Supercritical CO_2 Power Cycles Symposium

THERMODYNAMIC ANALYSIS AND MULTI-OBJECTIVE OPTIMIZATIONS OF A COMBINED RECOMPRESSION SCO2 BRAYTON CYCLE–TCO2 RANKINE CYCLES FOR WASTE HEAT RECOVERY

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ABSTRACT

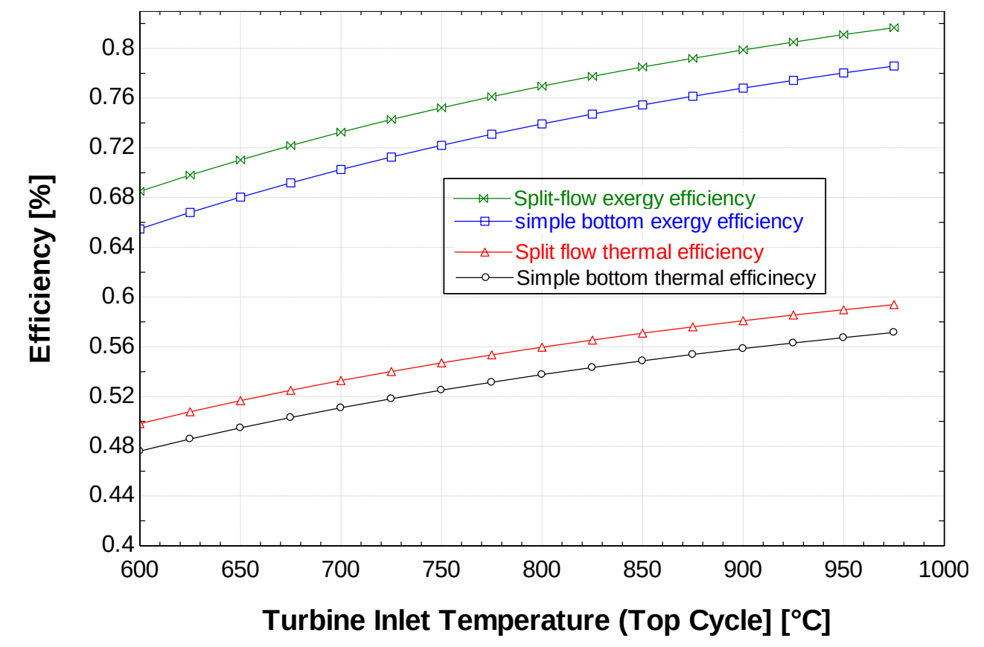
A thermodynamic analysis and optimization of a newly-conceived combined power cycle were conducted in this study for the purpose of improving overall thermal efficiency of power cycles by attempting to minimize thermodynamic irreversibilities and waste heat as a consequence of the Second Law. The power cycle concept comprises a topping advanced recompression sCO2 Brayton cycle and a bottoming tCO2 Rankine cycle. The bottoming cycle configurations included a simple tCO2 Rankine cycle and a split flow tCO2 Rankine cycle. The topping supercritical CO2 recompression Brayton cycle used a combustion chamber as a heat source, and waste heat from a topping cycle was recovered by the tCO2 Rankine cycle due to an added high efficiency recuperator for generating electricity. The combined cycle configurations were thermodynamically modeled and optimized using an Engineering Equation Solver (EES) software. Simple bottoming tCO2 Rankine cycle cannot fully recover the waste heat due to the high exhaust temperature from the top cycle, and therefore an advance split flow tCO2 Rankine cycle was employed in order to recover most of the waste heat. Results show that the highest thermal efficiency was obtained with recompression sCO2 Brayton cycle – split tCO2 Brayton cycle. Also, the results show that the combined CO2 cycles is a promising technology compared to conventional cycles.

