Utilization of Waste Heat Energy from Water Tanks in Industries

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Abstract

Heat utilization is one of the biggest wins for any industry. And big industries waste much heat from the water, gas, and other sources. Research focuses on optimizing the wasted heat in industry and making it reusable for further uses. This utilizes the wasted heat and ensures that folds increase the productivity of the overall industry. Moreover, limiting the usage of energy impacts less in the environment less. The heat generated from the wasted washing or dyeing water is stored and run through copper pipes to a tank. Several pipes are inserted inside the tank to maintain cold water flow. The cold water passing through the lines will regain the heat of the default dyeing water inside the tank, which will heat the cold water. This assures the saving of heating appliances and wasted water and ensures the utilization of wastewater in an ETP plant to a great extent. To ensure the validity, practicality, and full proof of the research, Quality function deployment (QFD), Functional Decomposition, Black Box, Cluster Diagram, and apparent surveys among the most prominent and most renowned industrialists have been implemented. The best of the materials through a proper testing test, observation, and validation have been selected; all the selected materials and method implementations are of verified reliability. The equipment can also withstand the environmental conditions in which it is used. More or less, 80% of the efficiency is ensured through the process, and the amount of waste throughout the operation is less than 5%.

Keywords
Industry 4.0, Sustainability, Cost-effectiveness, Thermodynamics and Waste Heat Water.

1.Introduction

1.1 Objectives
This product's main objective is to use the wasted heat and conserve a significant quantity of energy.Additionally, it can be a valuable component to improve efficiency, reduce waste, and ensure efficient heat dispersion.

1.2 The Novelty of the Product
The product's efficiency in wasting heat is what makes it novel. This item will recycle the heat and warm up the subsequent process. As a result, it can both conserve a significant quantity of heat and prevent global warming. Once more, this system is quite economical. The total system requires the least amount of money to build. Once more, the design of this item is straightforward. There aren't any convoluted links or paths visible. Even the system's total cost is minimal, compared to the cost of housing parts.

1.3 Application of the Product
RMG industries, pharmaceutical industries, timber industries, jute industries, cotton industries, tea industries, chemical industries, and sugar industries should receive the majority of the waste heat energy that is used.

2. Literature Review

Heat utilization via highly efficient design power cycles. The primary objective is to find the best methods for transforming lost heat into adequate engine energy(Zhang et al. 2022).A multiperiod heat integration strategy can reduce energy use, expenses, and CO2 emissions. The project focuses more on being a proper model to utilize wasted heat energy in productive parts and assisting and sustaining environmental safety(Möhren et al. 2021).A mathematical model of steam condensation is devised in the presence of a noncondensing gas. There are numerous exhaust gas sources. The model makes it possible to sustain them through those fields, which is difficult in the current environment(Arsenyeva et al. 2021). The framework is operationalized and the waste heat drivers in the integrated system are identified using the system dynamics modeling approach. After that, keep them going and put them in a recyclable form so that the squandered gas is fully utilized(Ziemele and Dace 2022). In this study, the heat exchanger's seven geometrical parameters are examined to reduce entropy generation and optimize efficiency. The optimization is done with the help of a genetic algorithm(Patel, Kumar, and Patel 2022). In this study, various flat tube heat exchanger designs for use as direct evaporators in heat pumps are experimentally analyzed(Westhaeuser et al. 2023). The article's main topic is waste heat produced by equipment using a heat pipe for other purposes(Martvoňová et al. 2021). Investigations were done into how a 1-2 tubular heat exchanger's various parameters were affected by the outer diameter and thickness of the tubes(Singh, Sahu, and Verma 2022). Here, the TPMS Schoen-G heat exchanger and printed circuit heat exchanger (PCHE) conjugated heat transfer of SCO2 was simulated using three-dimensional steady turbulent equations of Navier-Stokes with Reynolds average(Li, Li, and Yu 2022). Including a heat pipe heat exchanger, this study attempts to change the physical layout of the AII room's HVAC system, which is utilized to remove contaminated air (HPHE)(Sukarno et al. 2021).

3. Data collection and customer survey

The primary criteria are shown in the Pareto Chart (Figure 1: Pareto chart of criteria for Utilization of Waste Heat Energy) and the corresponding cumulative counts obtained from the survey data. From the chart, it is evident that a whopping 80% of the total count is found for several needs. Figure 2 shows that applicability in large production regions and ccost-effectivenessm make up a significant amount of customer requirements, where a moderate optimization of time and energy has less impact on thecustomer'ss interest. Additionally, the customers' circle places a high value on interest in investment, suitability in Bangladesh, efficiency as a preferable power source, availability of labor, manageable labor, time and energy optimization, good optimization of time and energy, durability, willingness to invest, and good efficiency.

