J Ther Eng, Vol. 7, No. 7, pp. 1704–1718, November 2021

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.18186/thermal.1025944

Research Article

Examining performance and optimization of a cogeneration system comprised with allam cycle and MED-TVC for generating power and drinking water: Case study: Kish island

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ARTICLE INFO

Article history
Received: 17 July 2020
Accepted: 8 December 2020

Keywords:
Multi-effect Distillationq; Allam Cycle; Exergy; Energy; Optimization

ABSTRACT

In this paper, a new thermodynamic cycle for power and fresh water production is presented, which includes MED-TVC desalinations and Allam cycles due to the important influence they have on the electric power industry in controlling and limiting greenhouse emissions. First, the Allam cycle analyzed and the appropriate location for heat-extraction identified to produce the required water vapor for the desalination system. It was determined that the heat site suitable for use in the desalination cycle is the heat from the outlet of the Compressor, which is estimated as 100 MW. The MED-TVC Desalination, one of the most suitable and most economical desalination, is used to combine the Allam cycle and desalination in the Kish district, located in the south of Iran. The proposed cycle is analyzed from the perspective of energy and exergy. The results show, the highest amount of exergy used to generate power in turbine and the amount of produced freshwater increase with increasing the capacity of Turbine. For this purpose genetic algorithm is used in two different scenarios to minimize and maximize the exergy destruction and produced fresh water respectively. The optimization of the system with genetic algorithm led to 18% decrease in total exergy destruction of the cycle in the first scenario and 7% decrease in the second optimization scenario. Furthermore, the efficiency of the cycle in first scenario and second scenario increased by 30% and 13% respectively. In the scenario optimization scheme, the amount of fresh water increased by 22%.

Cite this article as: Azadeh A, Alireza N, Alireza K, Alireza S. Examining performance and optimization of a cogeneration system comprised with allam cycle and MED-TVC for generating power and drinking water: Case study: Kish island. J Ther Eng 2021;7(7):1704–1718.

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This paper was recommended for publication in revised form by Regional Editor Younes MENNI

Published by Yıldız Technical University Press, İstanbul, Turkey

INTRODUCTION

In the coming decades, the world will face huge problems, such as extreme water shortages, climate change and energy shortages. Some of these problems (such as extreme water shortages) have threatened humans on Earth, while others (such as climate change) have shown long-term effects. For example, due to the steady production of fossil fuels for electricity production, the world is facing increasing levels of carbon dioxide in the upper atmosphere[1–3]. Consequently, the United Nation (UN) proposed some long-term action plans such as millennium development goals (MDGs) and sustainable development goals (SDGs) from the beginning of 21 century. Hence, the decision makers concluded that novel technologies are needed to solve and face these problems. Commonly-used technologies for reducing greenhouse gas emissions in fossil fuel systems face challenges such as high investment costs As humans rely heavily on fossil fuels, the production of carbon dioxide will increase dramatically. As a result, we need to speed up the development of lower-cost technologies to reduce fossil fuel pollution. [4–6]. Hence, investigations have identified different solutions to reduce costs and pollution. One of the most important solutions is Net Power, which has developed a new thermodynamic cycle that burns pure oxygen. It also absorbs nearly 100 percent of CO2 and other atmospheric emissions. Furthermore, its costs can compete with the best systems that will not absorb carbon dioxide. Net Power in partnership with Toshiba, Exelon and Kurt Schwa, commercialized the system; they designed and tested a model with 50MW of capacity for this system. This cycle generates electricity from natural gases that absorbs 100% carbon dioxide. Allam cycles have an important impact on the ability of the electric power industry to control and limit greenhouse gas emissions [7, 8].

