DESIGN IDEAS OF HEAT EXCHANGER IN WATER PIPELINE OUTLET FOR SINGLE HOUSEHOLD: A REVIEW

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ABSTRACT

Every single household has their own water pipeline that is very useful to fulfill their daily activities such as washing clothes, car, drinking water and for bathing. The problem they have to face is that the water they were using for daily activities is extremely hot because of outer surface of water pipeline exposed to the sunlight. This could cause an injury to the person skin, especially to the baby. It is a risk as the hot water came out unexpectedly. The objective of this project is to suggest a design for a heat exchanger to be installed at the outlet of water pipelines, specifically targeting the shower in a bathroom, for use in a single household. Essentially, heat exchangers in water pipelines are devices that enable heat transfer between two fluids of differing temperatures without allowing them to mix. The main idea usage of Heat Exchanger Water Pipeline is to cool down the hot water that flows directly from main water supply and flow out form the outlet pipeline at room temperature. Thus, this project will introduce design ideas that fulfill the user criteria and the CAD modelling of the selected design of water heat exchanger will be presented.

Keywords: *Design process; CAD modelling; heat exchanger; water pipeline outlet; and human skin*.

1. INTRODUCTION

Nowadays, even though there were a lot of advanced technology has been created, there still a problem that we need to be faced in our daily life. The major problem we have to face is the water we are using for daily activities is extremely hot. For example, when we take bath, the water flow out is hot and could cause injury to the person, especially to the baby. It is a risk as we do not know when the hot water came out. The water just flew out unexpectedly. This is due to the weather in Malaysia is very sunny. According to statistic, average maximum temperature in Malaysia is high at most of the places. Furthermore, the temperature is increasing year by year. Many locations in Peninsular Malaysia and northern Borneo showed warming trends of between 2.7–4.0 °C /100 years [1]. The hottest place recorded in Malaysia is Chuping district, Perlis which is 40.1°C. The intense heat from the sun causes the water in the pipeline from the main water supply to become hot. As a result, the water directly from the main supply reaches a high temperature and needs about 10 minutes to cool down before it can be used. At first people thought it can be handled just by store the water first before using it. But what if it is an urgent matter? Take as an example, a person was exposed to hot oil on hand when cooking at home of course the first thing we could washing it. So, what if the water flowing out is extremely hot? The injuries could be worst. Skin, the largest organ in the human body, is responsible for various functions, like preventing the intrusion of microorganisms and protection from dehydration [2]. Skin contact with various liquids was also identified as a factor which may influence different skin properties [3], and eventually lead to skin maceration [4], skin inflame, scalding, causing redness and itching. Not only hot substances or chemicals show damaging effects, but also urine, perspiration, or even water [5-7]. For hot fluid scalding, there are researchers recorded to 43 ◦C as the onset of injury [8]. This issue can be mitigated with an effective mechanical system known as a heat exchanger. A heat exchanger is a device designed to transfer heat between two or more fluids. Heat exchangers are used in both cooling and heating processes [9]. A heat exchanger is a device utilized to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, all at different temperatures and in thermal contact. Typically, there are no external heat or work interactions in heat exchangers. Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single- or multi component fluid streams [10]. In most heat exchangers, heat transfer between fluids occurs through a separating wall or in a transient manner into and out of a wall. Typically, the fluids are divided by a heat transfer surface, preventing them from mixing or leaking. Common examples of heat exchangers include shell-and-tube exchangers, automobile radiators, condensers, evaporators, air preheaters, and cooling towers, as illustrated in Figure 1 below.

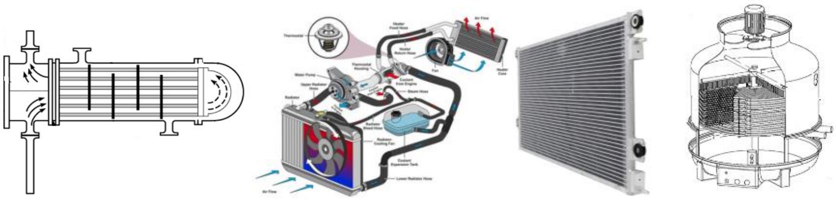

Figure 1: Common examples of heat exchangers

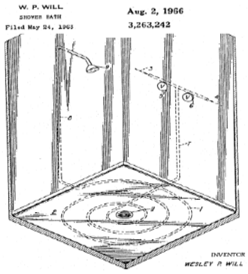

Figure 2: Shower bath with a shower water to floor heat exchanger (Will, 1963)

