)	7		1	1	1	1	1	1	1	1	1
Catlvl	A0							1	0		
Methlvl	A1								1	0	
Oillvl	A2						0			1	0
Temp	A3	read									
Timer	B2					1	1	1	1	1	1

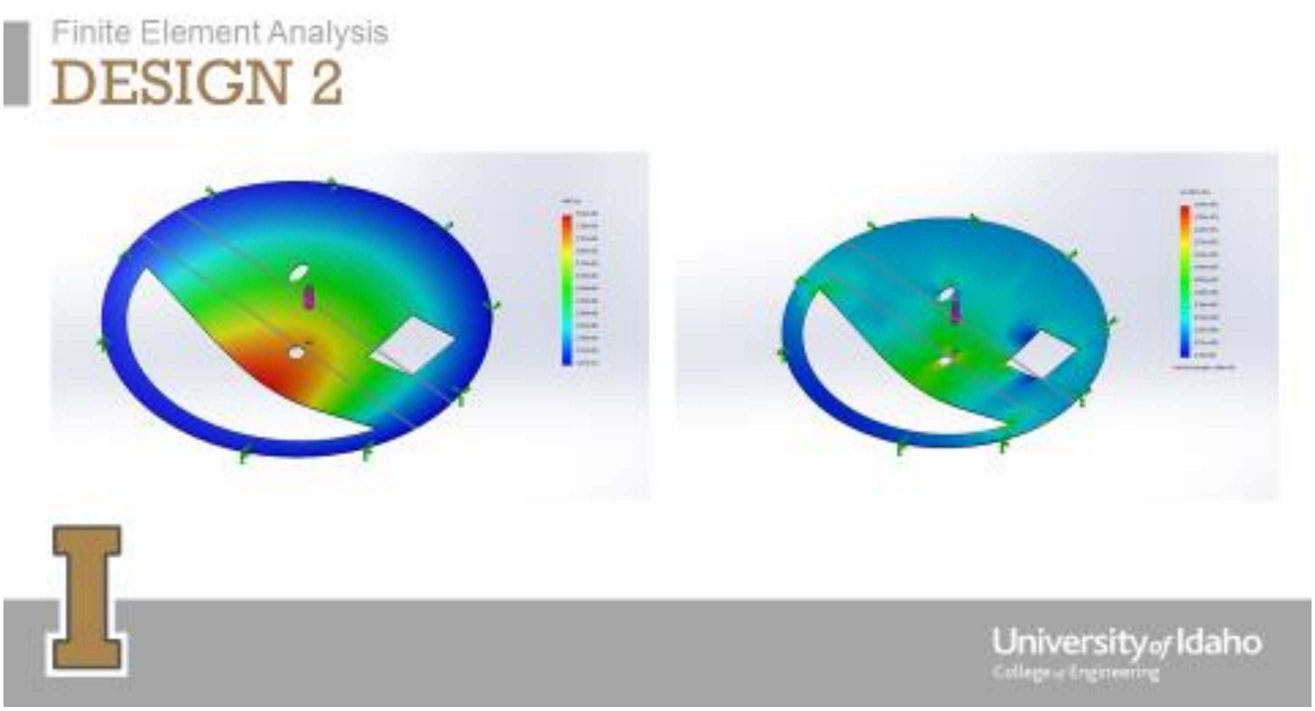
Appendix C: DEMFA

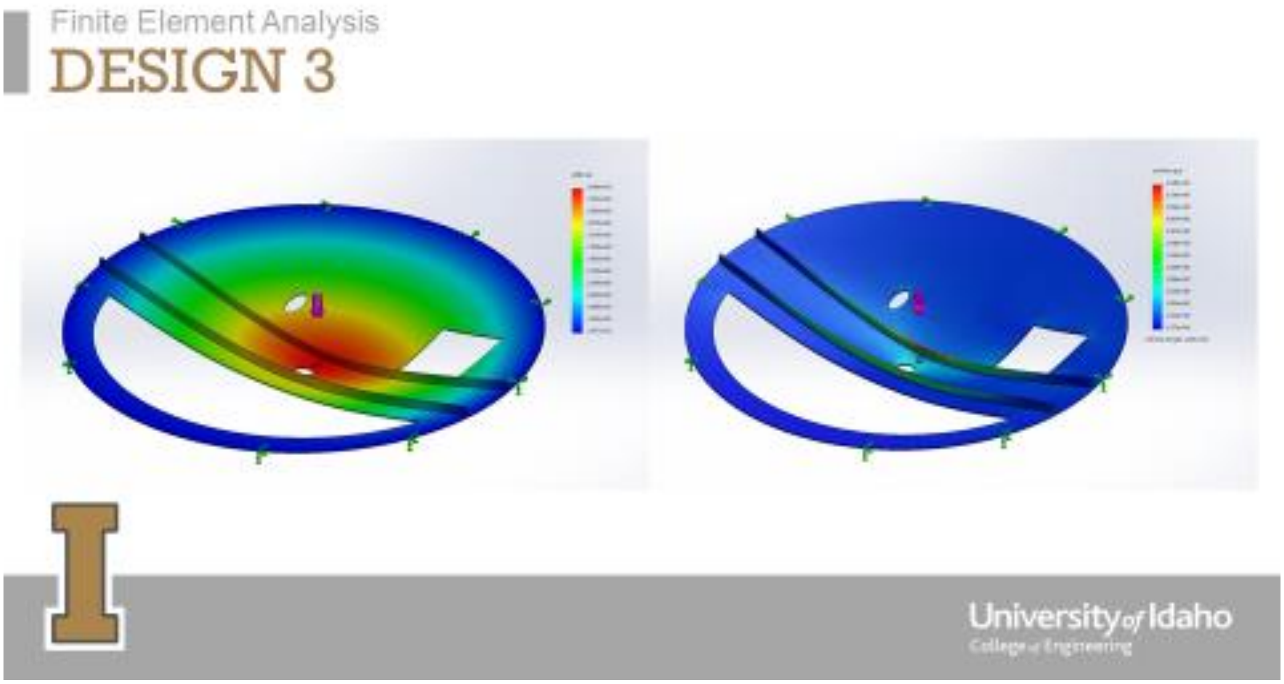
Table 3: DFMEA

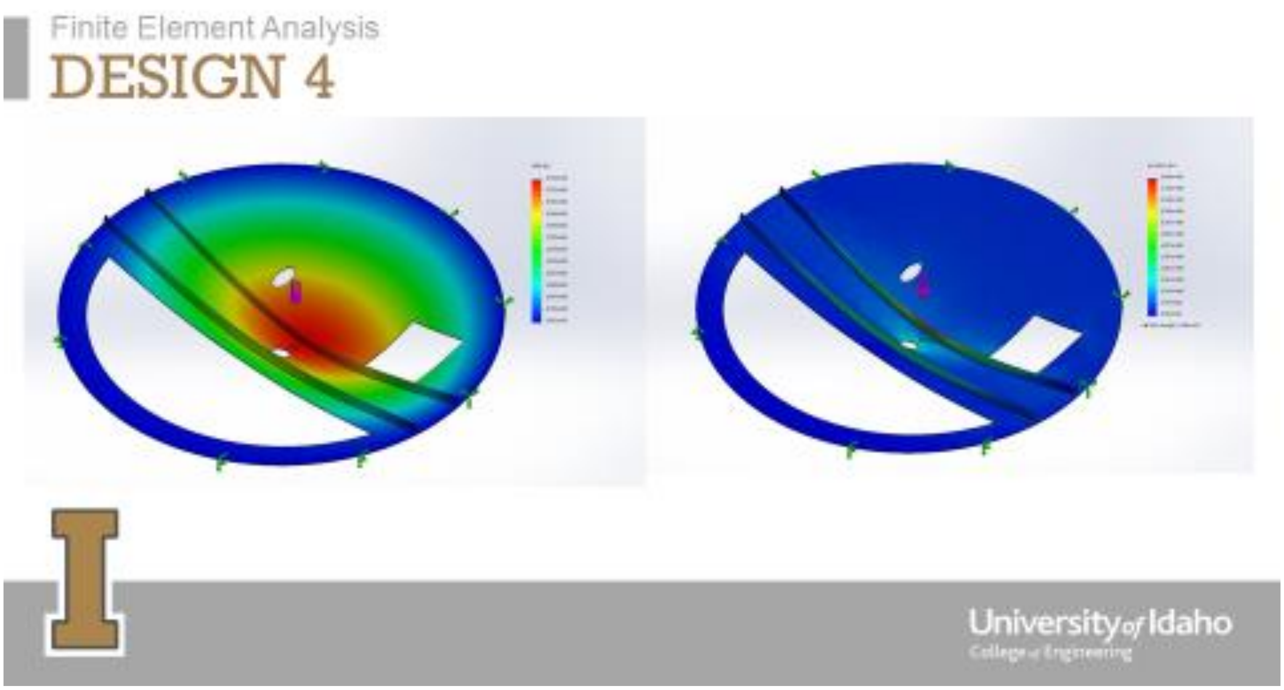
Description of component subsystem	Symptom	Effect	Failure Mode	Probability of failure	Severity of effect	Risk Priority	Remedial Action
Static Lid	Seal Leak	Gas Leaks	Toxic chemicals escape	2	1	2	Apply additional sealant
	Stress	Steel Deforms	Lid bends	1	3	3	None Available
			Joints separate	1	3	3	None Available
Dynamic Lid	Warping	Does not sit flush	Toxic chemicals escape	4	2	8	Thicker sealing material
Tank	Ignition source enters tank	Vapors ignite	Tank explodes	2	5	10	None Available
	Positive pressure build up	Lid pops open	Toxic chemicals escape	1	3	3	Include pressure release
	Negative pressure build up	Tank buckles inward	Structural damage	1	4	4	Include pressure release

