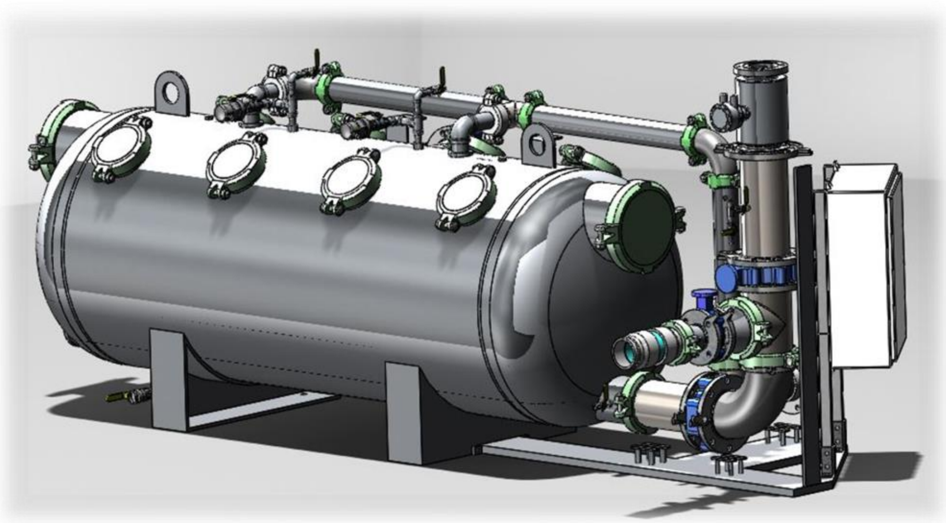
[Still verbose but a great improvement. You can all count on "A"s unless Albert returns a negative critique before I'm compelled to submit grades. Please look carefully for my edits. If you're gonna make a presentation at Sonitec in 14-01 you might as well tweak the report a bit.]

Process Water Swirl Filtration System: Value Proposal



Prepared for: Alfred Cerdan

Prepared by: Adeel Syed, Ghufran Sulehri, Khaleeq Siddiqui, Maaz Khan, and Mohammad Ali.

Consulting Engineers: Ms. Lucy Parrot, Mr. Josef Slanik, Prof. Vince Thompson, and Prof. Zsombor-Murray

December 16th, 2013.

H2F-600 Filtration Unit: Value Proposal

FACULTY OF ENGINEERING, MCGILL UNIVERSITY | MACDONALD ENGINEERING BUILDING, ROOM 270, MONTREAL QC, H3A OC3

Executive Summary:

Introduction and Objectives:

Sonitec-Vortisand is a leader in filtration services for various industries. Sonitec-Vortisand continuously strives to improve its offering through rigorous R&D programs. Through constant innovation to find ways to improve the quality of filtration, the company looks to provide their customers greater benefits at lower costs, and a simple mode of operation. With a sizable number of clients who have a severe shortage of space in their operations, Sonitec is actively researching ways to minimize the area its filtration systems occupy.

To accomplish their objectives, Sonitec decided to apply the principles of Value Analysis.

Thus, the objectives of the project are:

- Minimize footprint area of filtration units
- Reduce Cost
- Simplify design

Solutions:

Using Value Engineering, the team came up with the following solutions.

- Stack two filtration systems to double filtration capacity with the same base area.
- Simplify piping and unit design.
- Use high quality FRP vessels in place of Stainless Steel and PVC pipe instead of Carbon Steel

Savings (monetary, investment, payback, returns)

There are two recommended solutions. The first solution saves $19618 which is 34% of the original cost of $ 57700. The stacked option saves $18464, which is 32% of the original cost.

The implementation of the recommended solutions will require no further capital investment, since the design changes mainly involve a change in materials, in piping, and in the skid base.

Results (meeting of objectives)

The client desired a cost reduction of at least 30%. We exceeded the requirements with projected savings of 34% with our first solution and also designed the stacked solution with a cost reduction of 32% from the base cost. This solution in particular will extend clients' market penetration to customers who place a premium on space utilization.

Acknowledgements

We are immensely grateful to all our instructors, Ms Lucy Parrot, Mr. Joe Slanik, Professor Vince Thompson and Professor Zsombor-Murray, and to our client Mr. Alfred Cerdan for their support, guidance, and patience throughout our project.

Contents

List of Figures and Tables

Introduction

Value Engineering

Value Engineering or Value Analysis is a systematic methodology utilized in order to increase the value of a product, process, system, or service. It involves investigating the entire design of the product being analyzed, in order to identify areas of improvement, focusing on improving cost efficiencies and eliminating design flaws. As Value is defined as the ratio of "Satisfaction of Requirements" to "Costs" the ideal way to accomplish an increase in value is by maximizing satisfaction and minimizing costs.

Client: Sonitec-Vortisand

Founded in 1986, Sonitec has quickly become a leader in filtration technology for various industries – pharmaceutical, oil and gas, biotechnology, pulp and paper and others. Recently, Sonitec has installed its Vortisand systems for a range of distinguished organizations such as Microsoft, Ebay, and Conoco-Phillips.

Focusing on providing filtration systems for process water, Sonitec has earned a reputation for efficiency and reliability.

Figure 1: Main Production Plant

Team Members

The following picture shows the team members during the Value Engineering Conference.

Figure 2: Group Members

From left to right:

- Maaz Khan
- Adeel Syed
- Mohammad Ali
- Khaleeq Siddiqui
- Ghufran Sulehri

Initial Client Design

Description of process

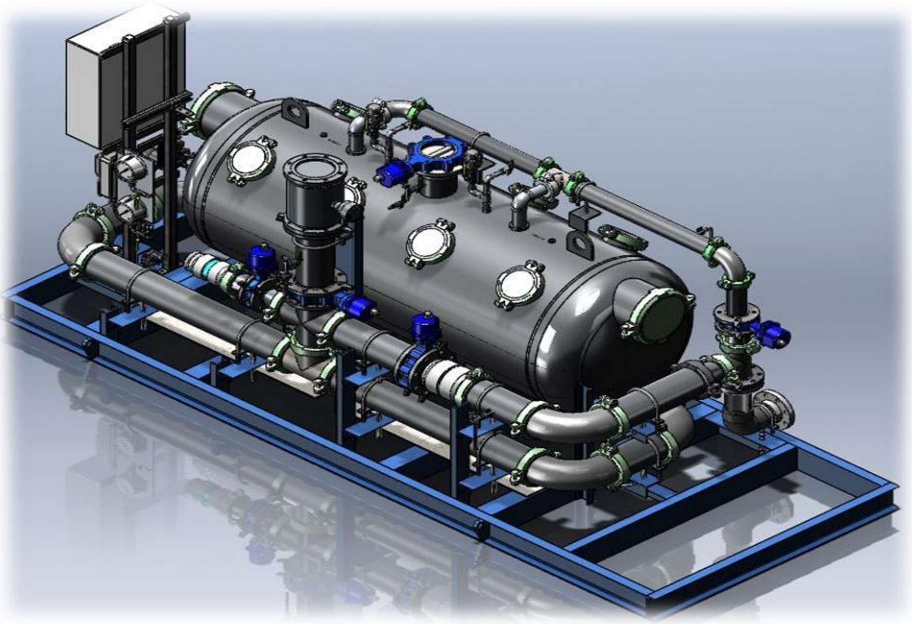


Figure 3: Isometric views of Client Design

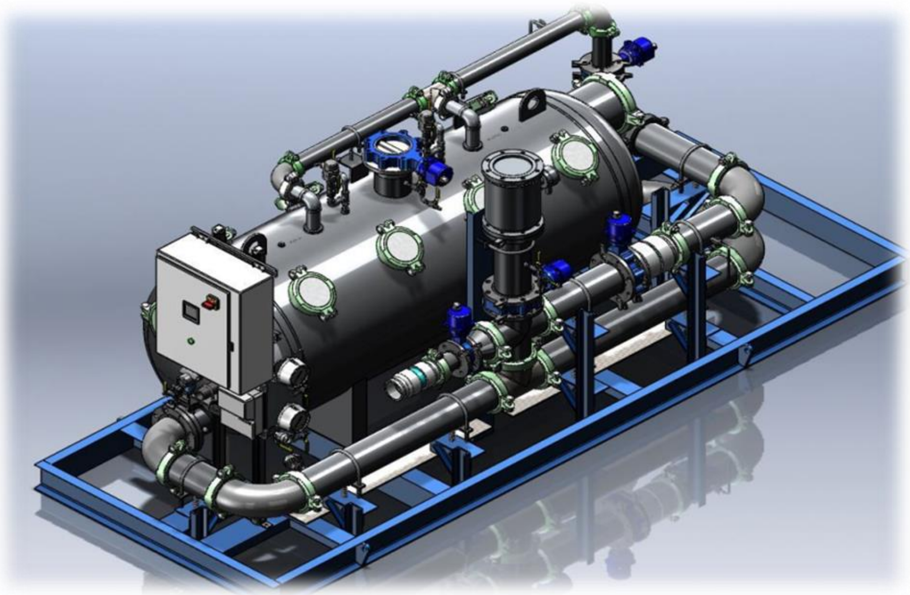


Figure 4: Isometric views of Client Design

The initial client design has two major functions which are described below:

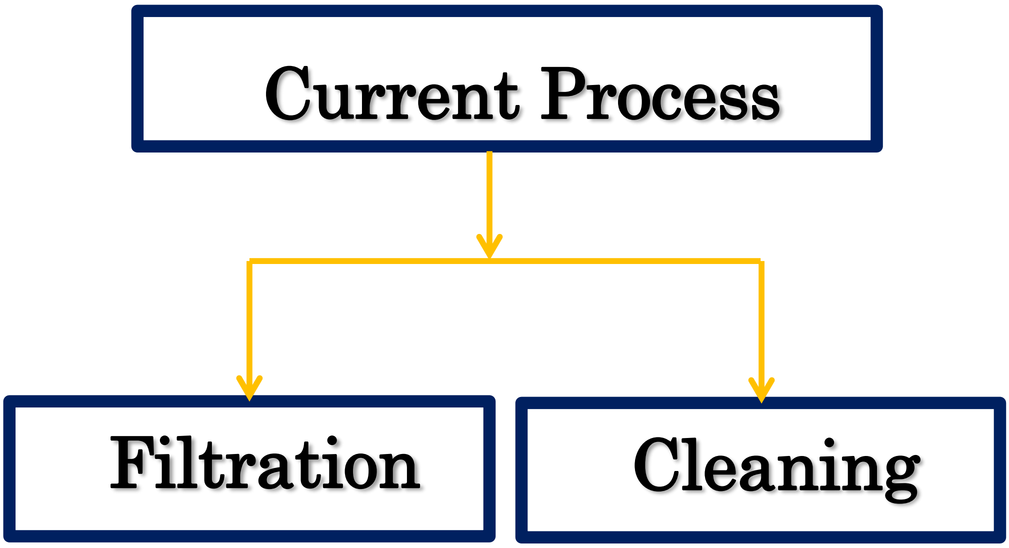


Figure 5: Process Breakdown

The filtration process can be summarized as follows:

1. Raw Water is pumped into the Inlet Pipe seen here in red ⌊No red⌋

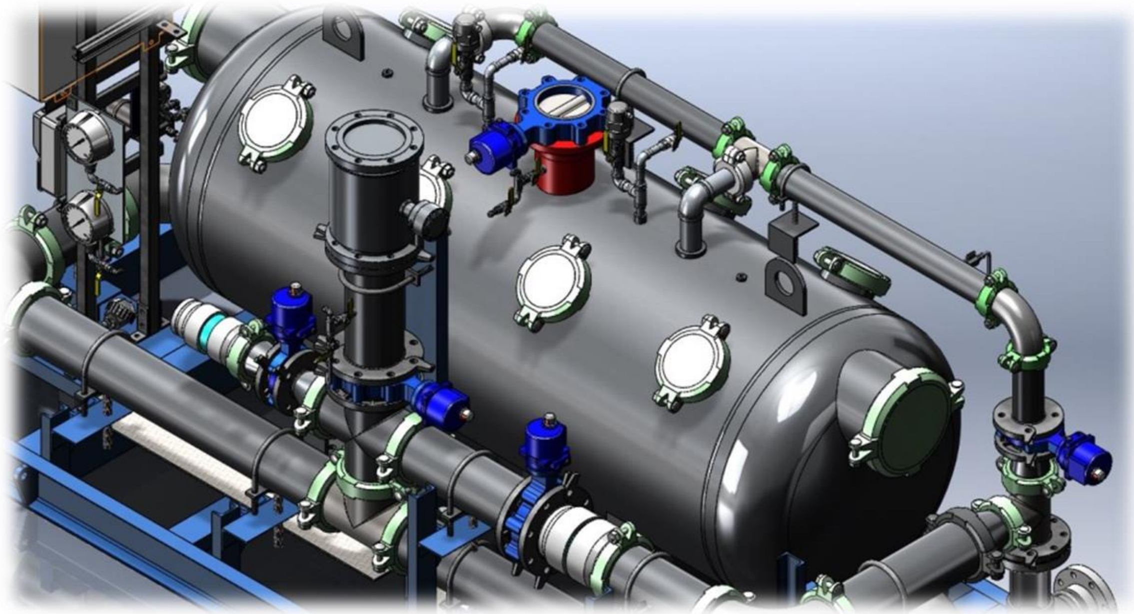


Figure 6: Raw Water into Inlet

2. The Flow enters the Pressure Vessel (seen below in green) and is filtered. All impurities bigger than 1 micron are removed

