中國機械工程學刊第四十三卷第六期第 499~507 頁(民國一百一十一年)
Journal of the Chinese Society of Mechanical Engineers, Vol.43, No.5, pp.499~507 (2022)

Numerical Flow Investigation of Hybrid Regenerator

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Keywords：Stirling cryocooler, Regenerator, Steady flow.

ABSTRACT

The regenerator is the core heat exchange component of the Stirling refrigerator, and its performance is determined by the configurations and physical properties of the wire mesh. This paper presents the investigation of frictional pressure drop correlation equations obtained from a steady flow numerical analysis for both uniform mesh and hybrid wire mesh regenerator with different wire mesh configurations, stacked aligned and misaligned configuration. Hybrid mesh regenerator comprises different wire-meshes as its porosity is arranged in fine to coarse or coarse to fine aspects. The numerical study uses a finite volume method (FVM) based CFD approach for different configurations of wire mesh regenerator. The working fluid is considered isothermal, and the viscosity is assumed to be a constant. Furthermore, the relationship between Reynolds number and the friction coefficient is numerically solved, providing insight into various configuration flow characteristics. The numerical study is validated by comparing the obtained correlations to previously published research, Reynolds numbers up to 550. The frictional drop correlations derived from the numerical analysis can be used to compute pressure drops in the regenerator's flow direction.

Paper Received February 2022. Revised August, 2022, Accepted September, 2022, Author for Correspondence: Shung-Wen Kang.

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INTRODUCTION

The regenerator is the core heat exchange component of the Stirling refrigerator. The performance of the regenerator is determined by the configurations and physical properties of the wire mesh. Therefore, the Stirling regenerator is the most important module of a Stirling engine. There is considerable work done on the Stirling regenerator. Most research in this field has primarily focused on optimizing Stirling performance to achieve high efficiency. It mainly focuses on the hydrodynamic characteristics of the Stirling regenerator. As a result, interpreting this occurrence through experimental, theoretical, and numerical studies is critical. Various types of Fine wire mesh are frequently used in the regenerators, having different wire diameters, weave structures, mesh density, and materials. The wire mesh screen is the most popular type of wire mesh used in regenerators. Most of research is done on the fluid characterization of the regenerator heat exchanger to determine the pressure loss within the regenerator component. Typically, the flow inside the Stirling regenerator is modelled as internal flow behavior using the Poiseuille law. This type of model is extensively studied and used to calculate the pressure and friction loss inside the regenerator. The correlations equation obtained by Kays and London (1984) are based on incompressible flow theory and are probably the most widely used. It was discovered while researching wire mesh screen matrices. They use different porosities ranging from 0.602 to 0.832. Armour and Cannon (1968) studied the hydraulic characteristics of different mesh screens in a circular channel with a single layer of a metal mesh screen. They developed a formula for estimate pressure loss based on fluid flow velocity, mesh screen porosity, and screen structure. Simon and Seume (1988) provided a thorough review of steady-state flow friction factor correlations and evaluate the compressibility and oscillating flow characteristics of Stirling r regenerators. Sodre and Praise (1997) conducted experiments to resolve the pressure and friction loss through a woven wire-mesh matrix. Here, the experimental data were correlated using a modified Ergun equation that considers the wall effect described by Ergun (1952). Miyabe et al. (1982) developed an experimental investigation and gave a universal equation. for flow friction loss and heat transfer coefficient for various wire mesh geometries. Hsu et al. (1999) developed a setup that can produce steady and oscillating flows for Reynolds numbers, from 1 to 2000, and obtain the friction factor correlation equation. while accounting for the boundary layer consequence in the transitional range Reynolds numbers. Choi et al. (2004) presented universal pressure drop correlations for oscillation frequencies ranging from 45 to 75 Hz, considering amplitude and phase angle. The pressure loss generated by the fluid passing through the stacking of wires mesh screens is mainly affected by two factors: form surface friction and fluid resistance, according to Thomas and Deborah (2000).

