Reduced Water Emissions in Fabric Care Appliances

Sponsored by Whirlpool Corporation

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ABSTRACT

Whirlpool Corporation wishes to improve the eco-efficiency of their fabric care appliances with regards to water and energy. This team seeks to design innovative solutions to filter chemistries and contaminants out of the water prior to disposal to allow for reuse. We performed major functional analysis, and used that to create preliminary design concepts. We identified strengths and weaknesses of each possible design, and chose the best design. This report contains the background and customer information as supplied by Whirlpool and the details of our design solutions and our design selection followed by engineering analysis of our design, and a more detailed design.

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INTRODUCTION

Whirlpool is the global leader in manufacturing and marketing in major home appliances. In addition to Whirlpool label, they also market brands such as Maytag, KitchenAid, Jenn-Air, Amana, and many others. In an age of environmental awareness, Whirlpool wants to be the leader in innovative and cutting edge technology to ensure that their products are eco-efficient. Today's consumers are more environmentally aware than ever and want to use more eco-efficient products. Current washing machines dump polluted water down the drain, making them very unfriendly to the environment. Our main goal was to reduce water emissions in the washing machine by designing a system that allows for the filtration, recovery, storage, and reuse of dirty wash water, so that Whirlpool can retain its goodwill for being an eco-friendly company, and keep its market share high by appealing to consumers who care about the environment.

INFORMATION SEARCH

The improvement in eco-efficiency of fabric care appliances combines a number of various engineering disciplines, and therefore requires an extensive level of research. Our team has researched the various operations and processes involved in the washing process, and how it all culminates in the design of a washing machine. We have met with our sponsor for the project at their world headquarters in St. Joseph, Michigan and discussed recent progress made in the industry, as well as Whirlpool's commitment to excellence in innovation. In order to understand the infrastructure of a washing machine, Whirlpool has provided one for us to tear down and then piece back together. Appendix A (pg 17) shows two of the tear down phases.

We have carried out an extensive patent search to familiarize ourselves with the industry and the current technologies available in related fields, and to ensure that we were not 're-inventing the wheel'.

Patents

The first step in our design process was to conduct research on technologies that are being used in the market, so that we have a platform from where to begin generating our design concepts. An important step in understanding the current filtration technologies is to understand some of the patents that have been issued on the subject. U.S. Patent number 5097556 describes a filtration device that uses ozone to clean the dirty wastewater. This system stores the water in a tank and it is sent through an ozone generator and is reused in the wash process. This is an innovative solution to cut down on the amount of water used during the wash cycle.

U.S. Patent number 5928490 describes a wash system that uses electrodes to oxidize the dirty wash water in order to eliminate the contaminants. This water is stored in a tank and reused during the wash cycle. There is also an extra tank of fresh water to make up for any water lost during the filtration process. The system contains one electrolytic cell with an enclosed compartment containing an anode and cathode near the opening to the surrounding liquid. Thus, when the compartment is immersed in water, it oxidizes deleterious components without damaging the fabric being washed.

Patent number 5493745, owned by Whirlpool Corporation, describes a water filtration and recirculation system that uses a pair of 2-way valves to direct the outflow of wash water either back into the wash tub, or out into the drainage system. The design implements a tubing manifold with a reversible pump to direct the water flow.

A method of cleaning water was patented by Robert James Popovics, (Pat. Number 5049252) and it describes a method of using opposite charges on electrodes, and passing a current through the water to ionize unwanted particles and attract them to the electrodes, resulting in a chemically neutral solution. This method is of interest to us, as its applications are very broad based, and may be adapted for a tubing manifold for recirculation.

Patent number 4595421, owned by Sharon T. Cohen, describes a method of cleaning deposits on electrodes using a rotating member with a semi-flexible head and radically projecting brushes that can scrape off residue that is accumulated on the electrode plate in a circular motion, while minimizing the damage caused on the electrode.

Maytag Corporation, which was recently taken over by Whirlpool, owns another patent, numbered 6402962, which describes a self-cleaning filter to be used in the same manifold as the recirculation system. The filter contains a bypass port, which lets water seep in to relieve the pressure gradient and to flush out the screen of residue on the filter, so that it can be used continually without having to clean it manually.

Our team decided to continue to research the use of the self-cleaning filter in our design solution, since it is already owned by Whirlpool Corporation and therefore we have access to all the intellectual property associated with the patent.

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

Our sponsors at Whirlpool Corporation asked us to design a filtration system that would be implemented into their current Duet Mid-Range WED9400SXX washing machine. They specified certain constraints and requirements for our design solution.

The addition of our proposed design must not exceed the current washer dimensions, and hence any additions to the interior that we propose must fit within the space available inside the washer. The space occupied by the storage bin at the base of the washer is expendable, and the storage bin can be replaced by our design. Hence the space we have for our design is limited by the size of this storage bin.

Our design must effectively filter out pollutants from the wash water, and store the filtered water, while preventing the build-up of bio-film in it. This requires our design to contain a tubing manifold that will contain filters in the line, and a storage tank to hold filtered water, while preventing the build-up of bio-film. This involves the neutralization of the chemical compounds in the wash water.

The filtration system we design must last a minimum of 6 months before the consumer has to make any changes to the filters in the washer. This is so that the modification we make does not hamper the user-friendliness of the washer, and reduces the effort the consumer has to put into the product.

Engineering Specifications

Although the majority of our goals in designing the water recycling system are inherently qualitative, there are certain specifications that we are asked to adhere to with our submission of a proposal.

Our sponsor has asked that our design's full implementation fit inside of the current model washer that they supplied to us. The current washer design has a compartment for storage at the bottom of the washer, which Whirlpool has decided to reallocate for storage and filtration system. This storage compartment measures 18.5” X 22” X 12”. This amounts to 2.83 ft^3. This would allow us to store up to 21.2 gallons of water.

Our overall goal in water use reduction is a 75% decrease in water intake, which amounts to approximately 3.5 gallons per load of laundry instead of 14 gallons, and a savings of approximately 2700 gallons of water load saved per machine per year.