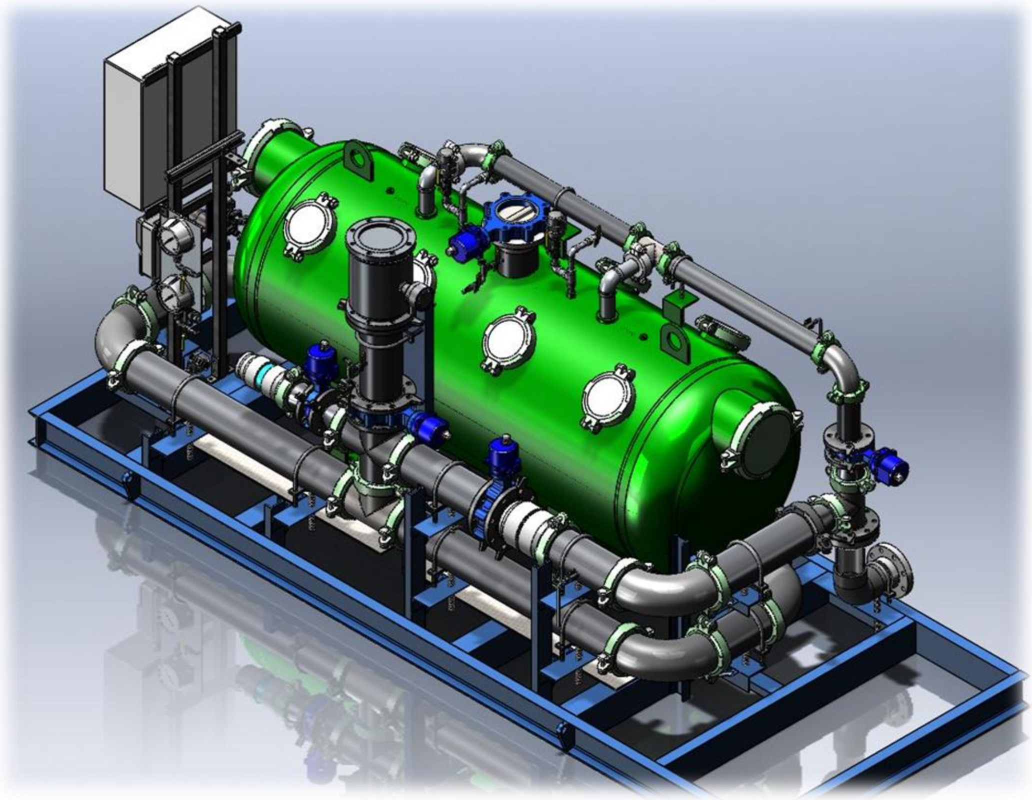


Figure 7: Water passes through Pressure Vessel

3. The filtered water then exits through the two outlets seen here in yellow

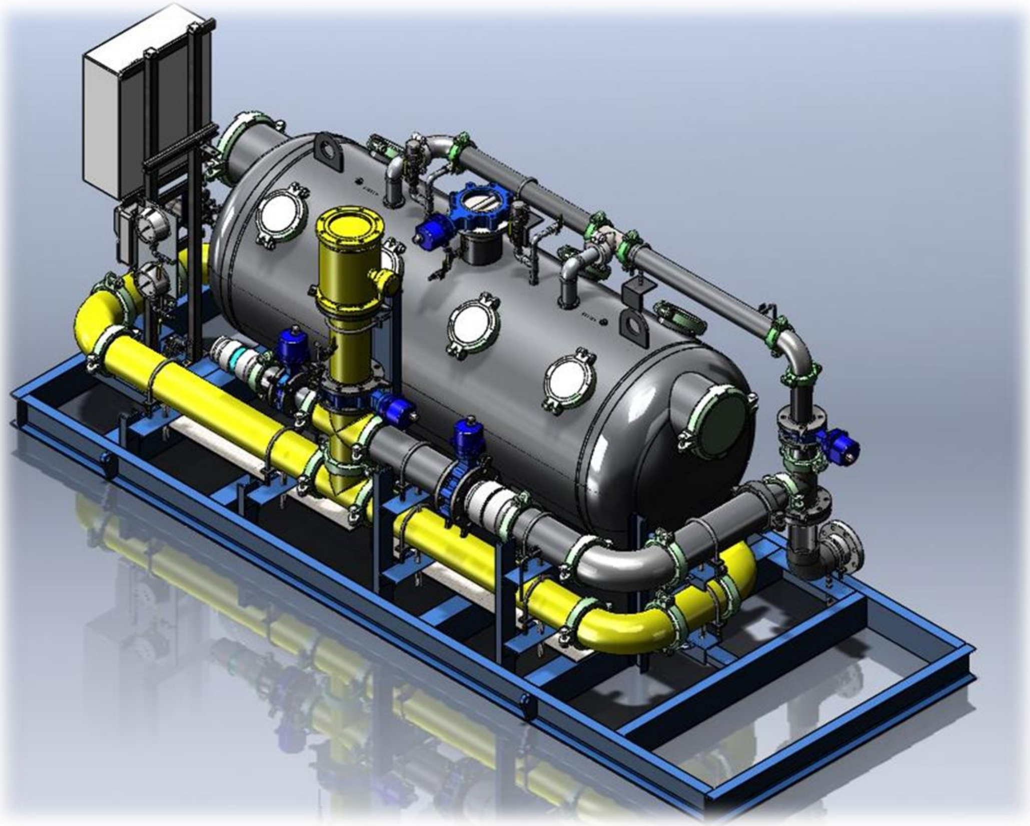


Figure 8: Exiting through the Outlets

As the impurities build up in the vessel its pressure increases and when the pressure reaches a level of 1.1 bar gauge the cleaning process is automatically initiated.

The cleaning process is summarized as follows:

1. To clean the media and to remove impurities, water is pumped into the outlets, passed through the filtration bed in the pressure vessel dislodging all waste material and then drained to waste using the Back Wash pipes (highlighted below in Pink).

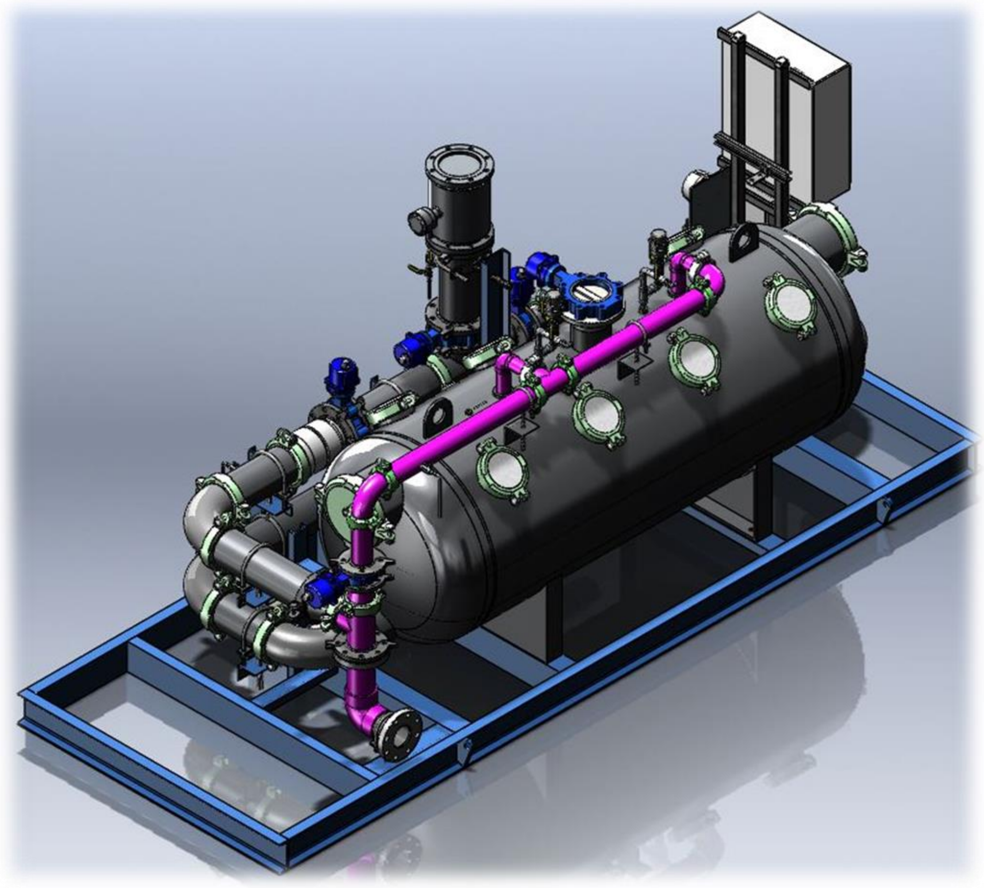


Figure 9: Back Wash Piping

2. When the pressure decreases to a level of 0.6 bar gauge the back wash process is halted and the front wash is initiated for a period of one minute. This is done to remove any residual impurities in the pressure vessel and to resettle the filtration media. Water is pumped through the inlet pipe; it passes through the material in the pressure and exits through the outlets. The water is then sent off to the waste using the front wash piping, highlighted below in turquoise. The front wash is connected to the back wash through the pipe highlighted and the water is sent off to the waste.

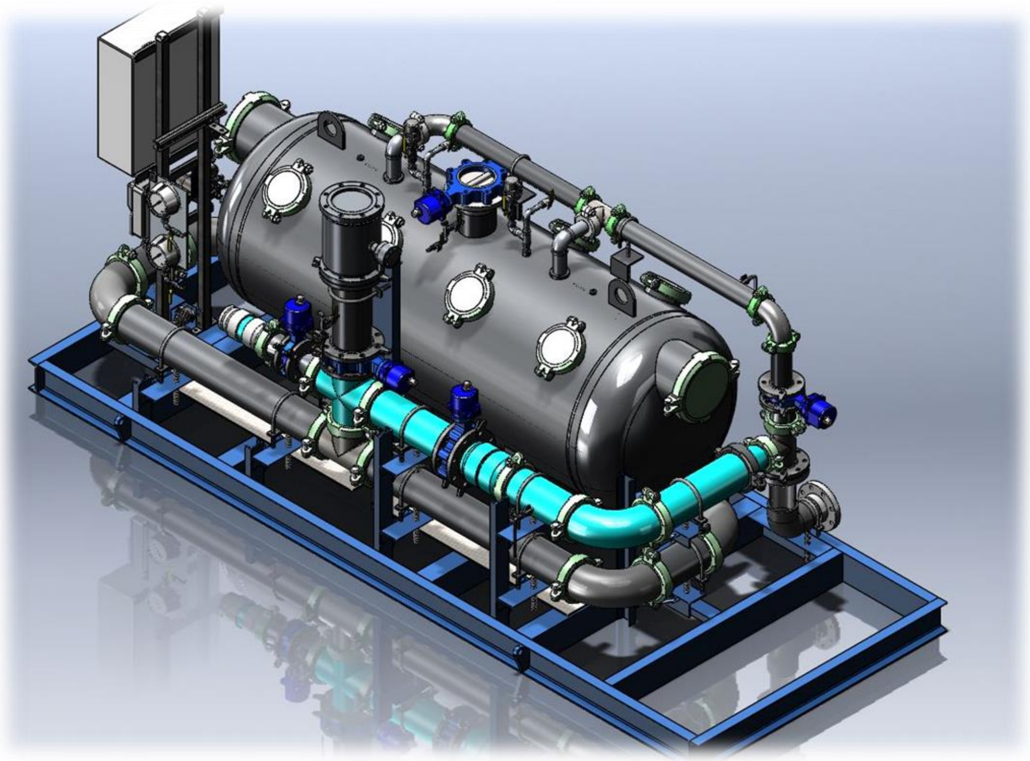


Figure 10: Front Wash Piping and Valves

Identification of key components (to focus VA on)

Based on our discussions with the client, we came up with the following list of items that we would concentrate our Value Analysis on. While the basic system flow was sacrosanct, the team was tasked with increasing the filtration capacity while covering the same ground area.

- Piping – Evaluate suitability of current design and make improvements to simplify design and to reduce piping cost.
- Reduction of Area covered by system. [You have capitalized key nouns throughout the manuscript. Maybe you'd like to reconsider.]
- Investigation of the possibility of using 2 systems in an assembly.
- The skid base and its alternatives.
- Different materials for pressure vessel.

Key constraints

There were of course some key constraints we had to design around. Based on our discussions with the client we came up with the following list of constraints.

- Maximum height for double system – 102 inches (this is from shipping considerations).
- Flow has to be injected perpendicular to the pressure vessel's cylindrical axis.
- Materials used have to be suitable for operation ~~between the~~ in a temperature range~~s~~ of -10 to 70 ~~degrees~~ Celsius.
- Pressure considerations

Project objectives

The aim of this project is to investigate various ways of improving the subsystems, assembly, and overall design of the filtration system, using value analysis methodology and guidelines. The following are our project objectives:

- Reduce or eliminate the skid to substantially reduce the cost of the unit
- Reduce the area covered or foot print of the filtration unit
- Optimize the cost of unit
- Explore the option of stacking two units together to reduce foot print and to improve the efficiency of the process

Methodology

The Value Analysis procedure involves a systematic analysis of the client's design ~~problem~~. [Be diplomatic.]
The 7 major phases are:

1. Organization
2. Information
3. Functional Decomposition
4. Creativity
5. Evaluation
6. Development
7. Implementation

[This capitalization is o.k. 'cuz it's a section in ToC.]

The first two phases were covered in the Initial Client Design section. We obtained an understanding of the initial design, the key parts and constraints, and of our objectives. In this section the Phases 3-5 (Functional Decomposition, Creativity, and Evaluation are included. The Development and Implementation will be covered in subsequent sections.

Function and Cost Analysis

[objective does not = function.]

In this step, we broke the objectives of the design into component functions. This enabled the team to understand the process fully, immediately translated into realizing which functional components are important and why so. This meant we could come up with proposals and possible solutions to the design problem. Of course, the team went through this stage repeatedly to increase its understanding.

To accomplish this, we used the following techniques.

1. Intuitive Research
2. Environmental Analysis
3. Sequential Analysis
4. Functional Diagram
5. Flexibility Table
6. Cost Analysis

Intuitive Research

In this step, as the name suggests, the team used its intuition and common sense to come up with possible solutions and alternatives to the design functions. This enabled the team to come up with the basic functions and constraints, which could be further developed with the other techniques mentioned above.

1. Clean Water
2. Reduce/Simplify Maintenance

3. Simplify Pipe Design

While these functions are very important, the team realized that they could be further divided into sub-functions which would clarify the design and possible solution further. Therefore, the team moved onto the next technique.

Environmental Analysis

The main objective of our client is to produce filtered water at a desirable flow rate. Along the way there are some environmental impacts starting from the raw water pumped into the system to the filtered water delivery outlet.

