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Simulation Study on Efficiency of Woven Matrix Wire and Tube Heat Exchanger

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ABSTRACT

Wire and tube heat exchanger has been utilized in refrigerators whose cooling performance depends on how much the wire are releasing heat. Wire efficiency is an important factor of the performance. The woven matrix is a new design of wire configuration on wire and tube heat exchanger. This research focused on optimization design of woven matix by varying wire pitch (p_w 5,7,9 mm) and three inlet massflows with controlling the hot fluid temperature at 353K. Computational Fluid Dynamic Simulation is used to determine heat transfer distribution of fluid in tube. The validation was conducted experimentally by measuring 9 temperature points at heat exchanger. This research revealed that p_w 7 mm with massflow rate 0.000571kg/s can decrease fluid temperature until it reaches 30ºC with all wires working to release the heat and it results 74% wire efficiency. Then, p_w 9 mm with massflow 0.0011kg/s has 64% wire efficiency, it was because the heat exchanger cannot decrease the fluid temperature to 303K. At high massflow, heat exchanger need more wire to decrease the temperature down to 303K. This research is recommended for cooling system widely applied in food industry, an optimal cooling system will reduce the cost of electricity consumption for cooler.

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NOMENCLATURE

h	Convection heat transfer coefficient	**Greek Symbols**	
A_w	Wire area	η_w	Wire efficiency
A_t	Tube area	**Subscripts**	
T	Temperature	t	Tube
p_w	Wire picth	w	Wire
		∞	Surrounding

1. INTRODUCTION

Heat exchanger has been widely used in power generation industry, food industry, manufacturing industry and even in our home appliances. Design of heat exchanger is very important for the application and performance. The optimal design can increase heat transfer performance [1].

The performance is a heat exchanger having high heat transfer. One of types of heat exchanger is wire and tube that is usually used in refrigeration system as a condenser which decrease temperature without changing a phase of a fluid [2]. Following the times, the wire and tube has many development design to increase its performance.

In the Wire and tube condenser, to decrease temperature optimally, some studies have investigated on design to optimize a performance, such an experiment who studied about energy saving and cost reduction of wire and tube designs [3]. Wei etal. [4] used the numerical approach to investigate the thermal performance of a new design of wire and tube condenser and another case predicted the performance of wire and tube using mathematical approach in matlab [5].

A design variation of wire and tube has been investgated by Arsana et al. [6] using numerical approach. The researchers have reviewed about the effect of design to wire and tube efficiency in single staggered design. This research obtained pitch wire and wire

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diameter p_w/d_w has a variations value of efficiency to temperature of inlet fluid. Then Arsana et al. [7] have studied to find out optimization p_w/l_w. Based on optimization studies using the Hooke-Jevees method, the maximum optimization factor (fre_f) is in the wire diameter (d_w) of 0.9 mm and the distance between wires (pw) of 11 mm. But, in another research a new design of wire and tube namely woven matrix design experimentally studied which use wire pitch variation and inlet temperature variation. According to this research, the woven matrix needs to be optimum design with massflow variations to reach optimal performance of the woven matrix design.

Lately, many studies have been conducted with computational fluid dynamic (CFD) to visualize fluid distribution with minimum cost and research performance of heat transfer. The research using CFD about heat transfer is very intersting to use. The research by Kostikov and Romanenkov [8] studied about approximation of convergence solution of CFD modelling. Sengupta et al. [9] used CFD for improved design of stove system. The reseach by Yamini et al. [10] provided numerical modelling of wind turbine. Rahate and Sarode [11] about design of air distribution system visualized the airflow. The research by Rani and Thermal [12] analyzed heat transfer and visualized airflow with fin variation effect. Gonul et al. [13] investigated airflow surrounding at wire and tube which had error arround 10% in modelling by CFD.

Based on previous work, the researchers have done a lot to study for wire and tube optimization. So, this research provide innovation using CFD simulation to figure out the optimization values of a single woven matrix with variations in pitch wires and massflow rates. The efficient heat exchanger will help to increase production and reduce an operational cost in industries or home activities. This research uses three models of wire and tube which is three wire pitch (5, 7 and 9 mm) with three variation of massflow. This research uses simulation approach with validation experimentally of one of wire and tube model. Analysis was conducted by heat transfer visualization, diagram of heat transfer efficient, and wire efficiency

2. MATERIALS AND METHODS

2. 1. Materials This research was conducted by developing the models using simulation with validation experimentally. In the first process, an experiment was performed as a reference and validation. Then simulate the other models with ANSYS Fluent software to obtain the parameters accurately. The detail of object is shown in Table 1.

