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A Computationally Efficient Heuristic Approach for Solving a New Sophisticated Arrangement of Cogeneration Combined Heat and Power Cycle

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Abstract

Cogeneration combined heat and power cycle components are continually optimized using new methods and solutions. Due to the interconnection of two different power generation cycles, the design of the cogeneration cycle is extremely complex and any changes in the structure directly affect the power, efficiency, costs, and other variables. To address this issue, a new arrangement of the cogeneration combined heat and power cycle is presented in this study, as well as a suitable fit function for exergy analysis and evolutionary algorithms used for model optimization. Several objectives are considered when optimizing, such as reducing costs, increasing profitability, etc. Optimization algorithms increased energy efficiency by 2.7% and exergy efficiency by 8.6%, indicating substantial long-term energy savings. A significant improvement was made in all desired parameters as well. Therefore, we can conclude that the upgraded algorithm considered in this study is effective in designing power generation cycles due to the particular importance of optimal design in power generation cycles.

Keywords: Cogeneration cycle, CHP, exergy, evolutionary algorithms, optimization

Cycle Overview

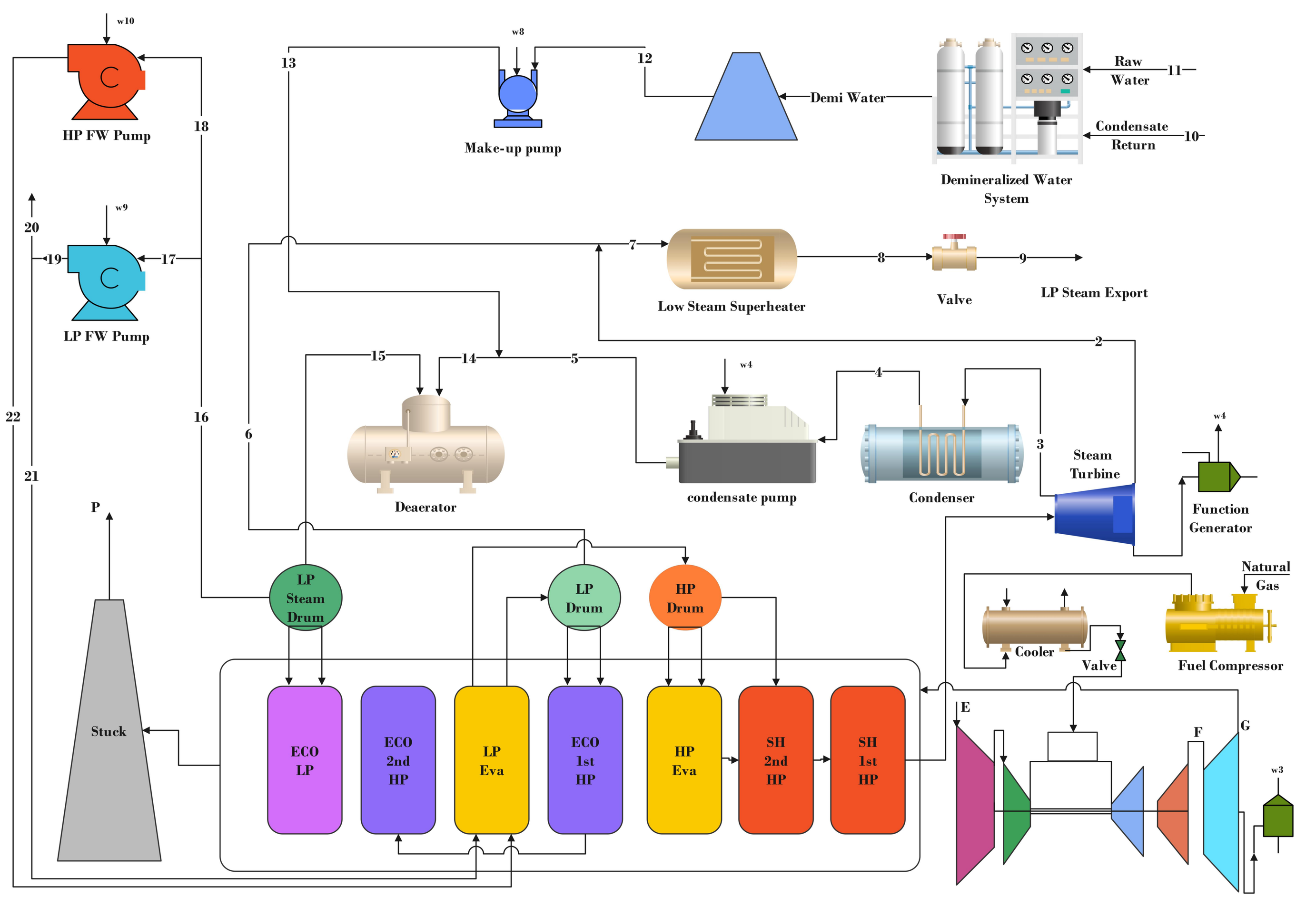


Fig.1. The considered arrangement of cogeneration combined heat and power cycle

The considered arrangement of cogeneration combined heat and power cycle is shown in Fig.1. Based on the interpolated relationships, enthalpy and entropy have been determined for each component as a temperature variable. Several parameters and variables are presented in Table 1 to model the objective functions of the program written to optimize the cogeneration cycle. The requirements following the compressor's first and second stages can be calculated using the input conditions given in Table 1, as well as the density ratio and interpolated relationships. For the cycle, methane gas is used as fuel. In Eq.1, the theoretical air percentage and mass flow rate of fuel are used to calculate the required airflow for combustion.

$$CH_4 + (0.01\lambda)(2n_{N2} + 2O_2 + 2n_{CO_2}CO_2 + 2n_{H_2O}H_2O)$$
