

Exergetic, Exergoeconomic and Exergoenvironmental Multi-Objective Genetic Algorithm Optimization of Qeshm Power and Water Cogeneration Plant

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Abstract: In this study, optimization of Qeshm power and water desalting cogeneration plant has been investigated. The objective functions are related to maximizing exergetic efficiency and minimization of exergoeconomic and exergoenvironmental parameters. Also, the integration of RO desalination with the existing plant has been evaluated based on these analyses. This plant includes two MAPNA 25 MW gas turbines, two heat recovery steam generators, and two MEDTVC desalination units. Thermodynamic modeling and simulation of the plant have been performed in MATLAB software. The thermodynamic simulation verified by Thermoflex software and plant data with high accuracy. Also, the computer code has been developed to perform exergetic, exergoeconomic and exergoenvironmental analysis. Multi-Objective Genetic Algorithm (MOGA) has been applied to find optimum objective functions and decision variables based on exergetic, exergoeconomic and exergoenvironmental parameters. Results show that in the optimum plant overall exergetic efficiency of the plant has been increased by 27.78%, and total exergetic cost and total exergoenvironmental impacts have been decreased by 0.93% and by 0.89%.

keywords: Cogeneration, MEDTVC Desalination, RO Desalination, Exergy Analysis, Exergoeconomic Analysis, Exergoenvironmental Analysis

Nomenclature		RR	Recovery Ratio				component
A	Area	s	entropy	Cr	compression ratio	$\dot{Y}$	environmental impact rate of the equipment
AC	Air Compressor	SA	specific area				
B	Brine	T	Temperature	CR	Capital Recovery Factor	$\dot{Z}$	Cost rate of the equipment
b	environmental impact per exergy unit	TIT	Turbine Inlet Temperature	D	Distillate		
$\dot{B}$	environmental impact rate	TVC	thermal vapor compressor	DE	Deaerator	Greek letters	
bm	environmental impact per mass unit	U	overall heat transfer coefficient	DP	Deaerator Pressure	γ	ratio of the specific heats
c	cost per exergy unit			EV	Evaporator	Δ	Difference
CC	Combustion Chamber	W	work	$\dot{E}$	Energy rate		
$\dot{C}$	cost rate	w	weight	Er	expansion ratio	ε	exergetic efficiency
CO	Condenser	x	mole fraction	ex	specific exergy	η	efficiency
N		X	salinity	$\dot{E}_x$	Exergy rate	ϕ	maintenance factor
D				f	exergoeconomic factor	ρ	density
cp	specific heat at constant pressure	y	environmental impact of the	F	Feed	π	osmotic pressure
				fb	exergo-environmental		

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	factor		
F	Feed Water	subsc	
W	Preheater	ripts	
PH			
G	gained output ratio	0	ambient condition
OR			
GT	Gas Turbine	fg	Flue gas
h	enthalpy	c	condenser
HP	High-	cwd	cooling water
EC	pressureEconomize		discharge
HP	High-pressure	D	Destruction
EV	Evaporator		
HP	High-pressure	e	effect
P	Pump		
HP	High-pressure	F	Fuel
SH	Super Heater		
HR	Heat Recovery	fb	flash box
SG	Steam Generator		
J	specific mass flow	fh	feed heater
	rate		
LH	Lower Heating	fw	feed water
V	Value		
$\dot{m}$	Mass Flow Rate	gc	gas cycle
M	multiple effect	hp	high-pressure
ED	desalination		
Mr	Mixing Ratio	i	counter of streams
M	molecular weight	k	counter of
W			components
n	number of effects	P	Product
N	annual operating	s	steam
	hours of the system		
NS	Nominal Size of	sat	saturated
	TVC		
ny	operating years of	sub	sub cooled
	the system		
P	Pressure	sup	superheated
PE	Purchase		
C	Equipment Cost	sw	seawater
PR	Performance Ratio		
Q	Heat Duty	super	
		script	
r	relative cost	s	
	difference	*	restricted dead state
rb	relative	0	global dead state
	environmental		
	impact difference		
$\bar{R}$	Universal Gas	CH	Chemical
	Constant		
RO	reverse osmosis	PH	Physical
rp	Pressure ratio		

1. Introduction

Freshwater means water that contains less than 1000 milligrams of salinity per liter of water [1]. However, most of the water present on the surface of the earth has a salinity of up to 10,000 ppm, and the free water is usually salinity in the range of 35,000 ppm to 45,000 ppm in the form of salts dissolved in water [2]. Our country is no exception. On the other hand, the shortage of Freshwater resources in Iran and, on the other hand, access to saltwater resources of the Persian Gulf in the south, and the Caspian Sea in the

north, necessitate the need for Freshwater supply from these resources for industrial, and domestic uses. The issue of Desalination has attracted attention in most countries of the world in recent years. Today, over 15,000 units of desalinating water units are operating around the world. The Middle East accounts for roughly 50% of the world's total freshwater production. Saudi Arabia, with about 26% of world freshwater production capacity, is the largest producer in the industry, and the United States with 17% is in the next category. In Saudi Arabia, thermal water desalination is most used[1]. The process of separating salt from saline water, like any other process, requires energy, and the amount of this energy is different for different methods of desalination. In a particular process, the amount of energy per unit volume of Freshwater produced depends on the chemical composition and degree of impurities of saline water and its thermodynamic characteristics[3].

Lack of energy and high and continuous costs of energy supply increased energy consumption, environmental pollution due to the consumption of fossil fuels and the deterioration of fossil fuels has led to issues of energy recovery in industrial and process units in recent years[4-8]. There is some investigation related to energy reduction in the process industries in Iran by exergy analysis.

The identification of the sources of energy losses by the exergy method for the Marun Mega-Olefin petrochemical complex has been done by Paashang et al [9]. Ghorbani et al investigated an integrated nitrogen rejection unit with LNG and NGL co-production processes based on the MFC and refrigeration systems through exergoeconomic analysis [10]. Ghazizadeh et al studied C3MR, MFC and DMR refrigeration cycles in an integrated cryogenic process with advanced exergoeconomic analysis [11]. An advanced exergetic analysis of the integrated separation process with considering optimization refrigeration system has been investigated by Hamed et al [12]. Sheikhi et al applied pinch and exergy analysis for optimization of the refrigeration cycle in the petrochemical complex [13]. Optimization of an integrated process configuration for IGCC with a Fischer-Tropsch has been evaluated with coal and biomass fuels by Shariati Niassar[14]. In the other research, Hadadi et al performed and evaluated optimization of water and wastewater network related to a gas refinery with considering pressure drop and pumping cost using conceptual, mathematical and evolutionary methods[15]. Exergoeconomic and environmental optimization of a 160 MW combined cycle power plant through MOEA has been done by KhoshgoftarManesh and Babaelahi[16].

Over the years, extensive research has been done on power generation systems and desalination systems. Tadros assessed the combination of a multi-stage flash (MSF) desalination unit with a variety of steam turbines, as well as a gas turbine, and boiler, in 1979, due to the extensive use of multi-effect desalination. In the study, the economics of these systems, and

thermodynamic characteristics were studied and optimization studies were carried out. The results have shown that a single unit of MSF can produce up to 1400 m³/h freshwater[17]. In 1997, Darwish et al. Used Exergy analysis to determine the cost and amount of energy consumed in the cogeneration system for the production of freshwater and power. To compare the energy consumption and cost, a variety of desalination methods as; multi-effect desalination (MED), Thermovapor compression (TVC), mechanical vapor compression (MVC), and reverse osmosis (RO) has been investigated[18]. Also, Wade in 1999, the cogeneration systems consisting of desalinating units and power generation units have been analyzed in terms of economics and energy. In his research, gas turbine power plants, combined cycle, and steam cycles, and their interconnections with MSF desalination, and reverse osmosis (RO) have been investigated using the reference cycle method, namely, the use of a single cycle for the production of electrical energy. The amount of energy allocated to produce Freshwater has been studied, and desalinating water was used as a MSF type. The results show that the MSF with a combined cycle power plant has the minimum cost allocation in all of the cases[19]. Then Dervish et al. (2004) suggested the use of gas turbines for Freshwater in Kuwait, due to the lack of freshwater in the country. They investigated several different combinations of gas turbine cycle and multi-stage flash desalinating water with a sudden drop in pressure, and oscilloscope [20]. In 2004, Cardona and Piacentino provided research to provide the optimal design of water, and energy generation units simultaneously. They investigated reverse osmosis and thermal desalination system with a sudden drop in pressure to improve system performance. They emphasized that the produced electrical energy could also be used to set up reverse osmosis, and auxiliary equipment, and tried to provide a measure based on exergy-economics and profit history for optimal design of such units. A thermoeconomic algorithm has been presented with an optimization method that has an objective function to allocate minimum cost to each component.[21]. In 2006, Wang et al. began his work on the integration of the MED-desalination system, and gas plant to have a cogeneration plant. With the integration of these two systems, the heating system required for the operation of the desalination unit was supplied through the waste heat of the gas plant. In that same year, he examined the gas turbine cycle by injecting steam and connecting it with thermal water desalination. Using a recovery boiler, the steam needed to be injected into the combustion chamber, and the desalination plant was produced. They concluded that the injection rate of steam injected into the combustion chamber would have a profound effect on water, and power production; this increase would increase the production of power but reduced the production of freshwater, and, on the other hand, increasing the input temperature to the turbine would increase the power and water production [22]. In 2007, they

carried out another study on the gas turbine plant by injecting steam into the desalination unit and to design another cogeneration system. From the analysis of the two different cycles in the previous and current research, they concluded that the fuel consumption for the production of freshwater during the steam injection process is 45% of total fuel, and in the wet air injection cycle, that is 31% to 54% of total fuel consumption in MEDTVC unit[23]. In 2009, KhoshgoftarManesh et al. Also performed a thermodynamic analysis, and multi-objective optimization of the combined heat, and power system with a thermal desalination unit, and nuclear reactor [24] while conducting research on dehumidification of water desalination process[25, 26]. In 2012, Amidpour et al. Reviewed, and optimized the integration of multi-effect evaporation thermal vapor compression water desalination (MED-TVC) to the gas plant. The results show that the evaporator has the maximum exergy destruction in the plant. In the very high-pressure steam injection with pressure about 30 bar the minimum cost of desalinated water has been occurred in the MED-TVC unit[27].