Researchers conducted on the Allam cycle are not enough and they are done mostly with the purpose of electricity production and controlling the greenhouse gasses emission. It is possible to use the wasted energy of the Allam cycle to make the cycle more efficient and increase its efficiency. On the other hand, due to the deterioration of fossil fuels, the issues of energy recycling in industrial and technological units have caught many researchers' attention in recent years. For this e, various technologies can be used for heat recycling in power plants. A Due ich CSP was combined with MED, The production of fresh water has always been one of the most important industrial issues. The desalination technology can be one of the most effective methods to utilize wasted heat in power units [9, 10]. Dual-purpose systems composed of two important sectors: power plants and desalination units. In fact, power plants (cogeneration, trigeneration, and multi-generation systems), by utilizing renewable and non-renewable energy sources, are the prime center for providing the normal required electrical energy as well as supplying the energy needed to start the desalination unit [11–13]. Therefore, it is noteworthy to include an investigation of the modeling, analysis, and control of hybrid systems, in which the desalination process is combined with the regenerated hot water to to set up an economically attractive energy production power plant.

A research conducted by G. Iaquaniello et al., [14] provided an innovative approach in which CSP was combined with MED and RO desalination processes. The system caused substantial cost-savings of desalinated water production per unit. The results of another study by Askari and Ameri., [15] showed that the Linear Fresnel solar field provides some amount of energy required for the Solar Rankin Cycle (SRC). SRC thermal energy is used to produce fresh water in the MED system. The authors discussed the proposed system's efficacy via numerical and statistical analysis, and studied parametrization process and incorporation of mathematical models to illustrate the productivity of the system in a hybrid cycle scheme. The study of Rankine cycle as well as water desalination plants was further discussed by Mansouri et al., Comparing the proposed ORC-RO-MD integrated system with ORC-RO system, authors concluded that their scheme outperforms ORC-RO economically and environmentally[16].

Hoseini and Mehdipour, proposed a system called a hybrid solar chimney to generate electricity and fresh water. In this study, the performance of two systems, solar chimney with a humidifier and a condenser was evaluated. In accordance with the results, in the first system, power generation increased, although, in some temperatures (40C, 20C, 10 C), the consumed energy for producing fresh water raised. In the second system, the amount of water produced and humidity output decreased with an increase in solar radiation[17]. Tamburini et al, combined heat and power retrofit (CHPR) and MED-TVC in a commercial-scale plant with a daily output of 36,000 cubic meters. The results show that increasing MED units, increases energy consumption and found that fuel influences CHP productivity[18]. Ghaebi and Abbaspour., [19] merged MED-TVC with triple-pressure HRSG for power and freshwater production. To evaluate the performance of the plant, they analyzed thermoeconomic and thermodynamic, which showed a significant increase in the efficiency of exergy. Torres et al., [20] introduced a scheme to use waste heat from CSP polygeneration plants in Venezuela and Chile to produce fresh water using MED devices. Investigations of this work showed that if the initial PTC investment cost decreases by 15% for Chilean, and by 25% for Venezuelan, the LEC and LWC can be reduced. Jabboury et al., shows can be mentioned as one investigating electric power generation and supply of energy for desalination, [21] which investigated the effect of functional variables of heat recovery boiler on the combined cycle units and desalination of sea water. Chacartegui et al., commented on the economic analysis and feasibility of connecting a desalination unit (MED) to a combined cycle unit [22].

Shakib et al., [23] combined recovery boiler with a desalination unit to simulate and optimize a cogeneration gas Turbine Hosseini et al., [24] Worked on optimizing the price of a combined desalination unit, along with exergy, environmental and reliability considerations. Demir and Dincer., [25] developed a hybrid system for electricity generation and freshwater including solar thermal power plant, natural gas generator, thermoelectric generator and Rankin cycle for desalination units. Sharan et al., [10] used a sCO2 Brayton cycle, as its efficiency is higher than steam-Rankine power cycle for the production of freshwater with the MED desalination unit and compared it with RO desalination unit. Techno-economical investigation of this work showed that MED desalination production cost is about 30% lower than that of RO system. Sharan et al., [26] suggested a scheme to produce freshwater using wasted heat of sCO2 Brayton cycle with the MED desalination unit. The proposed system not only produces more fresh water, but is also cost-effective. They also analyzed and optimized the different structures of the plant's MED (parallel,crossfeed, and feedforward). This analysis showed that the feedforward MED increases the production of freshwater and decreases costs by 7. 5% and 2. 6% respectively [27] In another investigation carried by Sharan et al., they added solar power to sCO2 Brayton cycle combined with the MED desalination unit. To achieve more capacity factor, two tanks for storing water were added to MED system he optimization of the water tank in the scheme increased the cost of water production by 19%, and the water capacity increased by 46. 4% to 75% [28].