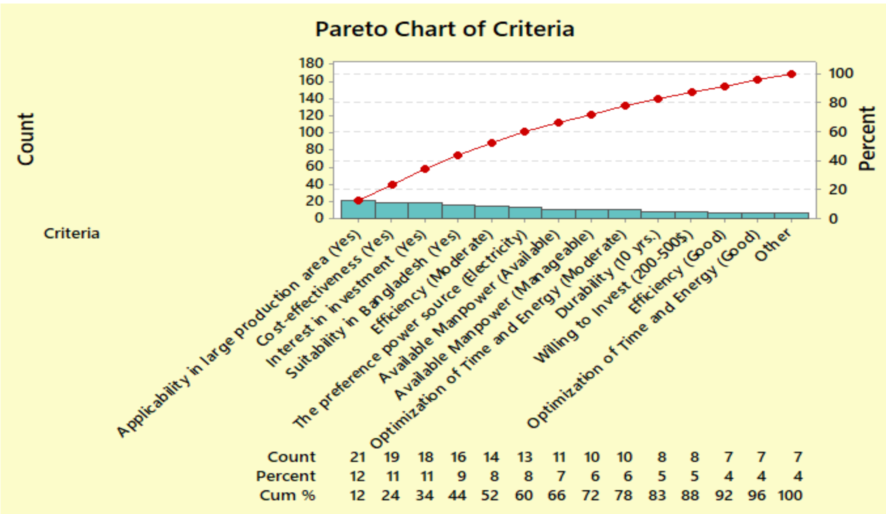
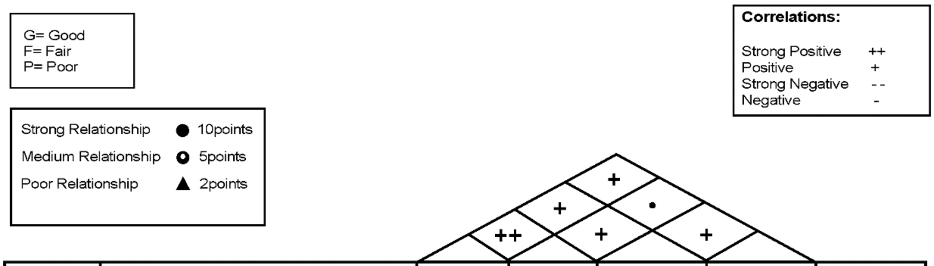


Figure 3. Pareto chart of criteria for Utilization of Waste Heat Energy

4. Methodology

4.1 Quality Function Deployment (QFD)

Analyzing the product concerning the client demand and market competition becomes a priority for any innovation. QFD is the ideal way of determining so and making the product sustainable, profitable, and worthy for the client. The Quality Function Deployment (QFD) table in Figure 2 (Quality Function Deployment for Utilization of Waste Heat Energy) details the relationship between the system's functional requirements, such as the flow meter, flow meter sensor, and storage tank, while the customer's requirements are cost effectiveness, manpower, time and energy efficiency, and durability. Figure 2's flow meter and motor receive a technical score of 110. Storage tank and sensor, on the other hand, receive 25 and 55 points, respectively. Which assigns the storage tank and sensor, respectively, an importance value of 8.33% and 18.33%, and the first two functional requirements a score of 36.67%. Although the flow meter and motor have the same amount of relevance, the motor is awarded the top spot because it is the most important component of the system.



1: Low 5: High	Desired Direction of Improvement (↑,0,↓)					
Customer Importance Rating	Functional Requirements (How's) → Customer Requirements-What's ↓	Storage Tank	Motor	Flow Meter	Sensor	Weighted Score
5.	Cost-effectiveness	○	●	●	○	G
4.	Man Power		○			P
3.	Power Source			●		F
2.	Time & energy efficiency		●	●	●	G
1.	Durability		●	●	●	G
	Technical Importance score	25	110	110	55	
	Importance %	8.33%	36.67%	36.67%	18.33%	
	Priorities rank	4	1	2	3	