Even though many theoretical investigations on the effect of uniform mesh regenerator, experimental and theoretical studies on hybrid wire mesh regenerator with different porosity are limited, Garg et al. (2020) investigated the impact of regenerator porosity on Stirling cryocooler performance. He contrasts uniform and non-uniform porosity here. The study discovered that using a hybrid mesh regenerator instead of a regenerator with a single porous matrix reduces the total cool-down time and power consumption, which depend on the configuration of the hybrid mesh regenerator. As a result, the hybrid wire mesh regenerator is recommended over the regenerator with a uniform mesh regenerator. Kumar and Kuzhiveli (2017) used the software REGEN 3.3 to conduct parametric research to investigate the influence of regenerator length and the operating frequency on the performance of a Stirling cryocooler, and they numerically evaluated the performance of an optimized multi mesh regenerator to that of a single mesh regenerator. They conclude that a multi mesh regenerator with finer mesh on the cold end and coarser mesh on the hot end can substantially improve its effectiveness. Gupta et al. (2018) also numerical analyze the performance of regenerator using the REGEN 3.3 software. A 45mm length and 5mm diameter is considered as an optimal design for a regenerator. Different mesh numbers are taken into consideration for making single mesh regenerator and multi mesh regenerator. They numerically analyze the coefficient of performance (COP), thermal stability and least ineffectiveness of the regenerator design. The design optimization of regenerator found that multi mesh regenerator to give better performance than single mesh regenerator design.

In addition to the analytical studies, a numerical investigation is carried out for the flow-through wire screen matrix. It is performed by using a variety of numerical discretization techniques. Several studies have recently used CFD to analyze the performance of the Stirling regenerator. Costa et al. (2013) presented a non-thermal equilibrium porous media modelling technique based on the finite volume method that characterizes fluid flow inside the regenerator. A detailed flow domain of the woven wire matrix is designed to study pressure drop coefficient for both stacked and wound woven wire matrix regenerators with varying boundary conditions and porosity. Novel Nusselt number correlation equations are derived to characterize and optimize stacked and wound woven wire mesh regenerators. Thombare and Umale (2015) studied the Stirling engine is at a phase angle of 80°. Its research focuses on regenerator length, wire mesh arrangement, wire mesh size, mesh porosity, and wire mesh material on regenerator effectiveness. Duygu (2020) studied the hydrodynamic properties of a regenerator matrix and are predicted using a porous medium modelling. A Stirling regenerator is designed to be used in the beta type Stirling engine, and CFD analysis of the designed regenerator is performed using a porous media model and the ANSYS Fluent software. Using CFD analysis, both resistance factors, pressure drops and friction factors of the regenerator matrix are calculated. These numerical studies propose that flow simulation is necessary to comprehend the flow of interest that characterize fluid flow friction behavior in regenerator systems.

As summarized above, most research work is carried out for uniform mesh regenerators, as they are the most used. To find optimum regenerator design, a multi mesh regenerator was designed. Even though relatively little research work is conducted for this type of regenerator, no specific pressure drops correlations exist in the literature. As a result, characterizing the pressure drop phenomenon in this type of regenerator remains necessary. So, the main objective of this report is to investigate the development of numerically obtained correlations and calculate the pressure and frictional losses inside the wire mesh regenerator with various mesh design configurations. In this regard, numerical models for various wire mesh regenerators are developed to attain pressure drop correlations for different wire mesh screen configurations. Then, the modelled design over a wide range of Reynolds numbers is verified by comparing the CFD results with established experimentally obtained correlations from other researchers.

Flow physics modelling uses a stepwise approach with increasing complexity in terms of flow physics modelling; it begins with steady and isothermal flow calculations using adiabatic wall function conditions. The first step of this study is to numerically optimize the pressure losses inside the Stirling regenerators and determine the pressure drop characteristics. Then, a 3D isothermal simulation with a fluid flow domain is executed, which provides essential insights into determining frictional losses for wire mesh with different configurations for different Reynolds values. In this problem, we apply to establish pressure drop correlation equations obtained from a CFD method. SOLIDWORKS design software was used to create these wire mesh screens with varying porosity and wire diameter. Temperature effects are not regarded as significant in these computations because the wire matrix domain (about 1.5 mm) is insignificant in computational domain length. Furthermore, the CFD model can estimate the fluid properties inside a wire mesh screen regenerator.