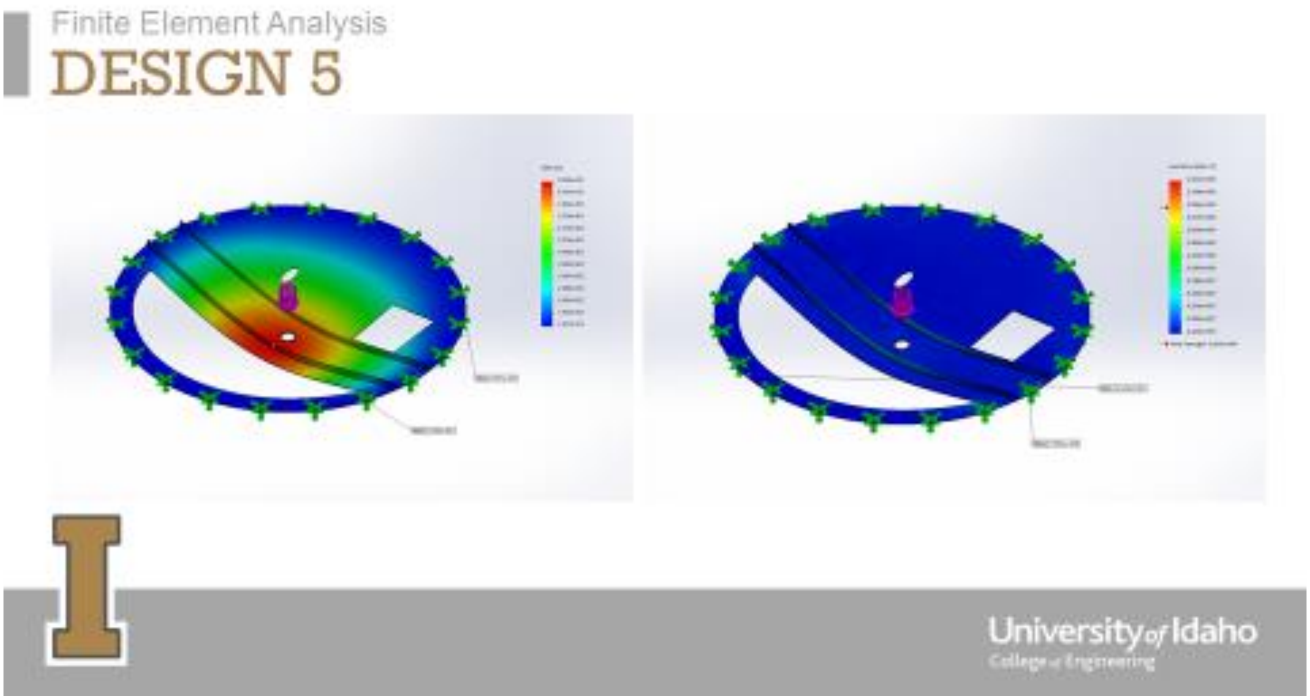
Appendix D: Finite Element Analysis





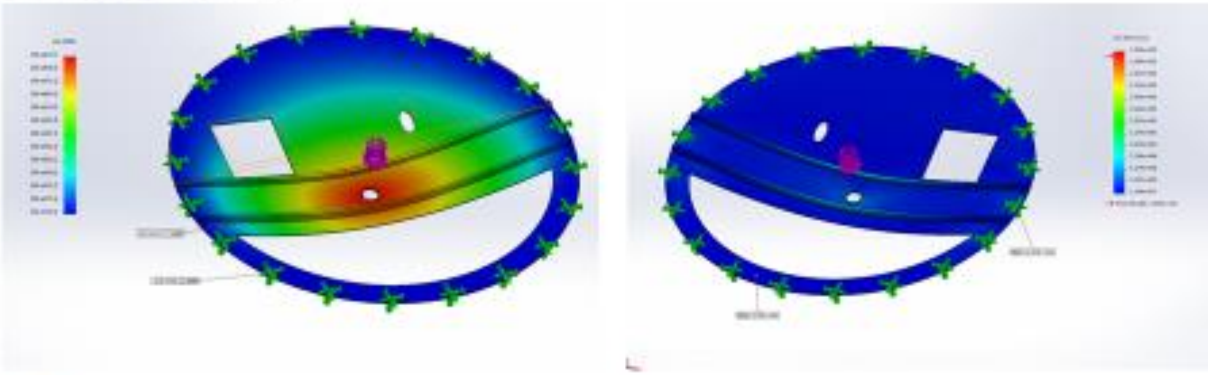

Finite Element Analysis
DESIGN 3
University of Idaho
College of Engineering


Finite Element Analysis
DESIGN 4
University of Idaho