Figure 4. Quality Function Deployment for Utilization of Waste Heat Energy

4.2 Functional Decomposition of the Product

The parts, their descendant, and their functions are the most vital things of the product. The buyer and the worker need to know about every function performed by the parts of the product. A chart in Figure 3 (Functional decomposition of Utilization of Waste Heat Energy) showing the Product's Functional Decomposition clarifies the system's whole function and performance. The storage section, main body, driver unit, and control unit are the four key units that make up the overall system. Two tanks—a washing/dying tank and a cold water tank—make up the storage part. Each tank has an inlet valve and an outlet valve. The primary body is composed of an inner shell made of a copper tank and an exterior part built of a narrow copper pipe. The AC power supply, the motor, and the fluid flow are the system drivers. Lastly, The control unit, which includes the principal controlling components such as the controller, motor, switch, flow meter, and temperature sensor.

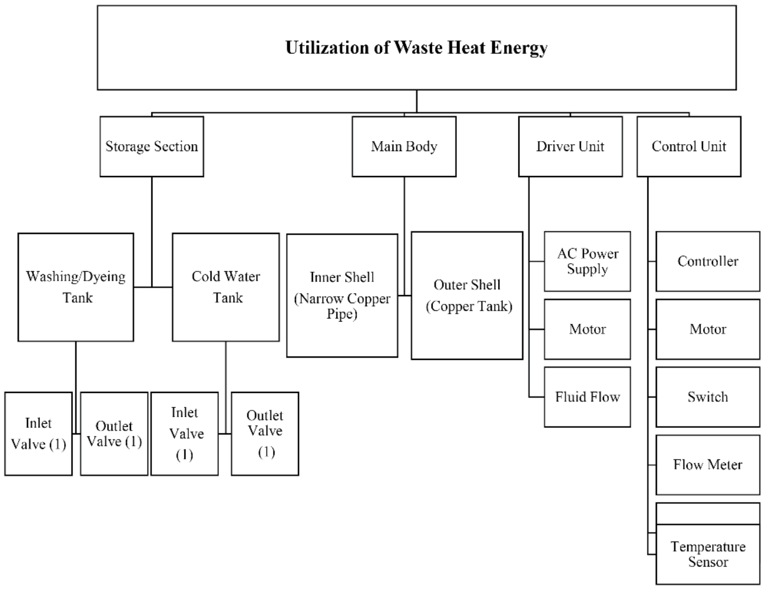


Figure 5. Functional decomposition of Utilization of Waste Heat Energy

4.3 Black Box

Black Box is an informative box that reveals information about the product without going deep into the product. In short, it gives what the product brings to its customers. Without knowing the final output of the product, the product will never attain the customer's satisfaction and make them understand the product. Figure 4 (Black box of automatic distribution channel) shows the input and output energy and material of the system. Thermal and electrical eneigies are given as input through the hot water tank and electrical energy flowing from the power supply source to the motor. Thermal energy is obtained as output in the pre-heated water. In the case of material, hot waste water is flown outside the narrow cold water pipe and at the same time, cold water flows through the hot waste water tank. As output, the waste water is sent to the ETP plant and fresh pre-heated water is flown to the washing/dyeing tank. Electrical signals, start and stop movements, and motion is used to control the system.

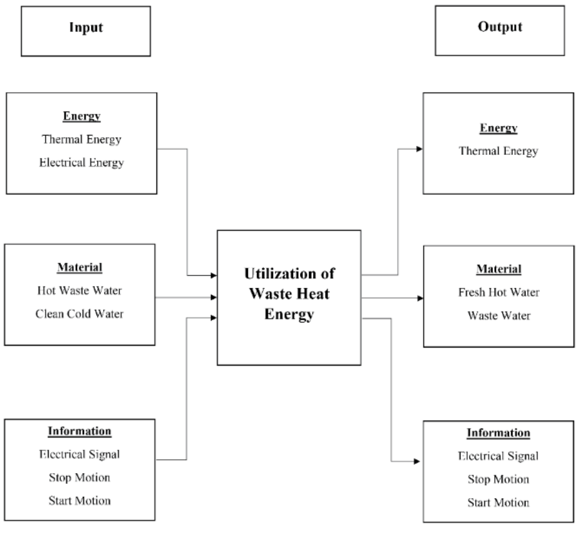


Figure 6. Black box of automatic distribution channel

4.4 Cluster Diagram

The stepwise process of the product's internal parts is visualized through a cluster diagram. It enables the client to understand the sequential mapping of the product most feasibly. Figure 5 (Cluster diagram for Utilization of Waste Heat Energy) depicts the energy transformation and material flow in detail. The electrical energy supply is given to the sensor which initiates the starting of the motor followed by the duct line and finally to the wshing/dyeing tank. As a result, electrical energy is converted to mechanical energy. On the other hand, a signal from the motor is received by another sensor which pushes the waste water through the hot water tank to the ETP plant. In this path flow, again electrical energy is converted to mechanical energy. So, the total energy conversion is between electrical energy and mechanical energy. Sums up that, cold water is converted to hot water and heat energy i.e. mechanical energy transfer takes place in this system.