COMPUTATIONAL PRINCIPLES

Computational domain and boundary conditions

Regenerator geometry is assumed to be an essential parameter of the Stirling refrigerator due to its impact on its performance. In this study, wire mesh regenerator models with different wire mesh configurations are designed in SOLIDWORKS CAD software and the region of the flow of interest is represented as a fractional part of the refrigerator regenerator. In the case of a hybrid wire mesh regenerator, it is assumed to be different wire-meshes as its porosity is arranged in fine to coarse or coarse to fine aspects. To investigate the hydrodynamic properties of the wire mesh screens, two distinct wire mesh configurations, stacked aligned and misaligned arrangement, #300, #400, #500 mesh and hybrid wire mesh #300/400/500, #500/400/300, are generated for each wire matrix with a volumetric porosity ranging from 0.67 to 0.80. Fig. 1 shows Design layouts of stacked wire mesh screens, Fig. 1(a) stacked aligned mesh screen and Fig. 1(b) stacked misaligned mesh screen configurations. The number of mesh screen layers for different wire mesh configurations are ranging from 23 to 32. These designs are made using experimental statistics such as wire diameter, pitch, and porosity, as shown in Table 1.

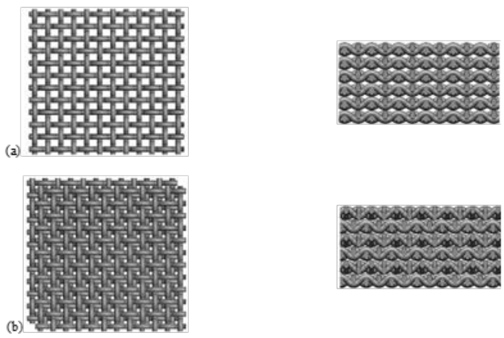


Fig. 1. Design layouts of stacked wire mesh screens (a) stacked aligned and (b) stacked misaligned configurations.

Table 1. Wire mesh regenerator parameters.

Mesh number	Wire diameter (μm)	Pitch (μm)	Hole size (μm)	Porosity
#300	32.3	83.5	53.3	0.80
#400	24.5	62.9	39.5	0.75
#500	24.5	50.3	26.1	0.67
#300-400-500	Same as above			0.71
#500-400-300				0.71

Most Stirling regenerators have a uniform porosity structure, as illustrated in Fig. 2(a). A regenerator consisting of varying porous matrices is called a hybrid mesh regenerator, as illustrated in Fig. 2(b). A hybrid mesh regenerator comprises different wire-meshes as the porosity of these meshes are arranged in fine to coarse mesh screen or coarse to fine mesh screen.

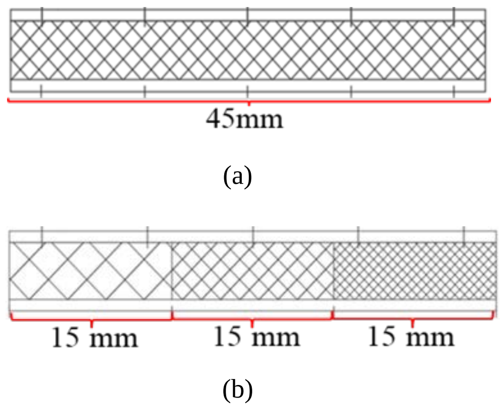
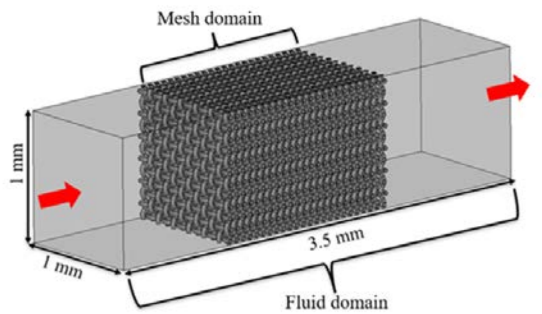


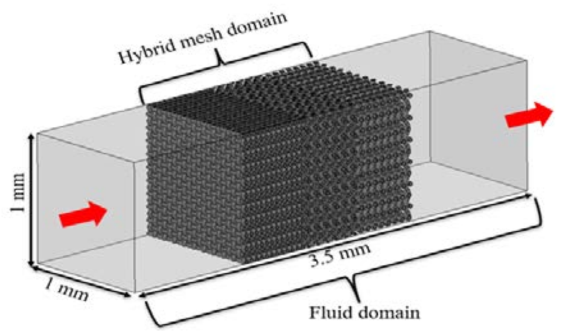
Fig. 2. Types of Stirling regenerator matrix.
(a) Uniform wire mesh regenerator (b) Hybrid wire mesh regenerator

Fig. 3 (a-b) illustrates the region of the flow of interest (geometry setup) for uniform mesh and hybrid mesh regenerator configuration in which the flow through wire matrix geometry is extensively analyzed as a representation of a differential part of a Stirling regenerator arrangement. As Cheadle et al. (2010) mention, the modelling of typical regenerator geometries would require detailed 3-D models with prohibitively long solutions times. For this reason, to capture the velocity and pressure drop profile, a small representative portion of the regenerator is modelled.

