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Performance Evaluation of Regenerators fitted with Stirling Engines for Different Porosities & Materials

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ABSTRACT: Performance of the Stirling Engines is dependent upon several factors & to of such major issues being related to porosity & the materials which can be used in the concerned application. Apart from performance enhancement, Stirling engines can also be useful for recovery of the waste heat as far as possible. Current research paper analyses the Stirling engines fitted with regenerators for three different materials Aluminium, Copper & Steel at four different porosities of 0.3, 0.5, 0.7 & 0.9 for both the aspects i.e., Performance enhancement & waste heat recovery. Results of the research indicate that porosity & thermal conductivity both affect the heat storage capacity of the regenerators. Material wise copper will store maximum heat because of its highest thermal conductivity & porosity of 0.9 will have maximum amount of heat being stored in the regenerators.

Keywords: Stirling Engines, porosity, waste heat recovery,Performance enhancement, thermal conductivity etc.

I. INTRODUCTION

A Stirling engine is a heat engine that is operated by the cyclic compression and expansion of air or other gas (the working fluid) at different temperatures, resulting in a net conversion of heat energy to mechanical work. More specifically, the Stirling engine is a closed-cycle regenerative heat engine with a permanent gaseous working fluid. Closed-cycle, in this context, means a thermodynamic system in which the working fluid is permanently contained within the system, and regenerative describes the use of a specific type of internal heat exchanger and thermal store, known as the regenerator. Strictly speaking, the inclusion of the regenerator is what differentiates a Stirling engine from other closed-cycle hot air engines.

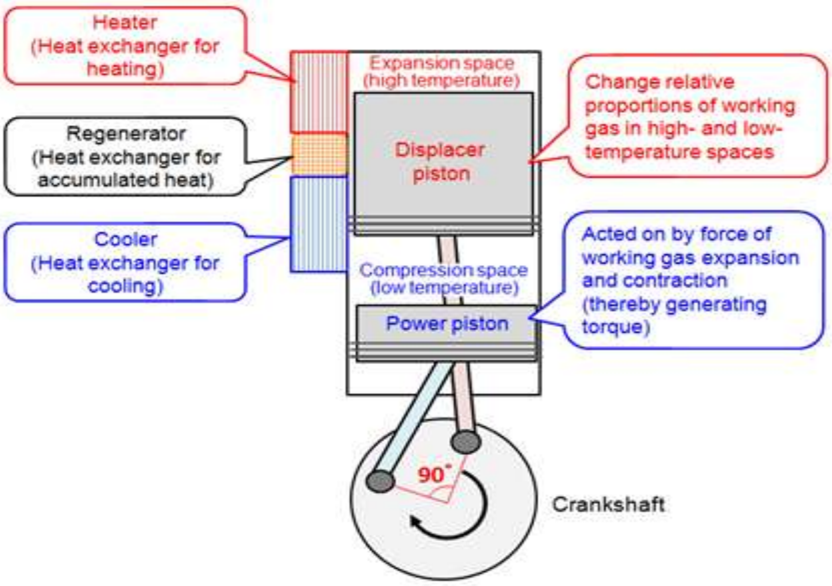

Fig.1 Working cycle of a β-Stirling Engine

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The primary effect of regeneration in a Stirling engine is to increase the thermal efficiency by 'recycling' internal heat which would otherwise pass through the engine irreversibly. As a secondary effect, increased thermal efficiency yields a higher power output from a given set of hot and cold end heat exchangers. These usually limit the engine's heat throughput. In practice this additional power may not be fully realized as the additional "dead space" (unswept volume) and pumping loss inherent in practical regenerators reduces the potential efficiency gains from regeneration.

The regenerator is the key component invented by Robert Stirling, and its presence distinguishes a true Stirling engine from any other closed-cycle hot air engine. Many small 'toy' Stirling engines, particularly low-temperature difference (LTD) types, do not have a distinct regenerator component and might be considered hot air engines; however, a small amount of regeneration is provided by the surface of the displacer itself and the nearby cylinder wall, or similarly the passage connecting the hot and cold cylinders of an alpha configuration engine.