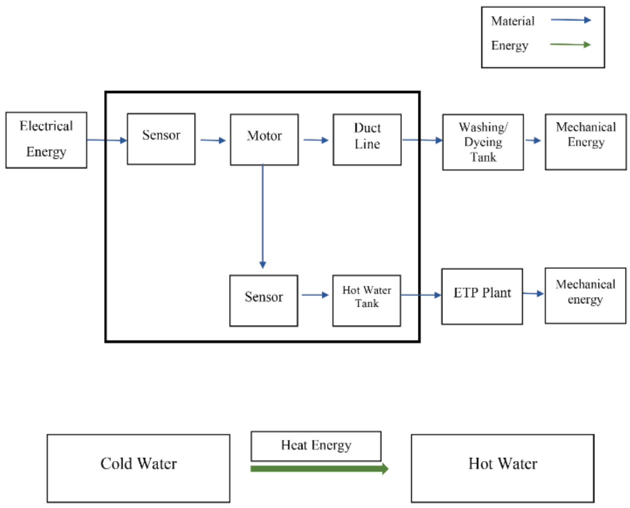


Figure 7. Cluster diagram for Utilization of Waste Heat Energy

4.5 Material Selection

4.5.1 Product 1: Transferring Pipe

Table 1 represents the determination of relative importance of goals using a digital logic method. The most critical criterion for selecting material for a transferring pipe is corrosion-resistant. Therefore, criteria like tensile strength, durability, cost-effectiveness, and availability are considered for selecting the appropriate material. All measures are compared, and the weighted factor or the relative emphasis coefficient is calculated according to priority basis and the number of positive decisions for each criterion.

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											
	1	2	3	4	5	6	7	8	9	10	Positive Decisions	Relative emphasis co-efficient α
Durability	0	0	0	1							1	0.1
Tensile Strength	1				0	1	1				3	0.3
Corrosion Resistance		1			1			1	1		4	0.4
Availability			1			0		0		0	1	0.1
Cost				0			0		0	1	1	0.1
	The total number of possible decisions (N) =										10	∑α=1

Table 2 representsa ranking system for the selected criteria. Some criteria, like tensile strength, have specific numerical values. So, comparing both materials is easy for this particular criterion. But the other standards like durability, corrosion resistance, cost-effectiveness, and availability do not have a specific numerical value. So, to compare the candidate materials on these criteria, the rating system from Table 2 is applied. The candidate materials are compared based on selected criteria. Materials are rated 1-5 according to their performance for a specific benchmark.

Table 2. Numerical Value (Rating)

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

Table 3 shows a comparison between the candidate materials based on the selected criteria. The tensile strength of stainless steel is 650 (MPa), and for mild steel, it is 450 (MPa). But the other standards like durability, corrosion resistance, cost-effectiveness, and availability do not have a specific numerical value. So, to compare the candidate materials on these criteria, the rating system from Table 2 is applied. The materials are rated for each standard based on practical knowledge and theoretical analysis. Stainless steel has higher corrosion resistance than mild steel, which indicates that stainless steel also has higher durability than mild steel. So, for these two criteria, stainless steel is rated higher.Mild steel is highly available and cheaper compared to stainless steel. On the other hand, cost fluctuates from time to time, depending on many aspects like availability, market supply, demand, etc. So, for both these criteria, mild steel is rated higher than stainless steel.

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

Selection Criteria/Material	Mild Steel	Stainless Steel	Selection Criteria	Mild Steel	Stainless Steel
Tensile Strength (MPa)	450	650	Durability	3	4
			Corrosion Resistance	3	5
			Cost Effectiveness	5	3
			Availability	4	3

Table 4 represents the final resultof the performance index for the candidate materials. After analyzing the rating for selected criteria and the weighted factor, the performance index for both materials is calculated. For mild steel, the performance index is 73.423, and for stainless steel, it is 93.5.
Result: Stainless steel is selected as the core material for this part due to the high- performance index of 93.5.