The inlet and outlet flow areas are set to approximately 1mm^2 and the wire matrix length is set at approximately 1.5 mm. To avoid reverse flow conditions at the boundary, the computational domain is extended in both directions in simulations. All the flow simulations are performed using atmospheric conditions. Helium density used here is 0.1785 kg/m³, dynamic viscosity 1.87x10^{-5} Kg/ms are used for simulation.



(a)



(b)

Fig. 3. 3-D view of the grid layout for the computational domain; (a) Uniform mesh and (b) Hybrid mesh configuration.

The mesh is a very important component for the numerical analysis and the mesh is generated using the ANSYS ICEM platform on the design models for the whole fluid domain. The tetrahedral mesh is created for all the cases with proper inflation layers. The total number of elements from computation differs for each design, and the mesh quality was checked using skewness, orthogonal quality. The computational domain comprises non-uniformly distributed hybrid mesh systems with over 54 million tetrahedral volume cells for the final mesh system. The tetrahedral cells are used inside the matrix with very fine mesh resolution in the close vicinity of the wire surfaces to resolve sharply varying velocity and pressure gradients. As the accuracy of the present numerical results may depend on the mesh resolution in the computational domain, the effects of the mesh resolution on the present flow are tested through a mesh independence study for different mesh models with varying mesh sizes. Table 2 shows the comparison of skewness and orthogonal quality for different mesh designs. Here, a total of 3 mesh designs with various mesh resolutions are compared. All simulations are done under the same working conditions for different mesh designs. Fig. 4 show the comparison of pressure drop along the length of wire mesh design for varying mesh designs. There is no significant difference among the computed values. In order to get accurate pressure drop values, mesh design 1 with 54 million elements is selected for all the solutions because there is no considerable difference among other cases.

Table 2. Comparison of skewness and orthogonal quality for different design.

	Mesh 1	**Mesh 2**	**Mesh 3**
Element size	Fine meshing	Medium meshing	Coarse meshing
Elements	58865941	54837856	3895551
Max. skewness	0.947	0.923	0.934
Avg. skewness	0.26	0.26	0.29
Max. Orthogonal quality	0.997	0.997	0.998
Avg. orthogonal quality	0.83	0.83	0.79

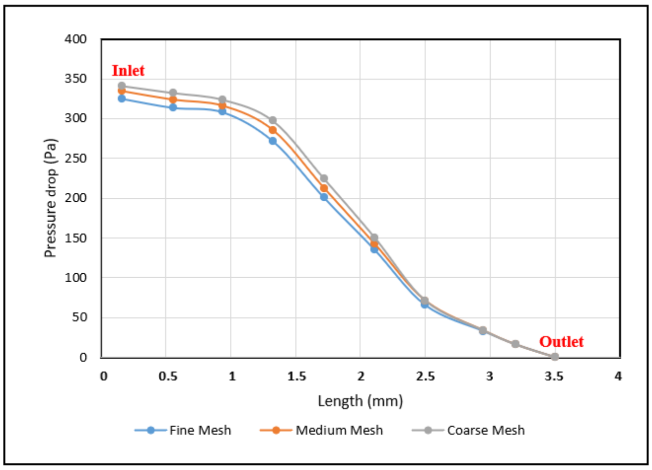


Fig. 4. Comparison of pressure drop for different designs.

Boundary conditions

For all the wire mesh screen design simulations are completed by taking the resulting boundary conditions into account:

1. Inlet velocity boundary conditions: To describe the fluid velocity profile inside the fluid domain, velocity inlet conditions are used.

2. Outlet pressure boundary conditions: The pressure inside the fluid domain is described using pressure outlet boundary conditions. Gauge pressure is set at the outlet boundary.