College of Engineering


Finite Element Analysis
DESIGN 5
University of Idaho
College of Engineering

Finite Element Analysis

DESIGN 6



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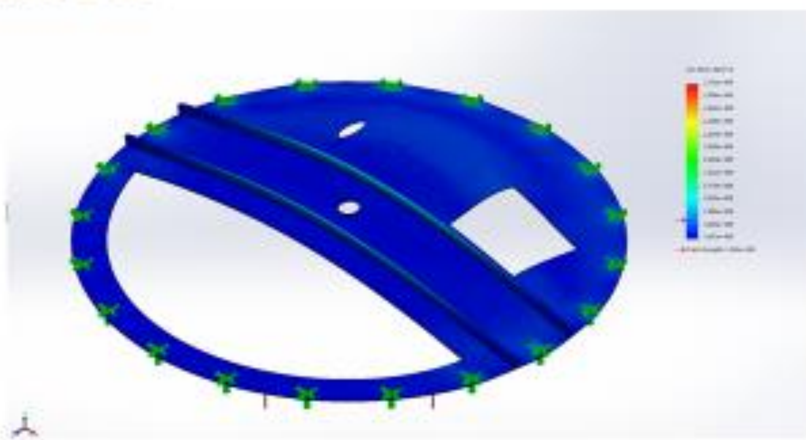
Finite Element Analysis

