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Advancements in heat exchanger design for waste heat recovery in industrial processes

Anand Kishorbhai Patel *

Department of Mechanical Engineering, LDRP- Institute of Technology & Research, Gandhinagar, Gujarat, India.

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Abstract

This project shows the efficiency of the heat exchanger model and how effectively the model can transmit from one medium to another medium. The heat recovery in the industrial process gets improved after using this model in the industries. The heat exchanger model has good accuracy in transmitting heat from one medium to another medium.

Keywords: Heat exchanger; Solid Works; Waste recovery; Energy consumption; Phase changing; Industrial

1. Introduction

One-third of energy consumption is imputable globally to different industrial sectors, with approximately 50% wasted in the form of heat ultimately. Optimization of heat waste is difficult in terms of quality and quantity in the industries. Therefore, significant environmental impacts are associated with the optimization of the availability of heat energy, the scope of recovering these energies, and cost reduction within the industries [1]. A waste heat energy framework can be implemented to provide an effective exchange balance and compatible analysis of the heat exchange analysis for industries. Three major stages among which the recovery of the heat energy takes place are in such frameworks, *multiple energy supplies*, *energy consumption*, and *harnessing waste energy* forming a loop [2].

1.1. Problem statement

Heat waste is a major issue created by industries in recent times which impacts the environment and harms the balance. Utilization of fossil fuels is the major limitation of the industries where mass emission and heat are introduced in nature. This phenomenon causes high pollution and warms up the environment [3]. Therefore, this produced heat must be optimized in different beneficial ways within the industries. Such implementation involved in heat exchanger, to utilize the produced heat for efficient use.

Aim

The main aim of this paper is to construct an advanced approach and design a heat exchanger for waste recovery in different industries.

Objectives

Attainment of the aim has been considered with the integration of significant objectives as follows:

- To evaluate the basic concept of heat exchangers for waste recovery in industries.
- To optimize the advanced technologies that can be deployed for designing the heat exchanger for a significant purpose.

* Corresponding author: Anand Kishorbhai Patel

- To elucidate the benefits and limitations of such technology in industries.
- To implement an effective heat exchanger for waste recovery with simulation software, ***SolidWorks***.

1.2. Research question

The research questions have been designed based on the determined objectives to achieve the goal of the paper.

- What is a heat exchanger for waste recovery for industrial purposes?
- What are the heat exchanger technologies for waste recovery?
- What are the benefits and limitations of such technology in industries?
- How to design a heat exchanger for waste recovery in different industries using SolidWorks?

1.3. Rationale

The research has been conducted to provide an effective way of optimization of losing heat energy caused due to several operations in the industries. Optimization over the heat loss, a global environmental impact can be optimized adequately which also will provide extensive benefits to the industrial sectors [4]. As the paper is based on the effective implementation of a heat exchanger for waste recovery, the paper is involved in investigating different advanced technologies and processes to optimize the effective way of implementation.

2. Literature Review

2.1. Introduction

The developer has been providing various information regarding the advancement in heat exchangers in the industrial process, this heat recovery process for the industrial processes. According to the data, waste heat recovery has been containing various approaches to recovery [5]. That recovery process has included the transfer the heat between gases and liquids, the developing process for mechanical and electrical power, along with here also involved a heat pump for heating or cooling facilities. Based on the data, the researcher also provides various data about the advantage and disadvantages of the heat exchanger and cost efficiency of the heat exchanger, hence also describing the research linkage with the aim [6].

The studies from [56, 57, 58, 59, 60, 61] Patel Anand et al. for heat exchanger includes enhancement of heat transfer in an heat exchanger by varying the geometrical configuration in it.

2.2. Implementation process of Heat Exchanger in industrial process

To ensure effective heat transfer and effortless integration within the system, several crucial procedures must be taken before a heat exchanger can be implemented in an industrial process [7]. An essential tool for transferring thermal energy between any number of fluids that are at distinct temperatures is a heat exchanger, which is frequently used in industrial processes like power generation, chemical synthesis, HVAC systems, and others.

- ***Design and Selection***: The initial stage is to identify the requirements for heat exchange, including the desired temperature change, fluid flow rates, and fluid pressure parameters [8]. The right kind of heat exchanger is then chosen by engineers based on things like fluid characteristics, space restrictions, and upkeep concerns. Heat exchangers of the plate, finned-tube, shell-and-tube, and double-pipe kinds are typical examples [9].
- ***Engineers select materials*** that can survive the working conditions and probable adverse effects of the fluids based on the fluids' biochemical and thermal properties. For effective heat transfer, materials should also ensure adequate heat conductivity [10].
- ***Sizing and Configuration***: The exchanger that transfers heat must be properly sized to transport heat at the necessary rates. Engineers determine the necessary heat transfer area while taking into account variables such as flow rates, heat exchanger types, and temperature differences between the fluids [11]. The design of the heat exchanger, including how the tubes, flexible fins, and flow routes are arranged, is also adjusted for effective heat exchange.