3. Boundary conditions: For all four sides of the fluid domain's design boundary, free-slip boundary conditions are used, and all the normal velocity gradients at the walls are assumed to be zero.

4. Wall boundary conditions: For simulation cases, to specify the interior wall boundaries among both wire mesh screens and fluid flow, we adopt standard wall functions and no-slip wall boundary conditions.

Numerical approach

In this present study, a three-dimensional (3-D) numerical study was conducted for wire mesh regenerator configurations. The design of the analysis was build based on the experimental wire mesh parameters. The working fluid is considered to be isothermal, and the viscosity is assumed to be a constant. As the Reynolds number exceeds inside the wire mesh configurations, the local uncertainties will arise due to turbulence inside the fluid domain, leading to convergence of CFD simulation. Fluid flow simulations are carried out in a turbulent model, and Navier–Stokes's equations are used to mathematically govern the fluid flow within the domain. A numerical flow solver is used based on the finite volume method with a second-order upwind scheme to solve the continuity and momentum equations for the laminar flow conditions. Entire fluid properties, such as fluid density and viscosity, are considered to remain constant. The total convergence criteria for all velocity and pressure components for the simulation is set at 10^{-6} to obtain high certainty because of the complex and uneven design of the current wire mesh media. In order to precisely characterize the turbulence and its consequence on pressure drop estimation inside the wire mesh design, standard k–ε turbulence model was used to simulate mean flow characteristics (Costa et al., 2013; Zhao et al., 2021) and the k and ε equations are.

$$u_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{v_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right) + v_t\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)\frac{\partial \bar{u}_i}{\partial x_j} - \varepsilon \quad (1)$$

$$u_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{v_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right) + C_1 \frac{\varepsilon}{k} v_t\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)\frac{\partial \bar{u}_i}{\partial x_j} - C_2 \frac{\varepsilon^2}{k} - R \quad (2)$$

$$v_t = C_\mu \frac{K^2}{\varepsilon} \quad (3)$$

The coefficients C_1, C_2, σ_k , σ_ε, C_μ are constants and the turbulence dissipation, equation for k– ε model contains a sink term, k is turbulent kinetic energy, ε is the turbulent kinetic energy dissipation rate and R which is the interpretation for the multiple scales of motion passing through the CFD model which changes the production term, v_t is the turbulent viscosity.

RESULTS AND DISCUSSIONS

Pressure drops

The numerical simulations for the stacked wire mesh regenerator with varied mesh orientation are done in this part by utilizing an FVM technique based numerical solution. Furthermore, the simulation results have been used to derive a pressure drop and friction factor correlation equation that can be used to match and compare with other research findings across a wide range of wire diameter, Re number, and porosity. The geometric parameter which is used to describe the flow passing through a porous aperture of wire mesh regenerator is the hydraulic diameter, d_h.

$$d_h = \frac{\varphi}{1-\varphi} d_w \quad (4)$$

The Reynolds number is used to describe the flow fields within the wire mesh matrix. It is measured as the ratio of fluid momentum to viscous force, as shown in Eq. (5):

$$Re = \frac{\rho_f V d_h}{\mu} \quad (5)$$

The Darcy–Forchheimer equation is used to determine the pressure loss in the regenerator. It's an empirical equation that correlates the pressure loss caused by friction in a porous media to the velocity of the flow inside the medium. It is mentioned in Eq. (6) that Darcy Forchheimer's Law is expressed as:

$$\frac{\Delta P}{L} = \frac{\mu}{k} V + \beta \rho_f V^2 \quad (6)$$

Where k is the Permeability coefficient (m^2), and β is the Forchheimer's Coefficient. The geometry of the regenerator has a very important role in pressure loss. Pressure loss and Friction factor in the regenerator is given in Eq. (7) as,

$$f = \frac{2\Delta P d_h}{L \rho_f V^2} \quad (7)$$

Putting Eq. (7) into Eq. (8)

$$f = \frac{2\mu d_h}{v k \rho_f} + 2\beta d_h \quad (8)$$

By evaluating Eq. (8) with respect to Re $_{max}$, it can be expressed as,

$$f = \frac{1}{Re}\frac{2d_h}{k} + 2\beta d_h \quad (9)$$

Here, $A = \frac{2d_h}{k}$ and $B = \beta d_h$ The basic form of friction factor correlation is given by the standard two-parameter Ergun Eq. (10) can be expressed as,