Table 4. Calculation of the Material Performance Index.

Selection Criteria	Weighted Factor, α	Mild Steel		Stainless Steel	
		Scaled Property, β	Weighted property α*β	Scaled Property, β	Weighted property α*β
Durability	0.1	69.23	6.923	100	10
Tensile Strength	0.3	75	22.5	100	30
Corrosion Resistance	0.4	60	24	100	40
Cost Effectiveness	0.1	100	10	60	6
Availability	0.1	100	10	75	7.5
Material Performance Index, $\Upsilon = \sum \alpha\beta$			73.423		93.5

4.5.2 Product 2: Heat Exchanger Tube

Table 5 is a representation of determination of relative importance of different criteria for the heat exchanger tube by using a digital logic method. Since the principal emphasis of the heat exchanger is to transfer heat as much as possible from the heated wastewater to the clean cold water to pre-heat the clean water for various operations like dyeing and washing. The thermal conductivity of the tube material is a crucial factor. Other criteria like tensile strength, corrosion resistance, cost-effectiveness, and availability are alsoconsidered. All requirements are compared with each other. The weighted factor or the relative emphasis coefficient is calculated according to priority basis and the number of positive decisions for each criterion.

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

Selection Criteria (Goals)	The number of positive decisions: 5(5-1)/2= 10											
	1	2	3	4	5	6	7	8	9	10	Positive Decisions	Relative emphasis co-efficient α
Thermal Conductivity	1	1	1	1							4	0.4
Tensile Strength	0				0	1	1				2	0.2
Corrosion Resistance		0			1			1	1		3	0.3
Cost Effectiveness			0			0		0		1	1	0.1
Availability				0			0		0	0	0	0
	The total number of possible decisions (N) =										10	∑α=1

Table 6 represents a ranking system for the selected criteria. Some criteria, like tensile strength, have specific numerical values, so comparing both materials is easy for this particular criterion. But the other standards like durability, corrosion resistance, cost-effectiveness, and availability do not have a specific numerical value. So, to compare the candidate materials on these criteria, the rating system from table 6 is applied. The candidate materials are compared based on selected criteria. Materials are rated 1-5 according to their performance for a specific benchmark.

Table 6. Numerical Value (Rating)

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

Table 7 shows a comparison between the candidate materials based on the selected criteria. Based on these criteria, copper and titanium are heat exchanger tubes' core materials. Tensile strength has specific numerical values, which are 210 (MPa) for copper and 240 (MPa) for titanium. The other criteria do not have e numerical value. So, the rating system from Table 6 is applied to these.The materials are rated for each criterion based on practical knowledge and theoretical analysis. Copper has 23 times better thermal conductivity than titanium; copper is better in corrosion resistance than titanium. So, copper is given a higher rating for both criteria. Cost fluctuates from time to time, depending on many aspects like availability, market supply, demand, etc. Titanium is very much costly compared to copper. Also, copper is readily available in comparison to titanium. So, copper gets the upper hand in both these aspects.

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

Selection Criteria/Material	Copper	Titanium	Selection Criteria	Copper	Titanium
Tensile Strength (MPa)	210	240	Thermal Conductivity	5	3
			Corrosion Resistance	4	5
			Cost Effectiveness	4	2
			Availability	4	3

Table 8 is for the performance index. Represents the calculation of the material performance index for both candidates. Finally, after analyzing the ratings and weighted factors, the material performance index is calculated, which is 91.5 for copper and 79 for titanium.

Result: Copper is selected as the core material for this part due to a higher performance index of 91.5.

Table 8. Calculation of the Material Performance Index

Selection Criteria	Weighted Factor, α	Copper		Titanium	
		Scaled Property, β	Weighted property α*β	Scaled Property, β	Weighted property αβ

Thermal Conductivity	0.4	100	40	60	24
Tensile Strength	0.2	87.5	17.5	100	20
Corrosion Resistance	0.3	80	24	100	30
Cost Effectiveness	0.1	100	10	50	5
Availability	0	100	0	75	0
Material Performance Index, ϒ = ∑ αβ			91.5		79