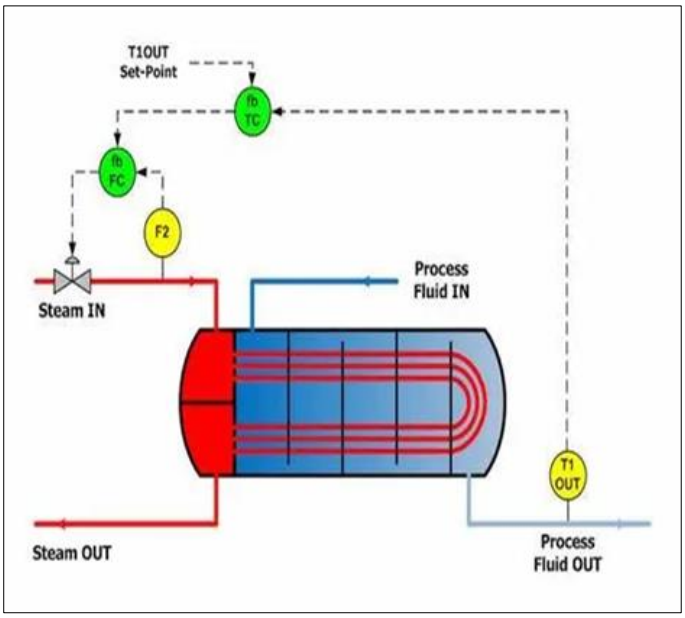

Figure 1 Heat Exchanger control

- ***Installation***: The heat exchanger is positioned and connected to the pipe system as part of the industrial process, frequently requiring careful positioning [12]. To avoid stress on the component, which could affect its longevity and achievement, proper alignment and assistance are required.
- ***Fluid Management and Routing***: The connections for the heat exchanger's input and outflow are part of the overall fluid circuit. Engineers ensure that fluids are routed properly, taking into mind things like flow direction, reductions in pressure, and avoiding air or gas pockets that could obstruct heat transfer [13].
- ***Insulation and Heat Conservation:*** The heat exchanger may be wrapped using substances that provide resistance to heating to reduce heat loss to the environment [14]. By doing this, energy waste is minimized and the method used to transfer heat is guaranteed to be as effective as possible.

The design of heat exchanger to could be improved or enhanced by looking at similar devices thermal performance analysis as documented in [62, 63, 64, 65, 66, 67, 68, 69, 70] Anand Patel et al. for Solar Air & Water Heater [71, 71] Patel Anand et al. for Solar Cooker.

2.3. Advantages and disadvantage of the Heat Exchanger

2.3.1. Advantages of Heat Exchangers

- ***Effective Thermal Energy Transfer***: Heat exchangers enable effective thermal energy transfer amongst fluids requiring direct mixing [15]. As a result, process efficiency is increased, and temperature management is optimized while using less energy.
- ***Energy Savings***: Heat exchangers help conserve energy by making it possible to recover thermal waste from exhaust gases or processing streams. This lowers operating costs and lowers the carbon footprint.
- ***Space Optimization***: Heating exchangers are small, space-efficient devices with a large surface area for heat transfer. This is especially helpful in sectors with constrained space [16].
- ***Temperature Control***: In manufacturing procedures, heat exchangers enable accurate temperature control. They can heat or chill fluids to particular temperatures ensuring stable processes and constant product quality.

2.3.2. Disadvantages of Heat Exchangers

- ***Initial Costs***: Designing, manufacturing, and installing heat exchangers can come with a high initial cost, especially for applications that are specialized or hostile regions [17]. However, permanent energy savings frequently offset these costs.
- ***Heat exchangers need routine maintenance*** to avoid corrosion, scaling, and fouling, which can eventually cause performance to suffer. Downtime and related costs might result from maintenance efforts.

- ***Complexity***: Some heat exchanger layouts can be complex and hard to construct, necessitating careful engineering and qualified maintenance workers [18]. This intricacy might make troubleshooting and repair difficult.