An early heat exchanger between shower water and the shower floor comes from inventor Wesley P. Will with a patent application 1963 [11]. He describes a shower equipped with a heat exchanger in the form of a coil located in the floor (see Figure 2). This setup allows the hot shower water to be cooled down on the floor before being dispensed at the shower head, with the added benefit of heating the shower floor for greater comfort. A more recent patent application by Christoph Rusch (2015), filed in March 2015, involves a system where incoming cold water is pre-heated using a heat exchanger that transfers heat from the shower's wastewater to the cold water (see Figure 3). Similar heat exchanger patent exists by Patrick (Gilbert, 2009) where the cold water also circulates under a plate and wastewater flows above [11].

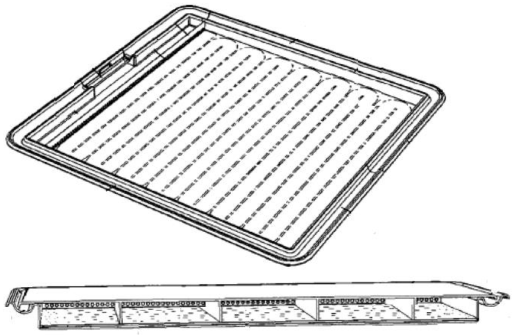

Figure 3: Shower heat exchanger system as detailed by Rusch (2015)

Even though there such many examples of heat exchanger product in existing market, but there still not enough design ideas and specification to fulfill the requirement of our water pipeline system. Therefore, this project was conducted with the purpose to propose the design ideas of water heat exchanger which functioned to cooling down the extremely hot water and return into room temperature water that flow through the shower in our bathroom. This project will be start from the basic step in design process until the development of CAD modelling of selected solution.

2. DESIGN METHODOLOGY

In the initial stages of designing a heat exchanger, the project designer must provide comprehensive images of the entire engineering system, individual system components, or specific parts. These images should clearly depict the system/component structure, size, performance, and other critical characteristics essential for manufacturing and utilization. This can be effectively achieved using a well-defined design methodology. It is important to recognize that the design methodology involves a complex arrangement. Additionally, the design approach for a heat exchanger must align with the system’s life-cycle design. The life-cycle design process encompasses the following stages:

- Problem Identification (including engagement with the consumer).
- Concept Development (choosing feasible designs and preliminary design work).
- Detailed Design of the Exchanger (including design calculations and other relevant factors).
- Manufacturing Process.
- Considerations for Use (including operation, decommissioning, and disposal)

A methodology for designing a new (single) heat exchanger is illustrated in Figure 4; it is based on experience and presented by Kays and London [12], Taborek [13], and Shah [14] for compact and shell-and-tube exchangers. This design process can be described as a case study approach, focusing on one instance at a time. Key design considerations include:

- Process and design requirements
- Thermal and hydraulic analysis
- Mechanical design aspects
- Manufacturing factors and cost implications
- Trade-offs and system-level optimization

These design considerations are typically not linear; there can be significant interactions and feedback among them, as illustrated by the bidirectional arrows in Figure 4. This often necessitates several iterations before the design is finalized. The overall design methodology is complex due to the need for numerous qualitative judgments, in addition to quantitative calculations. It should be emphasized that depending on the specific application, some (but not necessarily all) of the foregoing considerations of heat exchanger designs are applied in various levels of detail during the design process [10].