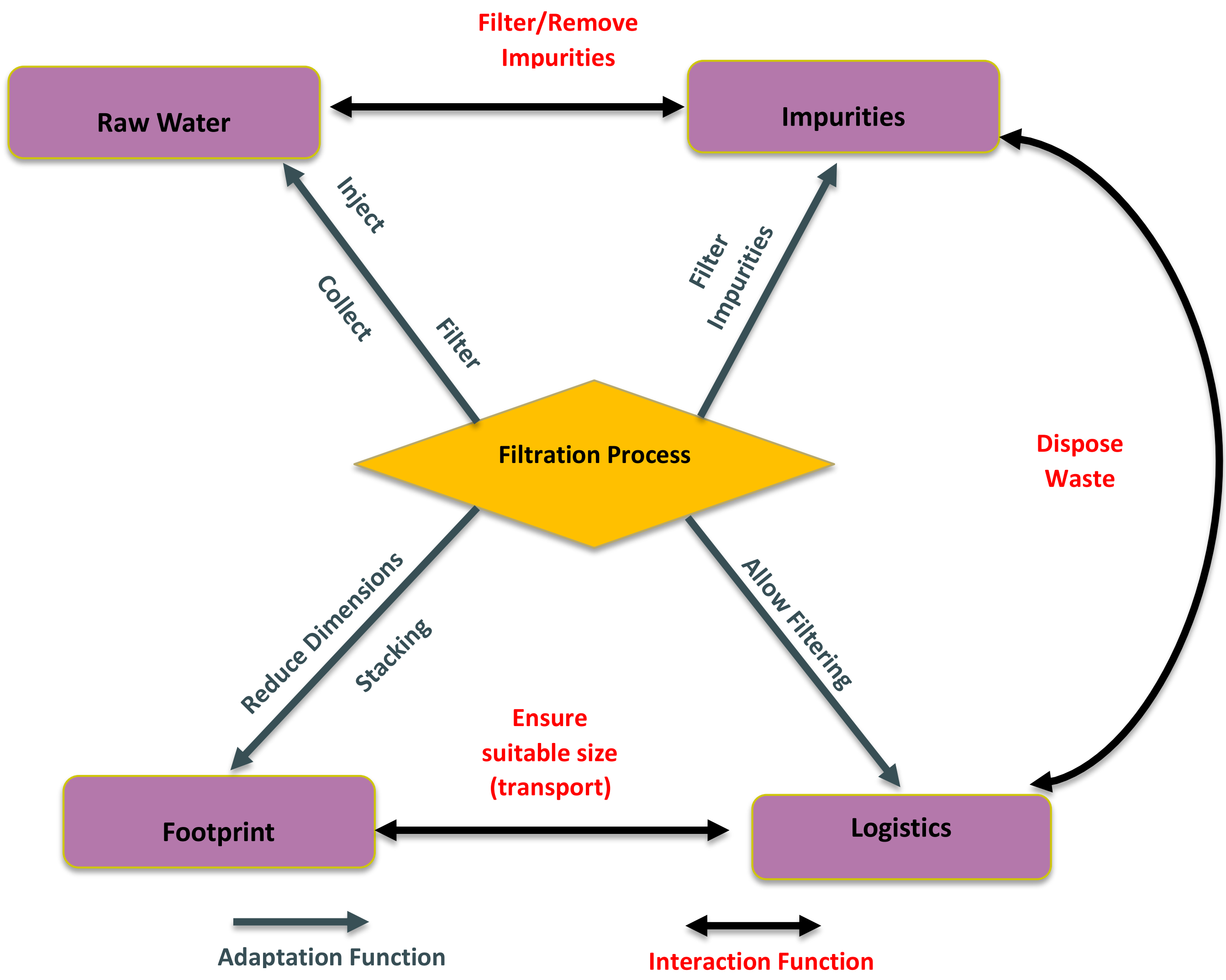


Figure 11: Environmental Analysis

The analysis shows the environmental elements affected by the main process of the company.

Relations of two types are then constructed:

- Adaptation Function- Functional Relationship between elements and process
- Interaction Function- Functional Relationship between elements

Sequential Analysis

A Sequential Analysis was performed to analyze the functions in the sequence they are performed thus making the functional decomposition of the filtration unit easier and therefore places emphasis on the order of performance and also identifies action verbs.

Sequences of Activities	Function verb	Function Noun
Skid	Support Attach Ease	Vessel and Structure Piping Maintenance
Pressure Vessel	Filter Facilitate Distribute Resist Prevent	Raw Impure Water Back Wash Flow of Injected water to collector Corrosion and Reaction Erosion
Internals/Collector	Collect Distribute	Raw Impure Water Water evenly
Piping	Transport	Raw water/Filtered water/ Backwash
Valves	Control Isolate	Flow of water System
Pump	Elevate Circulate Facilitate	Water Feed Backwash
Manholes	Allow Facilitate Mount	Access Maintenance Internals/Injectors

Table 1: Sequential Analysis

Functional Diagram

In a functional diagram the functions are broken down in a hierarchical fashion. If one moves from left to right on a functional diagram, the diagram describes how a function is performed, however, moving in the opposite direction explains why the function is performed.

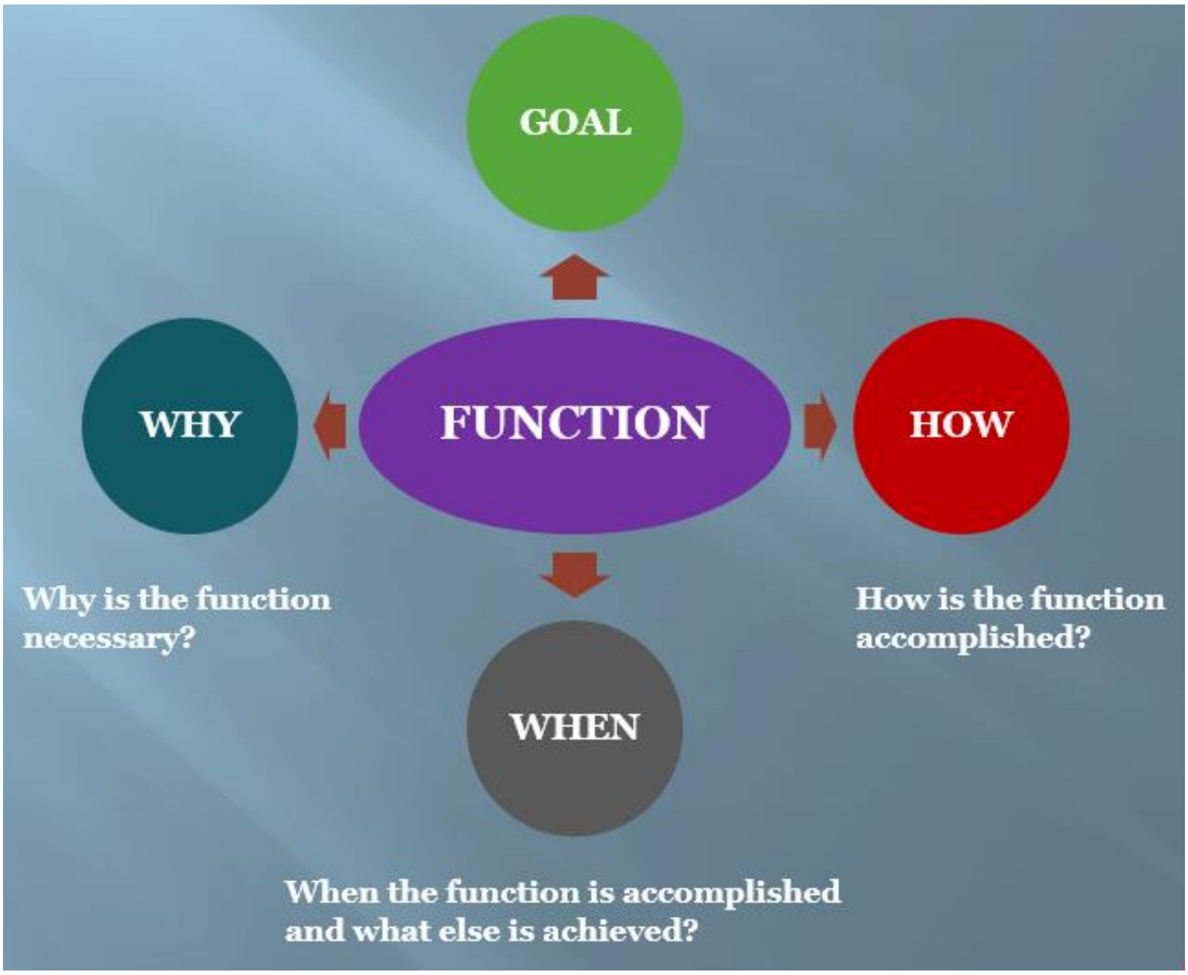


Figure 12: Funtional Diagram Processing

Our functional diagram was split into primary and secondary functions. Reference to fully expanded functional diagram is attached in the Appendix.

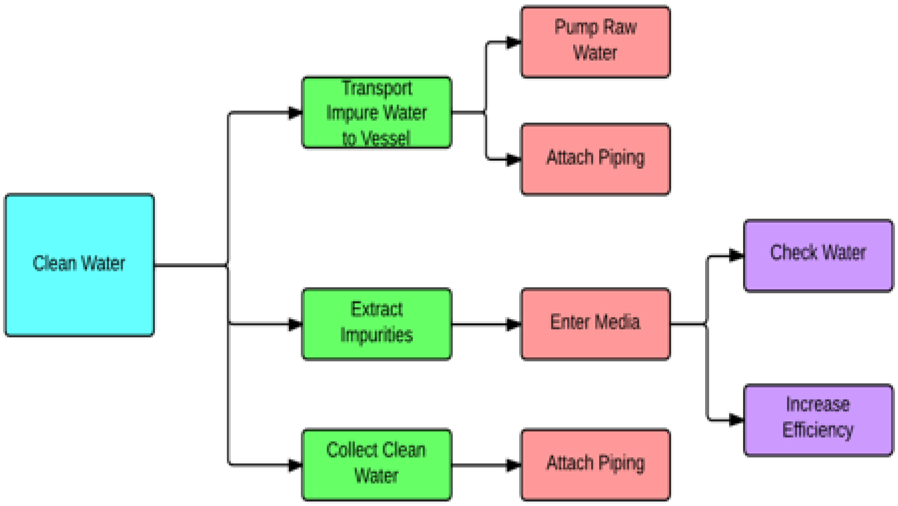


Figure 13: Primary Functions

The above diagram for the primary functions of the water filtration system:

Our primary function was to clean water and remove all impurities down to 1 micron in size. This primary function is achieved by transporting impure water to the vessel, extracting all impurities and collecting clean water at the end of the filtration process for use by the customer. The transporting of impure water is achieved through the use of pumps and attached piping. We extract the impurities by passing the water through the pressure vessel and into the media. This ensures we get the desired quality of water at the outlets. The clean water from the outlets is collected via piping and sent off through the exit for use by the customer.

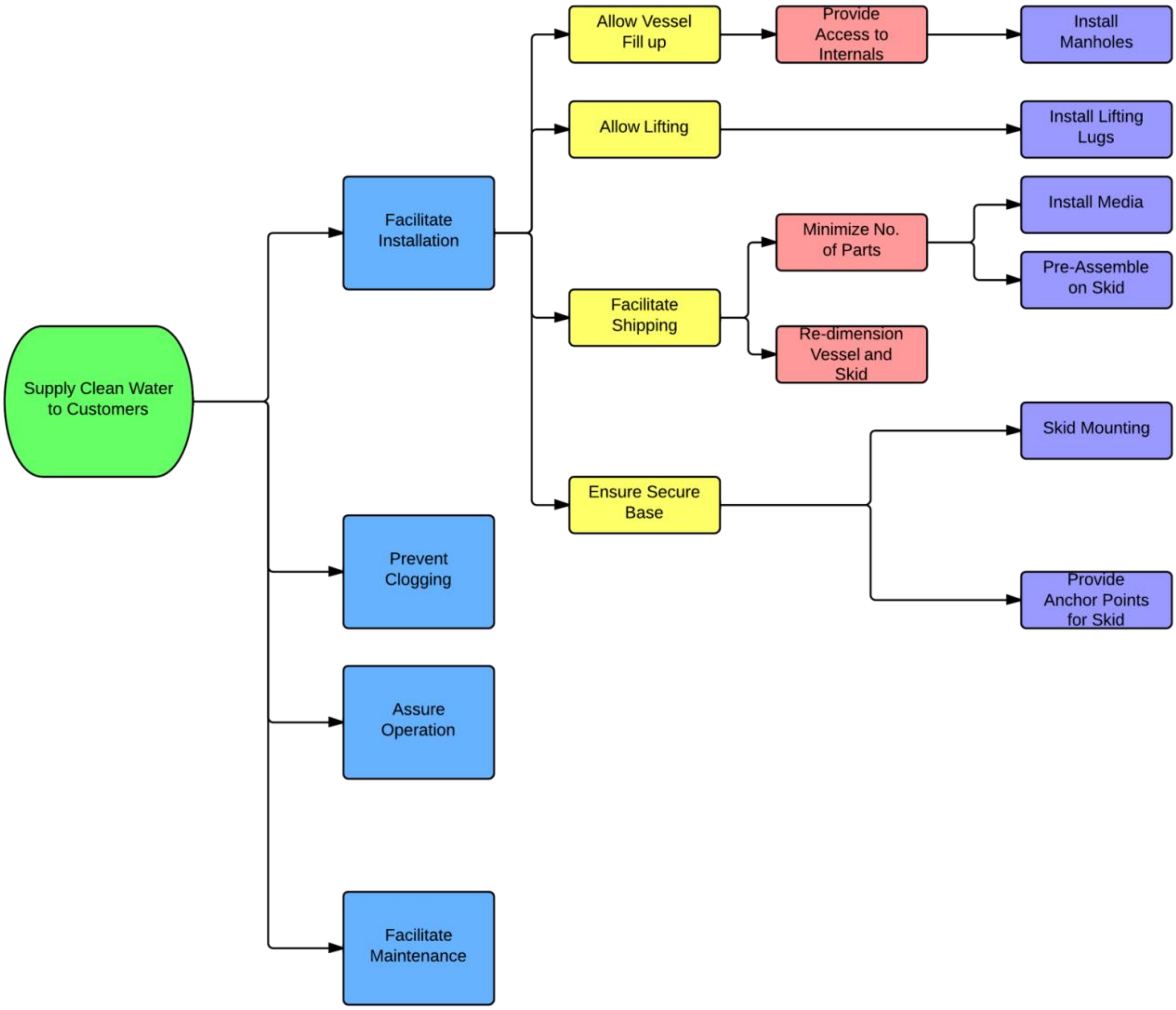


Figure 14: Secondary Functions

The above diagram highlights the secondary functions of the filtration unit:

The secondary functions of our filtration units are facilitate installation, prevent clogging, assure operation and facilitate maintenance. For clarity only one of the secondary functions is completely described in the diagram shown above. The fully expanded functional diagram is included in the Appendix.

Flexibility Table

After the team identified the functions, we then characterized them by measures of performance. We looked at three different aspects of each function. They are as follows:

- Criteria: How the function is accomplished or measured
- Level: Acceptable result for each criterion which could be a minimum, maximum or a fixed value.
- Flexibility: Indication of how much a level can be negotiated.