In 2014, Alzahrani et al. has been investigated a gas turbine cycle integrated with MEDTVC desalination and RO units. An energy recovery device related the thermal desalination unit to the gas turbine cycle. An exergy analysis has been performed to show the destruction of each component. Effect No.4 of the MED thermal desalination unit has 45% of the total exergy destruction [28]. In 2015, Eshoul et al. has considered a combined cycle power plant standalone and integrated with a MEDTVC desalination unit. They performed thermodynamic and exergy analyses on the case study. Also, the amount of the environmental impact as carbon dioxide has been obtained and the results show that the emission rises by increasing the ambient air temperature. Every 10°C increase in the ambient air temperature rises the plant efficiency by about 0.42% and decreases the output power about 5.3%[29]. In 2018, Eshoul et al. has considered a MEDTVC desalination unit lonely and done energetic, exergetic, and economic analysis on it. The results show that thermocompressor is the main source of the exergy destruction in this system. By using a preheater in this system, the cost of the desalinated water has been decreased [30].

In four papers, Kamali et al. [31-34] developed and then optimized a model for thermodynamic simulation of a multi-stage desalination. The developed model is then compared and validated with the experimental data of one of the Kish Island desalination currently in operation. The developed model is based on the basics of the design of the cell shell transducers, although there is no discussion of the economic aspects of the system under study in their research. Also, the impact of the required vapor suction site from the country on the optimal desalination performance is evaluated.

Several researchers have also focused more on MED, MSF, and RO desalination systems, as well as the combined use of these desalination.

Muginstein et al. [35] are evaluated the performance of two reverse osmosis desalination and multi-stage desalination steam desalination both desalination was connected to a combined cycle power plant. Darwish et al. [36] Given the shortage of freshwater in Kuwait, they suggested the use of gas turbines to produce freshwater, all of the researchers' multi-stage desalination plants were of a multi-stage type with a sudden pressure drop to the turbine. In this paper, the researchers investigated many combinations between thermal desalination and reverse osmosis with thermal power plants. Most of this paper focuses on general engineering calculations and does not include process modeling and simulation. Messineo et al. [37] also conducted a study similar to the work of Cardona et al. [38] except that there was no thermal coupling between multistage distillate desalination, reverse osmosis desalination, and only freshwater of these two freshwaters mix to get the desired quality of acid. Rensonnet et al. [39] also studied the various configurations of the combination of multistage distillation desalination and reverse osmosis desalination and thermoeconomic power plants.

Mokhtari et al evaluated (GT + MED + RO) hybrid system for desalination in the Persian Gulf. Promotion in performance of a GT + MED + RO to achieve more water production capacity

Talebeydokhti et al performed evaluation and optimization low-temperature MED system powered by CSP. The selection of integrated LT-MED with CSP-DEC is investigated [40].

Dynamic simulation of MED-TVC desalination integrated with nuclear reactor with high modeling accuracy has been performed by Dong et al. A lumped-parameter for nuclear desalination plant has been considered [41].

Performance evaluation of an auto-tuning area ratio ejector for the MED-TVC desalination process has been proposed by Gu et al [42]. Evaluation of varying motive steam to performance are considered.

Elsayed et al investigated a transient simulation of MED desalination with different feed configurations[43]. Backward feed, forward feed, parallel feed and parallel/crossfeed are considered. MED-TVC with parallel/crossfeed has the best response.

The integration of MED with the solar Rankin cycle powered by the linear fresnel solar field has been proposed by Askari and Ameri. In this regard, fuel consumption is reduced significantly by using the solar energy[44].

Dynamic modeling of a MED-TVC plant has been proposed by Guimard et al [45]. A dynamic model based on mathematical equations has been implemented. Also, transient operations related to disturbances are considered. Based on the brine levels in the effects Strategies for process control under

modification of regimes have been developed.

Shayesteh et al investigated to find 4E optimum the ORC-RO system parameters for Water–Energy–Environment nexus. In this regard, the environmental impacts index has been defined for the RO system [46]. Palenzuela et al evaluated based on Techno-Economic analysis between CSP+MED and CSP+RO in MENA Region[47].

As mentioned before, there is no study about simultaneous exergetic, exergoeconomic and exergoenvironmentthree-objectives optimization for power and desalination plants.

In this study, the Qeshm cogeneration plant with the gas turbine, HRSG and MEDTVC has been selected as a real case study to find optimum conditions based on Multi-Objective Genetic Algorithm (MOGA). In this regard, exergetic, exergoeconomic and exergoenvironmental optimization of Qeshm power and desalting plant have been investigated

2. Case study

The Qeshmpower/water cogeneration plant includes two MAPNA 25 MW gasturbines, two Heat Recovery Steam Generators (HRSG) and two MED-TVC desalination units. The technical characteristics of the Qeshm power/water cogeneration plant is indicated in table 1. As shown in Figure 1, the integrated RO with existing MED-TVC plant are investigated.

Table 1. Technical characteristics of the multi-generation combined cycle power plant

Parameter	Unit	Value
SiteLevel	m	302.0
AirCompressionratio	-	19.23
Ambient Temperature	C	35.00
Net Power Output of Gas Cycle	MW	25.67
Isentropic Efficiency of AC	%	90.00
Isentropic Efficiency of GT	%	93.00
Efficiency of CC	%	99.00
Turbine Inlet Temperature	C	1232
Fuel Type	-	NG
MED NO. of Effects	-	5
MED Distillate Flow Rate	ton/h	186.2
Salinity of Seawater	g/Kg	38.7
MED Recovery Ratio	-	0.2957
HRSG High-pressure	bar	53.3

Combustion Chamber	$\dot{m}_{air} h_2 + \dot{m}_{fuel} LHV_{fuel} \eta_{CC} - \dot{m}_{fg} h_4 = 0$	LHV_{fuel}, η_{CC}	Q_{CC}
	$\dot{m}_{air} + \dot{m}_{fuel} - \dot{m}_{fg} = 0$	ΔP_{CC}	T_4, P_4
	$P_4 = P_2 (1 - \Delta P_{CC})$	$T_2, P_2, \dot{m}_{air}$	$\dot{m}_{fuel}, \dot{m}_{fg}$
	$h_4 = h_{fg@T_4}$	[55]	
Gas Turbine	$W_{GT} = \dot{m}_{fg} (h_4 - h_5)$	η_{GT}	W_{GT}
	$T_5 = T_4 \left\{ 1 - \eta_{GT} \left[1 - r_{p,GT}^{\frac{1-\gamma_{fg}}{\gamma_{fg}}} \right] \right\}$	$T_4, P_4, \dot{m}_{fg}$	T_5
	$r_{p,GT} = P_4 / P_5$	$W_{net,gc}$	T_5
	$P_5 = P_0 + \sum \Delta P_{HRSG, fg}$	W_{AC}	
	$W_{net,gc} = W_{GT} - W_{AC}$		
	$h_5 = h_{fg@T_5}$		
	[48, 55]		

Table 3. Equations, inputs and outputs of the equipment of steam side

Component	Equations	inputs	outputs
High-Pressure Super heater	$\dot{m}_{fg} (h_5 - h_6) + \dot{m}_{hrsg} (h_{22} - h_{23}) = 0$	$\dot{m}_{fg}, T_5, P_5$	Q_{HPSH}
	$P_6 = P_5 - \Delta P_{HPSH, fg}$	$\Delta P_{HPSH, fg}$	T_6, P_6
	$P_{23} = P_{22} - \Delta P_{HPSH, s}$	$\Delta P_{HPSH, s}$	T_{23}, P_{23}
	$T_{23} = T_{sat, HPSH} + T_{sup, HPSH}$	$T_{sup, HPSH}$	$\dot{m}_{hrsg}$
	$Q_{HPSH} = \dot{m}_{hrsg} (h_{23} - h_{22})$	T_{22}, P_{22}	
	$h_6 = h_{fg@T_6}, h_{23} = h_{water@T_{23}, P_{23}}$	[48, 49]	
High-Pressure Evaporator	$\dot{m}_{fg} (h_6 - h_7) + \dot{m}_{hrsg} (h_{21} - h_{22}) = 0$	$\dot{m}_{fg}, T_6, P_6$	Q_{HPEV}
	$P_7 = P_6 - \Delta P_{HPEV, fg}$	$\Delta P_{HPEV, fg}$	T_7, P_7
	$P_{22} = P_{21} - \Delta P_{HPEV, s}$	$\Delta P_{HPEV, s}$	T_{22}, P_{22}
	$T_{22} = T_{sat@P_{22}}$	T_{21}, P_{21}	$\dot{m}_{hrsg}$
	$Q_{HPEV} = \dot{m}_{hrsg} (h_{22} - h_{21})$		
	$h_7 = h_{fg@T_7}, h_{22} = h_{g, water@P_{22}}$	[48, 49]	