In staying consistent with the company's initiative to manufacture products that require minimal upkeep, it is required that our system operate standalone for at least six months before any sort of maintenance need to be done. This amounts to approximately 130 full loads of laundry before any sort of filter replacement or manual adjustment.

Our implementation will employ a dynamic, real-time filtration system to operate during the wash cycle. Under these conditions, it is required that we prevent any particles over 1μm to pass through in the recycled water transport.

A fluid flush and replacement will occur between the wash and rinse cycles of the unit. After the rinse cycle is completed, the water is to be stored for use in the wash phase of the subsequent load's cycle. This water, because of the expected time between the use of the washing machine, needs to be virtually free of contaminants and soil in order to prevent bio-film and other adverse effects in the next use. Therefore, it is required that we prevent any soil over 0.5μm stay in the water reservoir between uses for any length of time. Table 1 below summarizes these specifications.

Engineering Specifications	
Size of our design solution	Less than 2.83 ft^3
Minimum particle size	Particles less than 1μm in diameter
Store filter water	Tub capacity = 4 gallons
Minimal Consumer Interaction	Filter change every 130 loads (6 months)

Table 1: Engineering Specifications

CONCEPT GENERATION

After our initial meeting with our sponsors from Whirlpool, we examined the wash cycle and brainstormed ways to eliminate contaminants in the wash water in order to reuse it. The first function of our design is that our design must remove pollutants from the water. In order to remove pollutants, we must filter the water. Filters have a tendency to clog, so we decided that we must either clean the filters or replace them. Storage of the filtered water was the next function that our design must include. Some problems arise such as bio-film buildup, which we need to prevent, as well as means of pumping the stored water back into the washer. Our design must fit into the empty spaces in the washer. Whirlpool has a storage bin under the washer that can be used for this purpose. Our design must fit in a space of less than 2.83 ft^3. Our design must be reliable in order to be incorporated into the dependable products of the Whirlpool Corporation. Similarly, minimal customer interaction with our system is optimal. It should not be a hassle for the consumer to use. For example, the customer should not have to change the filters frequently, or clean any part of the mechanism on a regular basis. These functions are illustrated in a FAST diagram in Appendix C (pg 18).

After we identified the necessary functions for our design, we created some preliminary design solutions. The first solution for filtration was the use of electrodes to polarize the water and draw the pollutant particles out. These particles are then flushed from the system and the rest of the clean water is sent to storage.

The next solution is a multi-stage filtration process. This process would gradually eliminate waste particles by size, and in turn produce clean water for re-use.

The next design was a belt-drive agitator to spin the clothes in the bottom half of the front-loading washer. This would effectively eliminate the use of the top half of the tub, allowing for a storage tank.

A main problem with the currents attempts to filter and recycle wash water is the clogging of the filters. We decided to use a self-cleaning filter that would use back pressure to clean the filter. This filter had been patented by Maytag Corporation, which has recently been bought over by Whirlpool, and hence does not count as an Intellectual Property violation.

After cleaning the wash water, we needed to design methods of storage. There is already a storage tub underneath the front-loading washer to store laundry accessories, and we plan to use this space for water storage instead.

Using a morphological chart, we related our preliminary designs to the functions that we require our final designs to entail. This morphological chart can be found in Appendix D (pg 18).

From this chart, we decided to combine some of our designs in order to produce the best products.

CONCEPT EVALUATION AND SELECTION

Multi-Stage Filtration

Whirlpool has not been able to complete a whole wash cycle using recycled water without any clogging. We examined a patent owned by Whirlpool that describes a self-cleaning filter used in a washing machine. We wanted to use the basic principles described in the patent, but add some additional features that would make it even better. In order to filter out the required amount of contaminants, we would add multiple layers of filters. This multi-stage filtration would help to sift out the small particles of pollutants in the dirty wash water. Three levels of filters would filter out particles from those greater than 1µm down to detergents at the sizes of .001-.1 µm. The filter contains a bypass port, so that if it gets too clogged, water can seep through to the other side of the filter and equalize pressure on both sides of the filter wall to release the particles gathered on it. This water is then drained off, eliminating the waste and allowing for later wash cycles. A sketch of this design can be found below in Figure 1.

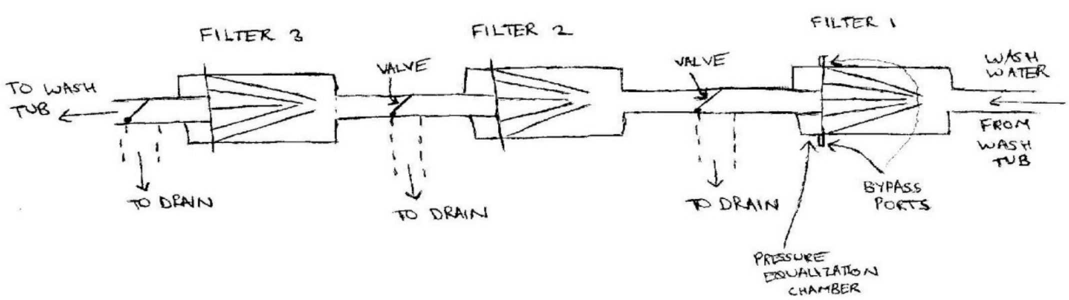

Figure 1: Multi Stage Filtration

A potential problem with this solution is the efficiency of the filters, and the self-cleaning mechanism. If the filters are not very efficient, it could lead to major problems as the clogged filters would constrict the flow of water and increase pressure in the manifold to a dangerous extent. Extensive testing of these mechanisms, after construction might show that this solution is not even feasible. Whirlpool owns the patents for the self-cleaning mechanism, but do not know its current effectiveness.

Electrodes

A possible solution to the filtration efficiency problem was to convert some of the tubing manifold into makeshift electrodes. This would pass a small current through the water in the wash water outlet tube, and charge the inside of the tube with the opposite charge. This would ionize the dissolved solvents, and attract them onto the charged wall of the tube, where they would collect until the cycle is over. Once this was done, the polarity of the electrodes could be reversed with the use of a controller, so that the solvents ionize again and dissolve into the rinse water that is to be disposed off as drainage. A sketch of this design is shown below in Figure 2.