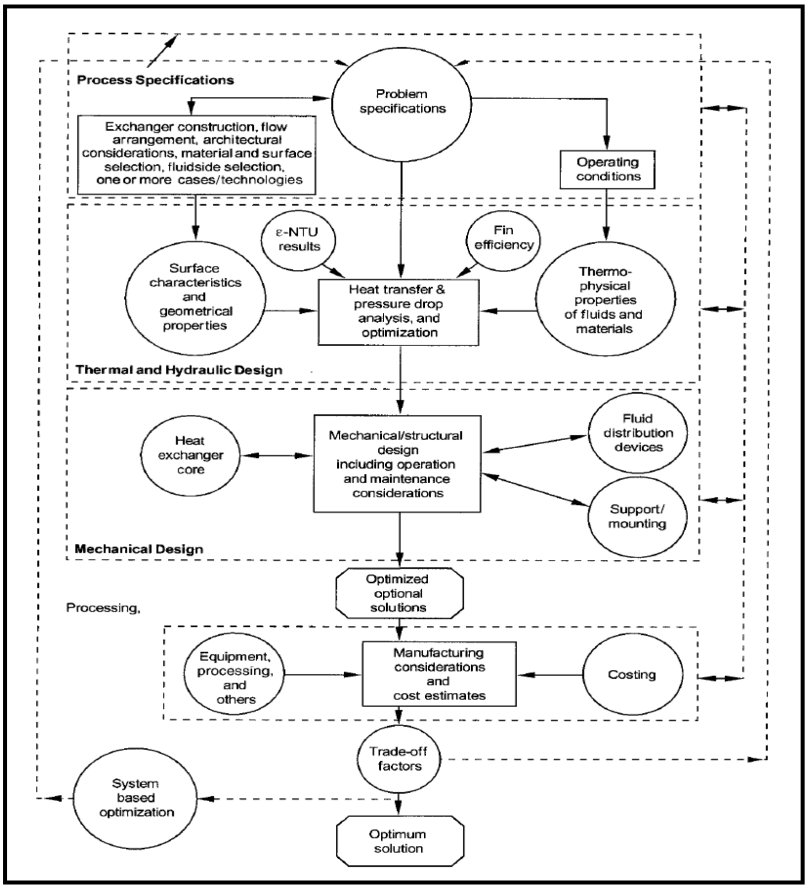

Figure 4: Heat Exchanger Design Methodology (Adapted from Shah, 1982; Taborek, 1988; Kays and London, 1998).

The process and problem specification (as indicated by the top dashed block in Figure 4) represent a crucial step in heat exchanger design. A heat exchanger design engineer can add significant value by collaborating closely with a system design engineer to develop "smart" specifications that ensure optimal system performance. These smart specifications should be developed through consultations with the customer, adherence to industry and customer standards, and the design engineer's own experience. Process or design specifications encompass all necessary information to design and optimize the exchanger for a specific function. This includes problem specifications related to operating conditions, exchanger type, flow arrangement, materials, and considerations for design, manufacturing, and operation. Additionally, the heat exchanger design engineer must provide both the essential and additional information required for the minimum input specifications. At this stage, the project focuses on developing the product concept or preliminary design using CAD modelling in SOLIDWORK 2016. It is essential to specify requirements and define the main objectives of the system design based on a thorough understanding of customer needs. Once the problem is clearly defined, the designer should evaluate various system design concepts and select one or more feasible design solutions.

3. IDEAS Of HEAT EXCHANGER FOR SHOWER

3.1 Direct-Contact Heat Exchanger

In a direct-contact heat exchanger, heat and mass transfer occur through the direct interaction of the fluids with the "fill" or surface within the exchanger. This design allows the fill to become fouled without impacting the energy transfer between the fluids in contact. Direct-contact exchangers are commonly used in applications that involve both mass and heat transfer, such as in evaporative cooling and rectification. Applications focusing solely on sensible heat transfer are less common. The enthalpy of phase change in such an exchanger generally represents a significant portion of the total energy transfer [10]. This kind of concept was adapted to the development of first idea in this project as shown in figure 5 below.