There have been some research on Allam Cycle. For instance, Rodriguez et al analyzed Exergy economics of a new Allam cycle. The analysis showed 50.1% efficiency for Exergy cycle and 53.9% efficiency for electricity [29]. Zhu et.al suggested an Allam Cycle by NG/O2 mixed with CO2 to generate energy with higher efficiency. This method improved efficiency about 2.96% [30]. Fernandz and et.al analyzed and studied sensitivity analysis of an Allam Cycle combined with an air separation unit. The result of this study showed that using air separation unit lead to increase in speed and efficiency of cycle and greater purity of CO2 [31]. Wang and et.al proposed combinatory Allam cycle consisting Allam cycle, air separation unit and ammonia production plant to generate electricity, water, fertilizer and co2 pipeline with higher quality and lower cost. The result of this proposal showed satisfactory performance in terms of the efficiency, cost and environmental impact [32]. Zarab and et.al developed a part-load model of Allam Cycle for compressors, pumps and turbine. Results indicates that usage of control strategy of cycle load increases the efficiency about 4.71%. Michel and et.al analyzed Allam cycle in electric system with storage of fluid Oxygen, aiming to increase efficiency. The analysis of the proposed system showed thermal efficiency increased, reaching 58% and cycle efficiency reached 66.1% [33]. As pointed out in the above literature review, researchers have not considered the MED-TVC cogeneration method using Allam cycle. In a study by Ahmadi et al the authors of this article, they discussed how to combine the Allam cycle with MED-TVC desalination and analyze the economic performance of the cycle. But the cycle in terms of energy and exergy was not discussed, as well as, the efficiency of the cycle and the amount of fresh water produced was poor [34].

Actual energy losses cannot be well expressed using the first law of thermodynamics because this law does not differentiate between quantity and quality of energy. For this reason, energy and exergy analysis of power plants is necessary. Therefore in this study, Energy and exergy analysis are used to determine what effect each component has on the performance of the cycle and how its efficiency can be increased. Finally, optimizing the performance of the proposed cycle to maximize the production of freshwater and reduce the destroyed. Therefore, this work consists of five sections. First, the literature review is introduced. Section two discusses the analysis of power production in any stages of Allam cycle and identification of the appropriate location for heat-extraction to produce the required water vapor used in the MED-TVC system. A thermodynamic model is presented on the basis of Allam cycle for cogeneration of desalinated water and electricity in Kish Island. Section three discusses energy and exergy of the combined cycle, and calculates the exergy rate of any current flow of the system, and determines exergy loss and exergy efficiency of the combined cycle. The fourth part focuses on system optimization that uses genetic algorithm to reduce exergy destruction and increase water desalination productivity. It also focuses on the identification of optimized cycle parameters. Section 5 is the conclusion of the study.

The novelty of this article is how use of energy wasted in Allam cycle and combined with MED-TVC desalination unit for power and fresh water production, energy and exergy analysis and optimization of the cycle to minimize the exergy destruction and maximize the produced fresh water.

