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PERFORMANCE ANALYSIS OF STAGGERED WIRE MESH MATRIX REGENERATIVE HEAT EXCHANGER

Arun Kumar[1] & S. K. Verma[2]

[1]Research Scholar, Department of Mechanical Engineering, NIT, Patna, Bihar, India

[2]Professor, Department of Mechanical Engineering, NIT, Patna, Bihar, India

ABSTRACT

Numerical analysis of staggered wired mesh matrix (SWMM) regenerative heat exchanger has been done and the performance of SWMM has been evaluated experimentally. The range of parameters considered was Reynolds number from 2208 to 4766 and porosity from 0.83 to 0.88. The experimental results revealed that the effectiveness of heat exchanger decreases with time for uniform mass flow rate and with the increase in mass flow rate for a given time.

KEYWORDS: *Effectiveness, Performance, Regenerative Heat Exchange (RHE), Staggered Wired Mesh Matrix (SWMM)*

Article History

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INTRODUCTION

A Heat exchanger is a device that is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In many heat exchangers, the fluid is separated by a heat transfer surface, and ideally, they do not mix or leak, Such type of heat exchangers are called as direct transfer type or recuperator. Heat exchanger in which there is intermittent heat exchange between the hot and cold fluids via a thermal energy storage and release through the exchanger surface or matrix are referred to as indirect transfer type, or simply regenerators [1]. Regenerative heat exchangers are usually found in high-temperature systems where a portion of the system's fluid is removed from the main process, and then returned. Because the fluid removed from the main process contains energy (heat), the heat from the fluid leaving the main system is used to reheat (regenerate) the returning fluid instead of being rejected to an external cooling medium to improve efficiency. Some of the heat supplied by an external source to working fluid is converted into useful work and while flowing out hot expanded gases from expansion space to the cooler the rest of the heat is stored in a regenerator. After cooling in the cooler and compressing in the compression space gases flows back to expansion space through the regenerator. The stored heat in the regenerator is given back to the working fluid during back-flow. This process is called as regeneration. The efficiency of the Stirling cycle machine depends on the efficiency of the regeneration process or regenerator [2-3]. The schematic diagram of a fixed bed regenerative heat exchanger is shown in Figure 1

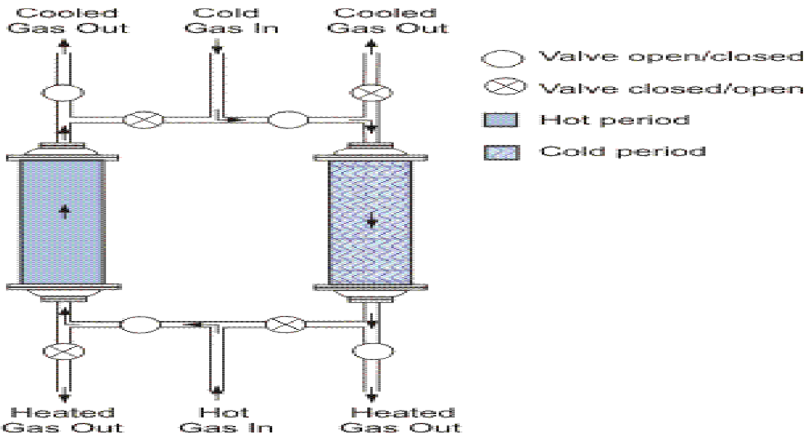

Figure 1: Schematic Diagram of Fixed Bed Regenerative Heat Exchanger [1]

The advantages of a regenerator over a recuperating (counter-flowing) heat exchanger is that it has a much higher surface area for a given volume, which provides a reduced exchanger volume for a given energy density, effectiveness and pressure drop. This makes a regenerator more economical in terms of materials and manufacturing, compared to an equivalent recuperator. The major disadvantage of rotary and fixed-matrix regenerators is that there is always some mixing of the fluid streams, and they cannot be completely separated [2]. In rotary regenerators the heat storage "matrix" in the form of a wheel or drum, which rotates continuously through two counter-flowing, streams of fluid. In this way, the two streams are mostly separated as shown in Figure 2. There is an unavoidable carryover of a small fraction of one fluid stream into the other.