4.5.3 Product 3: Outer Shell

Table 9 represents the determination of relative importance of different criteria for the outer shell by using a digital logic method. The outer shell of the heat exchanger covers the heat exchanger tube and contains waste hot water inside it. The outer shell does not require thermal conductivity to a greater extent. Instead, it has to be thermal resistant and should have insulative properties to efficiently transfer the heat to cold water with minimum heat loss. Also, the waste hot water from the washing and dyeing machine contains various chemicals that can be corrosive to the outer shell, as the shell remains directly in contact with the water. So, corrosion resistance is also a key factor for outer shell material selection. Therefore, the criteria selected for the outer shell material are thermal resistance, corrosion resistance, tensile strength, cost-effectiveness, and availability. All criteria are compared, and the weighted factor or the relative emphasis coefficient is calculated according to priority basis and number of positive decisions for each criterion from Table 9.

Table 9. Determination of Relative Importance of Goals Using Digital Logic Method

Selection Criteria (Goals)	The number of positive decisions: 5(5-1)/2= 10											
	1	2	3	4	5	6	7	8	9	10	Positive Decisions	Relative emphasis co-efficient α
Thermal Resistance	1	1	1	1							4	0.4
Tensile Strength	0				1	1	1				3	0.3
Corrosion Resistance		0			0			0	1		1	0.1
Cost Effectiveness			0			0		1		1	2	0.2
Availability				0			0		0	0	0	0
	The total number of possible decisions (N) =										10	∑α=1

Table 10 represents a ranking system for the selected criteria. Some criteria, like tensile strength, have specific numerical values, so comparing both materials is easy for this particular criterion. But the other standards like durability, corrosion resistance, cost-effectiveness, and availability do not have a specific numerical value. So, to compare the candidate materials on these criteria, the rating system from Table 10 is applied. The candidate materials are compared based on selected criteria. Materials are rated 1-5 according to their performance for a specific benchmark.

Table 10. Numerical Value (Rating)

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

Table 11 shows a comparison between the candidate materials based on the selected criteria. These criteria indicate that mild steel and aluminum are core materials for heat exchanger tubes. Tensile strength has specific numerical values, which are 450 (MPa) for mild steel and 90 (MPa) for aluminum. The other criteria do not have a numerical value, so a rating system from Table10 is applied. The materials are rated based on practical knowledge and theoretical analysis for each criterion. Aluminum has better chemical resistance than mild steel. Therefore, aluminum is rated higher than mild steel. But in the case of thermal resistance, mild steel has better resistance than aluminum. Cost fluctuates from time to time, depending on many aspects like availability, market supply, demand, etc.Aluminum is comparatively more costly than mild steel and less available than mild steel. So, for both cases, mild steel is rated higher than aluminum.

Table 11. Preferred material properties and selection criteria of the product.

Selection Criteria/Material	Stainless Steel	Aluminum	Selection Criteria	Stainless Steel	Aluminum
Tensile Strength (MPa)	650	90	Thermal Resistance	4	3
			Corrosion Resistance	4	5
			Cost Effectiveness	4	3
			Availability	5	3

Table 12 represents the performance index calculation based on weighted factor and their rating. Finally, after analyzing all criteria and their rating, the performance index for both materials is calculated. The value of the performance index is 94 for stainless steel and 74 for aluminum.
Result: Stainless steel is selected as the core material for this part due to the high-performance index 94.

Table 12.Calculation of the Material Performance Index

Selection Criteria	Weighted Factor, α	Stainless Steel		Aluminum	
		Scaled Property, β	Weighted property α*β	Scaled Property, β	Weighted property αβ
Thermal Resistance	0.4	100	40	75	30
Tensile Strength	0.1	100	10	20	2
Corrosion Resistance	0.3	80	24	100	30
Cost Effectiveness	0.2	100	20	60	12
Availability	0	100	0	60	0
Material Performance Index, $\Upsilon = \sum \alpha\beta$			94		74

4.6 Design Guidelines for low-cost automated distribution system

4.6.1 Applied design guidelines for reliability

This system focuses on preserving energy and heat from hot water waste by converting it into usable heat for diverse applications. This approach assures that various parts and components can be easily upgraded, repaired, and maintained for at least 10 years. Due to the automated nature of this distribution system, it guarantees some essential aspects, such as the computerized system being regulated by programs to prevent water waste by the user. An automated distribution system is created by utilizing structural design principles and reducing the overall volume of raw materials required. This system guarantees the removal of harmful compounds and contaminants and the transformation of wastewater into material that benefits both the ecosystem and the production of products.This system is made up of readily available, recyclable, standardized, and biodegradable parts that can be put together, lengthened, or shortened depending on the situation.

