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Experimental Study of Stack Porosity on the Performance of Thermoacoustic Refrigerator with Unparalleled Wire Mesh Stacks

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ABSTRACT

The effect of stack porosity on thermoacoustic refrigerator performance with different wire mesh stack designs is investigated experimentally in this paper. Thermoacoustic refrigeration is an innovative technique that employs the principles of thermodynamics and acoustics to achieve cooling effects without the need for hazardous refrigerants or mechanical components. Regardless of their potential, the wire mesh stacks' density and porosity are crucial characteristics that significantly impact the system's performance. The influence of three different types of wire mesh on the performance of thermoacoustic refrigerators was investigated in this study. The meshes used were #14, #16, and #18. The hydraulic radius, porosity, and clear opening differed for each variant. To determine which wire mesh structure was most effective in cooling, we tracked the changes in temperature in both the hot and cold heat exchangers. Based on the experimental results, it was observed that wire mesh #18 had a porosity of 72.6% and a hydraulic radius of 0.211 mm. This wire mesh demonstrated the most notable temperature reduction, decreasing by 4.8 °C and reaching a minimum temperature of 22.3 °C in the prototype model. The results indicate that thermoacoustic refrigerators can be improved with a larger porosity layout, leading to more noticeable temperature differences across the stack and better cooling efficiency. Findings from this study highlight the importance of optimizing parameters and designing stacks for sophisticated thermoacoustic refrigerator systems. These findings highlight the possible advantages of thermoacoustic refrigerators that use stacks of high-porosity wire mesh and give direction for future design considerations.

1. Introduction

An exciting new technology called thermoacoustic refrigeration uses the ideas of thermodynamics and acoustics to cool things down without using dangerous refrigerants or moving parts [1]. Using thermoacoustic resonance, a process in which sound waves cause temperature

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differences in a medium, this new method offers an environmentally friendly alternative to traditional cooling methods [2]. Traditional refrigerators use compressors and chemical refrigerants to cool, but thermoacoustic refrigerators work efficiently. This makes them environmentally friendly and suitable for many uses, such as cooling homes, preserving food, and cooling air [3]. The main idea behind thermoacoustic cooling is that sound energy can be turned into heat energy and back again. An intense sound wave causes areas of compression and expansion in a medium as it moves through it, which causes temperature changes in those areas. These temperature differences can cool things down by carefully designing the system's parts, like the stack and resonator [4]. Notably, thermoacoustic freezers have benefits like running quietly, being reliable over time, and being able to be expanded, which makes them more appealing for both home and business use [5].

In addition, the environmental advantages of thermoacoustic refrigeration go beyond its functioning. In contrast to traditional refrigerants like hydrofluorocarbons (HFCs) and chlorofluorocarbons (CFCs), which have adverse effects on the ozone layer and contribute to global warming, thermoacoustic systems employ inert gases or air as working fluids, ensuring that no harmful emissions are produced [6,7]. The inherent sustainability of thermoacoustic refrigeration aligns perfectly with global efforts to combat climate change and decrease greenhouse gas emissions. This makes it a promising option for achieving environmentally responsible cooling solutions [8]. In addition, there is a constant focus on research and development in thermoacoustic technology, which leads to continuous innovation and improvements in efficiency. Progress in stack design, material science, and system optimization holds excellent potential for improving the performance and versatility of thermoacoustic refrigerators in different environments [9]. It is crucial to foster interdisciplinary collaborations among scientists, engineers, and policymakers to expedite the implementation of thermoacoustic cooling and overcome obstacles such as cost-effectiveness, scalability, and integration into current infrastructure. Thermoacoustic devices work better when the frequency is high, according to research by Saat *et al.,* [10]. Particularly in thermoacoustic freezers, velocity amplitudes grow as the frequency increases. This emphasizes the significance of acoustic parameter consideration in frequency selection during system design and operation.

Thermoacoustic refrigerators were created by Anugrah [11] and Ramadan *et al.,* [12]. The design must adhere to solid thermoacoustic principles with components including a driver, heat exchangers, a resonator, and a stack. The temperature-controlling, noise-cancelling, energy-saving, and dependable thermoacoustic refrigerator must undergo rigorous performance testing. The thermal performance of various randomly stacked materials was examined in the study by Yahya *et al.,* [13]. Metal meshes, porous ceramics, and similar materials may be utilized in this context. Temperature differentials, acoustic frequencies, and pressure amplitudes were probably all experimental factors that were measured and controlled. Some materials may have superior heat transfer properties because of variations in thermal conductivity, pore size distribution, or porosity. Better, more functional designs of thermoacoustic refrigerators may be possible due to the study's recommendations for material selection and optimization. The work of Alamir [14] included building a loudspeaker-driven standing wave thermoacoustic refrigerator. The impact of varying driving circumstances on temperature distribution and total performance might have been explored in the study. Temperature profiles at both the hot and cold ends of the stack and along the stack will probably be displayed and evaluated. Research like this might help with the development of loudspeaker-powered standing wave thermoacoustic refrigerators.

The study by Bahrami and Ommi [15] provides helpful information about the efficiency and dependability of TADPTCs or thermoacoustically driven pulse tube cryocoolers. Using sophisticated statistical techniques, the research successfully measures uncertainties and pinpoints critical parameters impacting the system's efficiency. The results should be more robust and applicable to additional studies that include experimental validation and a more comprehensive range of factors. The study is a huge step forward for cryocooling technology, laying the groundwork for even greater advancements in the near future. Research by Cheng *et al.,* [16] makes a substantial improvement to thermoacoustic engine architecture. Pin-array stacks outperform circular-pore stacks in terms of heat transfer efficiency and total engine efficiency. It is crucial to address practical concerns like production complexity and cost and to conduct experimental research to validate the findings. Various working fluids and real-world operating situations should be investigated in future studies to harness the full potential of these revolutionary stack designs.