Performance evaluation, its enhancement and waste heat recovery process are analysed through CFD analysis in the current research. Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows. Computers are used to perform the calculations required to simulate the free-stream flow of the fluid, and the interaction of the fluid (liquids and gases) with surfaces defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved, and are often required to solve the largest and most complex problems. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows.

Problem Statement

Current research study is conducted in two ways. First way of analyzing this study is on the basis of porosity of the regenerator material. For the analysis purpose four different porosities of 0.3, 0.5, 0.7 & 0.9 are to be used. Second way for the analysis of current research study is on the basis of materials and three different materials are used in this study which are steel, copper & aluminium.

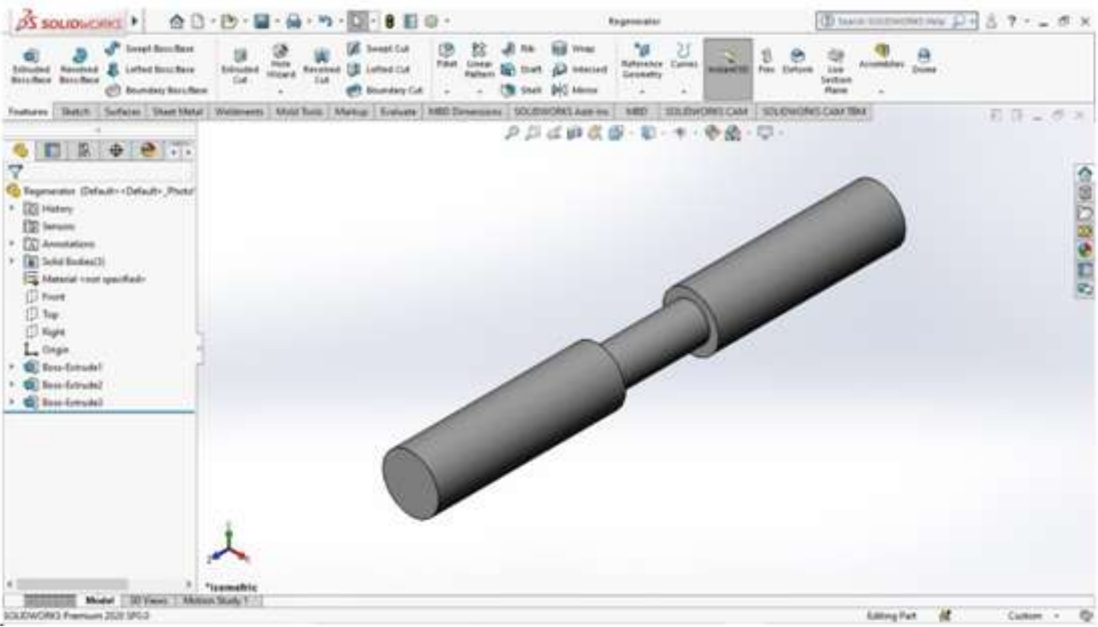

Fig. 2 Model of the regenerator modelled in Solidworks-2020

Different types of input and output parameters will be used for the analysis of Stirling engine in the current research study. Various input Parameters to be used in the current study are as follows-

- **Input Parameters**

Several parameters to be included are-

- Temperatures of hot (800K) and cold cylinders (300K)

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- Porosity of the materials (0.3, 0.5, 0.7 & 0.9)
- Different materials to be used as the material of regenerator like steel, copper & aluminium
- Working fluid to be employed is Air

➢ **Output Parameters**

Several output parameters are as follows-

- Temperature distribution

Analysis of the Stirling Engine

After creating solid model of Stirling engine with regenerator in Solidworks-2020, proceed as follows-

➢ Start the analysis process of the model in ANSYS Workbench through selecting the module of CFD analysis through Fluid Flow (Fluent).

