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Bio-Shield Medical Waste Processing Unit

Final Report

Senior Design MAE 4344

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1. Introduction and Problem Statement

Medical waste processors are large pieces of machinery which sterilize medical waste so that it may then be disposed of as non-hazardous waste. The primary components include grinders, conveyors, autoclave, steam generation, housing and frame. Recently, tests on medical waste have proven that static (non-rotating) autoclaves do not effectively disinfect hazardous materials. Although alternatives to the autoclave method of sterilizing waste exist, the autoclave has shown to be the most effective and environmentally friendly method. The solution to the unreliable static autoclave is a rotating autoclave, which has been developed by Bio-Shield, an up and coming company which hopes to redefine the medical waste sterilization market. Though they once operated a large format mobile medical waste grinding system, this quickly proved to not be financially viable. Responding to an industry need, the new goal of Bio-Shield is to place a fractional size system inside hospitals. By decreasing the scale of these processors to one-third of the developed load input, units will be able to be rented by hospitals and transported from one place to another to allow for extremely convenient methods of converting biomedical hazard into dumpster waste. Bio-Shield has agreed to pay for the final design of this unit and, once completed, it will serve to revolutionize the industry and create a brand new business in Oklahoma. The senior design team's goal was to evaluate the concept developed by Bio-Shield and identify strengths and weakness to implement as many improvements as possible.

2. Deliverables

The main deliverable our team completed was a space claim model. This model serves to identify the shape, size, and placement of all known major components. This can be found within the given files under Dropbox\Bioshield Project - Spring 2015 Senior Design\Solidworks\Assy. The second major deliverable was design work on the rotating autoclave. This included extensive research on ASME codes and standards, pressure vessel sizing, heat transfer calculations, and stress analysis on the agitator, which rotates the material within the autoclave. Finally, we have made an effort to compile all of the specifications and documentation given to the team by Bio-Shield and all of the individual research performed by the team members.

3. Work Done/Design tasks

3.1. Background Research/Hospital Visit

While the goal of this modified system is to be able to process waste from hospitals containing up to 1,200 beds, it was necessary to research exactly how much waste this would equate to each day in order to be able to accurately size all components of the system.

There have been relatively few studies focusing on the amount of waste generated at United States hospitals on a daily basis, and even fewer studies on the average density of medical waste. Furthermore, the few studies that have been conducted were undertaken some time ago, in the late 1980s and early 1990s. One study by Rutala, Odette, and Samsa in 1989 examined the waste generation at 441 hospitals throughout the United States and found that the amount of waste generated per bed per day varied widely with hospital size (Rutala et al., 1989). The average in this study was found to be 6.93 kilograms per bed per day, with infectious waste accounting for an average of 15% of this figure.

One of the few studies focusing on the density of medical waste was undertaken in 1989 by Milburn (Milburn, 1989). This study found that the average density is, as expected, highly dependent upon the composition of the waste and which material is dominant. Some of the less dense materials had densities as low as 5 pounds per cubic foot, while the densest materials had densities as high as 500 pounds per cubic foot. Upon studying one of the previous senior design projects focusing on the primary grinders for the system, it was noted that the team had established a density range with Bio-Shield of 3.5 to 5.5 pounds per cubic foot (Beats et al., 2012). For the purposes of this project and consistency with their design, we will focus on this range of densities for our calculations.

In addition to these studies, the team visited the Children's Hospital at the OU Medical Center in Oklahoma City and met with John Anglin, Assistant Director of Environmental Services, to discuss how this particular hospital handled their bio-hazardous waste. In this case, the hospital places all biohazard waste into marked red containers. Hospital staff will take the filled containers to the hospital loading dock, where an external company will haul away these containers in a truck six days of every week and supply the hospital with fresh replacement carts. The hospital generates an average of forty 95-gallon containers of waste every day. When asked about the composition of the waste, Mr. Anglin informed the team that there was little variation—a large amount of the waste is liquid, but any liquids are treated with coagulation agents to prevent spills, and most of the waste is placed into bags. Generally, linens are processed separately and rarely need to be placed into the biohazard bins. Sharps are placed into smaller, 8-gallon containers that are picked up less frequently by the waste handling company. When asked about the overall efficiency of this system, Mr. Anglin informed the team that the hospital had an on-site autoclave approximately 20 years ago, and that the hospital had recently been investigating returning to on-site waste treatment in an effort to cut costs. He also expressed interest in the Bio-Shield system.

3.2. Updated Design Concept

In order to maximize efficiency of the system and decrease its overall size, the team developed the concept of connecting each major component together at an angle of 40°, which eliminates the need for a primary conveyor and decreases the enclosure's overall length by approximately six feet. This updated design can be seen below in Figure 1.

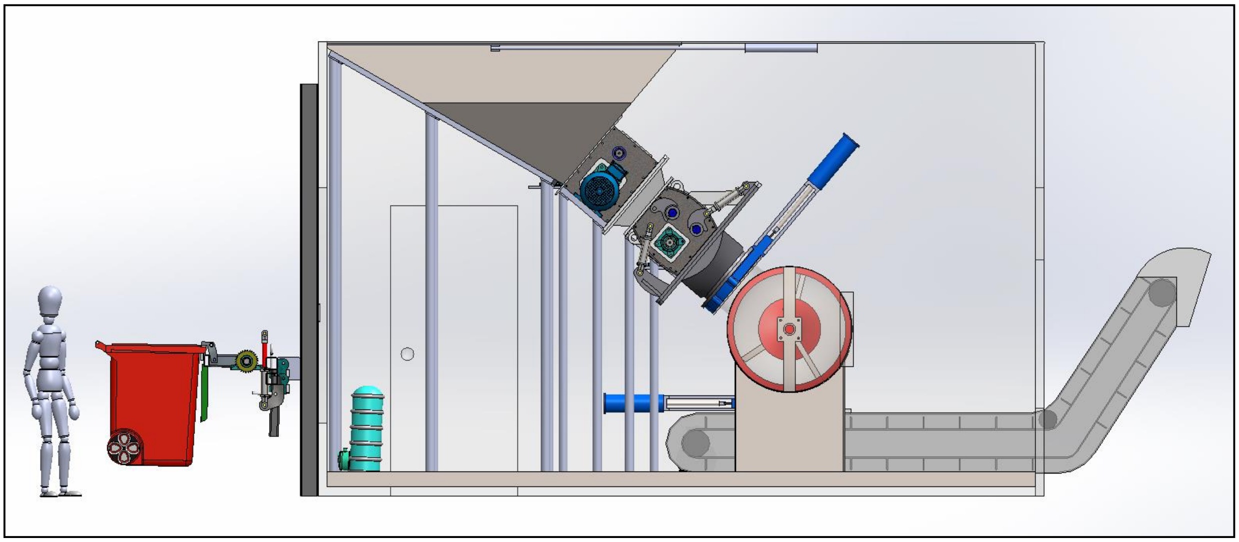


Figure 1: Updated Design Concept

3.3. Space Claim

The SolidWorks assembly of the space claim, shown in Figure 1, is labeled “ASSY with Enclosure”. The file location is Dropbox\Bioshield Project - Spring 2015 Senior Design\Solidworks\Assy. The space claim includes a model and the location of the safe carts, lift mechanism for safe carts, hopper, the hopper lid, the funnel from hopper to course grinder, course grinder, the funnel from course to fine grinder, fine grinder, funnel from fine grinder to autoclave, autoclave, knife gates, autoclave auger, auger shaft and bearings, Harris Quick Opening Door, autoclave saddle stand, exit conveyor, angled floor, waste water tank, and a rough sized model of all required pump, motors, and supports for the components.

3.4. Hopper

The hopper’s overall dimensions are a width of 96 inches, length of 116.6 inches, and a depth of 46 inches. The hopper’s material was chosen to be AISI 316 stainless steel sheet material with a thickness of 0.5 inches. AISI 316 stainless steel was chosen for its corrosion resistant properties and because it is a common material used in industry. The 0.5 inch thick sheet metal was chosen to ensure the material could hold the weight of the waste load without needing to check the design by running calculations. The hopper could easily use a much thinner sheet metal if calculations are performed to verify the design. The SolidWorks model is called NewHopper and is located in, Dropbox\Bioshield Project - Spring 2015 Senior Design\Solidworks\Assy.

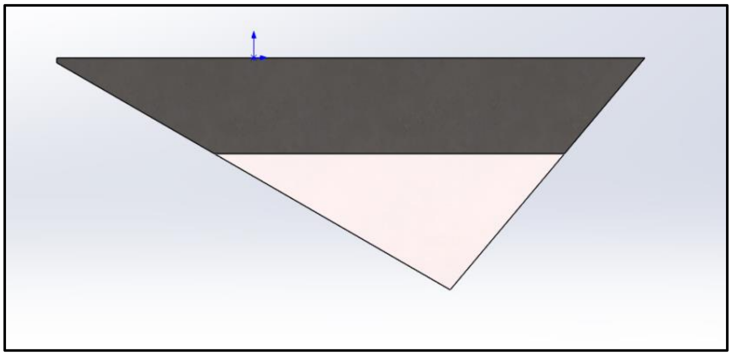
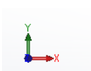


Figure 2: Hopper Side View



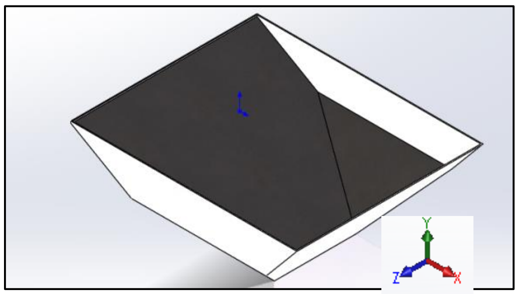


Figure 3: Hopper Isometric View

The target volume capacity for the hopper was 116 cubic feet. The current hopper has a volume capacity of 136 cubic feet. Given the relative size of the hopper compared to the overall size constraints of the system, the closest volume capacity, without going below 116 cubic feet, was a volume of 136 cubic feet. In the case that over filling occurs, this volume capacity was designed to hold 150% of the maximum waste load. The waste load of 77 cubic feet was derived from the maximum volume the auto clave could sterilize in one cycle. This load is equivalent to two sets of three 96 gallon safe carts.

3.5. Delta Feeder/Coarse Grinder/Fine Grinder

The delta feeder and coarse grinder are the first two components of the system to break apart the waste. The delta feeder is a rotating mechanism that forces large or hard objects into the coarse grinder to be shredded. The coarse grinder feeds directly into the fine grinder, which then feeds the waste into the autoclave.

There were several documents that were able to provide the team with information about the sizing and motor requirements for the delta feeder, coarse grinder, and fine grinder. The first of these documents was a design overview of all the major components that should be included in the 550 unit.[1] This document states that the purpose of the delta feeder is to control the rate at which waste is fed into the coarse grinder and also to force larger objects into the grinder.

[1] 550 – Design Overview.pdf

Additionally, the delta feeder should rotate in both directions and switch directions if a certain pressure is reached to prevent damage to grinder or delta feeder itself. As far as power is concerned, the delta feeder should be powered by an electric motor.

