Development of Low-cost Automated Zero Wastewater System to Step towards Industry 4.0

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Abstract

The following paper proposes the optimum uses of ETP-based water. It is known that ETP works as a waste purifier and treats the water obtained from industrial plants. This project aims to ensure proper reuse of the wastewater obtained from the ETP rather than throwing it into the environment directly. This project aims to work with the filtered water produced by ETP and put it to good use. The ETP wastewater is kept inside a reservoir and, later, passed through a unique and automated distribution system which leads to various end uses. This automated distribution system controls the wastewater supply to minimize resource waste. This project also includes using sludge obtained from the ETP plant by mixing it with concrete cement. Thus, the sludge will be reused to make storage components for a distribution system. The range of ETP wastewater uses can even be expanded with adequate execution based on the produced filtered water quality. Throughout ETP-based production, the field of operations can be distributed. Throughout ETP-based production, the field of operations can be distributed. And the overall goal of this project is "environmental sustainability" and complete wastewater management. If correctly implemented, this might be an ideal method for conserving vital water while safeguarding the environment. If correctly implemented, this might be an ideal method for conserving vital water while safeguarding the environment.

Keywords
ETP, Industry 4.0, Sustainability, Re-use, Waste Water and Environment

1 Introduction

For the welfare of the environment and society, wastewater treatment is highly necessary. It is a process of removal of hazardous contaminants from wastewater to make it suitable for reuse or discharge. In many industries, ETP plants are devoted to such treatments. But very few of them are concerned about reusing it. This project will introduce you to a very innovative way of reusing wastewater with the help of an automated distribution channel inside the industries. Thus, it will make sure the safety and utilization of water and resources as well.

1.1 Objectives

The issue of working with the reuse of water is still a matter of concern. Although there is information, there is a lot to work on. And the health concerns of this reused water will be a valid question. So, we'll focus on the parts where no health concern exists. Instead, our proposal focuses on using this water in other sources where the water doesn't need to be "safe to drink" pure. Fountains and toilet flashes can be some of their examples.

1.2 The Novelty of the Product

a) Reusing ETP wastewater: Although there is plenty of research-based successful projects for reusing waste sludge from ETP, hardly any programs for ETP wastewater management can be seen. So, this project is concerned with the proper utilization of wastewater.

b) Automatic Distribution System: The reusable wastewater will be distributed through an automatic distribution system. Thus, the water supply will be under an automated control system to minimize the waste of resources.
c) Reservoir made of sludge: In this system, there is a need for a storage tank for reserving reusable wastewater. As this project is concerned with waste optimization and a green environment ecosystem, the waste sludge will be mixed with concrete to make one important component, likea reservoir.

1.3 Application of the Product

The water obtained from the ETP will go through the distributor. The distributor will then channel this water into the various sections of the industry. Here, the ETP-based water can be put to use directly. Every day, a large amount of ETP-based water is produced, and we intend to put it to good use. The end uses where we can implement this water is the main purpose. The overall utilization of ETP wastewater will be directed to: Toilet flush, Watering plants, fountains, Cooling water for cleaning, Industrial area cleaning, Car wash, Construction & concrete mixing, Artificial Lake, Water jet loom, etc.

2 Literature Review

Utilizing wastewater in the concrete industry saves a significant amount of water and minimizes the need for fresh water. It also emphasizes the produced wastewater's physical, chemical, hardening, and rheological characteristics. Additionally, a significant amount of wastewater can be safely used in the concrete industry with a few modifications without causing any physical harm(Varshney, Khan, and Khan 2021). Both electro-coagulation and chemical coagulation can be utilized. However, EC performs better regarding BOD, COD, and pH. The CC had greater values than the EC did. Therefore, the EC is chosen for proper water analysis at the Effluent Treatment Plant for an accurate reaction and decision-making (ETP)(Singhai 2016). An automatic watering gardening system has been created to replace manual tasks and make the gardener's job considerably easier.

Additionally, there is research on greenhouse temperature and soil moisture. Making an automated distribution system will save a lot of time and labor because of these factors, providing valuable information(Mediawan, Yusro, and Bintoro 2018). Biogas generation can be increased by up to 10%, and more than 5% of the daily water utilized can be recovered by running ETP simulations. Soft water is used to rinse the equipment during the procedure. Then, use lye and hot water to wash the equipment. Microorganisms are removed by washing. After that, use soft water to remove any remaining lye. The cleaned-out water is reused by automatic CIP(Tiwari, Behera, and Srinivasan 2016).

All industries should consider sustainability. Although there are numerous sustainable methods, some obstacles can provide a challenge. The study demonstrates a sustainable approach to health and safety, environmental responsibility, and energy conservation. In the study, a model is suggested for overcoming the obstacles. The model effectively removes the obstacles and produces a beneficial result.