Thermoacoustic refrigerator design, stack shape modifications, and parameter optimization have been extensively studied. These attempts aim to improve thermoacoustic refrigerator heat transfer from sound sources. Acoustic waves from a sound source create a pressure gradient that moves heat around the system, cooling and exchanging heat. Despite the large research volume, stack wire mesh density and porosity are still underwhelmingly investigated. The stack's porosity affects flow dynamics, acoustic impedance, and heat transfer efficiency, making this necessary. Optimizing thermoacoustic refrigerators for different applications requires understanding how wire mesh density and porosity affect performance. In this regard, stack porosity research on thermoacoustic refrigerator performance is crucial. Other wire mesh densities can help researchers determine the best acoustic wave propagation and heat transfer combinations. This research could help design more efficient thermoacoustic refrigerators by understanding the trade-offs between acoustic impedance, heat transfer, and flow dynamics resistance. This study is needed because energy-efficient cooling and refrigeration systems are in demand. As sustainable and low-energy options become more critical, thermoacoustic technology may play a significant role. A better understanding of stack porosity and performance could make thermoacoustic refrigerators more competitive and applicable. The structure of this article is as follows. Section 2 presents the design, wire mesh design, and model of the thermoacoustic refrigerator. Section 3 presents the experimental setup of the thermoacoustic refrigerator. Section 4 examines and explores the impact of wire mesh variation. In Section 5 summarize several important conclusions.

2. Thermoacoustic Refrigerator Design

A schematic illustration of a thermoacoustic refrigerator is shown in Figure 1. This diagram visually represents the main components and their arrangement within the system. The thermoacoustic refrigerator uses acoustic waves to create temperature variations, which are then used for cooling. The process starts with an acoustic driver, usually a loudspeaker or a linear motor, that produces acoustic waves within the resonator. The acoustic driver receives input from a function generator to determine the wave's frequency and an amplifier to regulate its power. The selection of frequency and power level plays a critical role in determining the characteristics of the standing wave and directly impacts the refrigerator's performance.

After being generated, the acoustic wave travels through the resonator, causing areas of high and low pressure due to its oscillating nature. Consequently, the pressure fluctuations cause temperature variations within the resonator. Higher temperatures are typically found in high-pressure zones, while lower temperatures are associated with low-pressure zones. The resonator's design, including its length and shape, has a crucial impact on establishing pressure and temperature variations. The stack is positioned inside the resonator, comprising a sequence of meticulously arranged wire mesh discs. This aims to ensure a temperature difference on each side, effectively converting the sound energy into a difference in temperature. Heat is transferred from the colder to the hotter side as the acoustic wave travels through the stack due to the thermoacoustic effect. Two heat exchangers are strategically placed on either side of the stack to effectively utilize the temperature gradient for cooling purposes. The cold heat exchanger (CHX) is placed at the end with the lowest temperature, while the hot heat exchanger (HHX) is positioned at the hotter end of the stack. The CHX and HHX are crucial in transferring heat to and from the surrounding environment. The heat exchange plays a vital role in maintaining the desired temperature differential and ensuring optimal cooling efficiency.

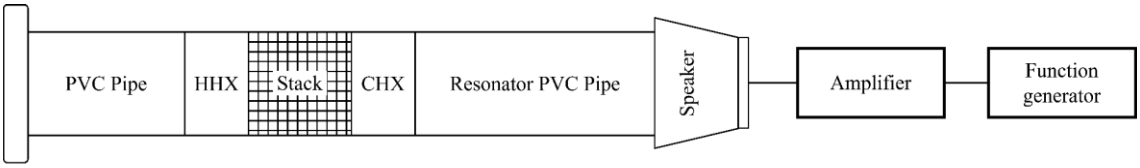

Fig. 1. Schematic illustration of a thermoacoustic refrigerator

The cold heat exchanger (CHX) and the hot heat exchanger (HHX) play a crucial role in the thermoacoustic refrigerator, enabling efficient heat transfer between the oscillating acoustic waves and the surrounding environment. The CHX and HHX have the same dimensions and are made of copper, which is known for its high thermal conductivity, mechanical strength, and durability. The heat exchangers are cylindrical, measuring 63.50 mm in diameter and 50 mm in length. They are designed to fit perfectly inside the PVC pipe that houses the wire mesh stack. The heat exchangers are designed with internal and external pores to enhance heat exchange efficiency. The inner pores have a diameter of 2 mm, and they come into direct contact with the oscillating acoustic waves within the thermoacoustic system. This pore size ensures a perfect equilibrium between promoting heat transfer and preserving structural integrity. The outer pores have a larger diameter of 3 mm and are designed to interact with external cooling or heating systems. The larger size of this component enhances its ability to dissipate heat to the surrounding environment, whether done through air, water, or any other cooling medium.

Following the manufacturing process, the CHX and HHX are meticulously placed inside the PVC pipe, strategically positioned at opposite ends to establish a conduit for the heat exchange procedure. The positioning of the heat exchangers plays a crucial role in the overall performance of the thermoacoustic refrigerator. To achieve the best possible heat transfer, aligning them accurately with the wire mesh stack is essential. The heat exchangers are inserted into the PVC pipe to create a compact and integrated assembly. This allows for efficient acoustic and thermal energy coupling within the thermoacoustic system. The CHX and HHX play a crucial role in maintaining the stability and structural integrity of the thermoacoustic refrigerator, apart from their primary function in heat exchange. The copper construction of the system provides firm support, enabling it to endure the mechanical stresses caused by the oscillating acoustic waves.

Figure 2 visually represents the heat exchangers, showcasing their cylindrical shape, dimensions, and pore structure. This visual representation provides a clear understanding of the configuration of the CHX and HHX and their relationship with the wire mesh stack within the PVC pipe assembly. After the assembly, the thermoacoustic refrigerator goes through performance testing to assess its cooling capacity and efficiency. The effectiveness of the CHX and HHX in transferring heat directly influences the refrigerator's performance. This impact can be seen in essential metrics like temperature differentials and coefficient of performance (COP). Thoroughly integrating these components is critical to achieve the desired refrigeration effects and maintain the system's long-term reliability.