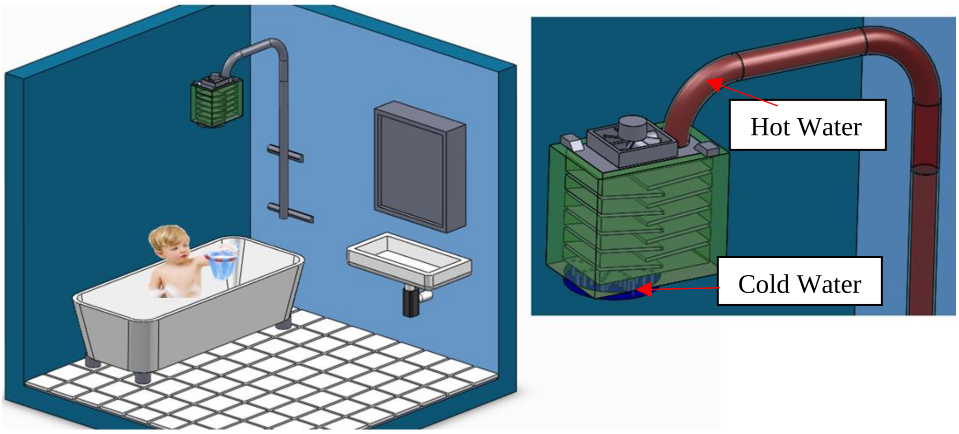

Figure 5: First Idea of Heat Exchanger

Heat transfer between two fluid streams can generally be achieved using either direct contact or surface-type heat exchangers. However, there are several limitations to using direct contactors. First, if the two fluid streams are in direct contact, they will mix unless the fluids are immiscible, as shown in Figure 5. This can lead to contamination depending on the degree of miscibility. Additionally, both streams must be at the same pressure in a direct contactor, which can result in extra costs. Despite these drawbacks, direct contactors offer several advantages. They do not have surfaces that can corrode, foul, or otherwise degrade heat transfer performance. They also provide potentially superior heat transfer for a given volume of heat exchanger due to the larger achievable heat transfer surface area and the ability to transfer heat with much smaller temperature differences between the two streams. Moreover, direct contactors typically have a significantly lower pressure drop compared to tubular heat exchangers. A final advantage is the much lower capital cost as direct contact heat exchangers can be constructed out of little more than a pressure vessel, inlet nozzles for the fluid streams, and exit ports [15].

3.2 Helical Coiled Tube Heat Exchanger

Helical coil heat exchangers, depicted in Figure 6, are widely used in various industrial applications, including solar energy systems, nuclear power plants, chemical and food processing industries, and numerous other engineering applications. Heat transfer rate of helically coiled heat exchangers is significantly large because of the secondary flow pattern developed in helical coil due to the centrifugal force (Dean Cell) caused by the curvature of the tube Dean [16]. Helical coils are well-established types of curved tubes that have been utilized in a broad range of applications.

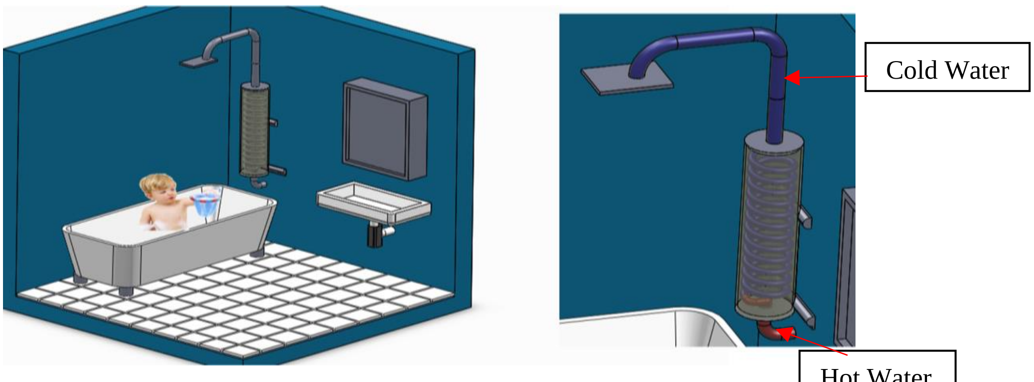

Figure 6: Second Idea of Heat Exchanger

The helical coiled configuration is highly effective for heat transfer equipment like heat exchangers and reactors due to its improved heat transfer performance, compact structure, and ability to provide a large heat transfer surface area within a small footprint. Several studies have indicated that helically coiled tubes are superior to straight tubes when employed in heat transfer applications [17]. The secondary flows generated by centrifugal forces in the fluid flowing through curved helical coiled tubes improve heat transfer in coiled tube heat exchangers. The strength of these secondary flows depends on the tube diameter (d) and coil diameter (D). Smaller tube and coil diameters result in more intense secondary flows. This increased intensity facilitates better fluid mixing, which in turn enhances the heat transfer coefficient for a given flow rate. Increase in tube and coil diameter reduces the secondary developed which reduces heat transfer coefficient [18].