2. 2. Simulation Setup There are 3 steps in simulation processes which are pre-processing, solving, and post-processing [7]. At the pre-processing conducted by designing wire and tube heat exchanger with a type of woven matrix wire. Detailed of simulation flow is shown in Figure 1.

TABLE 1. Specification detail of single woven matrix wire and tube heat exchanger

Properties	Value or Information
Wire and tube material	Steel
Heat exchanger height	445 mm
Heat exchanger width	436 mm
Tube out diameter	4.8 mm
Tube in diameter	3.2 mm
Wire diameter	1.2 mm
Wire pitch	5, 7, 9 mm
Total concentric tube	12
Tube pitch	40 mm
Fluid	Thermo oil-32
Specific heat (cp)	2000 J/kgK
Density (ρ)	856 kg/m^3

There are 3 methods that used in this study which are simulation set up, validation models and some equations to find out heat transfer coefficient and wire efficiency heat exchanger.

2. 2. 1. Pre-processing This step was designed for the simulation model. The simulation was conducted with a 3D geometry model.

2. 2. 2. Solving The next step of the simulation was solving, this step determined the boundary conditions of models. Detail of boundary condition is summarized in Table 2.

2. 2. 3. Post-processing First step visualize model which was the wire and tube model. The result of this

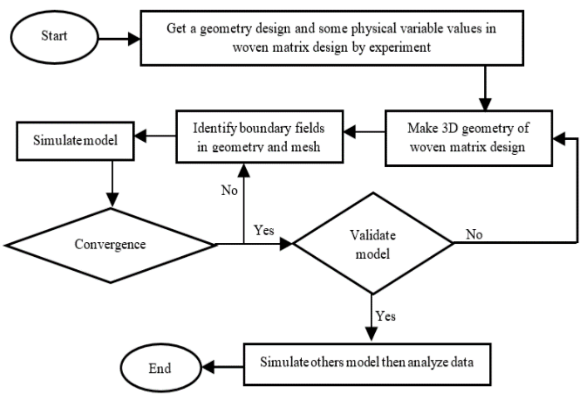

Figure 1. Simulation Flowchart

TABLE 2. Boundary condition of wire and tube simulation

No.	Parts of wire and tube	Boundary Condition
1	Inlet	Inlet Massflow
2	Outlet	Outflow
3	Wall Tube	Wall
4	Wall Wire	Wall

model showed the distribution of heat transfer of fluid in the tube. The second step was air simulation model, this result model showed how the movement of the air around the wire and tube heat exchanger.

2. 3. Validation Model The experiment was carried out at p_w 7 mm to obtain the data for validation. It was compared to simulation results with a maximum error 5% of 9 points on wire and tube heat exchanger that were measured with a thermocouple [7]. If the simulation have been valid, and then the simulation was processed on the next variable which was p_w 5 mm and 9 mm. The single woven matrix wire and tube and 9 points of thermocouple on the Heat Exchanger are shown in Figures 2 and 3.

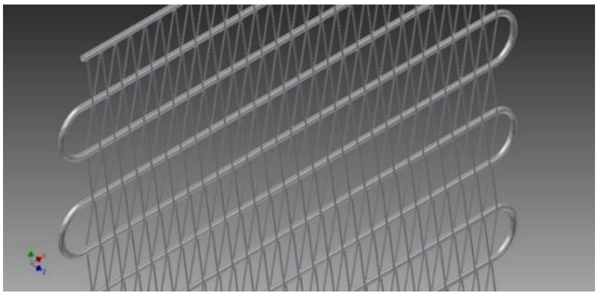

Figure 2. Single Woven Matrix Wire and Tube Heat Exchanger

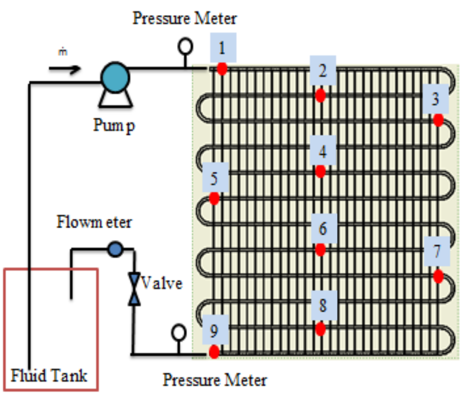

Figure 3. Experimental Setup

2. 4. Wire Efficiency Wire efficiency is the ratio between the rate of heat transfer by the wire with the maximum heat transfer rate that occurs when the entire surface of the wire is at the base temperature of the wire [7].