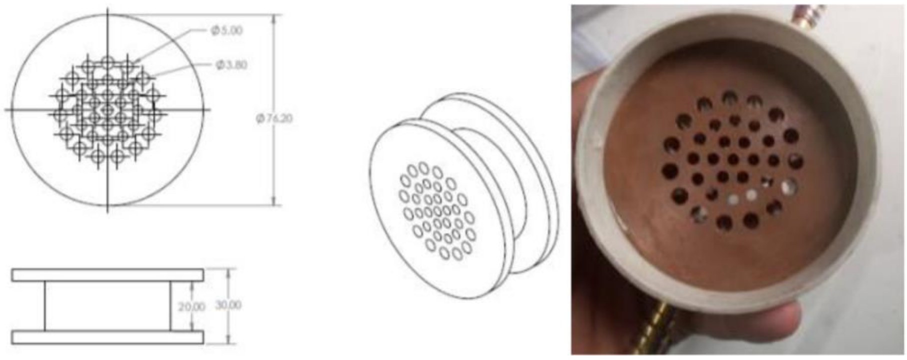

Fig. 2. Design of heat exchanger

The stack in this research is made of stainless steel 201 with a wire diameter of 0.32 mm. Figure 3 displays three different wire mesh sizes: wire mesh #14, wire mesh #16, and wire mesh #18. The wire mesh used in this research is pin arrays [17]. The wire mesh is cut into discs with a diameter of 63.5 mm using a fiber laser cutting machine. Different types of wire mesh have unique characteristics regarding mesh density and opening size, which impact the stack's acoustic properties and heat transfer capabilities. With its larger openings, wire mesh #14 enables a more significant amount of flow dynamics while potentially sacrificing some surface area for heat transfer.

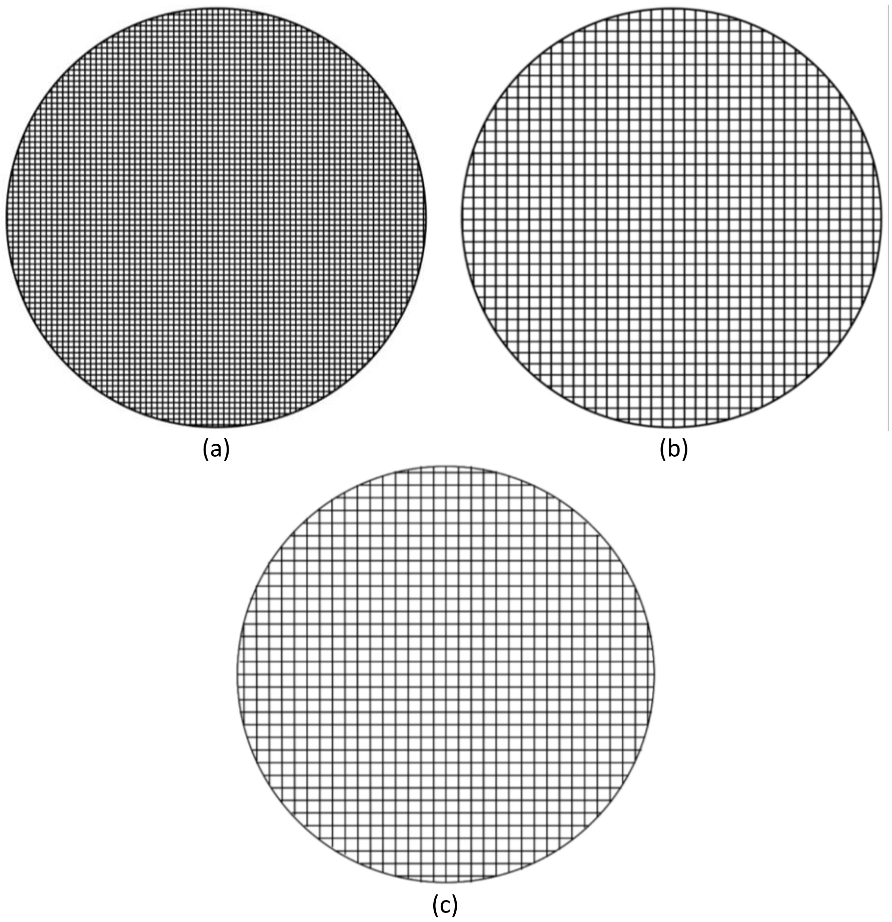

Fig. 3. Wire mesh density variations; (a) #14, (b) #16, and (c) #18

On the other hand, wire mesh #18 features a more compact mesh structure, resulting in a greater surface area for heat transfer. However, this may also lead to a potential increase in resistance to flow dynamics. Wire mesh #16 is a practical choice that balances flow dynamics and surface area. The selection of stainless steel 201 provides excellent mechanical strength and corrosion resistance, which is essential for preserving the stack's integrity when subjected to thermal and acoustic stresses. The use of fiber laser technology enables precise cutting, resulting in a stack manufacturing process that is highly accurate and consistent. This level of precision dramatically enhances the overall performance and reliability of the stack. The laser-cut wire mesh discs are meticulously assembled into the stack, guaranteeing precise alignment and spacing. The assembly process plays a crucial role in determining the formation of standing waves and, in turn, the cooling efficiency of the thermoacoustic refrigerator. The final stack is seamlessly incorporated into the thermoacoustic refrigerator setup, where it assumes a pivotal function in facilitating heat exchange. It efficiently converts acoustic energy into temperature differentials, enabling practical refrigeration applications.

