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Studies on Stirling Power Cycles- A Review

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Abstract

The Stirling power cycle consists of 2 isothermal processes (heat supply and heat removal processes) and two isochoric processes (compression and expansion processes). The past held an extensive amount of research towards improving the performance by varying different parameters and studying the effect on the respective output characteristics. Here a comprehension of all the past research has been discussed concisely to provide a review of the modifications and design considerations that are to be considered for improving the performance of cycle and its applications in various fields of engineering, i.e., Cryogenics, Solar power generation, etc., discussed in the past research. Besides this a summary is included that discusses the optimization and various applications of the Stirling power cycle

Keywords: *Stirling power cycle, Stirling, Stirling engine, NSGA, MATLAB*

1. INTRODUCTION

The Stirling cycle was developed by Robert Stirling and therefore named after him. Like petrol and diesel ideal cycles, the Stirling cycle also has two constant temperature heat supply and heat refusal processes, but the difference among them is that these cycles aren't reversible totally due to this irreversibility; these cycles have a comparatively lower efficiency when compared to the Carnot efficiency. While the Stirling cycle has completely reversible heat transfer processes. And vowing to the total reversibility of the processes, the reverse Stirling cycle has been made possible. The reversibility of the cycle implies that when supplied with mechanical work or power, the Stirling cycle can produce different effects at the heat and the sink, i.e., cooling and heating, thereby showing the potential for applications such as heat pumps for heating and cooling, including the potential use in cryogenics (ex: cryogenic cooler).The Stirling cycle is also referred to as a closed regenerative cycle as the working fluid which is a gaseous substance that is never allowed to leave the system, and it is an external heat engine; the name regenerative comes from the fact that an internal heat exchanger is used for the increase in the efficiency of the cycle.

The possibility of rising in the efficiency and the versatility of the cycle owing to its reversible processes when compared to the ideal Otto and Diesel cycles gives the Stirling cycle the edge in the ease of application in the field of cryogenics, power generation, and refrigeration, etc.

2. EARLIER STUDIES ON THE STIRLING POWER CYCLE

Wang et al. [1] studied the application of the Stirling cycle in low and medium-temperature heat recovery. Upon reviewing the technological details, they observed that the kinetic engine operating at medium temperatures is useful for solar thermal heaters of low concentration. While the thermo acoustic engines are more suited for recovery of low-grade heat and the LPS is more suited for the supply of water for fields in rural areas for agriculture as its power density and efficiency are lower compared to others and limited,

Guvenetal. [2] discussed the application to the cycle of Stirling in WHR for a heavy-duty truck. They used new dimensionless methods for optimizing the output of the 3 different types of engines chosen. i.e., β, α, and γ engines whose maximum shaft work (theoretical and dimensionless) is calculated and noticed that β is a better option which yields about 1% of the waste heat recovery, making it a reasonable option.

Katooliet al. [3] analysed the scope of using a Stirling engine to generate a cooling effect due to its reversibility. In this study, they performed experiments on three different types of engines operating on the Stirling cycle and noticed the average experimental COP neglecting the belt loss when evaluated using MATLAB to be about 0.25, and this mechanical work can be supplied by using it in conjunction with cheaper and greener alternatives of energy, i.e., solar power, hydropower, wind power, etc.

Chenget al. [4] studied the optimizing configuration of the engine to improve its power output and efficiency. Here the alpha type 4-cylinder DASE is used, and with the help of a theoretical study, they predicted the maximum performance in terms of power at the output at 12Nm torque and heating temperature of 1200K.Ahmadi et al. [5] analysed the optimization of the power cycle using a finite speed thermodynamic analysis, which accounts for the external irreversibility and makes use of the non-domination-based genetic algorithm (NSGA) to minimize the pressure losses.

Takeuchiet al. [6] focused on the optimization of the Stirling engine by overcoming its overheating of the heat transfer surfaces problem by using a heat transfer medium to facilitate low-temperature difference indirect heat transfer in a kinematic Stirling engine.Walker [7] conducted one of the earlier studies on optimizing the design parameters of a Stirling cycle for the maximum output when it acts as a prime mover and for the maximum heat removed from a system when it acts as a refrigerator using Schmidt equations.Ferreiraetal.[8] assessed the output characteristics of the engine with various renewable energy sources like biomass and solar energy. This study, upon experimentation, concluded that a Biomass fuelled engine is better as it overcomes the issues of solar energy intermittency.

Gomezet al. [9]investigated the application of the Stirling engine in electrical power generation when it is coupled with an electrospray dispersion system and a catalytic combustor. This system is found to give a gross fuel electric efficiency of 21%, which is significantly better than the commercial generators.Getieet al. [10] discussed the application of the Stirling engine instead of the VCR to reduce the use of harmful CFCs and greenhouse gases that lead to global warming. They reviewed the use of regenerative Stirling reverse cycle-based refrigerators in moderate, low-temperature applications.

Dai etal. [11] proposed a better practical engine powered by the Stirling cycle which consists of irreversible processes in heat transfer(non-isothermal), expansion, and compression (isochoric). By making use of irreversible processes, a more practical engine is developed and is optimized by using the MOPSOCD technique that helps the highest possible power for utilization more efficiently.Gadelkareemet al. [12] focused on the application of the Stirling cycle for designing a temperature regulated water storage and dispensing unit. The energy that is being rejected as part of the process in the cycle can be reused to generate a cooling effect. The cooling and heating of the water are based on the reverse Stirling cycle, thereby providing a cheaper and greener alternative.

