McGill

Department of Bioresource Engineering

BREE 495: Design III

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Final Report

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Executive Summary

The steriliser for fungal substrate is an autoclave that is specifically suited for substrate used in the culture of fungi. Initially, pasteurising wheat straw yielded four 60L columns in approximately 8 hours. The proposed design allows for the process to be favorable in cultivating the *Pleurotus* species and yielded eight 60L columns in approximately 4 hours. The frame was modelled and built to carry 500lbs of substrate. The steriliser is also modular and multifunctional allowing it to be repurposed as a steam boiler.

1. Introduction

Pleurotus thrive on cellulosic and lignocellulosic biomass. Shredded straw which has a high carbon to nitrogen ratio is the synthetic media on which our customers deliberate solid state fermentation. Nitrogen requirement is thought to be a great problem for wood decaying fungi. “To satisfy their nitrogen requirement Pleurotus fungi can parasitize on the bacteria, yeasts, and algae cells in nature and during the cultivation process” (Andres, S., 2012, pp. 270). In fact, this group of researchers observed appendage like mycelial structure used by the fungi possibly indicating it’s parasitic interaction with yeast. Some species produced fruiting bodies 2-4 days earlier, and total yield increased 25-100% when supplemented with certain yeast suspensions. Successful growth of Pleurotus has been achieved in submerged cultures; low concentration sulfite liquor supplemented with glucose (0-5%) was employed to successfully fruit *P. Florida sp.*, *P. ostreatus* and *P. eryngii* (Chang, S. T., 1978). The effects of CO_2 concentrations, pH and temperature on growth have been well documented. Mycelium growth can be be increased to 120% by increasing CO_2 to 20-25%. Specific species will respond differently to various conditions. In the case of our client, his particular strain has been selected for its tolerance towards alkaline media; a method for increasing resilience against competition.

The company MycoRise is in the process of scaling their oyster mushroom (*Pleurotus spp*) production. They have approached us with the goal of increasing their substrate pasteurisation capacity. They have identified this step as the main impediment regarding their production levels. The current pasteurization system is accomplished through hot water batch processing which takes place simultaneously in 2 propane-heated 200-L drums. Four 60L columns are produced in approximately 8 hours from 1.5 bales of wheat straw.

Initially, the analysis between hot water and steam pasteurization resulted in favour of a steam pasteurization system. However, during the design process, the client decided to change the criteria and the final decision was in favour of steam sterilization. The following will go over the various designs that were considered before reaching to the proposed solution. Indeed, the numerous patents mentioned below disclose methods and apparatus for sterilizing food in enclosed containers as well as sterilizing or pasteurization machines, all of which aided in the conception of the proposed design:

U.S. Pat. No. 1,157,017 discloses apparatus for sterilizing or cooking materials or substrates contained in a sealed system.

U.S. Pat. No. 1,437,882 discloses apparatus for continuously sterilizing materials or substrates in closed process and in large quantities.

U.S. Pat. No. 2,082,460 discloses apparatus for sterilizing and subsequently cooling food in closed containers, using a form of pressure cooker.

U.S. Pat. No. 4,739,699 discloses apparatus for pasteurizing or sterilizing edible foodstuffs.

U.S. Pat. No. 5,424,087 discloses methods of sterilizing canned food in a sterilizing kettle, using hot water for preheating and steam for sterilization.

The initial design was inspired by “the portable batch pasteurizer” U.S. Pat. No. 6276264 (Dumm, Richard Henry. 2001). Originally used for batch heating and cooling of fluids in a bulk container, the idea was to use the spiraling coils as a steam injection system which would ensure equal propagation of heat and vapor throughout the system. However, the system required several subsystems and a metal drum which limited scalability, production and cost effectiveness, which are characteristics that the client considered significant. Indeed, it lacked user-friendliness and simply didn't comply with the required output the client desired. This brought up the comparison between continuous and batch processing systems, which required looking into a continuous batch system.

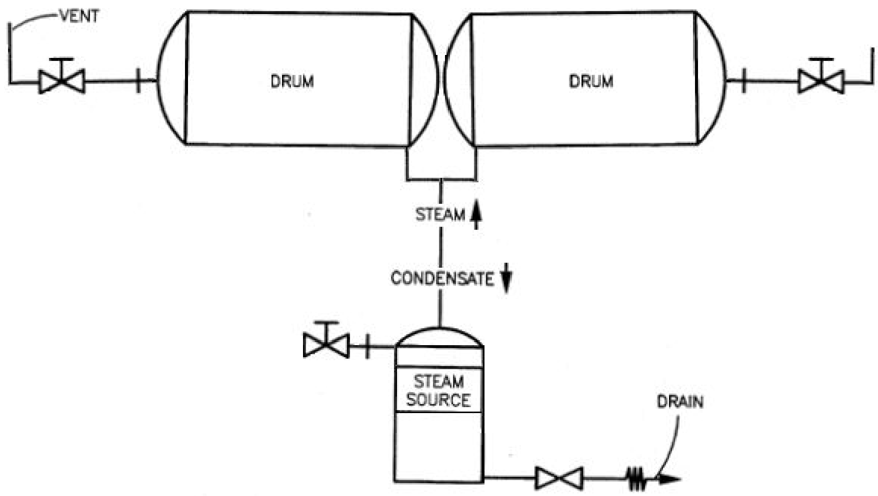
The following design proposal resembled the "High humidity steam cooker with continuously running conveyor" U.S. Pat. No. 4,582,047 (Williams, Charles E. 14 Apr. 1986.) This system utilises two separate steam sources, one internal and the other external, to heat the substrate. A heated pool of water at the bottom of the pasteurization chamber constitutes the internal steam source, whereas steam is additionally injected from an external source of water. In addition, an agor moves the substrate through the system and agitates it for heat transfer efficiency. The continuous aspect of this design seemed attractive in theory, yet the labour involved in building and operating such a system was impractical and time consuming. In addition, the maintenance and repairs involved at the end of its life cycle is too complex for the operator, thus lacking user-friendliness.

1.1 Proposed Design

Client desires high capacity autoclave made using readily accessible components. Individual components shall not exceed 400$ without permission and the budget is a total of 3000$.

Many iterations were proposed to the client. Upon researching techniques of business partners and competitors, client has settled on autoclave seen in **figure 2.1**. During operation steam source will simultaneously receive condensate. Drums will be inclined for gravity assisted condensate draining. Material supplied by the client include drums (standard stainless steel with appropriate lid, rated 60 psi) and, steam source (rated 150 psi, 2x 3000W resistive heating elements).

Figure 2.1: Autoclave



Goals here reinstated are (1) to support drums when loaded at client's desired capacity of 400lbs of material, and (2) connect drums and steam source in an manner which enables simultaneous steam flow (upwards) and condensate flow (downward). (3) Maintain fluctuating pressures below 15 psi using real time data during operation.

2. Analysis and Specifications

2.1. Components and Assembly

List of material, price and supplier can be found in figure 2.1.1 of appendix.

Sight tube:

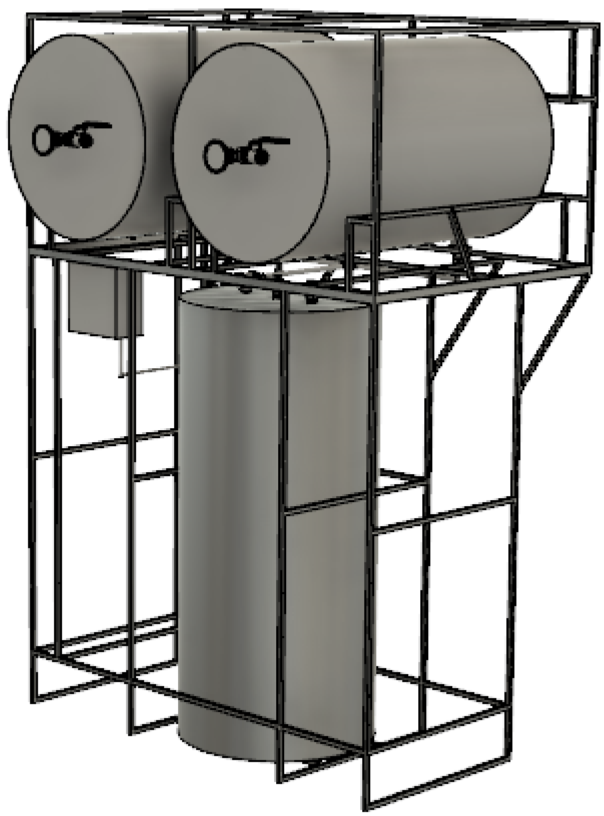
Part	Quantity	Total	System	Cost Type	Service Life

		Cost (CAD)	Component		(yr)
Stainless Steel Drum	2	950.00	Top Frame	Fixed	15
½ in. by ½ in. Standard Steel	1	153.98	Top and Bottom Frame	Fixed	15
Electric Water Heater 40 Gallon for GIANT	1	361.10	Boiler	Fixed	20
1/2" contitech all red flexsteel 250 pyrosyn (EPDM) Steam	1	91.77	Plumbing	Fixed	10
304 Stainless Steel Threaded Pipe Fitting Low-Pressure, Bushing Adapter, 3/4 Male x 1/2 Female	3	19.59	Plumbing	Fixed	15
Type 303 Stainless Steel Barbed Tube Fitting Tee for 1/2" Tube ID 1	1	12.88	Plumbing	Fixed	15
304 Stainless Steel Barbed Hose Fitting 1/2" Hose ID, 3/4 NPT Male End	3	49.32	Plumbing	Fixed	15
304 Stainless Steel Threaded Pipe Fitting Low-Pressure, Tee Connector, 3/4 NPT Female	3	43.98	Plumbing	Fixed	15
Worm-Drive Clamps for Firm	10	6.45	Plumbing	Fixed	15