Additionally, the insider perspective of various cases and the adoption of factors for policymakers(Trianni2017). The primary goal of the current action research is to evaluate the textile industries in Bangladesh in terms of their efficacy in wastewater treatment and their progress toward achieving zero discharge under the 3R plan. It also aims to develop an idea of the technical viability of ZLD systems in terms of the amount/percentage of recycled wastewater and the required time frame for installation(Centre and Management 2017). The following research objectives were created to analyze the available zero-waste practices, challenges, and solutions in the apparel industry and effectively achieve the study's goals. Find out if the clothing industry employs any zero-waste practices. Identify the obstacles or difficulties preventing the apparel industry from implementing zero-waste practices. Based on the analysis, identify strategies for incorporating zero-waste practices in the apparel sector(Hernandez2022). The textile industry is one of the major global businesses that offer employment without the need for specialized training and contributes significantly to the economies of many nations, including Bangladesh. Various chemicals and much water are used during the production process in the textile industry. Water is mostly utilized for putting chemicals on fibers and rinsing finished goods. This process generates highly concentrated wastewater in chemicals and dyes that may harm the environment and human health by containing traces of metals like Cr, Cu, and Zn. The wastewater from the textile industry can lead to dermatitis, skin ulceration, nausea, and hemorrhaging. The chemicals in the water prevent sunlight from penetrating and raise biological oxygen demands, which prevents photosynthesis and reoxygenation(Dey2015). This study reviews the laws and ordinances governing the standard of wastewater discharge from the textile industry. The information demonstrates that brand-specific recommendations and multi-brand consortia have varying discharge rules in different nations. Numerous rules and regulations in effect today do not require zero discharge. It would be beneficial to comprehend the current status of regulations to develop a new discharge guideline that will update the widely utilized guidelines produced by the Business for Social Responsibility (BSR). Even though these suggestions were presented in 2010, they require updating due to continually changing regulations and new industry targets for zero discharge. For this study, research was carried out to obtain wastewater discharge from the textile industry(Zero Discharge of Hazardous Chemicals Programme 2015).Typically, mixed stream treatment is used for textile wastewater. However, it is better to keep process streams distinct and treat them independently to reuse chemicals and water. The distinct treatment of process streams requires careful consideration of the effluent characteristics from the textile sector. This study of the literature gives a general overview of what is known about the different operations' wastewater and the techniques applied to characterize these streams(Taylor2008).

3 Data collection and customer survey

Figure 1 (Pareto chart of criteria for Low-cost Automated Zero Wastewater System) represents the most required criteria with cumulative correspondent counts from survey results. It is seen that 80 percent of the cumulative count is found for plenty of requirements. That means the major portion of customer requirements lay on the reliability of ETP wastewater, Application of wastewater in toilet flush, presence of ETP, preferable distribution pipe, preferable distribution system, preferable time range of service, reusing sludge and ETP wastewater, preferable cost of the distribution system, preferable reservoir, tendency of ETP installation & preferable application of ETP wastewater (industrial Cleaning). Figure 1 here has two different parameters in the vertical segment of the graph. If we put it in simple words, Figure 1 gives us the visual representation of which defect or problem should be given the most priority. By dealing with that 20 percent of the defects, we can assure the maximum stability of our product.