High-Pressure Economizer 2

$$\dot{m}_{fg}(h_7 - h_8) + \dot{m}_{hrsg}(h_{20} - h_{21}) = 0$$

$$P_8 = P_7 - \Delta P_{HPEC2,fg}$$

$$P_{21} = P_{20} - \Delta P_{HPEC2,s}$$

$$T_{21} = T_{sat,HPEC2} - T_{sub,HPEC2}$$

$$Q_{HPEC2} = \dot{m}_{hrsg}(h_{21} - h_{20})$$

$$h_8 = h_{fg@T_8}, h_{21} = h_{water@P_{21},T_{21}} \quad [48, 49]$$

$$\dot{m}_{fg}, T_7, P_7$$

$$\Delta P_{HPEC2,fg}$$

$$\Delta P_{HPEC2,s}$$

$$T_{20}, P_{20}$$

$$T_{sub,HPEC2}$$

$$Q_{HPEC2}$$

$$T_8, P_8$$

$$T_{21}, P_{21}$$

$$\dot{m}_{hrsg}$$

High-Pressure Economizer 1

$$\dot{m}_{fg}(h_8 - h_9) + \dot{m}_{hrsg}(h_{19} - h_{20}) = 0$$

$$P_9 = P_8 - \Delta P_{HPEC1,fg}$$

$$P_{20} = P_{19} - \Delta P_{HPEC1,s}$$

$$T_{20} = T_{sat,HPEC1} - T_{sub,HPEC1}$$

$$Q_{HPEC1} = \dot{m}_{hrsg}(h_{20} - h_{19})$$

$$h_9 = h_{fg@T_9}, h_{20} = h_{water@P_{20},T_{20}} \quad [48, 49]$$

$$\dot{m}_{fg}, T_8, P_8$$

$$\Delta P_{HPEC1,fg}$$

$$\Delta P_{HPEC1,s}$$

$$T_{19}, P_{19}$$

$$T_{sub,HPEC1}$$

$$Q_{HPEC1}$$

$$T_9, P_9$$

$$T_{20}, P_{20}$$

$$\dot{m}_{hrsg}$$

Deaerator Pressure Evaporator

$$\dot{m}_{fg}(h_9 - h_{10}) + \dot{m}_{de}(h_{15} - h_{16}) = 0$$

$$P_{10} = P_9 - \Delta P_{DPEV,fg}$$

$$P_{16} = P_{15} - \Delta P_{DPEV,s}$$

$$T_{16} = T_{sat@P_{16}}$$

$$Q_{DPEV} = \dot{m}_{de}(h_{16} - h_{15})$$

$$h_{10} = h_{fg@T_{10}}, h_{16} = h_{g,water@P_{16}} \quad [48, 49]$$

$$\dot{m}_{fg}, T_9, P_9$$

$$\Delta P_{DPEV,fg}$$

$$\Delta P_{DPEV,s}$$

$$T_{15}, P_{15}$$

$$Q_{DPEV}$$

$$T_{10}, P_{10}$$

$$T_{16}, P_{16}$$

$$\dot{m}_{de}$$

Feed Water Preheater

$$\dot{m}_{fg}(h_{10} - h_{11}) + \dot{m}_{fw}(h_{12} - h_{13}) = 0$$

$$P_{11} = P_{10} - \Delta P_{FWPH,fg}$$

$$P_{13} = P_{12} - \Delta P_{FWPH,s}$$

$$T_{13} = T_{sat,FWPH} - T_{sub,FWPH}$$

$$Q_{FWPH} = \dot{m}_{fw}(h_{13} - h_{12})$$

$$h_{11} = h_{fg@T_{11}}, h_{13} = h_{water@P_{13},T_{13}} \quad [48, 49]$$

$$\dot{m}_{fg}, T_{10}, P_{10}$$

$$\Delta P_{FWPH,fg}$$

$$\Delta P_{FWPH,s}$$

$$T_{sub,FWPH}$$

$$T_{12}, P_{12}$$

$$Q_{FWPH}$$

$$T_{13}, P_{13}$$

$$T_{11}, P_{11}$$

$$\dot{m}_{fw}$$

Deaerator

$$\dot{m}_{fw}h_{13} + \dot{m}_{de}h_{16} - (\dot{m}_{fw} + \dot{m}_{de})h_{14} = 0$$

$$P_{14} = P_{DEA}$$

$$T_{14} = T_{sat@P_{14}}$$

$$h_{14} = h_{f,water@P_{14}}$$

$$S_{14} = S_{f,water@P_{14}} \quad [48, 49]$$

$$T_{16}, P_{16}$$

$$T_{13}, P_{13}$$

$$T_{14}, P_{14}, S_{14}$$

$$\dot{m}_{de}, \dot{m}_{fw}$$

High-Pressure Pump	$W_{HPP} = \dot{m}_{fw}(h_{18} - h_{17})$	
	$P_{18} = P_{HPP}$	
	$s_{18s} = s_{17}$	T_{17}, P_{17}, s_{17}
	$h_{18s} = s_{\text{water}@p_{18}, s_{18s}}$	T_{18}, P_{18}
	$h_{18} = h_{17} + \frac{h_{18s} - h_{17}}{\eta_{HPP}}$	P_{HPP} W_{HPP} η_{HPP}
Desuperheater	$T_{18} = T_{\text{water}@p_{18}, h_{18}}$ [48, 49]	
	$\dot{m}_{desw} h_{25} + \dot{m}_{dess} h_{24} - \dot{m}_s h_{26} = 0$	
	$P_{26} = P_{25}$	p_{24}, T_{24}
	$T_{26} = T_{\text{sat}, DES} + T_{\text{sup}, DES}$	p_{25}, T_{25} p_{26}, T_{26}
	$h_{26} = h_{\text{water}@T_{26}, p_{26}}$ [48, 49]	$T_{\text{sup}, DES}$
Valve 1	$h_{27} = h_{26}$ [48, 49]	p_{26}, T_{26}, h_{26}
	$T_{27} = T_{\text{water}@p_{27}, h_{27}}$	p_{27}, T_{27}, h_{27} p_{27}
Valve 2	$h_{31} = h_{30}$	p_{30}, T_{30}, h_{30}
	$T_{31} = T_{\text{water}@p_{31}, h_{31}}$ [48, 49]	p_{31}, T_{31}, h_{31} p_{31}

Table 4. Equations, inputs and outputs of the equipment of MED-TVC

Component	Equations	inputs	outputs
MED-TVC	Performance : $PR = \frac{\dot{m}_D}{\dot{m}_s}, RR = \frac{\dot{m}_D}{\dot{m}_F}$ Mass Balance ith effect : $FX_F = BX_B, FX_F = B_e X_{B_e}$ Energy Balance ith effect $D_c \Delta h_{D_c} = Dh_D + Bh_B - Fh_F$ Boiling Point Elevation: $BPE_D = T_D - T_{D_{sat}}$ Area : $D_c \Delta h_{D_c} = A_e U_e (T_{D_{sat}}^{prev} - T_e)$ $U_e = 10^{-3} [1939.1 + 1.40562(T_{D_{sat}}^{prev} - 273.15) - 0.0207525(T_{D_{sat}}^{prev} - 273.15)^2 + 0.0023186(T_{D_{sat}}^{prev} - 273.15)^3]$ Terminal Temperature Difference: $TTD_e = T_c - T_e$ [56] Mass Balance ith flashbox : $D_{bd} + D_{fb} = D_{bd}^{in} + D_c$ Energy Balance ith flashbox : $D_{bd} h_{D_{bd}} + D_{fb} h_{D_{fb}} = D_{bd}^{in} h_{D_{bd}^{in}} + D_c h_{D_c}$ feedheater : $Q_{fh} = D_c (h_{D_c}^{in} - h_{D_c}^{out}) = \dot{m}_F (h_{\dot{m}_F}^{out} - h_{\dot{m}_F}^{in})$ $Q_{fh} = A_{fh} U_{fh} \frac{T_{\dot{m}_F}^{in} - T_{\dot{m}_F}^{out}}{\ln(\frac{T_{D_{c,sat}} - T_{\dot{m}_F}^{out}}{T_{D_{c,sat}} - T_{\dot{m}_F}^{in}})}$ $U_{fh} = 10^{-3} [1617.5 + 0.1537(T_{D_{c,sat}} - 273.15) + 0.1825(T_{D_{c,sat}} - 273.15)^2 - 0.00008026(T_{D_{c,sat}} - 273.15)^3]$ condenser : $Q_{cond} = D_c (h_{D_c}^{in} - h_{D_c}^{out}) = \dot{m}_{sw} (h_{sw}^{out} - h_{sw}^{in})$ $Q_{cond} = A_c U_c \frac{T_{sw}^{in} - T_{sw}^{out}}{\ln(\frac{T_D - T_{sw}^{in}}{T_D - T_{sw}^{out}})}$ $U_c = 10^{-3} [1617.5 + 0.1537(T_D - 273.15) + 0.1825(T_D - 273.15)^2 - 0.00008026(T_D - 273.15)^3]$	n $\dot{m}_D$ T_s x_{sw} TTD RR $T_e(n)$ $T_{sw,in}, P_{sw,in}$ $P_{motive-steam}$	SA $\dot{m}_s$ $\dot{m}_F$ $\dot{m}_{sw}$ $\dot{m}_{cwd}$ x_B PR

$$\dot{m}_D = \sum_{i=1}^n D(i)$$

$$\dot{m}_s = D_c(1)$$

$$\dot{m}_F = F(1)$$

$$\dot{m}_B = B(n)$$

$$\text{Specific Area : } SA = \frac{\sum A_e + \sum A_{fh} + A_c}{\dot{m}_D}$$

TVC :

$$E_r = \frac{P_{motive-steam}}{P_{suction}}$$

$$C_r = \frac{P_{discharge}}{P_{suction}}$$

$$M_r = \frac{\dot{m}_{motive-steam}}{\dot{m}_{suction}}$$

$$M_r = -1.9342 + 2.1525C_r + \frac{113.49}{E_r} - 0.52C_r^2$$

$$- \frac{14735.96}{E_r^2} - \frac{31.85C_r}{E_r} + 0.047C_r^3$$

$$+ \frac{900786}{E_r^3} - \frac{495.6C_r}{E_r^2} + \frac{10.02C_r^2}{E_r}$$

$$\dot{m}_s = \frac{\dot{m}_{s,1^{st} effect}}{1 + M_r}$$

[57]

Table 5. Equations, inputs and outputs of the equipment of RO

Component	Equations	inputs	outputs
RO	$RR = \frac{\dot{m}_D}{\dot{m}_F}$	$\dot{m}_F$	
	$RR = RR _{T=25} \times \frac{J_w}{J_w _{T=25}}$	T_{37}, p_{37}	
	$\dot{m}_F = \dot{m}_D + \dot{m}_B$	p_{Feed}	$\dot{m}_D, \dot{m}_B$
	$\dot{m}_F = \dot{m}_{cwl, MED}$	T	RR
	$\dot{W}_{RO} = \frac{\dot{m}_F (p_{Feed} - p_{37}) \times 100}{\rho \times \eta_{pump}}$	R	$\dot{W}_{RO}$
	$J_w = \frac{D_w C_w V_w}{RTe [^0 K]} \{ (p_F - p_D) - (\pi_F - \pi_D) \}$	$e = 2 \times 10^{-6} [m]$	p_{38}, T_{38}
	$\pi_i = \frac{385 \times sal_i \times T_i}{0.14507(1000 - 10 sal_i)}$	$V_w = 18 [m^3 / mol]$	p_{39}, T_{39}
		$C_w = \rho$	x_{39}
		MW_w	
		$k : \text{Boltzmann}$	
		$\eta_{RO-pump}$	
		[58]	
	T : average Temp. of RO		
	R : Universal Gas Constant		
	e : membrane thickness		
	V_w : water molar volume		
	C_w : water concentration		
	$D_w = \frac{k \times T [^0 K]}{3\pi_F \mu_w d_s}$		
	$\mu_w = 4.23 \times 10^{-5} + [0.157(T_F + 64.993)^2 - 91.296]^{-1}$		
	$d_s = 0.076 MW_w$		
	d_s : Stocks diameter		
	MW : Molcular Weight		
	$sal_B = \frac{sal_F}{1 - RR}$		
	$h_{39} = \frac{h_{37} - RR \times h_{38}}{1 - RR}$		

3. Methodology

3.1. Thermodynamic analysis

Thermodynamics means studying energy, turning energy into different modes, and the ability to work energy. At first, three thermodynamic laws were drafted, but according to the fourth law, the so-called zeroth law was called, because the law had one, two, three, and it was not a fundamental principle.