Hose and Tube Steel Screw, 5/16" Wide Band, 1/2" to 29/32" Clamp ID					
Brass On/Off Valve with Lever Handle, 3/4 NPT Female x 3/4 NPT Male	3	44.79	Plumbing	Fixed	10
Military Grade Pipe Thread Sealant Tape 14 Yard L x 1/4" Wide, .0032" Thick, 1.2 G/CC Density	1	3.11	Plumbing	Fixed	15
Pressure & Temperature Gauge Steel Case, 3-1/4" Dial, 1/2 NPT Center Back, 100 PSI1	2	50.40	Plumbing	Fixed	15
Auber Instruments SYL-2352 PID Temperature Controller	1	62.34	Electrical	Fixed	5
40A SSR	1	20.78	Electrical	Fixed	5
Heat Sink for SSR (40A)	1	12.94	Electrical	Fixed	20
Liquid tight K type, 2 in probe, 1/4 NPT	1	29.43	Electrical	Fixed	5
Stainless Steel 1/4 NPT Weld Bung	1	7.98	Electrical	Fixed	15
Liquid tight RTD sensor, 2 in, 1/2 NPT	1	37.47	Electrical	Fixed	5
9-PIN 3PDT ON/ON Toggle Switch, RTD	1	4.63	Electrical	Fixed	10

Liquid tight RTD sensor, 2 in, 1/4 NPT Thread Cable Option: 8 ft Braided Cable with XLRCON connector/cable	1	61.07	Electrical	Fixed	5
2” Stainless Weld Ferrule	2	9.65	Electrical	Fixed	15
2” Tri Clamp	2	16.14	Electrical	Fixed	15
2” PTFE Gasket	2	15.55	Electrical	Fixed	15
2” to 3/4” Female NPT	2	20.70	Electrical	Fixed	15
Heating Element Enclosure	2	89.29	Electrical	Fixed	20
10 AWG 3C Wire	10	36.99	Electrical	Fixed	20
BTE CPV Moule [Enclosure]	1	66.43	Electrical	Fixed	20
30A 250V Receptacle	1	6.43	Electrical	Fixed	20
40 gal distilled water	1	40.00	Boiler	Variable	N/A
Pressure relief valve	1	50.35	Boiler	Fixed	15
Vacuum relief valve	1	27.31	Boiler	Fixed	15
60 inch Sight tube	1	34.68	Boiler	Fixed	15

Gross Frame Dimensions Figure 4.1



Electrical System:

The resistive heating elements of the boiler are rated 12.5 A at 240 VAC. 10 ga solid-core copper wire was used uniformly for components operating at 240 VAC and 12.5 A and 25 A. Components operating at lesser current (< 1 A) were wired using 18 ga threaded-core copper wire. Sensor wires were wired using manufacturer's' wiring harnesses. A proportional integral derivative controller (PID) actuates a solid state relay (SSR) in response to input from one of two temperature sensors (resistance temperature detector type). A contactor wired in the normally closed position acts as a failsafe for the SSR and is actuated by the PID in the event of excessive temperature readings. A nine pin rotary switch allows the operator to select between two temperature sensors. Under normal operating conditions, the sensor located on the left drum is used. This provides an accurate measurement of the system's temperature and corresponding pressure. The second temperature sensor is used when isolating the boiler and drum (see section 2.6). A description of select components is presented below.

PID

The PID used is an Auber SYL-2352. This device is fully programmable features resistance temperature detector (RTD) input, SSR ready output, process high alarm function (0-250 VAC control), time proportional control and fuzzy logic enhanced PID control. It is powered from the 240 VAC supply. An SSR is used to actuate the heating elements due to fast duty cycle (and thus an ability to decrease hysteresis band), improved reliability, and increased time between service intervals. An appropriate heatsink is also installed per manufacturer's recommendations along with a cooling fan (Auber Instruments 40A SSR, 2007). The high alarm poles are in series with supply to the contactor coil (see section 3.5). In the case of SSR failure in the closed position, the contactor can open the circuit.

The controller features a manual mode (where the user defines the proportional, integral time, and derivative time constants) and an auto-tune function. Auto-tune cycles the control variable and measures the response variable in order to make approximations of the constants. In similar applications (brewing mash tuns at < 500 gallon capacity) auto-tune is highly effective, so it is expected that this feature will give sufficient performance. The cycle time for relay applications is recommended to be 20 seconds in order to increase longevity of the relay.

RTD

An RTD was chosen as the temperature sensor of choice due to its relatively high accuracy compared with thermocouples and ease of integration with the PID controller. The particular sensor used is nickel based with a maximum temperature of 300 C and an accuracy of ±0.15 C (Auber Instruments, 2010). It is encased in 304 stainless steel and features an XLRCON connector, braided wire, and ¼ inch NPT male thread.

2.2. Relevant Properties

Operating conditions are set just below 15 psi gauge. Using the conversion factor of 6.89 kPa/Psi we obtain 103.35 kPa gauge. Operational elevation will be approximately at sea level.

101.3 kPa will be taken as atmospheric pressure. Absolute pressure is 204.65 kPa (approximately 2 atmospheres). Calculating temperatures at 205kPa and interpolating between values of 200 and 225 of table A-5 (Çengel Y. A., 2015) we obtain corresponding temperature of 121 Celsius and Specific volumes of 0.001062 m^3/kg and 0.8673 m^3/kg for saturated liquid and saturated vapor respectively.

2.3. Modelling Heat Transfer

A heat transfer model to obtain interior temperatures of media filled bags is an unsteady state problem subject to inhomogeneous properties. Quantifying this will therefore be more appropriately suited to practical data gathering. An analysis of the energy transfer to the surrounding caused by natural convection of uninsulated barrels during steady state operation was performed (**figure 2.3.1**). This scenario was chosen to give a rough estimate. Inaccuracies in the model include the conduction from the drums to the support frame. Moreover, it is important to note that energy lost from front and back faces (when oriented horizontally) of the drums, along with energy flux to media was completely disregarded. An obtained result of 1 392 W transmitted to surrounding during steady state operation is a gross underrepresentation. This amounts to approximately a quarter of our boiler's capability, meaning that without barrel insulation, one of its elements would have to run almost continuously to maintain fluctuating/ semi steady state.

The inside surfaces of the drums and outside surfaces of the media filled bags will be at a lower temperature than the saturated steam in which it is in contact. "A gas at a temperature lower than its critical temperature is called a vapor and will easily condense to the liquid if the temperature becomes lower than the saturated Temperature." (Asano K., 2006. Pp. 177) Condensation/ evaporation rates must be taken into account to determine appropriate sizing of pipes and fittings connecting boiler and drums. As can be seen in (**figure 2.3.1**) we calculated a condensation rate of 0.0062 kg/s (which seems low). Condensation can take place in different ways: Film condensation (turbulent or laminar) and drop condensation. (Stephan K., 1992) In our system drop condensation will occur.

Air entrapped in system prior to steady state operation should be evacuated. If air is not removed from the drum before running system, heat transfer will be reduced. During startup/ramp up, operator will maintain valves connected to drum lids open. Movement of steam through drums will displace entrapped air. Progressively closing the valves might result in better performance. Another method would be to perform multiple air purges whereby pressure is left to accumulate. Drum lid valves would be opened thereby dropping pressure in the system, thus increasing boiling rate (water at above 100C but below atmospheric pressures) accelerating flow out.

2.4. Material Stress Analysis

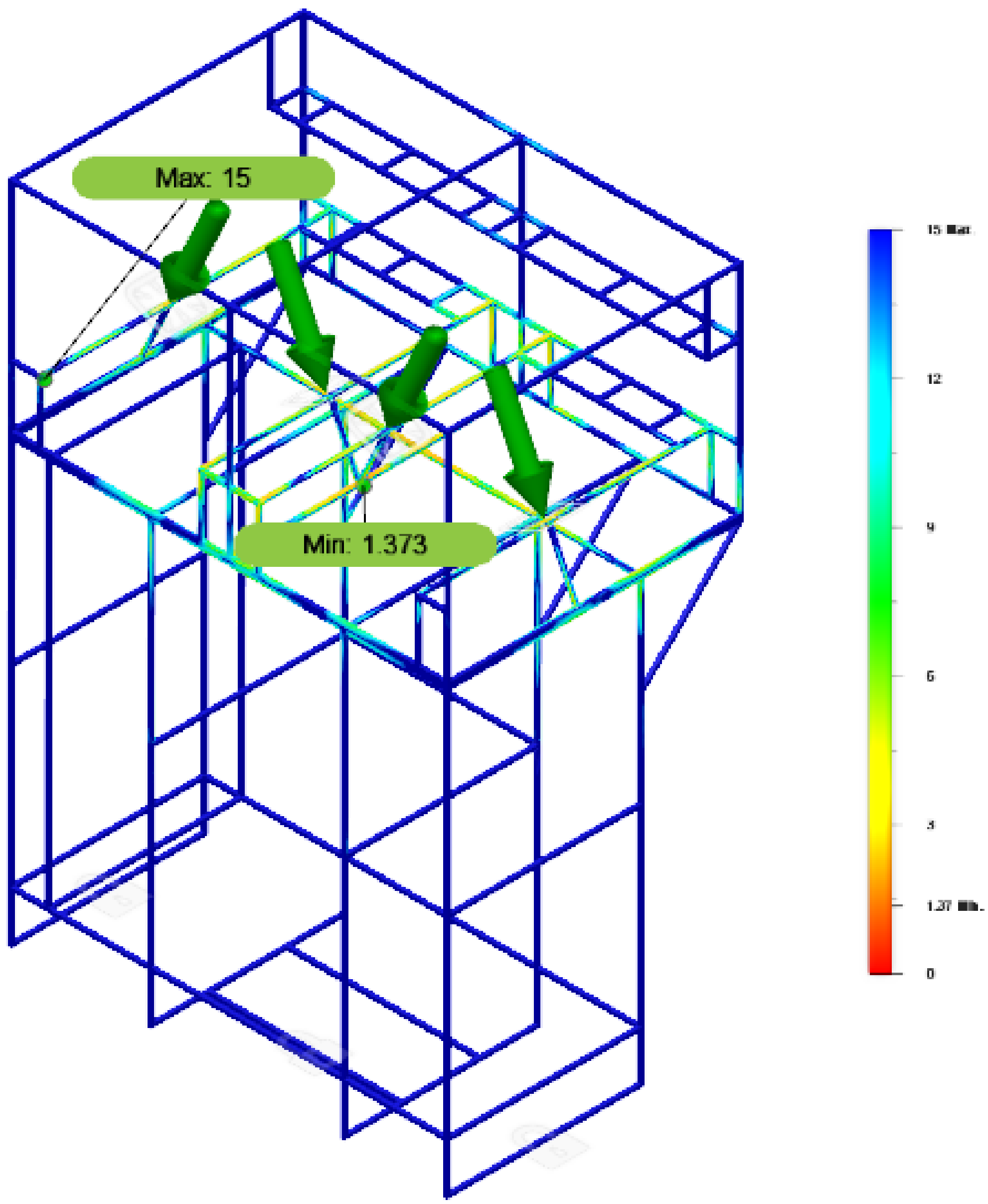
Modeled constructed frames in Fusion 360 (Using material properties found in **table 2.4.1**) and applied boundary conditions. Loads of 250 lbf applied on 4 chamfered areas of 3.727 in^2 (angulated in accordance with effective force) were chosen to approximate the loading conditions during operation (worst case scenario for the weight of the stainless steel drums + media during operation). As can be seen in **Figure 2.4.2** Minimum safety of factor obtain is approximately 1.4. This corresponds to maximum Von Mises stress of 21.9 kpsi on center of bottom frame.

