



ENERGY AND EXERGY IN A BRAYTON CYCLE-BASED POWER CONVERSION UNIT

The efficient operation of industrial plants has been the subject of many studies, due to an increased awareness of greenhouse gas emissions and dwindling natural resources. Condition monitoring is key to the efficient operation of a plant. Part of condition monitoring is fault detection and isolation (FDI). Various methods have been developed and implemented for the purpose of FDI in industrial plants. These methods are mostly based on process monitoring, requiring large amounts of data.

NUCLEAR & SMR

CHALLENGE:

With the predicted increase in nuclear and renewable (specifically solar) energy sources for electricity generation, the performance and efficiency of these systems are of concern. Recent advances in materials and technology, along with the high temperatures associated with nuclear and solar energy, make the Brayton cycle well-suited for these systems. Compared to other thermodynamic cycles, the Brayton cycle is ideal in terms of efficiency under the operating conditions associated with nuclear and renewable energy sources. In this case study, the energy and exergy values were determined at various points in a Brayton cycle-based power conversion unit (PCU) under steady-state conditions, for the purpose of fault detection and isolation.

BENEFITS:

With an expected increase in Brayton cycle-based power conversion units (PCU) and an energy efficiency mindset, the ability to monitor the condition and performance of such a system during operation is crucial. The benefits of using Flownex for this case study are:

- Ease of simulating a multi-domain system.
- Ability to calculate energy and exergy during simulation.
- Ease of introducing fault condition.
- Logging of parameters and exporting to 3rd party software.

SOLUTION:

A Brayton cycle PCU was simulated in Flownex, under steady-state conditions. During the simulation, relevant parameters were logged and used to calculate the energy and exergy in the cycle at various points. For the purpose of fault detection and isolation, the cycle was simulated under different fault conditions by means of changed component settings.



INTRODUCTION

The Brayton cycle PCU considered in this study is shown in Figure 1.

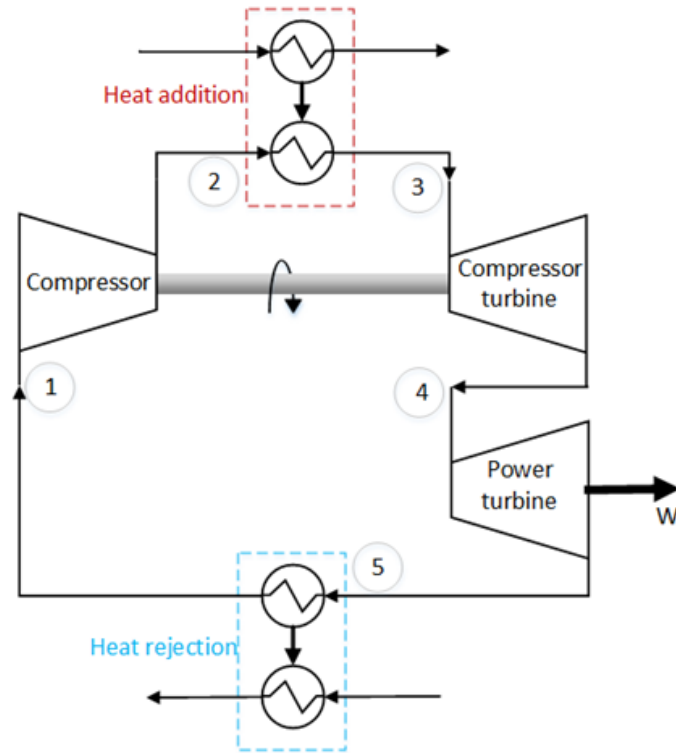


Figure 1: Brayton cycle-based PCU

The PCU consists of a compressor-turbine pair, heat addition and rejection elements and a power turbine. In this case, the working fluid (WF) is air, simulated as a single-phase gas. The WF enters the compressor at 1 at a specified temperature and pressure. The high pressure WF enters the heat addition element at 2. The high pressure and high temperature WF enters the compressor-turbine (CT) at 3, expanding as it drives the turbine, which in turn drives the compressor. The WF enters the power turbine (PT) at 4, where it further expands driving the power turbine, producing a net work output (W). The low pressure and low temperature WF enters the heat rejection element at 5, where the temperature is reduced to the required level, before entering the compressor again, repeating the cycle.