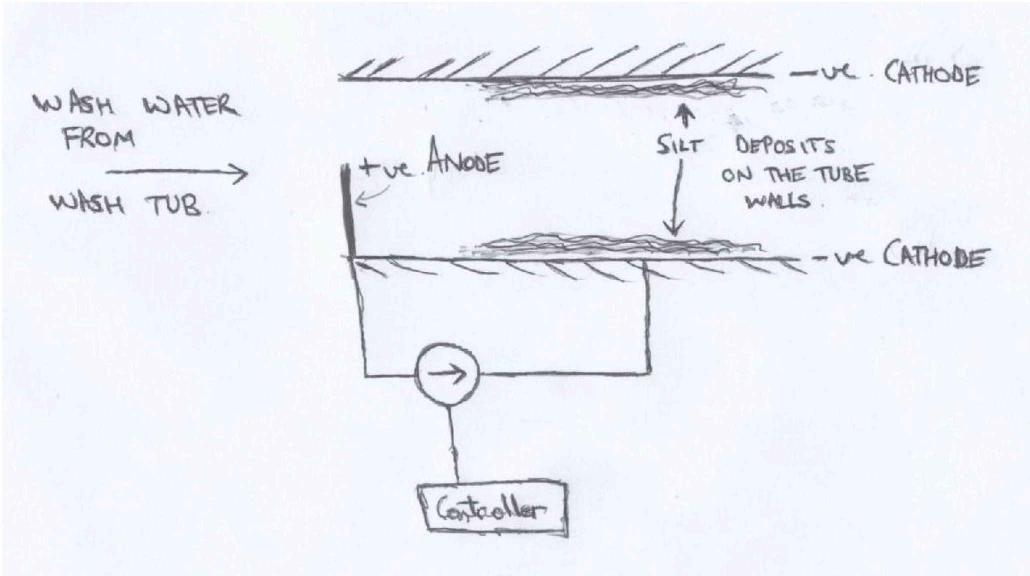

Figure 2: Use of Electrode

This would serve as a dual-purpose system, as it would eliminate the need to store filtered water, and the water would be filtered in a steady-state process, which would make the filtration system more efficient. Another advantage of using this system is that the cost of operating a system such as this is miniscule compared to the cost of running a washing machine. The electrodes need to be supplied at around 12V of potential difference and 5Ato be effective. This is a very small amount of energy, 60W, compared to the washing machine which uses 1.2kW per cycle, so that the only additional cost is that of supplying electricity to the electrodes to keep them charged.

A major problem with the system, however, is that in practice, particles generally get ‘glued’ to the electrodes, in a way that that requires physical scrubbing of particles off the electrode wall. A possible solution we identified to clean the electrodes, is the use of a device which has been patented by Sharon T. Cohen under patent number 4595421. This patent describes a device which consists of a rotating blade with finger-like projections that scrub the electrode wall to remove the particles that are deposited on it.

The issue with the use of this device is that there are severe space constraints in the washing machine, and that a device such as this would require complex parts to be installed within the tubing, which would restrict the flow of the wash water, and would be very difficult to maintain. This would require the consumer to clean out their wash system which is very undesirable.

Belt-Drive Agitation

The belt-drive agitator would help to eliminate the wasted space in the wash tub. In the front-loading machine, about half of the tub is actually used for the wash process. It is circular to help with the agitation. The belt drive would eliminate the agitation of the entire tub. Only the bottom have would be used for this conveyer-like action. The top half of the wash tub would then be free for water storage. We combined two of our designs to create the design using the top half as a water storage tank, while the clothes are circulated in the bottom half with the belt drive.

The thought behind this solution is good, but the current, proven wash cycle is changed completely. Years of research have gone into producing the current methods of agitation in the wash tub, and it is probable that the belt drive method would not effectively agitate the clothes to promote good washing. Also, the use of the top half of the tub for storage greatly reduces the usable tub space for large loads of wash. This would be undesirable for the current consumer.

Turbulent Flow Particle Separation

This design uses turbulent inducing pump in the tubing manifold to force the wash water into a "turbulent pattern", such that soil and other particles suspended in the water are projected onto the sides of the tubing as a result of their inertial properties. Once the particles are projected to the tube wall, they are trapped on an abrasive coarse lining on the inside of the tube wall. A sketch of this design is provided below in Figure 3.

