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Design and Optimization of Heat Exchangers Using Nickel-Based Alloys in using COMSOL Multiphysics

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الملخص

الهدف الأساسي من هذه المقالة هو تقديم عرض شامل حول التحقق من كفاءة المبادل الحراري باستخدام سبائك النيكل، مع الاستعانة ببرنامج كومسول متعدد الفيزياء .(COMSOL Multiphysics) يُستخدم هذا البرنامج لمحاكاة أداء المبادلات الحرارية ضمن أنظمة إنتاج الطاقة، وذلك من خلال إجراء تحقق مقارن يعتمد على تحليل العلاقة بين طول التغيير ودرجات الحرارة.

علاوة على ذلك، تُعتبر المبادلات الحرارية من المكونات الأساسية في أنظمة توليد الطاقة، حيث تضطلع بدور محوري في تحويل الحرارة الناتجة عن احتراق الوقود، أو التفاعلات النووية، أو حتى الطاقة الحرارية المركزة من مجمعات الطاقة الشمسية إلى طاقة ميكانيكية قابلة للاستخدام. تُبسط المبادلات الحرارية العمليات الحرارية التي تُعد جوهر المعدات المستخدمة في إنتاج الطاقة.

ومع ذلك، فإن تصميم المبادلات الحرارية يخضع لقيود معينة تؤثر على أنماط نقل الحرارة، مما يتطلب دراسة دقيقة لتحقيق أعلى كفاءة ممكنة. تم استخدام برنامج كومسول متعدد الفيزياء لإنشاء نموذج ثلاثي الأبعاد لعملية نقل الحرارة، وقد تم الاعتماد على البيانات التجريبية للتحقق من صحة التنبؤات التي أُجريت بواسطة النموذج.

من خلال حساب معادلة درجة الحرارة لنقل الحرارة على طول المعدن، عرضت المحاكاة نموذجًا لتوزيع درجة الحرارة (بين 273.15 كلفن و373.15 كلفن)، وكذلك توزيع السرعة (من 0 إلى 0.07 متر/ثانية) والطول (من 0 إلى 15 سم) بمرور الوقت. ثم تم حل معادلة درجة الحرارة لنقل الحرارة، والذي يتعرض لنطاق ضغط يتراوح بين 0.02 و3.12 باسكال. تم اختيار سبيكة النيكل لهذا الاختبار نظرًا لقدرتها العالية على توصيل الحرارة مقارنة بالمعادن الأخرى. كما أن خفة وزن النيكل ورقته يجعله مناسبًا لتصميم أنظمة نقل حراري ممتازة، مما يسهل استخدامه في التطبيقات التي تتطلب أداءً حراريًا عاليًا.

Abstract

This article's primary goal is to provide a presentation on the validation of heat exchangers using nickel alloys that employ metaphysical COMSOL's. The COMSOL program is used to simulate the operation of heat exchangers in power production systems, and it does so by using the comparative verification that you provided between the change in length and temperatures. Moreover, heat exchangers are an important component in power generation systems, where the task is to convert heat generated by fuel combustion, nuclear reactions, or by concentrating the output of solar collectors

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into mechanical energy. Heat exchangers simplify the processes that are at the heart of the equipment. Heat exchanger designs constrain the heat transfer patterns and fluid flow behavior that occur in the system. The COMSOL program was used to create a 3D finite element model of the heat transfer process. Experimental data was used to validate the model's predictions. By calculating the temperature equation for heat transmission along the metal, the simulation displays the heat transfer model together with the temperature distribution from 273.15 to 373.15 K, as well as the distribution of velocity (0 to 0.07 m/s) and length (0 to 15 cm) over time. The temperature equation was solved for heat transfer along the nickel, which experiences a pressure range of 0.02 to 3.12 Pa. Nickel was used for this test since it conducts heat more effectively than other metals. Because of its thin and lightweight nature, it is simple to design as an excellent refractory conductor.

Keywords: Nickle, Heat Exchanger, COMSOL Multiphysics

1 Introduction

Heat exchangers are incredibly integrated devices that are widely used in temperature control systems. Their primary function is to facilitate the transfer of energy between two or more fluid flows, each of which has different temperatures. The diversity of heat exchangers extends to various applications; moreover, they represent an important component in power generation systems, performing the task of converting heat generated from fuel combustion, nuclear reactions, or by concentrating the output of solar collectors into mechanical energy. Subsequently, this mechanical force is harnessed to drive electric generators, embodying the indispensable role that heat exchangers play in such systems. The heat exchanger is quite complicated. It should be noted that heat exchangers usually represent large investments in the field of power plant services. The process of building heat exchangers can be complex, often requiring distinctive approaches to overcoming challenges in their design and operation. Heat exchangers operate within the temperature limits dictated by the wall material, and they must transmit maximum energy with minimal pressure loss. Design optimization is an effective way to achieve this. Heat exchanger optimization is a key area of application in many fields.[3].