Creating a wire mesh stack requires a careful and precise approach, as each wire mesh disc must be layered individually. Every disc needs to be accurately aligned to guarantee the best possible performance. To accomplish this, the precise placement of the wire mesh hole is meticulously calculated from the outer edge of the circle to maintain uniformity across the entire stack. The accurate alignment of components is essential for achieving an even flow dynamics distribution and maintaining consistent thermal transfer properties. Each stack contains 120 pieces of wire mesh, and they are arranged according to the specific variations of wire mesh (wire mesh #14, #16, and #18). Precise layering is crucial to achieve the desired thermoacoustic effects, ensuring the proper acoustic impedance and promoting effective heat transfer. The exact arrangement of the stack components guarantees the consistent and dependable performance of the thermoacoustic system.

After ensuring the wire mesh layers are precisely stacked and aligned, carefully insert the entire stack into a PVC pipe. The PVC pipe offers a sturdy housing that effectively secures the stack in place, facilitating seamless integration with other components of the thermoacoustic refrigerator. The PVC pipe is cylindrical, measuring 60 mm in length and 63.5 mm in diameter. This allows for ample space for the stack and creates an ideal chamber for the standing wave. The stack and its housing are connected to the cold heat exchanger (CHX) and the hot heat exchanger (HHX). The connections are vital in enabling the stack to function effectively within the thermoacoustic system. They facilitate heat exchange between the CHX and HHX by utilizing the oscillating pressure waves generated by the thermoacoustic driver.

Figure 4 presents a schematic illustration of the wire mesh stack, showcasing its construction and seamless integration into the thermoacoustic system. This diagram represents the stack's assembly process and connection to the heat exchangers. It emphasizes the arrangement and positioning of the wire mesh layers within the PVC pipe. The finished stack plays a crucial role in the thermoacoustic refrigerator, facilitating heat transfer and the propagation of acoustic waves. The wire mesh discs' meticulous arrangement and precise alignment are optimized for system performance, resulting in the desired temperature variations necessary for efficient refrigeration.

The wire mesh stack utilized in the thermoacoustic refrigerator is a distinctive configuration referred to as a stacked wire mesh pin arrangement. This design differs from traditional stacked screens and possesses distinct characteristics and advantages that render it well-suited for enhancing the performance of thermoacoustic devices. The three-dimensional structure, high porosity, and enhanced surface area of this material make it an excellent option for enhancing heat transfer and acoustic wave propagation. The wire mesh pin arrangement greatly improves the performance of thermoacoustic devices by improving fluid flow and optimizing acoustic impedance. This highlights the crucial role of innovative stack design in advancing cooling technologies.

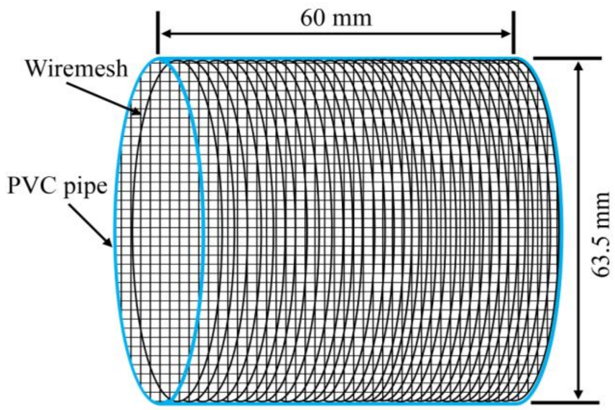

Fig. 4. Illustration of a wire mesh stack installation scheme

Depending on the stack's design, thermoacoustic refrigeration systems efficiently use acoustic waves to drive heat transfer. An innovative method for improving thermoacoustic refrigerator performance is presented in this study by means of a wire mesh pin array stack. This study utilizes a wire mesh pin array instead of orifice plates or parallel plate stacks. The wire mesh pin array combines the advantages of high porosity and greater surface area for heat transfer. The thermoacoustic refrigerator's acoustic and thermal performance are both set to be improved by this invention. Adjusting the acoustic impedance, which is critical for effective standing waves, is made possible by the wire mesh pin array. Orifice plates and stacks of parallel plates make this personalization more difficult.

Understanding a thermoacoustic refrigerator's flow dynamics and heat transfer characteristics requires carefully analyzing the wire mesh porosity. The stack's acoustic impedance and heat transfer efficiency are crucial for the refrigerator's performance, both of which are influenced by porosity. In this study, the porosity value for each wire mesh variation is calculated using an equation derived from the work of George and Swift, as shown in Eq. (1). This formula considers the geometric characteristics of the wire mesh, offering a dependable estimate of its porosity. Using precise parameters like wire diameter and mesh spacing, this equation provides a means to measure the open space within the wire mesh. This measurement is essential in understanding the flow of air and acoustic waves within the stack.

$$\phi = 1 - \frac{\pi n D_{wire}}{4} \tag{1}$$

$$rh = D_{wire} \frac{\phi}{4(1-\phi)} \tag{2}$$

$$n = \frac{1}{M} - D_{wire} \tag{3}$$

In addition, the hydraulic radius is determined using Eq. (2). The hydraulic radius is the ratio of the working fluid's cross-sectional area to the wetted surface's perimeter. It is significant in fluid dynamics and heat transport, especially thermoacoustic devices. In thermoacoustic systems, the hydraulic radius affects how easily the working fluid (typically gas) moves through the stack. A bigger hydraulic radius increases fluid flow, improving heat transfer and acoustic wave propagation. Due to its effect on acoustic waves and refrigeration temperature gradients, this parameter is crucial to stack performance. Eq. (3) is used to calculate the clear opening of the wire mesh. This measurement provides an insight into the average diameter of the openings in the wire mesh, offering a clear indication of the mesh's permeability. The size of the opening has a significant impact on both the flow dynamics and thermal exchange capabilities of the stack, which in turn affects the overall performance of the thermoacoustic refrigerator.