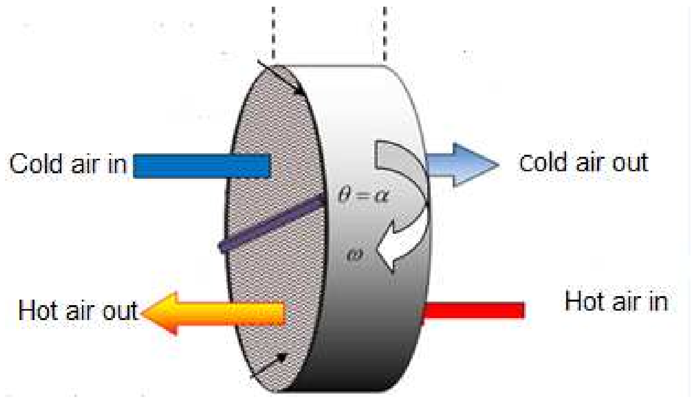

Figure 2

Saunders and Smoleniec [4] investigated the analysis of the thermo physical properties of fluids and matrix wall material throughout the regenerator. They found the error in the effectiveness less than 1 % due to variation in fluid and matrix specific heats. However, its significant influence on variation in specific heat of the gases and the matrix is anticipated. There are various kinds of materials which can be used for the regenerator matrix, such as steel wool, steel felt, wire mesh, fine pipes, spring mesh, stacked screen, packed balls, metal foils and parallel plates etc. Heggs and Carpenter [5], among others, proposed high heat capacity material near the outlet end of the cold gas flow path and low heat capacity neat inlet of cold gas path flow. Only 10 % of the heat surface area is required to have higher heat capacity material and 90% with low heat capacity material. Shah and Skiepko [6] have reported that any radial seal leakage location (at the hot or cold end of a regenerator) has a negligible effect on actual heat transfer on cold stream. Specific illustrative results of 5% and 10% leakages individually through radial, peripheral and axial seals for a gas turbine regenerator have been mentioned.

Skiepko et al. [7] presented three-dimensional temperature charts demonstrating how the longitudinal matrix heat conduction affects the matrix as well as gas temperature distribution. Vennkatarathnam et al. [8] investigated High-effectiveness Regenerators may require a stack of high thermal conductivity (copper or aluminum) perforated plates or wire screen alternating with low thermal conductivity spacers made up of plastic, stainless steel to reduce longitudinal heat conduction. Dragutinovic and Baclic [9] have presented exact analytical relation and computational algorithms for the evolution of temperature distribution and regenerator effectiveness on the term of four dimensionless groups as utilization factor, reduce length and unbalance factor and asymmetry factor. Pandelidis et al. [10] investigated the performance and heat and mass transfer processes that occur in regenerative heat and mass exchangers (HMXs) used for indirect evaporative air cooling. The results allow defining optimal geometric and operational parameters for the typical regenerative exchanger and regenerative exchanger with perforations. It was determined that the value of working to main air-flow ratio has a significant impact on the cooling performance of considered air coolers. Feng et al. [11] have performed an optimal performance analysis of a Stirling engine with heat transfer and imperfect regeneration irreversibility and derived a relationship between the net power output and thermal efficiency with imperfect regeneration. Costa et al. [12] have derived a pressure drop correlation equation from a numerical study by characterizing the pressure drop phenomena through process medium of both types stacked and wound woven wire matrices of a Stirling engine regenerator over a specified range of Reynolds number, diameter, and porosity. They found the flowing nature and complex scheme try dependent friction pressure drop characteristics within the Stirling engine regenerator system. Natarajan et al. [13] investigated a periodic regenerative heat exchanger and focused on dimensionless parameters, known as the reduced periods and reduced length to describe the performance of a regenerative heat exchanger. He concluded that, for a particular reduced length, the entropy generation due to finite temperature difference is in linear relation with the reduced period. Murphy et al. [14] performed on rolled and stacked regenerative heat exchangers and the objective is to determine how the heat transfer and pressure drop characteristics changed in a stacked and wire-screen (rolled) regenerative heat exchanger. The results show that flattening the screens by 15%, 30%, or 50%, did not improve the heat transfer rate to the matrix, but it did increase the total pressure drop. Rolling the screens caused a decrease in both wetted surface area and pore size so that heat transfer reduces and pressure drop increases. Rolling the screens also reduced the effectiveness of the regenerator.

Numerical Analysis

Heat Transfer

The regenerator heat exchanger matrix has been analyzed numerically. Schematic of SWMM Regenerative Heat Exchange is shown in Figure 3.