Heat exchangers are fluid transfer components that are part of heat-generating equipment. The refrigeration and air conditioning industries, for example, use a wide range of heat exchangers. Heat exchangers simplify the processes that are at the heart of the equipment. Heat exchanger designs constrain the heat transfer patterns and fluid flow behavior that occur in the system. In this study, we used nickel as the material for heat exchangers, which is a metal with a silvery-white and shiny appearance. It is the fifth most common element used in heat exchangers made of nickel. Because of its special qualities and benefits, nickel is increasingly utilized in heat exchangers. Here

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are some key points regarding nickel's application in heat exchangers, particularly in light of the research.

Nickel sheet is an excellent material for heat exchangers since it is lightweight and possesses good strength and hardness, which enhance thermal performance and are important for heat exchangers, especially those made of nickel. The high thermal conductivity of nickel allows for efficient heat transfer, which is critical in applications involving high temperatures. Additionally, nickel can be machined into various configurations, allowing for customization in the design of the heat exchanger discussed in this paper using COMSOL software, which enables us to evaluate the heat transfer performance under realistic conditions.

Nickel, like iron, is also a common element in meteorites and is found naturally in soil and water. The selected heat exchanger and its components have the necessary resistance and operating time to cope with internal service conditions. In general, nickel alloys are used at 100 °C in the processes discussed in the study. The approach to temperature applications makes heat exchange systems essential, especially in high-temperature situations. The solution is to use nickel alloys. In this paper, we describe the research approach to the COMSOL problem. This section also discusses the heat exchanger made of nickel metal in this simulator, along with simulation results and explanations using the multi-physics COMSOL program.

2 Mathematical Modeling

Based on this paper, it calculates and analyzes the temperatures of nickel-based heat exchangers and solve the relevant equations. These equations are processed using the COMSOL Multiphysics program. The size, geometry of the block, and the meshed block are shown in Figure 1.

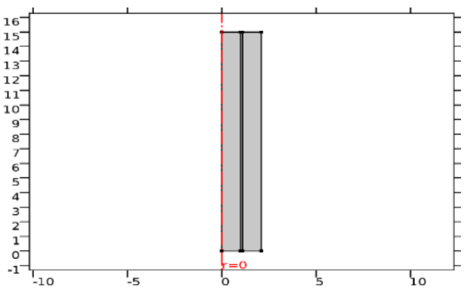

Figure .1. (a) 2D geometry of block

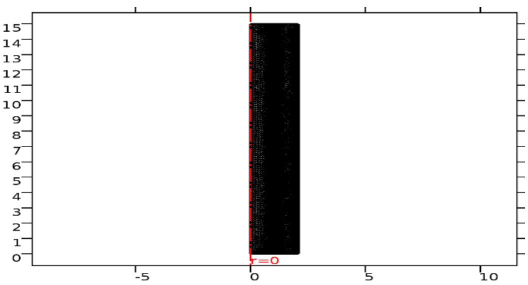

Figure.1.(b) Meshed block

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The following equations were used during data entry through the controller application, and some equations were specifically used for nickel in the heat exchanger industry. Liu, Xinyan, et al. (2024) conducted an experimental study of aluminum composites using COMSOL software, which provides effective guidance for the design and operation of alternative aluminum components.

2.1 Laminar Flow Equations

$\rho(u.\bar{\nabla})u =$ [5]

$\bar{\nabla}.[\rho I + \mu(\bar{\nabla}\, u + (\bar{\nabla}\, u)^{T})] + F$ [6]

$\rho\, \bar{\nabla}\, (u) = 0$ [7]

Here, ρ is the density, u is the velocity field, p is the pressure, μ is the viscosity

2.2 Fluid Properties 1 Equations

$\rho(u.\bar{\nabla})u =$ [5]

$\bar{\nabla}.[-\rho I + \mu(\bar{\nabla}\, u + (\bar{\nabla}\, u)^{T})] + F$ [8]

$\rho\, \bar{\nabla}\, (u) = 0$ [7]

2.3 Wall 1 Equations

$u = o$ [9]

2.4 Inlet 1 Equations

$u = -U_0 n$ [10]

2.5 Outlet 1 Equations

$[-\rho I + \mu(\bar{\nabla}\, u + (\bar{\nabla}\, u)^{T})]n = -\dot{p}_0 n$ [11]

$\dot{p}_0 \leq \rho_0$

where $\dot{p}_0$ (Pa) is pressure .