The flexibility level is divided into four categories, which are as follows:

- F0: No flexibility
- F1: Little flexibility
- F2: Some flexibility
- F3: Very flexible

This method allowed the team to understand which functions were important, which functions could be played around with, and appreciate the rigidity requirements of each function. All this was taken into further consideration in the development phase.

The Flexibility Table is included below:

Number	Function	Criteria	Level	Flexibility
1	**Filter Water**	Size of unfiltered particles	<= 1 micron	F0
1.1	Transport Impure water to vessel	Water Pump, Flow Rate	600 gpm	F2
1.2	Extract Impurities	Passes through media	particles<=1 micron	F0
1.3	Collect Clean Water	Flow Rate	600 gpm	F2
2	**Facilitate Installation**			
2.1.1	Allow Lifting	Weight	9000 lbs	F0
2.1.2		Number of parts	26	F1
2.2.1	Facilitate Shipment	Dimensions	100 inches height	F0
2.2.2		Number of parts	26	F2
2.3	Ensure Secure Base	Weight		F1
3	**Prevent Clogging**			
3.1	Collect Pollutant	Pressure level	Exclusive of 0.6 to 1.1 bar	F1
3.2		Switch Valves	Exclusive of 0.6 to 1.1 bar	F1
4	**Assure Operation**			
4.1	Power up System	Water flow in and out of system	600 gpm	F1
4.2.1	Control Operation	Pressure Levels	1.1 bar relative	F1
4.2.2		Operation of Valves	6 valves	F1
5	**Facilitate Maintenance**			
5.1	Access System Components	Have manholes	Maintenance hours required	F2
6	**Ensure System Reliability**			
6.1.1	Structural Integrity	Robustness	10 Years	F3
6.1.2		Resist Corrosion	10 years	F3

Table 2: Flexibility Table

Cost Analysis

After functional analysis was completed, each function was quantified on a cost basis.

In the Appendix, we have attached our cost analysis table (it is very detailed and quite lengthy) where functions from our filtration systems were organized on the top row and then components, equipment and machinery were listed down the first column. The components were then allocated a cost, as a value judgment, depending on how much was thought that it contributed to the respective functions.

Next, the client gave us a function worth, which was in his eyes the ideal worth of the function after our discussed improvements were carried out. This gave us an idea about which functions offer opportunities of cost reduction and which ones can tolerate an increased cost. Weightage was also calculated depending on what the function cost was worth in comparison to the total cost.

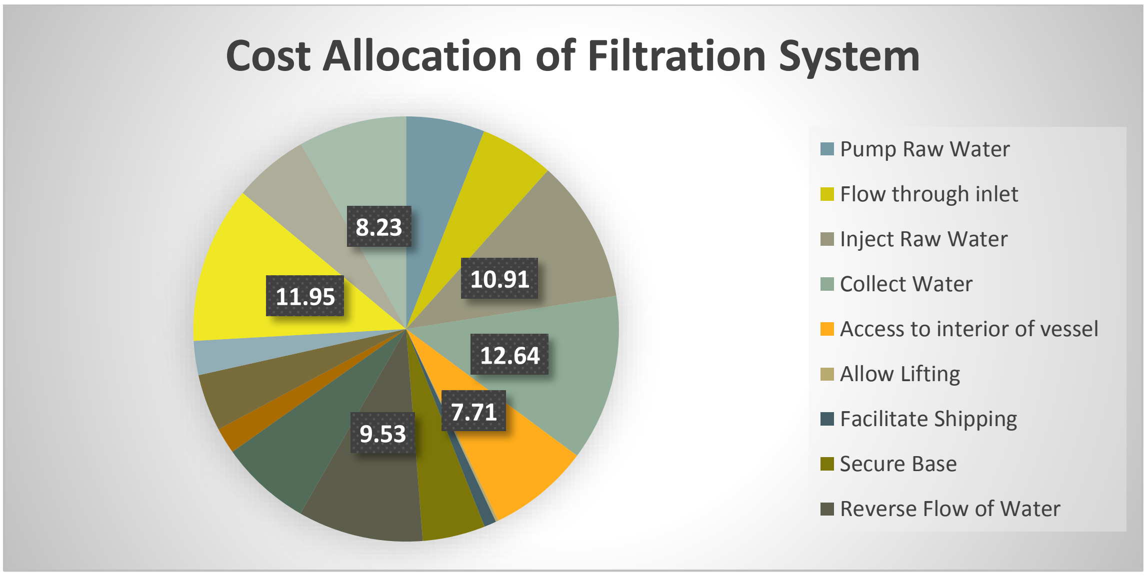
Function weighting according to function cost as a fraction of total cost was also calculated. [To comma or not to comma?]

The client was looking for a reduction in cost of about 30% from $57,740 to $39600. There were many functions in our system as it is a lengthy procedure to start with raw water and end up with the pure product. Along with the functions there are also many components in our system and there is not one or a few clear functions that dominate the costs.

The major functions that contribute to the costs are:

- Collecting water
- Injecting water
- Measuring process conditions
- Reversing flow of water
- Being Robust

The Pie Chart below demonstrates the cost allocation.



[Hard to tell which "pie-pieces" the %-numbers are meant to span. Furthermore they add t0 ~49%!]

Figure 15: Cost Function Allocation Pie Chart

Most of the functions required a reduction in costs, especially the six major functions listed above. The 'Detecting Pressure' function needs to be reduced considerably as the client wants the cost to be half as much. This however is out of the group's control as there is no relation to stacking or change in material. In addition this function does not have major weightage and is not on our top five functions we aim to reduce; therefore it won't be addressed intensively.

It is promising to see that the five important functions relate, either directly or indirectly to an improvement to the material or stacking the pressure vessel. This will aid us in trying to accomplish the specified target cost that the client has aimed for.

["gave imagination free rein" is a little less manic that "imagination run wild".]

Creativity

In this phase, the team used its creativity to come up with ideas and solutions. We ignored the feasibility and practicality of the concepts being generated, and let our imagination run wild. This brainstorming session helped us to come up with some very interesting ideas, some of which were developed further. It was very important to consciously decide not to judge each suggestion – we treated each idea with the respect that it could be ideal solution. Once a team member came up with an idea, we spent a minimum on 2 minutes on thinking of how to make it better and how to make it work. This enabled us to convert seemingly inutile suggestions into ideas with great potential. It also meant that we did not let any possible solution slip through.

unusable?

Brainstorming results

We came up with the following list of initial ideas.

1. Stack the vessels.
2. Join Inlets and Outlets for stacked piping.
3. Join backwash and exit piping.
4. Eliminate second outlet.
5. Reduce front piping.
6. Reduce width by moving piping to the side. (and therefore piping)
7. Remove front wash pipe.
8. Join backwash for stacked unit (for both vessels)
9. Modify material.
10. Reduce skid size.
11. Make skid detachable for ease of transport.
12. Media to be transported in bags.
13. Bags to be placed in the manhole accesses.
14. Bags to be easily opened.

Evaluation of concepts

[deficiencies or drawbacks, You get demerits for traffic violations.]

In this phase, we analyzed the relative merits and demerits of each suggestion that arose through the Creativity Phase. This enabled us to judge which suggestions had potential or promise. The team also combined different suggestions and different aspects of different suggestions.

Gut Feel Index

Every team member ranked each suggestion based on their gut feeling. This enabled the team members to judge each suggestion, which allowed the team to select the ideas with the most potential. The team chose a scale of 1-10, with 10 being best. The ideas with a certain minimum score (5) were selected for further research and development. The others were discarded. It’s important to note that thanks to the initial Value Analysis Phases of Information, Function, and Cost Analysis, we were able to come up with solutions that were for the most part worthy of consideration and further development.

The Gut Feel Index Table is attached in the appendix.

Proposals

Introduction:

After extensive brainstorming and functional analysis session, we came up with four proposals that meet our client's requirements recognized in the functional decomposition. A combination of these proposals is used in different scenarios to provide the best solution to our client that focus on increasing the overall value of the process.

Concepts at a Glance

- **Pipe modification**
- **Simplified skid design**
- **Stackable skid design**
- **Material modification**

Proposal 1: Pipe Modification

Description:

The first proposal offers our client ~~with~~ an alternative pipe arrangement of the filtration unit. The number of outlets is reduced from two to one. In doing so, the main functions of the unit, such as backwash and front wash, ~~can be focused on~~ are confined to one side of the unit.

The next step was to incorporate Front Wash and backwash through the same outlet pipe. This was achieved by attaching the outlet pipe to the waste pipe using a Tee joint and an automatic valve. The figure below shows the new pipe design.

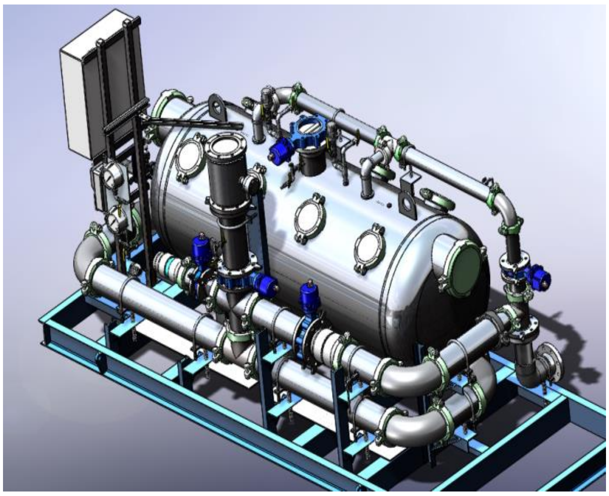


Figure 16: Piping Reduction

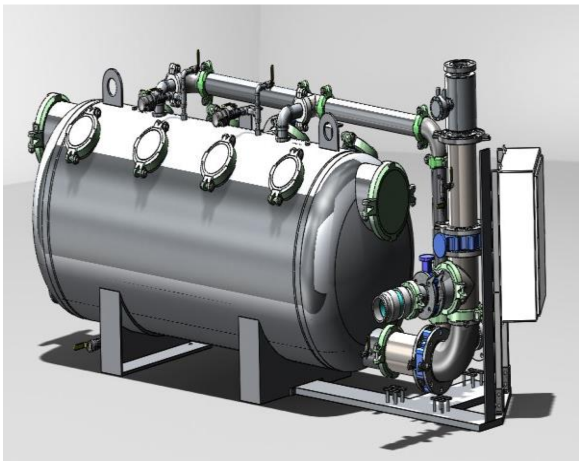


Figure 17: After Piping Reduction

Discussion:

Reducing the number of outlets from two to one eliminates the needs of extra piping needed for the second outlet. Also, connecting the waste pipe with the outlet pipe eliminates the separate pipe needed for front wash.

The modified pipe arrangement results in pipe reduction of 132 kg and considerable reduction in footprint. Also the processes previously severed served by three different pipes are now achieved through a single pipe arrangement; simplifying the overall design of the whole unit while not compromising on the efficiency of the filtration unit.

Proposal 2: Simplified Skid Design

Description:

Our second proposal essentially builds on our first one that focuses on alternate pipe arrangement. Our second proposal provides a detachable skid for the new pipe design. The new skid will be bolted to the ground and provides housing for the U bolt which supports the piping. The skid extends upwards to provide support to the outlet pipe.

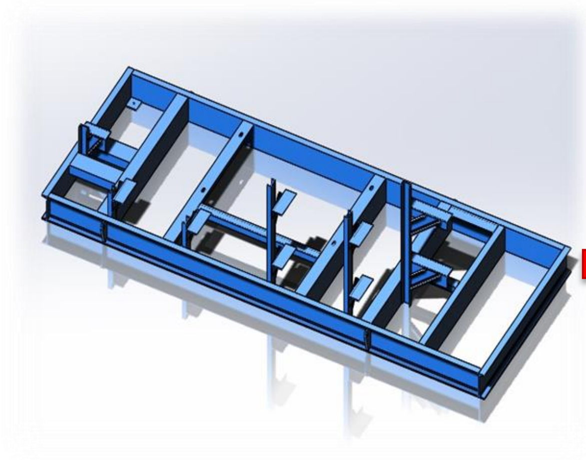


Figure 19: Original Skid Design

Figure 18: New, Reduced Skid Design

[Now I see. Using the tank as supporting structure is not bad if you can avoid damage in transit.]

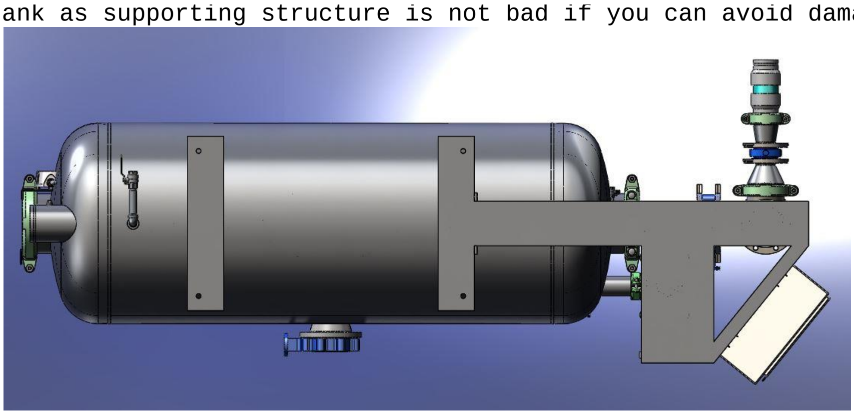


Figure 20: New, Reduced Skid Design, Bottom View

Discussion:

The previous skid was much larger in size and had a large footprint as it needed to support a large section of piping. The previous skid was also difficult and expensive to manufacture.

With the new piping design there was no need to have such a large skid as piping was reduced considerably. The new skid is much smaller in size and easier to manufacture. Since it is detachable, it will be easier to transport the skid. The cost reduction in skid will be of considerable amount and also the footprint is reduced with this new design.

