Fabrication and study of Jet Impingement Heat Exchanger in a Stirling Refrigerator using CFD

K Mohan kumar, A Rama Krishna, G Raghavendra, C Raghuveer Reddy

Abstract— Refrigerators operating based on the Stirling cycle are the most efficient heat pumps. They offer the possibility of using some environmentally-friendly working fluids such as water, air, or helium, thus avoiding the environmental damage. Three different fluids were employed as the working fluid. The tested fluids were water and a nanofluid which consisted of dispersed silica particles with a volume fraction of 20 and 40%. The unique heat exchanger with two inlets and a single outlet was implemented on the cold side of the Stirling cooler. On the experimental side, the nozzle diameter size of 4, 6 and 8 mm is taken for comparison. For the sake of repeatability, the experiments were conducted 5 times and the temperature values obtained from each location were averaged among the five tests. The flow cases were simulated using commercial CFD software.

Index Terms—CFD, Nanofluid, Silica, Nozzle,stirling cycle,fluids,temperature,

1 INTRODUCTION

Stirling cycle is different from the conventional refrigeration cycles like Rankin cycle. Helium and water are employed as working fluids and there is no phase change in the whole cycle. More or less from last 170 years ago, the Stirling refrigerator was conceived for making ice. However, it was not until the 1950s that the first commercial Stirling refrigerator was developed by Philips. [1] According to the number of expansion and compression spaces, a Stirling system can be classified as either a single-acting Stirling system (with one expansion space and one compression space) or a double-acting Stirling system (with multiple cylinders). Stirling coolers can have variable cooling capacities due to input voltage; they may be distinguished as similar devices to the variable capacity compressors. Another significant advantage of the Stirling coolers is that they can keep their high efficiencies even in low cooling capacities. [2]

Closed loop of working fluid or fan systems may be used in the application of free piston Stirling coolers to refrigeration units. In closed loop systems, a working fluid of choice (i.e. water, nanofluid, etc.) is circulated through the system by aid of a circulation pump. Recent year's research is radically changing towards the nano and the nano fluids due to impart unique magnetic, physical, mechanical properties. The most common available nanoparticles are Silica, Alumina, Titanium, Iron oxide, Zinc oxide, Ceria and Zirconium. In the present years increase in manufacturing industries have lead to the creation of solid particles to the nanometric scale, which in turn lead to the creation of nanotechnology and 'nanofluids', Choi [3] . These fluids constitute a very interesting alternative to the other cooling appliances, Lee and Choi [4]. The term nanofluids usually refer to a mixture composed of saturated fluid where nanoparticles are in suspension. Nowadays many nanofluids have been developed based on different applications. [5]. From the previous researches of Masuda et al [6], Wang et al [7], Chon et al [8], Choi et al [9], Eastman et al [10], Roy et al[11], Angue Mitsa et al[12], it has been absorbed that the nanofluids have higher thermal conductivities than the base fluids. Various experiments have been conducted by Mare [13] to show that the heat transfer capabilities are higher for nanofluids than the base fluids.

Jet Impingement is a technique in which a liquid jet with high velocity impinges on a surface and flow out from the surface. Jet Impingement has higher heat transfer capabilities compared to conventional cooling method.

So as an attempted a heat exchanger was designed and fabricated for another study was exposed to a CFD analysis. Heat transfer variations of the nanofluids in this jet-impingement heat exchanger were studied using fluent software along with Gambit. Different working fluids which are water, silica nanofluid with volume fraction 20% and silica nanofluid with volume fraction 40% were compared to find out the best choice to be employed as the working fluid by varying the velocity by chancing the nozzle diameter in a Stirling refrigeration unit inflow system

2 EXPERIMENTYAL PROCESSOR

A free piston Stirling cooler is driven by a linear motor which is sealed with in the pressure vessel of the cooler. The cross section of the cooler is given in the figure 1 it contains acceptor, rejecter, displace spring, regenerator, displacer, piston, linear motor, casing and displacer rod.

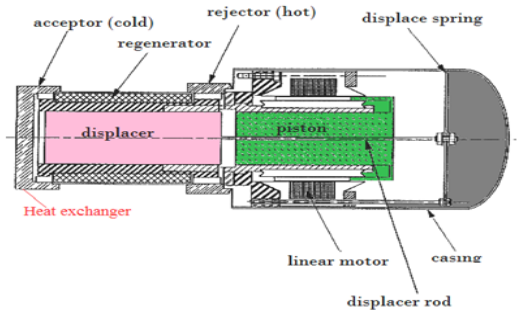

Fig. 1 cross section of a free piston Stirling cooler.

A three dimensional solid model of three with varying the inlet nozzle diameter was created in AutoCAD and exported to Gambit for the analysis. The solid model is as shown in the figure 2. It has two inlets and one outlet; both the inlets are cylindrical and out let. The model was meshed and studied with different inputs by using CFD.