Information about the coarse grinder can be found in the same design overview document. The primary purpose of the coarse grinder is to reduce the size of the waste by breaking down large objects such as bags and sharps containers. This document states that the coarse grinder must be accessible for maintenance, and that it must be able to allow objects that will damage the blades to pass through the grinder. A solution to this problem has been found by adding a hydraulic cylinder that would open and allow the obstruction to pass if a certain pressure was reached.

The purpose of the fine grinder is to further reduce the size of the waste before the material enters the autoclave chamber in order to speed up the sterilization process. The design of this component has been completed by a senior design team in 2012, and the final report from this senior design project provided calculations to determine the required speed of blades, wear analysis, and motor requirements.[2]

No calculations have been completed by the Spring 2015 senior design team on the delta feeder, coarse grinder, or fine grinder. This is because it is not in our scope of work to design or redesign these components. The larger 1500 unit had a working delta feeder design, as mentioned in the "Design Overview" document, and thus will have to be adapted to fit the smaller unit. The coarse grinder design will need to be analyzed to determine if it can handle the appropriate amount of waste. Finally, the fine grinder has been wholly designed and is ready to be fabricated for testing.

CAD models for the delta feeder, coarse grinder, and fine grinder have been completed in SolidWorks. The models for the delta feeder and coarse grinder are currently only space-claim models and will need to be designed in greater detail before fabrication. The coarse grinder has been completely modeled by the Compact Medical Waste Shredder project team, and is detailed in the final report. Below are three figures that show the current models for each component.

The delta feeder shown in Figure 4 was designed and modeled by the original 550 design team, and the design has not been changed by the Bio-Shield senior design team. Currently the model is being used as a space-claim. According to the "Design Overview" document, an acceptable design exists and has been used on the 1500 unit. Due to this fact, the senior design team will not be modifying the current delta feeder design.

[2] Beats, Andrew, Bellmyer, Mark, and Storey, Andrew. "Compact Medical Waste Shredder." MAE 4344 Final Report, Group 14. Fall 2012.

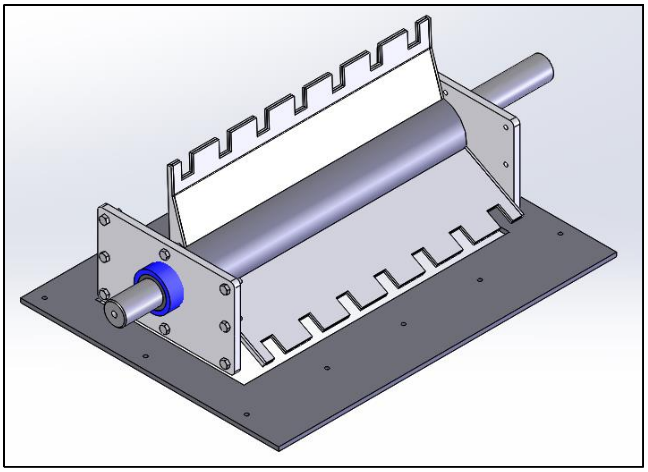


Figure 4: Delta Feeder model in SolidWorks.

The coarse grinder, shown in Figure 5, has currently been modeled in detail but does not have the calculations to show that it can handle the necessary amount of waste. However, the model does include all of the necessary features required by the team. Because the coarse grinder has been pulled from the previous 550 unit design, the team is assuming the space requirements will be the same for the new design.

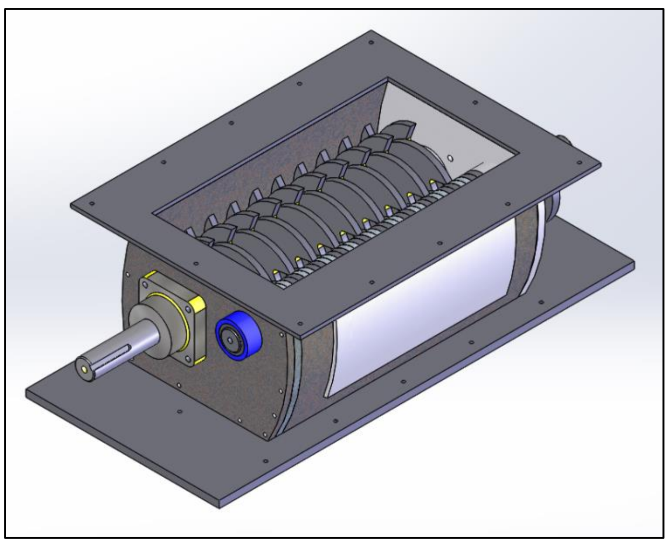


Figure 5: Coarse Grinder model in SolidWorks.

Figure 6 shows the SolidWorks model created by the Compact Medical Waste Shredder team in the fall of 2012. This is a complete design that meets all of the requirements for the fine grinder, and thus does not need to be changed. It has been included in the space-claim assembly for the 550 unit design.

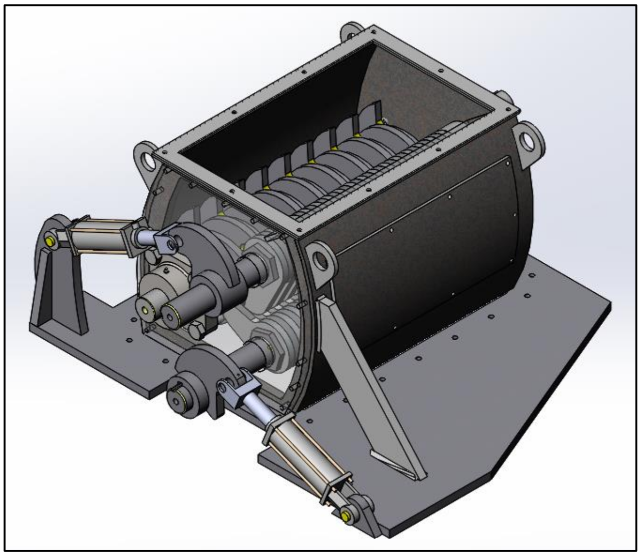


Figure 6: Fine Grinder model in SolidWorks.

3.6. Knife Gates

In order to seal the inlet and outlet ports of the autoclave, knife gates will be used. The Bio-Shield Design Overview document specified the use of knife gates to seal these ports. These knife gates must be able to withstand the temperatures and pressures of the autoclave, and must be resistant to corrosion. Because of this environment, stainless steel knife gates have been chosen. Stainless steel knife gates are commercially available from several manufacturers. The team has found a manufacturing company, DeZurik, to have knife gates available to fit the needs of the system. These knife gates are made of cast stainless steel, have round ports to mesh with the autoclave, and have hydraulic actuators to move the gate. A knife gate to fit the above requirements will have to be found using a manufacturer's catalog. Figure 7 below shows the DeZurik knife gate chosen.[3]

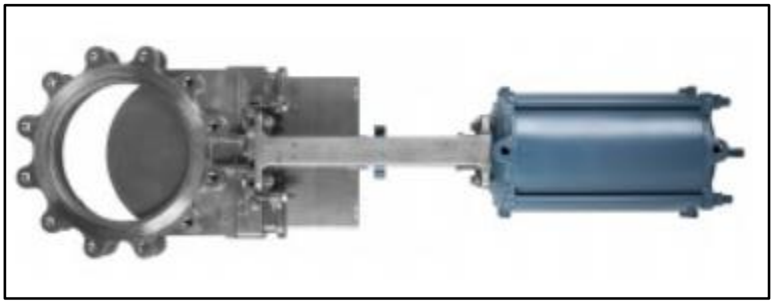


Figure 7: DeZurik Stainless Steel Knife Gate.

[3]DeZurik Stainless Steel Knife Gate <http://www.dezurik.com/products/product-line/gate-valves/knife-gate-valves/dezurik-cast-stainless-steel-knife-gate-valves-kgc/extended-service-life-cast-stainless-steel-knife-gate-valves-kgces/55/14/>

According to the “550 – Design Overview” document, “[a] spray or other type of device should be incorporated that cleans the bottom knife gate so that residue material does not remain and cause leakage on subsequent cycles.[4]” The current team did not look at incorporating this nozzle, and so it will need to be considered once further design is completed.

3.7. Autoclave

3.7.1. Shell and Head Thickness

The autoclave had to be designed to ASME section VIII division 2 standards. The ASME code was referenced along with Pressure Vessel Handbook 14th edition by Eugene F. Megyesy, which is a condensed version of the code to simplify the code. These calculations and assumptions need to be certified and checked by a licensed PE to be validated.

When calculating the thickness of the shell, we had two equations that were given in ASME code. One was for calculating the circumferential stress and the other for the longitudinal stress. Knowing the pressure, the team utilized the thickness equation below which checks against circumferential stress.

$$t = \frac{PR}{SE - 0.6P}$$

This equation is formed off the internal radius of the vessel. Below is a table with definitions of the variables:

	Variables	unit
P	MAWP	psi
S	Stress value	psi
E	Joint Efficiency	
R	inside radius	inches
D	inside diameter	inches
t	wall thickness	inches
C.A.	corrosion allowance	inches

Pressure, radius, diameter, and corrosion allowance were all assumptions made after understanding the size constraints and material that would be used for the autoclave. The joint efficiency is a value given from ASME and is predicated on what type of fabrication welding will be utilized. As a factor of safety, a single joint butt weld with a joint efficiency of 0.6. The stress value was selected from a table within the ASME code and is a function of the material type and the maximum temperature of the system. As the material is very corrosive, we selected stainless steel for the material and performed calculations for both 304 and 316 to identify the best option for our system. Following shows the assumed values and the given results:

[4] 550 – Design Overview.pdf

Given Parameters Shell:			
D	41.25	inches	
R	20.625	inches	
E	0.6	single butt joint weld	
S	15000	psi	304 Stainless Steel
S	12800	psi	316 Stainless Steel
P	50	psi	
t	0.134804	inches	Using 316 Stainless Steel
t	0.114967	inches	Using 304 Stainless Steel

The two calculated values are the minimum allowable thickness that may be used for the shell of the autoclave.

In addition to circumferential stress, the longitudinal stress also needed to be check. Typically the circumferential stress drives the thickness, but in this case the tangential stress was higher. Below are the equation used and the results:

$$t = \frac{PR}{2SE + 0.4P}$$

Given Parameters Shell:			
D	41.25	inches	
R	20.625	inches	
E	0.6	single butt joint weld	
S	15000	psi	304 Stainless Steel
S	12800	psi	316 Stainless Steel
P	50	psi	
t	0.067051365	inches	Using 316 Stainless Steel
t	0.05722808	inches	Using 304 Stainless Steel

From above, the circumferential thickness calculation is shown to be larger than the longitudinal stress thickness calculation.