$$f = \frac{A}{Re} + 2B \quad (10)$$

The purpose of the present study is to estimate the pressure loss inside the uniform and hybrid wire mesh regenerators. The detailed numerical results for two specific mesh configurations stacked aligned and misaligned are presented. The fluid's pressure drop vs inlet velocity through a stacked aligned and misaligned configuration for uniform wire mesh is illustrated in Fig.5 and 6. It is noticed that all the trendlines are approximately a straight line concerning the fluid's inlet velocity, it is perceived that all the trendline follows the straight line thus second-order polynomial, which resembles Forchheimer's law (Eq. (6)), and both aligned and misaligned mesh configuration follows the same trendline. The volumetric porosity has an inverse influence on the pressure drop, which states that the low volumetric porosity of the regenerator generates the maximum pressure drop. All numerical studies are performed under the same working fluid density and viscosity.

When the present stacked wire mesh model is further examined, it is observed that pressure drops obtained for misaligned wire mesh configurations are approximately 27% higher than aligned wire mesh configurations. As a result, the perfectly aligned wire mesh can be interpreted as an ideal design in terms of efficiency. It is, however, difficult to achieve using traditional manufacturing processes. Here, #500 mesh configurations have more pressure drop than other mesh regenerators since it has low porosity. In the case of hybrid wire mesh pressure drop values for #300/400/500 and #500/400/300 are the same due to their same volumetric porosity.

Table 3 shows one of the CFD pressure drop results acquired from the simulation for uniform wire mesh regenerator models with aligned and misaligned mesh configurations for both (a) uniform wire mesh regenerator and (b) hybrid wire mesh regenerator. It is observed from the pressure contours from the post-processing that the pressure drop gradually decreases inside the wire mesh configurations. Thus, it can be noted the pressure drop is a function of the regenerator length.

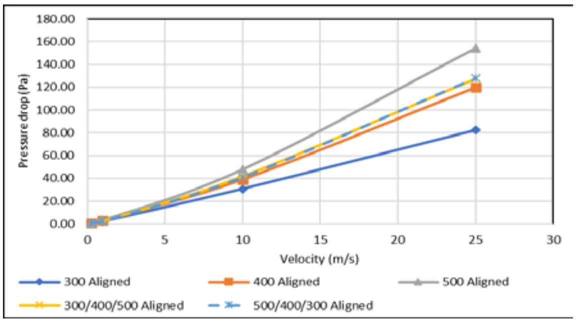


Fig 5. Pressure drops vs velocity for aligned configuration for uniform mesh regenerator.

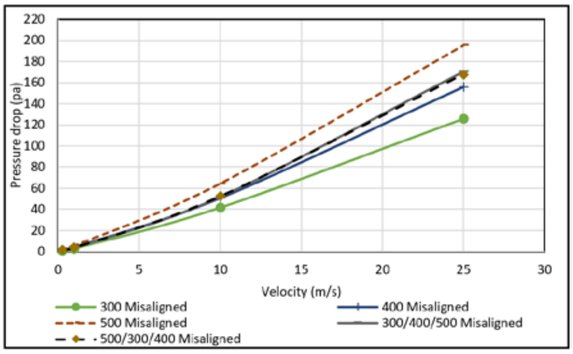
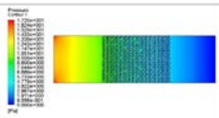


Fig. 6. Pressure drops vs velocity for misaligned mesh configuration for uniform mesh regenerator.

Table 3. (a) #300 uniform mesh pressure drop contour for aligned and misaligned mesh configuration.

Mesh	Velocity (m/s)	Aligned mesh configuration	Misaligned mesh configuration
300 mesh	25 m/s		

(b) #300/400/500 hybrid mesh pressure drop contour for aligned and misaligned mesh configuration.