3. Experimental Setup

The thermoacoustic refrigerator utilized in this study is depicted schematically in Figure 5. The main parts and layout of the system are illustrated in this image. A refrigerator has two independent heat exchange loops, one for the cold heat exchanger (CHX) and one for the hot heat exchanger (HHX). Regulating and recirculating the coolant independently in each loop is possible thanks to its separate pump and reservoir. The CHX loop keeps the surrounding air at a cold temperature so that the thermoacoustic refrigerator cools down. Here, the thermal-acoustic process generates heat, and the coolant water is circulated from its reservoir through the CHX to absorb that heat. The reservoir stores coolant and regulates its temperature, and the pump keeps the flow rate constant to keep heat transfer efficient.

A radiator is an additional HHX loop component similar to the pump and reservoir in the previous model. An essential part of the HHX, this radiator is there to release all that excess heat. Thermostatic refrigerators work by absorbing heat from the hot side and then releasing that heat into the surrounding environment through a radiator to keep the operating temperature steady. To keep the system from overheating and guarantee its durability in the long run, this cooling mechanism is crucial. Both heat exchanger loops in this study use cooling water as their circulating medium. Among the many benefits of this option is its high thermal conductivity and stability, two factors critical to the effective operation of the thermoacoustic refrigerator.

Two pressure transducer sensors measure the amplitude of the applied pressure to monitor the system's acoustic performance and ensure it stays within safe parameters. Capturing high-pressure oscillations within the resonator is possible with these sensors due to their maximum range limit of 1.2 MPa. To keep the system within its operational safety margins, the data acquired from these sensors helps understand pressure dynamics. At 107 Hz, the standing wave is established in the resonator, which is the resonance frequency of the thermoacoustic refrigerator. The standing wave can be formed, and the wire mesh stack and heat exchangers can accommodate the resonator's 700 mm length. The efficiency and cooling capacity of the refrigerator are affected by this frequency and the length of the resonator, which are essential design considerations.

Thermocouple sensors record temperature measurements on CHX and HHX in thermoacoustic cooling devices. Each heat exchanger has these accurate, fast-response sensors strategically placed to catch temperature changes. While the thermoacoustic device operates at 107 Hz, data is collected throughout 15 minutes. The thermoacoustic effect, which promotes heat transmission between CHX and HHX, requires this frequency to create a standing wave pattern. Researchers record temperature trends every 90 seconds or 1.5 minutes and measure how quickly the system responds to the acoustic driving force. A balance between frequent measurements and data collecting and analysis is achieved with this interval.

The thermocouple sensors record temperature changes at each heat exchanger during the experiment, indicating thermoacoustic processes. Researchers can use these data points to measure the stack temperature gradient and heat exchanger performance. The data-collecting approach captures crucial information to assess the thermoacoustic cooling device's efficiency and usefulness. Researchers can spot patterns, anomalies, and system stability by monitoring temperature changes regularly. After 15 minutes, the data are examined to calculate the CHX-HHX temperature difference.

This temperature differential shows the thermoacoustic refrigerator's cooling capacity and efficiency. The obtained data helps confirm theoretical models, optimize stack and heat exchanger design, and highlight areas for improvement. Researchers can optimize the thermoacoustic cooling device's performance by studying temperature trends and modifying operating factors like frequency and power.