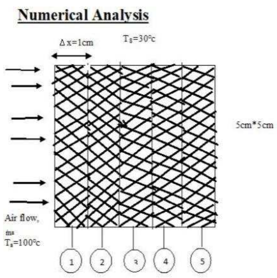

Figure 3: Schematic of SWMM

Regenerative Heat Exchanger

Energy balance for one of the axial nodes is given below.

Energy transported in - energy transported out - energy lost to surroundings = rate of energy accumulation of node.

Or, ṁaCpa (Tm-1p–Tmp)-Tmp-TPΔxR=ρcpΔV(Tmp+1-Tm)pΔτ (1)

The above equation is solved to give

Tmp+1=FṁaCPa Tm-1P + [1-F(ṁacPa+PΔxR)]TmP+FPΔxRT (2)

Where F=ΔxρcΔv

The energy storage relative to 30^0C has been calculated from the equation

E=m=15ρcΔvTm-30 (3)

as a function of time.

The effectiveness of heat exchange is given by

ϵ=Actual Heat transfer Maximum possible heat transfer

ϵ= mCph Th -mCpaTca/(mCpmin(Th-Tc) (4)

Where m is mass flow rate, This temperature of the hot fluid, Tc is a temperature of the cold fluid. Cph is the specific heat of hot fluid, Cpa is mean average specific heat, Tca represents mean average temperature.

Friction Factor

When the fluid flow inside the wire mesh regenerator some losses of energy takes place due to a viscous action of flowing fluid. Loss of energy in this case, is usually known as friction losses. To measure this friction losses Darcy introduces a factor ‘f’ which is known as Darcy friction factor. It is defined as the friction-resistant per unit wetted area per unit velocity and derived as:

f=ΔP ×dhL12×ρ×V2 (5)

ΔP =Pressure drop.

v = bulk mean velocity inside the regenerator.

= density of gas.

dh = hydraulic diameter of the regenerator.

EXPERIMENTATION

Schematic diagram of the experimental setup is shown in Figure 4. Hot air and cold air passes through regenerator alternatively. The electric heater was used to heat the air. The wire mesh matrix used in regenerator as a heat transfer surface is shown in Figure 5.Specifications of the mesh matrix is Screen wire diameter = 0.5mm, Number of screen = 28 and 33, Regenerator size = 50mm×50mm×50mm, Screen material: Aluminium. Matrices of different geometry in order to have different priority were used in the experiment. A blower was used to provide the required fluid flow through the regenerator. The mass flow was measured with the help of the orifice meter. A temperature of fluid at inlet and outlet of the regenerator was measured with the help of thermocouple. The temperature of the wire matrix inside the regenerator was measured with the help of thermocouples. The location of thermocouples is shown in Figure 4. The Pressure drop across the regenerator was measured with help of U tube manometer. The photographic view of the experimental setup used in the experimentation i/s shown in Figure 6.