Mesh	Velocity (m/s)	Aligned mesh configuration	Misaligned mesh configuration
300/400/500 mesh	25 m/s		

Friction factor correlation for wire mesh configurations

In this section, fluid flow simulations are accomplished using a finite volume method based approach for various mesh regenerators with different mesh configurations, and a pressure drop friction factor correlation equation is derived. Fig. 7 represents the relation between the friction factor coefficient versus the Reynolds number for CFD results obtained with an aligned and misaligned wire mesh configuration with a different porosity range. while the friction factor is derived from the obtained pressure drop data (Eq. (8)). In the range of Reynolds number up to 550 investigated, and the friction coefficients obtained from #300-mesh regenerator having a porosity of 0.80 have the highest friction factor, followed by #400, #300/400/500, #500/400/300 and #500 wire mesh regenerators. Whereas there is no significant difference in friction factor for obtained #300/400/500 and #500/400/300 wire mesh regenerators due to the same volumetric porosity. Therefore, based on the present study, we can say that the volumetric porosity directly influences the friction factor. However, as it shown in Fig. 7, regenerator volumetric porosity has an apparent effect on pressure drop for different mesh designs. As a result, a parametric study is carried out for a wide range of wire mesh porosity to analyze the impact of wire mesh porosity on pressure drop and to obtain the friction factor correlation equation for each mesh configuration. Finally, a friction factor correlation based on the two-parameter Ergun equation is derived (Eq. 10) in terms of Reynolds number. The specific correlation equation for aligned and misaligned mesh configurations is given in Table 4.

The purpose of the present study is to estimate the frictional pressure loss inside the wire mesh regenerator. To validate the present study, the numerical results for a stacked wire mesh regenerator are obtained and compared to the empirical correlations proposed by different researchers; Miyabe et al. (1982), Armour and Cannon (1968), Choi et al. (2004), Thombare and Umale (2015), and Duygu et al. (2020) over a wide range of regenerator parameters such as wire diameter, porosity and correlation equations presented in Table 5.

Fig. 8 shows the comparison of CFD results with another research. Here the friction factor results are interpolated to develop a correlation equation suitable for estimating pressure drops in the regenerator's flow direction. The friction coefficient obtained from the misaligned mesh shows similar and decent correspondence to these research correlations.

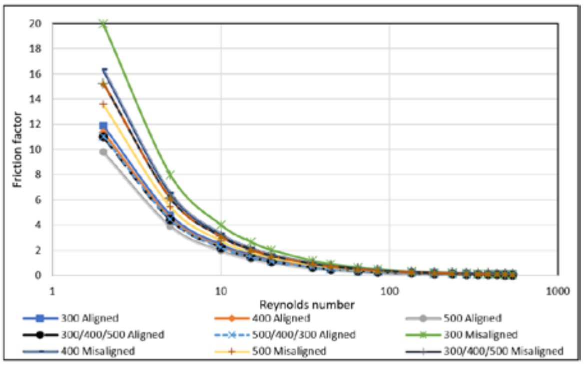


Fig. 7. Comparison of friction factor vs Reynolds number for aligned and misaligned mesh configuration for uniform mesh.

Table 4. (a) Correlation equation for aligned wire mesh configuration.

Mesh	Friction factor correlation
300 aligned mesh	$f = \frac{23.62}{Re} + 0.075$
400 aligned mesh	$f = \frac{22.78}{Re} + 0.016$
500 aligned mesh	$f = \frac{19.63}{Re} + 0.003$
300/400/500 aligned mesh	$f = \frac{21.96}{Re} + 0.025$
500/400/300 aligned mesh	$f = \frac{22.08}{Re} + 0.024$

(b) Correlation equation for misaligned wire mesh configuration.

Mesh	Friction factor correlation
300 aligned mesh	$f = \frac{38.87}{Re} + 0.018$
400 aligned mesh	$f = \frac{32.69}{Re} + 0.033$
500 aligned mesh	$f = \frac{27.07}{Re} + 0.038$
300/400/500 aligned mesh	$f = \frac{30.42}{Re} + 0.052$
500/400/300 aligned mesh	$f = \frac{30.46}{Re} + 0.051$

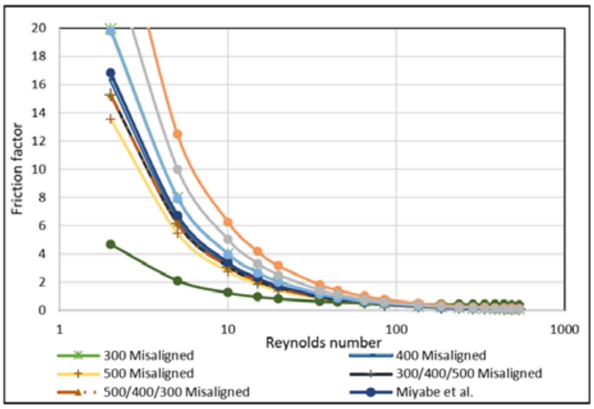


Fig. 8. Comparison of CFD friction factor with another researcher.