4.6.2 Applied design guidelines for maintainability:

The selection of pipe, reservoir, etc. was concerned with corrosion resistance material and corrosive materials were avoided during material selection because the majority of the components of this system remain in a wet environment. The components in this system are also quick and simple to replace. Standard fasteners and pipes are used in this system, which reduces the need for spare parts and, ultimately, lowers the cost. Even the design itself is really well thought out, and it can easily guarantee that the product is secure and will easily last for more than ten years. Because there are no sharp edges anywhere in the design, it is secure.

5.7 Designing &Modeling

5.7.1 Designing

Figure 5. is the digital sketch of our Utilization of Waste Heat Energy project. This sketch consists of the full process flow from beginning to end.

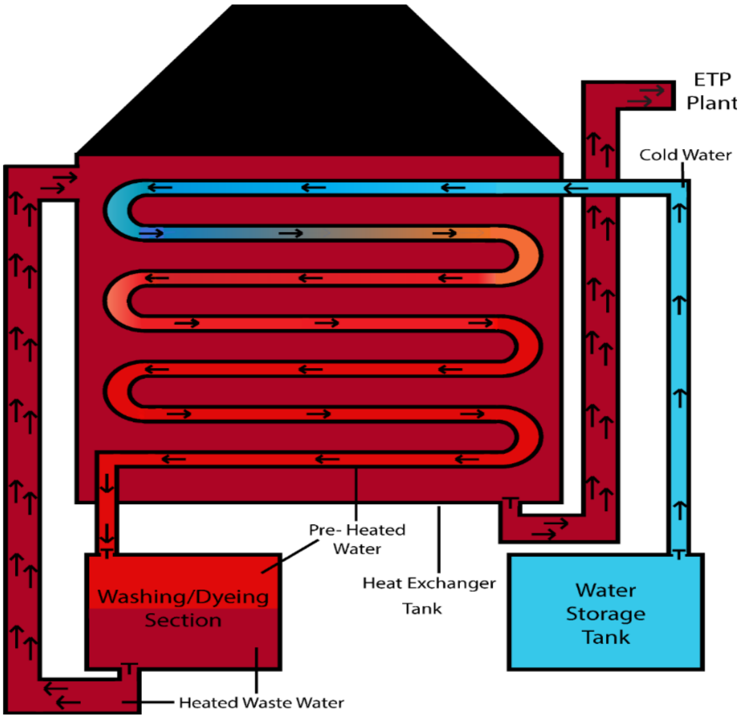


Figure 5. Digital Sketch of Utilization of Waste Heat Energy

4.7.2 Modelling

Figure 6. is a 3D model representation of the utilization of waste heat energy project. This distribution process is fully automated using a PLC controller. These channels can be extended further according to the applications.

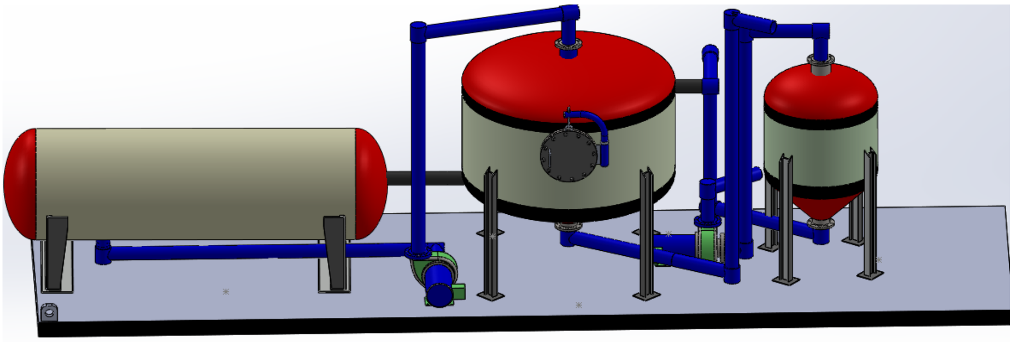


Figure 8. 3D model of Utilization of Waste Heat Energy

4. Result and Discussion

The Utilization of Waste Heat Energy from Water Tanks in Industries makes use of the heat that would otherwise be wasted in the industry and converts it into reusable heat that may be used for heating, power conservation, dyeing, heating, and other purposes. Utilizing materials and costs effectively is one of the project's standout features that guarantees complete client validation. The project's longevity ensures sustainability, and the optimum factory productivity is guaranteed by the low-cost, high-efficiency use of heat. The project's final product ensures that every industry receives the best advantage and the right outcome, much like most other studies dealing with that efficiency and usage. To create an industry with optimal usage and heat treatment, be it in any ETP plant or production plant, 'Utilization of Waste Heat Energy from Water Tanks in Industries' comes into significant consideration.