2.6 Heat Transfer in Fluids 1 Equations

$\rho C_p\, u.\bar{\nabla}\, T + \bar{\nabla}.q = Q + Q_p + Q_v d$ [12]

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$$q = -k \bar{\nabla} T \qquad [13]$$

where ρ (kg/m³) is density, C_p (J/kg.K) is heat capacity, and *k* (W/m.K) represents thermal conductivity. Q (W/m³), T (K) temperature, source inside the computational domain.

2.7 Thermal Insulation 1 Equations

$$-n.q = 0 \qquad [14]$$

2.8 Heat Transfer in Solids 1 Equations

$$\rho C_p\, u.\bar{\nabla}\, T + \bar{\nabla}.q = Q + \mathrm{Qted} \qquad [15]$$

$$q = -k \bar{\nabla} T \qquad [13]$$

where C_p is the specific heat, and *k* is the thermal conductivity. Here, ∇t is the tangential derivative.

2.9 Temperature 1 Equations and 2 Equations

$$T = T_0 \qquad [16]$$

2.10 Outflow 1 Equations

$$-n.q = 0 \qquad [14]$$

3 Results and Discussions

Significant values are used in each scenario to validate the simulation results against temperature measurements ranging from 25 to 100 °C and changes in length from 0 to 15 cm. The use of nickel-plated heat exchangers for this model is featured in the COMSOL program. This method allows calculations to be performed using COMSOL, but its accuracy depends on the heat transfer. It clearly shows that the simulation is performed..

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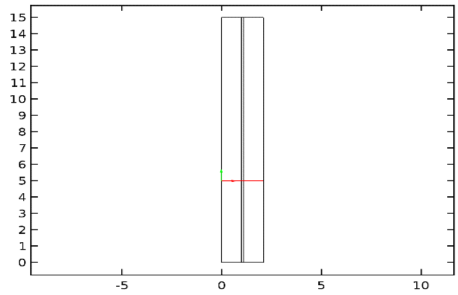

Figure. 2. **(a)** Data set: Cut Line 2D 1

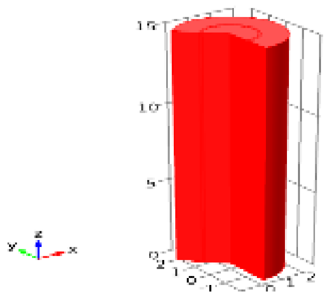

Figure. 2. (b) Data set: Revolution 2D1

Figure 2 (a, b) above shows the solution to the query dataset: Study solution and cut line 2D through the temperature variation during the heat exchanger process in the nickel block .

3.1 Plot Group

COMSOL generates several plots, which are graphs of the results from the nickel process in the heat exchanger. The findings are divided into the following sections. The velocity magnitude is shown in the figures below in both 2D and 3D dimensions. The distribution ranges from a velocity of 0 to 0.07 m/s and a length of 0 to 15 cm. The plot is shown in blue at 0, rising to 0.07 m/s, represented by dark red.

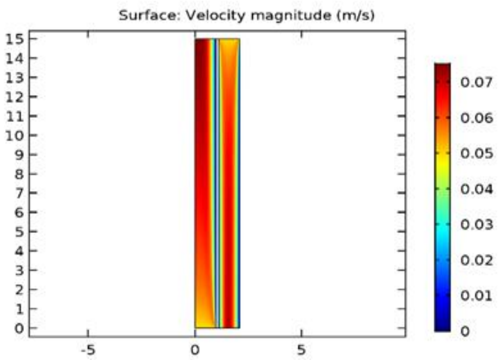

Figure. 3. (a) surface2D velocity magnitude

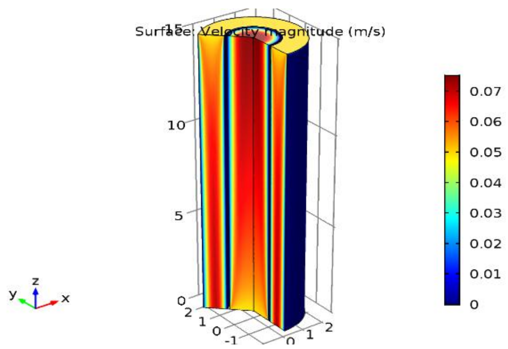

Figure 3. (b) surface3D velocity magnitude

3.3 Pressure (Spf)

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At this stage, the researcher demonstrates the effect of pressure on the length of the heat exchanger. From this data, we notice that initially, the effect shown in blue is 0.02 Pa, then it rises to 3.12 Pa, with the dark red color represented below.