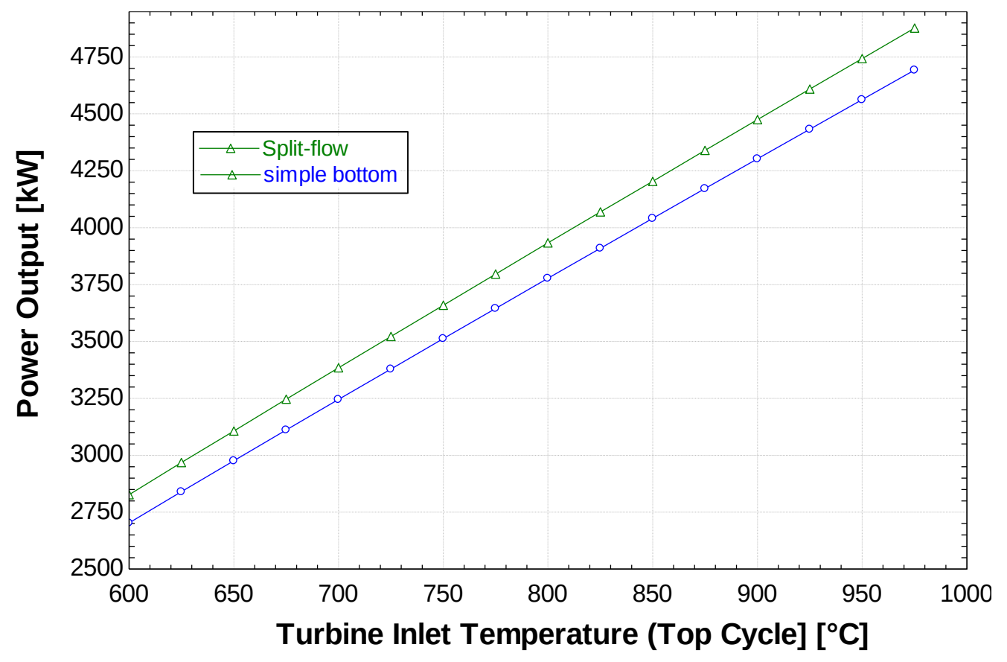
INTRODUCTION

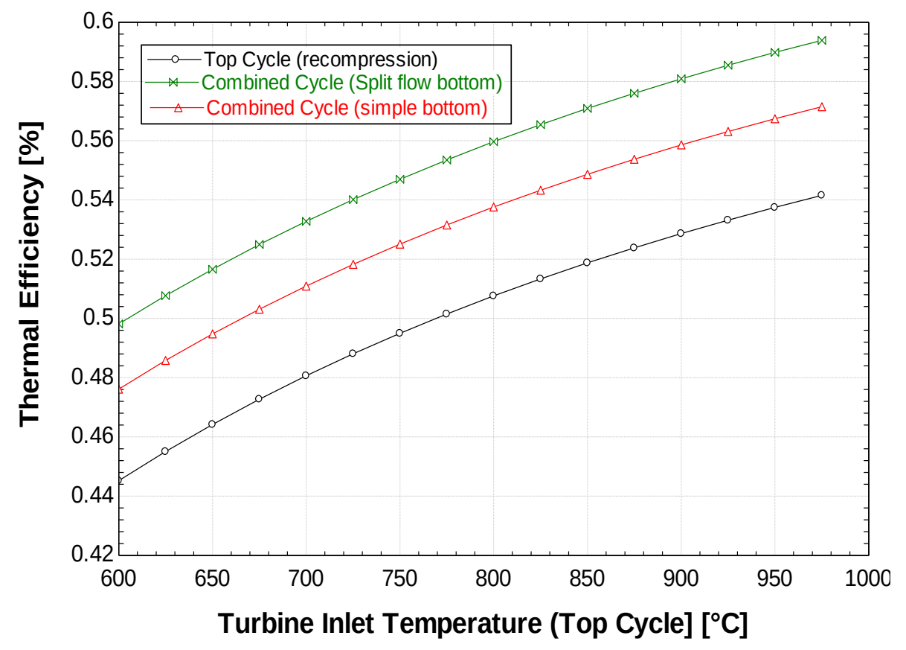
The unprecedented growth in the world population and economic activity, along with rising concerns about environmental issues, mean that energy efficiency will play a vital role in the development of future energy systems. Conventional power plants centered on a single prime mover are highly inefficient (<39%), losing most of their energy as waste heat [1]. Motived by limited energy resources, the accelerating growth of energy demand, cost, and growing environmental concerns, there has been a focus on improving such poor energy production efficiency