Buckling analysis was performed to obtain the locations which might be subjected to greatest displacement under excessive loading. Results can be see in figure **figure 2.4.3**.

Top frame is the component which is more susceptible to failure. Welds were not considered in simulation environment. In reality due to defects introduced during manufacturing (such as weld decay) material properties are inhomogeneous. **Figure 2.4.4** provides locations where welded interfaces of top frame will be subjected to greatest Von Mises stresses.

It Is important to note that distributed load is simulated on a greater area than will be the case in reality. The following approximation was made: load is homogeneously distributed along bearing surface. The simulation represents worst possible case scenario where drums and media combined would weigh a total of 500 lbf each. Therefore a minimum design safety factor of 1.373 was deemed satisfactory to account for the discrepancies in our model. These include the aforementioned manufacturing defects and the fact that both our frames were modeled as a rigid body; when in reality they are separate and detachable. Care must be taken to ensure as much contact area as possible in between frames occurs when assembled. Notably: welds planar with contact interfaces must be ground flush to avoid interference and clamped fixed together upon delivery and assembly. Model has been publicly available: http://a360.co/2nPz7i7

Figure 2.4.2: Fusion 360 Simulation Overview With Loads of 250 lbf applied on 4 chamfered areas of 3.727 in^2 (angulated in accordance with effective force)



Note: Numbers represent safety factors

2.5. Standard of Operation

The operational procedure of the system requires very little user input. The operator must initially fill the drums with material sealed in autoclavable bags. The lid must be adequately fastened to the system using a torque wrench. The system is turned on by a switch mounted on a face plate. This commences the water boiling process within the water heater. The user must open both valves on the drums and wait until the air has been evacuated. Once steam starts coming through the valves, the user must close both valves and monitor the heating process. The RTD thermocouple reads the temperature of the drums, sends the data to the PID which actuates the resistive heating elements in order to maintain the setpoint of 121°C. Throughout this process, the user must monitor the entire operation. If the user requires a second consecutive cycle, he must press on the RTD sensor switch, which switches the incoming signal of the PID from the drums RTD thermocouple to the water heaters RTD thermocouple. After, he must manually turn off the valve connecting the drums to the water heater. The user must wait until the pressure in the drums cools to 1 psig and may only then open the valves on both drums. Once the drums cool to room temperature, the user can open the lids and take out its contents. Once the drums are refilled and the lid has been properly secured according to the same standards initially described, one can open the valve connecting the drums to the water heater. To cool the entire system, the user must shut off the machine, wait until the pressure in the drums cools to 1 psig and may only then open the valves on both drums. A vacuum relief valve is considered in case the user lets it cool to full vacuum.

3. Prototyping, Testing and Optimization

The initial prototype of the proposed design consisted of buying a miniature autoclave and running it on an electric stove. The design of these autoclaves are already standardardized. The optimization of our design focused on scaling up the capacity while remaining modular and mobile. Throughout our design iterations, the ability for the machine to be multi-functional and easily scalable was considered. The current design is a two piece modular system which can act as an autoclave and a steam boiler. The dimensions of the design allow it to fit through a standard door and can be connected to an electrical dryer plug. A face plate mounted on the left side of the system acts as the user interface to control the state of the system. Tri-clamp fittings are used for the connection from the water heater to the drums. This allows one to connect or disconnect additional drums to the system thereby adjusting its scale to the users requirements.

3.1. Prototyping, testing and optimization of frame

Calculation and assumptions found in addendum (Appendix: **Calculation 2.4**) are erroneous due to assumption errors. It was not removed due it playing a pivotal role in the coming of our design; giving insight on how the geometry of our frame came to be. Having not outsourced the frame design due to prohibitive cost, assembly was performed taking into account client's dimensional requirements solely. Stress analysis was only performed too late in the design process which necessitated the stepwise additions of various frame elements.

Erroneous assumptions made in crude material analysis (see euler's equation in **section 2.4**), our progressive increase in the employability of finite element analysis (FEM) and miscommunication with the client led to the necessity of iteratively adding structural components (As can be seen in **figure 3**). The frame will accomplish its desired use, however, a combination of factors led to a poorly optimized result. Prototyping on this scale prohibited the complete reconstruction of the frame. Support elements added on March 23, 2017 (as can be seen in **Figure 3.2.1**) were due visual deflection analysis. On March 31, 2017, "zero stress" members were implemented to prevent operator induced aberrant cyclical elastic deformation from shaking structure during dynamic loading. Upon consultation with a junior mechanical engineer, many concerns were expressed regarding structural features and the erroneous assumptions utilized in the initial fabrication. It is to be noted that the skeleton of the frame was constructed with 0.5 in x 0.5 in solid steel bar thinking it would reduce cost and weight of final structure. In fact, this has likely to have led to the opposite. Structural components such as square tubing or I beams have a much higher second moment of area to weight ratio. The suggestion we model results using FEM greatly improved our appreciation of static stress distribution within structure, and was pivotal in coming to terms with amature mistakes made thus far. A major improvement in the optimization of our developmental approach occurred with a contingency. In a meeting held April 1, 2017 the client also expressed the desire for the possibility of filling the drums with water when lids be facing up (as can be seen in **figure 3**). FEM was performed for various scenarios proposed prior to element addition. After a variety of iterations, a design which exhibited safety factor of 3.6 was agreed upon. Additional elements were welded to top frame. Main reason for the overdesign of this feature was a mistake made in the initial calculations resulting in a boundary conditions being applied which was 25 times greater than actual. **Figure 3** displays corrected safety factor. The additionally incorporated top frame elements along with the client requesting yet another change (whereby the frame's fronts were to be mounted flush during operation; laid forth April 6th, 2017) also rendered previous analyses obsolete. Frame models we're updated and analyzed. Safety factor had decreased to below acceptable level. Further leading to the additional elements included on April 7, 2017 and seen **Figure 3.2.1 (5).** Exact placement of elements we're determined using FEM to iteratively optimized until desired safety factor was reached.

3.2. Pressure Vessels and Relevant Standards

The design, construction, and hydrotesting of our prototype follows ASME Section VIII standards. It specifically refers to those pressure vessels that operate at pressures, either internal or external, that exceed 15 psig. The design is built to achieve an operating pressure just below 15 psig. Thus the design pressure components are non code i.e. they are outside the scope of ASME Section VIII standards. A hydrotest will be performed at 1.5x the operating pressure to ensure safety during operation of the machine. Relief and venting for air i.e nitrogen, oxygen and carbon dioxide, is already properly considered through on/off valves. Pressure is constantly maintained below 15 psig through a PID, proportional–integral–derivative controller, by monitoring temperature with a RTD thermocouple which is directly proportional to pressure. The PID controller achieves IP54 rating when installed with rubber seal. A pressure and vacuum release valve set at 15 psig is added to the design as an external mechanical fail safe. As such, there are no codes or standards that specify requirements to apply several classes of material used in pressure vessel construction, and also to fabrication methods such as welding, forging and brazing. All the material and fittings purchased are rated above the maximum operation pressure and temperature.

3.3. Operational Hazards, Safety and Risk Management

Thermal water expansion of tank causing water to flow into connection lines

At 20 Degrees Celsius liquid water's density is 998.3 kg/m^3. It decreases to 943.1 kg/m^3 when heated to 120 Celsius. To accompany the change in density a subsequent change in volume will ensue. Taking the tank volume as 36 US gallons / 0.00378541 US gallon/m^3 = 0.135m^3. Ignoring water loss due to vaporization, the final volume will occupy 0.144 m^3. Variation in volume is approximately 9L. The tank shall be filled up with no more than 128 L to prevent water from thermally expanding into connecting lines.

Flash Evaporation of Water

Leaks will undergo throttling process accelerating steam into operating space. If leak occurs post pressurization, turning off the elements will not cause the steam to stop. The energy accumulated by the water will be enough to produce steam until liquid within the tank reaches saturated vaporization temperature of the surroundings i.e. approximately 100 Degrees Celsius.

Structural Metastability

Preventing structure from toppling over during operation in necessary. A reasonable degree of Structural metastability considering forces applied during operation shall be ensured.

Material failure

Failure could occur in many instances. When assembled, structure shall not yield. In operation, batch loading and unloading will fluctuate stress on structural elements (Fatigue). Possibility of creep induced failure in hence an option. Local vibrations might increase creep.

Water Level

Nucleation of vapour occur on the resistive elements. In a scenario where the elements remain erroneously supplied/powered and steam exits system through a pressure release valve, leaking connection, crack or hole, water level will decrease. If the element becomes exposed to air, temperatures will increase; air in contact with the resistors will dissipate comparatively much less energy as supposed to liquid water. This is a possible fire hazard, the water tank's insulation and electrical components would be the first components susceptible to degradation and or combustion.

Boiler Fouling

Employing Deionized water and sealing steam exposed biomass will prevent condensate from accumulating excessive mineral and organic matter content.

Risk of Excessive Pressure Buildup

Mitigated using rated blow off valves. If the inlet/outlet is clogged, it would cause only bottom portion of system to accumulate pressure. The operator would then shut off power to the system.

Vacuum Induced Cooling

Upon cooling, contained air water mixture will cause vacuum. Crumpling of drum or connective elements.

Operator Equipment

System components will increase in temperature during operation.

Failure of Solid State Relay

The contactor coil is actuated by the PID's high temperature alarm, opening the circuit to the heating elements in the event of relay failure.

Failure of RTD Sensors

In the event of faulty readings from the RTD sensors, excessive pressure may build in the system. This failure would be addressed by the risk of excessive pressure buildup procedure previously discussed.

Servicing

The SSR service life is mostly dependent on thermal cycling (thermal fluctuations from heating and cooling cycles) (Cyrdom, 2011). In our estimation with a cycle time of 20 seconds and active cooling system the relay should be replaced every 5 years.