CONCLUSION

The realistic CFD analysis of a regenerator, therefore, depends on the appropriate modelling of the regenerator section. The CFD models were created by using SOLIDWORKS cad software. Here, the mesh is designed according to wire mesh parameters. Mesh independence study is conducted to ensure that the solution obtained is independent of the mesh resolution. This study is carried out for different models with various mesh sizes. The mesh grid model provides a good agreement to predefined mesh conditions such that there are no significant changes in other mesh designs. The CFD simulations are performed for ten wire mesh structures with aligned and misaligned configurations to determine the hydrodynamic parameters. The following points can be concluded from the study:

1. It is found that #500 mesh configurations have more pressure drop than other mesh regenerators because it has the smallest porosity, and #300/400/500 and #500/400/300 mesh have no significant difference.

2. Wire mesh porosity plays an essential role while studying the pressure drop across the regenerator. A regenerator wire mesh with lower porosity has the highest pressure drop. For example, the highest-pressure drop is that the #500 mesh with 0.657 porosity has the highest pressure drop.

3. The friction coefficient is calculated for different mesh configurations, and it is found that the friction coefficient of #500 mesh is the smallest and #300 mesh is the largest. This is due to the porosity of #500 mesh, which makes it difficult for fluid to enter the regenerator.

4. The friction factor obtained from the #500/400/300 and #300/400/500 mesh regenerator has no significant differences in the friction factor values. This is due to the same volumetric porosity for both cases.

5. The misaligned case has the highest friction factor when comparing aligned and misaligned mesh configuration for friction factor. When the present wire mesh model is analysed, it is found that the pressure drop obtained from an aligned mesh configuration is 27% lower when compared to a misaligned cased due to its structural design.

6. However, the proposed CFD results show a decent correspondence with the other research journals. Notably, for different wire mesh configurations, the friction factor correlation equation formulas better fit the numerical results with the two-parameter Ergun form.

ACKNOWLEDGMENT

The authors gratefully acknowledge the funding and support from Ministry of Science and Technology of Taiwan under the project contract No. MOST 107-2622-E-006-005 -CC2.

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NOMENCLATURE

A_{ff} Free flow cross-sectional area of regenerator (m^2)
A_r Cross-sectional area of Regenerator (m^2)
D_w Wire diameter (m)
d_r Regenerator outer diameter (m)
d_h Hydraulic diameter (m)
f Friction factor
Δx The thickness of the porous medium (m)
K Permeability coefficient (m^2)
L Length of regenerator (m)
N Number of mesh screens
ΔP Pressure drops (Pa)
Q Volumetric flow rate (ml/min)
Re_{max} Reynolds number
t The thickness of the mesh screen (μm)
V The velocity of the fluid (m/s)
W Pitch of wire mesh screen (m)

Greek symbols

φ The porosity of mesh screens
ρ_f The density of the fluid (Kg/m^3)
μ Kinematic viscosity (kg/ms)
β Forchheimer's Coefficient.

混合網目再生器的流力數值分析

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摘 要

再生器是史特靈製冷機的核心換熱元件，其性能由金屬絲網的構型和物理特性決定。本文對具有不同絲網配置、堆疊對齊和錯位配置的均勻網目和混合網目之再生器進行穩態流力數值分析研究，並獲得摩擦壓降之相關方程式。混合網目再生器包括不同的金屬絲網，其孔隙率以細到粗或粗到細的方式排列。數值研究使用基於有限體積法 (FVM) 的 CFD 方法來處理不同配置的絲網再生器。工作流體被視為等溫，並且設定黏滯係數為常數。此外，數值求解雷諾數和摩擦因子的關係式，提供了對各種配置流動特性的深入了解。通過將獲得的相關性與先前發表的研究（雷諾數高達 550）進行比較來驗證數值研究。從數值分析得出的摩擦降相關性可用於計算再生器流動方向的壓降。