Proposal 3: Stackable Unit

Description:

Another requirement put forward by our client was to increase the production but restrict the footprint increment. In fact the aim of our team was to reduce the overall foot print. The option of stacking one unit on top of the other provides our client with a perfect opportunity to accomplish this goal. As mentioned earlier the extra piping removed from the front of the vessel and moved to the side saved us a significant amount of skid. Furthermore stacking the units and connecting the inlet, outlet and backwash pipes added to the total value of the unit. The following is the computer aided model (CAD) done by our team:

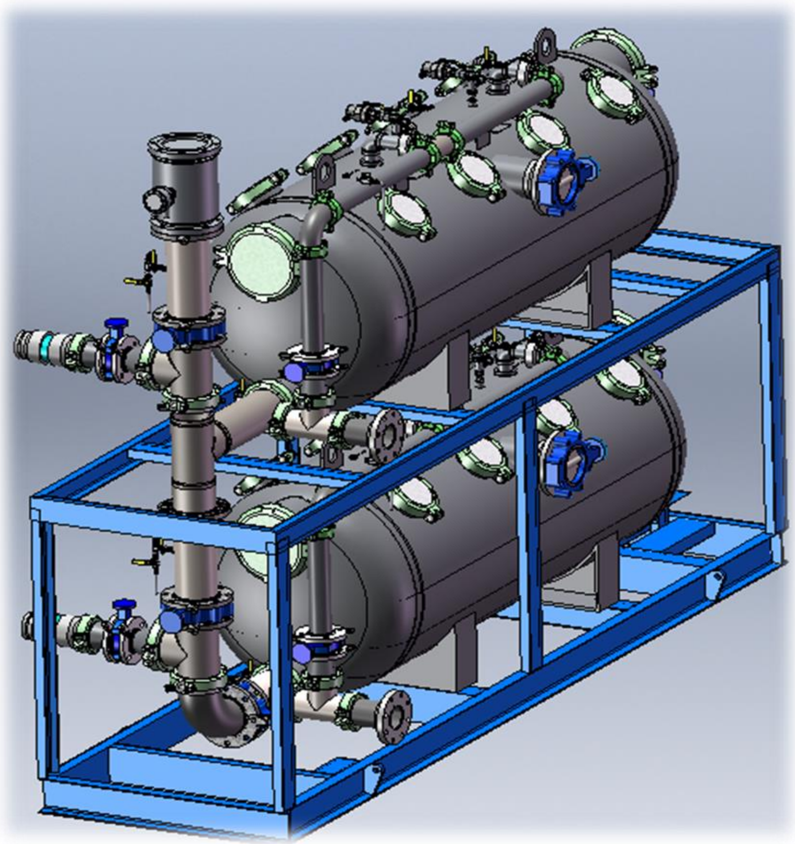


Figure 21: Stackable Unit Isometric View

Discussion:

This proposal incorporates the idea of having a second base on top which is supported by columns strong enough to lift the 9000lbs second vessel. The stress analysis performed on the structure proves that this structure can bear such a load on top. Also an important consideration here is to install a steel sheet as a base for the second vessel for appropriate distribution of load. Moreover the beams installed are the I-beams. Following is the analysis performed on the structure:

This proposal would act as a bench mark in the market and would allow Sonitec Inc. to ship multiple units to the end user conveniently. A few accomplishments are as follows:

Prominent Achievements:

- The target of our team was to stay with in the **102"** height limit and proposal was successfully completed within **99"** height.
- The over width of the design was reduced by **66 %** which far exceeds the expectations.
- The inlet to the vessels was made perpendicular to the initial design and aids in the height restriction.

Proposal 4: Material Modification

Description:

The next proposal to our client was to explore the possibility of using alternate material for the unit. This includes the basic vessel unit as well as the piping of the unit. The following table provides an outline of the current material and proposed material along with the benefits this offers.

Table 3: Material Properties Review

Current Pressure Vessel	Proposed Pressure Vessel	Current Piping	Proposed Piping
Stainless Steel	***Fiber Reinforced Plastic (FRP)***	***Carbon Steel***	***Poly Vinyl Chloride (PVC)***
Light Weight Material	Half the weight of SS	High Tensile Stress	Amorphous structure gives great strength
Reasonably cost efficient	Approximately half the cost of SS	Good Value for Money	Much lower cost than Carbon Steel
Resists bacteria and germs (non-porous)	Superior corrosion Resistance verses metal	0.2% of carbon gives it flexibility	Great Flexibility especially for elbows and tees
Low, conductive material	Good insulating material	Great Durability	Durability as good as Carbon Steel

Discussion:

The current pressure vessel is made of stainless steel and the idea after thorough research was to design a pressure vessel made out of Fiber Reinforced Plastic (FRP). This would result in a dramatic reduction in weight and would cost almost half as much when compared to
has greater corrosion resistance
the original design. Moreover, the proposed material ~~is a better resistor to corrosion~~ and is ~~acts as~~ a better insulator. This increases the applications of the filtration unit globally.

Another proposition was to alter the piping from existing carbon steel to Poly Vinyl Chloride
is just as strong(?)but much less costly.
(PVC) which provides equivalent amount of strength but greatly reduces the cost. Other beneficial properties include the flexibility of the material for bends and elbows and also greater durability when compared to the original design.

The above mentioned propositions would allow Sonitec Inc. to reduce costs significantly and thereby increase their profit margins. As mentioned earlier, the reduction in weight would also allow multiple units to be shipped at the same time and that too for numerous customers worldwide.

Scenarios

The four proposals mentioned earlier lead to multiple scenarios which the client could incorporate in their production. These scenarios build on top of each other and together account for the increase in overall value of the equipment.

Our team came up with four different scenarios, evaluated them and then proposed a final recommendation to the client. Following is the outline of the scenarios:

Scenario I:

- Alter the piping of the vessel by removing it from the front and moving it to the side by making use of multiple joints.
- Eliminate the original skid and instead come up with a detachable unit that houses the piping and the junction box.

Scenario II:

- Alter the piping of the vessel by removing it from the front and moving it to the side by making use of multiple joints.
- Stack the units on top of each other by interconnecting the inlets, outlets and the backwash of the system.

Scenario III:

- Alter the piping of the vessel by removing it from the front and moving it to the side by making use of multiple joints.
- Eliminate the original skid and instead come up with a detachable unit that houses the piping and the junction box.
- Modify the material of the vessel from Stainless Steel to Fiber Reinforced Plastic (FRP).
- Modify the material of the pipes from Carbon Steel to Poly Vinyl Chloride (PVC)

Scenario IV:

- Alter the piping of the vessel by removing it from the front and moving it to the side by making use of multiple joints.
- Stack the units on top of each other by interconnecting the inlets, outlets and the backwash of the system.
- Modify the material of the vessel from Stainless Steel to Fiber Reinforced Plastic (FRP).
- Modify the material of the pipes from Carbon Steel to Poly Vinyl Chloride (PVC).

The above mentioned scenarios would account for progressive reduction in cost as well as the weight and the footprint. This altogether would increase the value of the final product significantly. The calculations for the stress are shown above and the cost analysis follows these Scenarios.

Merit Analysis

The cost/merit analysis graph was designed to evaluate the best design out of the four scenarios that were proposed. Criteria were then set and depending on the importance and priority, a specific weightage was allocated for the respective criteria. The merit points were then accumulated giving us a total for each scenario and compared giving us a clear winner. The stacked and single pressure vessels were isolated for the cost-merit analysis, as there are obvious differences between the two, and furthermore give a more accurate analysis.

The different options were judged on the following criteria:

Weight

One of the main reasons materials were discussed as an improvement to the design was the reduction in weight. This would also help in transporting the product especially due to its sheer size and the fact that some of the client's customers are located extremely far from their Headquarters.

Footprint

Perhaps the most important criterion in our analysis that the client was adamant about was reducing the footprint and dimensions. Reductions in footprint would help the company be more cost efficient as the skid is a relatively expensive component of the system. Stacking two pressure vessels vertically was also initially brought up to overcome this problem.

Accessibility

Another important criterion that covers a few areas of concern, accessibility covers maintenance and ease of transport. Questions were raised on how easily the manholes can be reached especially when stacking takes place. Other points included how the system would fit in a specific area for transport and possibly also the convenience of assembling and dismantling the system.

Safety

With all industrial systems, safety is a big issue and this criterion was tough to improve on as the current setup took most of the factors into consideration. Whilst designing the stacked

PVs, there were discussions of how to ensure safety at what could possibly be risky heights even though not too high or dangerous.

Aesthetics

Many ~~Most people~~ judge a book by its cover and the team believed aesthetics are important in a manufacturing system especially to help improve the reputation and sales of the company. Therefore it made the comparison table even though it was not highly prioritized by the client.

Merit Analysis Table

Table 4: Merit Analysis Table

Criteria	Weight	Scenario 1	Scenario 2 (per PV)	Scenario 3	Scenario 4 (per PV)	Original
Weight Merit Score	4	6 24	6 24	8 32	8 32	5 20
Footprint Merit Score	8	7 56	9 72	7 56	9 72	4 32
Accessibility Merit Score	5	9 45	7 35	9 45	7 35	6 30
Safety Merit Score	2	7 14	7 14	7 14	7 14	6 12
Aesthetics Merit Score	1	8 8	8 8	7 7	7 7	6 6
Total Merit Score		147	153	154	160	100
Cost (1000s)		$48	$49	$36	$37	$58
Savings		17%	16%	34%	32%	N/A

The criteria detailed above was used to obtain a Merit-Analysis Table. This enabled the team to compare all the different options to see which one is the best.

The most important criterion for the merit was the footprint. We can also see quite clearly that Scenario 3 results in the biggest cost-savings, of 34%, but at a slightly lower merit score of 154. Scenario 4 is very close, with 32% in savings and a higher merit score of 160.

Cost Merit Graph

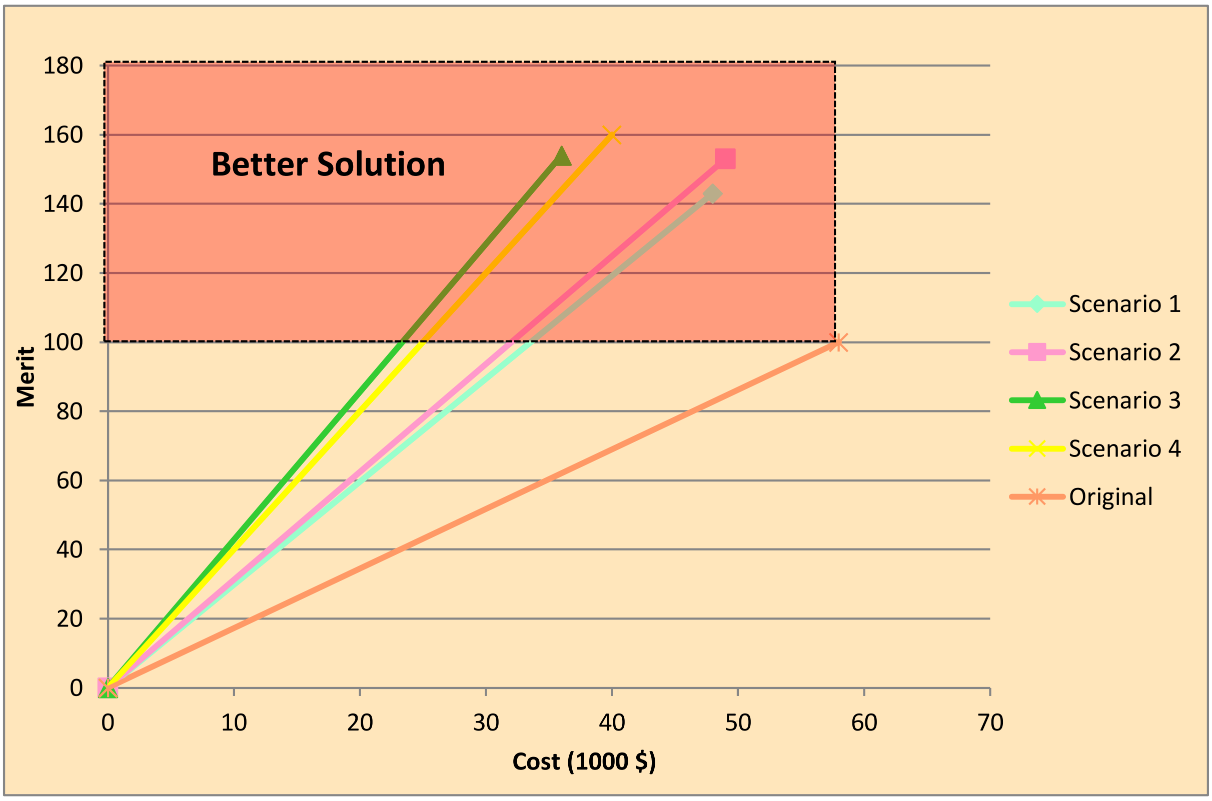


Figure 22: Cost-Merit Graph

The cost merit graph gives us a clear indication to whether our scenarios were better and cheaper.

Anything to the left of the original cost a better cost is achieved and anything above the current scenario amounts to a better functioning design. The overlapping area in red gives us the better solution in comparison to the original design. The highest slope of the curve gives us the winning scenario with the highest merit and the lowest cost.

As seen on the graph, the highest slope was for Scenario 3, which was the single pressure vessel with changes in material and piping, closely followed by scenario 4, the stacked vessel with alterations in material and piping.

Final Designs: Detailed Analysis

Scenario III: Altered Piping, Detachable Skid and New Materials

Description

As per our cost-merit analysis, Scenario 3 is one of the most beneficial designs that we came up with. It combines three sets of proposals to form an optimum design that not only reduces the footprint of the filtration unit, makes the process very efficient and also significantly reduces the cost of the original design.

An isometric view of the CAD of Scenario 3 is given below.

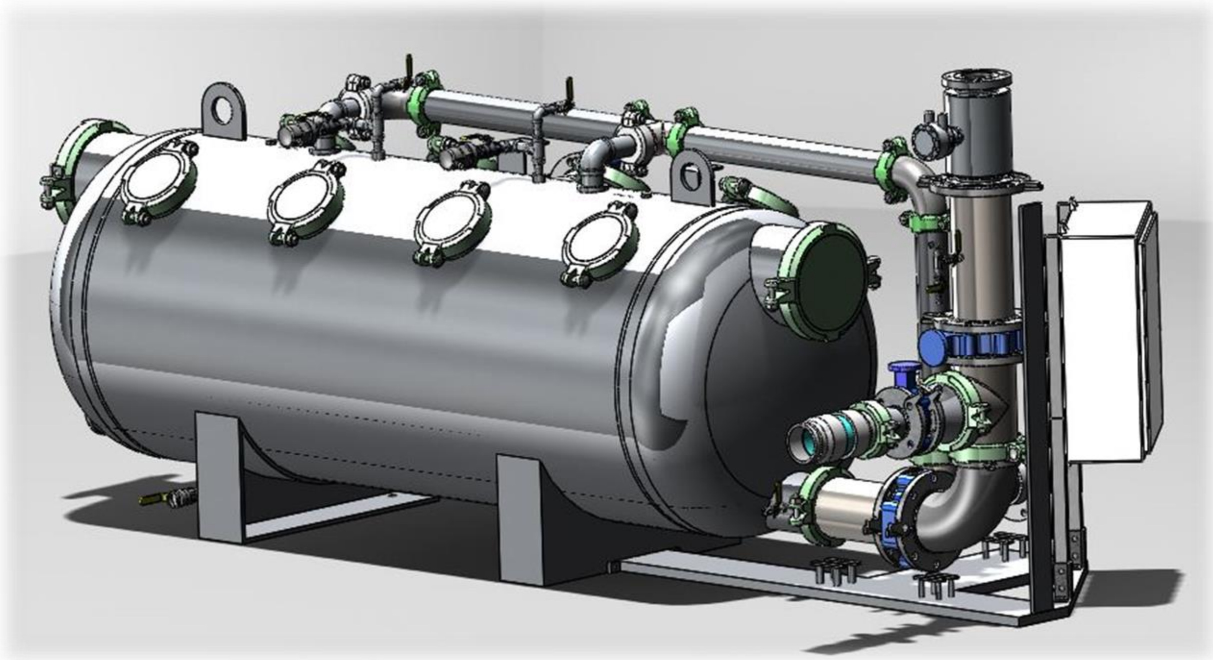


Figure 23: Isometric View-Scenario 3

In Scenario 3, the Piping is significantly altered. The outlet pipes are reduced from two to one which does not have a major impact on the production of filtered water but significantly improves the process efficiency and also decreases the total foot print of the unit.