Many power plants and heat engines generate useful work by converting energy. In all of them, energy translates into a mechanical component and leads to the production of work. This energy conversion is based on the first law of thermodynamics.

Mass and energy balances for each component are given as equation (1) & (2)[48, 49]:

$$\dot{m}_{in} - \dot{m}_{out} = 0 \quad (1)$$

$$\dot{E}_{in} - \dot{E}_{out} = 0 \quad (2)$$

The base thermodynamic equations of each component are expressed in Table 2, 3, 4, and 5 respectively as follow.

The number of water desalination unit equations that must be solved simultaneously is relatively high because all of these equations must be solved in the number n of the simultaneous operation that increases the number of involved equations. On the other hand, the user in the analysis input, which makes the coding more complex, and requires more flexibility, can change the number of effects. Therefore, to provide this flexibility, MED coding modeling is used in the EES software environment. Nevertheless, the rest is coding in the MATLAB software environment. This decision is causing a disruption in the simultaneous implementation of the code developed in both software, which is not desirable; because we intend to analyze all parts of the system simultaneously with the implementation of the model, and the results of one section, on effect other sectors.

To solve this problem, the MACRO coding environment of the EES software utilizes the interfacing between the two software. In this way, when the developed model is implemented in MATLAB software, the instruction to run EES software, which includes the water desalination model MED, is issued by the MACRO environment. By doing this, by running the MATLAB software, the EES application is executed, and the problem described is resolved.

3.2. Exergy analysis

To overcome the flaw in the separation of the first, and second laws of thermodynamics, we first obtain the general rule of the lost labor in general. In this section, the overall results will be simple. The potential of a system that only has a heat exchange environment is called its exergy state or thermodynamic access to its dead state. Exergy is the maximum useful work that can be obtained from a material stream or energy: as stated, useful work will be maximized if the process is reversible. Therefore, reversible work with exergy has a relationship.

The physical and chemical exergy values form the exergy of material streams can be calculated by equation (3) & (4).

The specific chemical exergy for methane can be obtained as equation (5)[48].

$$ex^{PH} = (h - h_0) - T_0(s - s_0) \quad (3)$$

$$ex^{CH} = \sum x_k ex_k^{CH} + \bar{R}T_0 \sum x_k \ln(x_k) \quad (4)$$

$$ex_{methane}^{CH} = 1.037 \times LHV_{methane} \quad (5)$$

The chemical exergy of seawater streams (molar basis) in kJ/kmol is given as follow[50, 51]:

$$ex_{sw}^{CH} = n_s(\bar{\mu}_s - \bar{\mu}_s^0) - n_w(\bar{\mu}_w - \bar{\mu}_w^0) \quad (6)$$

Which n_s is moles number of salt in seawater, and n_w is that of water.

Moreover, $\bar{\mu}_s$ is the molar chemical potential of salt in seawater in kJ/kmol, and $\bar{\mu}_w$ is that of water.

The superscript zero indicates the global dead state so that $\mu^0 = f(P_0, T_0, \text{salinity}_0)$, and $\text{salinity}_0 = \text{salinity}_{feed}$.

The chemical exergy of seawater streams (mass basis) can be obtained in kJ/kg[50, 51]:

$$ex_{sw}^{CH} = mf_s(\mu_s^* - \mu_s^0) - mf_w(\mu_w^* - \mu_w^0) \quad (7)$$

Which mf_s is a mass fraction of salt in seawater, and n_w is that of water.

Moreover, μ_s^* is a chemical potential of salt in seawater in kJ/kg at restricted dead state condition, and μ_w^* is that of water.

The superscript * indicates the restricted dead state so that $\mu^* = f(P_0, T_0, \text{salinity}_{i\text{-th stream}})$.

The total exergy of a material stream is given as follow[48, 49]:

$$ex_i = ex_i^{CH} + ex_i^{PH} \quad (8)$$

The exergy rate of the material streams can be determined as follow[48, 49]

$$\dot{Ex}_i = \dot{m}_i \times ex_i \quad (9)$$

The exergy destruction rate and exergetic efficiency of each component can be calculated by equations 10 and 11[48, 49].

$$\dot{Ex}_{D,k} = \dot{Ex}_{F,k} - \dot{Ex}_{P,k} \quad (10)$$

$$\varepsilon_k = \frac{\dot{Ex}_{P,k}}{\dot{Ex}_{F,k}} \quad (11)$$

The fuel and product exergy rate are two major values that can be defined in each component of the cycle. Table 6 shows the exergy rate of the fuel and product streams in equipment.

Table 6. Fuel and Product exergy streams of the equipment

Component	$\dot{Ex}_F \dot{Ex}_P$
-----------	-------------------------

Air Compressor	$\dot{W}_{AC}$	$\dot{E}x_2 - \dot{E}x_1$
Combustion Chamber	$\dot{E}x_2 + \dot{E}x_3$	$\dot{E}x_4$
Gas Turbine	$\dot{E}x_4 - \dot{E}x_5$	$\dot{W}_{GT}$
High-Pressure Super heater	$\dot{E}x_5 - \dot{E}x_6$	$\dot{E}x_{23} - \dot{E}x_{22}$
High-Pressure Evaporator	$\dot{E}x_6 - \dot{E}x_7$	$\dot{E}x_{22} - \dot{E}x_{21}$
High-Pressure Economizer 2	$\dot{E}x_7 - \dot{E}x_8$	$\dot{E}x_{21} - \dot{E}x_{20}$
High-Pressure Economizer 1	$\dot{E}x_8 - \dot{E}x_9$	$\dot{E}x_{20} - \dot{E}x_{19}$
Deaerator Pressure Evaporator	$\dot{E}x_9 - \dot{E}x_{10}$	$\dot{E}x_{16} - \dot{E}x_{15}$
Feed Water Preheater	$\dot{E}x_{10} - \dot{E}x_{11}$	$\dot{E}x_{13} - \dot{E}x_{12}$
Deaerator	$\dot{E}x_{13} + \dot{E}x_{16}$	$\dot{E}x_{14}$
HRSG Pack	$\dot{E}x_5 - \dot{E}x_{11}$	$\dot{E}x_{23} + \dot{E}x_{25} - \dot{E}x_{12}$
High-Pressure Pump	$\dot{W}_{HPP}$	$\dot{E}x_{18} - \dot{E}x_{17}$
De-super heater	$\dot{E}x_{24} + \dot{E}x_{25}$	$\dot{E}x_{26}$
Process Heat Exchanger	$\dot{E}x_{28} - \dot{E}x_{29}$	$\dot{E}x_{36} - \dot{E}x_{35}$
Valve 1	$\dot{E}x_{26}$	$\dot{E}x_{27}$
Valve 2	$\dot{E}x_{30}$	$\dot{E}x_{31}$
MED-TVC	$\dot{E}x_{27} + \dot{E}x_{32}$	$\dot{E}x_{34} + \dot{E}x_{30} + \dot{E}x_{37} + \dot{E}x_{30}$
RO	$\dot{E}x_{37} + \dot{W}_{RO-pump}$	$\dot{E}x_{38}$

3.3.Exergoeconomic analysis

Exergoeconomic or thermoeconomic is a branch of engineering that combines exergy analysis with economic principles, and thus provides designers of a system with information that is not available through routine analysis of energy and economic research, but for the design, and operation of an optimally priced system is critical. Therefore, the objectives of exergy control analysis include the separate calculation of the costs of each product produced by the multi-product system, the perception of the process of cost formation, and system flow, the optimization of specific variables in a single component, and the overall optimization of the system.

Different methods have been proposed for exergy-cosmetic analysis. In this research, a special cost method for exergy has been used. This cost-based approach to exergy units, exergy efficiency, and auxiliary equations for different components of the thermal system is based. This method involves the identification of exergy flows, the identification of fuel and product for each component of the thermal system, and the use of cost relationships.

In Exergy pricing, an expense is assigned to each exergy stream. These exergy currents include the exergy transmitted by the inlets and outlets, by work and by heat. Table 7 shows the purchased cost of equipment.