PRESSURE DESIGN

- Pressure Results:
  - 3 Psi till permanent deformation occurs



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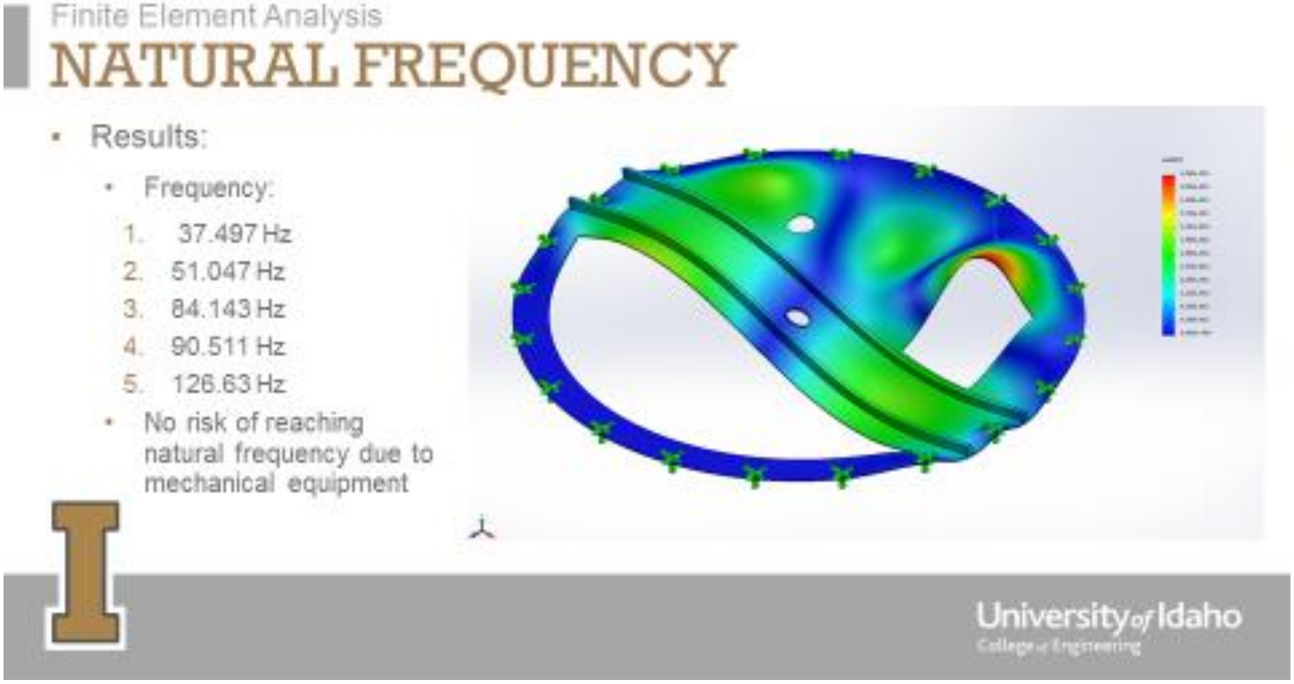
Finite Element Analysis
NATURAL FREQUENCY
Results:
Frequency:
1. 37.497 Hz
2. 51.047 Hz
3. 84.143 Hz
4. 90.511 Hz
5. 126.63 Hz
No risk of reaching natural frequency due to mechanical equipment
University of Idaho
College of Engineering