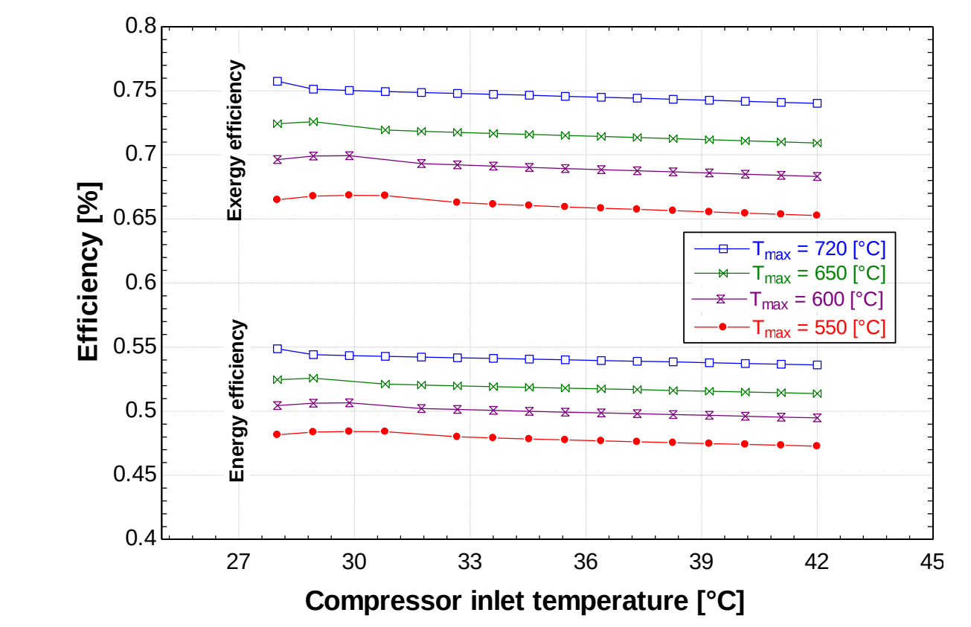
	Wang [3]		Akbari [6]	Yari [4]	Wang [7]	Besarati [8]	Pichel [9]
Top cycle	sCO2	sCO2	sCO2	sCO2	sCO2	sCO2	sCO2
Bottom cycle	tCO2	ORC Isopentane	ORC Isopentane	ORC Isopentane	tCO2	ORC (R245ca)	ORC (R134a)
Main compressor inlet temperature [C]	32		35	35	32	55	30
Main compressor inlet pressure [MPa]	7.4		7.4	7.4	8	-	7.4
Maximum pressure [MPa]	20.72		22.2	24.3386	20	25	25
Turbine inlet temperature [C]	550		550	650	550	800	500
HTR effectiveness [-]	86%		86%	86%	95%	95%	95%
LTR effectiveness [-]	86%		86%	86%	95%	95%	95%
Turbine efficiency [-]	90%/70%		90%/87%	90%/80%	90%/85%	90%/87%	93%/85%
Compressor/Pump efficiency	85%/80%		85%/80%	85%/80%	89%/85%	89%/85%	89%/80%
Pressure drop [-]	negligible		negligible	negligible	negligible	negligible	50 kPA/HX
Combined Cycle efficiency	0.449	0.4523	0.4422	0.49	0.4672	0.5433	0.435