$$\rightarrow (2\lambda N_{N_2})N_2 + (2\lambda - 2)O_2 + (2\lambda N_{CO_2} + 1)CO_2 + (2\lambda N_{H_2O} + 2)H_2O$$

$$\dot{W}_{bottoming\ Cycle} = \dot{W}_{Genrator} - (\sum \dot{W}_{Pumps})$$

$$(\dot{W}_{net})_{Plant} = (\dot{W}_{net})_{Gas\ Cycle} - \dot{W}_{bottoming\ Cycle}$$

$$FUE = \frac{[(\dot{W}_{net})_{Plant} + \Delta\dot{H}_{Process}]}{[(\dot{m}_{fuel}).LHV]}$$

$$PHR = \frac{(\dot{W}_{net})_{Plant}}{\Delta\dot{H}_{Process}}$$

Exergy efficiency can be obtained as follows:

$$\varepsilon_{plant} = \frac{(\dot{W}_{net})_{Plant} + \Delta\dot{H}_{Process}}{\dot{E}_f}$$

Table 1. Application Input

Variables	Unit	Limitations
Pump pressure after condenser P5	Bar	0<P5<10
Low-pressure boiler	Bar	0 <P16<10
Medium-pressure boiler	Bar	10<P19<20
High-pressure boiler	Bar	30<P19<100
High-pressure to medium-pressure steam flow rate	-	0<X1<1
Mass ratio of middle floor steam to total turbine inlet steam	-	0<X2<1
Desuperheater vapor cooling mass ratio to medium pressure vapor	-	0<X3<1
Inlet steam temperature to turbine	OC	200<T1<650
Theoretical air mass percentage of gas turbines	-	200<λ<400
Gas turbine compression ratio of gas generating section	OC	2<rp<5
Medium-pressure preheater outlet steam temperature and high pressure second stage Tb4	OC	Tb3<Ta6<Tb5
Medium-pressure evaporator outlet gas temperature	OC	Tb5<Ta6<Ta5
High-pressure preheater outlet steam temperature	OC	Tb7<Tb6<Ta9
High-pressure evaporator exhaust gas temperature	OC	Tb9<Ta4<Ta3

Table 2. The considered reference values for high efficiency cogeneration

Constants	Amount	Constants	Amount
Ambient Temperature	15°C	The efficiency of pumps D, C, E, and compensatory water pump	80%
Relative humidity	60%	Steam turbine efficiency	80%
Boiler heat loss	0.02	Efficiency of gas generators	80%
Boiler pressure drop	0.05	Fuel injection compressor efficiency	80%
Minimum chimney temperature	130	Turbine efficiency of gas production sector	82%
Turbine output steam quality	98%	Gas cycle power generation turbine efficiency	91%
Percentage of waste steam in the process	30%	Efficiency of steam and gas turbine generators	98%
Condensed water vapor temperature returned from the by-process	60	Condenser Pressure	0.07
Injection pressure	40	Fuel mass flow rate	1.45

Our research focused on thermodynamic optimization based on various objective functions, including enhancing Energy and Exergy efficiency, and heat to power ratio as shown in Table 3.