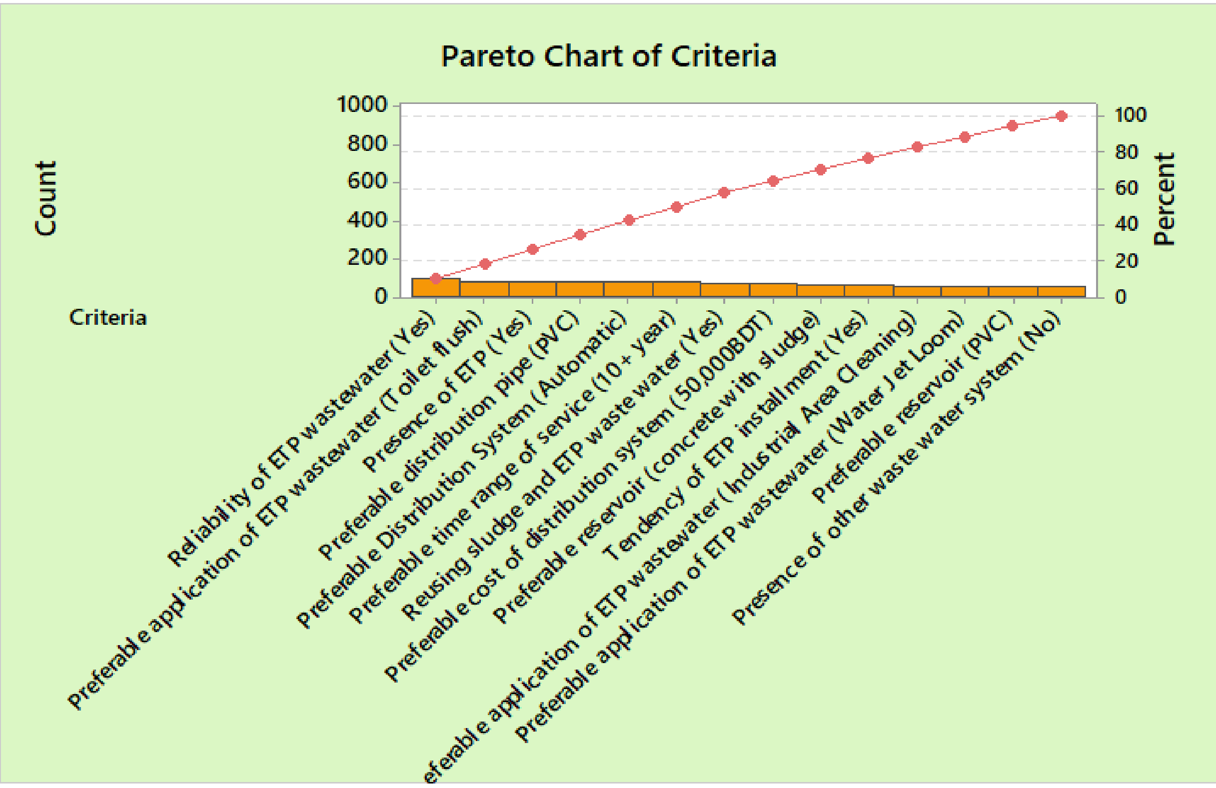
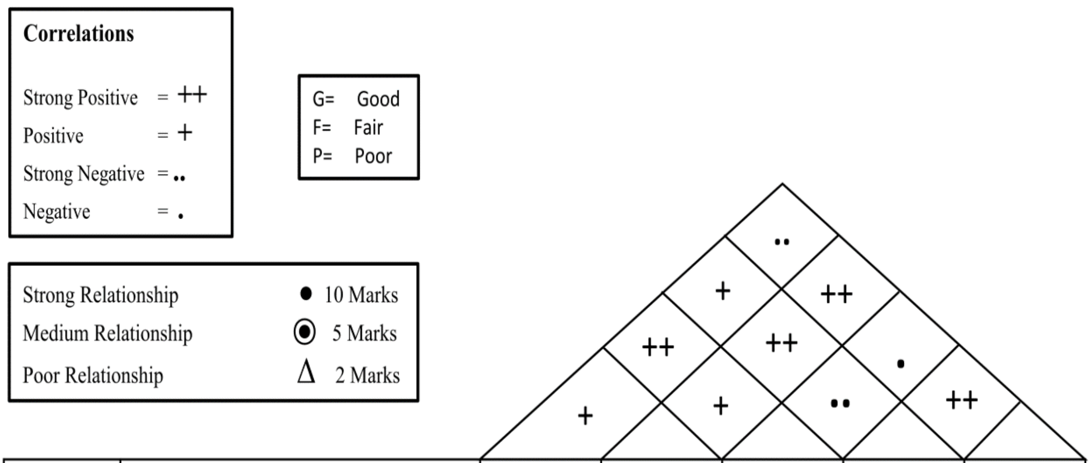


Figure 1. Pareto chart of criteria for Low-cost Automated Zero Wastewater System

4 Methodology

4.1 QFD

Before completing a final product, they must first learn and understand the customer's requirements and needs/wants. Feature of a good product is that it has good technical features and a meaningful connection with the customer. Customer needs and satisfaction should be the top priority. According to a popular customer survey and the House of Quality,a table shown in Figure 2, it is seen that Toilet Flush is the most demanding one of them all. This is harmless to the human body and a huge amount of water can be saved in the process. In figure 2, the House of Quality table suggests accordingly. It has the most important score. The other priorities here are an automated distribution system and low cost. They are ranked second and third in importance in the table. Other factors in the table include service and safety. They are ranked fourth and fifth, respectively. This gives us an idea of their relative importance compared with each other and a view of what the customer wants.



	Desired Direction of improvement (↑, 0, ↓)						
Customers importance Rating	Functional Requirements(How's) → Customer Requirements-(What's) ↓	Micro controller	Distribution Pipe	Moisture Sensor	Pump	Reserve Tank	Our Product
	End use − Toilet Flush		●		●	●	F
4	Automated Distribution System	●	●	●	●	●	G
3	Low Cost	◉	●	Δ	●	◉	F
2	Service	●	●	●	●	Δ	G
1	Safety	◉	Δ	Δ			P
	Technical importance score	80	142	68	140	109	
	Importance %	14.84%	26.35%	12.62%	25.97%	20.22%	
	Priorities rank	4	1	5	2	3	

Figure 2. Quality Function Deployment for Low-cost Automated Zero Wastewater System

4.2 Functional Decomposition

Figure 3(Functional decomposition of Low-cost Automated Zero Wastewater System) here shows the functional decomposition system. ETP plant will provide the water and sludge. The water from the ETP will then be kept in a reservoir, and a water level indicator will be present for safety purposes. A pH meter and a water hardness measure will be used to evaluate the water's quality before it is delivered to us. As shown in the figure: 3, the distribution system will be entirely automated with components like relay circuits and sensors. This entire automated system will be much more effective and will give us the upper hand. Additionally, the system will receive pipes and a pump. The water will then be given to the plants in a fully automatic manner. A simple job like watering plants can also be done in an advanced and effective way. This component completes the process and comprises an Arduino, a moisture sensor, an extension board, and a water sprinkler.