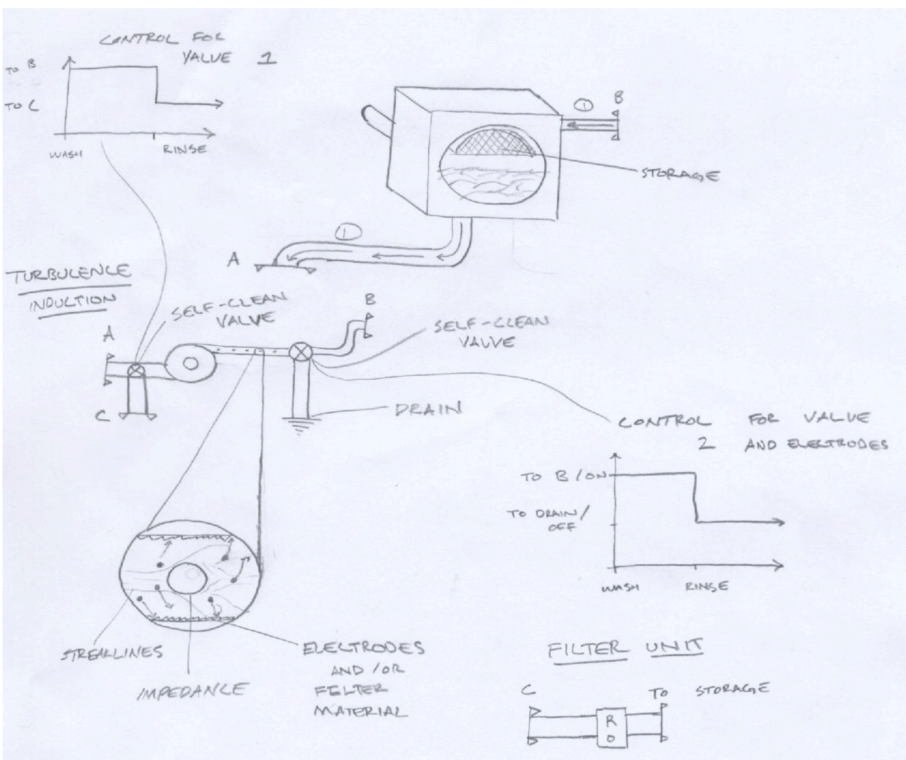

Figure 3: Turbulent Flow Particle Separation

One of the primary advantages to the turbulent flow system is that it requires no filter material to clear the wash water of larger contaminants and therefore has a longer life expectancy without maintenance than other systems. Another advantage is that the throughput on this system would be as fast as the draining from the tub, so there would be no added downtime to the appliance. This is because there is no dependence on decanting or limited flow rates on the filtering system. It is also possible to use the pump already in place in the washer as a part of this system, if a proper routing and valve system were used to manipulate flow.

A downside to this design is that the research and development will be lengthy. Turbulent flow is a relatively uncharted territory of fluid mechanics, so it is realistic to infer that the pursuit of a system that would effectively trap particles without lining the pipe with filter chemistry or crippling the flow rate of the wash water could take a few months at the very least.

Water Storage Tank
We would incorporate our design of a water storage tank in the section underneath the washing machine in order to reuse the water that we clean through either one of our filtration mechanisms. A brief sketch of this tank can be found below in Figure 4
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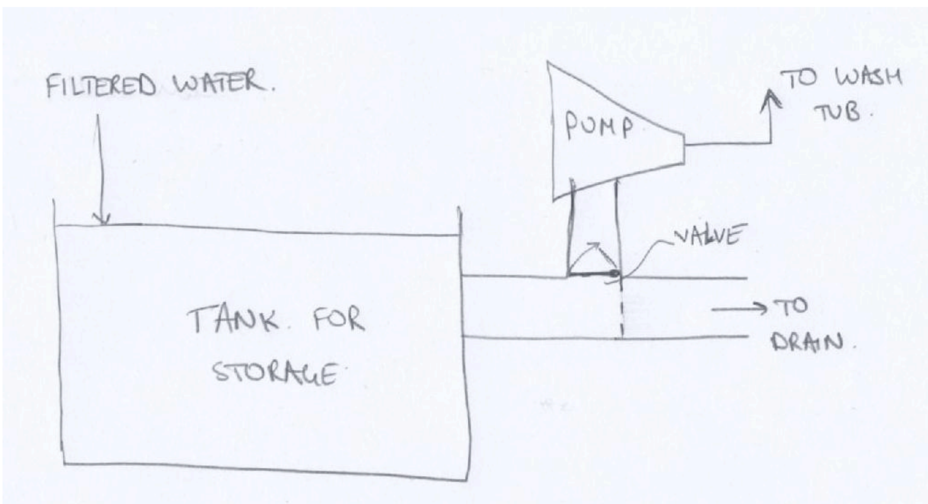


Figure 4: Water Storage and Recovery Tank

We summarized the pros and cons of our design concepts using a Pugh Matrix (Appendix E), to identify the optimal design solution. After analyzing our concepts in great detail, we agreed on our final design concept.

SELECTED CONCEPT

The best design to pursue is the multi-stage filtration design along with the water storage tank. The design would involve the use of Maytag's patent number 6402962, which describes the self-cleaning filter. Our design will use three of these filters in series with each other, with variable filter materials, to effectively filter out particles of varying sizes. The design would involve a series of pipes that connect the filters to and from the storage tank, and the wash tub. The filters produce a certain amount of backwash that contains residue due to the bypass valves that allow for self-cleaning. To flush out backwash from the filters, there will also be a line that dumps filter backwash into the drainage, attached to all three filters. In addition, this design will require the use of the storage tank, which will hold the filtered water until the next use. This design will also require an electric pump that will be used to force the filtered water back into the wash tub when required.

ENGINEERING ANALYSIS

In selecting a pump to run the proposed system, considerations were made regarding all significant sources of energy loss in the flow of the recycled water. These energy losses are due primarily to friction in the flow, elevation changes, and pressure gradients across the filters being used.

Friction Loss in Pipe

Loss of flow energy due to friction in the flow is characterized by a term in the Bernoulli equation called viscous head. Assuming laminar flow and a constant pipe diameter, this term is represented as follows:

$$hv = f * (L*V2) / (2*D*g)$$

Where L is the length traveled by the flow, V is the flow velocity, D is the diameter of the piping, g is the gravitational constant, and f is the pipe friction factor. In laminar flow, the friction factor is:

$$f = 64/Re$$

Where Re is the Reynolds number of the flow, in this case given by:

$$Re = V*D / v$$

with v representing the kinematic fluid viscosity.

Inputting known values and conservatively estimating unknowns, these calculations amount to a total head loss from friction of about .9 inches in 8 feet of PEX tubing.

Elevation Change

In order to estimate the head loss associated with bringing the liquid to the top of the machine during recycling, it was conservatively assumed that the fluid would have to be brought up the entire height of the unit, which is 38 inches.

Pressure Loss in Filters

No figures are given from the distributor in terms of pressure loss across the filters selected. Therefore, an estimated range was necessary in choosing potential pumps. During research of a large selection of filters available, pressure gradients ranged from .12 psi all the way up to 8 psi, but the majority of filters had a pressure drop less than 2 psi. The use of three filters means that our pressure drop is expected to be less than or equal to around 6 psi. This pressure drop represents a head loss of about 13.8 feet.

FINAL DESIGN

A final design was selected based primarily on overall performance. The multiple-stage filtration is a proven method for decontamination, and is the most cost-effective, robust, and versatile option.

The typical wash cycle consists of three fills of the wash tub, amounting to the use of approximately 14.57 gallons of water. The implementation of multiple stage filtration exploits the difference in standards for water cleanliness in the two cycles. After the first drain of the wash cycle, the exhaust flow is processed through three stages of filtration, and pumped back into the wash tub for the second fill. This process is repeated for the third fill of the wash tub.