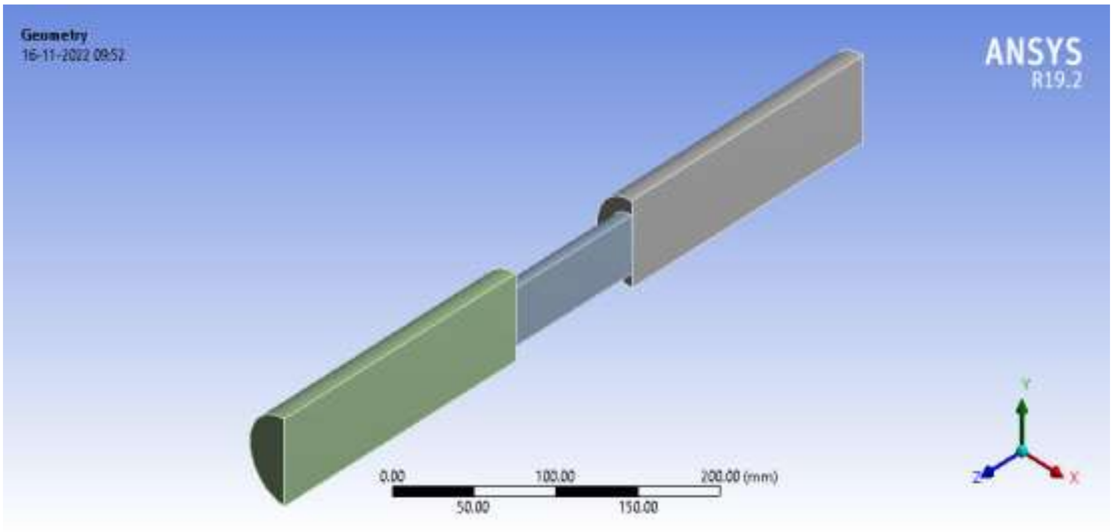

Fig. 03- Geometry of the Piston

➢ Select the Stirling engine with regenerator material according to the requirement.
➢ Assign the material to the Stirling engine with regenerator
➢ Create meshing of Stirling engine with regenerator.

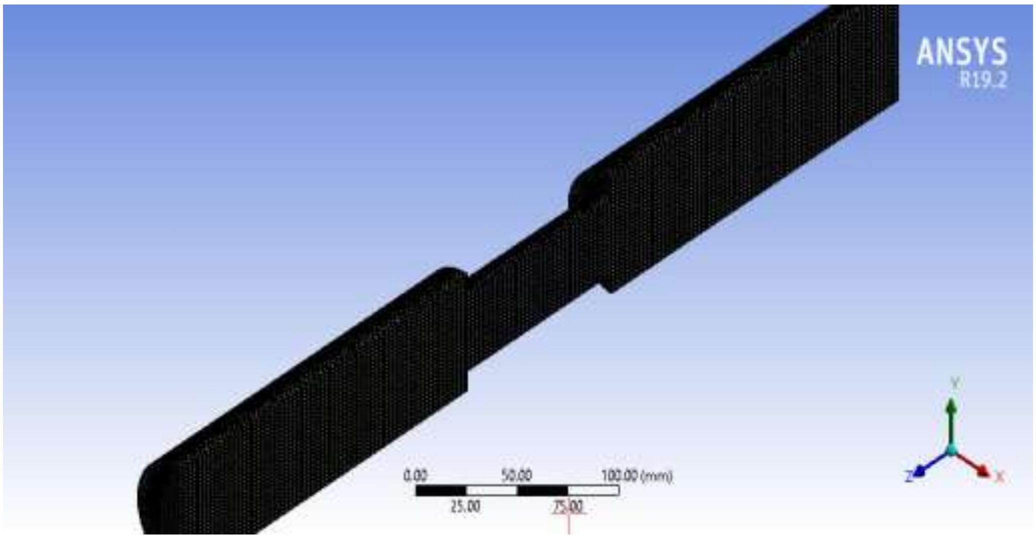

Fig. 05- Meshing of the Stirling engine with regenerator

After applying the material to the part, the process of meshing is performed in order to convert the component into large number of small parts which are either one dimensional, two dimensional & three dimensional. All the parts consist of 2 components namely nodes &elements as shown in figure 06. Number of elements used are 766000 & and number of nodes used are 805523.