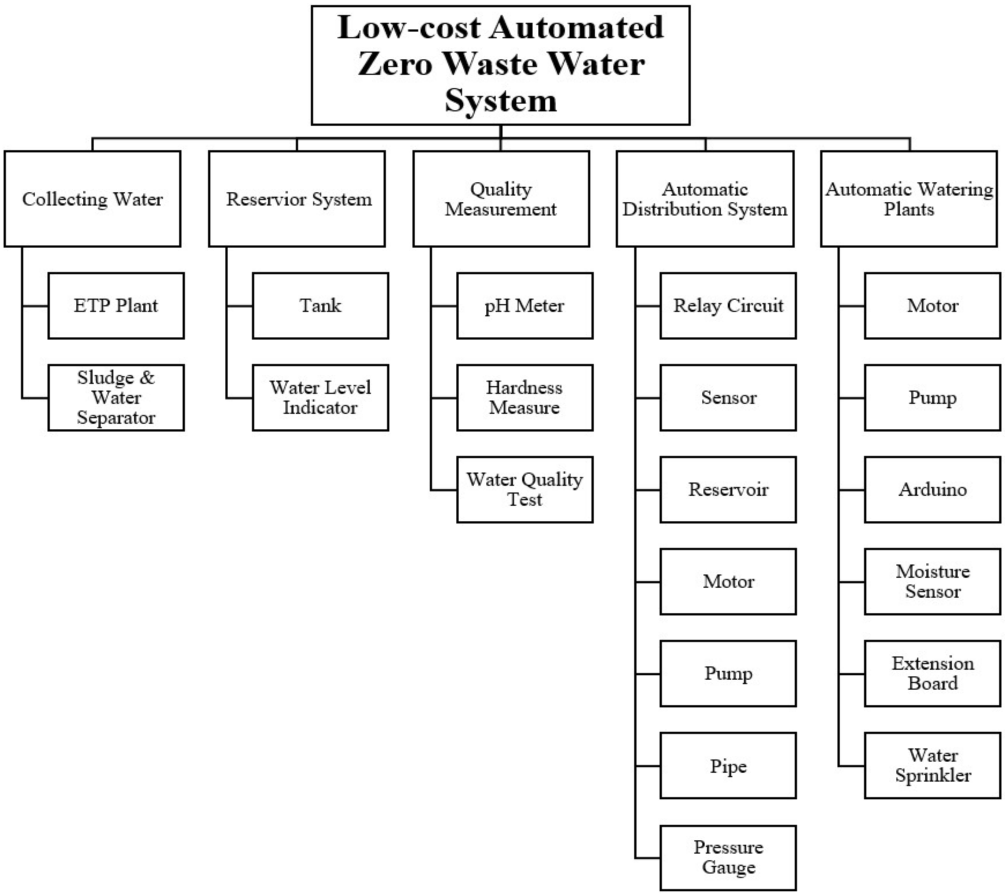


Figure 2. Functional decomposition of Low-cost Automated Zero Wastewater System

4.3 Black Box

Figure 4 (Black box for Low-cost Automated Zero Wastewater System) represents the black box diagram. This provides us with the idea of simpler input and output information. The "Blackbox" here in figure 4 perfectly gives us the idea of the Automatic Distribution Channel. Here, in the input section, we have Energy, ETP wastewater, and Electrical signal. Electrical and Hydraulic are the prime sources of energy. As input material, we have ETP wastewater and Electric signal as information. For the output section in figure 4, we will get Rotational motion, ETP wastewater, and start/stop motion moisture control. The ETP wastewater in the output section will have various end uses. Moisture controlling will be done by start and stop motion. The distribution channel completes the process. The distribution channel is fully automatic. The automatically distributed channel is the key factor here in figure 4. As it connects and maintains the flow of input material to the output material in the final destination.