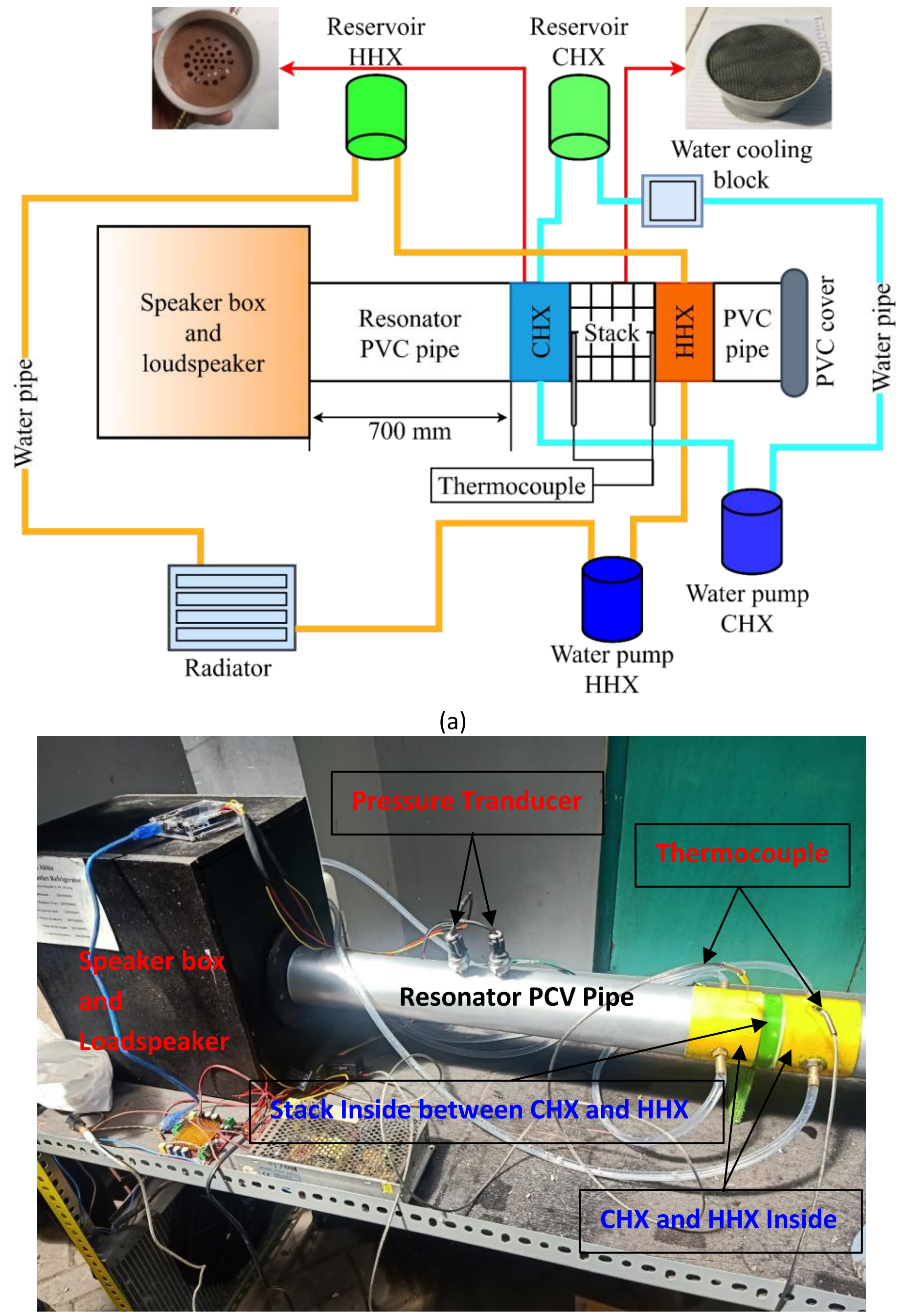

Fig. 5. (a) Schematic diagram and (b) Photograph of a thermoacoustic refrigerator

4. Result and Discussion

4.1 Analysis of Wire Mesh Porosity Configuration

The configuration results of wire mesh variations concerning porosity, clear opening, and hydraulic radius are depicted in Figure 6. This figure presents a detailed examination of various wire mesh designs, demonstrating the influence of different mesh densities on essential factors related to thermoacoustic performance. Wire mesh #14 features a 1.49 mm clear opening, 0.133 mm hydraulic radius, and 62.5% porosity. These parameters show that wire mesh #14 has moderate porosity among the three versions. Its reduced porosity signifies a denser wire mesh construction, which increases clear opening and thermal conductivity through the surface area. Due to greater mesh spacing, this arrangement may increase flow dynamics resistance and alter acoustic wave propagation. Wire mesh #16 has 68.1% porosity, 0.17 mm hydraulic radius, and 1.26 mm clear opening. The mesh's higher porosity than wire mesh #14 improves flow dynamics, lowering acoustic resistance and accelerating wave propagation. The mesh is less dense than Wire mesh #14, but the wires are closer together, narrowing the clear hole. This may balance thermal conductivity and flow dynamics resistance. Wire mesh #18 has 72.6% porosity, the greatest of the three. Its hydraulic radius is 0.211 mm, and its clear opening is 1.09 mm. High flow dynamics capacity and porosity enable efficient acoustic wave propagation with low impedance. The smaller visible openings than wire mesh #14 and #16 indicate narrower gaps and increased porosity. This shape improves flow dynamics, reduces resistance, and may diminish heat exchange surface area.

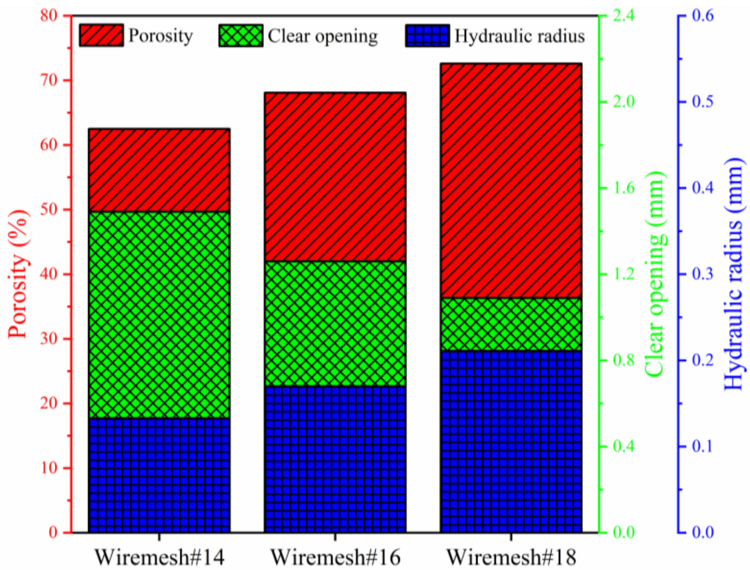

Fig. 6. Porosity, clear opening, and hydraulic radius configuration in wire mesh variations

When the wire mesh is denser, the average diameter of the gaps within it tends to be greater, as indicated by the clear opening value. This may appear to go against common intuition, but it results from the numerous smaller openings formed when wires are densely packed. Increasing the clear opening value can improve thermal conductivity by providing a larger surface area for heat exchangers [18]. However, it may also result in higher resistance to flow dynamics, which can impact the acoustic performance. Hydraulic radius, which pertain to the radius that allows fluids to flow, exhibit a comparable pattern to porosity. Thinner spokes result in higher hydraulic radius, which suggests a greater fluid flow capacity through the mesh [19]. This characteristic is vital in thermoacoustic applications, where efficient flow dynamics is crucial in sustaining the acoustic wave and promoting heat transfer.

The porosity of the wire mesh is crucial in determining the flow dynamics and acoustic impedance through the stack [20]. It represents the ratio of open spaces within the mesh to the total volume. As shown in Figure 6, the relationship between wire mesh tightness and porosity is evident. This is due to the lower density of wires, which results in more significant gaps and facilitates increased flow dynamics. A high porosity generally enables more efficient acoustic wave propagation, although it can potentially limit the stack's surface area for heat transfer. The interconnections among these parameters—porosity, clear opening, and hydraulic radius—are crucial in fine-tuning the wire mesh configuration for thermoacoustic systems [21]. Finding a harmonious equilibrium between these factors is vital to attain the best possible performance. Acoustic wave propagation may be enhanced by high porosity, but it could potentially lead to decreased heat transfer efficiency. On the other hand, a higher clear opening value can improve thermal performance while raising acoustic resistance.

