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How to Attain Regenerator Effectiveness Greater than 50% in Stirling Engines

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Extended Abstract

Stirling engines have the potential to alleviate some of the increasing global demand for clean energy due to their ability to use a wide range of heat sources and their high thermal efficiency. Much of their advantage stems from the use of a regenerator, which exchanges thermal energy with the working fluid after each isothermal expansion and compression stroke, thus minimizing the amount of thermal energy the heater and cooler must either add or reject, respectively, which augments Stirling engine efficiency. Accordingly, regenerator design and development has received much attention in past research, and has been a focal point in the process of enhancing Stirling engine performance and efficiency. Characteristics of an effective regenerator are a high thermal storage and heat transfer capacity, a limited resultant pressure drop, and a sufficient temperature gradient to ensure that the working fluid alternates between target temperatures, T_H and T_L. It was recently established that in order for a regenerator to attain an effectiveness greater than 50%, it must be divided into discrete components, also referred to as sub-regenerators [1]. We answer some of the interesting questions that arise in the design of regenerators, including: how does the regenerator thermal mass ratio and number of sub-regenerators influence the effectiveness of regenerators? How can one design a regenerator to attain 95% effectiveness or higher? Does stacking wire meshes reduce the regenerator to a single regenerator and limit its effectiveness to a maximum of 50%? A comprehensive investigation was undertaken to determine the influence of the regenerator thermal mass ratio and number of sub-regenerators on regenerator effectiveness and Stirling engine efficiency. The findings can be used to improve the design and performance of Stirling engine regenerators.

In this study, a discrete one-dimensional transient heat transfer model of a regenerator was developed to determine the thermal response of the regenerator and working fluid, simultaneously. A parametric analysis of the transient model revealed that only the regenerator thermal mass ratio influences the system settling temperature (regenerator and working fluid), and the remaining transient parameters proved to be inconsequential. Accordingly, a steady state heat transfer model was developed to quantify the system settling temperature, and expressions for regenerator effectiveness and Stirling engine efficiency were derived to incorporate the influence of the regenerator thermal mass ratio and number of sub-regenerators. The results of this study showed that increasing the regenerator thermal mass ratio and number of sub-regenerators increases regenerator effectiveness and Stirling engine efficiency, and it was revealed that a uniform sub-regenerator mass distribution provides maximum regenerator effectiveness. Additionally, an expression for the maximum effectiveness a regenerator can attain was derived, and the steady state heat transfer model was validated using experimental results, where it was determined that stacking sub-regenerators, such as wire meshes, provides sufficient thermal contact resistance to produce a temperature gradient. As a result of this study, Stirling engine designers can select a value of regenerator thermal mass ratio and number of sub-regenerators to attain 95% regenerator effectiveness or higher by using the derived expressions, and the influence of the regenerator thermal mass ratio and number of sub-regenerators on Stirling engine efficiency was quantified.

References

[1] D. Dai, F. Yuan, R. Long, Z. Liu and W. Liu, “Imperfect regeneration analysis of Stirling engine caused by temperature differences in regenerator,” *Energy Convers. Manag.*, vol. 158, pp. 60-69, 2018.