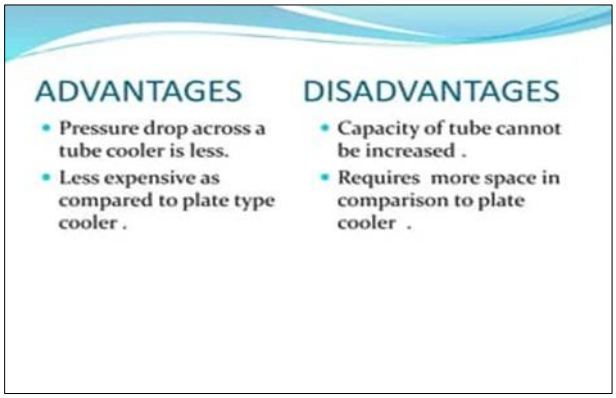

Figure 2 Heat Exchangers Advantage or Disadvantages

- ***Pressure Drop***: The efficiency of the entire system may be impacted by pressure drops that heat transfers can create in the path of the fluid [19]. When adding heat exchangers in current networks, this is very important.
- ***Fluid compatibility***: To prevent chemical reactions involving the fluids as well as heat exchanger surfaces, it is essential to use the right materials for heat exchangers. Corrosion and system breakdown might result from using incompatible materials [20].

2.4. Cost efficiency of Heat Exchanger

Imagine an industrial operation where waste or exhaust streams are produced by elevated temperatures of fluids. As responsible energy guardians, heat exchangers stop these streams. They use the heat that is recovered to raise the temperature of entering fluids, much like a conductor bringing an ensemble into tune. By eliminating the need for external heating systems, this planned dance of energy transmission lowers energy consumption and, consequently, operational costs. Beyond only lowering energy expenses, this efficiency is beautiful. Industrial equipment's durability and vitality are influenced by heat exchangers [21]. They become protectors against excessive temperatures that might hasten the aging of gear by optimizing and controlling the temperature. This oversight also covers the area of process integrity. The elegance of cost-effectiveness, however, extends outside the boundaries of the factory [22]. Heat exchangers represent environmental stewardship. Their success in reducing energy use fits in with environmental laws and sustainability programs. The company's decreased carbon footprint and dedication to green business procedures show that it not only excels in its financial records but also values the health of the environment [23]. Interestingly enough, heat exchangers' artistic merit goes beyond just serving a purpose. Their physical layout is the definition of effectiveness in small areas.

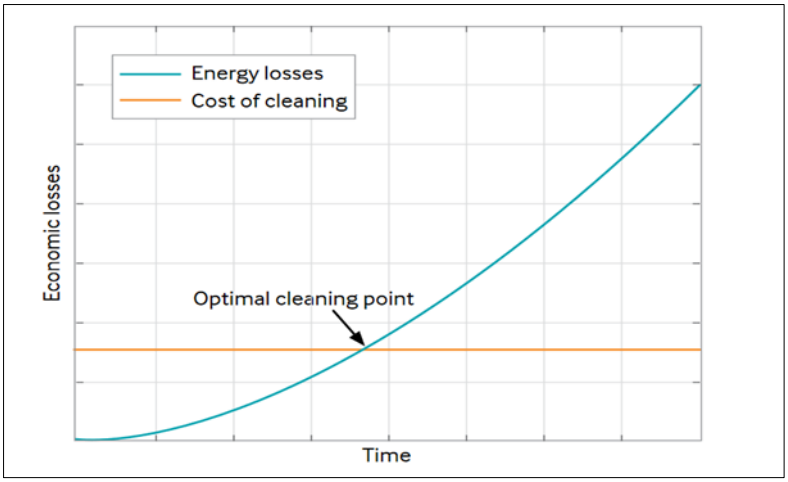

Figure 3 Heat Exchanger

These gadgets act as quiet sentinels in sectors where space is at a premium and maximize the transfer of heat surface area without requiring cumbersome installations [24].

The heat exchanger has been containing various benefits, which help to decrease structural damage, and harmful pollutants, and also deduct energy from cost. Hence their result help to improve the indoor air quality and it also affect the home occupants. According to the data this process has been included with the installation cost, operational cost, and also energy savings process [25]. The installation process of the heat exchanger has been affected via investment and this has been also included with the purchasing of required components. Hence the cost efficiency of the heat exchanger has been creating essential challenges and also including the different methods, which is help to achieve the goal [26]. Using techniques in the deve, elopement process is focused on the modify the extant "***HENs***" to fetch power conservations and overwhelm grid blockages. According to the data, this installation process has been containing a large amount for installation. This installation process has been included with the ***"Floor area"*** as per the square feet, infiltration rate, fuel oil cost per gallon, and electricity cost per hour [27].

2.5. Linkage to Aim

The main aim of this project is that develop an advanced approach and a heat exchanger for waste recovery in different industries. This heat exchanger of waste recovery is help to develop the basic concepts of heat recovery in industries. It also describes the process of using the advanced technologies that can be deployed for inventing the heat exchanger for paramount intent. It also describes which type of technology the industry needs and their installation and use purposes. Thus, here researcher has been using ***MATLAB***, for the implementation of a heat exchanger for the waste recovery process, and to complete the simulation process.