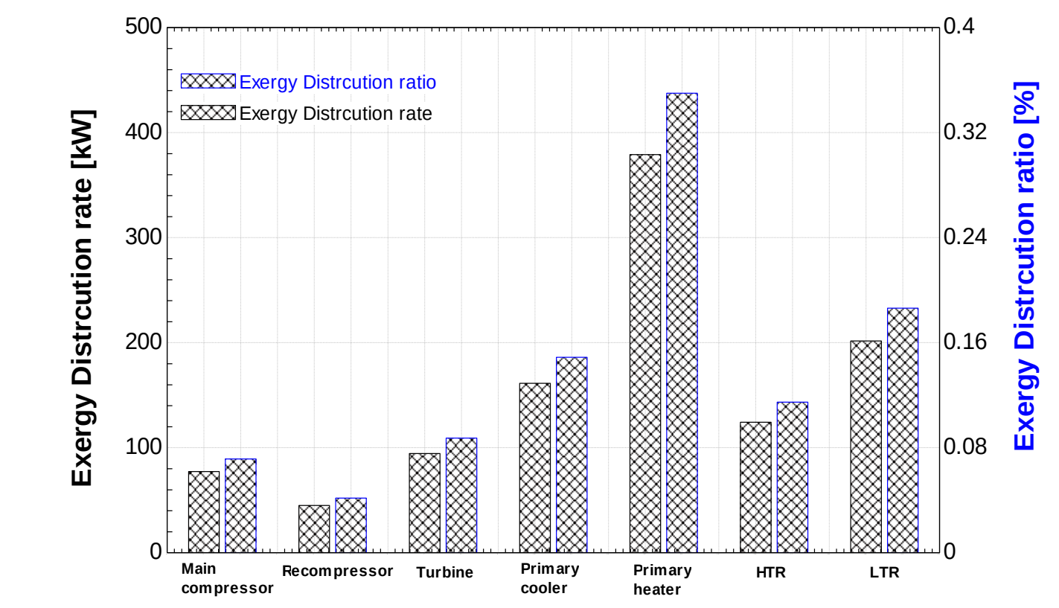
OUTCOMES

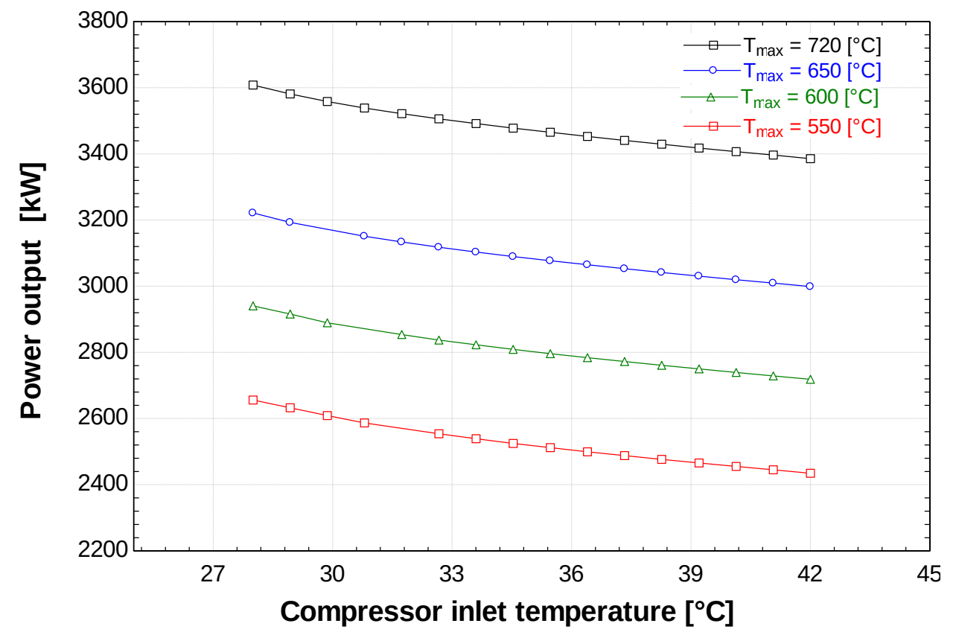












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SYSTEM ANALYSIS

Two configurations are considered in this study are: a topping recompression sCO2 Brayton cycle and a bottoming cycle configurations included a simple tCO2 simple Rankine cycle and a split flow tCO2 Rankine cycle.