$$\eta_f = \frac{q\ fin}{q\ maks} = \frac{h_i A_w (T_w - T_\infty)}{h_i A_w (T_t - T_\infty)} \quad (1)$$

3. RESULT AND DISCUSSION

3. 1. Contour of Single Woven Matrix Wire and Tube Temperature The results of the simulation are displayed in the form of a contour visualization of the wire and tube temperature and air velocity. It is shown in Figure 4.

According to Figure 4 (a) the massflow 0.0011 kg/s has a contour color that dominated by red, yellow and green. This indicates that the fluid in the wire and tube is still hot or above the ambient temperature. At this condition, wire and tube is able to decrease the fluid temperature to 320 K (47 °C). The massflow 0.000571 kg/s Figure 4 (b) and 0.000549 kg/s Figure 4 (c) began to appear blue temperature contours which shows the heat exchanger has decreased the fluid temperature to reach an ambient temperature of 30 °C.

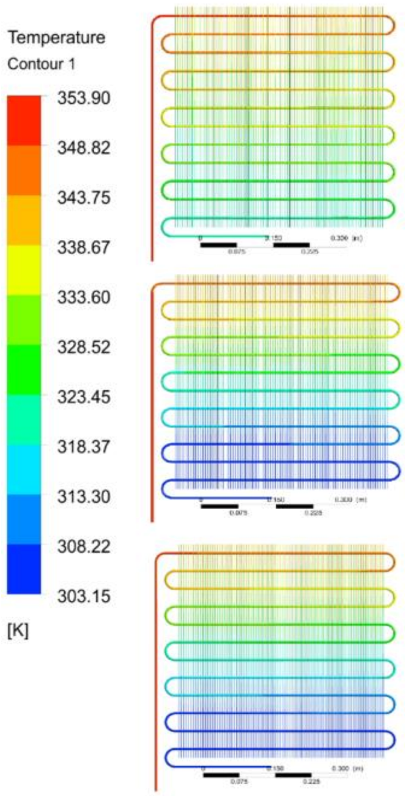

Figure 4. Contour of Temperature Single Woven Matrix Wire and Tube 5 mm

The results above showed at p_w 5 mm, the slower massflow can decrease temperature to optimal performance. However, overall heat transfer at p_w 5 mm does not maximal as wire and tube has reached optimal temperature to 30 ºC at 3/4 of the entire surface of the wire and tube. This occurs because more narrow wire picth requires the higher inlet temperature [6, 7].

According to Figure 5 (d), the massflow 0.0011 kg/s decreases the fluid temperature to 325 K (52 °C). Figure 5 (e) the massflow 0.000571 kg/s and Figure 5 (f) 0.000549 kg/s began to appear blue temperature contours where it shows that the heat exchanger has cooled the fluid temperature to reach an ambient temperature of 30 ºC. At a distance of 7 mm wire and tube work with the whole of wire discharged the heat, so the heat transfer occurs at the entire surface of the wire and tube.

This indicates that wire and tube at p_w 7 mm has good performance at three mass flow rates and good performance at inlet temperature of 353 K.

According to Figure 6 (g), the massflow 0.0011 kg/s indicates that the fluid in the wire and tube is still hot. At this condition, wire and tube decrease the fluid temperature to 328 K (55 ºC).

Unlike the p_w 5 and 7 mm, at the massflow 0.000571 kg/s and 0.000549 kg/s, according to Figure 6 shows that the heat exchanger at p_w 9 mm with massflow 0.000571 kg/s (h) was able to decrease the fluid temperature down to 309 K (36 ºC). Whereas for the massflow 0.000549