Since in the new design only one outlet was used all the piping could be shifted to one end further reducing the need for lengthy pipes. The front wash pipe was also completely eliminated as it was deemed redundant and superfluous to the needs of the filtration unit.

In Scenario 3, the outlet is connected to a reducing tee which has two ends of Nominal Pipe Size (NPS) 6", however one of its ends it of 4" NPS. This is done so that the connection to the Back Wash pipe is achieved easily. The Back Wash pipe is 4" NPS and therefore a reducing tee eliminates the need for a reducer.

To completely eliminate the front wash pipe, an extra valve was required which separated the exit from the back wash.

During the forward filtration process all the valves shown below in red are closed. This prevents the filtered water from going to the waste.

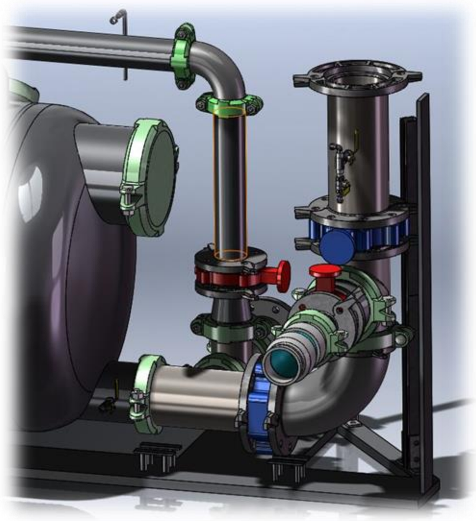


Figure 243: Closed Valves during the filtration process

When the cleaning process initiates, water is pumped through the outlets and it exits through the backwash piping. To achieve this in our new design the valves are operated such that the impure water goes to the waste and does not contaminate the rest of the piping. A pictorial description of the operating valves is given below. All closed valves are shown in red.

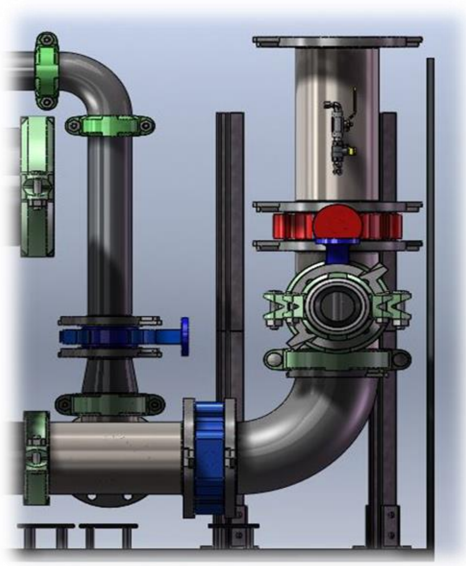


Figure 255: Closed Valves during the backwash process

For the front wash all valves are closed and valve on the pipe connecting the outlet to the backwash is left open. All closed valves are shown below in red.

⌊Looks black to me.⌋

Figure 264: Closed Valves during the forwardwash process

This new piping design achieves both the functions of transporting filtered water and front rinse through the same piping, hence making a drastic dent in the original cost and significantly improving the cost of the filtration unit.

A new skid design has also been proposed. We decided to eliminate the original skid as it was very expensive and was a major chunk of the cost of the original design. The skid was also very expensive to build and manufacture thus driving the cost upwards.

The new skid design is detachable, which means Sonitec Inc. can supply the skid separately and this would ease the logistics of transporting the unit to the customer. The new detachable skid is made out of stainless steel as opposed to the galvanized iron in the previous design. This also reduces the cost significantly. The detachable skid is attached to the saddles that support the pressure vessel through blots. It also has provisions to attach the piping through U-blots. The junction box can also be easily attached to the new skid.

Figure 27: New Skid Design

Apart from being significantly cheaper, easier to manufacture and transport, the new skid also offers the added benefit of having very less footprint as compared to the previous design.

The final branch of this scenario deals with the change in the materials. A detailed analysis was done on the best possible materials for the piping and the pressure vessel which would lead to appreciable decrease in cost without impacting any of the major functions.

The Pressure Vessel is changed to Fiber Reinforced Plastic from the present Carbon Steel and the piping is changed to PVC from the existing Stainless Steel.

These two changes alter the cost significantly as analyzed in the sections below.

Scenario IV: Stackable Unit

As discussed earlier, a combination of design concepts were integrated with value engineering methodologies to come up with the final design of the stackable unit. Along with Scenario 3, Scenario 4 was also deemed to have the highest value in cost merit graph. It offers:

- considerable amount of pipe reduction with the new pipe design
- the new skid design allows the vessels to be stacked on each other with significant reduction in footprint
- The new material proposed results in cost reduction of more than 32%

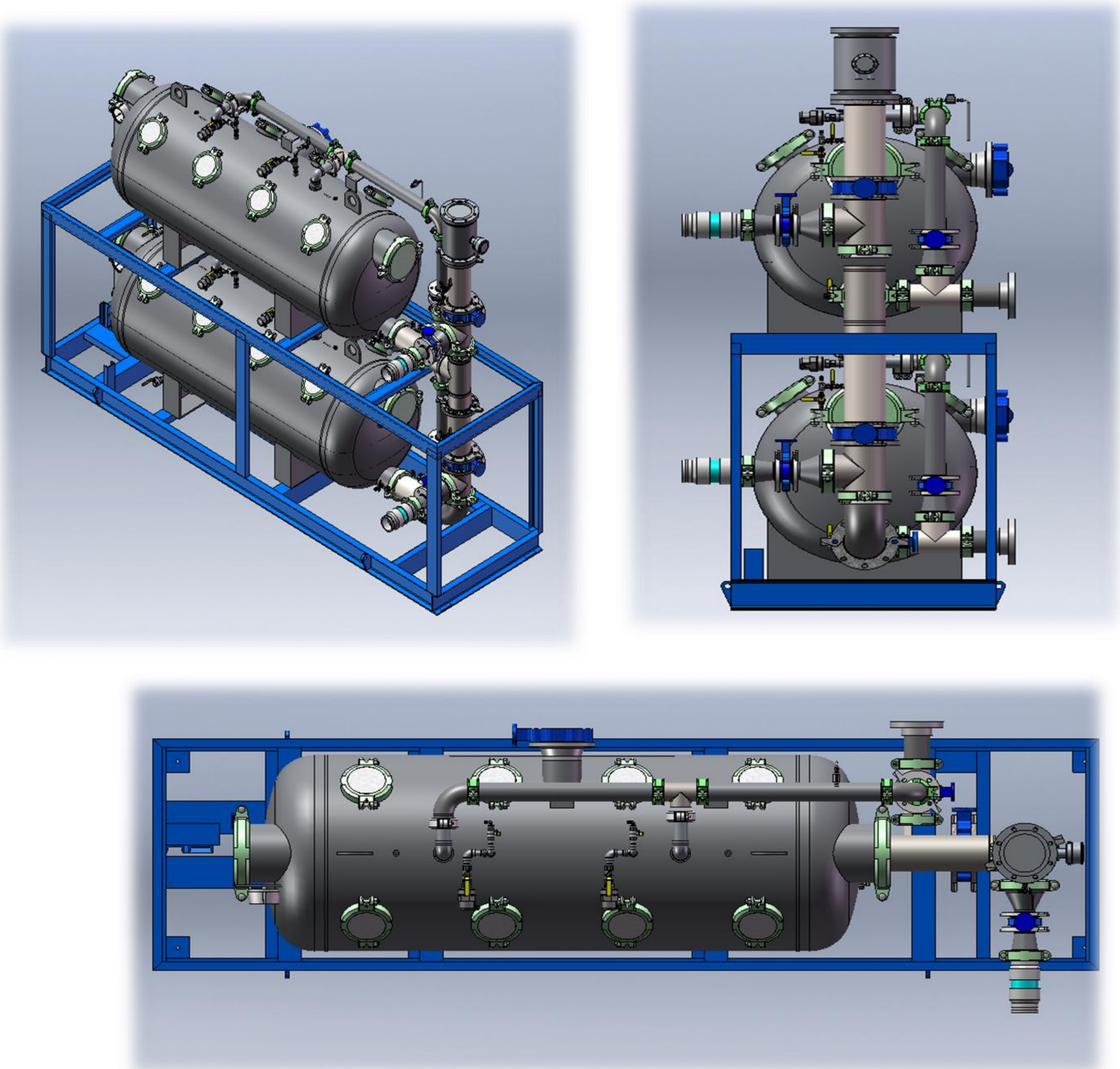


Figure 287: Skid Views: Isometric, Side, and Top

Features

Skid:

The skid is an integral part of the unit as it supports the vessel and the piping of the unit. In Current design, the skid only supports one vessel and has a very high footprint. For the stackable option, the structure of the skid is such that it supports two units on top of each other and the piping. The new design takes into consideration the following requirements:

- The dimensions of the skid for a lesser a footprint
- The structure of the skid needs to have high integrity to support both the vessels

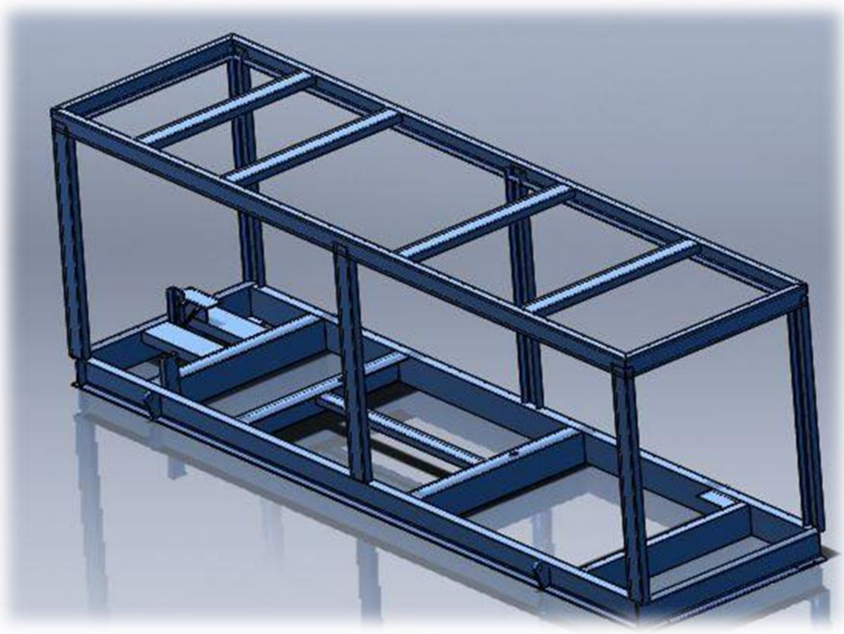


Figure 29: Skid Outline

Dimensions:

Current skid design had a very high footprint as the skid needs to support the extra piping that was on the side of the vessel. Even though the new skid design supports two units, the alternate arrangement of the piping made it possible to reduce the footprint by 66% compared to two units that are not stacked.

The current single vessel has the following dimensions:

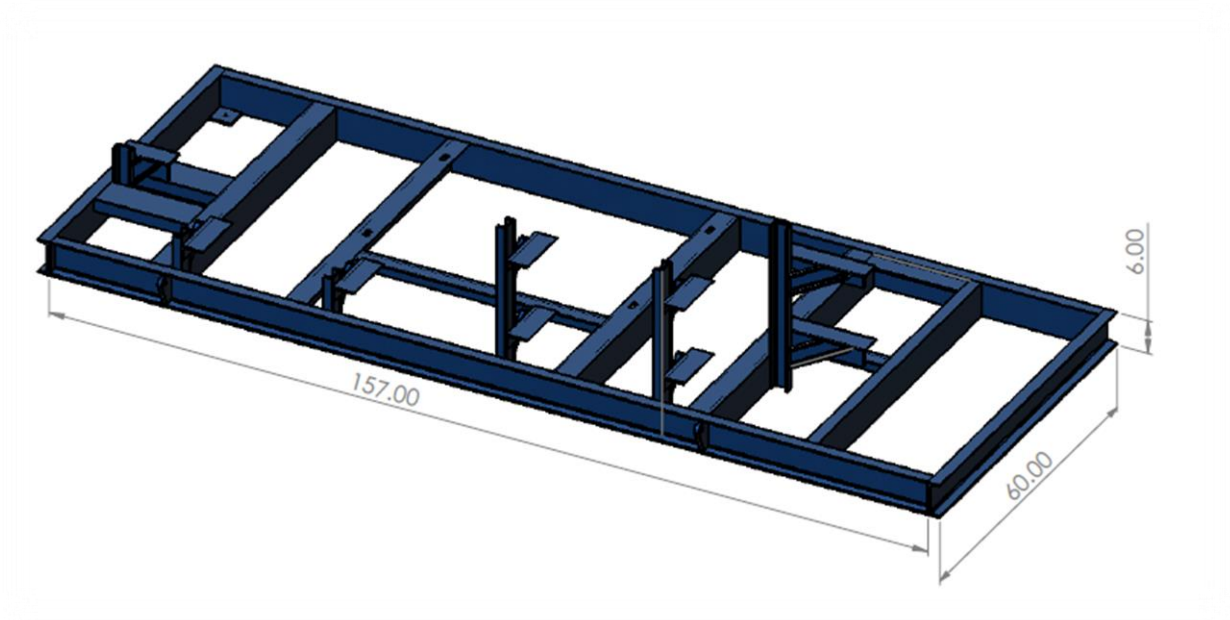


Figure 30: Original Skid Dimensions

Whereas the stackable skid has the following dimensions:

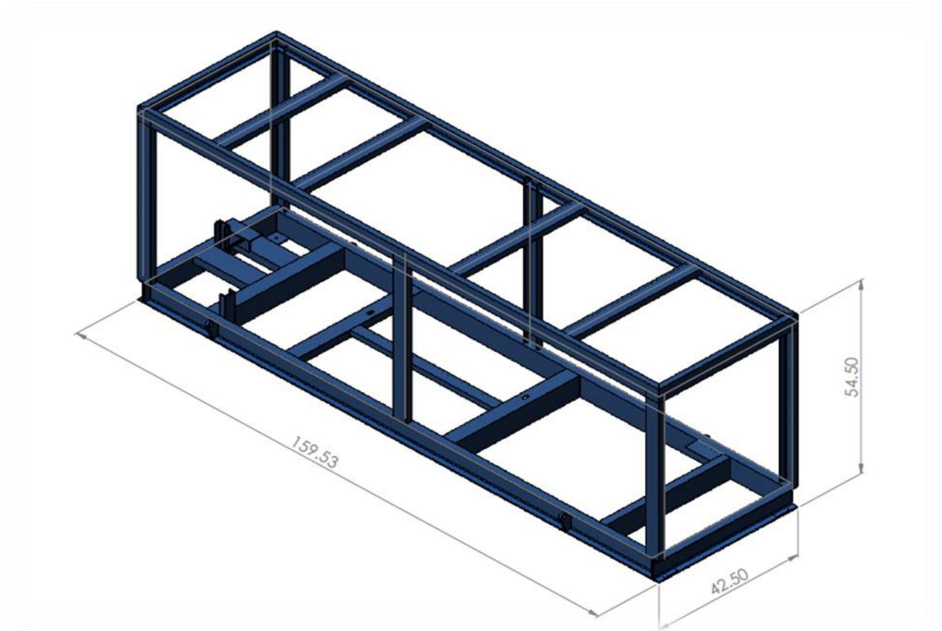


Figure 30: Stacked Skid Dimensions

Footprint Reduction:

Compared to Single Vessel: $\frac{60-42.5}{60} \times 100\% = \mathbf{29.1}\%$

Compared to double Vessel: $\frac{120-42.5}{120} \times 100\% = \mathbf{64.5}\%$

Height Target:

One constraint during the design of the skid was that the overall height of both units stacked on each other was not to exceed 102 inches. Keeping this in mind, the current height of the skid only was 54.50 inches. With this height, the total height of the stackable unit comes to 99 inches which is still under our customer's requirement.

This was achieved by reducing the height of the supports for the vessel and changing the orientation of the inlet pipe and pressure valves from vertical to horizontal. To make sure that the vessel support could endure the weight of the vessel with the new height, their width was increased.

The new skid resulted in significant footprint and height reduction. However, the new design of the piping resulted in length increment of 2.53 inches (2% increment) which is very miniscule compared to the overall length of the skid.

Structure Integrity and stress analysis:

In order to make sure that the skid can support the weight of the two units, the second base on top is supported by columns strong enough to lift the 9000lbs second vessel. The stress analysis performed on the structure proves that this structure can bear such a load on top. Also an important consideration here is to install a steel sheet as a base for the second vessel for appropriate distribution of load. Moreover the columns installed are the HSS (HSS 38x38x4.8 mm) columns, which come from the Handbook of Steel Construction (10^{th} Edition) for the given weight. We solved for the maximum weight the skid would experience, used a safety factor of 20%, and then used tributary analysis to come up with a distribution of loading on the skid. Since the maximum load occurs on the middle columns, we took their force value as the limiting case. For simpler ordering purposes, we recommend buying the same size of column for all 6, instead of smaller ones for the middle two. The analysis and the calculations are attached in the Appendix.

Piping:

The piping of the new design was modified in order to remove unnecessary material and reduce overall footprint. This new piping was moved to one side of the vessel and concentrated at the single outlet of the vessel. This new arrangement of piping incorporates the use of pipe joints which include elbows, tee-joints (normal and reducing tee) and flanges. Also an additional valve was installed to prevent mixing of clean and impure water once the front wash is completed. These components are shown in the pictures below:

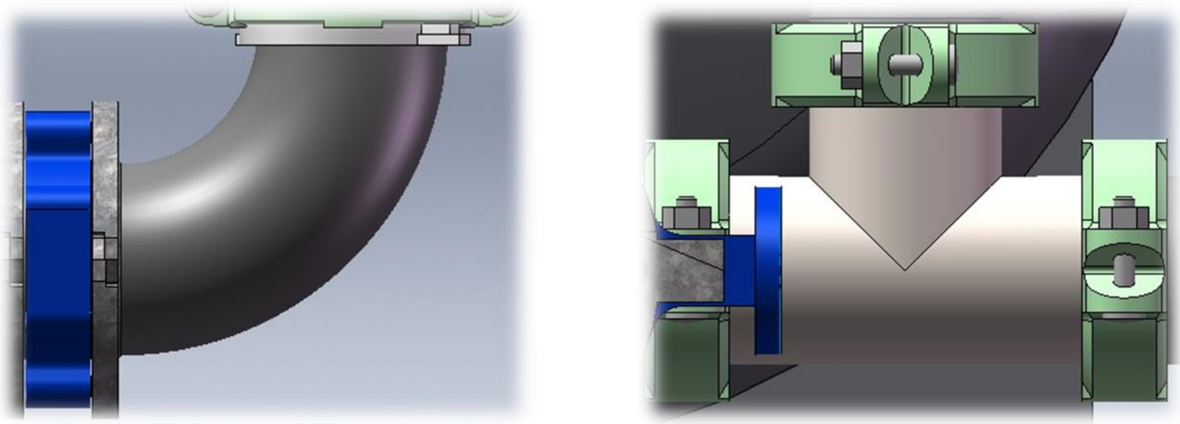


Figure 31: Additional Elbow and T Joints

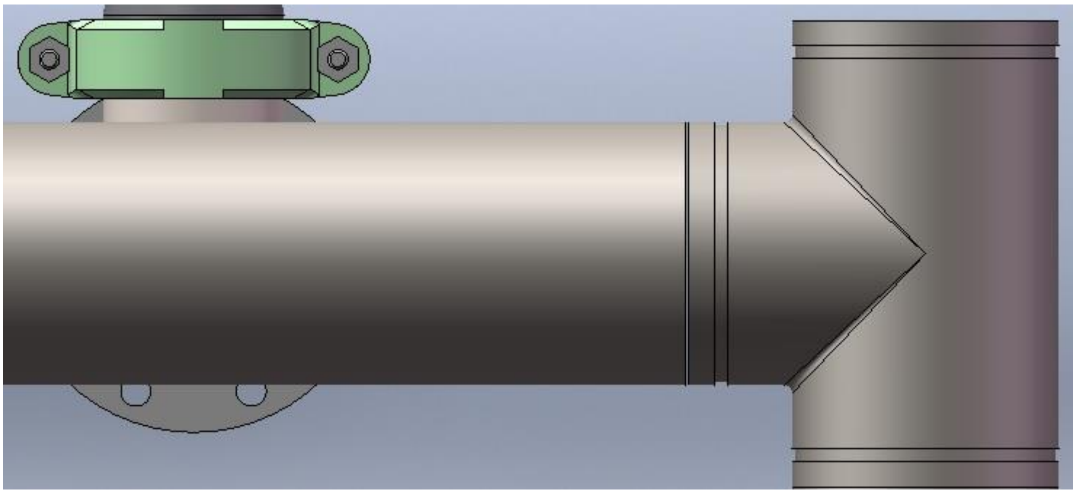


Figure 3231: Pipe Section

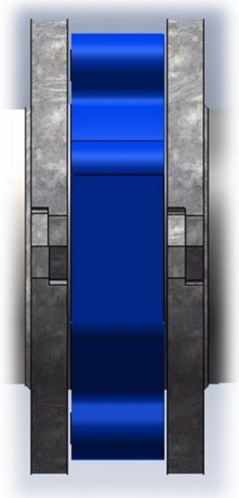


Figure 32: Valve

Moreover, this design interconnects inlets, the outlets and the backwash pipes between both the vessels. This is done to ensure ease in operation and maintenance. The benefit this arrangement offers is that if one vessel is out of service, the other can function properly without compromising production. The skid here is hidden to ensure clarity of design

This shown here as follows:

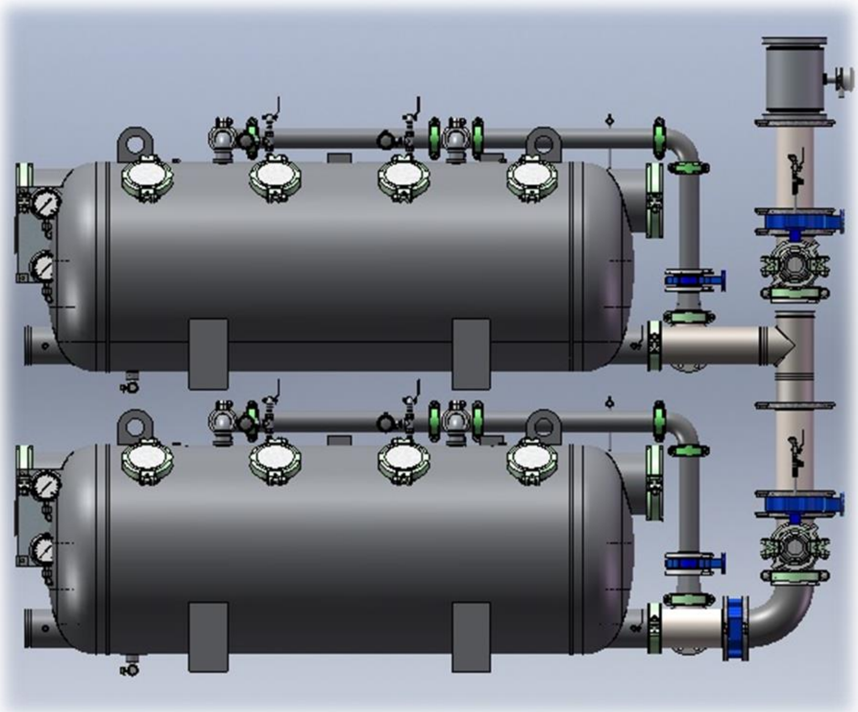


Figure 334: Pressure Vessel Connections

In order to stack the vessels and stay within the height restriction, the orientation of the inlet was changed and made perpendicular to the original design and now resides on the back if the vessel. This lowers both the vessels and also aides in the connection between both the inlets. The side view is shown here for the inlet:

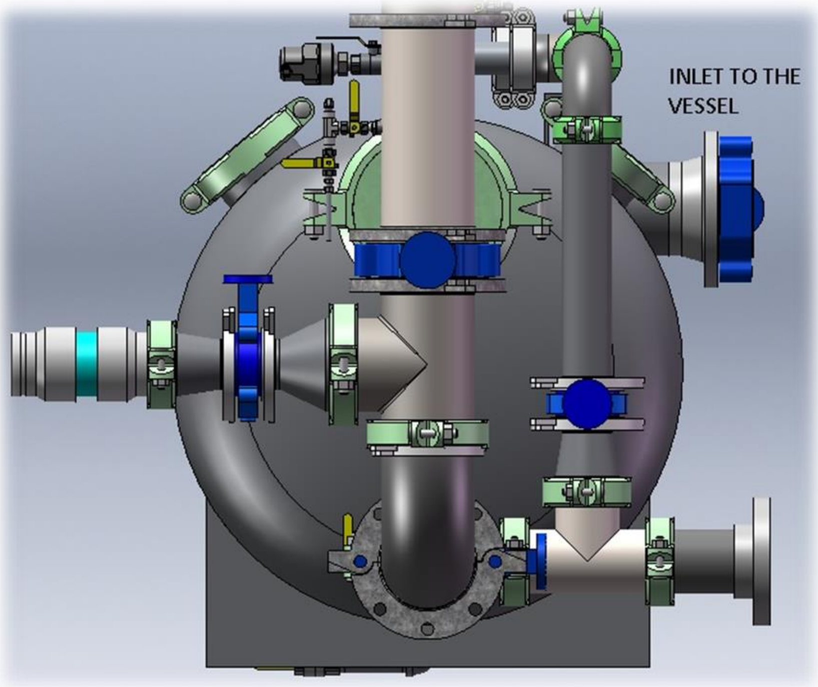


Figure 34: Side View of the Vessel showing the Inlet on the top right.

The impure water enters from the side, passes through the vessel while getting filtered and exits from the right side at the bottom. Now the valves to the waste exit and back wash are closed and the water exits from the outlet for clean water. Once the pressure reaches 1.1 bar inside the vessel, the self-cleaning mechanism is initiated and water flows in through the backwash inlet. Now the valves for the clean water exit, the waste exit are closed and water flows inside the vessel in reverse, goes out from the top and flows through the waste outlet. Also when the back wash stops, and the water is allowed to settle, the valve to the clean water exit is closed and the water flows through the waste outlet until clean.

Cost Analysis for Scenarios III and IV:

Piping was reduced quite significantly on the original design with components like T joints to incorporate more processes more efficiently.

The other major change was to alter the materials of the PV and the piping. This would contribute to a dramatic reduction in costs. Currently, the PV is of Stainless Steel and the piping of Carbon Steel. Through research, the group recognized that the costs could at least be halved for these two components and additional research proved that the materials would not hinder the structural integrity of the system e.g. the PVC piping could handle the design pressure.

Table 5: Scenario III Cost Reduction Table

Component	Original Cost	New Cost	Percentage Savings
Piping	\$10000	\$1500	85%
Skid	\$3000	\$300	90%
Vessel	\$12500	\$5600	55.2%

Table 6 : Scenario IV Cost Reduction Table

Component	Original Cost	New Cost	Percentage Savings
Piping	\$10000	\$1500	85%
Skid	\$3000	\$1300	56.67%
Vessel	\$12500	\$5600	55.2%

We can clearly see that of the few functions whose cost we could reduce, we have done so spectacularly.

Final Recommendations

The team used Value Engineering Principles to analyze the existing design and the client requirements. This enabled the team to identify key areas for improvement, and also come up with different solutions in order to increase the overall value of the product that Sonitec Inc. manufactures. The proposals provide an in-depth analysis on the modifications required to increase this value. This is in terms of both cost reduction as well as the reduction in the covered area of the equipment. After a reasonable analysis of the different proposals and scenarios, the team was able to conclude that the best suggestions addressing the client's needs are as follows:

- Scenario III – This incorporates a detachable skid design instead of the original base which covers a large portion of ground. Also the modification of vessel material to Fiber Reinforced Plastic (FRP) and pipe material to Poly Vinyl Chloride (PVC) reduces the weight as well as cuts costs by a significant amount.

