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Energy Conversion from Internal Combustion Engines Exhaust Gases using the Inverted Brayton Cycle

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ABSTRACT

In this study, we demonstrate the capability of the IBC (Inverted Brayton Cycle) to convert the energy from exhaust gases of an internal combustion engine into mechanical energy. For this purpose, we analyzed two energy systems. The first system is the IBC installed in series with a gas turbine, combining the Joule-Brayton cycle with the inverted Brayton cycle (JBC-IBC). The second system is the IBC installed in series with a diesel engine, combining the Diesel cycle with the inverted Brayton cycle (DC-IBC).

Keywords: gas turbine, Diesel engine, energy conversion, inverted Brayton cycle, exhaust gases.

1. Introduction

The exhaust gases from internal combustion engines, such as diesel engines and gas turbines, contain a significant amount of heat generated during combustion. Recovering this heat allows for its utilization in useful applications such as heating processes, electricity generation, etc. This recovery can ensure a significant improvement in overall engine efficiency and a reduction in fuel consumption. The conversion of energy from exhaust gases requires the development and use of advanced technologies, which stimulates research and development of new technological solutions to make internal combustion engines more efficient and less polluting. A new opportunity can be represented by the direct exploitation of exhaust gases through an inverted Brayton cycle (IBC), in which the gases expand at a lower pressure than the environment, are cooled, and then recompressed to environmental pressure. The inverted Brayton cycle is considered as a promising technology for the conversion of energy from exhaust gases [1-3].

In the initial stage of our work, we presented validation cases of the simulation tool used for modeling the performance of the different systems. In the second stage, an energy analysis was conducted. The results of this analysis showed that, under the chosen baseline conditions, the IBC installed in series with either a gas turbine or a diesel engine presents a potential solution for harnessing the exhaust gases of internal combustion engines, resulting in improved performance of both energy systems, such as power and efficiency. The third stage of our work involved performing a sensitivity analysis to estimate the influence of each major component on the overall system and identify necessary optimizations. The main factors analyzed included the turbine expansion ratio, ambient temperature, turbine inlet temperature, exhaust gas flow rate, and heat exchanger efficiency. The simulation results demonstrated the effect of each parameter on the system's performance, highlighting the need for optimizing the IBC system based on design conditions.

Exhaust gases from internal combustion engines contain various atmospheric pollutants, as well as carbon dioxide (CO_2) and other greenhouse gases responsible for climate change. In the final part of our work, an environmental analysis was conducted, which showed that the energy conversion of these exhaust gases holds significance in terms of reducing pollutant emissions and greenhouse gases. This study thus contributes to highlighting the potential of the IBC, which offers interesting prospects for improving the performance of internal combustion engines in the current context of increasing environmental concerns and the transition towards cleaner energy sources.

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2. Results and Discussion

Figure 1 shows the evolutions of thermal efficiency and net wort according de pressure ratio compared to those found in litterature. The discrepancy in the results did not exceed 2%.

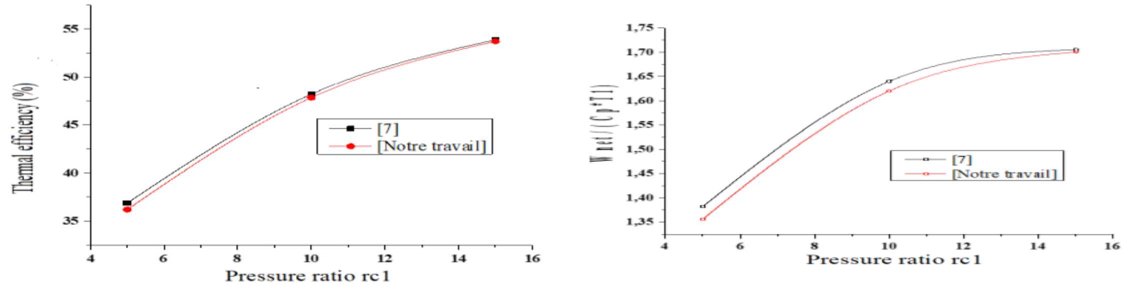

Figure 1. Thermal efficiency and ne work comparison according to the topping cycle pressure rate

Figure 2 indicated that power gains and thermal efficiency improvements can reach up to 22% and 7%, respectively, in the case of the gas turbine, and 4% in the case of the diesel engine.

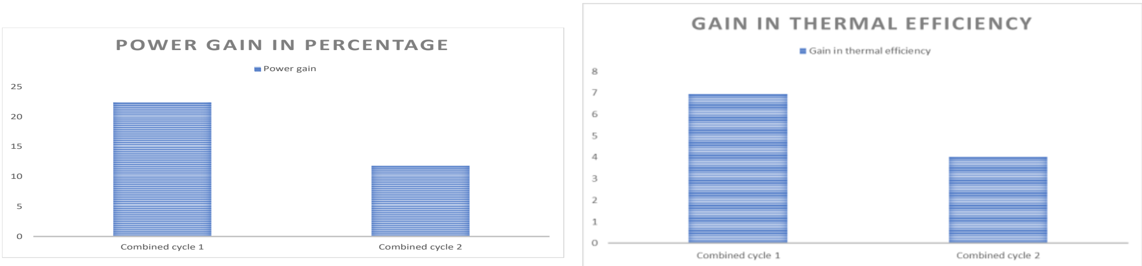

Figure 2. Comparison of the power and thermal efficiency of the three cycles

Figure 3 indicates an increase in power and thermal efficiency with the increase in the compression ratio rc2 up to a maximum value reached for an optimal compression ratio rc2 of approximately 3. Beyond this optimum, a reduction in power net thermal efficiency and energy efficiency is observed

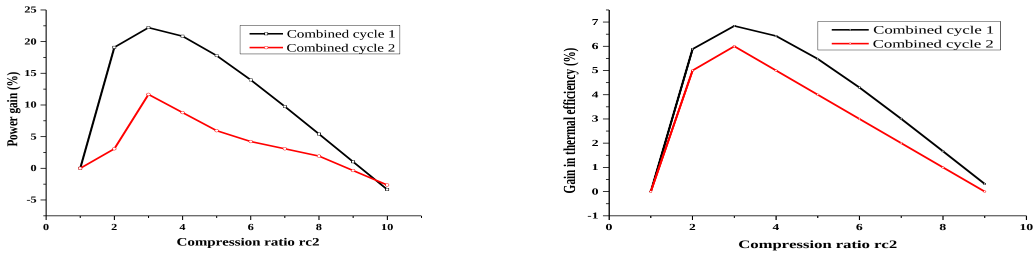

Figure 3. Power and thermal efficiency gains obtained with the combined cycles as a function of pressure ratio

3. Conclusions

This study thus contributes to highlighting the potential of the IBC, which offers interesting prospects for improving the performance of internal combustion engines in the current context of increasing environmental concerns and the transition towards cleaner energy sources.

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