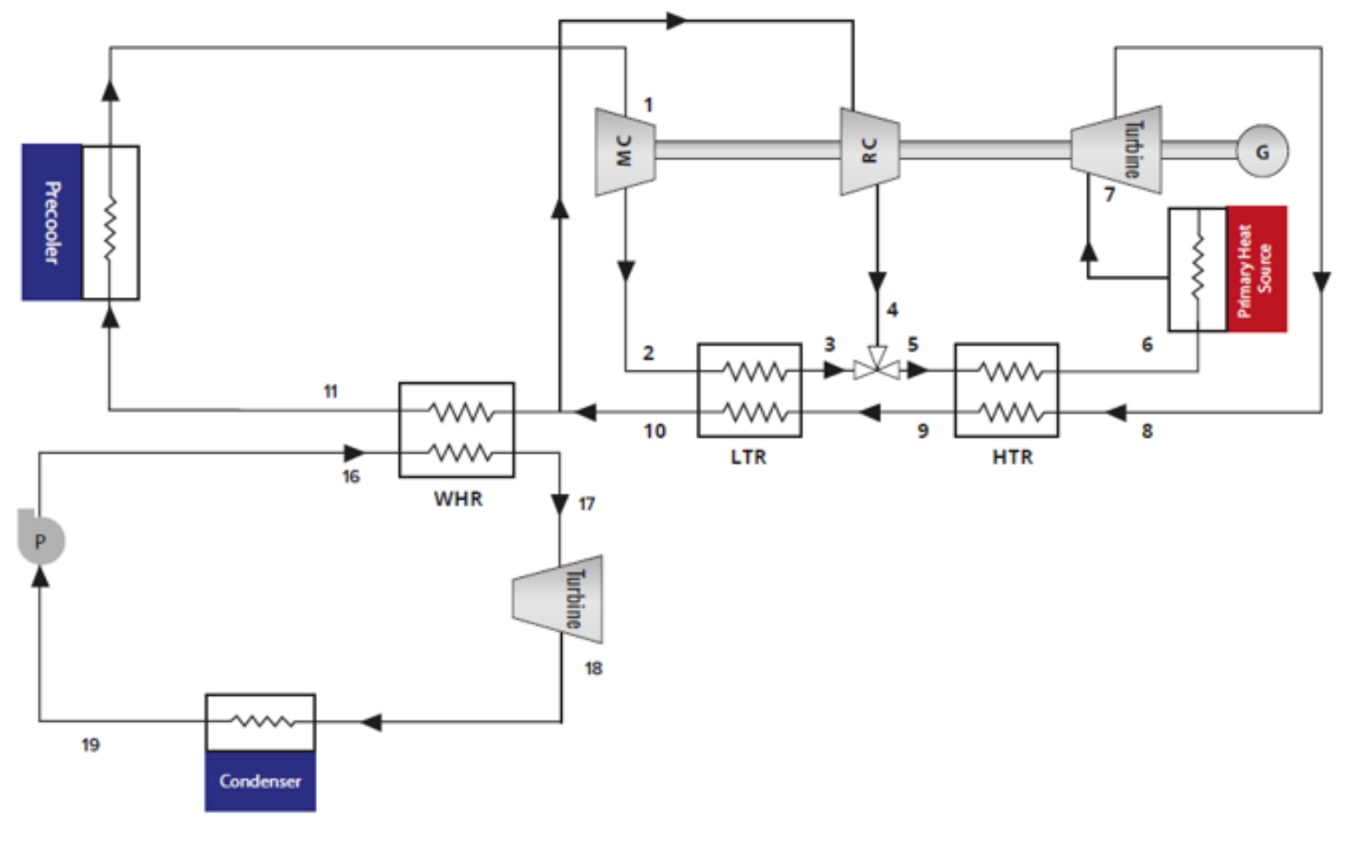


Figure 1 Recompression CO2 Brayton cycle with simple bottom Rankine cycle

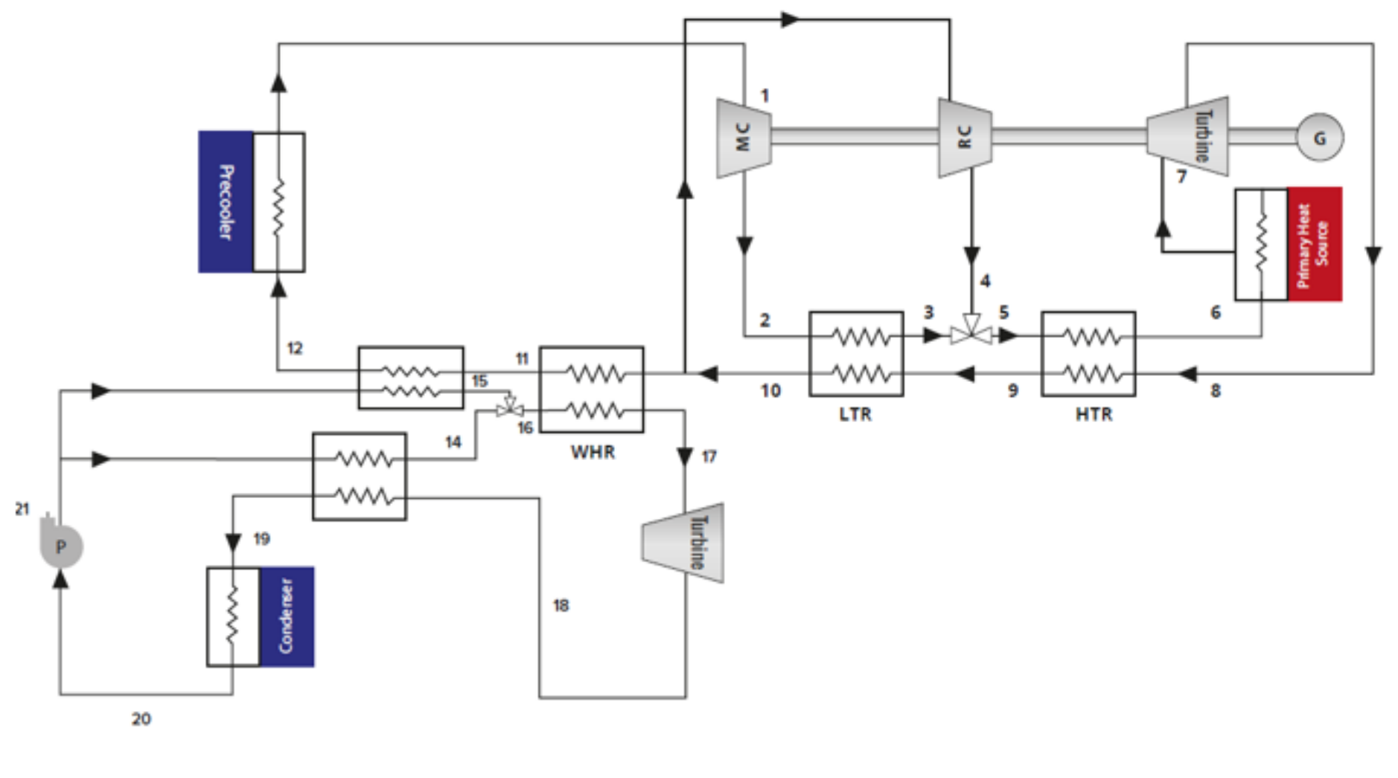
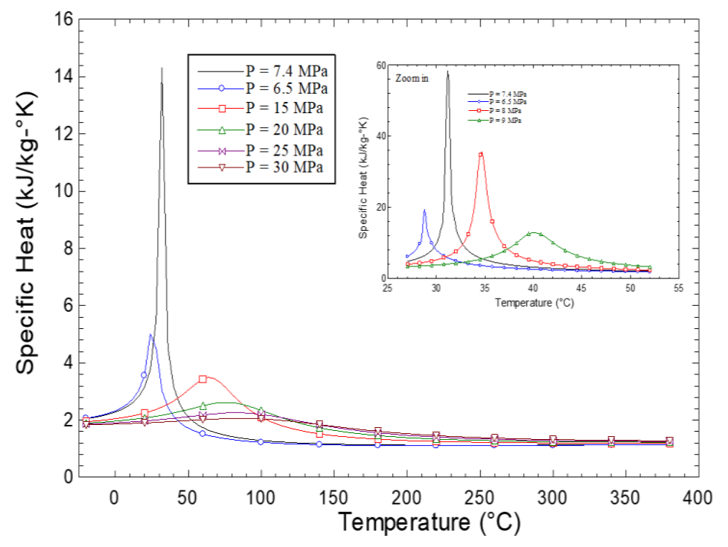


Figure 2 Recompression CO2 Brayton cycle with split flow bottom Rankine cycle

During the turbomachinery modeling, some basic assumptions are considered: (i) The cycle is assumed to function in a steady state of operations (ii) the turbine expansion, the compressors and the pump are considered adiabatic with a given isentropic efficiencies (iii) Kinetic and potential energy effects are negligible (iv) each component of the cycle is sufficiently insulated.