The heads of the autoclave have similar variables to the shell and utilize the above table for definitions and assumptions. In order to maximize our space within the unit, the team selected a 2:1 Ellipsoidal head design. The equation to calculate the thickness is:

$$t = \frac{PD}{2SE - 0.2P}$$

The results from our assumptions and design:

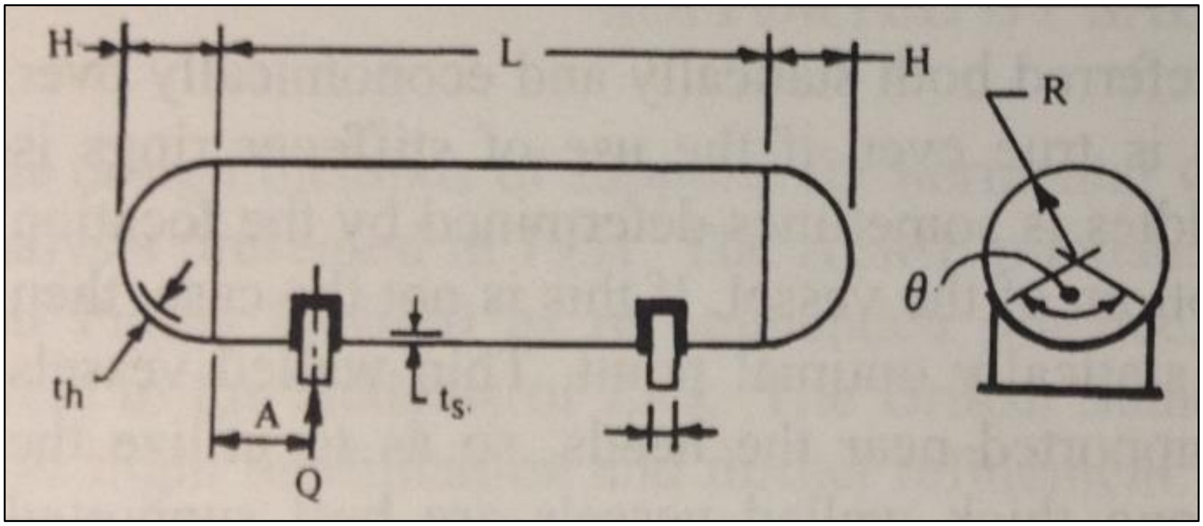
Given Parameters Head:					
R	20.625	inches			
D	41.25	inches			
S	15000	psi	304 Stainless Steel		
S	12800	psi	316 Stainless Steel		
E	0.6	Single butt Joint Weld			
P	50	psi			
t	0.134365	inches	316 Stainless Steel		
t	0.114647	inches	304 Stainless Steel		

From the results, the team found that the head and shell minimum thickness were very similar. The team recommends using a 0.125”guage 11 304 Stainless Steel, which was a standardized thickness. A 0.1562” gauge 9 316 Stainless steel would be sufficient as well.

3.7.2. Saddle

Along with the general thickness of the autoclave we needed to verify that the legs would be sufficient to hold up the vessel. This required a thorough understanding of the internal components. Similarly to the vessel, we needed a sound understanding of what the system was going to experience and what all the variables would affect the calculations. Shown below are the variables involved in the equations, values for variables, and brief description of each. The image provided shows exactly how the variables relate to the autoclave.

Variables	Value	Unit	Description
H	10.3125	inches	Head Length
L	41.25	inches	Length of Vessel
A	4	inches	Shown in Picture
Q	1410	lbs	Load
t_h	0.125	inches	head thickness
t_s	0.125	inches	shell thickness
R	20.625	inches	radius of shell
K1	0.335		constant
K2	1.171		constant
K3	0.319		constant
K4	0.88		constant
K5	0.401		constant
K6	0.013		constant
K7	0.76		constant
K8	0.603		constant
Theta	120	degrees	Shown in Picture
b	4	inches	Saddle Width
P	50	psi	pressure



Most of the variables were calculated during the shell thickness calculations, but a few are unique to these calculations. Q is the load that one saddle will see during service and has been calculated to be 1410 pounds. The team assumed an agitator weight of 322 pounds and shell weight of 405 pounds. These were obtained from the estimator on SolidWorks after we had modeled the autoclave and agitator. ASME code requires the internal weight to be derived from the assumption that the vessel will be filled with water. With that assumption, it was found that 2093 pounds of water would fit into the remaining space in the autoclave which gave a total weight of 2820 total and that means that each leg would see 1410 pounds each. The K values are all given in tables or chart approximations that are found within the ASME code. The saddle thickness was then assumed and checked to determine if we had a sufficiently thick saddle to support the static load of a full autoclave. The equations are found in the appendix.

The conclusions made from these calculations were that a 4" wide saddle support system would be sufficient for our system.

3.7.3. Agitator

Background:

Bio-Shield's main innovation and selling point for both its larger mobile unit (1500 Unit) and its smaller model (550 Unit) center on its rotational autoclave. This patented system (US 6446887 B1) features an internal agitator with dual augers attached to a single shaft (see Figure 8).

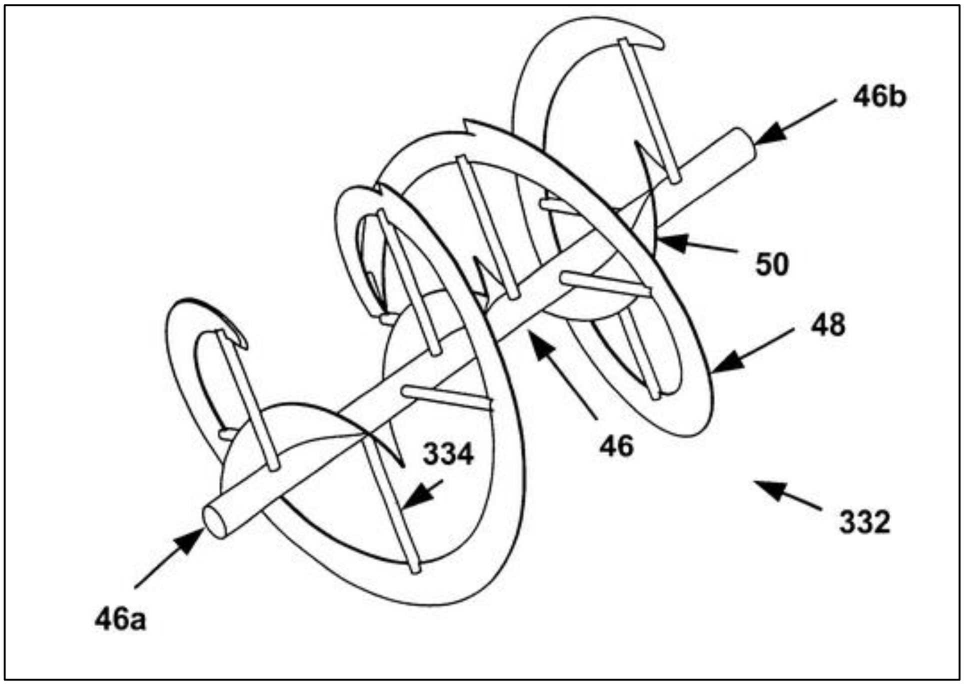


Figure 8: Bio-Shield Agitator Patent

The two augers are attached in opposing directions so that while one auger advances clockwise, the other advances counterclockwise. A small motor attached to the shaft spins the agitator at a low speed (less than ten revolutions per minute). Through this motion, the waste inside the autoclave is evenly mixed, thereby evenly exposing the waste to the steam inside the autoclave. This acts to increase the rate of heat transfer of the waste and decreasing the amount of time that the waste must stay within the autoclave before it can exit the system.

Implementation:

In order to maintain Bio-Shield's intellectual property and ensure that the new system will have sufficient mixing capabilities, this conceptual design was utilized in the current design of the 550 Unit. However, because of the addition of the Harris Quick Opening Door, the supports for the agitator within the autoclave had to be modified. The team first looked into a double-bearing support method, leaving the agitator shaft cantilevered inside of the autoclave. Due to the complexity and tight tolerances associated with this method, however, the team instead opted for a simply supported beam. The modified model is located in an assembly (\Bioshield Project - Spring 2015 Senior Design\SolidWorks\Agitator\Agitator Assembly.SLDASM) and is comprised of an inner auger attached to a shaft (\Dropbox\Bioshield Project - Spring 2015 Senior Design\Solidworks\Agitator\Shaft.SLDPRT), one half of the outer auger (\Dropbox\Bioshield Project - Spring 2015 Senior Design\Solidworks\Agitator\Left Outer Helix.SLDPRT), and the second half of the outer auger (\Dropbox\Bioshield Project - Spring 2015 Senior Design\Solidworks\Agitator\Right Outer Helix.SLDPRT). The agitator shaft is simply supported by two bearings (\Dropbox\Bioshield Project - Spring 2015 Senior Design\Solidworks\Agitator\Shaft bearing.SLDPRT) supported on one end by a support inside the autoclave (\Dropbox\Bioshield Project - Spring 2015 Senior

Design\Solidworks\Agitator\Mounting end for bearing.SLDPRT) and by the autoclave itself on the other end. A cutaway view of the autoclave and agitator assembly as implemented in the current design can be seen in Figure 9: Autoclave/Agitator General Arrangement.

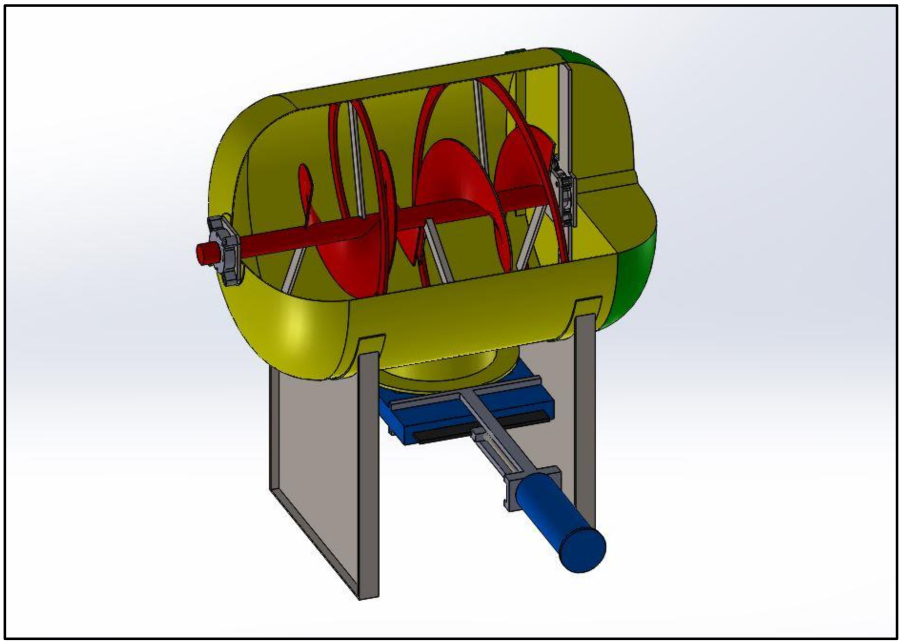


Figure 9: Autoclave/Agitator General Arrangement

Finite Element Analysis – Overview:

In order to ensure that the dimensional modifications to the agitator do not affect the structural integrity of the agitator, a finite element analysis was performed on the agitator. The agitator was modeled in SolidWorks and meshed. A global mesh size of 0.5 inches was used due to the relatively small size of the assembly. The supporting legs for the outer auger were bonded to the outer auger using global contact bonds. While this is not the most accurate method of bonding these components, it will give more of a safety factor in analysis as a result of higher stresses due to the sharp change in geometry between the supports and the auger. All material in the agitator is 316 Stainless Steel. Two main load cases were considered based on the basic operation of the agitator. In both load cases, the bearings are fixed on the outward-facing flanges of the bearings, as shown in Figure 10.