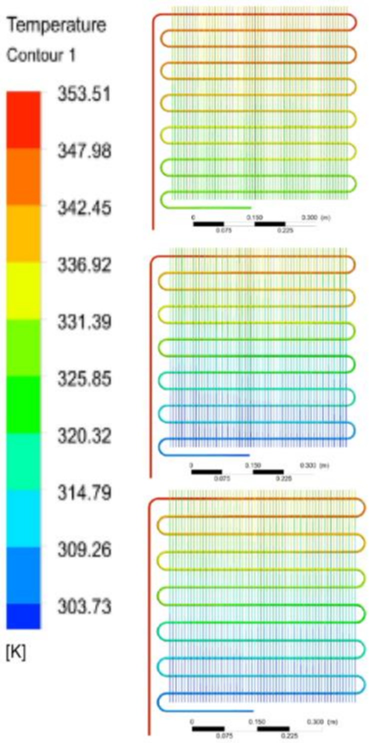

Figure 5. Contour of Temperature Single Woven Matrix Wire and Tube 7 mm

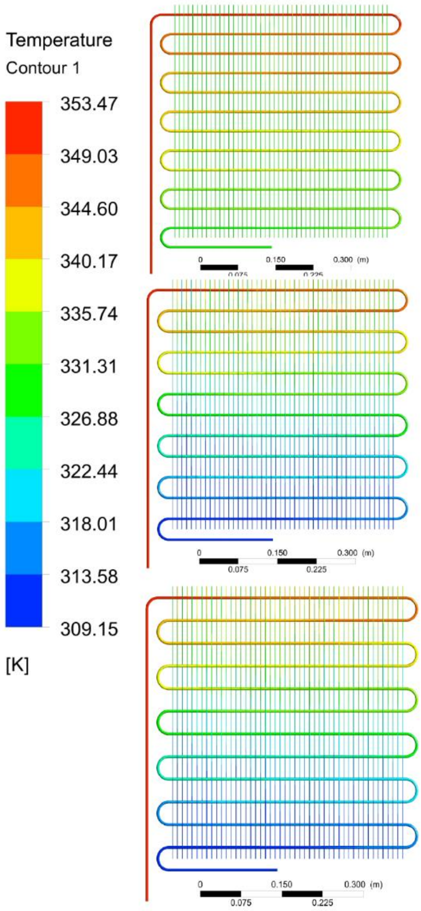

Figure 6. Contour of Temperature Single Woven Matrix Wire and Tube 9 mm

kg/s (i) it was able to decrease the fluid temperature to 310 K (37 ºC).

The p_w 9 mm does not reach the ambient temperature in outlet. This indicates for this design has less performance than p_w 7 because the heat transfer area is not as high as the other designs [7].

3. 2. Wire Efficiency (η_w)

Wire efficiency is the ratio between the rate of heat transfer by the wire with the maximum heat transfer rate that occurs when the entire surface of the wire is at the base temperature of wire. The wire efficiency of single woven matrix wire and tube is shown in Figure 7.

Figure 7 shows the effect of the wires pitch (p_w) on wire efficiency of single woven matrix wire and tube. Heat exchanger p_w 5 mm with massflow 0.0011 kg/s influences the value of wire efficiency. At this condition the heat exchanger decreased the fluid temperature to 47 ºC, the efficiency value in this condition is 73%. At the same wires pitch but with 0.000571 kg/s massflow rate, the heat exchanger can decreased the fluid temperature to 30 ºC in 2/3 of the overall surface area of the heat

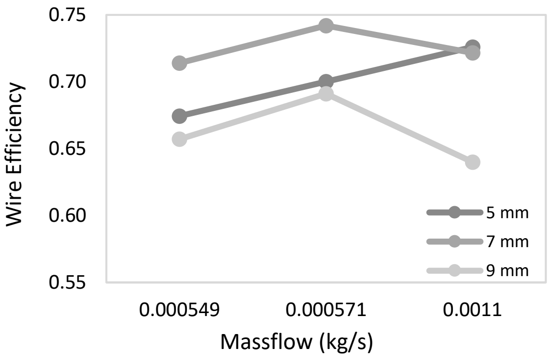

Figure 7. Wire Efficiency

exchanger. This shows that the heat transfer process doesn't occur equally, it means that in the last 1/3 of the heat exchanger area there was a wire that doesn't work release the heat because the design is not optimal for this condition [7]. The wire efficiency has a value of 70%. For the same reason as the 0.0011 kg/s mass flow, at a wires pitch 5 mm with 0.000549 kg/s has a wire efficiency value of 67%**.**

Heat exchanger p_w 7 mm with 0.0011 kg/s massflow decreased the fluid reaches temperature 52^o C, this causes the wire efficiency at Pw 7 mm was smaller than 5 mm which is equal to 72%. This shows that at the high massflow, more wire was needed to increase the efficiency value. Heat exchanger p_w 7 mm with 0.000571 kg/s massflow, heat transfer occurs equally. In this condition the heat exchanger could decreased the fluid temperature until it reaches 30^o C with all wires working to dissipate the heat, so the wire efficiency value was 74%. For the same reasons p_w 7 mm at 0.000549 kg/s could cool the fluid to ambient temperature, but the wire efficiency at this condition was only 71% this was because the T_w value of 47.85 ^{o}C, smaller than p_w 7 mm with a 0.000571 kg/s massflow which had a T_w value of 48.55 ^{o}C.