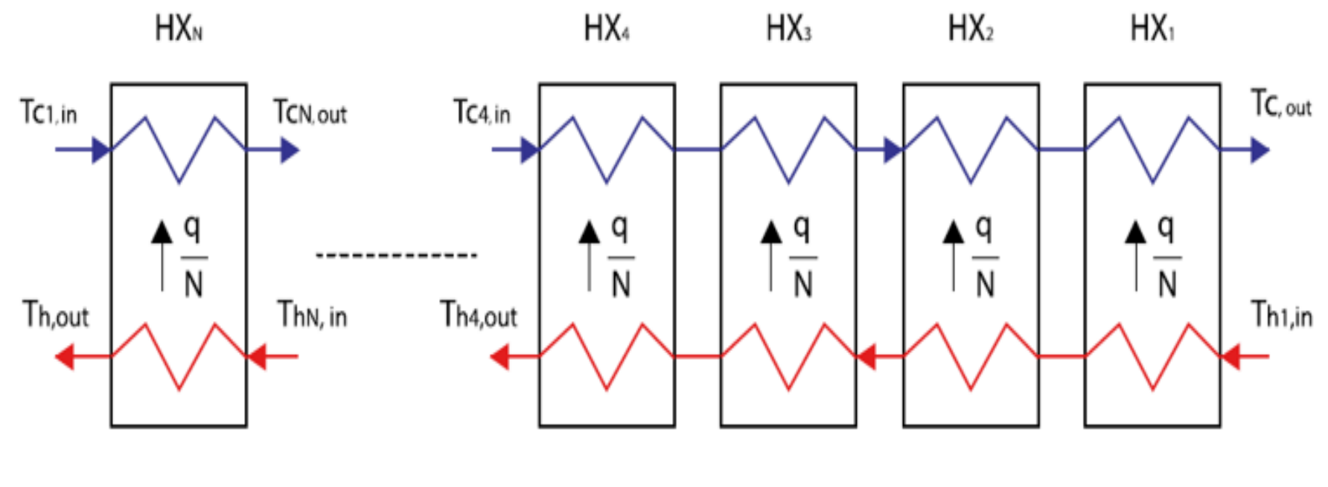


Figure 3. HX nodes

The conventional techniques to analysis heat exchangers (log-mean temperature difference and effectiveness-NTU) are made based on assumptions setting to govern the equations such as constant specific heat capacity. These techniques are not valid for recuperators operating under inconstant capacitances such as CO2 near critical point. To overcome this phenomenon, by either developing a numerical complex model or dividing the heat exchanger into numerous small sub heat exchangers (Nodalization).

CONCLUSION

The energy and exergy analysis of the two advanced combined cycles were conducted in this chapter. The internal irreversibilities (exergy destruction) and external irreversibilities (exergy losses) for each component were investigated in order to provide appropriate guiding improvements. The top sCO2 recompression Brayton cycle's waste heat is utilized by a bottom sCO2 Rankine cycle for the purpose of improving both efficiency and power output. The two cycles comparison is based on the parametric analysis of the maximum cycle operating temperature. The result demonstrate that the new-conceived cycle, sCO2 recompression Brayton coupled with a tCO2 split-flow Rankine cycle, surpasses the simple combined cycle, sCO2 recompression Brayton coupled with a tCO2 simple Rankine cycle, in respect to energy and exergy efficiencies and power output.

Based on the exergy analysis, primary heater has the highest thermodynamic losses, follow by the low temperature recuperator (LTR). On the other hand, the turbine and compressors have the lowest thermodynamic losses. The high potential improvements of the cycle should be focused on the heat exchangers and especially primary heater and low temperature recuperator. Cost analysis are important and it is going to be the future work.

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