2.6. Literature gap

The researcher has been providing various data which is essential for the research and developing process, during the research, they encountered various issues. Lack of time, lack of data, as well as lack of team efficiency, the researcher has been encountering issues. Optimizing the objective in the model researcher finds out the errors in the model.

2.7. Summary

By absorbing and reusing waste energy from the environment, heat transfer devices are the definition of cost-effectiveness because they cut energy consumption and operating costs. Their exact temperature control improves the integrity of the production process, raising the quality of the goods and reducing waste. Beyond monetary gains, heat exchangers support sustainability objectives by reducing carbon footprints and abiding by environmental laws. Their small size makes the most use of available space and produces long-term ROI. In essence, exchangers of heat are unsung heroes balancing energy flows, extending the life of equipment, and building a more productive and environmentally conscious industrial world.

3. Material and method

3.1. Introduction

The section on methodology has been describing the data about the developing strategy and also provides the effective selection of the research approach and philosophy. Their researcher has been considering the various steps which are essential for defining the steps of research and using the data. Hence developers also crucially analyze the data and choose the appropriate approach for the research method. The researcher justifies their approach properly and provides the proper data regarding using of tools and techniques for developing the model. Hence also provide the ethical consideration of the method which is to define the various data which is essential for the project.

3.2. Research approach

According to the data, this research approach has been furnishing the proper manner and support to achieve the aim of the research process, for this reason, quality research has been proceeding. There are two types of research approaches ***"the inductive approach"*** and ***"the deductive approach"***, hence here researcher has taken the "inductive research approach" and this approach has been able to provide new ideas for inventing heat exchangers for waste materials in the industry [28]. Thus, this approach has been helping to extract new ideas and provide the proper information those are creating suitable benefits for associated human beings.

3.3. Justification of research approach

The inductive research process has been a process that helps to develop the theories on the research topics and it also provides a specification of the preserved or used data [29]. This process has been starting with the data collection process and it also helps to identify the patterns to create the new theories. Using this approach researchers are more flexible for the study and this study is dependent on the information of the necessary data with the information. Hence this inductive research approach has contained several benefits, and this is beneficial for the research. Those benefits are-

3.3.1. Flexibility

The ***"Inductive research"*** process is known as the flexible research process it has permitted researchers to change their research topics and use techniques based on their data collection [30]. Researchers can study new topics and phenomena, that they cant be previously studied or thought about.

3.3.2. Cost efficiency of installing Heat Exchanger

According to the data, this research process has helped to generate new ideas and concepts, and different theories. These theories are helpful to create new interventions or programs, this method also produced the original thoughts and focal points, which are not allowed in the deductive research approach [31].

3.3.3. Discovers probabilities

Examining the information and devoting hypotheses almost its motivations might aid researchers forecast the results of a corporate function transformation. Staining these marks or manipulating statements in the information can assist the researcher comprehend the probability of something emerging in the need [32].

The "inductive research process" has been following some stages for the research, which are- ***"Data collection", "pattern recognition"***, and ***"Theory development"***.

3.4. Research Strategy

The researcher has been using ***"Action-oriented"*** research techniques also known as a collaborative research process with participants and the community. The goal of this research technique has been to create solutions that can be applied to actual issues. It works with the stakeholders, and their research findings also supply information and serve as a decision-making tool [33]. The numerous critical components for this specific research approach have been included in this strategy. These include ***"collaboration", "problem-solving orientation", "participatory approach", "action and change",*** and ***"reflexivity".*** Iterative and dynamic, the action-oriented search method is a process [34]. The goal of this process has been to produce information and solutions that can be used to address challenges in the actual world.

3.5. Data collection

The process of secondary data collection has been involves collecting information those are already been existed and recorded by someone else [35]. The secondary data collection process has been following some steps which are essential for the collection process. Those are-

3.5.1. Identify the research objectives

In this process, the researcher has been determining the specific information which is required and the main aim of collecting secondary. This process has helped to narrow down the search for relent sources.