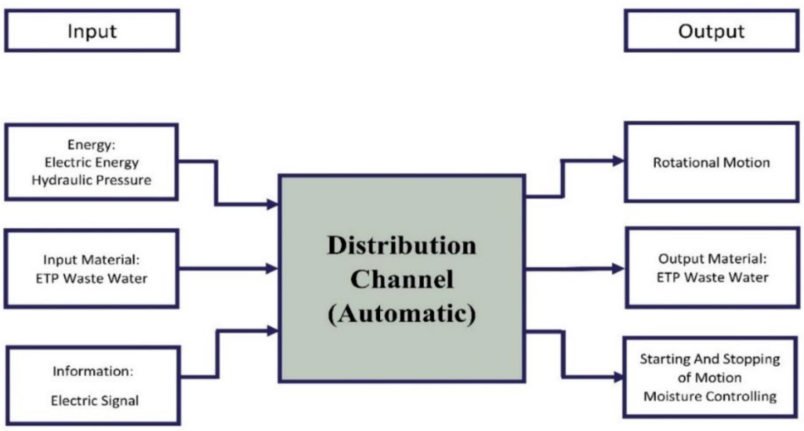


Figure 3. Black box forLow-cost Automated Zero Wastewater System

4.4 Cluster Diagram

A cluster diagram is used to illustrate the product's interior components' sequential manufacturing process. This diagram shows the transformation of energy and material. Here in Figure 5 (Cluster diagram for Low-cost Automated Zero Wastewater System) shows the energy transformation and material flow in detail. At first, water is collected from the ETP plant. Then it's reserved in the reservoir. By using, a microcontroller, as well as a sensor, distribution pipes, and motor pump, can be controlled. Finally, end users can use water for watering plants, toilet flush, etc., transferring energy to kinetic energy. Thus, distributed wastewater is achieved from undistributed wastewater.

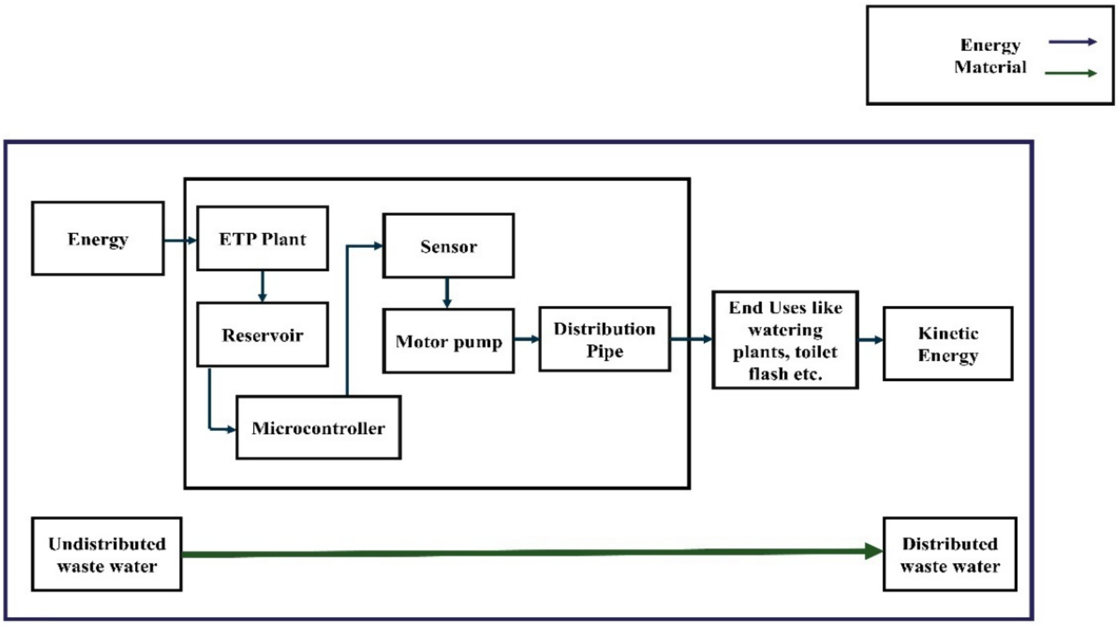


Figure 4. Cluster diagram for Low-cost Automated Zero Wastewater System

4.5 Material Selection

4.5.1 Reservoir

Table 1 is about the characteristics and their relative importance compared to others. As the table indicates, the "cost" of the reservoir shows the maximum impact as the main operation of the project is to reduce water wastage and thus save money. Other important criteria are also compared with the others, and a final relative emphasis coefficient is calculated.

Table 1.Determination of Relative Importance of Goals Using Digital Logic Method

Selection Criteria (Goals)	The number of positive decisions: 5(5-1)/2= 10										Positive Decisions	Relative emphasis co-efficient α
	1	2	3	4	5	6	7	8	9	10		
Sustainability	0	1	0	0							1	0.1
Corrosiveness	1				1	0	0				2	0.2
Reservoir Thickness		0			0			0	0		0	0
Storage Capacity			1			1		1		0	3	0.3
Cost				1			1		1	1	4	0.4
	The total number of possible decisions (N) =										10	∑α=1

Table 2 consists of some numbers (1-5) to rank the importance of the mentioned criteria. The most important one will be rated as 5 and the least 1.