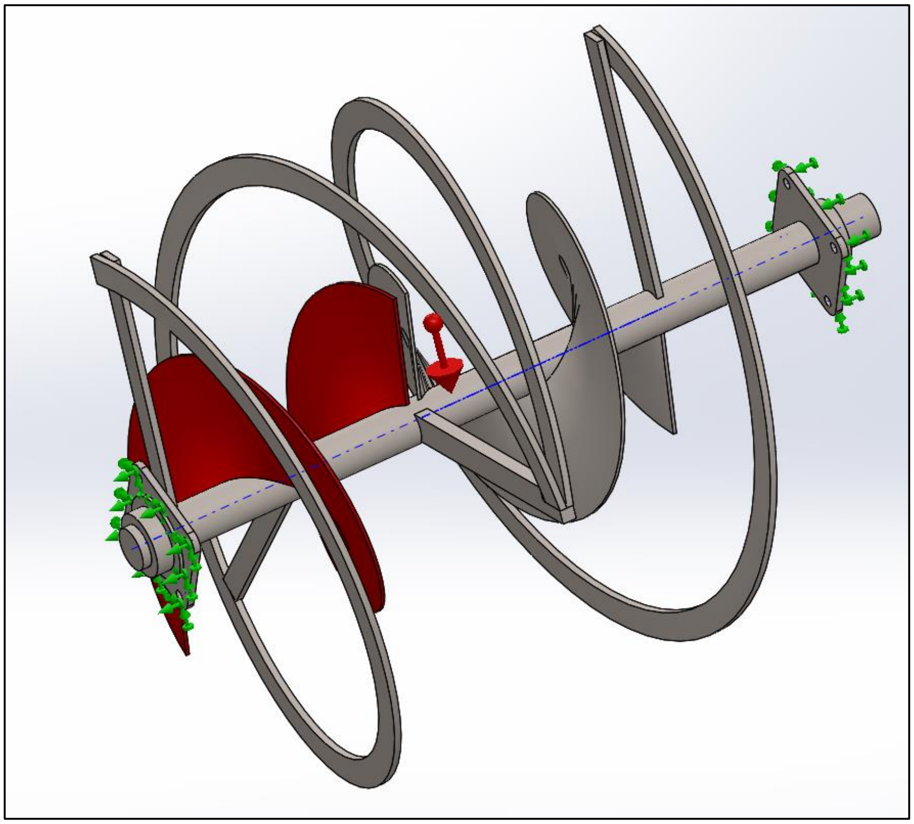


Figure 10: Agitator Fixtures

Finite Element Analysis – Load Case 1: Max Load Applied Inward:

The first load case centered on the waste itself pushing against the agitator in normal operation. In its mixing mode, the agitator rotates to push the waste toward the center of the autoclave. For that reason, this load case applied the maximum load that the autoclave would see on each one of the inward-facing flanges of the agitator, as shown in Figure 11.

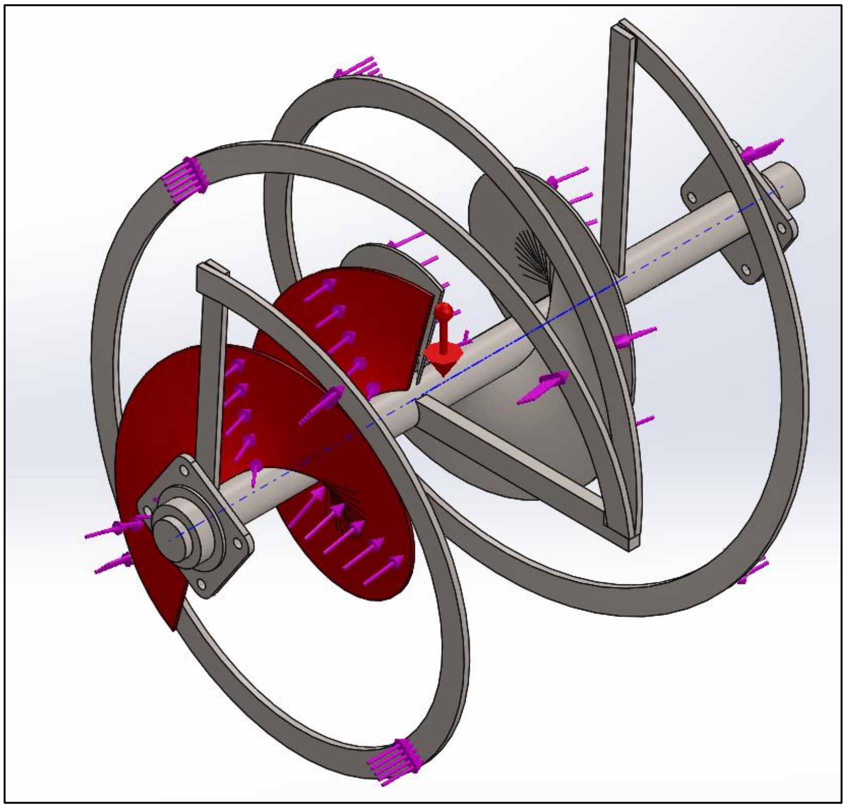


Figure 11: Load Case 1 Loads

The load is determined below and is based on a full load of six carts each loaded with the waste density as stated in a previous senior design team's final report (\Dropbox\Bioshield Project - Team Files\Grinder Documents\MAE 4344 Final Report.pdf pages 11-12). While this density is within the range specified in that document, further analyses of different waste densities should be conducted by future teams.

$$P_{max} = V\rho = 6\frac{carts}{load}\left(96\frac{gallons}{cart}\right)\left(0.13368\frac{ft^3}{gallon}\right)\left(3.5\frac{lb}{ft^3}\right) = 275\ lb_f$$

Although the agitator will rotate, because the rotational speed is low, and the motor power will be very minimal, torque effects will be negligible and were not included in the static finite element analysis. Furthermore, because the rotational speed will be so low, a frequency analysis was not performed on the agitator. Finally, pressurization effects inside the autoclave are minimal (15 psig) and were not included in the analysis.

Resulting Von Mises stresses can be seen in Figure 12. The maximum Von Mises stress is 32.8 ksi, well below the 42([5]) ksi yield stress of 316 Stainless Steel. Furthermore, the maximum displacement in the longitudinal (z) direction was approximately 0.5 inch,

[5] http://www.matweb.com/search/DataSheet.aspx?MatGUID=50f320bd1daf4fa7965448c30d3114ad

while the displacements in the x and y directions were negligible. Longitudinal displacements are shown in Figure 13, x displacements are shown in Figure 14, and y displacements are shown in Figure 15.