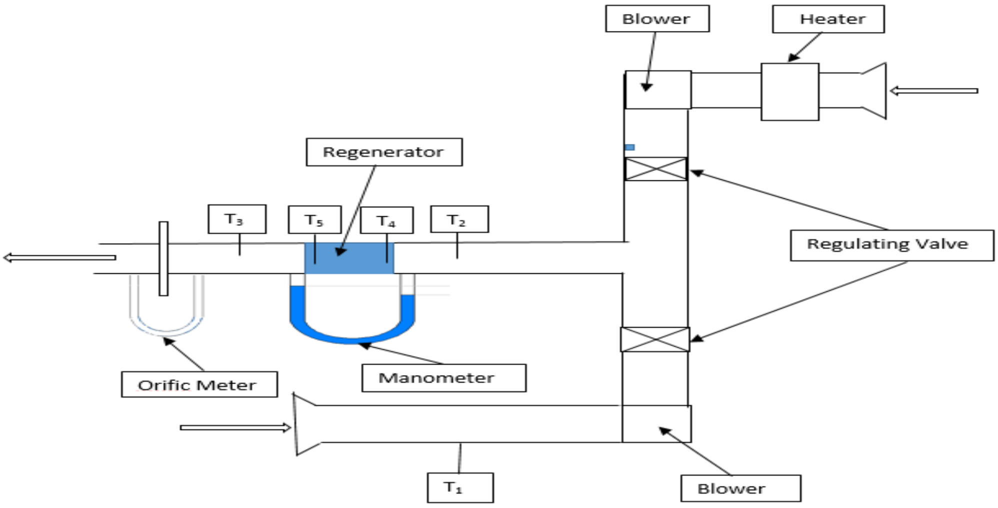

Figure 4: Schematic Diagram of Experimental Setup

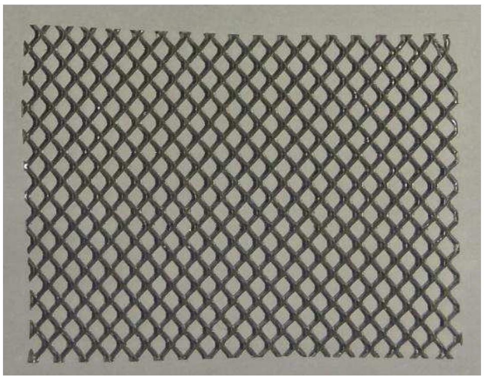

Figure 5: Wire Mesh Matrix

Figure 6: Photographic View of Experimental Setup

RESULTS AND DISCUSSIONS

Results of the calculations using Eq. 3 are shown in Figure 7 for two velocities.

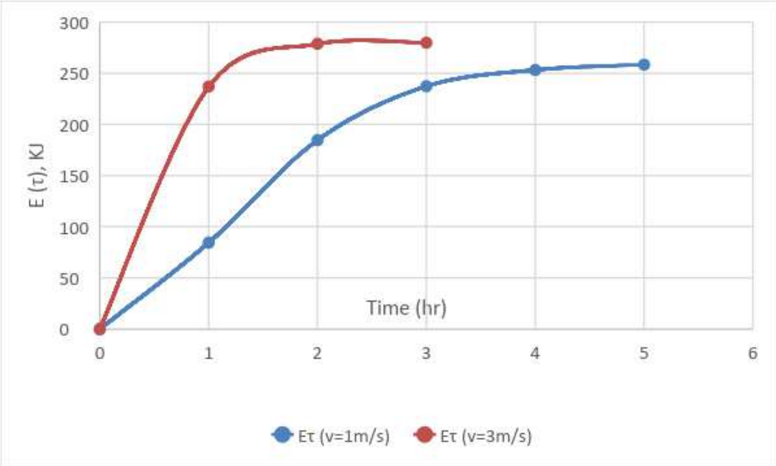

Figure 7: Energy Storage VS Time

Figure 8 shows a variation of the temperature of wire mesh having 0.5 mm wire diameter at 60 mesh and 0.83 porosity with time during heating. Whereas Figure 9 shows a variation of the temperature of wire mesh having 0.5mm wire diameter at 60 mesh and 0.83 porosity with time during cooling. Mass flow rate was kept constant at 0.005025 kg/sec.

Figure 10 shows the variation of the effectiveness of RHE with time. Whereas Figure 11 shows the variation of the effectiveness of RHE with mass flow rate.