3.4. Economic Consideration and Tangible Benefits

Hot water batch processing takes place simultaneously in 2 propane-heated 210-L drums. Water is reused twice before being discarded due to buildup of dissolvable compounds and particulates which, if not removed, would negatively impact yield. It was calculated that approximately 6 - 8$ of propane and 85 liters of water are consumed for a yield of four pounds (corresponding to one column).

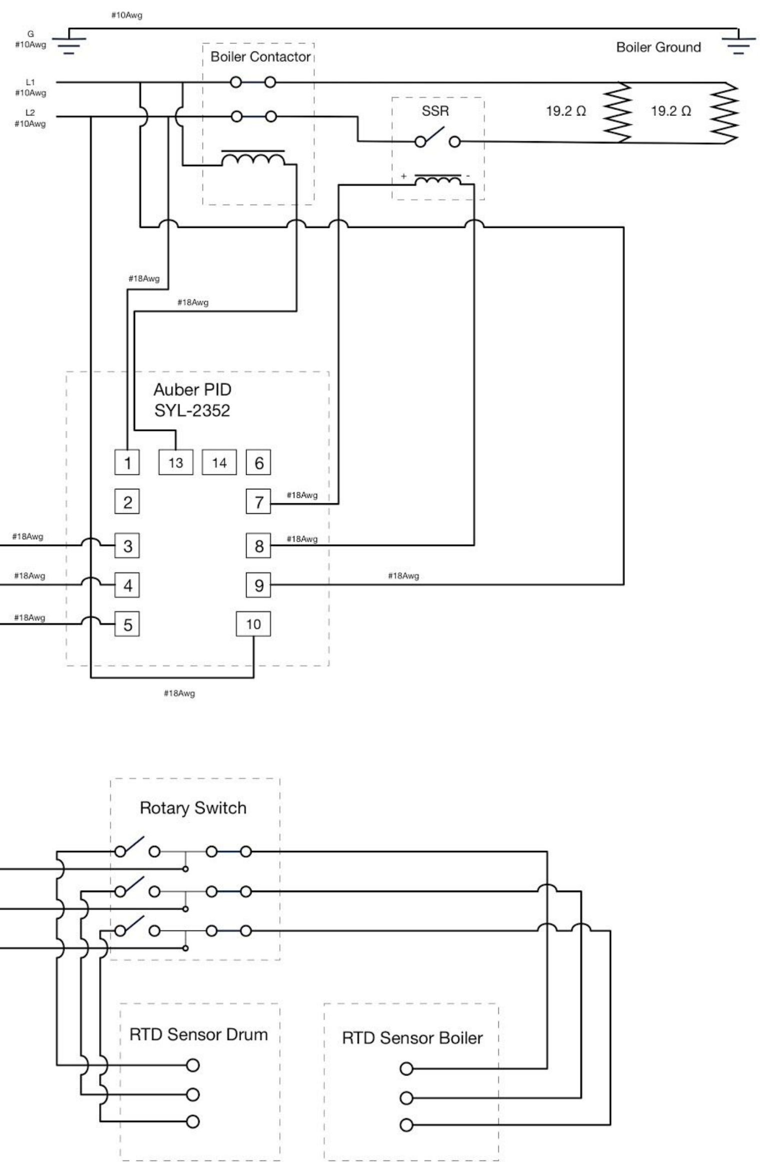
Operation Cost

The operating costs associated with the autoclave include water consumption, labour, and power consumption. Labour was deemed negligible in terms of cost for our client. Total working time with the autoclave is 9 hours. Water consumption is in the form of distilled water required to initially fill the tank (40 gal) and some amount of water lost as steam during operation. While the amount lost is difficult to estimate, it does not seem reasonable to expect more than a 1-2 percent loss during normal operation. Startup heating time (defined as time to take boiler temperature sensor from 25 to 121.0 °C) is 6 hours. Heat loss at steady state is approximately 1500 watts with a treatment time of 3 hours. Therefore, total power consumption is defined by:

$$(1500W)(3.0h) + (6000W)(6h) \ = \ 40\ 500\ Wh \ = \ 41\ kWh$$

Item	Quantity	Unit Cost ($/unit)	Total Cost per Use
Distilled Water	1 gal	1.00	1.00
Power	41 kWh	0.0582	2.40
		Total	3.40

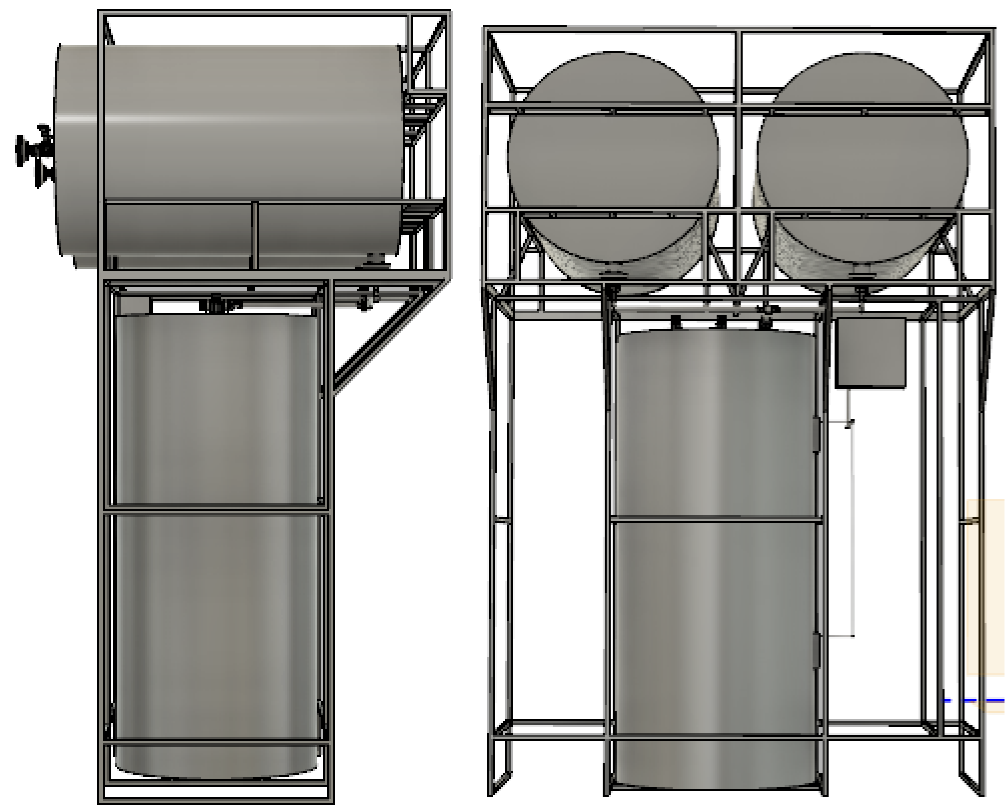
3.5. Circuit diagram



5. Results and Conclusion

5.1. Results

Figure 4.2: **Side and Back View of the Proposed Design**



The design shown in **figure 4.2** is an exact representation of our current model, however it is not the final design. Further iterations include the possibility of incorporating a cooling system and further automation. **Figure 4.3** shows the incomplete system during testing. The temperature increased from 73F to 220F inside the boiler and initial heating takes approximately 6h. Once heated, it takes approximately 3 days to cool to ambient temperature. Sterilising cycles can be interrupted to extract and input more substrate. Interruptions are achieved by closing the water heater valve and letting the drums cool before releasing its pressure. Cooling time is estimated to be in the range of 20 min to 30 min. It depends on the pressure achieved during the operation. The maximum operational pressure is 13.5 psi due to the pressure relief valve. The time required for a sterilization cycle at 246F (13.5psi), excluding start-up time, varies on the substrate and can be around 3h. This allows the client to make multiple sterilization cycles throughout the day.

Figure 4.2: **Front View of the Current Prototype**

5.2. Future Improvements

Back gassing during welding will prevent precipitation of chromium carbide on stainless steel. This will reduce local stress concentration factors and will be necessary if higher operational pressures are desired. Moreover when stainless steel fixtures are subjected to weld decay, adjunct female or male attachment bonding will be compromised. A maintenance plan must be established in order to extend the operational life of the design.

5.3. Acknowledgements

We would like to thank Mark Brettschneider and Louis-Philippe Dessureault for their support, for without them, this project wouldn't have been possible. We extend our thanks to Scott and Tom at the Macdonald machinery shop for their help advice and always reminding us to do our due diligence.

6. References

Asano, K. (2006). *Mass transfer: From fundamentals to modern industrial applications*. Weinheim: Wiley-VCH.

Auber Instruments. (2007). *40A SSR*. Model: MGR-1D4840. Available at: http://www.auberins.com/index.php?main_page=product_info&cPath=2_30&products_id=30

Auber Instruments. (2010). *Liquid tight RTD sensor, 2 in, 1/4 NPT Thread*. Model: PT100-L50NPT. Available at: http://www.auberins.com/index.php?main_page=product_info&cPath=20_15&products_id=189

Bergman, T. L., & Incropera, F. P. (2011). *Fundamentals of heat and mass transfer*. Hoboken, NJ: Wiley.

Budynas, R. G., Nisbett, J. K., & Shigley, J. E. (2015). *Shigley's mechanical engineering design*.

Cyrdom. (2011). *Solid Statements*. Available at: http://www.crydom.com/en/tech/newsletters/solid%20statements%20-%20life%20expectancy%20of%20ssrs.pdf

Çengel, Y. A., & Boles, M. A. (2015). *Thermodynamics: An engineering approach*.

Holman, J. P. (2010). *Heat transfer.* Boston Mass.: McGraw Hill Higher Education.

Stephan, K. (1992). *Heat transfer in condensation and boiling*.

7. Appendix

Figure 2.1.1: Component Invoice/Receipts

McMASTER-CARR

Invoice

330-995-5500
330-995-9600 (fax)
cle.sales@mcmaster.com

Purchase Order	**STERILISER**
Total (US Dollars)	**$241.28**
Invoice	**19138792**
Invoice Date	**3/17/17**
Payment Terms	**2% 10, Net 30**

Deduct $0.00 on merchandise if paid by 3/27/17.