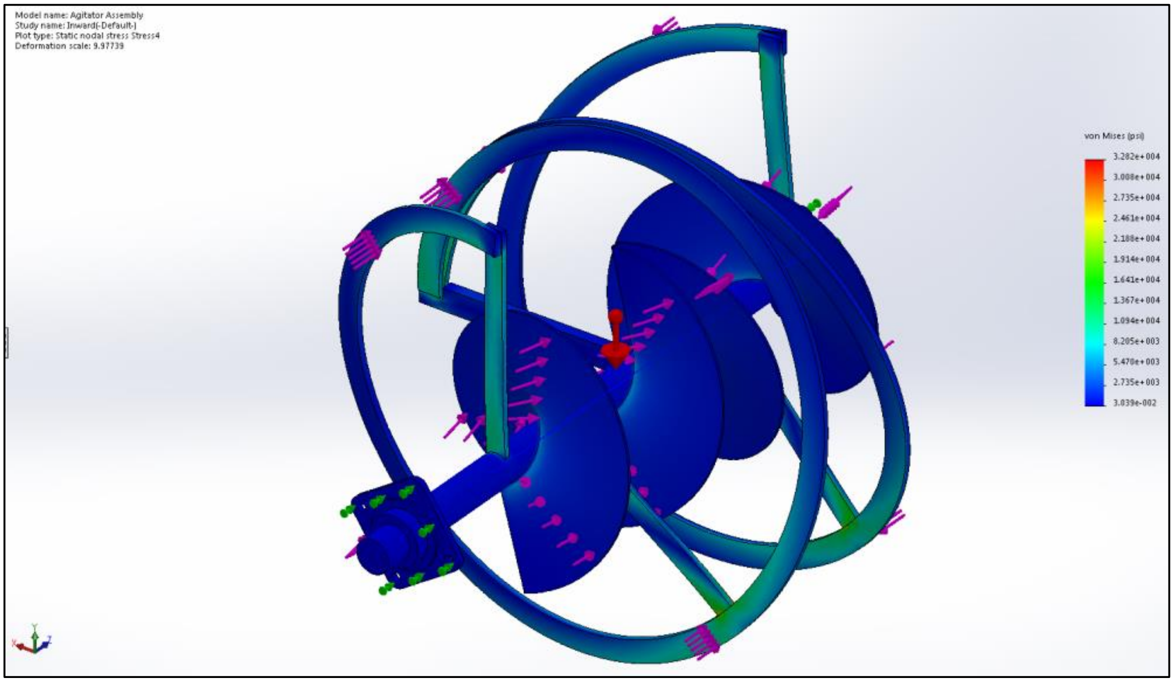


Figure 12: Load Case 1 Von Mises Stress

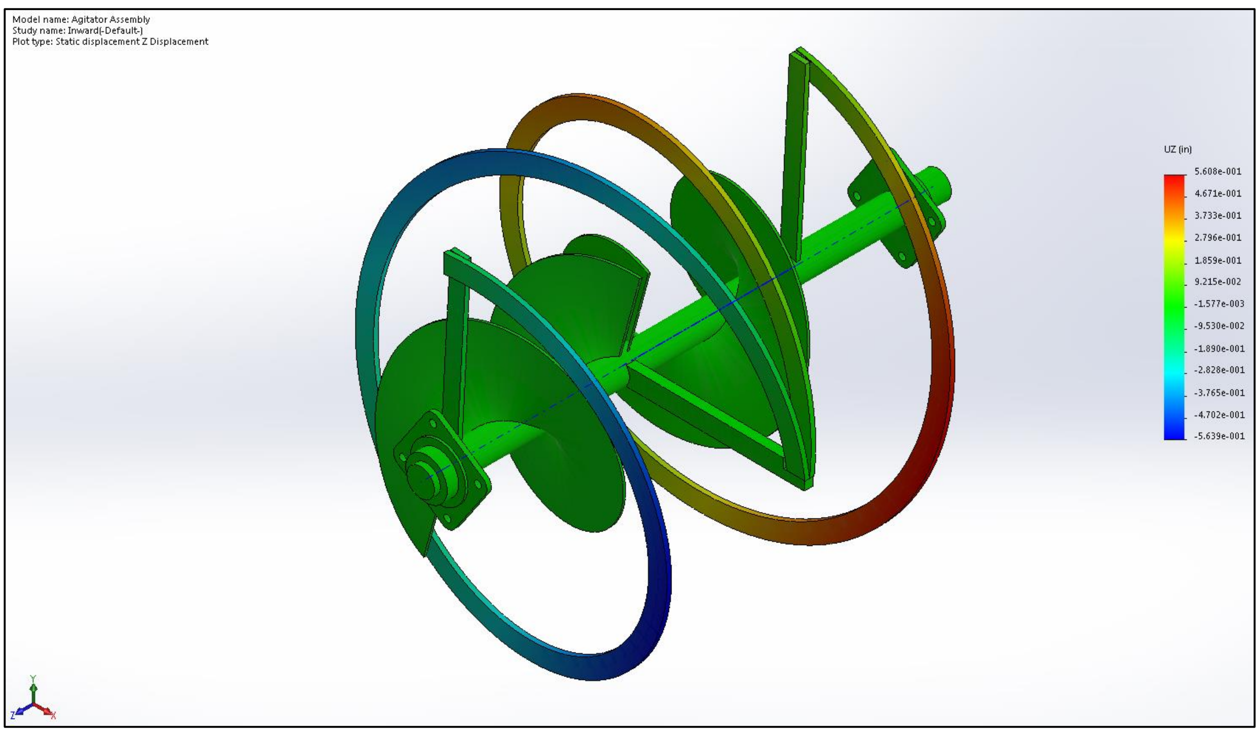


Figure 13: Load Case 1 Longitudinal (Z) Displacements

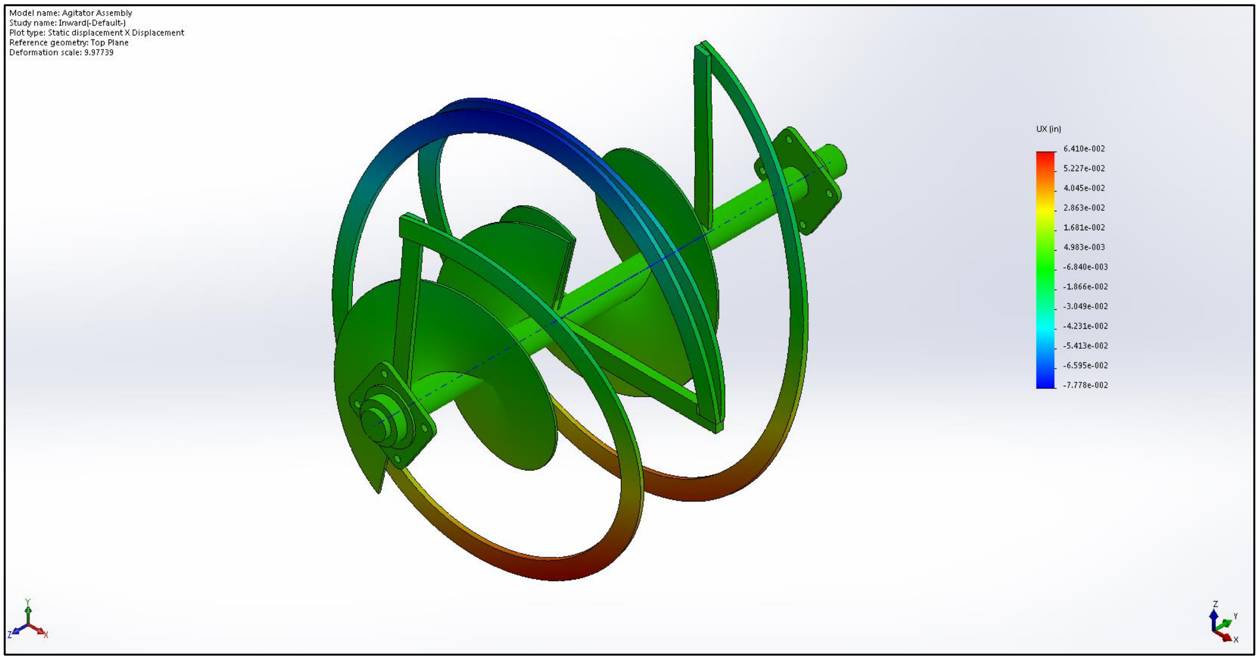


Figure 14: Load Case 1 X Displacements

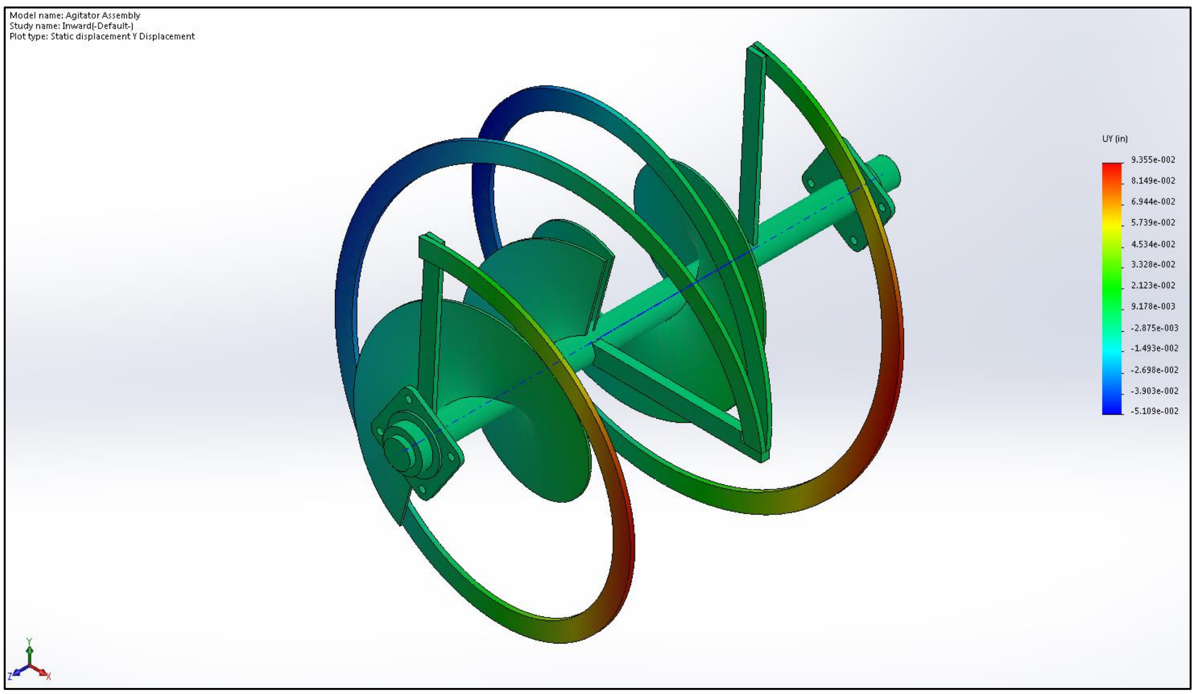


Figure 15: Load Case 1 Y Displacements

<u>Finite Element Analysis – Load Case 2: Max Load Applied Down:</u>

The second load case considers a situation in which the waste is wedged on the top of the agitator. For that reason, this load case applied the maximum load that the autoclave would see on each one of the upward-facing flanges of the agitator, as shown in Figure 16. The load is the same as the previous load case, 275 pounds. Furthermore, fixtures are the same as in Load Case 1 and can be seen in Figure 10.

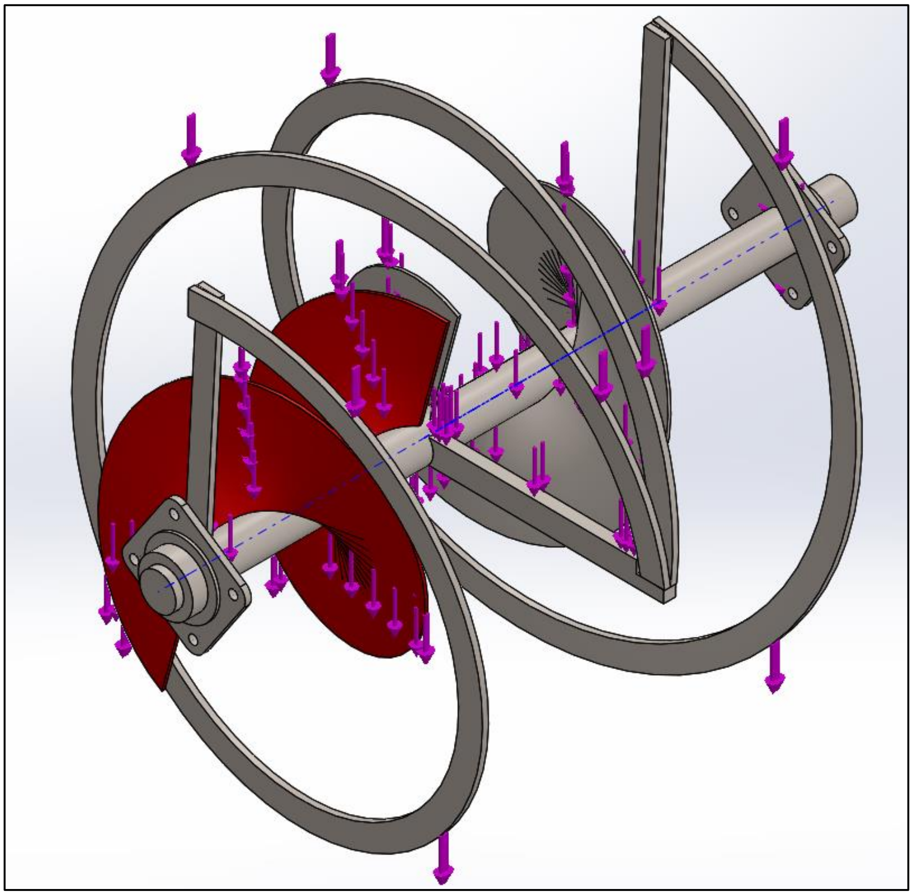


Figure 16: Load Case 2 Loads

Again, although the agitator will rotate, because the rotational speed is low, and the motor power will be very minimal, torque effects will be negligible and were not included in the static finite element analysis. Furthermore, because the rotational speed will be so low, a frequency analysis was not performed on the agitator. Finally, pressurization effects inside the autoclave are minimal (15 psig) and were not included in the analysis.

Resulting Von Mises stresses can be seen in Figure 17: Load Case 2 Von Mises Stress. The maximum Von Mises stress is 25.2 ksi, well below the 42([6]) ksi yield stress of 316 Stainless Steel. Furthermore, the maximum displacement in the longitudinal (z) direction was approximately 0.1 inch, while the displacements in the x and y directions were negligible. Z displacements can be seen in Figure 18, x displacements can be seen in Figure 19, and y displacements can be seen in Figure 20.