The flow rates supported by the filters selected, as quoted by the distributor, are all sufficiently large that they will not impede the drainage flow or the inlet flow for the wash tub. The smallest flow rate supported is 5 gallons per minute. This is the rate through the smallest filter (5 micron).

After the wash cycle, the unit is drained entirely of the used wash water. Standards for clean rinse water are much more demanding, so fresh water must be drawn from tap.

Upon completion of the rinse cycle, the used water is processed through the three stages of filtration, and subsequently routed (via a valve after the filters) to a reverse osmosis (RO) system, and then into the storage tub.

The next time the washing machine is used, the first fill of the wash tub is drawn from the storage tub. Therefore, this system ideally eliminates three of the four fill stages of the wash tub, reducing water used by the fabric care appliance by roughly 75%.

The robustness in this design is that it can be aligned with Whirlpool's innovative architecture strategy to support multiple brand platforms. The filters selected can be modularized for different lines of fabric care appliance, and tailor-fit to the expected contamination for a certain lifestyle or geographic region. Variations in design parameters such as micron-rating of the filters and the number of filters used can be applied to designate fulfillment of many customer requirements, including but not limited to average time between customer interactions and maintenance, cost of the unit, and cleanliness of the recycled wash water.

Based on our design calculations, we found parts that were readily available in the industry. Our design will use three filters of varying micron ratings to remove particles of different sizes. A rough CAD model of this system is shown in figure 5, below.

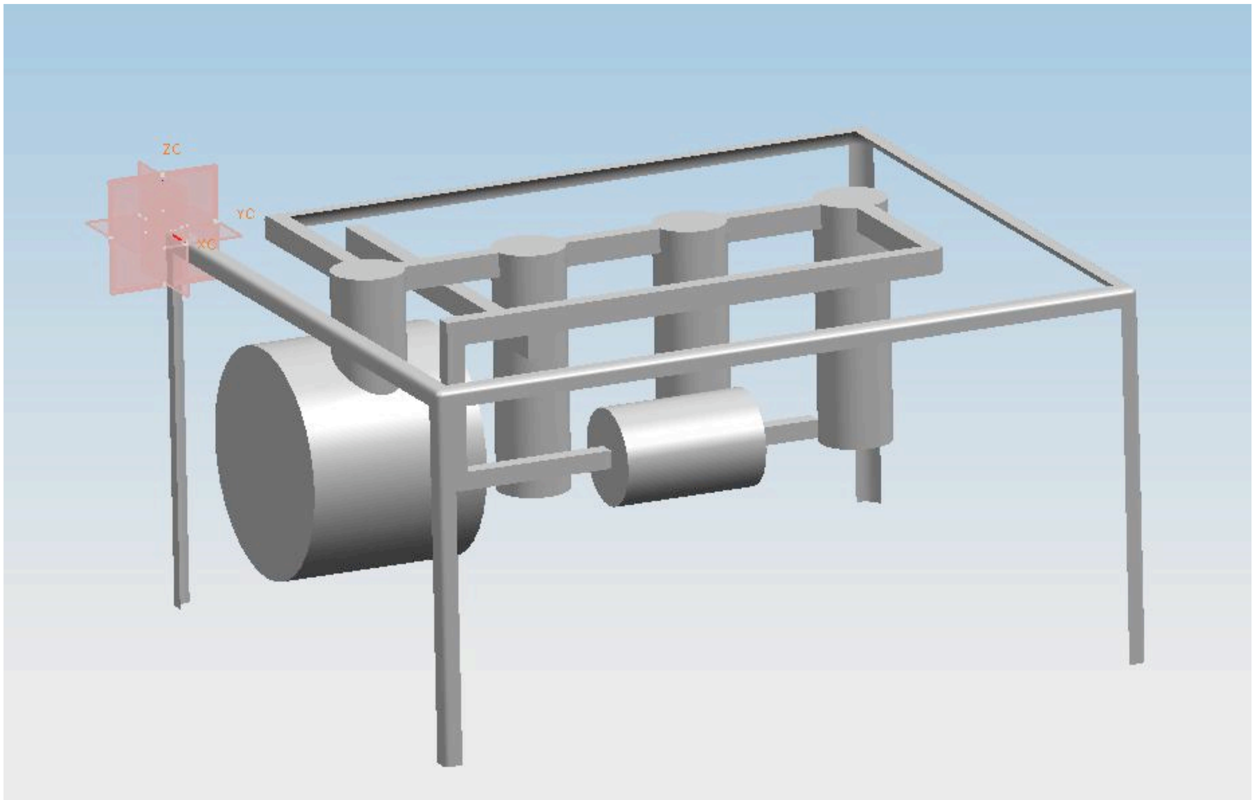


Figure 5: Filter System CAD Model

Our design for water storage is a molded tank that fits around the filter system components in the pedestal. A CAD model is shown below in figure 6.