Billed to
MCGILL UNIVERSITY
RM 216
3465 RUE DUROCHER
MONTREAL PQ H2X 0A8
CANADA

Shipped to
Attention: Samuel Eichhorn Bilodeau
McGill University
C/O Samuel Eichhorn Bilodeau
6615 Rue Chardonneret
Laval PQ H7L 4B2
Canada

Mail Payment to: McMaster-Carr
PO Box 7690
Chicago IL 60680-7690
USA

Your Account: 245792200

Samuel Eichhorn Bilodeau placed this order.

Line		Product	Ordered	Shipped	Balance	Price	Total
1	5670K68	Type 303 Stainless Steel Barbed Tube Fitting Tee for 1/2" Tube ID	1 Each	1	0	12.88 Each	12.88
2	2129T19	FEP Clear Tubing for Chemicals 1/2" ID, 5/8" OD, 10 ft. Length	1 Each	1	0	60.90 Each	60.90
3	5361K43	304 Stainless Steel Barbed Hose Fitting 1/2" Hose ID, 3/4 NPT Male End, Packs of 1	3 Packs	3	0	16.44 Per Pack	49.32
4	4464K52	304 Stainless Steel Threaded Pipe Fitting Low-Pressure, Tee Connector, 3/4 NPT Female	1 Each	1	0	14.66 Each	14.66
5	5388K17	Worm-Drive Clamps for Firm Hose and Tube Steel Screw, 5/16" Wide Band, 1/2" to 29/32" Clamp ID, Packs of 10	1 Pack	1	0	6.45 Per Pack	6.45
6	47865K44	Brass On/Off Valve with Lever Handle, 3/4 NPT Female x 3/4 NPT Male	1 Each	1	0	14.93 Each	14.93
7	6802K22	Military Grade Pipe Thread Sealant Tape 14 Yard L x 1/4" Wide, .0032" Thick, 1.2 G/CC Density	1 Each	1	0	3.11 Each	3.11
8	4013K62	Pressure & Temperature Gauge Steel Case, 3-1/4" Dial, 1/2 NPT Center Back, 100 PSI	1 Each	1	0	25.20 Each	25.20
9	4464K312	304 Stainless Steel Threaded Pipe Fitting Low-Pressure, Cross Connector, 1/4 NPT Female	1 Each	1	0	11.98 Each	11.98
10	50925K316	Compact Extreme-Pressure Steel Pipe Fitting Reducing Adapter, 1/2 NPTF Female x 1/4 NPTF Male	1 Each	1	0	5.38 Each	5.38
11	47865K41	Brass On/Off Valve with Lever Handle, 1/4 NPT Female x 1/4 NPT Male	1 Each	1	0	9.29 Each	9.29

Notes

Your order is subject only to our terms and conditions, available at www.mcmaster.com or from our Sales Department.

These items are controlled by the U.S. Government and authorized for export only to the country of ultimate destination for use by the ultimate consignee or end-user(s) herein identified. They may not be resold, transferred, or otherwise disposed of, to any other country or to any person other than the authorized ultimate consignee or end- user(s), either in their original form or after being incorporated into other items, without first obtaining approval from the U.S. government or as otherwise authorized by U.S. law and regulations.

Merchandise	214.10
Canadian GST/HST	11.49
Shipping	15.69
Total (US Dollars)	$241.28

Packing List	Shipped	Weight	Carrier	Tracking
8532136-01	3/17/17	8 lb	Purolator Air	CPK005361482

February 23, 2017

Auber Instruments Inc — - $112.17 USD

Payment

Paid with

VISA x-1442

You'll see "PAYPAL *AUBERINSTRU" on your card statement.

Exchange rate

$151.70 CAD = $112.17 USD

1 CAD = 0.74 USD

Shipped to

marc brettschneider
13 lamarche
saint anne de bellevue QC h9x2a4
Canada

Track your shipment

LZ634464137US

February 24, 2017, Sent by USPS

Status: Shipped

Transaction ID

0TK919421R302591V

Seller info

Auber Instruments Inc

770-569-8420

http://auberins.com

auberins@gmail.com

Invoice ID

67448-1487905489-[auberinscom]

Purchase details

Stainless Steel 1/4 NPT Weld Bung Item #BUNG14NPT	$5.95 USD
Liquid tight K type, 2 in probe, 1/4 NPT Thread*** Item #TC-K50MMNPT	$21.95 USD
Heat Sink for Solid State Relay, 25A*** Item #HS25	$9.65 USD
25A SSR*** Item #MGR-1D4825	$9.95 USD
1/16 DIN PID Temperature Controller (For SSR)*** Item #SYL-2352	$46.50 USD

Amount	$94.00 USD
Shipping	true
Total	**$112.17 USD**

March 20, 2017

Auber Instruments Inc - $79.22 USD

Payment

Paid with

VISA x-1442

You'll see "PAYPAL *AUBERINSTRU" on your card statement.

Exchange rate

$109.10 CAD = $79.22 USD

1 CAD = 0.73 USD

Shipped to

marc brettschneider

13 lamarche

saint anne de bellevue QC h9x2a4

Canada

Track your shipment

LZ637544143US

March 21, 2017, Sent by USPS

Status: Shipped

Transaction ID

69524498M4892144H

Seller info

Auber Instruments Inc

770-569-8420

http://auberins.com

auberins@gmail.com

Invoice ID

68140-1490030406-[auberinscom]

Purchase details

40A SSR*** Item #MGR-1D4840	$15.50 USD
Liquid tight RTD sensor, 2 in, 1/4 NPT Thread Cable Option: 8 ft Braided Cable with XLRCON connector/cable Item #PT100-L50NPT	$45.55 USD

Amount	$61.05 USD
Shipping	true
Total	**$79.22 USD**

Need help?

If there's a problem, make sure to contact the seller through PayPal by **September 16, 2017**.

March 23, 2017

Auber Instruments Inc — - $42.68 USD

Payment

Paid with

VISA x-1442

You'll see "PAYPAL *AUBERINSTRU" on your card statement.

Exchange rate

$58.71 CAD = $42.68 USD

1 CAD = 0.73 USD

Shipped to

marc brettschneider

13 lamarche

saint anne de bellevue QC h9x2a4

Canada

Track your shipment

LZ637990962US

March 24, 2017, Sent by USPS

Status: Shipped

Transaction ID

73Y614914N2516723

Seller info

Auber Instruments Inc

770-569-8420

http://auberins.com

auberins@gmail.com

Invoice ID

68249-1490318796-[auberinscom]

Purchase details

Liquid tight RTD sensor, 2 in, 1/2 NPT Thread*** Item #PT100-L501/2NPT	$27.95 USD
9-PIN 3PDT ON/ON Toggle Switch, RTD Sensor Switching*** Item #TS3	$3.40 USD

Amount	$31.35 USD
Shipping	true
Total	**$42.68 USD**

Need help?

If there's a problem, make sure to contact the seller through PayPal by **September 19, 2017.**

Affordable Distillery Equipment

Affordable Distillery Equipment LLC
HCR 7 Box 329A
Doniphan, MO 63935

Phone: 417-778-6100
Phone: 417-778-6249

INVOICE

MB031716

PURCHASER

Marc Brettschneider
13 Lamarche
Saint Anne De Bellevue QC
Canada H9X2A4

SHIP TO:

SAME

Date	Your Order	Our Order #	Sales	FOB	Ship Via	Terms	Tax ID
03-17-17			KB		USPS		

Quantity	Description	Unit Price	Total
2	2” Stainless Weld Ferrule	$3.60	$7.20
2	2” Tri Clamp	$6.02	$12.04
4	2” PTFE Gasket	$2.90	$11.60
2	2” to 3/4” Female NPT	$7.72	$15.44
2	Heating Element Enclosure	$33.30	$66.60
		Subtotal	$112.88
	This invoice is for the express shipping	Tax	$60.56
		Shipping	
		Total	$173.44

Phone: 438-868-3438
Email: myco-rise@mail.com

McMASTER-CARR
330-995-5500
330-995-9600 (fax)
cle.sales@mcmaster.com

Receipt

Purchase Order	**STERILISER 2**
Paid (US Dollars)	**$119.72**
Invoice	**21371896**
Invoice Date	**3/28/17**

Billed to

ATTENTION: MAXIME EICHHORN BILODEAU
MCGILL UNIVERSITY
RM 216
3465 RUE DUROCHER
MONTREAL PQ H2X 0A8
CANADA

Shipped to

McGill University
C/O Samuel Eichhorn Bilodeau
6615 Rue Chardonneret
Laval PQ H7L 4B2
Canada

Information About Your Payment

Credit Card	Visa Ending- 7904
Date	3/29/17
Name on Card	Maxime Eichhorn Bilodeau
Your Account	245792200

Samuel Eichhorn Bilodeau placed this order.

Line		Product	Ordered	Shipped	Balance	Price	Total
1	4464K271	304 Stainless Steel Threaded Pipe Fitting Low-Pressure, Bushing Adapter, 3/4 Male x 1/2 Female	3 Each	3	0	5.53 Each	16.59
2	4013K62	Pressure & Temperature Gauge Steel Case, 3-1/4" Dial, 1/2 NPT Center Back, 100 PSI	1 Each	1	0	25.20 Each	25.20
3	4464K52	304 Stainless Steel Threaded Pipe Fitting Low-Pressure, Tee Connector, 3/4 NPT Female	2 Each	2	0	14.66 Each	29.32
4	47865K44	Brass On/Off Valve with Lever Handle, 3/4 NPT Female x 3/4 NPT Male	2 Each	2	0	14.93 Each	29.86