- Scenario IV – This scenario stacks the original vessels on top of each other to increase filtration instead of setting them in a tandem arrangement. Again the modified materials and reduced skid size increases the value when compared to two original vessels arranged side by side featuring all the designs of the initial product.

Once the proposals are implemented, they will enable the client to obtain cost savings of 34% (scenario III) and 32% (scenario IV), respectively. The improved design solution means the client will be able to reduce cost, and also provide a better product at lower price, and thereby gaining market share and distinguishing itself from the competitors. The stacked solution means that the client will be able to provide a differentiated product, optimized for customers who place a premium on space. This will lead to increased applications and hence greater sales and with superior profits.

Since there is no requirement of any higher capital investment than current expenses on the original product, both these solutions can easily be implemented. The ideas proposed are supported by calculations and computer aided models which are attached in the report. A copy of CAD files has also been provided to the client to study the modifications along with this report.

Appendix

Gut Feel Index

Table 7: Gut Feel Index

Gut Feel Index						
Idea	**Adeel**	**Ghufran**	**Khaleeq**	**Maaz**	**Mohammad**	
Stack the vessels.	10	10	10	10	10	**10**
Join Inlets and Outlets for stacked piping.	10	8	5	2	3	**5.6**
Join backwash and exit piping.	7	9	7	6	7	**7.2**
Eliminate second outlet.	3	8	7	7	6	**6.2**
Reduce front piping.	8	8	8	8	9	**8.2**
Reduce width by moving piping to the side. (and therefore piping)	10	10	10	9	9	**9.6**
Remove front wash pipe.	3	7	8	7	8	**6.6**
Join backwash for stacked unit (for both vessels)	8	8	9	8	7	**8**
Modify material.	10	10	10	10	10	**10**
Reduce skid size.	9	8	8	9	8	**8.4**
Make skid detachable for ease of transport.	7	8	9	5	5	**6.8**
Media to be transported in bags.	5	7	7	9	7	**7**
Bags to be placed in the manhole accesses.	7	7	8	9	6	**7.4**
Bags to be easily opened.	4	4	3	9	4	**4.8**

All scores are out of 10, with 10 being the best and 0 being the worst. All ideas with scores greater than 5 were developed further.

Functional Diagrams

Since the functional diagram was very detailed, we included just one fully expanded branch in the main report. The full diagram is below. It has been divided into two, since the expanded diagram is too big to appear in a single page.

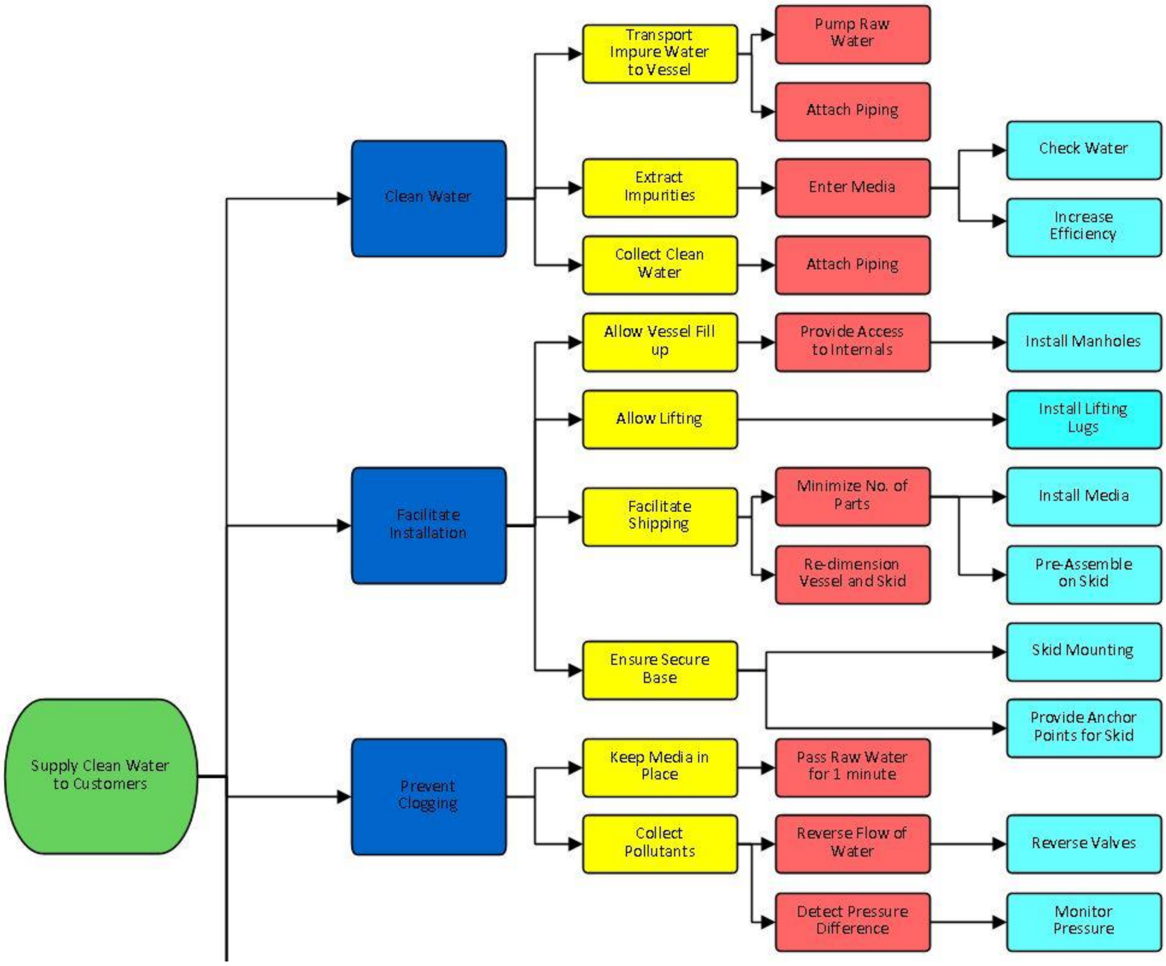


Figure 35: Functional Diagram Part 1

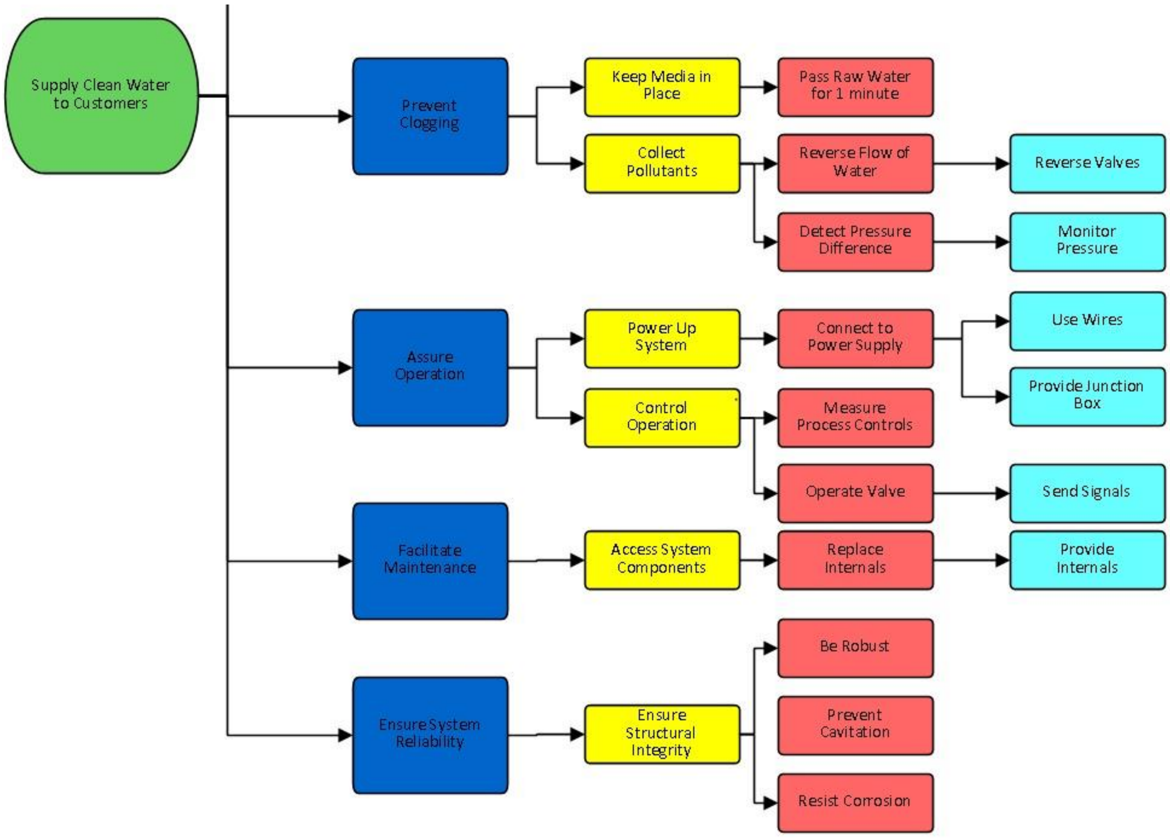


Figure 36: Functional Diagram Part 2

Stress Analysis

Key Assumptions:

- The steel sheet perfectly distributes the weight of the upper pressure vessel over the 6 vertical columns.
- Tributary area force division concept used to determine weight division.
- Columns are simply supported.
- HSS-columns used for columns.
- Beam to column, and sheet to column connections are outside of designer scope; they exist but calculations to determine their size will not be performed. This stress calculation has been deemed acceptable by the client.

Key data:

Length (l):	155.215 in		
Breadth (b):	38 in.		
Area:	5898.2 in^2		
Weight to be born =	9000 lbs.	included safety factor:	0.2
Weight used:	10800 lbs.		

We observe that the force on the middle vertical columns is double that on the ones in the corner. We expect that, from the very nature of tributary force analysis. We therefore will solve for the forces on the middle columns and take them as our limiting factors. We are using a 10% safety factor, which indicates the nature of assumptions in our analysis.

The distributed force

$W \frac{lb}{in^2} = \frac{10800\ lbs}{5898.2\ in^2} = 1.83\ \frac{lb}{in^2}$ =

is multiplied by the breadth to obtain the one dimensional distributed force on the columns.

$$W.b\frac{lb}{in} = 69.6\ \frac{lb}{in}$$

Through tributary analysis, we note that the force on the middle columns is:

$$\frac{W.b.l}{2}\ lb = 5400.0\ lb$$

We obtained this through multiplying the one-dimensional distributed force by the tributary length which is: $\frac{l}{2}$.

We then obtain the force on one of the middle columns by dividing the above force by 2.

$$F_{middle\ column} = \frac{W.b.l}{4}\ lb = 2700.0\ lbs$$

Now, we use this load value in the Engineering Handbook. With a height of 54.5 in, that is 1.3843m, for a load weight of 2700 lbs, that is 12.001 kN.

We find that our initial idea of using I-Beams is not practical, since the minimum load I-Beam columns are designed for at our height, is 150 kN, which means an overdesign of more than 10 times. Therefore we researched HSS (Hollow Structural Sections) with dimensions of 38 x 38 x 4.8 mm. This satisfies our conditions of 2700 lbs, with a height of 54.5 in.

Cost Analysis Data

A detailed cost analysis is provided above in the functional and cost analysis section. Below we have a cost analysis table where functions from our filtration systems were organized on the top row and then components, equipment and machinery were listed down the first column. The components were then allocated a cost, as a value judgment, depending on how much we thought that it contributed to the respective functions.

Next, the client gave us a function worth, which was in his eyes the ideal worth of the function after our discussed improvements were carried out. This gave us an idea on which functions needed cost improvements and which ones could tolerate an increased cost. Weightage was also calculated depending on what the function cost was worth in comparison to the total cost.

Cost-Funtion Analysis Table

Table 8: Cost/Function Analysis Table

	Pump Raw Water	Flow through inlet	Inject Raw Water	Collect Water	Access inside vessel	Allow Lifting	Facilitate Shipping	Secure Base	Reverse Flow of Water	Detect Pressure Difference	Preserve Media	Rinse (1 min)	Connect to Power Supply	Measure Process Conditions	Resist Corrosion	Being Robust	Cost of Components
Inlet pump (Raw water feed)	1000		300									300					$1,600.00
Piping (Inlet Piping)	750	3250															$4,000.00
Supports (Piping for inlet)																250	$250.00
Injector			1000														$1,000.00
Collector				2000													$2,000.00
Lifting Lugs Skid						80	20										$100.00
Lifting Lugs Vessel						40	10										$50.00
Skid (Base)							500	2500									$3,000.00
Anchor Plates and bolts								250									$250.00
Wiring													700				$700.00
Junction Box Control Panel	300		400	300	200				300	500				500			$2,500.00
Differential Pressure Transmitter (DPT)										3500							$3,500.00
Flow Meter														5000			$5,000.00
Inlet Flow Control Valve	500		3500														$4,000.00
Wiring	600		600	500	1000							200	500	1100			$4,500.00
BW Piping									4000								$4,000.00
BW Piping Supports																300	$300.00
BW Pump									600								$600.00
Flow Controller			200						300								$500.00

Rinse (On/Off valves)											400	500					$900.00
Rinse Piping											500	1500					$2,000.00
Pressure Vessel				4500	2500										3300	2200	$12,500.00
Safety Valves																2000	$2,000.00
Manual Air Vent					450												$450.00
Filtration Media											240						$240.00
Programming	300		300		300				300				300	300			$1,800.00
Function Cost	$3,450	$3,250	$6,300	$7,300	$4,450	$120	$530	$2,750	$5,500	$4,000	$1,140	$2,500	$1,500	$6,900	$3,300	$4,750	$57,740.00
Function Worth	$2,000	$2,000	$5,400	$5,400	$5,200	$400	$800	$2,000	$3,200	$2,000	$2,000	$400	$400	$4,000	$2,400	$2,000	$39,600.00
Value Index	1.73	1.63	1.17	1.35	0.86	0.30	0.66	1.38	1.72	2.00	0.57	6.25	3.75	1.73	1.38	2.38	1.80
Function Cost	$3,450	$3,250	$6,300	$7,300	$4,450	$120	$530	$2,750	$5,500	$4,000	$1,140	$2,500	$1,500	$6,900	$3,300	$4,750	57,740 $
Percent	5.98	5.63	10.91	12.64	7.71	0.21	0.92	4.76	9.53	6.93	1.97	4.33	2.60	11.95	5.72	8.23	100.00
Function Worth																	