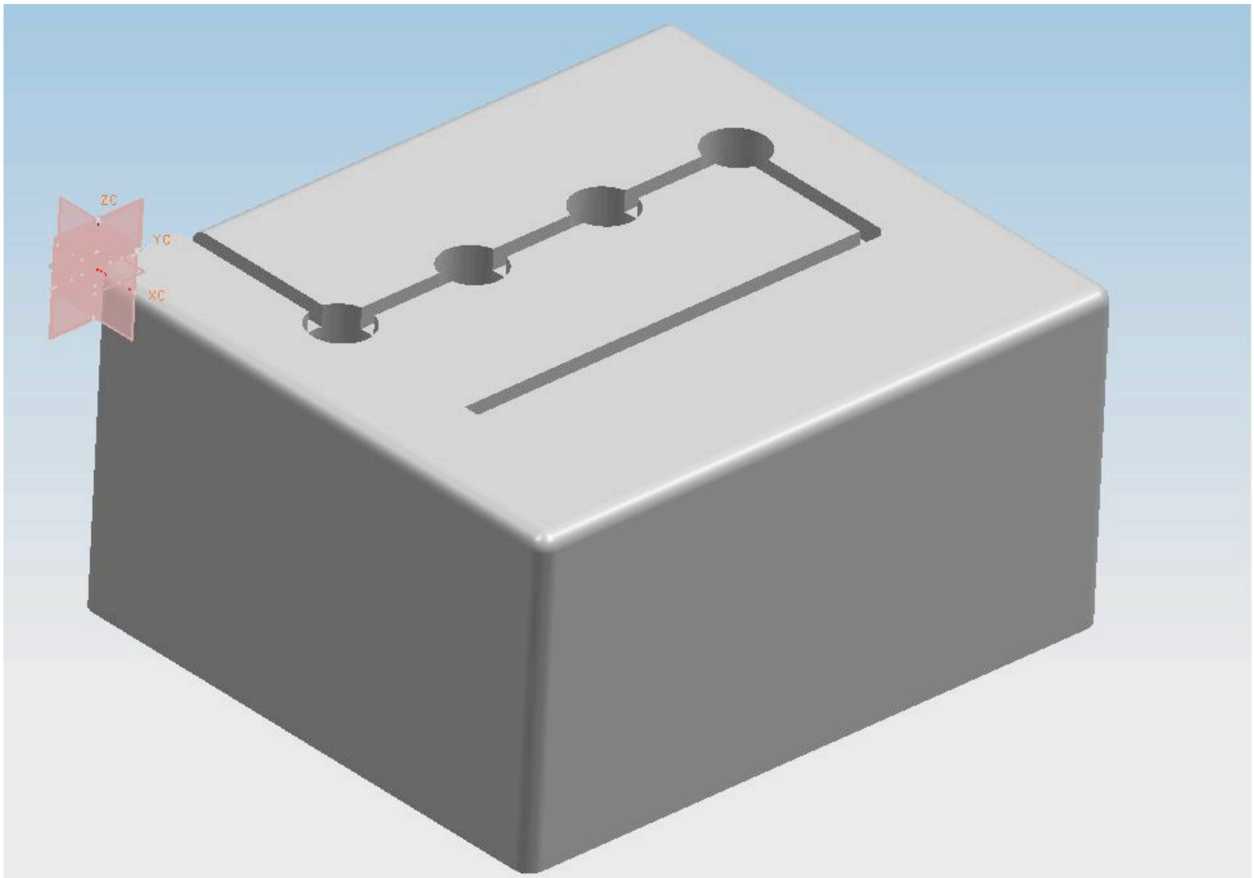


Figure 6: Storage Tank CAD Model

Drawings of each component of the assembly are in Appendix G. All three filters will fit on a standard ¾" diameter pipe. The first filter, made with cellulose, has a micron rating of 20 and will remove sediment and rust, allowing a maximum flow rate of 10 gpm, at a cost of $4.13. The next filter, will be used to remove taste, odor and chlorine, will be made from Carbon/Cellulose, and will allow a maximum flow rate of 8 gpm. This filter will cost $28.40. The last filter will be used to remove oil, grease and other pollutants. For this purpose a polypropylene filter will be used that has a maximum allowable flow rate of 5 gpm, and a micron rating of 5. This filter will cost $52.14. (McMaster-Carr.com)

All these filters have flow rates over 2 gpm, and hence they will not disrupt the laminar flow along the pipes, keeping our usage of Bernoulli's Equation valid.

The most fitting pump for our design purposes is a 1/3 hp submersible sump pump, which costs around $120. The parts in our final design are summarized below in a Bill of Materials. Although there is a large additional cost due to the addition of our filtration system, the additional cost per washer will be considerably lower if the design is implemented on a full scale, as bulk discounts will be negotiable.

Quantity	Part Description	Purchased From	Part Number	Price
1	Cellulose Filter 20 Micron Cartridge	McMaster-Carr	7191K11	4.13
1	Carbon/Cellulose Filter 8 Micron Cartridge	McMaster-Carr	4448K47	28.4
1	Polyprpoylene Filter 5 Micron Cartidge	McMaster-Carr	4422K81	52.14
1	1/3 hp Sump Pump	McMaster-Carr	9989K54	97.71
1	5 ft 3/4" PEX tubing	McMaster-Carr	51275K85	1.18
2	Rubber Backed Al sheets (24"X24"X0.25"	McMaster-Carr	9525K711	174.8

Table 2: Bill of Materials

MANUFACTURING AND TESTING PLANS

Storage Tub

The storage tub is to be manufactured in two parts. The model in Figure BLANK is to be split horizontally, at the same level that the inlet and exhaust lines enter the system. Splitting this part at this plane allows us to avoid any side tooling in the manufacturing process for the holes in the manufacture of the unit. The two halves of the tub will be injection molded thermoplastic, such as polyethylene. These parts will then be ultrasonically welded together.

Tubing

The tubing will be polyethylene, and will be manufactured through extrusion. This material was selected for its chemical durability, its low energy of extrusion, its low cost, and its consistency in similar applications.

Filters

The filters for our proposed prototype were all selected and ordered from McMaster Carr (www.mcmaster.com). No manufacturing of these is necessary. Assembly and insertion may require a human operator on the working line, however, and the filters used ultimately will need to fit the size constraints of their mounting in the storage tub.

Pump

The pump for our proposed prototype was selected and ordered from McMaster Carr (www.mcmaster.com). No manufacturing of this unit is necessary, but this unit will also require manual insertion in the unit.

PROJECT PLAN

Our sponsors at Whirlpool assigned us the task of creating a design solution that would reduce waste water emissions into the environment. The process was a two-term project, with this semester being the first. The team that takes over our project next semester will need to focus on testing of materials, and prototyping.

At the end of this semester, we have a design solution that satisfies our sponsor's needs. Additional testing needs to be conducted to check the efficiency of the filter materials and the resulting water flow-rates. Also, there is a need for further research and testing regarding Whirlpool's patented self-cleaning filters. To test the filtration materials, we ordered a set of the three filters that we planned on using in our design, but due to time considerations, we were unable to carry out testing of the filters ourselves. The filters are placed in the ME 450 assembly area for the use of the next team, if required.

CONCLUSIONS

Our sponsors at Whirlpool asked us to design a water storage and recovery system that would minimize water emissions into the environment, in order to increase the eco-efficiency of their Duet HT midrange series washers.