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- Apply boundary conditions
- Defining different Reports
- Initialization
- Running the Calculations

For the current research study, a Stirling engine with regenerator was studied for its performance against different materials namely Aluminium, Copper & Steel for different porosity values of 0.3, 0.5, 0.7 & 0.9. all these permutations & combinations were examined through ANSYS simulation through CFD analysis using ANSYS (Fluent).

Some of the results obtained are as follows-

- Results for Aluminium
  - Porosity of 0.3

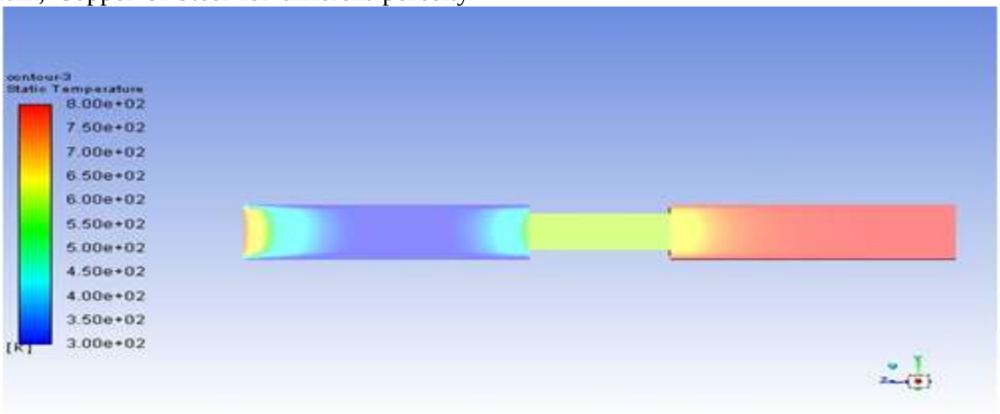

Fig. 06 Temperature Distribution for porosity of 0.3

  - Porosity of 0.5

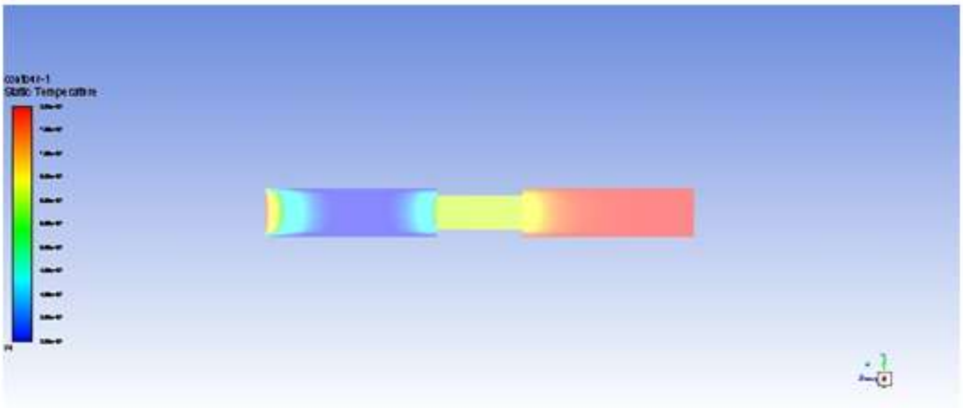

Fig. 07Temperature Distribution for porosity of 0.5

  - Porosity of 0.7

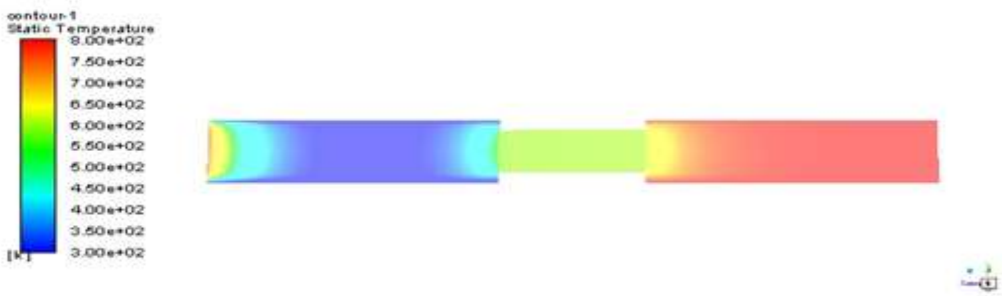

Fig. 08Temperature Distribution for porosity of 0.7

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- Porosity of 0.9

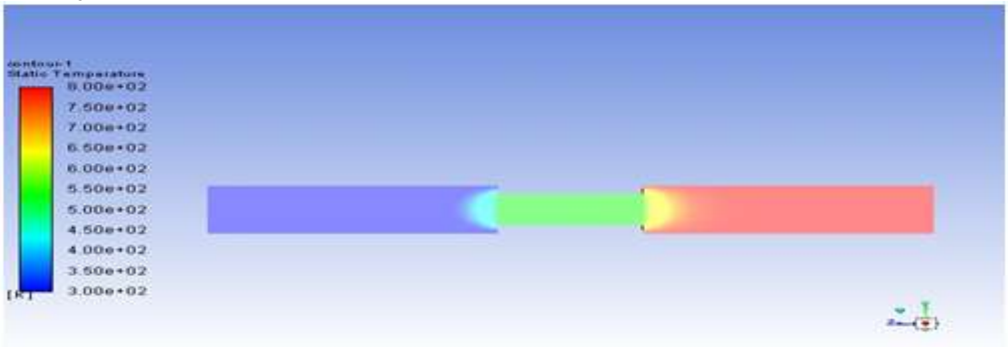

Fig. 09 Temperature Distribution for porosity of 0.9

Result Analysis

Current setup of Stirling engine with regenerator has been analysed for its performance through CFD analysis on ANSYS (Fluent) regarding temperature distribution. Three different materials namely Aluminium, Copper & Steel have been analysed having four different porosity values of 0.3, 0.5, 0.7 & 0.9. Data analysis is being presented here for reference-