Table 2.Numerical Value (Rating)

Very High	5

High	4
Medium	3
Low	2
Very Low	1

Table 3 consists of major selection criteria. Sustainability, corrosiveness, Reservoir thickness, storage capacity, and the final cost. Using the previous ranking system from table 2, they are compared in the context of PVC, Steel, and concrete. The following table will provide an idea on this matter.

Table 3.Preferred material's properties and selection criteria of the product

Selection Criteria/ Material	PVC	Steel	Concrete
Sustainability	2	3	5
Corrosiveness	3	1	5
Reservoir Thickness	2	3	4
Storage Capacity	1	3	5
Cost	5	1	4

The Material Performance index was calculated using scaled and weighted properties in Table 4. It required the assistance of the weighted factor. PVC, steel, and concrete have material performance indices of 62, 36, and 92, respectively. Result: With the highest value of 92, concrete can be considered the most effective part of the material.

Table 4.Calculation of the Material Performance Index

Selection Criteria	Weighted Factor, α	PVC Scaled Property, β	Steel Weighted property α*β	Concrete Scaled Property, β	Weighted property α*β	Scaled Property, β	Weighted property α*β
Sustainability	0.1	40	4	60	6	100	10
Corrosiveness	0.2	60	12	20	4	100	20
Reservoir Thickness	0	50	0	75	0	100	0
Storage Capacity	0.3	20	6	60	18	100	30
Cost	0.4	100	40	20	8	80	32
Material Performance Index, $\Upsilon = \sum \alpha\beta$		8	62		36		92

4.5.2 Distribution Pipe

Table 5 is for the distribution system and its selected criteria. The factors here are Ultimate strength, Durability, Cost, and availability. Again, the relative emphasis co-efficient is the margin to determine their importance compared to each other. With the highest value of 0.5 ultimate tensile strength is the defining factor for the distribution pipe. Since the distribution pipe will be shifting the water to the end-use areas so the strength should be at its peak. Thus, possess a higher value.

Table 5.Determination of Relative Importance of Goals Using Digital Logic Method

Selection Criteria (Goals)	**The number of positive Decisions: 4(4-1)/2=6**							
	1	**2**	**3**	**4**	**5**	**6**	**Positive Decision**	**Relative emphasis co-efficient α**

Ultimate Tensile Strength	1	1	1				3	0.4
Durability	0			1	1		2	0.2
Cost		0		0		1	1	0.3
Availability			0		0	0	0	0.1
	The total number of possible decisions (N) =						6	$\sum\alpha=1$

The significance of Table 6 is just like table 2. The following table consists of some numbers (1-5) to rank the importance of the mentioned criteria. The most important one will be rated as 5 and the least 1. Again, this number is just for relative comparison among the discussed criteria. So, the numbers will state the importance it imposes on the other characteristics. These numerical values are compared with the factors of the distribution pipe.

Table 6.Numerical Value (Rating)

Very High	5
High	4
Medium	3
Low	2
Very Low	1

Table 7 implies the preferred materials (Distribution pipe) strength, durability, and cost identifier. After doing mechanical tests, the tensile strength of PVC is 90 MPa. For stainless steel, the value is 550. After comparing it with many measures, stainless steel is the most preferable according to strength. For comparing cost, durability & availability, the following table in the right portion confirms it.

Table 7. Preferred material's properties and selection criteria of the product

Selection Criteria/Material	PVC	Stainless Steel	Selection Criteria	PVC	Stainless Steel
Tensile Strength (MPa)	90	550	Durability	2	5
			Cost	5	2
			Availability	4	2
Tensile Strength (MPa)	90	550	Durability	2	5

Table 8 is for the performance index. Weighted factor, scaled property, and weighted property is the main theme here. Comparing PVC and stainless steel we can see that stainless steel has the higher value material performance index. A higher value material performance index indicates that stainless steel will be the best choice with every characteristic and other properties combined. The ultimate tensile strength, durability, cost, and availability were tasks into consideration.

Result: Stainless steel will be the ideal material for the distribution system line. Its overall performance index is the most, making it the preferable one over PVC.

Table 8.Calculation of the Material Performance Index

Selection Criteria	Weighted Factor, α	PVC		Stainless Steel	
		Scaled Property, β	Weighted property α*β	Scaled Property, β	Weighted property, α*β
Ultimate Tensile Strength	0.5	16	8	100	50
Durability	0.33	40	13.2	100	33
Cost	0.17	100	17	40	6.8
Availability	0	100	0	50	0
Material Performance Index, ϒ = ∑ αβ			38.2		89.8

4.6 Design Guidelines for low-cost automated distribution system

4.6.1 Applied design guidelines for reliability

I. Ensure the sustainability of resources:

This system focuses on saving plenty of water by turning industrial wastewater into reusable water for various purposes. Again, this project reuses the sludge by mixing it with cement in an applicable ratio and producing concrete. This concrete can be used for the manufacture of reservoirs. Thus, the use of plastic can be avoided regarding the construction of reservoirs.