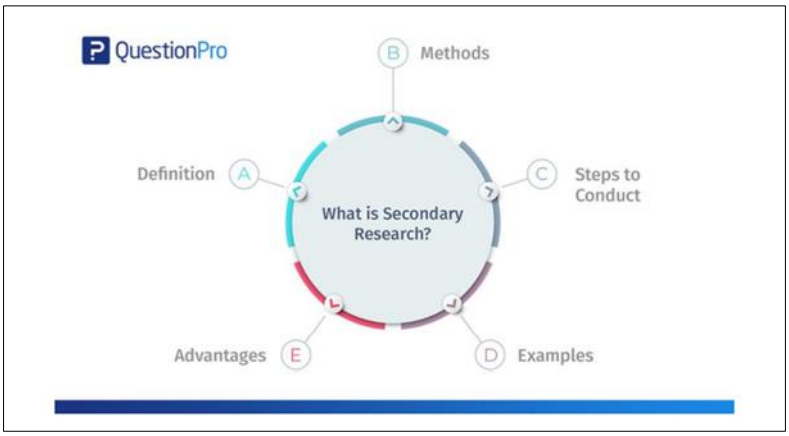

Figure 4 Secondary data collection process

3.5.2. Define the scope

In this phase, the researcher has been determining the period, geographic area, and other types of relevant sources for the data collection process. This has been focusing on the research and making sure that the collected data required is capable of the research objectives [36].

3.5.3. Evaluate data sources

Assess the credibility, reliability, and relevance of the identified data sources and consider factors such as the reputation of the source, the methodology used in data collection, and the validity of the data.

3.6. Data analysis

To find relevant insights, patterns, and trends, data must be carefully examined, cleaned, modified, and evaluated. Making well-informed decisions is facilitated by a well-structured data analysis process, whether it be in the context of business, research, or investigations [37]. The process of data analysis is generally described as follows:

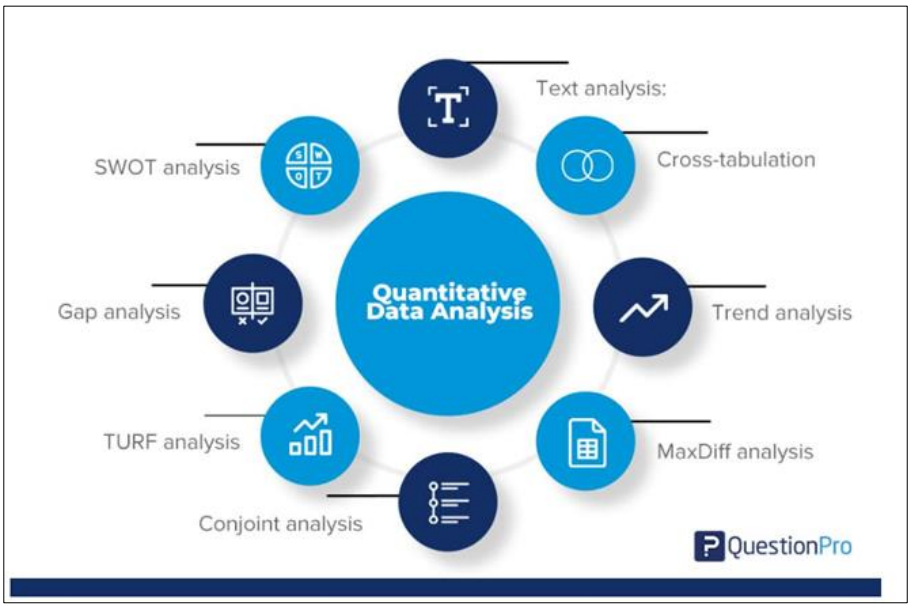

Figure 5 Data analysis

- ***Data exploration:*** Visualize and investigate the data to gain a basic knowledge of its composition, distribution, and patterns. This facilitates developing hypotheses and identifying potential insights.

- ***Data collection:*** Obtain critical information from a variety of sources while assuring its integrity and accuracy. Databases, spreadsheets, APIs, sensors, surveys, and other pertinent technology can be used to achieve this [38].

3.7. Tools and Techniques

Heat exchangers for waste materials in the industry can be designed and analyzed using the computer-aided design (CAD) program Solidworks [39]. Solidworks offers a variety of methods and tools that can be used for this, including:

- ***3D modeling:*** By taking into account the size, geometry, and components of heat exchangers, Solidworks users may build intricate 3D models of these devices [40].
- ***Assemblage modeling:*** Using Solidworks, users may put together different heat exchanger parts, like tubes, fins, headers, and baffles, to form a full system.
- ***Simulation and analysis:*** Solidworks offers simulation tools for evaluating heat exchanger performance. To improve the system's design, users can simulate heat transfer, fluid flow, and pressure decrease inside the system.

3.8. Ethical consideration

Ethical consideration is the set of principles, it has been guiding the designing process and practices. This principle has been used in voluntary participation, informed consent, anonymity, confidentiality, potential risks, and result communication [41].