Table 3. The objective functions

Energy Efficiency	FUE
Exergy Efficiency	ε_p
Heat-to-Power Ratio	HPR

To make modelling accurate, it is essential to apply constraints that prevent the problem from being in impossible states, for example, ensuring a minimum quality of steam output from turbines and preventing corrosion in the chimney. This actually avoids obvious repercussions or consequences that would violate physical laws. Our results can be characterized by the negative thermal state of the gas during the recovery converter. The study has prevented such results from occurring by applying appropriate restrictions similar to those in Table 2 for program inputs. It has been shown that this is correct using the same results from the practical cycle .

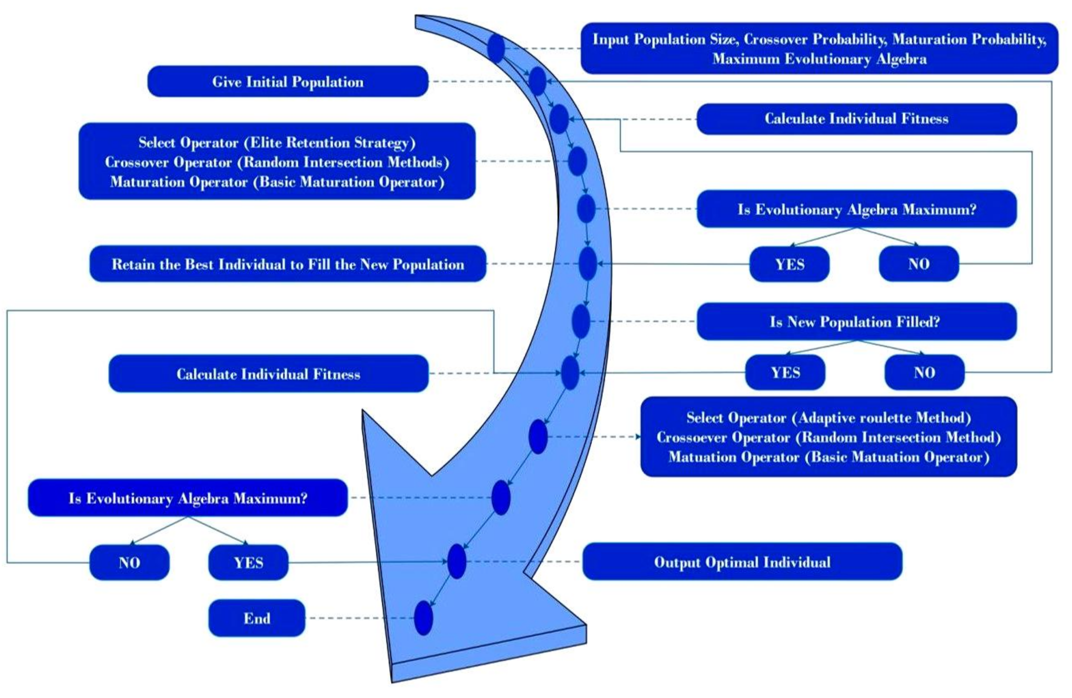
Discussions & Results

An algorithm that combines accuracy, precision, and completeness in exchange for speed and efficiency is used for the considered CHP cycle in this research. This algorithm can solve NP-complete problems, known as impossible problems. It is a coding technique for problem-solving model. Solution codes are created according to patterns based on the input problem. Each candidate solution is evaluated for suitability by the function, which is usually selected randomly. After several generations, the algorithm gradually converges towards the optimal solution. It is necessary to go through several repetitions before stopping the algorithm. Due to the large number of optimal points in this study and the number of interrelationships, this algorithm seems to be the most effective approach for optimizing the entire system. The input parameters section of Table 2 lists the decision variables and the scope of their change in cycle optimization.