[6] http://www.matweb.com/search/DataSheet.aspx?MatGUID=50f320bd1daf4fa7965448c30d3114ad

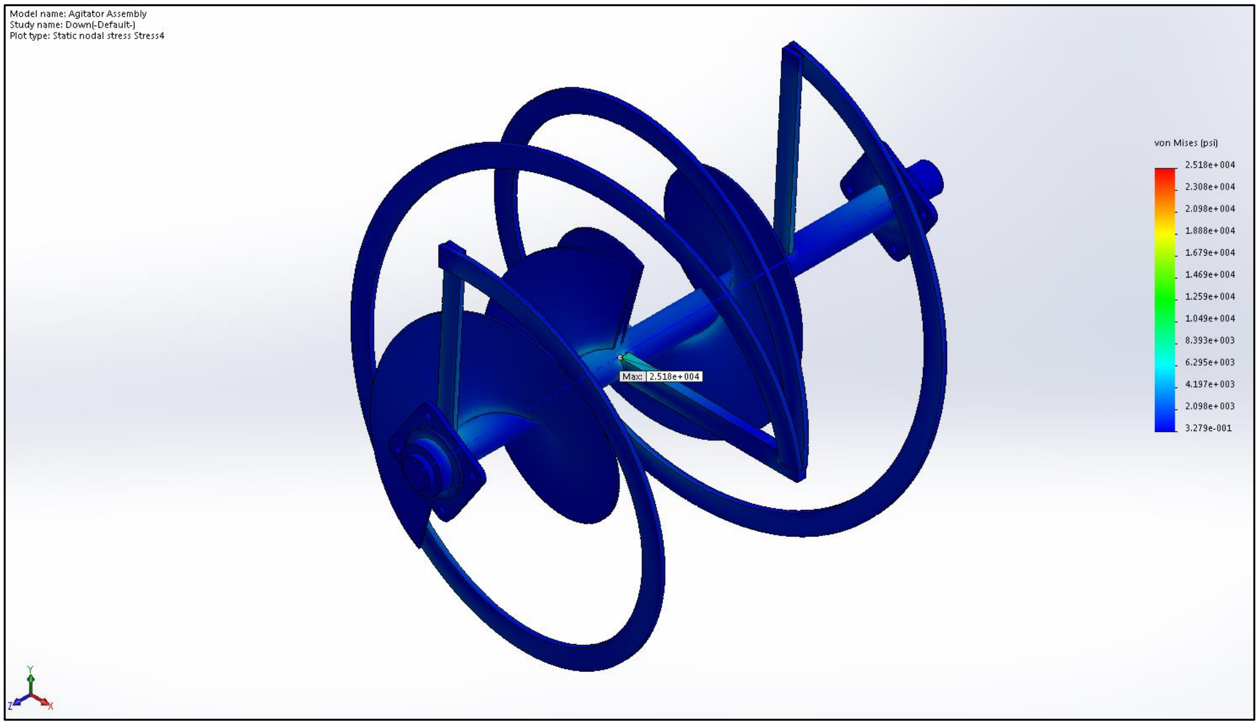


Figure 17: Load Case 2 Von Mises Stress

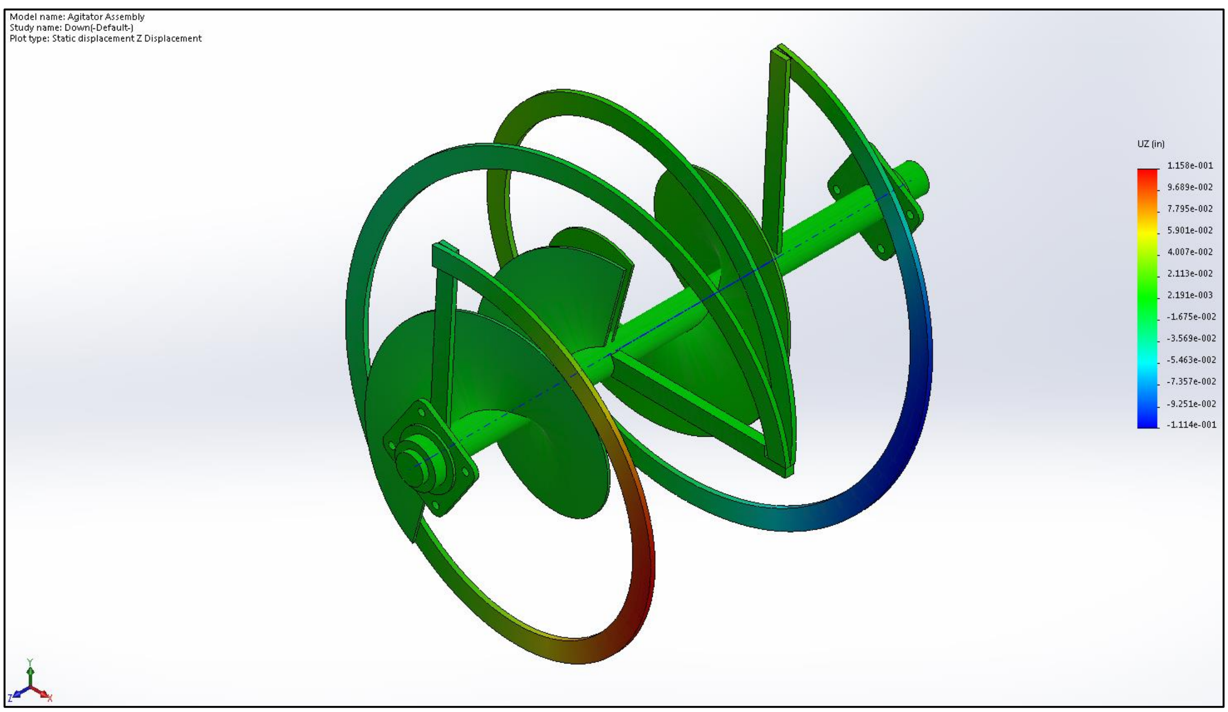


Figure 18: Load Case 2 Z Displacements

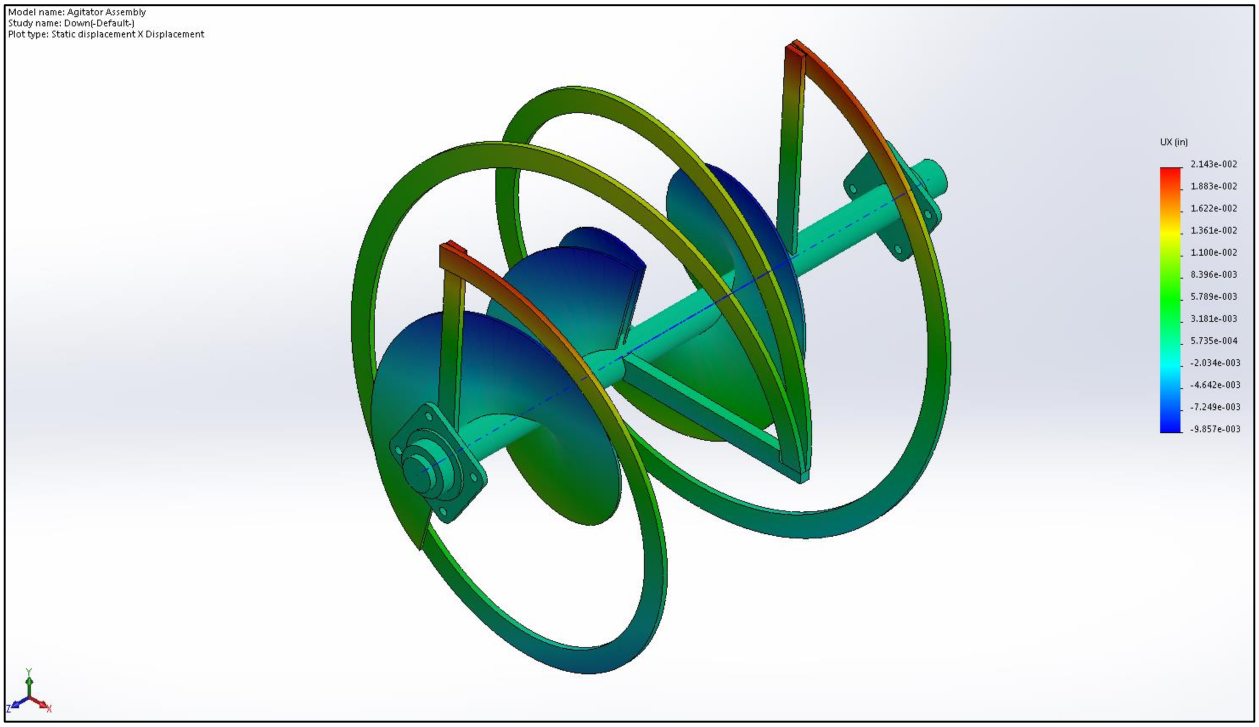


Figure 19: Load Case 2 X Displacements

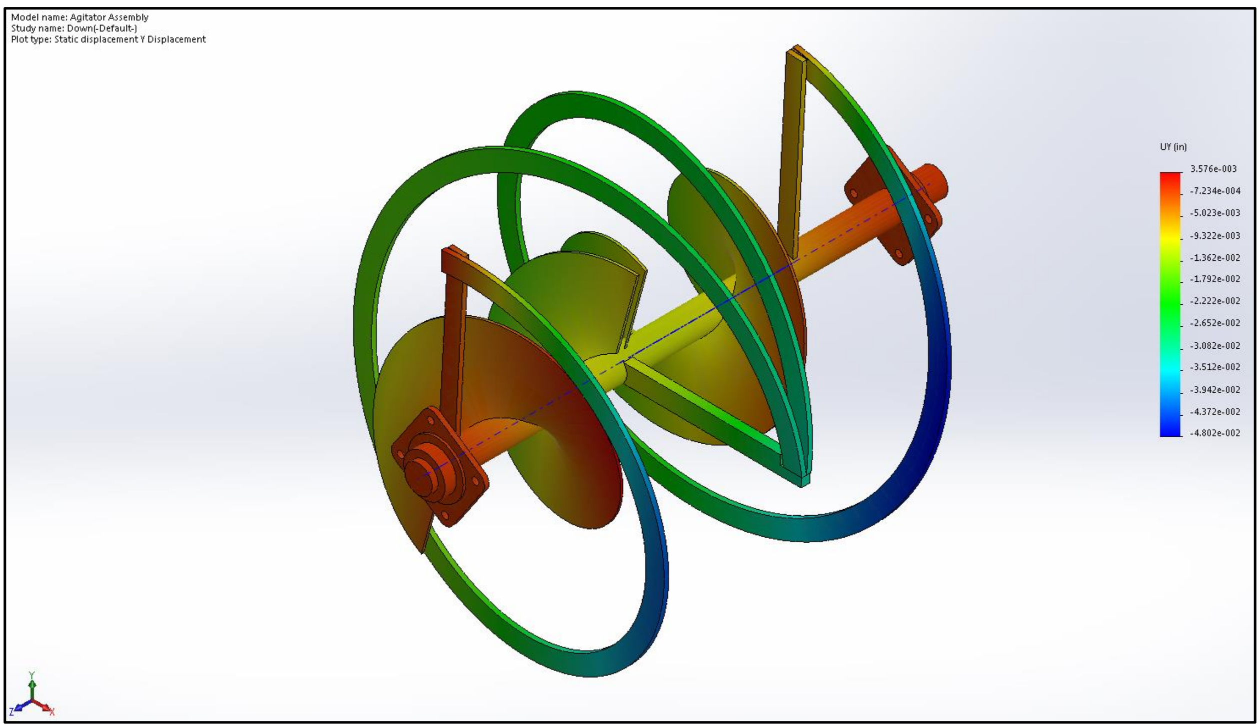


Figure 20: Load Case 2 Y Displacements

3.7.4. Harris Quick Opening Door

In order to fulfill Bio-Shield's requirement that the autoclave was easy to access, the Harris quick opening door was selected. This component is both ASME approved and can be fitted to our system. The door may be pivoted 90 ° to allow full access into the autoclave to increase ease of maintenance. These doors are made and designed by Melco steel.