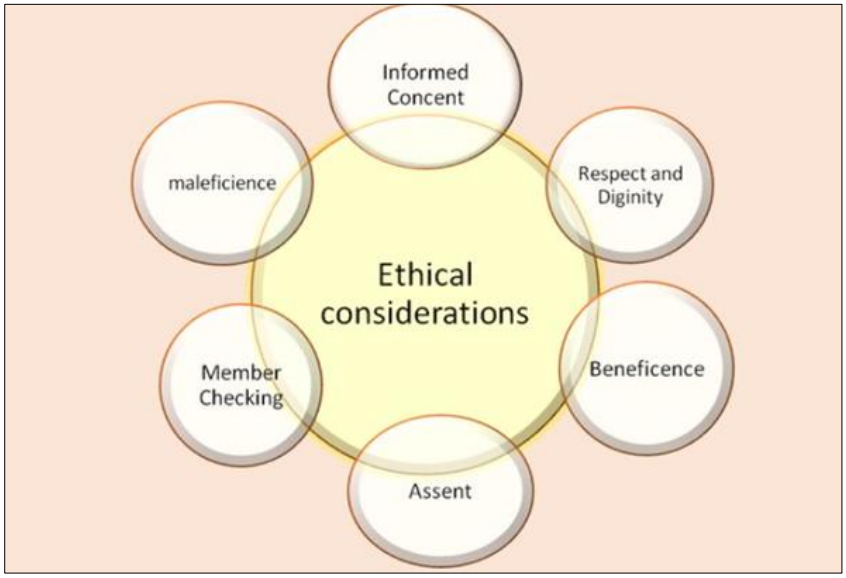

Figure 6 Ethical Consideration in Research

This has provided the data regarding the research and described which types of hazards are available.

4. Results

The entire work has been performed based on the utilization of the equipment of the solid works and the advanced techniques of the heat exchangers. The design will help in evaluating the function of the system that can be deployed for optimizing the heat for different purposes. The system is comprised of the process of heat exchanging of heat from a heated terminal to a cooler one. This system is responsible for the adequate exchange of heat that can be implemented in different applications [53].

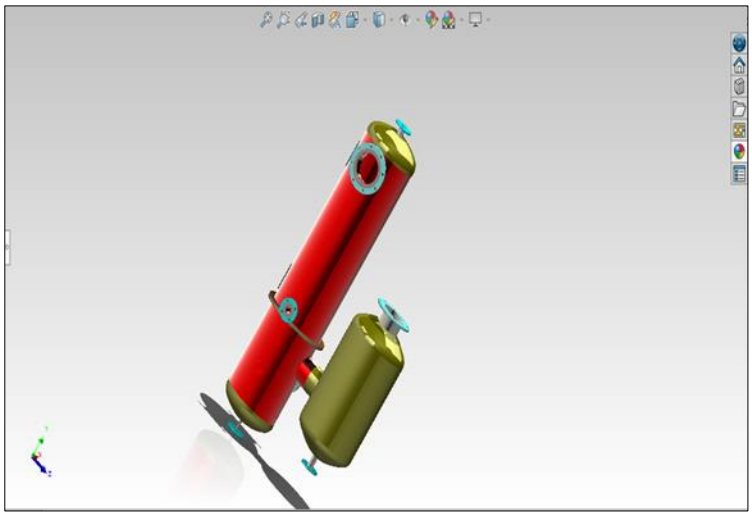

Figure 7 Final model

The above image shows the final view of the model, this is used to show the final model of the heat exchanger. Flow in and flow out at the tube side, tube bundle, shell, and other components are present in the image [54].

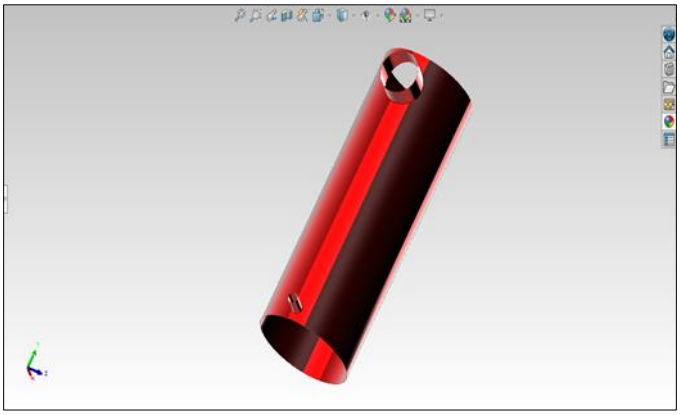

Figure 8 Upper part of the heat exchanger

The upper part of the heat exchanger is shown in the above image; this upper part contains the tubes of the model.