Table 4. Results calculated from the simulated model and actual cycle results

Point	Modeling Values		Actual values	
	Temperature (°C)	Pressure (MPa)	Temperature (°C)	Pressure (MPa)
A	15.00	16.00	15.00	16.00
B	1.01	15.00	1.01	15.00
C	1.01	16.00	1.01	15.00
D	40.00	35.00	40.00	35.00
E	16.00	15.00	1.01	15.00
F	5.10	965.24	3.59	733.60
G	1.06	614.34	1.06	494.65
H	1.06	130.00	1.01	130.00
1	87.00	442.64	46.00	450.00
2	16.24	245.73	16.00	335.70
3	0.07	39.00	0.07	38.97
4	0.07	39.00	0.07	38.97
5	6.37	39.03	6.50	39.17
6	16.24	202.10	16.00	201.30
7	16.24	204.18	16.00	283.72
8	16.24	202.10	16.00	201.30
9	16.24	202.10	16.00	201.30
10	3.00	60.00	3.00	60.00
11	3.50	15.00	3.50	15.00
12	0.05	32.00	N.A.	32.00
13	6.37	32.09	6.50	32.16
14	6.37	36.58	6.50	36.58
15	4.21	145.43	1.70	115.12
16	4.21	145.43	1.70	115.12
17	4.21	145.43	1.70	115.12
18	4.21	145.43	1.70	115.12
19	16.24	145.66	16.00	115.57
20	16.24	145.66	16.00	115.57

Fig. 2. shows the algorithms used to optimize the considered arrangement of cogeneration combined heat and power cycle



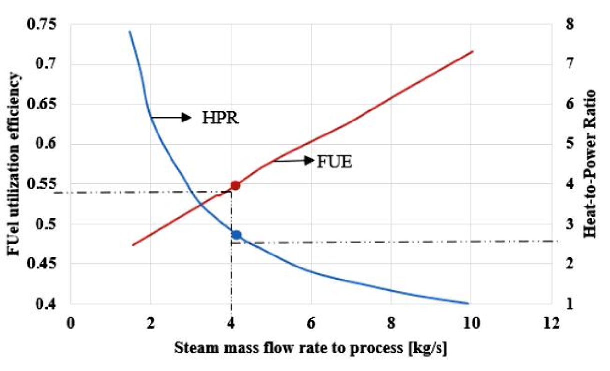


Fig.3. FUE & HPR changes to the steam flow rate

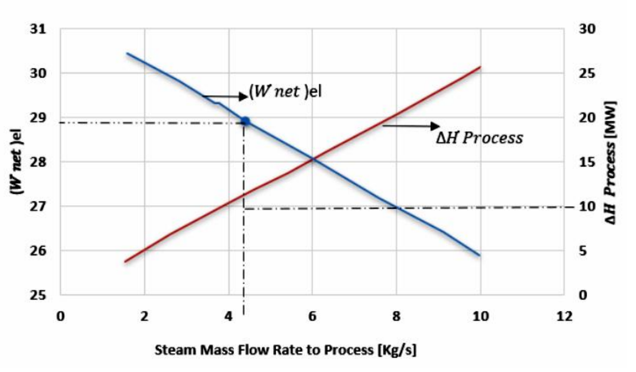


Fig.4. Outlet energy changes to the steam flow rate

Table 5. Algorithm Results

Algorithm Results Without Pinch Method		Algorithm Results With Pinch Method		Error	Simulation Measured Value	Actual Measured Value	Variable
Recovery Percentage	Amount	Recovery Percentage	Amount				
10.3%	32.1 (MW)	6.5%	31.0 (MW)	0.7%	29.3 (MW)	29.1 (MW)	$(\dot{W}_{net})$
-	10.9 (MW	-	11.0 (MW)	- 0.9%	10.9 (MW)	11.0 (MW)	$\Delta\dot{H}_{Process}$
7.4%	2.9	3.7%	2.8	0%	2.7	2.7	HPR
7.2%	0.59	5.4%	0.58	0%	0.55	0.55	FUE

Conclusion & Future Research

The purpose of this research was to improve efficiency, reduce costs, and increase profitability through thermodynamic optimization of a new arrangement of the cogeneration combined heat and power cycle. This study also examined suitable fit functions for exergy analysis and evolutionary algorithms for model optimization. The objectives of optimization include reducing costs, enhancing profitability, etc. A significant amount of energy will be saved in the long run based on these results, as energy efficiency increased by 2.7% and exergy efficiency by 8.6%. Furthermore, all of the desired parameters improved significantly over the actual outcomes. Additionally, if pinch and proximity temperatures are not limited to predetermined values, better results are achieved. Based on the particular importance of optimal design in power generation cycles and the results of this study, we can conclude that heuristic algorithms can be used effectively in designing power generation cycles.

Towards more optimal results in the future, hybrid algorithms may also be considered. To further improve prediction accuracy, more parameters can be included in the model.