Table 7. Purchase Equipment Cost of the equipment in [\$]

Component	equation
Air Compressor	$44.71m_a \cdot r_{p,AC} \cdot \ln(r_{p,AC}) \cdot \frac{1}{0.95 - \eta_{AC}}$ [49]
Combustion Chamber	$\frac{28.98m_a}{0.995 - \frac{P_{out}}{P_{in}}} \cdot (1 + e^{(0.015(T_{out} - 1540))})$ [49]
Gas Turbine	$479.34 \frac{m_{fg}}{0.93 - \eta_{GT}} \cdot \ln(r_{p,GT}) \cdot (1 + e^{(0.036 \cdot T_{in} - 54.4)})$ [59]
HRSG	$6570[(\frac{Q_{EC}}{\Delta T_{EC}})^{0.8} + (\frac{Q_{EV}}{\Delta T_{EV}})^{0.8} + (\frac{Q_{SH}}{\Delta T_{SH}})^{0.8}] + 21276 m_w + 1184.4 m_{fg}^{1.2}$ [59]
Deaerator	$6570(\frac{Q_{DEA}}{\Delta T_{DEA}})^{0.8}$ [52]
Pump	$3540W_{Pump}^{0.71}$ [60]
Valve	$8.07 \times 0.989 \times \dot{m} \times (\frac{T_i}{P_i})^{0.05} \times P_e^{-0.75}$ [61]
Desuperheater	$1060 \times \frac{\dot{m}}{\rho}$ [61]
MED	$\sum PEC_{effects} + \sum PEC_{feed-heaters} + \sum PEC_{flash-boxes} + PEC_{condenser}$ $PEC_{HX} = 12000 \left(\frac{Area}{100} \right)^{0.6}$ [52]
TVC	$2 \times 8.07 \times 0.989 \times \dot{m} \times (\frac{T_i}{P_i})^{0.05} \times P_e^{-0.75}$ [61]
	$PEC_{membrane} + PEC_{pretreat} + PEC_{RO-pump} + PEC_{RO-valve}$ $PEC_{membrane} = NO_{membranes} \times PEC_{one-membrane}$ $PEC_{one-membrane} = 7846$
RO	$PEC_{pretreat} = 996 \times \xi_1 \left(\frac{\dot{m}_{RO-feed}}{\rho} \times 24 \times 3600 \right)^{0.8}$ [61, 62] $\xi_1 = 1.399$: inflation factor $PEC_{RO-pump} = 393000 \xi_1 + 701.19 \times 14.5 \times P_{RO-feed}$ $PEC_{RO-valve} = 8.07 \times 0.989 \times \dot{m} \times (\frac{T_i}{P_i})^{0.05} \times P_e^{-0.75}$

The cost rate of the equipment can be obtained as equation 9[49].

$$\dot{Z}_k = \frac{\Phi_k \times PEC_k \times CRF}{3600 \times N} \quad (9)$$

Φ_k : the maintenance factor: 1.06[48, 49].

N : the annual operating hours of the system: 7446 ~ 8000 hours[48, 49].

CRF : the capital recovery factor[48]:

$$CRF = \frac{i \times (1+i)^{ny}}{(1+i)^{ny} - 1} \quad (10)$$

i : interest rate

ny : the working years of the system that considered 25 years[48, 49].

the exergoeconomic balance equation for each component in the cycle can be written as follow[48].

$$\dot{C}_{P,k} = \dot{C}_{F,k} - \dot{C}_{L,k} + \dot{Z}_k \quad (11)$$

$$\sum_e \dot{C}_{e,k} + \dot{C}_{w,k} = \dot{C}_{q,k} - \sum_i \dot{C}_{i,k} + \dot{Z}_k \quad (12)$$

$$\dot{C}_i = c_i \cdot \dot{E}x_i \quad (13)$$

The exergy destruction's cost rate of the equipment is given as follows [48].

$$\dot{C}_{D,k} = c_{F,k} \cdot \dot{E}x_{D,k} \quad (14)$$

The exergoeconomic factor for each component can be calculated as follow[48].

$$f_k = \frac{\dot{Z}_k}{\dot{Z}_k + c_{f,k} \cdot \dot{E}x_{D,k}} \quad (15)$$

The relative cost difference of the equipment is another parameter that can be obtained as equation 16 [48]:

$$r_k = \frac{c_{P,k} - c_{F,k}}{c_{F,k}} = \frac{1 - \varepsilon_k}{\varepsilon_k} + \frac{\dot{Z}_k}{c_{f,k} \cdot \dot{E}x_{P,k}} \quad (16)$$

3.4. Exergoenvironmental analysis

The exergoenvironmental analysis includes three steps. First, an exergy analysis has been determined for each stream of the cycle, and in the second step the

environmental impacts of each component in the process of the manufacturing has been calculated, and then in the third step the exergoenvironmental balance equation has been developed to calculate the environmental impact of each stream in the cycle.

The exergoenvironmental balance equation for each component can be written as follow[52].

$$\dot{B}_{P,k} = \dot{B}_{F,k} - \dot{B}_{L,k} + \dot{Y}_k \quad (11)$$

$$\sum_e \dot{B}_{e,k} + \dot{B}_{w,k} = \dot{B}_{q,k} - \sum_i \dot{B}_{i,k} + \dot{Y}_k \quad (12)$$

$$\dot{B}_i = b_i \cdot \dot{E}x_i \quad (13)$$

The exergy destruction's environmental impact rate of the equipment can be found in equation 14[52].

$$\dot{B}_{D,k} = b_{F,k} \cdot \dot{E}x_{D,k} \quad (14)$$

The exergoenvironmental factor for each component can be obtained as equation 15[52].

$$fb_k = \frac{\dot{Y}_k}{\dot{Y}_k + b_{f,k} \cdot \dot{E}x_{D,k}} \quad (15)$$

The relative environmental impact difference of the equipment are given as follow :[52]

$$rb_k = \frac{b_{P,k} - b_{F,k}}{b_{F,k}} = \frac{1 - \varepsilon_k}{\varepsilon_k} + \frac{\dot{Y}_k}{b_{f,k} \cdot \dot{E}x_{P,k}} \quad (16)$$

Environmental impact of the equipment multiplying weight, and environmental impact per mass unit of the components:[52]

$$y_k = w_k \times bm_k \quad (17)$$

Which y_k is the environmental impact of the component in pts, and w_k is the weight of the component in tons.

bm_k is environmental impact per mass unit of the component in pts/ton which is a function of the component's material, and it can be derived from Eco-indicator 99 knowing the material composition of each component[53].

The weight function of each component is given in table 8.

Table 8. Weight function of the equipment in tons

Component	equation
-----------	----------

Air Compressor	$\frac{100 \times P_e \times d_{AC} \times FS_{AC}}{2 \times \sigma_{AC}}$	
	$FS_{AC}=2$: safety factor of AC	[52]
	$\sigma_{AC}=16$: rupturing stress of AC in MPa	
	d_{AC} : diameter considering $\dot{m}$ and velocity=15m/s	
Combustion Chamber	$\frac{100 \times P_e \times d_{CC} \times FS_{CC}}{2 \times \sigma_{CC}}$	
	$FS_{CC}=2$: safety factor of CC	[52]
	$\sigma_{CC}=45$: rupturing stress of CC in MPa	
	d_{CC} : diameter considering $\dot{m}$ and velocity=6.2m/s	
Gas Turbine	$\frac{100 \times P_e \times d_{GT} \times FS_{GT}}{2 \times \sigma_{GT}}$	
	$FS_{GT}=2$: safety factor of GT	[52]
	$\sigma_{GT}=6$: rupturing stress of GT in MPa	
	d_{GT} : diameter considering $\dot{m}$ and velocity=13m/s	
Deaerator	$2.49 \times \dot{m}_w^{0.7}$	[52]
Pump	$0.0061 \times \dot{W}_{pump}^{0.95}$	$\dot{W}$ in KW [52]
Super heater	$8.424 \times \dot{Q}_{SH}^{0.87}$	$\dot{Q}$ in MW [52]
Evaporator	$13.91 \times \dot{Q}_{EV}^{0.68}$	$\dot{Q}$ in MW [52]
Economizer	$2.989 \times \dot{Q}_{EC}^{0.97}$	$\dot{Q}$ in MW [52]
MED	Environmental Impact of MED can be calculated directly and independent of its weight	
TVC	$0.001 \times 33.96 \times \sqrt{(0.5992 \times NS_{TVC})^{3.056}}$	
	NS_{TVC} : Nominal Size of TVC	
	$NS_{TVC} = 0.1277 \times \sqrt{(1.188 \times 3600 \times \dot{m}_{1st \text{ effect motive steam}})^{0.9819}}$	
RO	Environmental Impact of RO can be calculated directly and independent of its weight	

The weight function of TVC is derived and proposed in this paper using technical data of TVCs in different nominal sizes manufactured by KADANT incorporation.

Environmental impact rate of RO in $\frac{mpts}{h.m^3}$ distillate using interpolation data gathered, and can be calculated by equation [54]:

$$\dot{Y}_{RO} = 0.0195 \times \frac{\rho \times \dot{W}_{RO}}{3600 \times \dot{m}_{RO-distillate}} + 0.00595 \quad (18)$$

The environmental impact rate of MED in $\frac{mpts}{h.m^3}$ distillate is equal to $\dot{Y}_{MED} = 1.277$ [54].

3.5. Optimization

In short, the Genetic Algorithm (GA) is a programming technique that uses genetic evolution as a problem-solving paradigm. The problem to be addressed is input, and the solutions are coded according to a pattern called fitness function, and each path Evaluates the candidate solution, most of which are selected at random. Genetic Algorithm (GA) is a computer science search technique for finding optimal solutions and search problems. Genetic algorithms are one of a variety of evolutionary algorithms that are inspired by the science of biologics such as inheritance, mutation, natural selection, and natural

selection.

The optimization procedure in the genetic algorithm is based on a random-directed procedure. This method is based on the theory of gradual evolution and Darwin's fundamental ideas. In this method, a set of random parameters is randomly generated for several constants called populations, after executing a numerical simulator that represents the standard deviation and Or we fit that set of information to that member of that population. We repeat this procedure for each of the created members, and then call upon the genetic algorithm operators, including fertilization, mutation, and next-generation selection, and this process will continue until the convergence criterion is satisfied.