- **Data Analysis for different materials at porosity of 0.3**

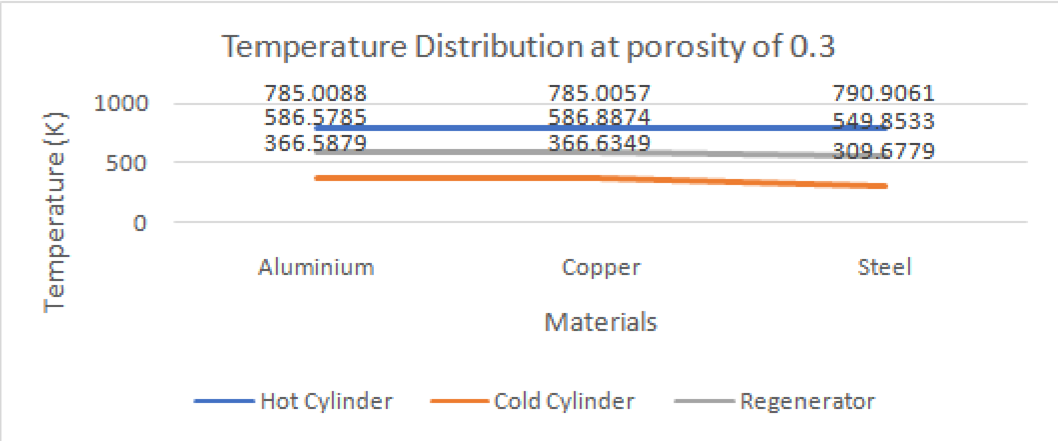

Fig. 10 Result analysis for different materials at porosity of 0.3

Above fig. shows the temperature distribution for all three materials at all the sections of Stirling engine with regenerator. Copper material is showing minimum temperature of hot cylinder among all three materials & Steel is showing maximum temperature of hot cylinder among all three materials. Steel material is showing minimum temperature of cold cylinder among all three materials & Copper is showing maximum temperature of cold cylinder among all three materials. Hence Copper material will have maximum convective heat transfer to the cold material & Steel material will have minimum convective heat transfer to the cold cylinder. Steel material is showing minimum temperature of regenerator among all three materials & Copper is showing maximum temperature of regenerator among all three materials. Now copper has maximum thermal conductivity out of these three materials and Steel has lowest thermal conductivity & hence it can be concluded that Thermal conductivity of the material is directly proportional to average heat which a regenerator can store.