Davey et al. [13] analysed on the use of the Stirling cycle for the development of a Miniature Stirling cycle cooler. The use of this cooling mechanism has the advantage of no wear, zero frictional losses, and the money saved in the absence of the need for lubrication and external sealing. This finds an application in the cooling of electronic equipment at a low cost. Ahadiet al. [14] focussed on the influence of the coating on thermal efficiency and the decrease in heat loss in the engine working on Stirling, modelled by more realistic and perfectly insulated operating conditions. This study observed the increment of thermal efficiency and drop in the heat loss with varying thickness and varying materials of the coating.

Qiuet al. [15] studied the scope of integrating the Stirling engine into the CHP (Combined Heat and Power) systems. But to do this, the FPSE (Free Piston Stirling Engine) is modified to decrease the separation of flow and losses in thermal energy, this is manufactured by additive manufacturing, and upon experimentation is found to have high chemical energy to electrical energy conversion efficiency.

3. CONCLUSION

This literature review done using above mentioned papers in this study helps us draw the following conclusions.

- The Stirling cycle, due to its totally reversible processes, can be used for both energy production and refrigeration.
- The Stirling cycle, due to its ability to act as a reversed cycle, finds its use in WHR.
- The Stirling cycle, due to its higher efficiency and power generation capability, can be used instead of conventional energy generators.
- The Stirling cycle can be used as an alternative to traditional refrigeration systems as it avoids the need for harmful CFCs.
- The Stirling cycle, like any other cycle, makes use of various computational techniques like NSGA and MOPSOCD for better optimization of design parameters to achieve better work output and thermal efficiencies.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1] Wang, K., Sanders, S. R., Dubey, S., Choo, F. H., & Duan, F. (2016). Stirling cycle engines for recovering low and moderate temperature heat: A review. *Renewable and Sustainable Energy Reviews*, *62*, 89-108.

[2] Güven, M., Bedir, H., & Anlaş, G. (2019). Optimization and application of Stirling engine for waste heat recovery from a heavy-duty truck engine. *Energy Conversion and Management*, *180*, 411-424.

[3] Katooli, M. H., Moghadam, R. A., & Hajinezhad, A. (2019). Simulation and experimental evaluation of Stirling refrigerator for converting electrical/mechanical energy to cold energy. *Energy conversion and management*, *184*, 83-90.

[4] Cheng, C. H., Yang, H. S., & Tan, Y. H. (2022). Theoretical model of a α-type four-cylinder double-acting stirling engine based on energy method. *Energy*, *238*, 121730.

[5] Ahmadi, M. H., Hosseinzade, H., Sayyaadi, H., Mohammadi, A. H., & Kimiaghalam, F. (2013). Application of the multi-objective optimization method for designing a powered Stirling heat engine: design with maximized power, thermal efficiency and minimized pressure loss. *Renewable Energy*, *60*, 313-322.

[6] Takeuchi, M., Suzuki, S., & Abe, Y. (2021). Development of a low-temperature-difference indirect-heating kinematic Stirling engine. *Energy*, *229*, 120577.

[7] Walker, G. (1962). An optimization of the principal design parameters of Stirling cycle machines. *Journal of Mechanical Engineering Science*, *4*(3), 226-240.

[8] Ferreira, A. C., Silva, J., Teixeira, S., Teixeira, J. C., & Nebra, S. A. (2020). Assessment of the Stirling engine performance comparing two renewable energy sources: Solar energy and biomass. *Renewable Energy*, *154*, 581-597.

[9] Gomez, A., Berry, J. J., Roychoudhury, S., Coriton, B., & Huth, J. (2007). From jet fuel to electric power using a mesoscale, efficient Stirling cycle. *Proceedings of the Combustion Institute*, *31*(2), 3251-3259.

[10] Getie, M. Z., Lanzetta, F., Bégot, S., Admassu, B. T., & Hassen, A. A. (2020). Reversed regenerative Stirling cycle machine for refrigeration application: A review. *International Journal of Refrigeration*, *118*, 173-187.

[11] Dai, D., Liu, Z., Long, R., Yuan, F., & Liu, W. (2019). An irreversible Stirling cycle with temperature difference both in non-isothermal and isochoric processes. *Energy*, *186*, 115875.

[12] Gadelkareem, T. M., EldeinHussin, A. M. T. A., Hennes, G. M., & El-Ehwany, A. A. (2019). Stirling cycle for hot and cold drinking water dispenser. *International Journal of Refrigeration*, *99*, 126-137.

[13] Gavey, D., Werret, S., Peskett., Bradshaw., T.W., & Delderfield, J. (1986). Miniature Stirling cycle. Adv Cryog Eng Plenum Press, NewYork, USA. 151-249.

[14] Ahadi, F., Azadi, M., Biglari, M., & Madani, S. N. (2021). Study of coating effects on the performance of Stirling engine by non-ideal adiabatic thermodynamics modeling. *Energy Reports*, *7*, 3688-3702.

[15] Qiu, S., Gao, Y., Rinker, G., & Yanaga, K. (2019). Development of an advanced free-piston Stirling engine for micro combined heating and power application. *Applied energy*, *235*, 987-1000.