3.7.5. Heat Transfer

In order to analyze the heat transfer we attempted many different methods, all of which were transient. The first method attempted was the lumped system analysis. In order to do this, we needed to find the Biot number of the waste. This is found by having a sound understanding of the system and utilizing the following equations:

$$Bi = \frac{hL_c}{k} \qquad L_c = \frac{V_{volume}}{A_{surface}}$$

It was found that the lumped method would be invalid. After consulting with Dr. Ehsan Moallem, we determined that a good estimate for our heat transfer coefficient would be 5000 W/mK. Using this and various values thermal conductivities the system would experience, it was found that the Biot number was over 0.1 and thus this method was invalid.

Next, problem was treated as a one-dimensional transient conduction problem. To do this we modeled the waste as a flat surface insulated on all sides except for the top surface. To be able to utilize the first term approximation of one-dimensional transient conduction we had to check the Fourier number, and it must be greater than 0.2.

$$Fo = \frac{\alpha t}{L^2}$$

The Fourier was significantly less than 0.2 and we therefore needed to perform the full analysis. To perform the analysis, we used excel. In order to accomplish this, we found many different properties of the materials that could be found going through our system. The governing equations are as follows:

$$\theta = \sum_{n=1}^{\infty} \frac{4\sin(\lambda_n)}{2\lambda_n + \sin(2\lambda_n)} e^{\lambda_n^2 \tau} \cos\left(\frac{\lambda_n x}{L}\right) = \frac{T(x,t) - T_\infty}{T_i - T_\infty}$$

λ is a function of the Biot number and is found in a table within the heat and mass transfer book. Upon completion of the calculations it was determined that we didn't have an acceptable estimate for the heat transfer coefficient. After performing research on better estimates for the heat transfer coefficient for medical waste, the team was still at a loss for a solution. Due to time limitations, the team was unable to attain a reasonable value and turned to a simplified energy balance.

The assumptions made for this were that the temperature difference was going to be from 20° C to 270°. The inside environment is going to be exposed with saturated steam at 15 psig. We first wanted to determine how much energy would be necessary to attain the required temperature difference. We then found how much steam, at the necessary pressure and temperature, would need to be supplied to the system to reach the calculated energy value. The last step was calculating how much steam could enter the system. It was concluded that we needed 7.2 MJ of energy. To provide this much energy the system needs 3.3 kilograms of steam. These were found using basic energy equations.

$$Q = mCp\Delta T \quad \& \quad Q = mh_{fg}$$

To find the energy needed, we assumed an average specific heat from all of the various items that would be found in the autoclave. To find the mass, it was assumed the highest density of the waste since this would require the most energy to achieve the necessary temperature difference.

To find the amount of steam that could enter into the autoclave we used the ideal gas model. This method is invalid because steam is not an ideal gas. With this ideal gas assumption, this showed that we were able to provide enough steam to meet the demands of our system. To provide a factor of safety and help promote heat transfer, the team has decided to add Duraband band heaters to the outside shell of the autoclave.[7] These will give us the necessary added energy to ensure sterilization of the waste. Analysis needs to be performed on how much steam can be supplied to the inside of the autoclave using the proper assumptions.

We will implement thermocouples into the side of the autoclave so the user will be able to ensure the temperatures were met during the sterilization process. There will also be a calcium silicate blanket on the outside of the autoclave to insulate and mitigate heat loss to the surroundings.

All calculations and material properties are in Dropbox\Bioshield Project - Spring 2015 Senior Design\Calculations\Autoclave. These have not been included in this document due to the number of iterations that were performed and because the lumped method and one dimensional transient conduction method proved to be invalid.

3.8. <u>Supports</u>

In order for our angled component concept to be feasible, we had to develop supports for each component. These supports were created from 316 stainless steel tubing. 316 was selected

[7] Duraband Band Heaters <http://www.tempco.com/Catalog/Section%201-pdf/Mica%20Band.pdf>

because it is the 2nd most common steel, heat resistant up to 2000°F, more resistant than other steels to corrosive elements, and is marine grade. These were modeled simply, with four legs and a plate that attaches to the bottom of the respective component (seen in Figure 22: Hopper Support and Figure 21: Grinder Supports). The only complexity of these components comes from modifying the leg length based on angle and height, and modifying the base of the legs to fit with the angled floor. In our model, the base of the legs are flat and not flush with the floor.

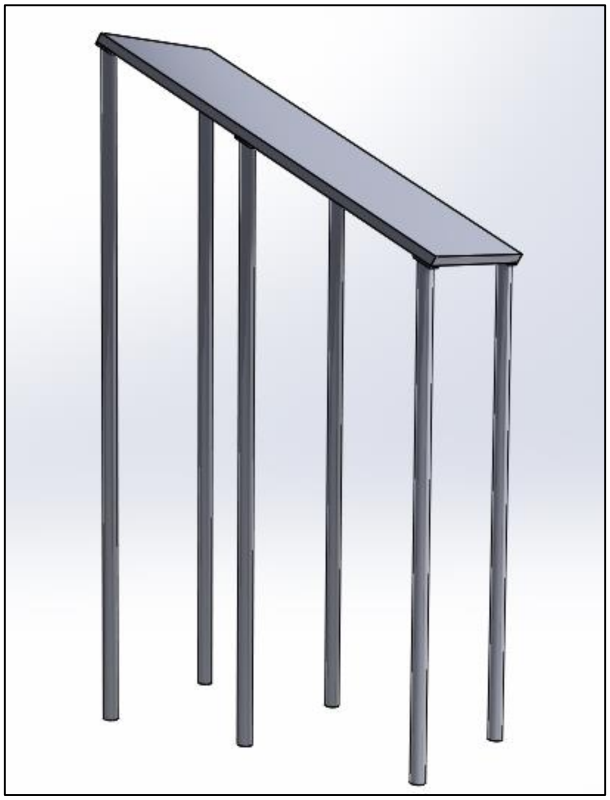


Figure 22: Hopper Supports

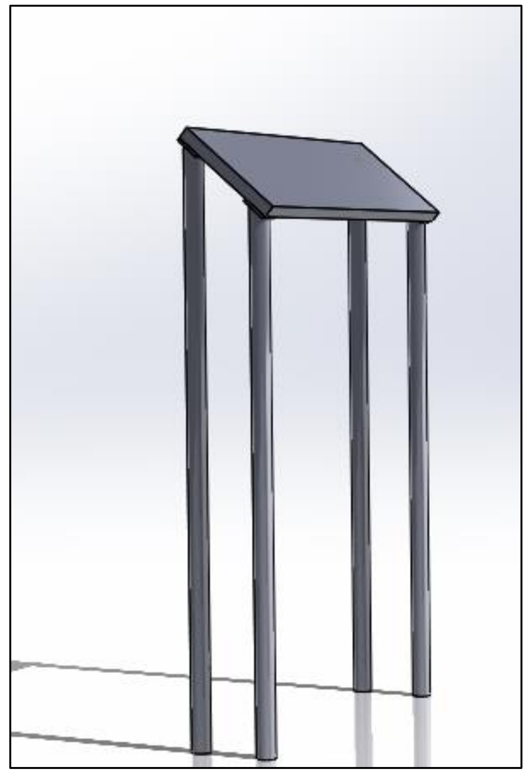


Figure 21: Grinder Supports

3.9. <u>Wastewater Handling</u>

After each load of waste is run, water and other fluids have leaked from the components and will be pooled at the bottom of the enclosure. These liquids will need to be sterilized before they can leave the system, and so Bio-Shield has stated the need for a wastewater system to store the liquids in a tank where they will be heated and sterilized before it can be sent to the sewer. The "JYD550" Bio-Shield document specifies heating the fluids to 180°F and held at that temperature for 30 minutes prior to discharge from the system.

In order to transport the water from the bottom of the enclosure to the grey water system, a slanted floor will be placed in the bottom of the enclosure to pool the wastewater in the center of the floor, and a small pump will be used to move the water into the grey water system.

The team decided that a commercially available grey water tank would be the best solution, and found several grey water tanks utilizing heat for sanitation. The grey water system the team decided to go with was the Aquaback Distillation Recycling Module. This unit can process 20 gal/hour of waste water, weighs approximately 60 pounds, and uses 400W of power during operation. If a larger waste water processing capability is needed, several DRMs can be linked together. A picture of the chosen grey water system is shown in Figure 23 below.

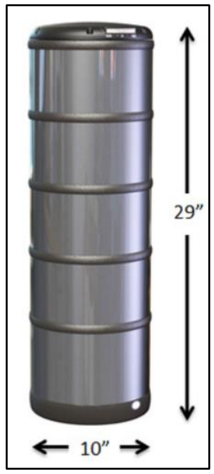


Figure 23: Aquaback Distillation Recycling Module.[8]

3.10. Control Panel

Background:

Because Bio-Shield created its original conceptual design in 2003, many aspects of the design could be improved as a result of advancements in technology in the ensuing twelve years. Most prominently, it was noted in our initial design review of Bio-Shield's concept that the control room inside of the unit (see Figure 24) could be reduced significantly in size.

[8] Aquaback DRM <http://www.aquaback.com/technology/products/drm>

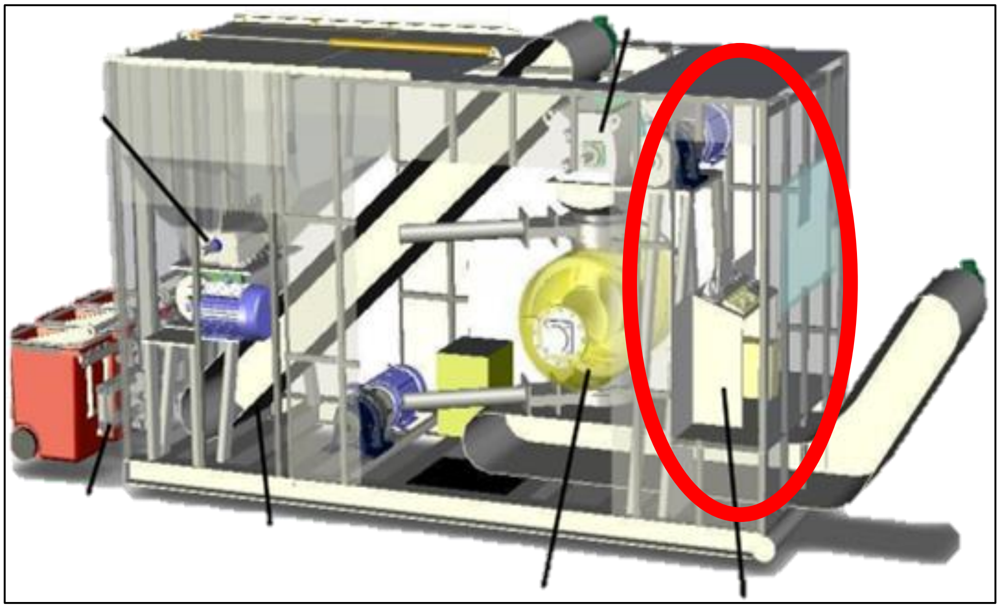


Figure 24: Control Room

Implementation:

After review, it was concluded that necessary controls for the unit could be contained within a tablet app rather than a large control room. This will completely eliminate the need for a control room as well as power requirements and additional material for the control room. Furthermore, it will also reduce the complexity of the system.