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- **Data Analysis for different materials at porosity of 0.5**

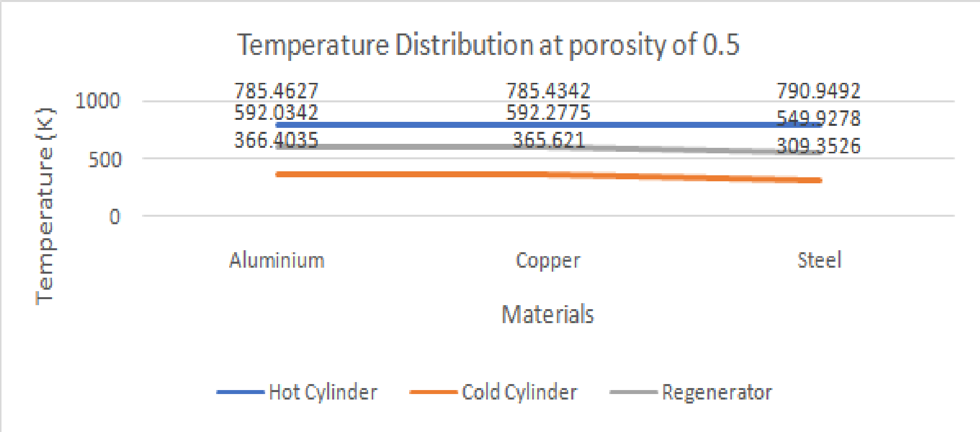

Fig.11 Result analysis for different materials at porosity of 0.5

Above fig. shows the temperature distribution for all three materials at all the sections of Stirling engine with regenerator. Copper material is showing minimum temperature of hot cylinder among all three materials & Steel is showing maximum temperature of hot cylinder among all three materials. Steel material is showing minimum temperature of cold cylinder among all three materials & Copper is showing maximum temperature of cold cylinder among all three materials. Hence Copper material will have maximum convective heat transfer to the cold material & Steel material will have minimum convective heat transfer to the cold cylinder. Steel material is showing minimum temperature of regenerator among all three materials & Copper is showing maximum temperature of regenerator among all three materials. Now copper has maximum thermal conductivity out of these three materials and Steel has lowest thermal conductivity & hence it can be concluded that Thermal conductivity of the material is directly proportional to average heat which a regenerator can store.