At p_w 9 mm on 0.0011 kg/s massflow, the wire efficiency has the smallest value between p_w 5 and 7 mm. This was because at the fast massflow more wire was needed to increase wire efficiency. Wire efficiency at p_w 9 mm with 0.0011 kg/s massflow has a value of 64%. Heat exchanger p_w 9 mm at 0.000571 kg/s and 0.000549 kg/s also has a small wire efficiency, in both conditions the heat exchanger couldn't decreased the fluid to reach an ambient temperature. The high temperature of the out fluid causes the value of the divider (T_t - T_∞) to be high. So the wire efficiency values for p_w 9 mm at the 0.000571 kg/s and 0.000549 kg/s were 69 and 66%, respectively.

Referring to research was conducted by Arsana et al. [6] that the wire pitch affects value of wire and tube efficiency. That research showed a small wire pitch p_w/d_w = 0.015 had the highest wire efficiency value at a fluid inlet temperature of 80 ^{o}C, the wire efficiency was 82%. This was in line with this research that at the high temperatures heat exchanger requires more wires to achieve an optimal values. In addition, at the high mass flow rate, the heat exchanger with p_w 5 mm just has an efficiency 67% because high massflow made the wire didn't have time contact to absorb the heat from fluid flow. Beside this, the visualization using CFD as research describes clearly and more imagines the mind in analysing heat transfer [8-10].

4. CONCLUSION

According to this result, the simulation study of wire and tube heat exchanger has obtained the optimal design is p_w 7 mm with massflow rate of 0.000571 kg/s which indicates the highest efficiency wire is 74%. It occurs as in this condition the heat exchanger has been able to decrease the fluid to an ambient temperature with all the wires working to transfer the heat.

Based on this research the optimal design depends on the characteristic of every condition. This design can help to improve the optimal design for wire and tube which is be able to use for refrigeration system in home appliance or industry. This work is also useful for other researches of refrigeration system and CFD applications.

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Persian Abstract

چکیده

مبدل حرارتی سیم و لوله در یخچال ها بسیار مورد استفاده قرار گرفته است ، عملکرد خنک کننده خوب به این بستگی دارد که سیم بتواند گرما آزاد کند. کارایی سیم عامل مهمی در عملکرد است. پیکربندی سیم ماتریس بافته شده طراحی جدیدی از سیم و لوله است. این تحقیق بر روی طراحی بهینه سازی ماتیکس بافته شده با گام سیم متغیر (Pw 5،7،9 میلی متر) و سه جریان انبوه ورودی با کنترل دمای مایع گرم در ۸۰ درجه سانتی گراد متمرکز شده است. شبیه سازی محاسباتی دینامیک سیالات (CFD) برای تعیین توزیع انتقال حرارت مایع در لوله استفاده می شود. اعتبار سنجی به طور آزمایشی با اندازه گیری ۹ نقطه دما در مبدل حرارتی انجام می شود. این تحقیق نشان داد که Pw 7 میلی متر با سرعت جرم kg / s۰.۰۰۰۵۷۱ می تواند دمای مایع را کاهش دهد تا زمانی که به ۳۰ درجه سانتیگراد برسد در حالی که تمام سیم ها برای آزاد کردن گرما کار می کنند ، در نتیجه کارایی سیم ۷٤٪ است. پس از آن ، Pw 9 میلی متر با جریان توده kg / s 64۰.۰۰۱۱ درصد بهره وری سیم دارد ، به این دلیل است که مبدل حرارتی نمی تواند دمای سیال را به oC۳۰ کاهش دهد. در جریان جرم زیاد ، مبدل حرارتی به سیم بیشتری نیاز دارد تا دما را به ۳۰ درجه سانتیگراد کاهش دهد. این تحقیق برای سیستم خنک کننده توصیه می شود که به طور گسترده ای در صنایع غذایی استفاده می شود ، یک سیستم خنک کننده بهینه هزینه برق مصرفی کولر را کاهش می دهد