4.2 Wire Mesh Temperature Analysis

A thermoacoustic refrigerator system with three different types of wire mesh was used to measure temperature changes over 900 seconds (Figure 7). Both the hot heat exchanger (HHX) and the cold heat exchanger (CHX) show their temperature trends on the graph, and the graph clearly shows how the two behave differently with different wire mesh configurations. From the first to the 900th second, the temperature in the hot heat exchanger rises consistently, showing that heat accumulates consistently over time. Consistent with the basic thermoacoustic process, which involves transforming acoustic energy into thermal energy and increasing the temperature at the HHX, this pattern holds across all permutations of wire mesh. This rising trend indicates that the system successfully produces the heat necessary to form a temperature gradient.

On the other hand, the temperature in the cold heat exchanger shows a consistent decline for the whole 900-second period, indicating the inverse tendency. The fact that the temperature is going down regardless of the wire mesh type shows that the thermoacoustic system works to cool the cold end by transferring heat from the CHX to the HHX [22]. The thermoacoustic refrigerator cannot perform its intended function without this cooling capability [23]. Figure 7(a), Figure 7(b) and Figure 7(c) show the three different versions of wire mesh #14, #16, and #18, respectively, and the corresponding temperature trends. The general pattern is consistent even when other parameters like mesh density and porosity vary; this points to a resilient design and the system's capacity to keep the predicted temperature gradient. The temperature extremes reached within the 900-second timeframe are also shown on the graph. The hot and cold heat exchangers may reach 31.4 °C and 22.3 °C, respectively. These data demonstrate the system's ability to produce a large temperature differential, which reflects the highest and lowest temperatures observed during the experiment.

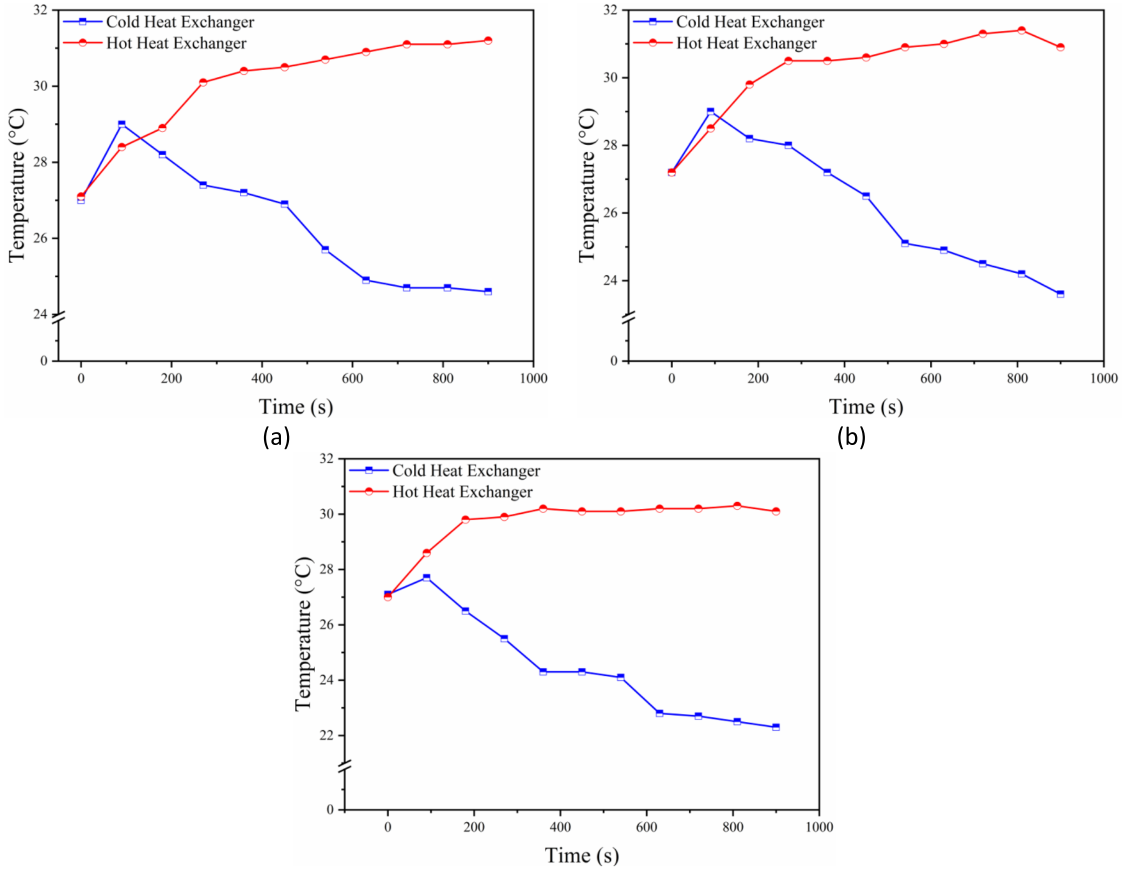

Fig. 7. Examining the temperature distribution on CHX and HHX for wire mesh (a) #14, (b) #16, and (c) #18

4.3 Analysis of Maximum Temperatures HHX and CHX

The maximum temperature that can be achieved on the hot heat exchanger (HHX) and cold heat exchanger (CHX) is presented in Figure 8. The observed maximum temperature on the hot heat exchanger (HHX) is 31.4 °C when using wire mesh #16. The wire mesh configuration balances porosity and clear opening, allowing for moderate flow dynamics and efficient heat transfer. This ultimately leads to the temperature that has been observed. The temperature at HHX plays a crucial role in determining the amount of energy the thermoacoustic process transfers to the hot side. This, in turn, directly impacts the efficiency of heat dissipation in the system.

Meanwhile, the lowest temperature on the cold heat exchanger (CHX) is achieved using wire mesh #18, measuring 22.3 °C. This wire mesh variation exhibits higher porosity, increasing flow dynamics through the stack. The improved flow dynamics leads to more efficient acoustic wave transmission and improved cooling at the CHX, leading to reduced temperatures. The wire mesh #18's porosity enhances the efficiency of the pathway for the oscillations of the standing wave, facilitating the absorption of heat and its subsequent transfer away from the cold side.