Commonly, three criteria are considered as a stop criterion:

- Algorithm execution time
- The number of generations created
- The convergence of error criteria

Table 9. Objective Functions of the system

Objective Function	Symbol	Unit
Total Exergetic Efficiency of the System	ψ_{total}	%
Total Exergetic Cost Rate of the System	$\dot{C}_{total}$	$\$.min^{-1}$
Total Exergoenvironmental Impact Rate of the System	$\dot{B}_{total}$	$pts.min^{-1}$

Table 10. Decision Variables of the base case system

No.	Decision Variables	Symbol	Unit	Constraint
1	Number of MED's Effects	n_{MED}	---	3-12
2	Recovery Ratio of MED	RR_{MED}	---	0.1-0.6
3	Evaporator Pinch Temperature Difference	$\Delta T_{Pinch, EV}$	$^{\circ}C$	5-75
4	Feed Water Preheater Approach Temperature	$\Delta T_{Approach, FWPH}$	$^{\circ}C$	0-15
5	Economizer Approach Temperature	$\Delta T_{Approach, EC}$	$^{\circ}C$	0-10
6	Superheater Superheated Temperature	$T_{Sup, SH}$	$^{\circ}C$	5-80
7	Compressor Ratio of TVC	$r_{p, TVC}$	---	1.5-5
8	Feed Pressure of RO	$P_{Feed, RO}$	bar	10-60

4. Results and discussion

As stated, the studied cycle included the steam cycle of the Qeshm combined cycle power plant and one water desalination unit. To start the thermal water desalination, a discharge from the line of the LP steam cycle of the power plant has been used. In the following, the reason for using this section is the combined cycle, and then the results of the exergy analysis of this cycle and the effect of discharge on

the operation of the power plant are explained. In a power plant, there is a combination of points that can be used as a source of energy in other heating systems, such as hot water sprinklers. These points include the heat dissipated by the outlet of the power plant chimney, the steam outlet from the LP line, and the entrance to the condenser, the discharge line of the LP and HP. Regarding the use of waste heat from the chimney, which is done by adding an auxiliary cycle

to the end of the boiler, it should be noted that this mode cannot supply the pressure required for the commissioning of the thermocouple. However, it is suitable for use in other types of water Thermal desalination unit without Thermo compressor. In the case of the steam outlet from the LP line, and the use of the first stage of the desalination system instead of the condenser, it should be noted that this steam not only does not have the ability to supply the pressure required for the commissioning of the thermocouple compressor, but because of its low temperature, It is also not used in other types of thermal desalination. Concerning the withdrawal of the HP line due to the high steam pressure at this stage and that this pressure is outside the pressure range of the thermocouple compressors, the idea of using high-pressure turbine steam line steam for use in MED-TVC

It is also excluded. Here, the idea of using an auxiliary burner in a power plant boiler and supplying a desirable water supply can be made into mind. Nevertheless, because of the increased energy consumption in this case and the goal of recycling and reducing energy consumption in the survey.

The project for the production of electricity, and water Qeshm, to save fossil fuels and increase the efficiency of gas power plants, was exploited with a capacity of 50 megawatts of electricity and 18 thousand cubic meters of Freshwater.

The thermodynamic properties of the cycle include: mass flow, temperature, and pressure are presented in table 11. The exergy rate of each stream is indicated in this table, and the cost rate and environmental are determined.

Table 11. Thermodynamic, exergoeconomic and exergoenvironmental data of all material streams

	$\dot{m}[Kg/s]$	$T[^\circ C]$	$P[bar]$	$\dot{E}x[MW]$	$c[\$/GJ]$	$\dot{C}[\$/h]$	$b[pts/GJ]$	$B[pts/h]$
1	83.58	35.00	1.0032	0.174	0.000	0.000	0.000	0.000
2	83.58	489.46	19.2923	36.73	13.93	1842.4	5.423	717.01
3	1.37	35.00	30.6400	72.79	6.50	1703.2	2.875	753.42
4	84.95	1232.2	18.5206	90.06	10.94	3548.5	4.536	1470.7
5	84.95	515.81	1.0302	19.31	10.94	760.82	4.536	315.32
6	84.95	491.33	1.0294	17.91	10.94	705.67	4.536	292.47
7	84.95	276.51	1.0200	7.161	10.94	282.14	4.536	116.94
8	84.95	228.41	1.0155	5.251	10.94	206.89	4.536	85.75
9	84.95	183.03	1.0138	3.713	10.94	146.31	4.536	60.64
10	84.95	177.36	1.0136	3.541	10.94	139.51	4.536	57.82
11	84.95	166.42	1.0132	3.220	10.94	126.88	4.536	52.58
12	12.71	75.46	1.2360	0.162	17.54	10.233	6.639	3.872
13	12.71	94.81	1.200	0.306	25.86	28.511	8.261	9.107
14	12.94	104.78	1.200	0.399	27.23	39.115	8.462	12.16
15	0.24	104.78	1.200	0.0075	27.23	0.7331	8.462	0.228
16	0.24	104.78	1.200	0.1061	27.45	10.488	7.978	3.048
17	12.71	104.78	1.200	0.399	27.23	39.115	8.462	12.16
18	12.71	106.03	53.30	0.477	25.61	43.981	8.231	14.14
19	12.41	106.03	53.30	0.466	25.61	42.964	8.231	13.81
20	12.41	186.40	52.55	1.594	19.73	113.22	6.783	38.92
21	12.41	264.90	51.75	3.327	17.05	204.19	5.853	70.11
22	12.41	266.10	51.75	12.02	14.97	647.49	5.679	245.66
23	12.41	317.50	50.00	13.01	15.12	708.15	5.735	268.59
24	5.66	317.50	50.00	5.934	15.12	323.01	5.735	122.51
25	0.29	106.03	53.30	0.011	25.61	1.017	8.231	0.327
26	5.95	278.90	50.00	5.900	15.31	325.17	5.783	122.84
27	5.95	217.11	12.90	4.882	18.50	325.17	6.989	122.84

28	6.75	315.00	50.00	7.052	15.12	383.85	5.735	145.59
29	6.75	82.22	1.236	0.120	15.12	5.981	5.735	2.269
30	5.95	67.50	16.00	0.064	18.50	4.244	6.989	1.603
31	5.95	67.79	1.236	0.056	21.25	4.251	8.014	1.603
32	316.42	35.00	1.0132	0.000	0.000	0.000	0.000	0.000
33	123.19	48.71	1.0132	1.498	0.000	0.000	0.000	0.000
34	51.72	48.15	4.500	0.206	471.2	349.83	487.1	361.64
35	141.48	35.00	2.000	0.367	0.000	0.000	0.000	0.000
36	141.48	65.00	1.400	1.170	89.75	378.18	34.01	143.32
37	141.51	45.00	1.0132	0.089	0.000	0.000	0.000	0.000
38	70.87	45.00	1.0132	0.224	161.12	129.94	38.98	31.437
39	70.65	46.45	1.0132	2.774	0.000	0.000	0.000	0.000

Table 12. Comparison of main parameters of thermodynamic modeling in Thermoflex with those of first law analysis programmed in MATLAB concerned with the streams

	$\dot{m}[Kg/s]$				$T[^\circ C]$				$P[bar]$		
	MATLAB	Thermoflex	Error [%]		MATLAB	Thermoflex	Error [%]		MATLAB	Thermoflex	Error [%]
1	83.58	83.53	0.06	35.00	35.00	0.00	1.0032	1.003	0.02		
2	83.58	83.53	0.06	489.46	488.6	0.18	19.2923	19.5	1.07		
3	1.37	1.419	3.45	35.00	35.00	0.00	30.6400	30.64	0.00		
4	84.95	84.94	0.01	1232.2	1232.2	0.00	18.5206	18.72	1.07		
5	84.95	84.94	0.01	515.81	515	0.16	1.0302	1.0302	0.00		
6	84.95	84.94	0.01	491.33	491.4	0.01	1.0294	1.0294	0.00		
7	84.95	84.94	0.01	276.51	279.1	0.93	1.0200	1.02	0.00		
8	84.95	84.94	0.01	228.41	230	0.69	1.0155	1.0155	0.00		
9	84.95	84.94	0.01	183.03	183.3	0.15	1.0138	1.0138	0.00		
10	84.95	84.94	0.01	177.36	177.4	0.02	1.0136	1.0136	0.00		
11	84.95	84.94	0.01	166.42	166.1	0.19	1.0132	1.0132	0.00		
12	12.71	12.76	0.39	75.46	75.59	0.17	1.2360	1.236	0.00		
13	12.71	12.76	0.39	94.81	94.81	0.00	1.200	1.2	0.00		
14	12.94	13.00	0.46	104.78	104.8	0.02	1.200	1.2	0.00		
15	0.24	0.24	0.00	104.78	104.8	0.02	1.200	1.2	0.00		
16	0.24	0.24	0.00	104.78	104.8	0.02	1.200	1.2	0.00		
17	12.71	12.76	0.39	104.78	104.8	0.02	1.200	1.2	0.00		
18	12.71	12.76	0.39	106.03	106.1	0.07	53.30	53.3	0.00		
19	12.41	12.46	0.40	106.03	106.1	0.07	53.30	53.3	0.00		
20	12.41	12.46	0.40	186.40	186.4	0.00	52.55	52.55	0.00		
21	12.41	12.46	0.40	264.90	264.9	0.00	51.75	51.75	0.00		
22	12.41	12.46	0.40	266.10	266.1	0.00	51.75	51.75	0.00		
23	12.41	12.46	0.40	317.50	317.5	0.00	50.00	50.00	0.00		
24	5.66	5.668	0.14	317.50	317.5	0.00	50.00	50.00	0.00		
25	0.29	0.299	3.01	106.03	106.1	0.07	53.30	53.3	0.00		
26	5.95	5.967	0.28	278.90	278.9	0.00	50.00	50.00	0.00		

27	5.95	5.967	0.28	217.11	217.2	0.04	12.90	12.9	0.00
28	6.75	6.788	0.56	315.00	317.5	0.79	50.00	50.00	0.00
29	6.75	6.788	0.56	82.22	82.22	0.00	1.236	1.236	0.00
30	5.95	5.967	0.28	67.50	67.74	0.35	16.00	16.00	0.00
31	5.95	5.967	0.28	67.79	68.02	0.34	1.236	1.236	0.00
32	316.42	343.4	7.86	35.00	35.00	0.00	1.0132	1.0132	0.00
33	123.19	123.1	0.07	48.71	47.68	2.16	1.0132	1.014	0.08
34	51.72	51.72	0.00	48.15	47.14	2.14	4.500	4.50	0.00
35	141.48	141.61	0.09	35.00	35.00	0.00	2.000	2.00	0.00
36	141.48	141.61	0.09	65.00	65.00	0.00	1.400	1.40	0.00
37	141.51	141.51	0.00	45.00	45.06	0.13	1.0132	1.014	0.08
38	70.87	70.64	0.33	45.00	48.74	7.67	1.0132	1.013	0.02
39	70.65	70.87	0.31	46.45	46.91	0.98	1.0132	1.013	0.02

The stream No.4, which is the output stream of the combustion chamber, has the highest exergy rate among all cyclic flows. This flow is about 90 megawatts of exergy. In addition, the flow of the outlet from the combustion chamber has the highest cost rate in the cyclic flows. This stream costs around \$ 3,548.5 per hour per cycle. It also has the highest altitudinal rate throughout the entire cycle. In this process, the rate of annoyance is about 1471 mpts per second. The reason for the high rate of exergy in this flow is the high temperature, and pressure of the exhaust stream from the combustion chamber. Also due to the use of fossil fuels in the combustion chamber, the cost, and degree of contamination of this stream is high. Nevertheless, after the flow of the outlet from the combustion chamber, the fuel flow into it has the highest exergy rate. It has an exergy content of about 73 megawatts. The cost of the fuel flow is about \$ 1703 per hour, and its pollution is about 753 mpts per hour.