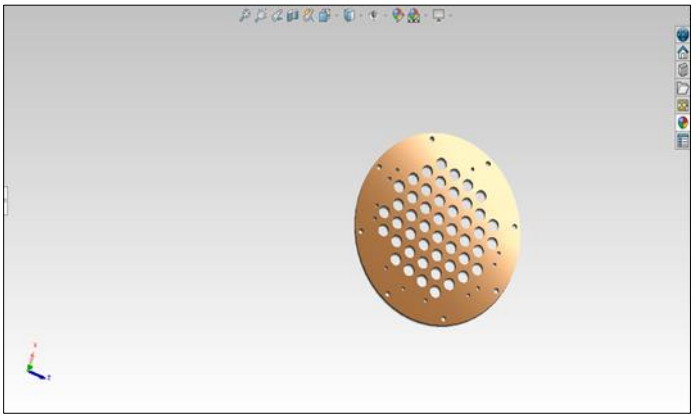

Figure 9 Tube side flow in

The above image shows the data about the tube side flow, this flowing medium is also known as the "tube side" medium. The flowing medium outside of the tube is known as the "Shell side" medium. According to the data, the tubes each entry contains one entry and one discharge [51].

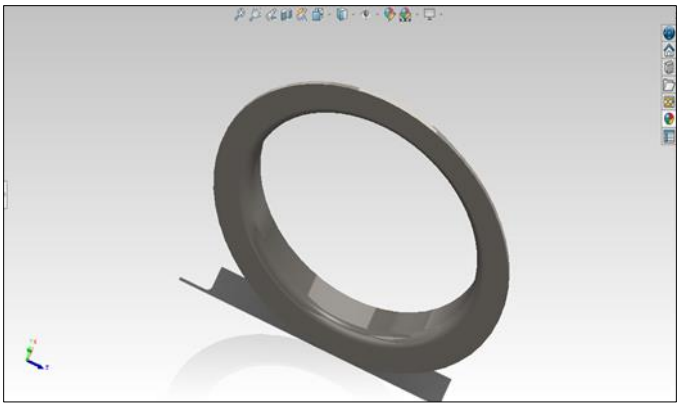

Figure 10 Shell side flow in

The shell heat exchanger is used for the water to cool oil, oil is known as the shell side medium, while water is known as the tube side medium. The oil has been enters through the top left inlet and flows through the heat exchanger, this process has been continue till reaching the lower right discharge.

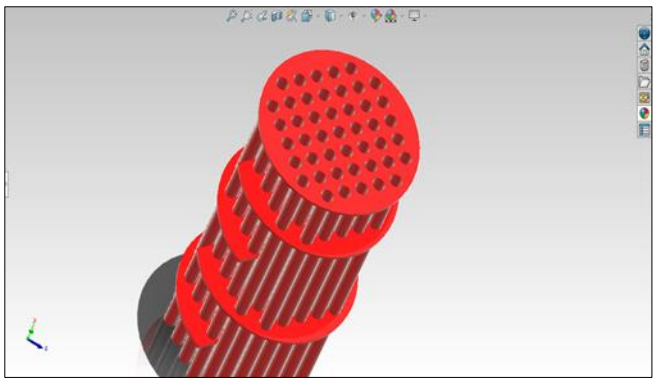

Figure 11 Flow path

The flow path of water is shown in the above image, this path shows the bundle of tubes that is present in the heat exchanger. These tubes provide the surface for heat transfer in the heat exchanger model [52].

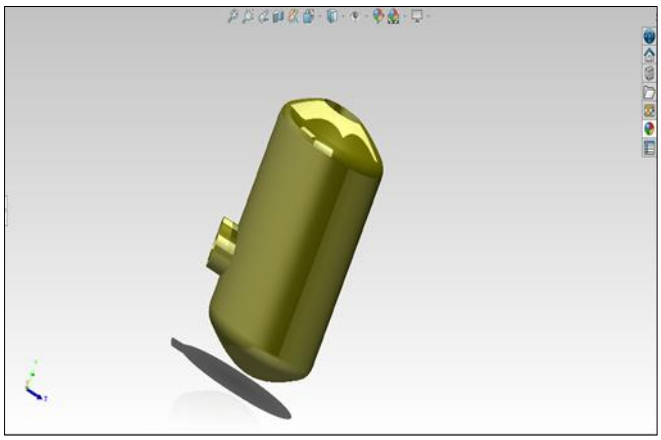

Figure 12 Separator

The above image shows the data about the separator of the heat exchanger, this has been held to split the flow arrangement and the heat exchange arrangement. This heat exchanger has been categorized into two or more heat exchangers. It has helped to recover the heat from the different lean and semi-lean absorbent streams [55].