5. Cost Estimation and Break-even analysis

Getting to know the volume completed of the product to reach the investment and step into profit is essential. Break-even analysis will ensure the client receives a brief idea about the product's business benefits and expected fruitful features.

Figure 7 (Break-even analysis of Utilization of Waste Heat Energy) illustrates that the variable cost per unit product is $13,356. The selling price per unit is $20,000. The fixed cost per year is $1,900,000. A total of 600 units are sold within a year. After analyzing these values, the break-even point according to sales of this product is found $5600. And the break-even point, according to units is around 300 units.

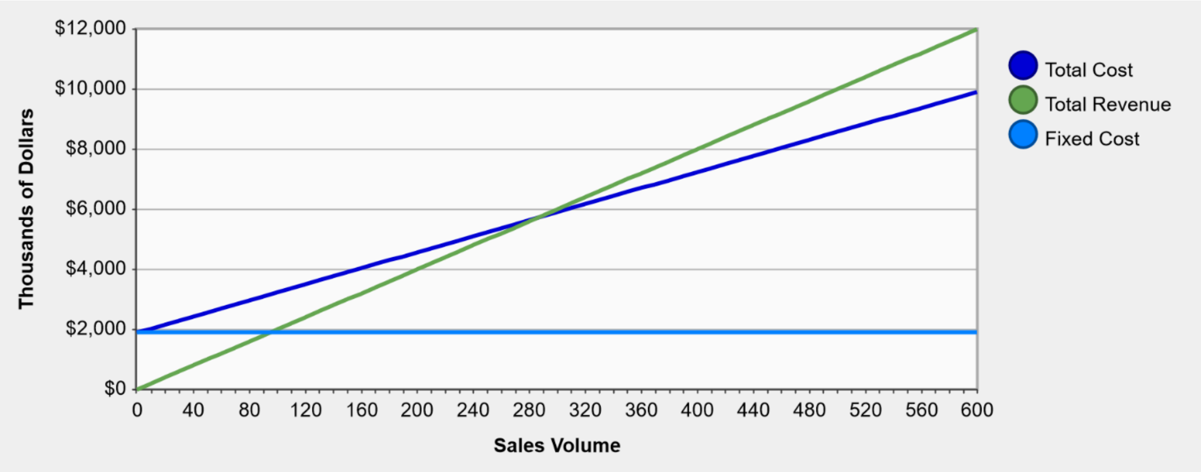


Figure 9. Break-even analysis of Utilization of Waste Heat Energy

Conclusion

The Utilization of Waste Heat Energy's primary goals is energy conversion and effective waste heat energy utilization. Making advantage of the heat that is wasted during wet processes like boiling, washing, dyeing, and finishing is the fundamental objective of the Idea. Because this system will use waste heat rather than releasing the heat into the environment, industrialists will be required to maintain the system's eco-friendliness.Whiletransporting the trash to the ETP plant, the method protects thermal energy from the wastewater.Additionally, this technique will be particularly effective in the present period since, even as most of the world updates daily, energy is becoming increasingly scarce. So, by using less energy, this process is an example of sustainability. Moreover, efforts have been made to minimize energy usage worldwide, and one of the most effective methods is the utilization of waste heat.Even though this product is hoped to be both beneficial for the environment and all customer needs. This product will be among the most intriguing and timely as the globe moves closer to Industrial Revolution 4.0 and sustainability.

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Biographies

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Shafin Mustafa Chowdhury is currently studying at the Bangladesh University of Textiles (BUTEX) under the Department of Industrial Production and Engineering. Since his university life, he has proved to be a worthy researcher in his basic subjects or his primary subject. He is an enthusiastic researcher mainly focused on the field of Engineering Materials, Manufacturing Processes, Product Designing, Automation, Thermodynamics, and Heat Exchange are some of his prior interests. Even studying textile and development subjects and the environment, his desire for Industrial research and development never seemed under the bar. Besides spending most of his time in sports, blogging, and participating in different clubs, he has been an outstanding candidate for research and publication works.