3.3 Heat Exchanger with Tube-Fin Design

These exchangers can be categorized into conventional and specialized tube-fin types. In a conventional tube-fin heat exchanger, heat transfer between the two fluids occurs through conduction through the tube wall. However, in a heat pipe exchanger (a specialized type of tube-fin exchanger), tubes with both ends closed act as a separating wall, and heat transfer between the two fluids takes place through this ‘‘separating wall’’ (heat pipe) by conduction, and evaporation and condensation of the heat pipe fluid [10]. This kind of concept was adapted to the development of first idea in this project as shown in figure 7 below.

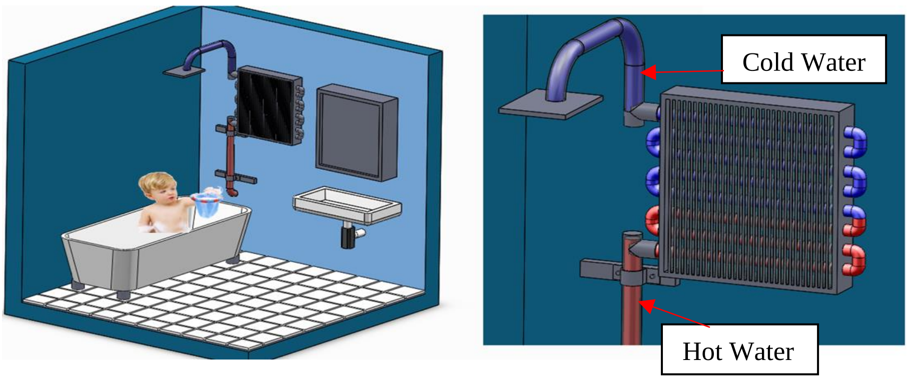

Figure 7: Third Concept of Heat Exchanger

Tube-fin exchangers are employed when one fluid stream operates at a higher pressure or has a significantly higher heat transfer coefficient compared to the other fluid stream. As a result, these exchangers are used extensively as condensers and evaporators in air-conditioning and refrigeration applications, as condensers in electric power plants, as oil coolers in propulsive power plants, and as air-cooled exchangers (also referred to as fin fan exchangers) in process and power industries [10]. To minimize the size of heat exchangers, fins are used on the gas side to increase the surface area and the heat transfer rate between the heat exchanger surface and the surroundings. Both the conduction through the fin cross section and the convection over the fin surface area take place in and around the fin [19]. When the fin is hotter than the fluid it is exposed to, the surface temperature of the fin is typically lower than the base (primary surface) temperature. If heat is transferred to the fin from the ambient fluid by convection, the fin surface temperature will exceed the fin base temperature, which reduces the temperature gradient and consequently the heat transfer through the fin. Finned exchangers are also utilized when one fluid stream is at high pressure. The temperature range is constrained by the material used and the manufacturing technique. All above causes that finned tube heat exchangers are used in different thermal systems for applications where heat energy is exchanged between different media [19].

4.0 CONCLUSION

This project focuses on understanding heat exchangers by exploring various designs and types, detailing their functions, mechanisms, and the associated advantages and disadvantages, particularly in the context of developing a new heat exchanger for a shower component. It outlines the fundamental design process, selection considerations, and common applications for different types of heat exchangers. The objective is to create a design concept for a heat exchanger suitable for the outlet of a water pipeline system. The proposed design aims to effectively cool the water temperature in a single household pipeline, offering immediate heat transfer for short-duration domestic use, such as showering or under tubs and basins, with minimal energy savings compared to costs. However, to validate the design, further analysis and experimental testing are required to assess heat transfer efficiency, pressure drop performance, fatigue characteristics due to vibration, the quality and longevity of fin-to-tube/plate joints, as well as pressure and temperature cycling, corrosion, and erosion properties. These additional tests and improvements will be crucial for advancing towards a commercial product. Heat exchanger design is a complex task, necessitating not only feasible solutions but also the optimal or near-optimal design approach.

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