The temperature investigation of the wire mesh versions demonstrates substantial variations in cooling efficiency across the various designs. Wire mesh version #14, with a moderately porous structure, caused a temperature reduction of 2.4 °C from the starting temperature, reaching a minimum temperature of 24.6 °C. This decrease suggests a moderate cooling ability since the structure's porous nature allows sufficient but restricted air movement and heat transmission. Wire mesh variation #16, which has a little greater porosity than #14, exhibited an enhanced cooling effect.

The temperature decreased by 3.6 °C, reaching a minimum temperature of 23.6 °C. The more significant decrease can be ascribed to the higher velocity of air passing through the stack, enabling improved heat transfer. Variant #16 has enhanced cooling performance, indicating a superior equilibrium between acoustic impedance and thermal conductivity. Of the three options, wire mesh #18 showed the greatest decrease in temperature, with a significant drop of 4.8 °C, resulting in a low temperature of 22.3 °C. The increased porosity of this type enables enhanced flow dynamics, resulting in reduced resistance and improved heat transfer efficiency. The minimum temperature obtained indicates that wire mesh #18 is the most efficient configuration for reaching lower temperatures in the cold heat exchanger (CHX). It is a potentially optimal choice for applications that demand great cooling efficiency.

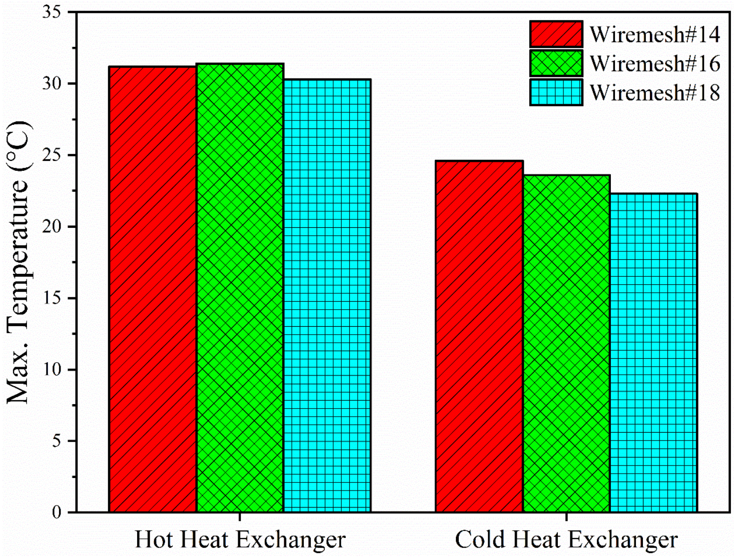

Fig. 8. Maximum temperature at HHX and CHX

The temperature increase observed at the hot heat exchanger (HHX) reached 3.5%, suggesting a moderate temperature rise on the hot side of the thermoacoustic refrigerator. This increase demonstrates the heat generated by the thermoacoustic process as acoustic waves create areas of high pressure, resulting in the buildup of thermal energy at the HHX. This slight increase in temperature is essential for comprehending the dynamics of heat exchange and evaluating the effectiveness of the hot side. On the other hand, the temperature decrease at the cold heat exchanger (CHX) was significantly more pronounced, reaching a reduction of 9.3%. The noticeable temperature decrease highlights the thermoacoustic system's impressive cooling abilities. Acoustic waves generate low-pressure zones, causing heat to be transferred from the CHX and leading to a significant reduction in temperature. The cooling efficiency of thermoacoustic refrigerators is a crucial performance metric, as it indicates their ability to achieve considerable temperature differentials.

This discovery highlights a crucial correlation between wire mesh porosity and temperature outcomes in thermoacoustic systems [24]. As observed with wire mesh #18, increased porosity generally results in enhanced flow dynamics and decreased resistance, promoting better heat transfer and cooler temperatures at the CHX. This feature benefits applications requiring lower temperatures for cooling or refrigeration purposes. On the other hand, when the porosity is reduced, the mesh structure becomes more compact, causing flow dynamics to be limited and acoustic impedance to increase [25]. Based on the observed data from wire mesh #16, this configuration can raise the HHX temperature. The decreased porosity results in improved heat retention and reduced heat dissipation rates, resulting in elevated temperatures on the hot side [12]. Although this feature may not be optimal for maximum cooling, it can be advantageous for other uses, such as heat engines or thermal energy storage. The correlation between porosity and temperature in the thermoacoustic refrigerator highlights the significance of choosing the appropriate wire mesh arrangement to fulfil precise cooling goals. Although there is a general correlation between higher porosity and cooler CHX temperatures, it's important to note that it can also lead to a decrease in heat transfer efficiency because of a smaller surface area [26]. Thus, achieving the ideal equilibrium between flow dynamics, heat transfer, and temperature gradients is paramount to designing highly efficient thermoacoustic systems.

5. Conclusions

Stack porosity's effect on thermoacoustic refrigerator performance was studied experimentally, revealing its relevance to cooling efficiency. A thermoacoustic cooling device with wire mesh #18 with 72.6% porosity and 0.211 mm hydraulic radius was tested to see how different porosity configurations affected performance. The prototype model reached 22.3 °C with this setup, resulting in a 4.8 °C temperature drop. These results suggest that thermoacoustic refrigerator cooling depends on porosity. The increased porosity of wire mesh #18 improves flow dynamics and acoustic wave propagation, improving heat transmission and decreasing cold heat exchanger temperature. Increased stack open area enhances heat dissipation, suggesting higher porosity improves cooling performance. This investigation shows that wire mesh #18—with the maximum porosity—reduces temperature best. Because increasing porosity improves flow dynamics and lowers acoustic impedance, thermoacoustic cooling devices can better control temperature. Additionally, the study emphasizes stack design optimization in thermoacoustic systems. By adopting high-porosity designs, designers can make thermoacoustic refrigerators with lower cold side temperatures, enhancing performance.

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