Cycle Description

The structure of the cycle consists of two parts: the power plant, which relates to the Allam cycle, and the MED-TVC Desalination used to generate freshwater. The desalination unit is a multi-stage thermal type consisting four main parts of steam-circulator, thermo-compressor, condenser and five operators. In this system, the seawater enters the condenser first, then by heat exchanging heat with the steam inside the condenser tube, the seawater's temperature increases and part of it goes out of the system as the cooling water and the rest goes to the next steps. In the first step, the water is sprayed onto the evaporator pipes. As a result of the steam heat in the tubes (which has been supplied by an external source), water passes through the thermo-compressor and reaches the favorable pressure and then enters into the first stage of evaporator pipes. Part of it evaporates and the steam formed in the first stage goes to the second stage and flows through the second stage of evaporator pipes causing the feeding water to be evaporated and the remaining steamed water is added as wastewater at the bottom of the evaporator. It exits and this process continues until the end. At the final stage, the produced steam enters the condenser. After increasing the temperature, the seawater entered the condenser would release out of the outlet. The MED-TVC desalination system have been validated with the actual operating data of in Bandar Abbas thermal power plan. Allam cycle functions with the carbon dioxide cycle as a high-pressure fluid and a Brayton-type cycle with a low-pressure ratio that works with a unique turbine with an input pressure of 200 to 400 bars and operates at a pressure ratio of 6 to 12 bar. The cycle consists of a combustion chamber that burns fuel with pure oxygen at high pressures to provide a high-pressure feed steam for rotating the turbine. In this turbine, the output gas enters the recuperator at 727°C and a pressure of 30 bar and is discharged at 43°C. This flow loses its moisture to the humidifier during the cycle before it enters the compressor and then enters the compressor at a temperature of 29°C and 17°C. A part of the compressor gas flow is removed from