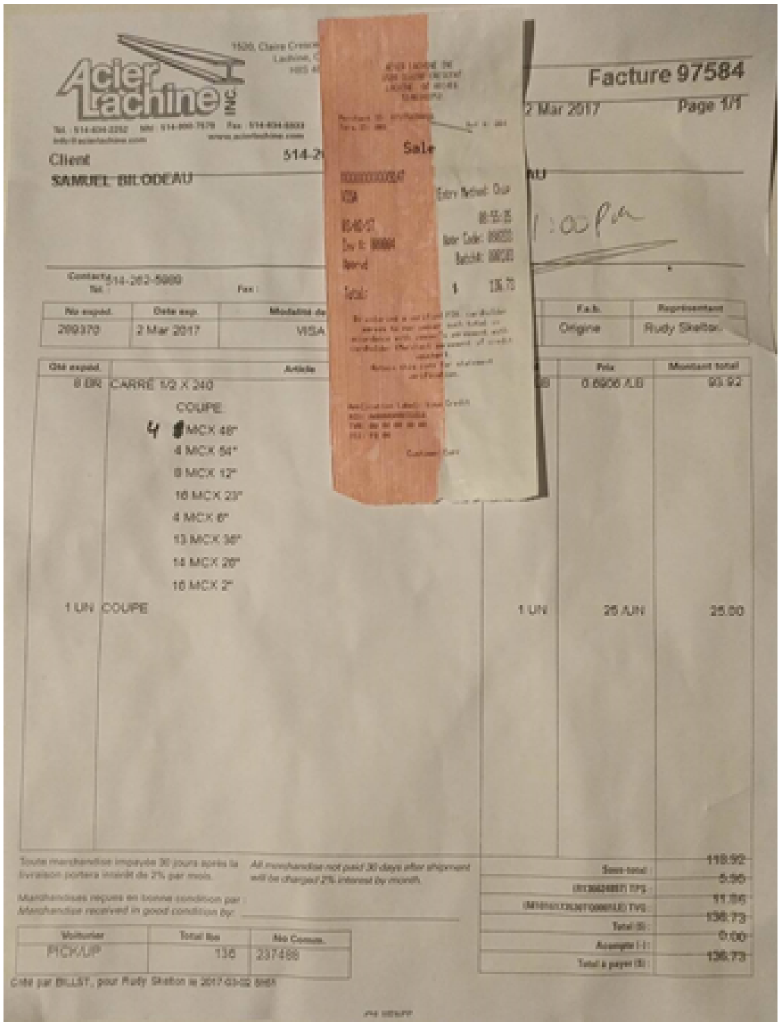
Merchandise	100.97
Canadian GST/HST	5.70
Shipping	13.05
Total (US Dollars)	$119.72
Payment Received 3/29/17	(119.72)
Balance Due (US Dollars)	$0.00

Notes

Your order is subject only to our terms and conditions, available at www.mcmaster.com or from our Sales Department.

These items are controlled by the U.S. Government and authorized for export only to the country of ultimate destination for use by the ultimate consignee or end-user(s) herein identified. They may not be resold, transferred, or otherwise disposed of, to any other country or to any person other than the authorized ultimate consignee or end- user(s), either in their original form or after being incorporated into other items, without first obtaining approval from the U.S. government or as otherwise authorized by U.S. law and regulations.

Packing List	Shipped	Weight	Carrier	Tracking
8889337-01	3/24/17	5 lb	Purolator Air	CPK005377139



Acier Lachine INC

1520, Claire Crescent, Lachine

www.acierlachine.com

Facture 97584

2 Mar 2017 — Page 1/1

Client: SAMUEL BILODEAU

Contact: 514-262-5989

Sale — VISA — Total: 136.73

1:00 pm

No expéd.	Date exp.	Modalité de paiement	F.a.b.	Représentant
269370	2 Mar 2017	VISA	Origine	Rudy Skelton

Qté expéd.	Article		Prix	Montant total
8 BR	CARRE 1/2 X 240		0.6906 /LB	93.92
	COUPE			
	4 MCX 48"			
	4 MCX 54"			
	8 MCX 12"			
	16 MCX 23"			
	4 MCX 6"			
	13 MCX 36"			
	14 MCX 26"			
	16 MCX 2"			
1 UN	COUPE	1 UN	25 /UN	25.00

Toute marchandise impayée 30 jours après la livraison portera intérêt de 2% par mois. *All merchandise not paid 30 days after shipment will be charged 2% interest by month.*

Marchandises reçues en bonne condition par : *Merchandise received in good condition by:*

Voiturier	Total lbs	No Consom.
PICK/UP	136	237488

Sous-total	118.92
TPS	5.95
TVQ	11.86
Total ($)	136.73
Acompte (-)	0.00
Total à payer ($)	136.73

Créé par BILLST, pour Rudy Skelton le 2017-03-02

Acier Lachine INC

Facture 98652

Page 1/1

Client: SAMUEL BILODEAU — 514-262-5989

Contact: 514-262-5989

Achat — VISA

No expéd.	Date exp.	Modalité de paiement	F.a.b.	Représentant
261606	28 Mar 2017	VISA		Vivian Woodberry

Qté expéd.	Article	Prix	Montant total
1 BR	CARRE 1/2 X 240	15 /BR	15.00
	COUPE		
	6 PCS 24"		
	2 PCS 47"		

Payé Visa

Voiturier	Total lbs	No Consom.
PICK/UP	17	239026

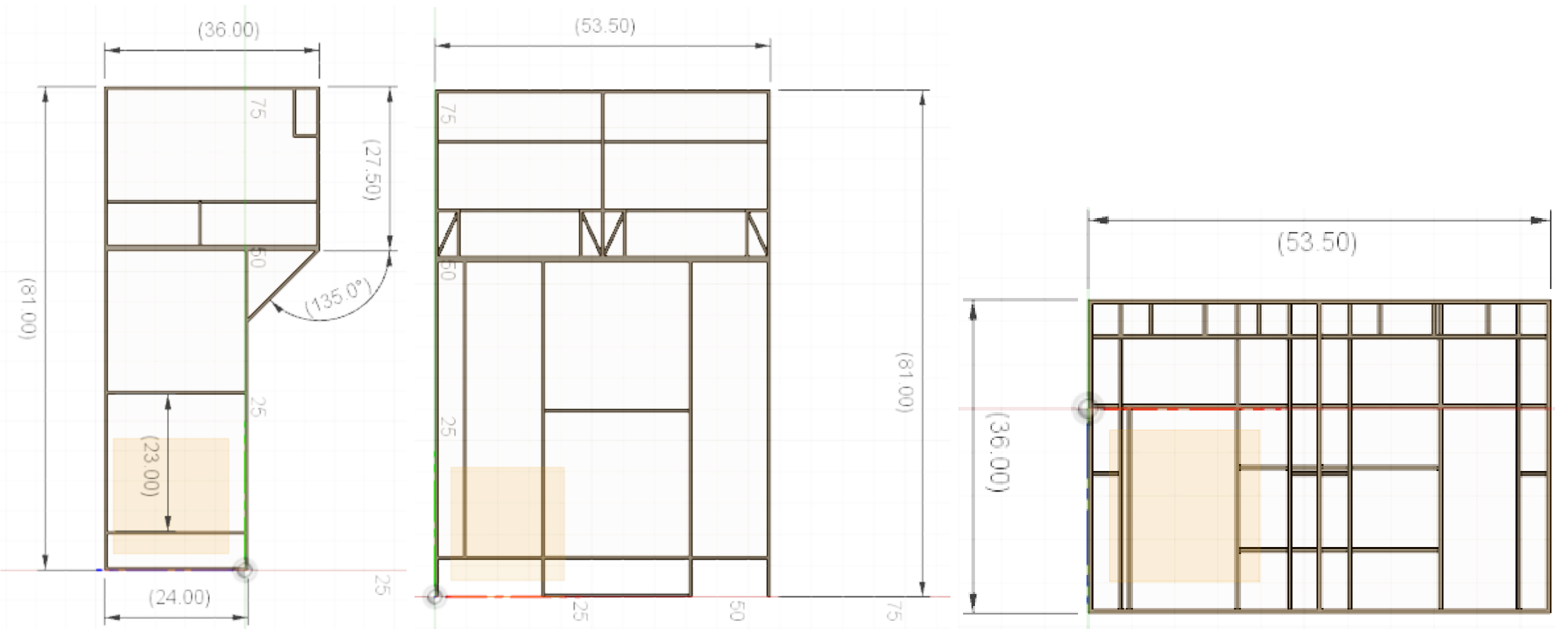
Sous-total	15.00
TPS	0.75
TVQ	1.50
Total ($)	17.25
Acompte (-)	0.00
Total à payer ($)	17.25

Créé par BILLST, pour Vivian Woodberry le 2017-03-28

CLIENT

Figure 2.1.1. Sketches (Overconstrained)

Right **Front** **Top**



Notes: Dimensions in inches

Figure 2.3.1: Heat Transfer Calculations

Properties & specifications:

$D_o = 24\,in = 0.6096$

$D_i = 24 - 2\cdot(1/16\,in)$
$= 23.875\,in = 0.606\,m$

$\left.\begin{array}{l} T_w = 120°C \\ T_\infty = 30°C \end{array}\right] \quad T_f = 75°C = 348\,K$

air @ atm pressure & T_f

348 K: $\mu = 2.0728E{-5}$
$\nu = 2.0444E{-5}$
$K_{air} = 0.02957\ W/m\cdot K$
$Pr = 0.70729$
$\beta = \frac{1}{T} = 0.002874\ 1/K$

Assumptions
- no conduction resistance in drum (thin material).
- ambiant temp of 30°C
- Approximating system as a long horizontal cylinder:
- No convection except for naturally induced (closed room)
- No heat transfer from plane faces (lid & "bottom")

using the Churchill & Chu eq.

$$\bar{Nu}_D = \frac{\bar{h} D}{k_f} = \left\{ 0.60 + \frac{0.387\, Ra_D^{1/6}}{[1+(0.559/Pr)^{9/16}]^{8/27}} \right\}^2$$

Range: $10^{-5} < Ra_D < 10^{12}$
Properties @ T_{film}.

where $Ra = Gr \cdot Pr$

$$Gr_d\, Pr = \frac{g\beta(T_w - T_\infty)d^3}{\nu^2} Pr = \frac{(9.8)(0.002874)(90)(0.61)^3}{2.0444E{-5}} Pr$$
$$= 974E6 = Ra_D$$

from table 7-1 : p 334 (Holman, heat transfer 10th ed)

for horizontal cylinders w/ Ra_D b/w 10^4 & 10^9

$C = 0.53$ & $m = 1/4$

$$Nu_d = 0.53\,(Gr_d\,Pr)^{1/4} = 0.53\,(974E6)^{1/4} = 93.63$$

$$h = \frac{k\,Nu_d}{d} = \frac{0.02957\ \frac{W}{m\cdot K} \cdot 93.6}{0.61\ m} = 4.54\ \frac{W}{m^2\cdot °C}$$

heat transfer per unit length:

$$\frac{q}{L} = h\cdot\pi\cdot d\,(T_w - T_\infty) = 4.54\cdot\pi\cdot 0.61\,(120-30) = 783\ \frac{W}{m}$$

length of drum = 0.889 m

heat transfer from uninsulated barrels to surroundings

x2 barrels
$(2)\ 783\ \frac{W}{m}\cdot 0.889\,m = 2.696\ W = 1392\ W$

taking the latent heat of condensation/vaporisation as 2265 kJ/kg.