The compressor consumes 62% of the power output by the gas turbine. The amount of heat exchanged in each of the heat exchangers through MATLAB coding, and thermoflow simulation is shown in Table 12. Also, the amount of error between computer code, and Thermoflex simulation has been reported. The performance ratio of each sweetener is another important parameter. This amount for MEDTVC is about 8.7. This value represents the proportion of sweet water produced to steam consumption. This amount for RO is 0.5.

The exergy destruction rate in each component has been presented in the figure 2.

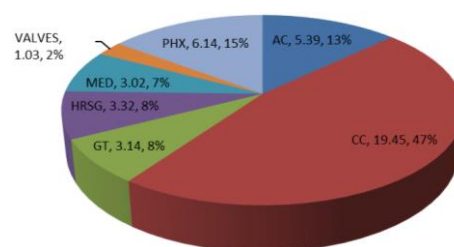


Figure 2. Exergy destruction distribution of the equipment in MW and percent

According to Fig. 2, the highest rate of exergy degradation is related to the combustion chamber, which accounts for about 45.5% of the total exergy destruction of the cycle. The combustion chamber has about 19.5 megawatts of exergy destruction. The process heat exchanger is the next device that has the highest rate of exergy destruction. This equipment has about 6.14 megawatts of exergy destruction, which is about 15% of the total exergy destruction of the cycle. The exergy destruction of the air compressor is 13%, and the gas turbine has 8% of total exergy destruction. The MED unit also has a 7% destruction of the exergy cycle.

The ever-increasing demand for water, and services resulting from population growth, and rising standards of living, and health, on the one hand, and the limitation of water resources and droughts and climate change, on the other hand, is the view of planners and water experts from unconventional waters (sewage, wastewater, and saline water). Also, the disposal of industrial, and urban wastewater, and the penetration of existing contaminations into surface water, and groundwater resources is a major concern in many countries, including Iran. Sewage treatment and its application in various uses negatively affects the release of wastewater to the environment, and the health of human societies. Based on this, in this paper, the methodology of economic and environmental assessment of sweet water production from Persian Gulf and the economic and environmental assessment

of this project has been addressed. The exergoenvironmental and exergoeconomic analysis

results are presented in table 13.

Table 13. Investment cost rate, exergoeconomic factor and relative cost difference, environmental impact rate, exergoenvironmental factor, relative environmental impact difference and exergetic efficiency of the equipment

Component	$\dot{Z}[\$/h]$	$f[\%]$	$r[\%]$	$\dot{C}_D[\$/h]$	$\dot{Y}[h\ pts/h]$	$fb[\%]$	$rb[\%]$	$\dot{B}_D[pts/h]$	$\varepsilon[\%]$
<i>Air Compressor</i>	109.41	32.96	21.98	222.58	5.2704	0.572	14.74	92.08	87.16
<i>Combustion Chamber</i>	28.4	4.31	21.70	629.78	25.856	0.989	21.62	261.18	82.24
<i>Gas Turbine</i>	58.4	32.04	4.87	123.84	32.297	6.253	4.68	51.33	95.56
<i>High-Pressure Super heater</i>	5.51	25.66	54.83	15.97	7.4787	11.17	41.22	6.62	71.04
<i>High-Pressure Evaporator</i>	19.78	19.58	29.50	81.20	2.0242	0.601	23.73	33.66	80.83
<i>High-Pressure Economizer 2</i>	15.71	69.32	33.20	6.96	0.2438	0.845	10.19	2.88	90.76
<i>High-Pressure Economizer 1</i>	9.67	37.45	58.11	16.15	0.2304	0.344	36.36	6.69	73.34
<i>Deaerator Pressure Evaporator</i>	2.95	98.44	77.45	0.05	0.1708	18.93	23.80	0.02	57.15
<i>Feed Water Preheater</i>	5.65	4.05	221.6	133.83	0.0580	0.010	122.3	55.46	44.99
<i>Deaerator</i>	0.11	8.40	3.65	1.26	0.0171	0.436	3.34	0.39	96.77
<i>HRSG Pack</i>	59.27	18.71	37.52	257.54	10.206	0.955	25.86	106.74	79.85
<i>High-Pressure Pump</i>	0.08	5.08	51.05	1.56	0.0497	0.768	48.49	0.65	67.36
<i>Process Heat Exchanger</i>	0.3	0.09	765.2	334.16	0.0237	0.001	764.4	126.74	11.57
<i>MED-TVC</i>	28.91	8.75	186.2	301.27	24041	67.87	677.3	113.81	38.04
<i>RO</i>	96.17	42.75	728.3	128.77	1746.8	24.69	810.4	53.27	24.72

The highest rate of purchase is related to the air compressor, and then desalination unit also have a high cost rate. The cost of exergy destruction in the combustion chamber has the highest rate, and it costs \$ 630 per hour. The cost of exergy destruction in the combustion chamber is approximately 3 times the air compressor, and 5 times the gas turbine. Similarly, the rate of emissions associated with exergy destruction in the combustion chamber has the highest rate.

Genetic algorithms are better because of their strength and durability than other methods based on artificial intelligence. Unlike older artificial intelligence systems, the genetic algorithm is not quickly interrupted by slight changes in input values or by significant amounts of noise in the system. Also, in the search for a large state space, a multimodal state

space, or a multidimensional procedure, the use of genetic algorithms has many advantages over conventional search techniques in other optimization techniques such as linear programming, random search, or the first search methods have depth, first level or praxis. The objective functions are produced by Genetic programming and the functions are presented in Table 13.

Figure 3 shows the optimal pareto front solutions for two Objective Functions (OFs) (exergetic efficiency and total exrgetic costs). In addition, Figure 4 and 5 determine pareto front optimal solutions for total exergetic cost vs exergetic environmental impacts OFs and exergetic efficiency vs exergetic environmental impacts OFs respectively.

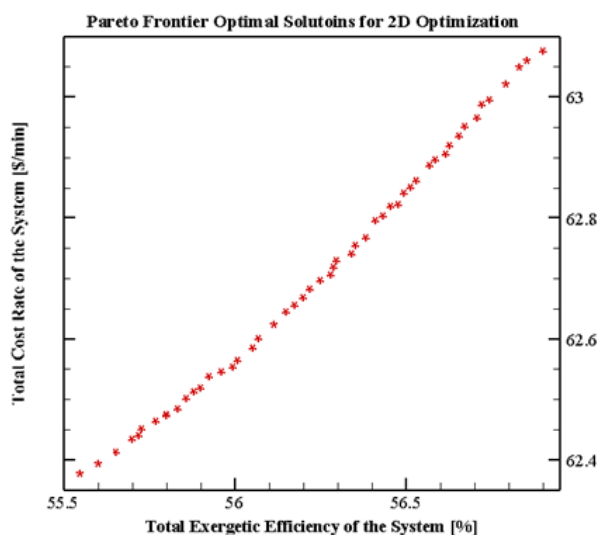


Figure 3. Optimal Pareto Front Solutions for Two-Objective Functions -Base Case (Total Costs vs Exergetic Efficiency)

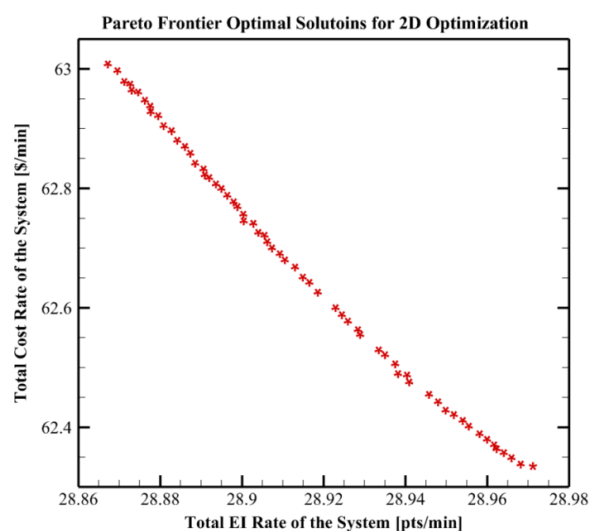


Figure 4. Optimal Pareto Front Solutions for Two-Objective Functions -Base Case (Total Exergetic Cost vs Exergetic Environmental Impacts)

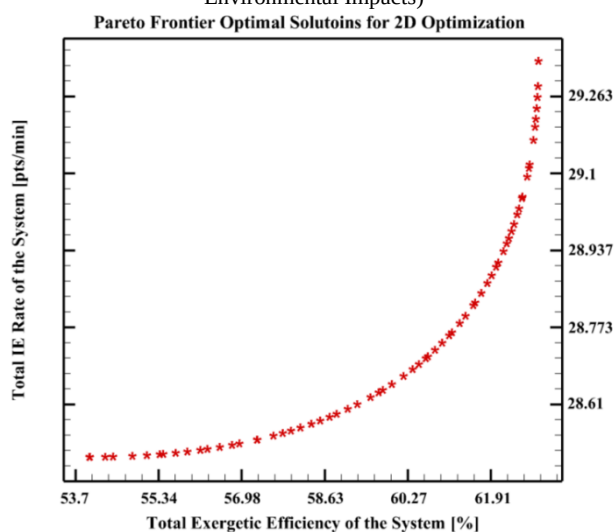


Figure 5. Optimal Pareto Front Solutions for Two-Objective Functions -Base Case (Exergetic Efficiency vs Exergetic Environmental Impacts)

Table 14 and 15 are indicated the optimized variables of the objective functions and decision variables.

As shown in the results, the overall exergetic efficiency of plant has been improved by 27.74%. Also, the exergetic cost of plant has been reduced by 0.93 \$/min and exergoenvironmental impacts has been decreased by 0.85 pts/min.