- **Data Analysis for different materials at porosity of 0.7**

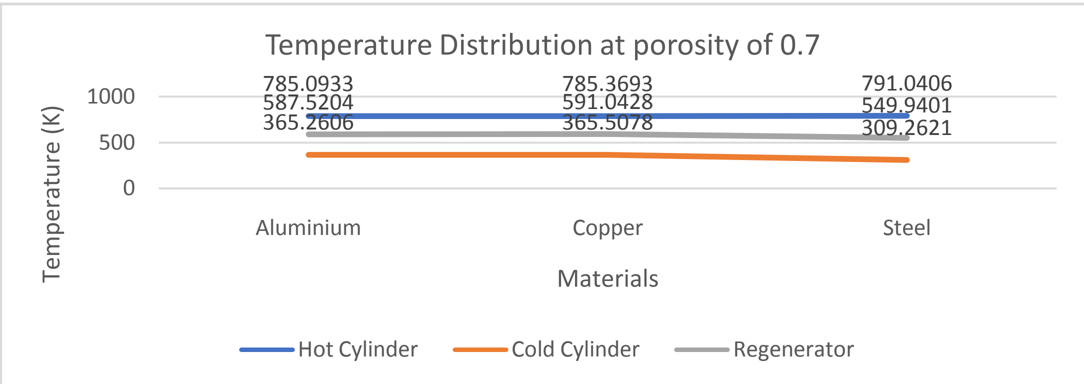

Fig.12 Result analysis for different materials at porosity of 0.7

Above fig. shows the temperature distribution for all three materials at all the sections of Stirling engine with regenerator. Aluminium material is showing minimum temperature of hot cylinder among all three materials & Steel is showing maximum temperature of hot cylinder among all three materials. Steel material is showing minimum temperature of cold cylinder among all three materials & Copper is showing maximum temperature of cold cylinder among all three materials. Hence Copper material will have maximum convective heat transfer to the cold material & Steel material will have minimum convective heat transfer to the cold cylinder. Steel material is showing minimum temperature of regenerator among all three materials & Copper is

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showing maximum temperature of regenerator among all three materials. Now copper has maximum thermal conductivity out of these three materials and Steel has lowest thermal conductivity & hence it can be concluded that Thermal conductivity of the material is directly proportional to average heat which a regenerator can store.

- **Data Analysis for different materials at porosity of 0.9**

Below fig. shows the temperature distribution for all three materials at all the sections of Stirling engine with regenerator. Copper material is showing minimum temperature of hot cylinder among all three materials & Steel is showing maximum temperature of hot cylinder among all three materials. Steel material is showing minimum temperature of cold cylinder among all three materials & Copper is showing maximum temperature of cold cylinder among all three materials. Hence Copper material will have maximum convective heat transfer to the cold material & Steel material will have minimum convective heat transfer to the cold cylinder. Aluminium material is showing minimum temperature of regenerator among all three materials & Copper is showing maximum temperature of regenerator among all three materials. Now copper has maximum thermal conductivity out of these three materials and Steel has lowest thermal conductivity & hence current result is deviating from the other results that Thermal conductivity of the material is directly proportional to average heat which a regenerator can store.

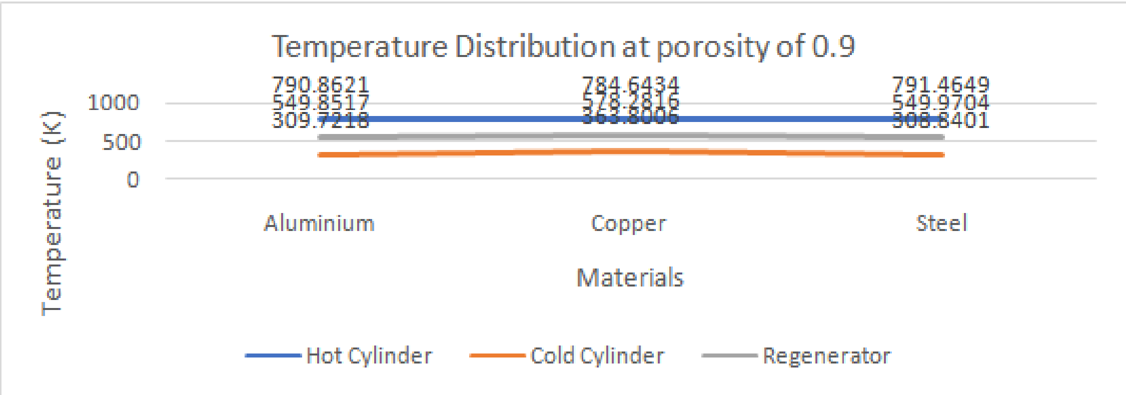

Fig.13 Result analysis for different materials at porosity of 0.9

II. CONCLUSIONS

Various conclusive remarks are presented here for reference-

- Porosity of the materials does affect the amount of heat which can be stored in the regenerator & hence same material having different amount of porosity will produce different amount of heat storage.
- Thermal Conductivity of the materials is directly proportional to the heat storage capacity of regenerator.
- In this research three material, aluminium, copper & steel were used. Thermal conductivity for Aluminium, Copper & Steel is 237 W/mK, 401 W/mK & 26 W/mK respectively & hence according to the point mentioned above heat storage capacity of copper regenerator will be highest & that for Steel regenerator will be minimum.
- Although all the results were following the same pattern but at porosity of 0.9, aluminium is representing minimum heat storage.

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