5. Discussion

Industrial heat exchangers are implemented for different purposes that ultimately optimize the heat and transfer it in a usable form on the premises. Such applications of heat exchangers have included manufacturing, storage, power generation, air and marine support, and chemical engineering [42]. The most common types of exchangers used in industries are *shell and tube heat exchangers* that perform the entire process. Implementation of proper insulation level is the major way of optimizing the reduction of heat gain in the systems. However, the design of such heat exchangers occurs with some limitations including sizing and rating. The sizing problem is associated with the requirement of the dimension of the heat exchanger that is required to be integrated into a significant industry [43]. The rating complexity is engaged with the heat transfer rate, the outlet temperature of the fluid of the medium, and the inlet temperature. Thus, optimization of the most effective sizing and rating is necessary for implementing heat exchangers in the industries. Major heat exchangers used in the industries include *finned tube heat exchangers*, *plate heat exchangers*, and *shell and tube exchangers* based on different working principles. Such operations are induced by *thermodynamics* [44].

The heat exchanger is used to transmit heat from "one medium to another medium". This is used to improve heat transfer efficiency in the model. Analyzing the results of the simulation work's implemented system, which successfully converts heat into usable forms, can guarantee that the objectives set forth are achieved [45]. It may be said that the heat exchanger's implementation has been properly planned out, with accurate measurements of the functionality needed to be integrated into the specified purpose. To maximize the efficiency of the heat produced in the industries, the heat can be effectively transferred in cold form [46]. The implementation of such a system is successful in the industries where it has been assumed to be used [47]. The application of the heat exchanger in many sectors is made simple by the integration of the parameters in SolidWorks.

The integration of increasingly sophisticated functions and operational generalized systems is necessary for this simulation system to continue to be improved to effectively optimize heat [48]. The successful application of more modern software and features, such as phase change technology, quick 3D printing, and green energy initiatives, can facilitate the future scope of such a study. The chosen objective may have a greater impact on these heat exchange strategies [49]. These are the technology that can automatically create prototype exchanger parts, ensuring the perfect fit. With more sophisticated technologies, environmentally friendly thermal management strategies can be used to support the environment more precisely [50].

6. Conclusion

6.1. Critical Evaluation

The recovery process of the produced heat in industries is the potential for economic viability rather than the installation of a system of renewable energy integration aiming at the reduction of net energy consumption across a sector. Integration of such systems in the industries is proved to be the least requirement of operating in harnessing the energy with much effort. Most companies can seek less time and effort to implement such waste optimization with this suggested heat exchanger system. However, identification of the best way of energy recovery within an industry has been provided with an efficient process of outcome analysis of the simulation system which has been proposed here. It is the most appropriate solution to the piecemeal optimization of the objectives.

6.2. Summary of the Achievements

Achievements of the determined objectives can be ensured with the analysis of the outcome of the implemented system of the simulation work which effectively converts the heat into usable forms. It can be affirmed that the implementation of the heat exchanger has been adequately structured with proper measurements of the functionalities required to be integrated into the determined purpose. Conversion of the produced heat in the industries is effectively transferable in the cold form to optimize the heat efficiently. Deployment of such a system is effective in the industries as has been presumed to be performed. Integration of the parameters in ***SolidWorks*** creates an unchallenging way of implementation of the heat exchanger in different industries. The simulation outcomes justify the achievement of the aim of this paper significantly. The entire index represents an effective selection of the sources and the sinks based on performance.

Research recommendations

Based on the optimized solution and the factors of the heat exchanger it can be recommended that the measurement of some facts can facilitate the entire work. Such factors included the simulation equipment, the effective connection between the sources and the sinks, and the integration of effective software which will stimulate the practical work. As the proposed framework is based on effective recovery WHE in different industries, and implementation of such a reconfigurable system of exchange heat, it must be processed with advanced optimizations. Analysis of the major factors is responsible for providing an effective evaluation of the entire requirements and environment of the work.

Future works

Further improvement of this simulation system is involved in the integration of more complex functionalities and operable generalized systems aiming at the effective optimization of heat. The future scope of such research can be facilitated with the effective implementation of advanced software and more advanced features such as *phase change technology*, *rapid 3D printing*, and *green energy initiatives*. These approaches of heat exchange can be more impacted by the determined purpose. These are the technologies that can produce the prototypes automatically in the exchanger parts which ensures the ultimate fit. The utilization of eco-friendly solutions for thermal management can be implemented with more advanced technologies to support the environment more precisely. Improvement of the flow rate in the heat exchanger is the major reason for facilitating the entire work of exchanging heat from a higher temperature to a lower one. These are some of the major optimizations of future developments that can be constructed to obtain effective heat exchange within the industries.

Compliance with ethical standards

Statement of ethical approval

The present research work does not contain any studies performed on animals/human's subjects by any of the authors.

Statement of informed consent

Informed consent was not required as there was no involvement of individual participants in the study.

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