Sensitivity analysis for objective functions has been performed based on variation of fuel LHV, ambient temperature, interest rate and exergy cost of fuel. The results of sensitivity analysis related to variation of fuel LHV, ambient temperature, interest rate, exergy cost of fuel have been demonstrated in Figure Fig.6-Fig.9 respectively.

Table 14. Selected Optimized solution for objective functions using MOGA

cases	ψ_{total} [%]	$\dot{C}_{total}$ [\$\cdot min^{-1}\$]	$\dot{B}_{total}$ [pts. min ⁻¹]
Optimized (MOGA)	59.88	63.08	28.64
Base Case	46.86	64.01	29.49

Table 15. Selected Optimized solution for objective functions using MOGA

	n_{MED}	RR_{MED}	$\Delta T_{pinch,EV}$	$T_{app,PH}$	$T_{app,EC}$	$T_{sup,SH}$	$p_{r,TVC}$
MOGA	8	0.60	6.43	2.70	7.45	74.12	4.98
Base Case	5	0.30	72.58	9.97	1.20	53.56	2.08

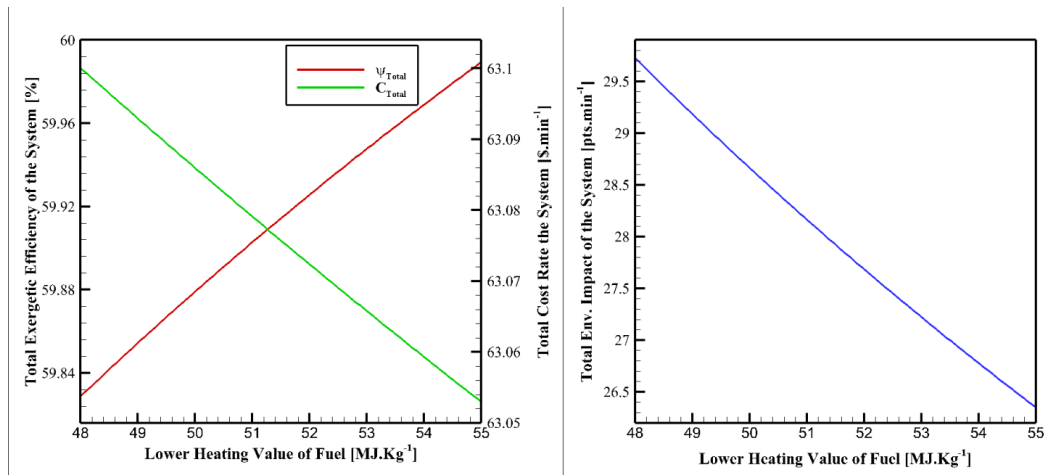


Figure 6. Sensitivity analyses based on variation of Fuel LHV

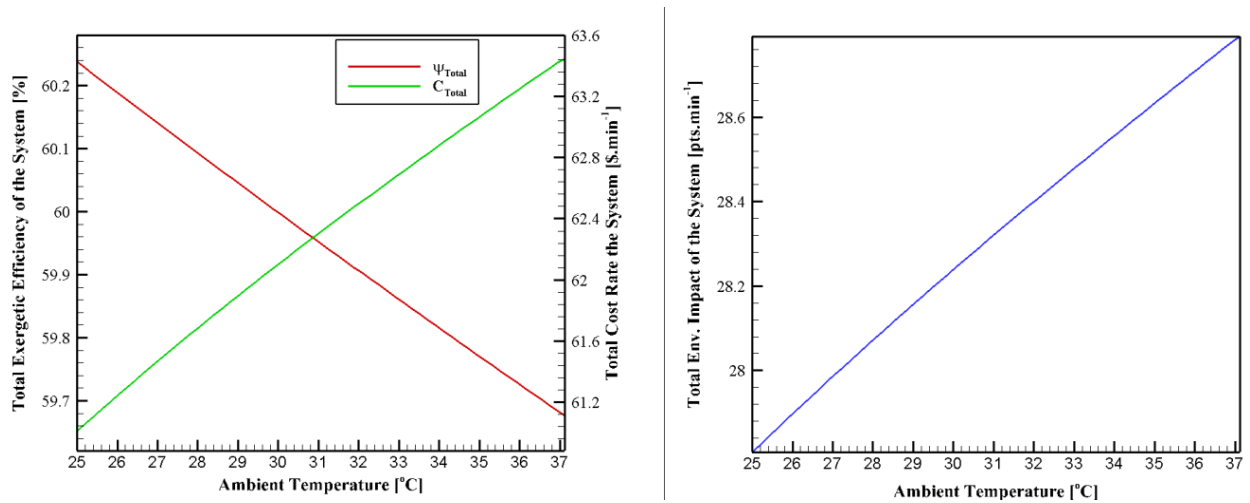


Figure 7. Sensitivity analysis of OFs based on variation of ambient temperature

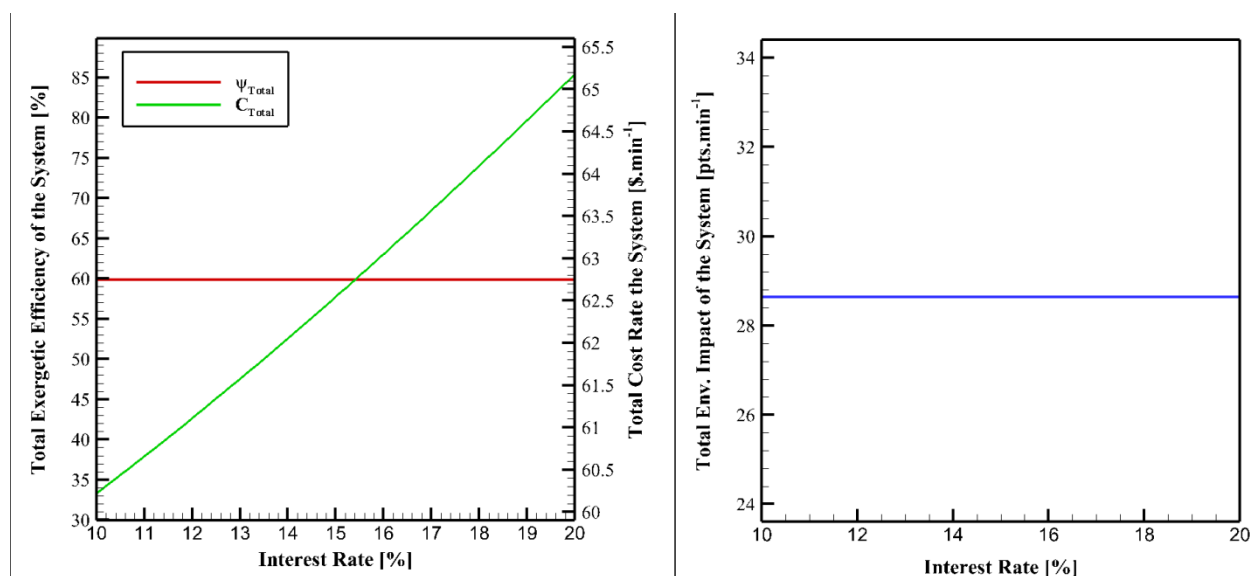


Figure 8. Sensitivity analysis of OFs based on variation of interest rate

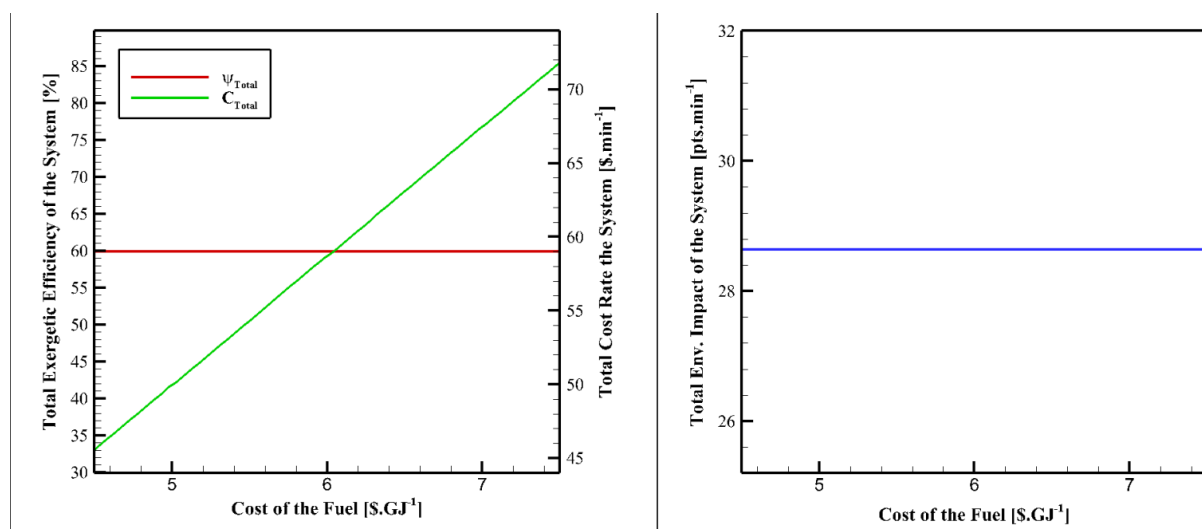


Figure 9. Sensitivity analysis of OFs based on cost of fuel

5. Conclusion

In this study, energetic, exergetic, exergoeconomic and exergoenvironmental analysis and optimization of Qeshm MED-TVC cogeneration plant based on 25 MW, MAPNA Gas Turbine prime mover have been considered. In this regard, the computer program has been developed. Also, the integration of the RO desalination system has been investigated. MOGA optimization of existing plant-based on overall exergetic efficiency, total exergetic costs and total exergoenvironmental impacts have been done. The results indicate the optimum scenario has a good performance in view of exergetic, exergoeconomic and exergoenvironment.

The optimum plant overall exergetic efficiency has been increased by 27.78%, and total exergetic cost and total exergoenvironmental impacts have been decreased by 0.93% and by 0.89%.

In the future research, the advanced exergetic, exergoeconomic and exergoenvironmental analysis can be done to better show the performance of system

in the base and optimum cases precisely.

In addition, other recently optimization algorithms can be examined and evaluated. Finally, the use of renewable energy to improve the plant performance can be studied.

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