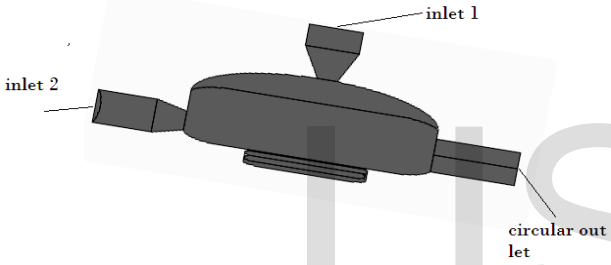

Fig. 2 heat exchanger with two valves.

The jet-impingement heat exchanger designed in this study has rectangular slot (8mm x 3mm) outlet on the side and a circular jet (d = 4, 6 and 8 mm) on the top and one on the side of the heat exchanger both spraying the fluid towards the cold head of the cooler as given in Figure 1 above. Different working fluids were tested and compared. One of the working fluids was water, while the other one was a nanofluid having silica parti-cles with a volume fraction of 20 and 40%. The particles were mixed with water. Mixing of the nano particles and water was conducted by the manufacturer by colloidal dispersion with the dispersant. The fluid enters the Heat exchanger from both the inlets and leaves the Heat exchanger from the Outlet. The fluid has the volumetric flow rate of 2 Gallons per minute and it enters with the temperature of 295 K. The heat absorption rate of the lower part of the Heat exchanger is 30 W.

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3 RESULTS AND DISCUSSION

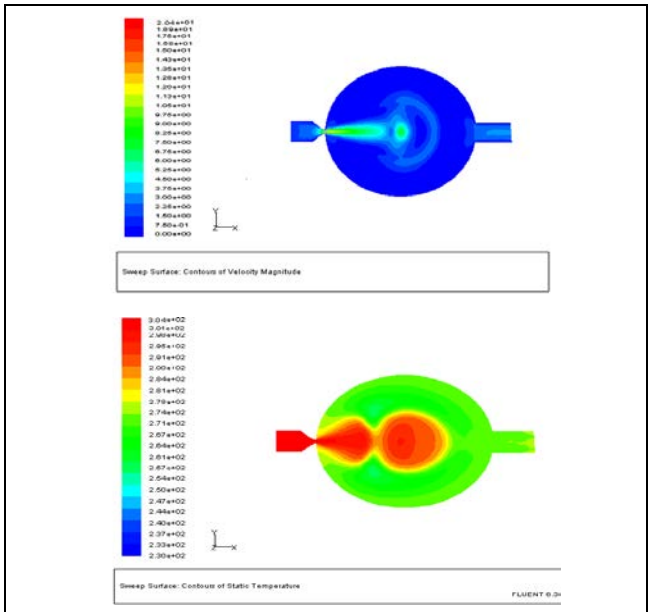

Fig. 3. velocity and Temperature distribution contour plots for 4 mm diameter nozzle with water input

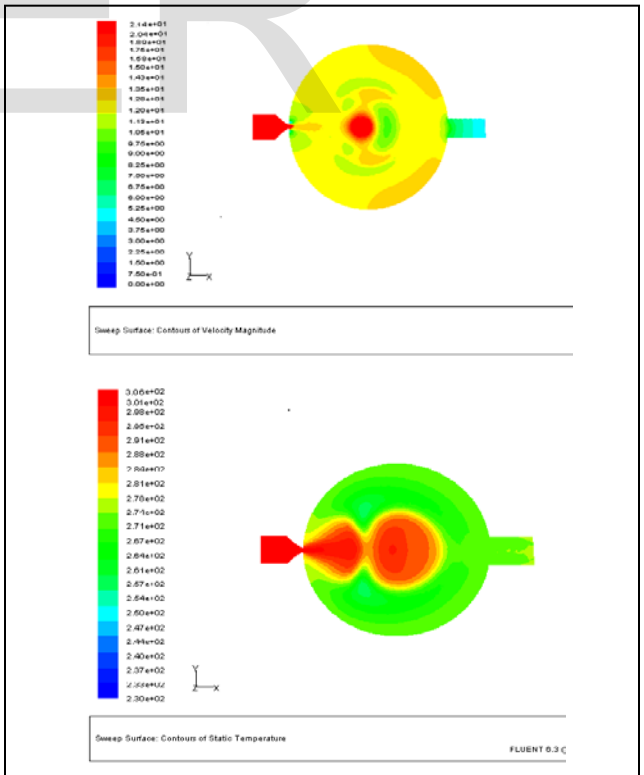

Fig. 4. velocity and Temperature distribution contour plots for 4 mm diameter nozzle with nano silica 20%.