Our specific goal was to design a system that would filter contaminants and particles from the water used in a wash cycle and reuse it for the rinse cycle, cutting down water usage by at least 75% for each load. In order to design such a system, we conducted a patent search to make sure we knew about the relevant technology being used in the market, and to make sure we were not 'reinventing the wheel'.

Following the design process, we created a FAST diagram to create a functional decomposition of the system that was desired. The FAST diagram showed us that the most important function our system had to perform was the filtration of wash water from the wash tub. Using this FAST diagram, we were able to generate design concepts that would satisfy our engineering requirements using a Morphological chart. We then analyzed our designs using a Pugh matrix and arrived at a consensus for the final design concept.

We considered the use of electrodes, self-cleaning filters, and agitation using a belt drive, and found that they did not help satisfy our needs as they either did not work, or were a safety hazard in their use. Therefore, after careful deliberation, we arrived at the conclusion that the use of turbulent flow mechanisms to aid in filtration would be the most practical method of physical soil separation.

Our design utilizes the space currently at the base of the washer to add in a storage tank and filtration system, which will be used to filter the wash water as it is drained out of the tub, and store it in a tank. Once the tank is full, the water will be re-pumped into the wash tub for the second wash cycle. Our design uses 3 filters that allow varying micron sized particles to pass through, connected in series with each other, and a storage tank and pump which will be used to drive the water back into the wash tub.

We found that our final design was both energy and cost efficient. By adding the small pump to the wash system, we estimated that only $0.72/year would be added to your electrical bill. That was found using an average electrical cost of $0.084/kWhr and a pump efficiency of 60%. Assuming the average of 208 washes per year (Whirlpool) we found that our design uses 757.64gal/year. This is a savings of 2272.92 gallons of water every year. Using an average water cost of 880gal/dollar we calculated the consumer would save $2.48 a year. The largest cost to the consumer would be due to replacing damaged filters. The average cost of these filters would be in bulk would be near $20.

REFERENCES

www.uspto.gov
www.google.com/patents
www.mcmaster-carr.com

BIOS

Pieter Boshoven grew up in Chelsea, Michigan, just west of Ann Arbor. He graduated Summa Cum Laude from Chelsea High School. He was captain of the golf and tennis teams, and earned all-state honors in tennis as a senior. In school he excelled in both math and science, and therefore he decided that engineering would be a good fit for college. Growing up a die-hard Michigan fan, Pieter always supported the maize and blue, so it was fitting that he came here for college. The past two summers, Pieter has interned at Process Results, Inc. located in Saline, Michigan. It is a small engineering firm that specializes in processes. Pieter is set to graduate in May with a B.S in Mechanical Engineering with a minor in Mathematics, and he hopes to find a permanent position in the engineering field or in Finance.

Stefan Kalmbach was born and raised in Chelsea, Michigan, just west of Ann Arbor. He graduated with honors from Chelsea High School in 2004. Being from a family of Michigan fans and having a strong interest in engineering made the University of Michigan College of Engineering the perfect fit for Stefan. Along with classes he has enjoyed assisting in a part-time research opportunity. After graduating in May he hopes to begin his career in the area to be close to his family. When spare time can be found he enjoys cheering on U of M athletics and playing various sports including tennis, soccer, and golf.

Abhishek Poddar was born in Mumbai, India, and went to London, England for high school. He came to Michigan to pursue a bachelor's degree in Mechanical Engineering, and is also pursuing a minor in Economics. He hopes to use his knowledge of Mechanical Engineering to do his part in the development of India as an emerging economy. Apart from academia, his interests lie in soccer, tennis, and music.

Justin Van Houten was born in Traverse City, Michigan. He is the first Michigan student in his family, and is currently studying Mechanical Engineering with a minor in Mathematics and a possible second major in Electrical Engineering. He possesses a passion for design and hopes to pursue a career in independent consulting and patent law upon graduation.

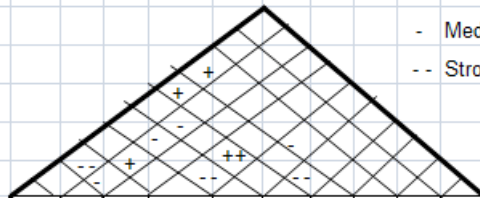
Appendix A: Tear-down diagrams

confidential information omitted

Appendix B: Quality Function Development (QFD)

Quality Function Development (QFD)