METHODOLOGY

The objective of this simulation is to determine the energy and exergy characteristics of the cycle under steady-state conditions. The energy and exergy are determined under normal conditions and fault conditions. The energy and exergy values are exported to 3rd party software for further processing.

The Flownex model of the PCU is illustrated in Figure 2. In the simulation, the heat addition and rejection elements are simulated as heat exchangers. The output of the PT is controlled at a specified setpoint through a PID controller, controlling the pressure of the working fluid at the inlet to the compressor. The temperature of the working fluid at the compressor inlet and CT inlet is controlled through the respective heat exchangers at 25°C and 900°C.

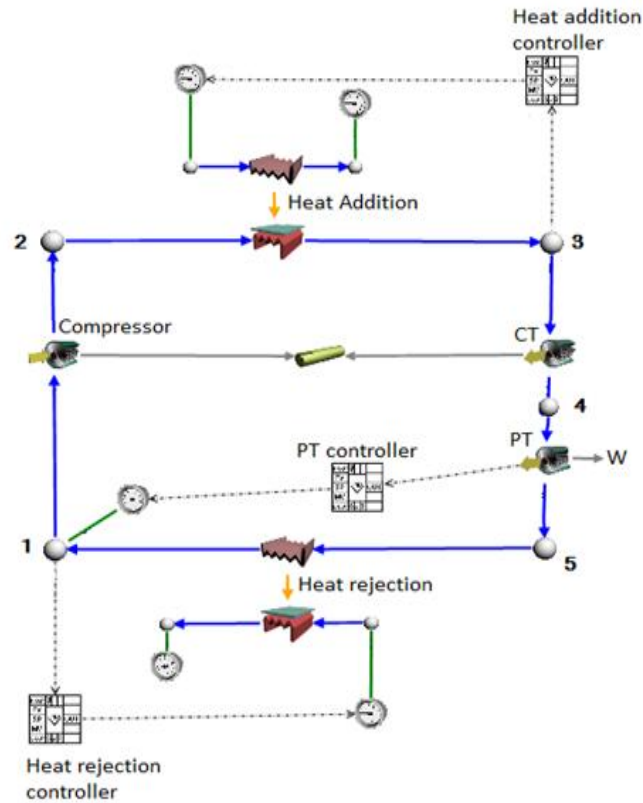


Figure 2: Flownex model of a Brayton cycle-based PCU

The Flownex model is a simplified version of a more complex model that was validated against PBMR data (van Niekerk et al., 2003).

RESULTS

Various faults and fault magnitudes were simulated. With a 10% reduction in the compressor pressure ratio, the energy and exergy characteristics were determined. The energy at each node for normal and fault conditions are shown in Table 1 and the exergy change across each component is shown in Table 2.

Table 1: Energy change across components, under normal and fault conditions

Component	Δ Energy flow (kJ/s)	
	Normal	Fault
Compressor	227.58	235.65
Heat addition	1079.23	1079.23
Turbine	-232.22	-240.46
Power turbine	-100	-100
Heat rejection	-974.58	-1029.18

Table 2: Exergy change across components, under normal and fault conditions

Component	Δ Exergy flow (kJ/s)	
	Normal	Fault
Compressor	183.11	187.48
Heat addition	661.43	694.212
Turbine	-261.12	-271.38

Component	Δ Exergy flow (kJ/s)	
	Normal	Fault
Power turbine	-111.76	-110.58
Heat rejection	-471.65	-499.73

CONCLUSION

Flownex was successfully used to simulate a Brayton cycle-based PCU. The error-based method proposed by Du Rand (2007) was also applied to this cycle, and the results were presented. Similar outcomes were obtained using the enthalpy and entropy error-based method as were observed with the energy and exergy residual-based method. The exergy ratios for each fault condition were shown, illustrating how different faults at varying magnitudes affected the performance of each component. Detecting and isolating faults using energy and exergy, as well as employing exergy as a performance measure for each cycle component, will provide significant value for condition monitoring and maintenance planning.

References:

- W.M.K. van Niekerk, P.G. Rousseau, and G.P. Greyvenstein. Operation and simulation of a three-shaft, closed-loop, Brayton cycle model of the PBMR power plant. In Proceedings of International Congress on Advances in Nuclear Power Plants, 2003.
- C.P. du Rand. Health monitoring of a Brayton cycle-based power conversion unit. PhD thesis, Computer and Electronic Engineering. North West University, 2007.