II. Ensure healthy input and output materials:

This system ensures the elimination of hazardous substances and pollutants, as well as the conversion of wastewater into useful material for products and the ecosystem.

III. Ensure minimal use of resources during production:

The automated distribution system is designed by applying structural techniques and minimizing the total volume of raw materials needed.

IV. Ensure minimal use of resources during use:

Because this distribution system is automated, it ensures some incorporating features, such as the automated system being controlled under programs to prevent the user from wasting water.

V. Ensure appropriate durability of the product and components:

This system ensures lifelong durability, easy repair, maintenance, and upgrading of different parts and components.

VI. Enable disassembly, separation, and purification:

This system consists of easily accessible, recyclable, standardized, and biodegradable components that can be assembled, extended, or reduced according to the requirements.

4.6.2 Applied design guidelines for maintainability

Design Guidelines for Maintainability at low-cost automated distribution system:

I. As most of the components of this system remain ina moist environment, the selection of pipe, reservoir, etc., was concerned with corrosion resistance material and corrosive materials were avoided during material selection.

II. There is a standard interface between every part of distribution pipelines. So the extension or reduction of this system, according to the end users, will be faster and easy enough.

III. Quick and easily replaceable components (e.g., PVC pipes) are used in this system.

IV. This system consists of standard fasteners and pipes, which reduce spare parts and eventually reduce the cost.

V. As the zero-water waste system is fully automated, it requires less manual labor overall. And it saves a huge amount of time and resources along with a huge saving in cost. The impact here is huge.

VI. The design has its weakest link. PVC pipes used for ETP-treated water distribution are the weakest link in the distribution system. They are relatively cheap & replaceable. This makes the control system easy to operate, thus making the whole system much easier.

VII. The design consists of a modulus system. If any part or components face any failure, the modulus system enables the complete replacement of a broken model to repair it. Also, no special hand tools are required & used. In the distribution line, using available components, we can reduce the usage of special tools.

4.7 Designing and Modelling

Figure 6 (3D model of a Low-cost Automated Zero Wastewater System) here is a 3D model representation of a low-cost Automated Zero Waste Water System project. The model in figure 6 tries to give us a simple idea of the whole system and its procedure. This distribution process is fully automated using a PLC controller. Which means that it has sensors and controllers to fully operate the function automatically. This model shows a concrete reservoir, motor, PLC-controlled system, and distribution pipes for four different channels. The reservoir stores the water, the motor pumps it and the PLC controller is used to operate the system. These channels can be extended further according to the applications.

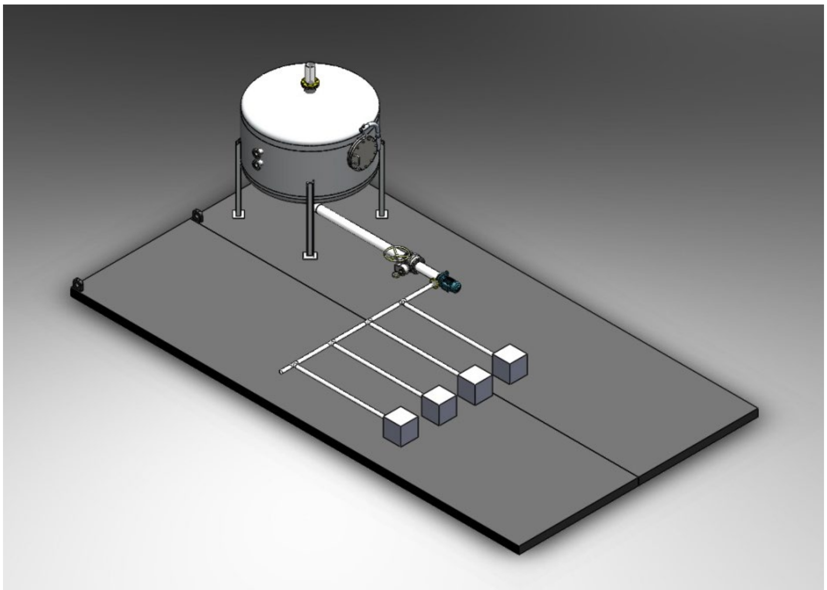


Figure 5. 3D model of a Low-cost Automated Zero Wastewater System

5 Result and Discussion

The outcome of the Low-Cost Zero Waste Water System project is to bring environmental friendliness to the industries. Analyzing the project's principles, there is no doubt that it is a well-mannered project where the best use of ETP wastewater is ensured with a low-cost automated distribution system. From material selection through final product assembly, time, cost, and energy are all optimized. The best programmable logic controller for the distribution system ensures the electro-mechanical distribution process. Also, the optimized comparison shows the selected materials regarding their cost, durability, availability, and so on. The final material for each section is selected based on stress analysis results. Although the full project has developed under much experimental work and analysis, there are still some limitations of this project. This is a complex project, and without trained people in maintenance, this project may not run with sufficient effectiveness as there are some electro-mechanical sensitive parts in use.

