Evaluation of power and freshwater production based on integrated SCO2 combined Brayton cycle-organic Rankine cycle- RO desalination

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Abstract

In order to improvement of the efficiency of the gas turbine and heat recovery of waste heat, a novel power and fresh water production system is proposed. This system is included combined supercritical CO2 regenerative Brayton cycle based on gas turbine, an organic Rankine cycle and Reverse Osmose (RO) desalination system. In this regard, thermodynamic modelling and simulation are performed for integrated cycle. In addition, exergetic and exergoeconomic analysis are reported for the proposed system parametric studies have been performed to evaluate the effect of system parameters on the exergy destruction and the unit cost of power and fresh water.

Furthermore, the computer code has been developed for thermodynamic, exergetic and exergoeconomic analysis and comparison of integrated system. The results shows the

proposed combined regenerative S-CO2 cycle, ORC and RO desalination system is promising improvement for gas turbine waste heat recovery, and it has advantages of deep recovery of waste heat, high exergetic efficiency and low power and freshwater costs.

Exergy analysis

This paper focuses on a part of thermodynamics that is common between energy, exergy and entropy, and specifically emphasizes the division of these three domains. Also, some forms of energy (such as work-centered) are non-entropy, and as a result entropy is just a subset of a part of the energy domain. Similarly, exergy is a subset of energy, and based on this, some systems (such as air under atmospheric conditions) have energy but do not have any exergy. Most thermodynamic systems (such as steam in the power plant) have energy, entropy and exergy, and thus appear in the common space of these three.

The physical and chemical exergy are calculated as equation (1) and (2).

$$ex^{PH} = (h - h_0) - T_0(s - s_0) \qquad (1)$$

The total exergy is the sum of physical and chemical exergy.

$$ex^{CH} = \sum x_k \bar{ex}_k^{CH} + \bar{R}T_0 \sum x_k \ln(x_k) \qquad (2)$$

The exergy of each stream can obtain as follow.

$$\dot{Ex}_k = \dot{m}_k \times ex_k \qquad (3)$$

The exergy destruction rate can calculate as equation (4).

$$\dot{Ex}_{D,k} = \dot{Ex}_{F,k} - \dot{Ex}_{P,k} \qquad (4)$$

COMPONENT	$\dot{E}_F$(kW)	$\dot{E}_P$(kW)	$\dot{E}_D$(kW)
Air compressor	40978	35090	5888
Combustion chamber	125510	101590	23920
Gas turbine	74650	70010	4640
Heat exchanger 1	7610	6070	1540
Heat exchanger 2	16860	13730	3130
Heat exchanger 3	7520	5550	1970
Heat exchanger 4	860	560	300
Heat exchanger 5	4040	2850	1190
Turbine of CO_2 Cycle	13470	11910	1560
Compressor of CO_2	3528	2890	638
Cooler 1	810	120	690
Cooler 2	520	120	400
Turbine of cyclopentane	3440	530	2910
Pump	29.6	20	9.6
RO Desalination	20584	8950	11634

Exergoeconomic analysis

In exergoeconomic analysis, taking into account thermodynamic and economic parameters simultaneously, the optimal condition for the operation of the system is obtained thermodynamically and economically. The purpose of this analysis is to minimize the production cost of a thermal system with a specific product level or to maximize the amount of product production over the lifetime of the system with a fixed total cost.The economic balance equation can write as follow.

$$\dot{C}_{P,k} = \dot{C}_{F,k} - \dot{C}_{L,k} + \dot{Z}_k \qquad (5)$$

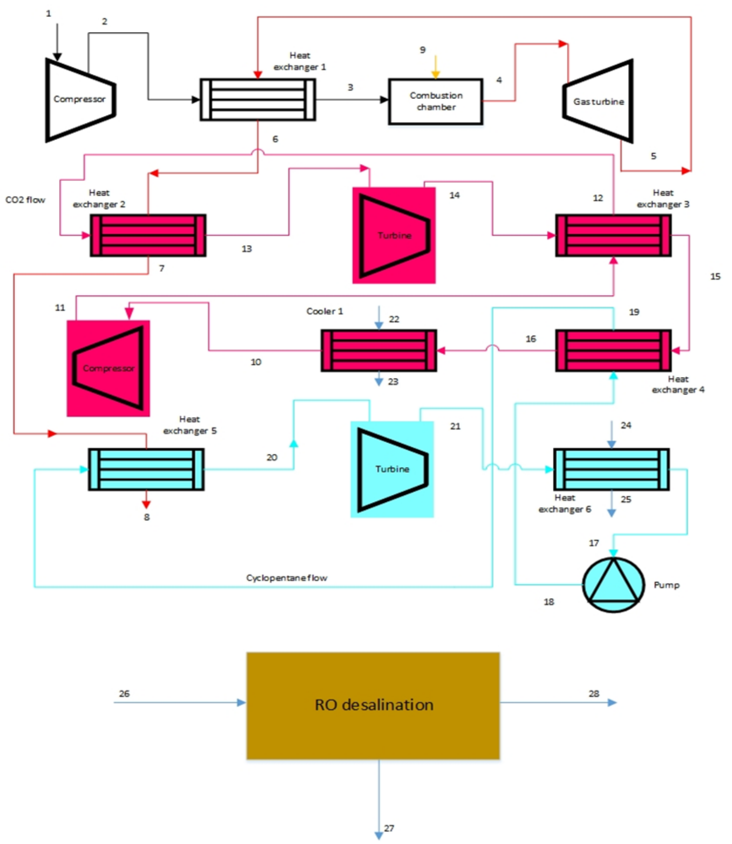
The economic balance equation in each component as follow.

$$\sum_e \dot{C}_{e,k} + \dot{C}_{w,k} = \dot{C}_{q,k} - \sum_i \dot{C}_{i,k} + \dot{Z}_k \qquad (6)$$

The cost of destruction can obtain as follow.

$$\dot{C}_{D,k} = c_{F,k} \dot{E}_{D,k} \qquad (7)$$

Combined Brayton, CO2 supercritical, organic Rankine and RO desalination cycle



COMPONENT	$\dot{C}_{F,k}$	$\dot{C}_D$	$\dot{C}_{P,k}$	$\dot{Z}+\dot{C}_D$
Air compressor	33113.04	194.9	36431.95	243.1
Combustion chamber	16293.1	75.6	33120	313.2
Gas turbine	211680.3	506.3	29160.03	513.5
Heat exchanger 1	29140.6	44.8	27415.74	56.4
Heat exchanger 2	15431.3	48.3	33198.65	190.33
Heat exchanger 5	28514.85	33.9	59237.05	49.8
Turbine of SCO_2 cycle	51120	79.7	51480	114.9
Heat exchanger 3	54467	107.3	72840.64	119
Heat exchanger 4	51120	15.33	66220.71	22.93
Cooler 1	40289.8	27.8	35400	41.3
Compressor of CO_2	51479.59	32.84	125155.43	41.94
Turbine of cyclopentane	9312.7	27.1	77392.94	33.03
Cooler 2	60840	24.3	3102	32.1
Pump	77400	0.74	138600	1.39
RO Desalination	7779.32	90.4	226907.58	734.55

Conclusions

The thermodynamic simulation shows the proposed cycle produces about 30.61 MW net power and 263.2 kg/s freshwater. In addition, the proposed system has been evaluated in view of exergetic and exergoeconomic analysis. As shown, the most exergy destruction is related to combustion chamber and then RO desalination.

The exergy destruction results show that the maximum exergy destruction in the cycle has occurred in the combustion chamber by the rate of 40% of total exergy destruction of the plant.

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