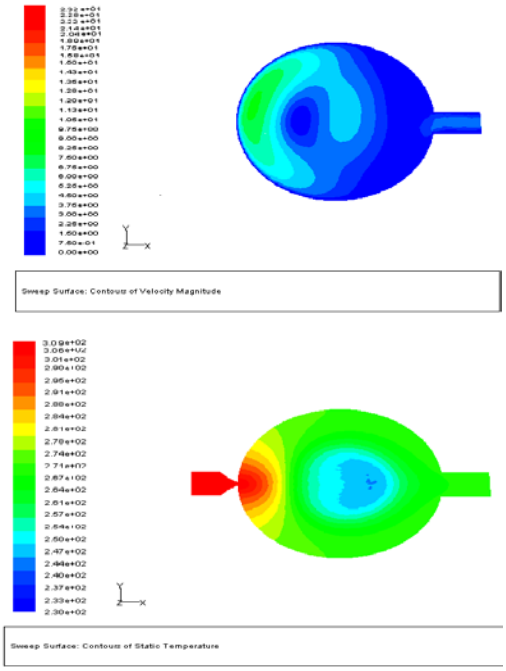

Fig.5. velocity and Temperature distribution contour plots for 4 mm diameter nozzle with nano silica 40%.

Fig 2-5 shows the velocity and temperature counter plots for 4 mm nozzle diameter of with different coolants. Temperature and velocity distributions within the jet-impingement heat exchanger were obtained using fluent software. The results were found to be in close agreement with the experimental results. Temperature and velocity behaviours of fluid particles at the early stage of the fluid circulation are given in Figures. These sketches represent the values at the mid-plane of the jet-impingement heat exchanger.

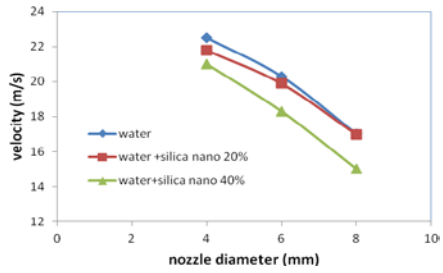

Fig 6 velocity of the coolant with respect to nozzle diameter

Figure 6 shows the velocity of the coolant with respect to nozzle diameter and different coolant used in the analysis. From the figure it is observed that the velocity of the water coolant is high when compared to the other coolant as the nano percentage increase there is a slight decreases in velocity. The maximum velocity is observed for the 4mm diameter in all the cases.

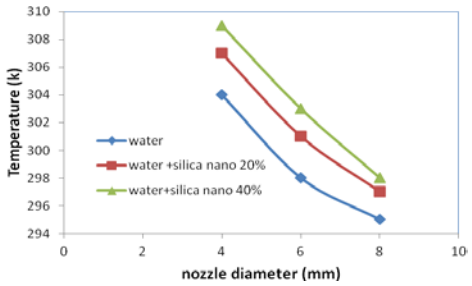

Fig 7 effect of temperature with respect to nozzle diameter.

Fig7 shows the effect of temperature with respect to nozzle diameter and different coolant used in the analysis at the out let valve. It is observed that for the nano coolant of 40 % silica the heat observed is more than compared to other coolant. It is also observed that the maximum heat removed from the system when 4mm nozzle is used this may be due to high pressure the heat dissipation is more.

4 Conclusion

Based on the above analysis the following conclusions are drawn.

A free piston Stirling cooler with a jet-impingement heat exchanger on its cold head was implemented into a Refrigerator.

Three different working fluids, water and a nanofluid (20% silica in H_2O and 40 % silica in H_2O), were tested and the results were compared with varying the nozzle diameter.

The maximum heat removal from the system is observed for the nano fluent of 40% silica in H_2O for the 4mm diameter nozzle.

References

[1] G. Walker, Cryocoolers part 1: fundamentals, plenum press, New York, PP. 95-10, 1983.

[2] S. Celik, S. Nageshwaran, and K. Bachu, "Experimental Analysis of a Stirling Refrigerator Employing Jet-Impingement Heat Exchanger and Nanofluids," International Refrigeration and Air Conditioning Conference.Paper, 1098.http://docs.lib.purdue.edu/iracc/1098, 2010.

[3] S. Choi, "Enhancement Thermal conductivity of fluids with nanoparticles,"ASME publications, 1995.

[4] S. Lee, "Applications of metallic nanoparticles suspension in advance cooling systems," ASME publications, 1996.

[5] Nanophase technology corporations, Romeoville IL, USA.

[6] H. Masuda, and A Ebata, "Alteration of thermal conductivity and viscosity of fluids by dispersing ultrafine particles," 1993.

[7] X. Wang, X. Xu, "Thermal conductivity of nanoparticles-fluid mixture," 1999.

[8] C.H Chon, K.D Kihm, and S.P Lee, "Empirical correlation of finding the temperature and particle size for nanofluid thermal conductivity enhancement," 2005.

[9] S.U Choi, and Z.G Zhang, "Anomalous thermal conductivity enhancements in naofluid suspensions," 2001.

[10] J.A Eastman, S.U.S Choi, S Li, and W. Yu, "Anomalous increase of effective thermal conductivities of Ethylene Glycol based nanofluids containing copper nanoparticles," 2001.

[11] G.. Roy, and C.T Nguyen, "Temperature dependent thermal conductivity evaluation of alumina based nanofluids," 2006.

[12] H. Angue Minsta, "New temperature dependent thermal conductivity data for water based nanofluids".

[13] T. Mare, A G Schmitt, "Experimental and viscosity study of nanofluids".