approximation of generated condensate during steady state operation.

$$\frac{2.696\ \frac{J}{s}}{2265E3\ \frac{J}{kg}} = 0.00062\ kg/s \text{ of condensate. (per barrel)}$$

Calculation 2.4

/** Weight of supported components we're overestimated to be 800lbs (steel drums + 100% water saturated media). Approximating our system as long columns with central loading with both ends rounded or pivoted (**Figure 2.4.1**), the critical force for the pin-ended column is given by the *Euler column formula*. 0.5 inch square mild steel columns were employed in making the frame. (Budynas R. G., 2015. Pp. 195)

Euler equation: $P_{cr} = pi^2 EI / l^2$

Where:

P_{cr} = Critical Load

E = Modulus of Elasticity = 30 Mpsi for Carbon Steel

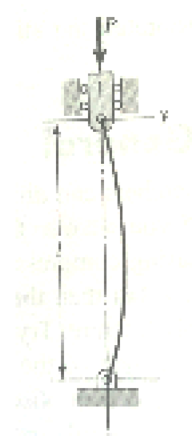
I = Second Moment of Area = $(0.5^4 / 12) = 0.00521 \text{ in}^4$

l = Column Length = 54 in

We obtain P_{cr} = 530 lbf

If the system was to be supported by an individual column it would fail by buckling. Indeed the columns which comprise our structure would more realistically be modeled as being eccentrically loaded due to deviations from the ideal model introduced during manufacturing. Defects such as load eccentricity and crookedness are present in our system due to erroneous welding procedures and tool tolerances. Not being able to adequately calculate column eccentricity, increasing design factor of our ideal model was the approach chosen. 8 vertical columns we're employed in the construction of the system. Assuming equal point load distribution on pin ended columns: a safety factor of 5 would be attained. **/

Figure 3.2.1:



(Budynas R. G., 2015. Pp. 195)

Table 2.4.1: Material Properties for Steel

Density (lbmass / in^3)	0.2836
Young's Modulus (psi)	3.046E+07
Poisson's Ratio	0.3
Yield Strength (psi)	30023i

Ultimate Tensile Strength (psi)	50038
Thermal Conductivity (Btu / (s*in*F))	7.49E-04
Thermal Expansion Coefficient F^{-1}	6.667E-06
Specific Heat (Btu / (lbmass*F))	0.1146

Ref: Fusion 360 Material Library

Figure 2.4.4: Buckling Analysis

A. Front View (Scenario 1: 10x Load) **B. Front View (Scenario 2: 16x Load)** **C. Back View (Scenario 3: 19x Load)**

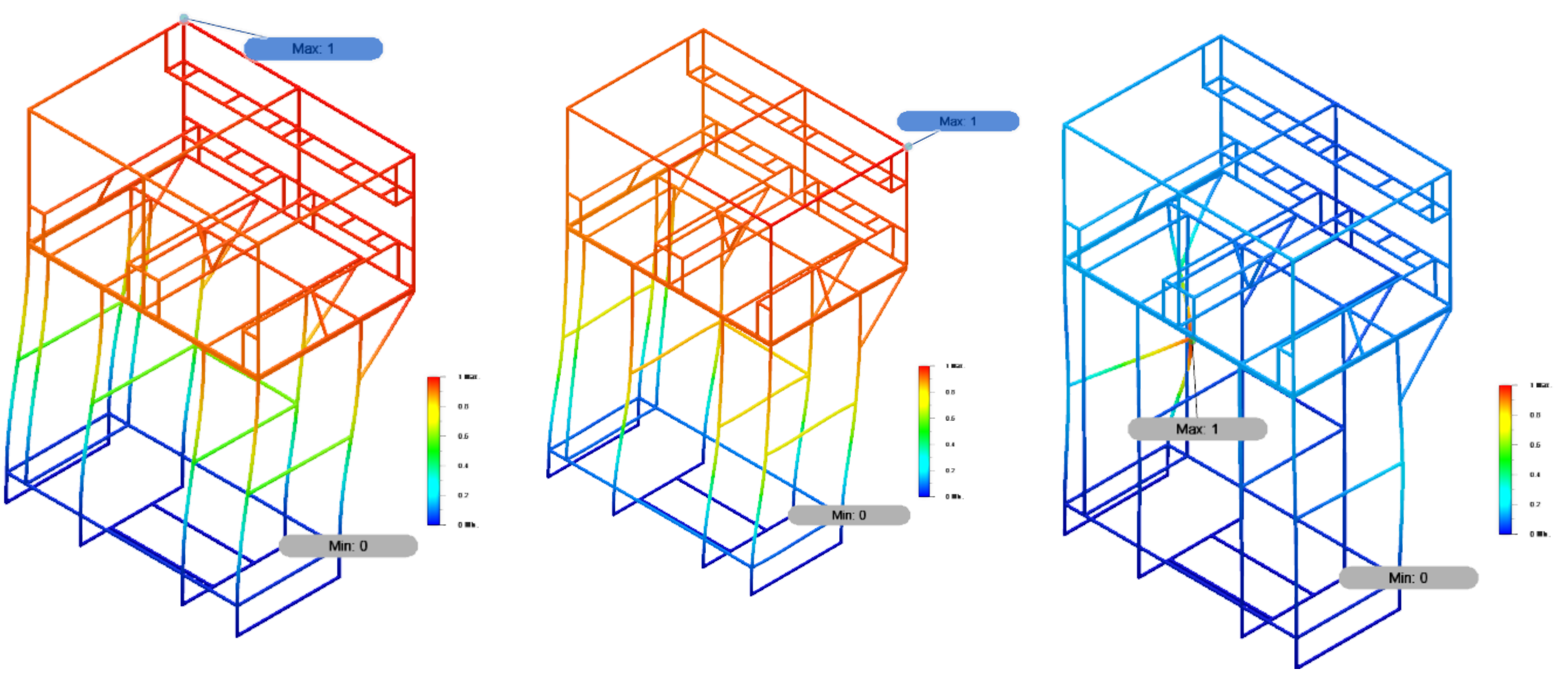


Figure 2.4.3: Top Frame Static Stress Analysis & Maximum stress near welds

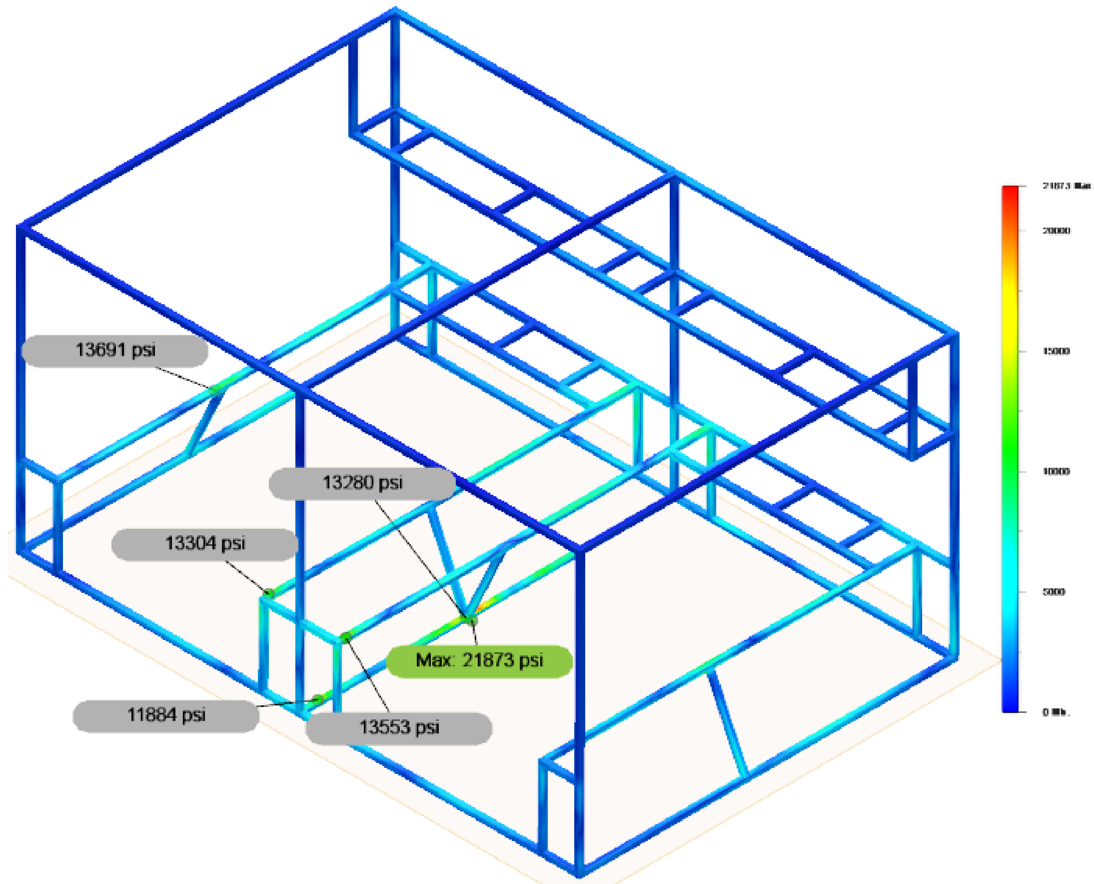


Figure 3.2.1: Bottom Frame Iterations

1: February 3, 2017 | **2: March 17, 2017** | **3: March 23, 2017** | **4: March 31, 217** | **5: April 7, 2017**