3.11. Enclosure

Bio-Shield has previously established a footprint limitation for the enclosure of 9.5 feet by 12.5 feet by 25 feet, along with a weight limitation of 22,000 pounds. The enclosure meets the dimension requirements but the weight limitation was not evaluated. The length of the enclosure is 18 feet and the length of the enclosure plus the trashcans and lift system is currently 24 feet which greatly surpasses Bio-Sheild's initial length requirements. If desired, the enclosure length can be shortened further. The enclosure has windows, an access panel, and a door to ensure safe operation and facilitate easy maintenance. The enclosure will need to insulate the interior mechanisms from the environment in which the system is placed. The enclosure will also need to accommodate connections for plumbing, electricity, steam lines, and a HEPA filter inlet/outlet The SolidWorks model is labeled Enclosure and is located in Dropbox\Bioshield Project - Spring 2015 Senior Design\Solidworks\Assy

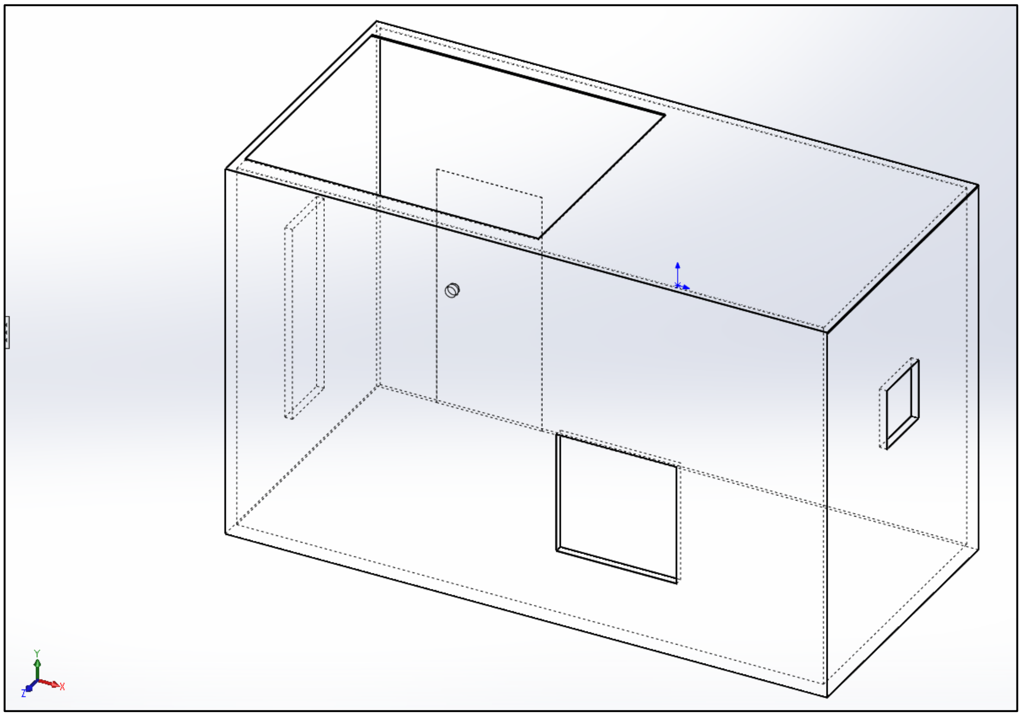


Figure 25: Enclosure Isometric View

4. Current Design

4.1. Detailed Description

Our final design (see Figure 26) connects the hopper, coarse grinder, fine grinder, and autoclave together at an angle of 40° using bolts. The autoclave has a shell and head thickness of 0.125”. The shafts on the autoclave are sealed to protect against corrosion. The enclosure has dimensions of 24’ x 9.5’ x 12.5’and includes an opening for the exit conveyor, viewing windows, and a door. The floor of the enclosure is angled in order to allow wastewater to flow to the center, where it is pumped to a water sterilization tank. Each component has a set of supports made of 316 stainless steel tubing.

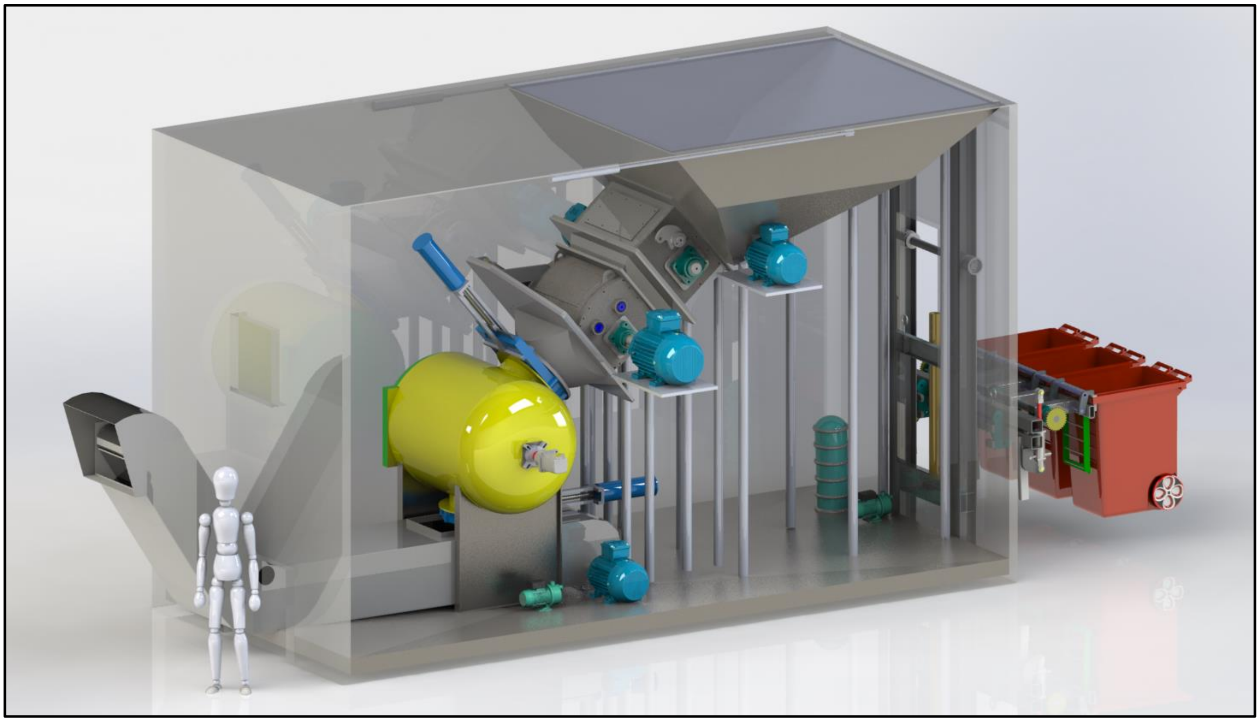


Figure 26: Current Design Concept

4.2. Evaluation

This design maximizes the efficiency of process flow and the space available. It minimizes the overall dimensions of the enclosure from 25’ (Bio-Shield original concept) to 18’ in length. A downside to our design is that, while it increases accessibility to the autoclave, it does not increase the ease of maintenance to the other components.

5. Summary of Money Spent

Because of the theoretical nature of this project, the only money spent was that for transportation to Oklahoma City to visit the OU Medical Center Children’s Hospital, which cost around $15.

6. Future Work

The immediate next steps to be taken by the team that will pick up where our work leaves off will be to create a design for the course grinder similar to that of the fine grinder, verify the sizing of various hydraulic motors needed by performing calculations, designing a method of steam entry into the autoclave, finalizing the autoclave design, and designing a HEPA filter and wash-down system. Additionally, the enclosure design will need to be finalized which will involve a finite element analysis, support modification, and consideration of plumbing and wire design. The long term work will involve creation of drawings for manufacturing, testing and validation of the design, certification, and manufacturing.

7. Appendices

7.1. Saddle Calculations

Longitudinal Bending At the Saddles:

$$S_1 = \pm \frac{QA\left(1 - \left(\frac{1 - \left(\frac{A}{L}\right) + \left(\frac{R^2 - H^2}{2AL}\right)}{1 + \frac{4H}{3L}}\right)\right)}{KR^2 t_s}$$

Longitudinal Bending At Mid-span:

$$S_1 = \pm \frac{\frac{QL}{4}\left(\left(\frac{1 + 2\left(\frac{R^2 - H^2}{L^2}\right) - \left(\frac{4A}{L}\right)}{1 + \frac{4H}{3L}}\right)\right)}{\pi R^2 t_s}$$

Tangential Shear in Shell:

$$S_2 = \frac{(K_4 Q)}{R t_s}$$

Tangential Shear in Head:

$$S_2 = \frac{(K_4 Q)}{R t_h}$$

Tangential Shear, Additional Stress in Head:

$$S_3 = \frac{(K_5 Q)}{R t_h}$$

Circumferential at Horn of Saddle:

$$S_4 = \frac{Q}{4t_s(b + 1.56\sqrt{Rt_s})} - \frac{12K_6QR}{Lt_s^2}$$

Circumferential at Bottom of Shell

$$S_5 = -\frac{K_7Q}{t_s(b + 1.56\sqrt{Rt_s})}$$

Results:

S1 at saddle	331.7608
S1 w/ k8	184.3116
S1 at midspan	126.5894
S2 for head	481.28
S2 for shell	481.28
S3	219.3105
S4	-6605.2
S5	1317.915

Values are below the maximum allowable limit for the material

7.2. Energy Balance

rho	5.5	lb/ft^3	T1	120	celcius			
v	15.4	ft^3	T2	20	celcius			
m	84.7	lbs	hf	2707.32	kJ/kg	Assumed 1Bar of pressure		
m	38.42	kg	hg	507.89	kJ/kg	Assumed 1Bar of pressure		
Cp	1869.2	J/kgK	Avg. of all waste					
Q needed	7181466	J	Energy needed to get temperature difference of waste					
m steam	3265.149	g	required to meet demands of of Q needed					
NOT VALID BUT SHOWN FOR HISTORY OF WHAT OCCURRED								
Mass we can put into the system								
pv=mrt								
m	3.375098	kg	steam we can put into the system					
R	461.5							
T	393	K						
P	103421	Pa						
V	0.5196	m^3						

8. References

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T. Milburn, "Biomedical Waste Incineration BACT Application Considerations, "Proceedings of the Third National Symposium on Infectious Waste Management, Chicago, IL, April 1989, as cited in R. Barton, G. Hassel, W. Lanier, and W. Seeker, State of the Art Assessment of Medical Waste Thermal Treatment EPA Contract 68-03-3365 and ARB Contract A832-155 (Irvine, CA: Energy & Environmental Research Corp., 1989).