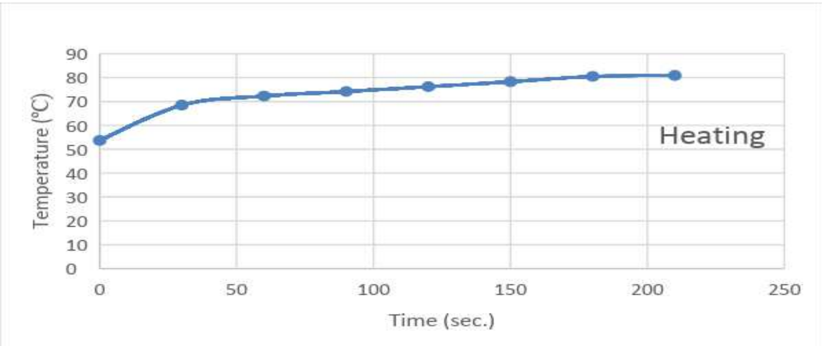

Figure 8: Temperature VS Time

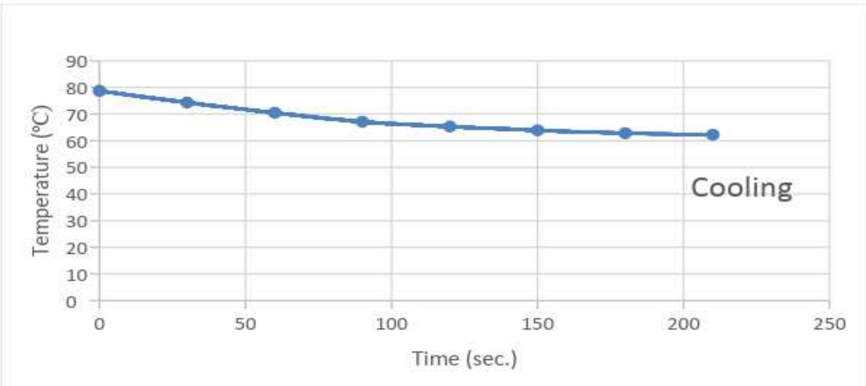

Figure 9: Temperature VS Time

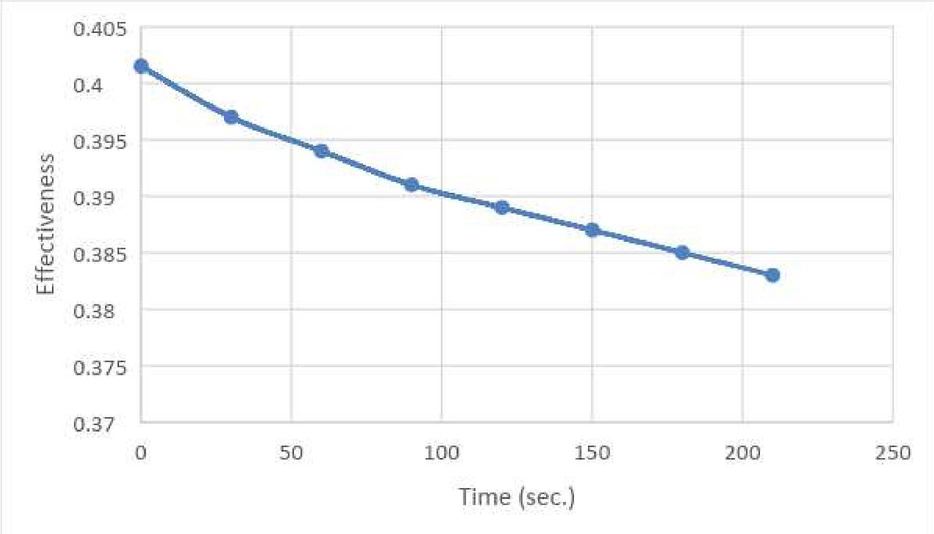

Figure 10: Effectiveness VS Time

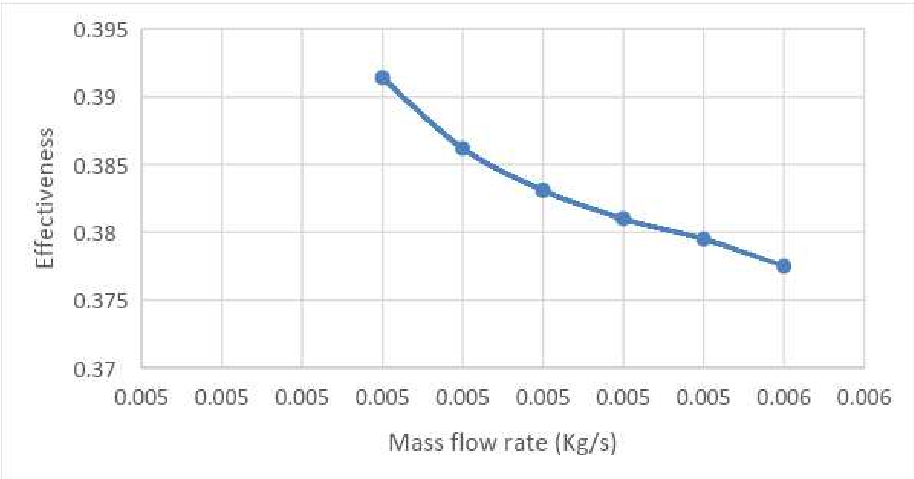

Figure 11: Effectiveness VS Mass Flow Rate

CONCLUSIONS

- Charging period for SWMM regenerative heat exchanger has been found much more than the discharging period for the same mass flow rate of the hot and cold fluid.
- Effectiveness of SWMM regenerative heat exchanger decreases with an increase in mass flow rate of air through it.
- Effectiveness of SWMM regenerative heat exchanger also decreases with time even the mass flow remains constant.
- Fluid friction increases with a decrease in porosity.

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