Appendix E: Cost

Part Nan	Quan	Manufac	Part Nu	Product Description	Use Description	# of U	Unit C	Shipping	Cost
Tank Fitting	1	Amazon	1145K55	Weld-on Fitting for Flat Tanks, Easy-Weld Steel, 1 Pipe Size, 2-3/8" OD	Tank access ports	6	$ 5.80	$ -	$ 34.80
1/8" Viton	1	Amazon	8969K73	Viton gasket sheet, Plain Back, 1/8" Thick, 12" x 24"	Viewport Mounting	3	$ 46.60		$ 139.80
Rod Ends	1	McMaster Carr	2434K23	Fully Threaded 304 Stainless Steel Rod End 3/8"-16 Thread Size, 3/8" Hole Diameter, 3-1/2" Length	Used to make dynamic lid clamps	16	$ 13.74	$ -	$ 219.84
3/8-16 nut	50	McMaster Carr	94804A320	Type 316 Stainless Steel Hex Nut 3/8"-16 Thread Size, 9/16" Wide, 21/64" High	Used to make dynamic lid clamps	1	$ 9.37	$ -	$ 9.37
3/8 washer	100	McMaster	92141A031	Type 18-8 Stainless Steel Flat Washer 3/8" Screw Size, 0.406" ID,	Used to make dynamic lid clamps	1	$ 5.64	$ -	$ 5.64
3/8" - 1-1/2"	5	McMaster Carr		Type 316 Stainless Steel Hex Head Cap Screw 3/8"-16 Thread, 1-1/2" Long, Fully Threaded	Used to make dynamic lid clamps	4	$ 5.09	$ -	$ 20.36
Tank Plug	1	McMaster Carr	4464K256	Type 304 Stainless Steel Threaded Pipe Fitting 1 Pipe Size, Hex Head Plug, 150 PSI	Tank plug for access ports	4	$ 8.49	$ -	$ 33.96
3/8-1" Bolts	50	McMaster Carr	92620A624	High-Strength Grade 8 Steel Cap Screw 3/8"-16 Fully Threaded, 1" Long, Zinc-Plated	Static Lid Mounting	1	$ 14.18	$ -	$ 14.18
3/8" Nuts	50	McMaster Carr	92018A430	Nylon-Insert Nonmarring Flange Locknut Zinc Yellow-Chromate Plated Grade G Steel, 3/8"-16 Thread	Static Lid Mounting	2	$ 7.62	$ -	$ 15.24
3/8" Washer	50	McMaster	98023A031	Grade 8 Steel Flat Washer Corrosion-Resistant Coated, 3/8"	Static Lid Mounting	3	$ 7.40	$ -	$ 22.20
1/4" Seal Washer	10	McMaster Carr	95630A217	PTFE Flat Washer 1/4" Screw Size, 0.260" ID, 0.337" OD	Viewport Mounting	2	$ 3.23	$ -	$ 6.46
1/4-1" Bolts	25	McMaster Carr	93190A542	Type 316 Stainless Steel Hex Head Cap Screw 1/4"-20 Thread, 1" Long, Fully Threaded	Viewport Mounting	1	$ 6.40	$ -	$ 6.40
1/4" Nuts	100	McMaster Carr	94804A029	Type 316 Stainless Steel Hex Nut 1/4"-20 Thread Size, 7/16" Wide, 7/32" High	Viewport Mounting	1	$ 9.05	$ -	$ 9.05
1/4" Split Lock Washer	100	McMaster Carr	92147A029	Type 316 Stainless Steel Split Lock Washer 1/4" Screw Size, 0.260" ID, 0.487" OD	Viewport Mounting	1	$ 5.21	$ -	$ 5.21
1/4" Washer	100	McMaster	90107A029	Type 316 Stainless Steel Flat Washer 1/4" Screw Size, 0.281" ID,	Viewport Mounting	1	$ 8.25	$ -	$ 8.25
Pyrex Glass	1	McMaster	8476K21	Fire and Safety-Rated Wire Reinforced Glass 5/16" Thick, 10" Wide	Viewport Glass	1	$ 45.45	$ -	$ 45.45
Handle	1	McMaster Carr	5187A2	Weld-on Stamped 304 Stainless Steel Oval-Grip Pull Handle, Dull Finish, 6-5/16" Overall Length, 1-1/2" Projection	Dynamic Lid Opening	1	$ 8.97	$ -	$ 8.97
Stainless Tube	1	Online Metals		STAINLESS SQUARE TUBE 304 - 1.5" x 1.5" x .12" - 48"	Used to make dynamic lid clamps	1	$ 44.56	$ 30.99	$ 75.55
Stainless Flat Bar	1	Online Metals		Stainless Steel Flat Bar - 1.5 x.25 - 36"	Used to make dynamic lid clamps	1	$ 25.36	$ -	$ 25.36
Stainless Flat Bar	1	Online Metals		Stainless Steel Flat Bar - 1" x.25" - 48"	Used to make dynamic lid clamps	1	$ 20.03	$ -	$ 20.03
Stainless Steel Flat Bar	1	Online Metals	F5141	1/2 X 1 304 Stainless Steel Flat	Static Lid Bracing	2	$ 47.61	$ -	$ 95.22
Stainless Steel Plate	1	Pacific Steel	S410	10 GA. (.135+/-) thick T304 Stainless Steel Sheet - Dull Mill Finish	Static Lid	1	$ 660.00	$ -	$ 660.00
Gasket	25 ft	Paramount		Gore 3/8"-25ft joint sealant	Static Lid Sealant	1	$ 130.08	$ 16.84	$ 146.92
						Grand Total			$1,628.26