+ Medium Positive
- Medium Negative
- - Strong Negative

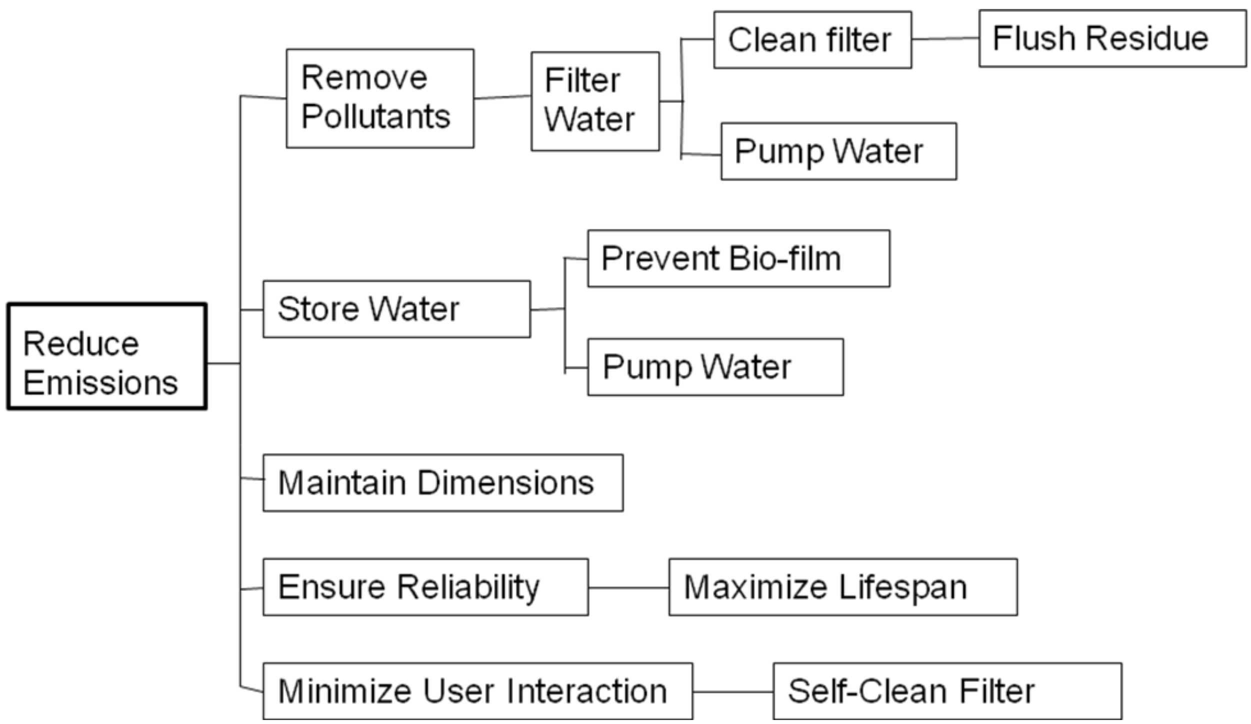


(+) => more is better
(-) => less is better

	Weight*	Fit in current wash system	Filter out pollutants	Store filter water	Neutralize chemistries to prevent build-up	Affortable	Keep filter from clogging	Easy to use				Benchmarks: U.S. Patent #6402962 (self-cleaning filter)	U.S. Patent #5049252 (electoloysis)
Explore Filtration Technologies	10		9	1	9		3					9	9
Design Water Recovery Method	9	9		9		3		9				3	3
Design Water Storage System	9	9		9		3		1					
Prevent Bio-film Build-up	9	3	1	9	9		3						
Filter contaminated water solution	9	3	9	1	9		9					9	9
Nuetralize Chemistries	4				9		1					9	9
Reuse Wash Water for Rinse Cyc	3	9		9				3				3	
Aesthetically Pleasing	2	9				1		1				1	1
Needs to Fit Washer Dimensions	2	9		9		1		1				3	1
Cost Efficient	9			3	3	9	3						3
Measurement Unit		µm		gall									
Target Value		<1µm		>4 gall									
Importance Rating		**3**	**7**	**6**	**4**	**2**	**5**	**1**					
Total		279	180	334	315	139	169	103	0	0	0		
Normalized		0.18	0.12	0.22	0.21	0.09	0.11	0.07	0.00	0.00	0.00		

Key:
9 => Strong Relationship
3 => Medium Relationship
1 => Small Relationship
(blank) => Not Related

Appendix C: FAST Diagram



Appendix D: Morphological Chart

Function	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Remove Pollutants	Multi-Stage	Turbulent Flow	Electrodes	Heating Water	Radial Filter
Store Water	Tank in Pedestal	Tank in Wash Tub	Additional Space		
Clean Filter	Backwash	Self-Cleaning	Disposable Filters	Mechanical Cleaner	
Maintain Dimensions	Place in Pedestal	Place Around Wash Tub	Storage in Wash Tub		
Minimize User Interaction	Long-lasting Filters	Self-Cleaning Filters			

Appendix E: Pugh Matrix

Customer Requirement	Weight	Electrodes	Multi-stage Filtering	Water Storage in Wash Tub	Belt Drive Agitation	Self Cleaning Filter with Bypass	Turbulant Flow Mechanism	Water Storage Tank in Bottom Container
Fit in current system	4		-	+	+			+
Filter out pollutants	8	+	+			+	+	
Store filtered water	7			+	+			+
Prevent build-up	5		-	+		+	-	+
Prevent clogging	6		-			+	+	
Easy to use	1	-		-				+
Cost efficient	2	-						
		-2	-3	1	0	0	3	4
		2	2	3	2	4	-1	-1
		0	-1	2	2	4	2	3
	V	8	-4	15	11	22	12	17

Appendix F: Gantt Chart

Project Name	Owner	Days	Start	End	23-Oct	25-Oct	30-Oct	1-Nov	6-Nov	8-Nov	13-Nov	15-Nov	20-Nov	22-Nov	27-Nov	29-Nov	4-Dec	6-Dec	11-Dec	13-Dec	18-Dec
Design Proposal Project Plan	Team 26	**56**	23-Oct	**18-Dec**																	
Consulting and Further Research Phase	**Team 26**	16	**23-Oct**	**8-Nov**																	
Meet with Sponsors	**Team 26**	0	25-Oct	25-Oct																	
Meet with Fluid Mechanics Professionals	**Team 26**	13	25-Oct	6-Nov																	
Complete Finalized Design Proposal	**Team 26**	3	6-Nov	8-Nov																	
Implementation and Environmental Regulations Coherence Phase	**Team 26**	12	**8-Nov**	**20-Nov**																	
Understand Current Regulations	**Team 26**	5	8-Nov	13-Nov																	
Infer Future Regulations and Trends	**Team 26**	5	8-Nov	13-Nov																	
Unit Hardware Cost	**Team 26**	2	13-Nov	15-Nov																	
Mfg. Implementation Cost	**Team 26**	2	15-Nov	17-Nov																	
Full Financial Analysis	**Team 26**	3	17-Nov	20-Nov																	
Modeling and Report	**Team 26**	**28**	**20-Nov**	**18-Dec**																	
Develop Part Models	**Team 26**	7	20-Nov	27-Nov																	
Develop Static System Model	**Team 26**	4	25-Nov	29-Nov																	
Develop Interactive / Moving System Model	**Team 26**	7	29-Nov	6-Dec																	
Write Project Report	**Team 26**	7	4-Dec	11-Dec																	
Write up Design Expo Documentation	**Team 26**	3	4-Dec	7-Dec																	
Write up Proposal	**Team 26**	4	7-Dec	11-Dec																	
Present to Sponsor	**Team 26**	0	13-Dec	13-Dec																	

Appendix G: CAD Drawings