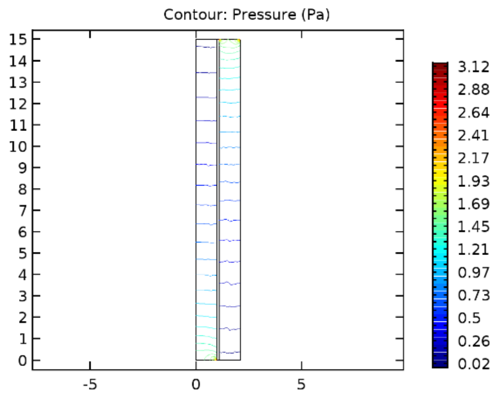

Figure. 4. Contour: Pressure (Pa)

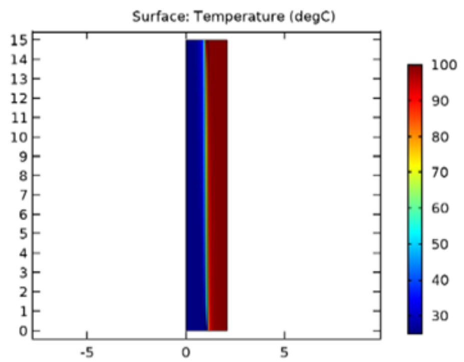

Figure. 5. Surface 2D : Temperature (degC)

The final drawing duration, with a temperature range of 273.15–373.15 K, shows the simulation lifting process in both 2D and 3D modes in the figures below. In 2D, dark red represents areas with lower temperatures, while blue in 3D indicates the same. Yellow in 2D and dark red in 3D represent areas with higher temperatures. This is the last stage of the term. As shown in Figure 6 below, the temperature distribution in the heat exchanger is broad. Nguyen, Trung Kim, et al. (2021) extended this model to simulate the total heat coefficient and pressure drop of water flow in such a heat exchanger.

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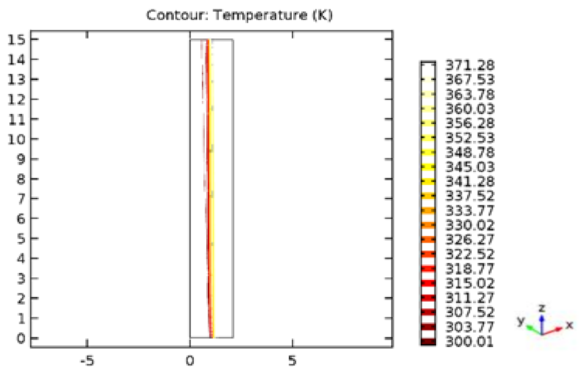

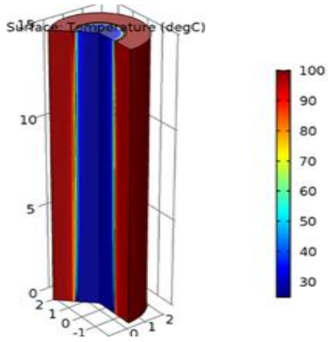

Fig. 6(a). Surface: Temperature (degC) Fig. 6 (b). Contour: Temperature (K)

3.4 1D Plot Group

The relationship between temperature (°C) and arc length (Arc) is depicted in this graph. The relationship between temperature and height shows that heat constancy increases with height from 0 to 0.7 cm and that temperature rises from 0.71 to 0.86 cm in height. After that, stability returns to heat as height increases from 0.87 to 1.2 cm, with heat increasing from 0.8 cm to 1.2 cm. Finally, we observe an increase in temperature up to 100 °C as length increases.

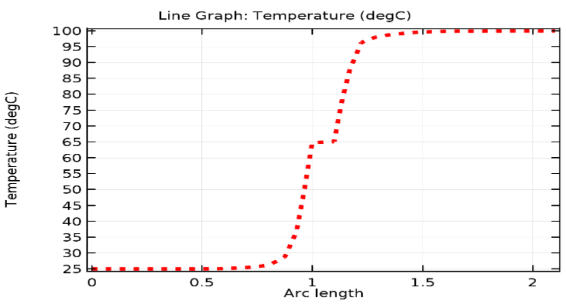

Figure. 7. Line Graph: length (Arc) and temperature (degC)

4 Conclusion

This study aims to simulate the operation of a nickel-metal heat exchanger using the software COMSOL. A three-dimensional finite element model was developed to predict the heat transfer process. The model was validated through experimental measurements. The simulation provides a heat transfer model that includes the temperature distribution from 273.15 K to 373.15 K, as well as the distribution of velocity (0 to 0.07 m/s) and length (0 to 15 cm) over time. The temperature equation was solved for heat transfer along the nickel, which experiences a pressure range of 0.02 to 3.12 Pa. Nickel was chosen for this study due to its high thermal conductivity

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and suitability for modeling as a thin, lightweight metal. It is considered the fifth best metal for thermal conductivity, making it a valuable material for heat exchangers. It is important to conduct similar studies on a larger range of metals in both laboratory experiments and simulation programs, as heat exchangers are commonly used in various fields, particularly in the oil industry.

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