6 Cost Estimation and Break-even analysis

Figure 7 (Break-even analysis of Low-cost Automated Zero Wastewater System) here shows us the break-even analysis of our project. The break-even analysis gives the overall idea of all the costs and revenues and their point of intersection. The variable cost per unit product is 201.08 USD. The unit cost is $257.42. The fixed cost per unit is $879.12. Within a year, 25 goods are sold. This number is an average expected value. After analyzing these values, the breakeven point of this product is found to be 15.6038. So, from Figure 7 we can get the idea about this break-even point of the product to, later on, implement this knowledge to further usages.

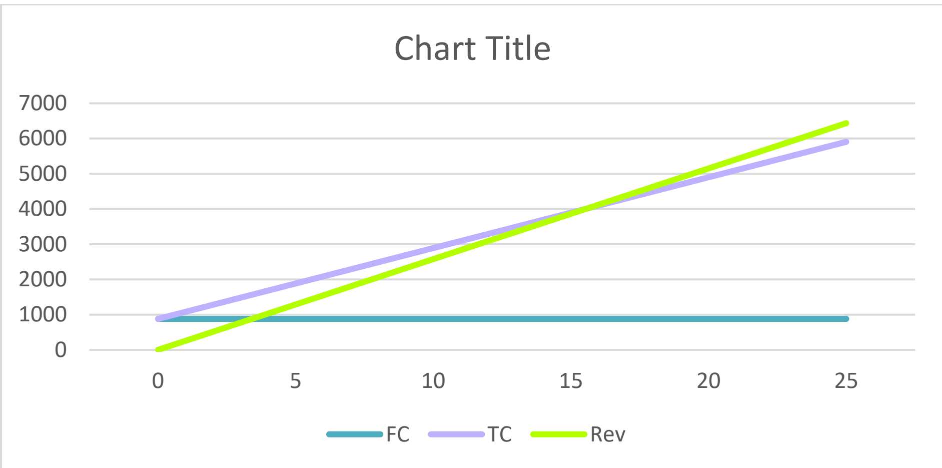


Figure 6. Break-even analysis of Low-cost Automated Zero Wastewater System

7 Conclusion

The entire zero waste water idea focuses on properly using industrial wastewater and utilizing it to good use. The whole concept of this project is to utilize the tons of wastewater that ETP plants releases. Rather than throwing them into the environment, this idea will pressure industrialists to maintain an environment-friendly, non-bio hazardous waste management system. Apart from utilizing wastewater as a resource, this project will ensure the proper maintenance and continuous improvement of ETP wastewater quality. The entire distribution system of collected ETP wastewater is automated. And either this automated distribution system will be installed within the industry or the existing distribution system will be modified to accommodate it. These industries can recycle ETP wastewater, saving tons of water, resources, and money and contributing to environmental improvement.

Furthermore, the entire distribution channel has been subjected to an appropriate amount of stress-strain analysis and a series of quality development procedures. And either this automated distribution system will be installed within the industry, or the existing distribution system will be modified to accommodate it. These industries can recycle ETP wastewater, saving tons of water, resources, and money and contributing to environmental improvement. Furthermore, the entire distribution channel has been subjected to an appropriate amount of stress-strain analysis and a series of quality development procedures. These will meet the customer requirements given by the industry. The material used in the distribution channel and other sites also uses environmentally friendly material. This entire project is the most effective and concerned about the environment. As the world is approaching Industrial Revolution 4.0, this project will surely be an interesting and well-timed one.

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Biographies

Nusrat Jahan Brishty is currently studying at the Bangladesh University of Textiles (BUTEX) in the Department of Industrial and Production Engineering. This person has been working on Industrial Revolution 4.0 and most of her work is concerned with environmental issues, and she has been implementing them for over a year. Her recent research focus is on optimized manufacturing processes, energy analysis, efficiency measurement, and green supply chain management. She has experience operating CNC milling machines. She has worked on several AutoCAD and Solidworks projects and made a remarkable performance in Automation, Manufacturing Processes, Product Designing, and Controlled programmers’.

Zaif Parvez is currently studying at the Bangladesh University of Textiles (BUTEX) in the Department of Industrial and Production Engineering. His earlier research areas included Industrial Development, Production Analysis, Supply Chain Management, Quality Control and Management, Engineering Materials, Automation, Robotics, and Product Design were some of his earlier research areas. Additionally, he has vast experience visiting numerous industries and researching ways to optimize the overall cost of running an industry. He engages in Solidworks designing, programming, and other activities. He hopes to work as a researcher to develop green industries.

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