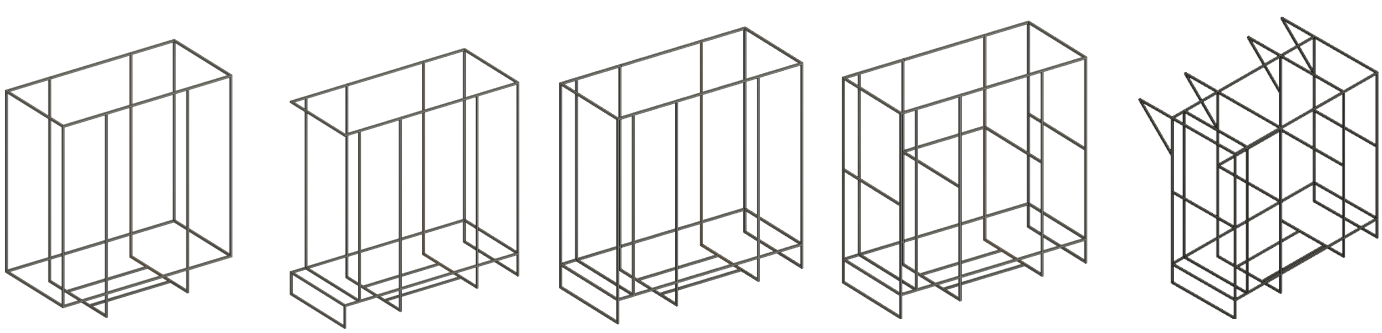
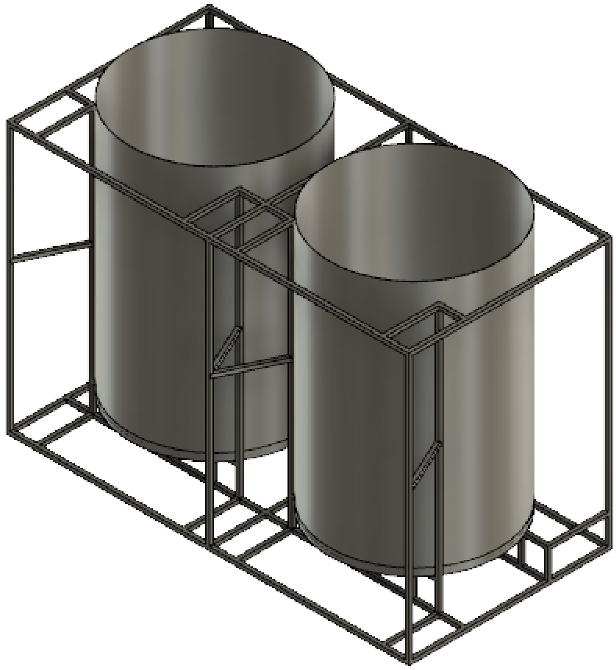
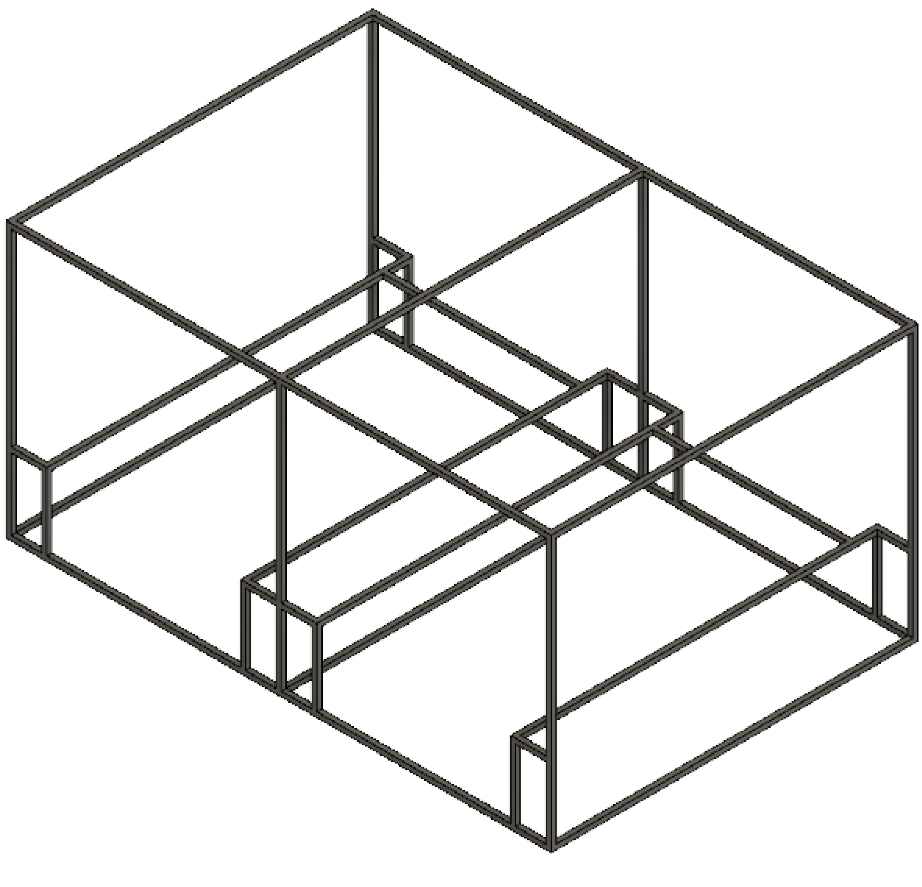


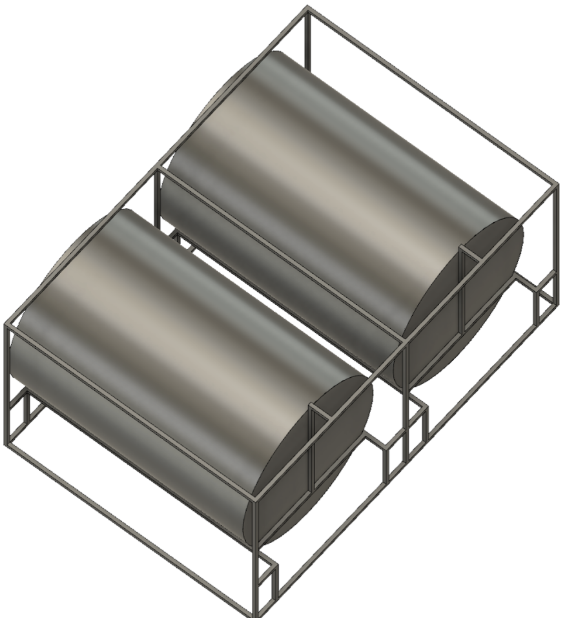
Figure 3: Water Filled Drums



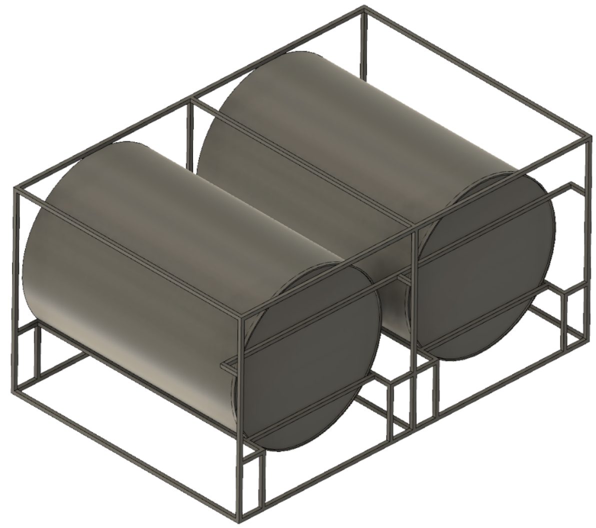
Top frame as March 17, 2017



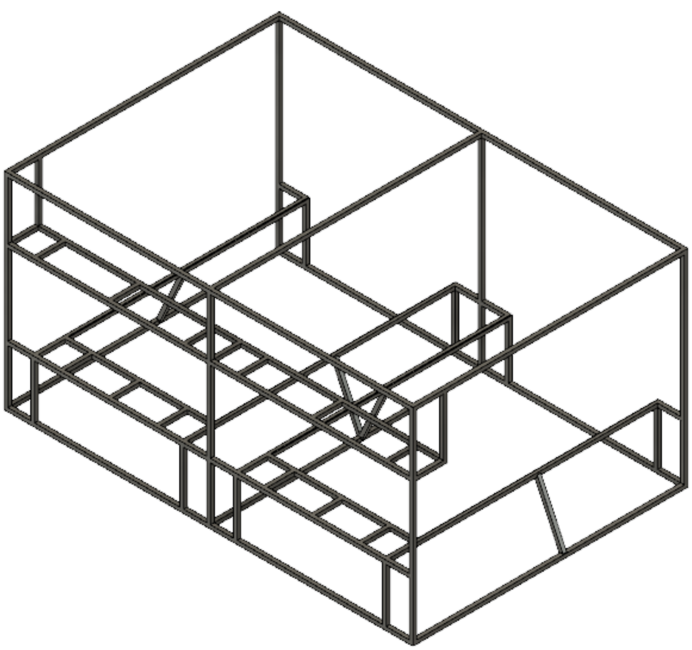
Iteration 1

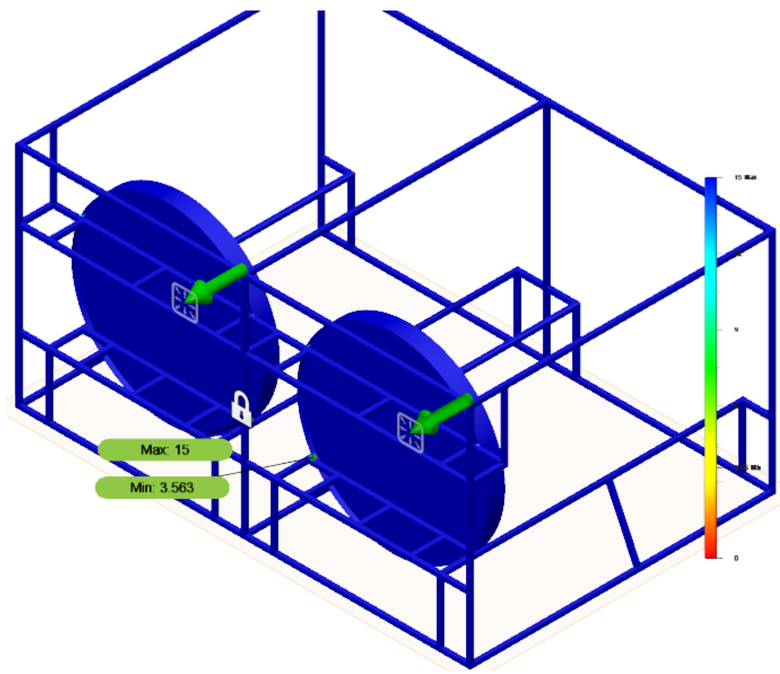


Iteration 2



Improved model with Combination of Iteration 1 and Iteration 2





Notes: minimum safety of factor is 3.6. In this simulation Steel drum bottoms were modelled to be thicker and width of bottom rim was approximated as 0.125 in. 1.5 psi applied on inside surfaces of drums to simulate 600 lbf (weight of water filled drum).