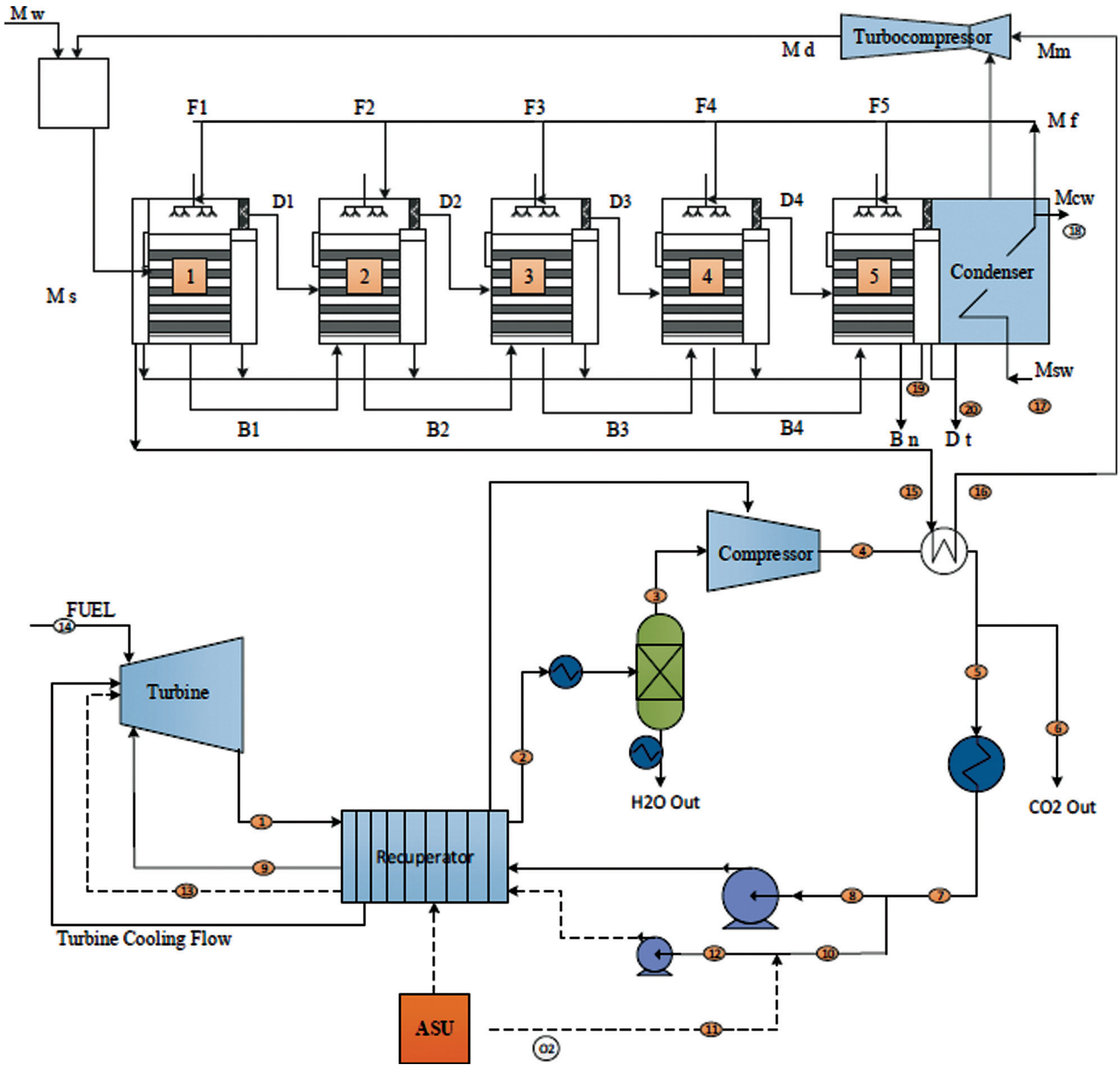


Figure 1. General schematic of Allam cycle using natural gas combined with MED-TVC desalination.

the cycle for sale, and the rest of the cycle flows into the recuperator and then enters the turbine from two different paths. The first part of the stream flows directly into the recuperator through a circulator pump at a pressure of 310 bars. Having combined with oxygen, the other part of the stream is pumped through the oxygen pump to the desired pressure and preheated by using the turbine output stream. Oxygen is carried out at the entrance to the turbine of the oxidation reaction, and the turbine gas enters the turbine at 1150°C.

In order to use the energy wasted in the Allam cycle and use it in the production of fresh water, the mainstream power output of the turbine in the Allam cycle is recycled using a recuperator. According to the analysis of the power production at all stages of Allam cycle as shown in Figure 2, it is observed that the highest amount of power is produced in the compressor. Therefore, the compressor is used as a source of energy for desalinating water, and the other points in the cycle have no thermal value necessary for heat recovery. The thermal value is the proper temperature for heat recovery to produce steam required in desalination. According to the design, the steam output temperature should be 189°C. The heat recovery site which is suitable for the desalination cycle would be the heat of the exhaust gas from the compressor and its heat is estimated at 100 MW based on the simulation results.

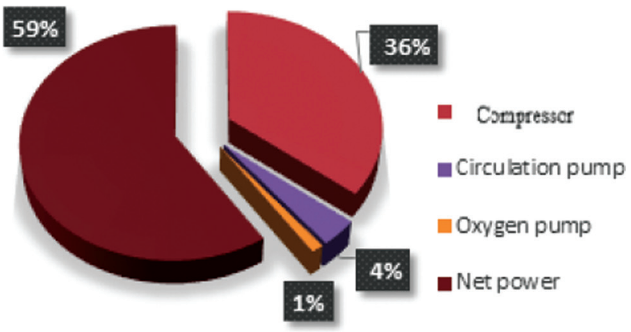


Figure 2. The Contribution of components to power generation in Allam Cycle.

SIMULATION

In order to simulate the Allam cycle, the input characteristics of the Allam cycle are first obtained. Specifications of different parts of the Allam cycle's entrance with natural gas are shown in table 1.

Table 1. Summary of stream flow of a simplified commercial scale natural gas Allam cycle [7]

Stream	Temperature (°C)	Pressure (bar)	Mass Flow (Kg/s)
1	727	30	923
2	43	29	546
3	17	29	563
4	23	100	909
5	23	100	881
6	23	100	28
7	16	100	881
8	16	100	689
9	717	312	586
10	16	100	191
11	16	100	41
12	2	99	233
13	717	310	233
14	266	330	10

Table 2. Comparison between the results obtained from the present model and Ref [7,29]

Allam Cycle	Expected Value ref [7]	Present work	MED-TVC parameters	Expected Value ref [35]	Present work
Net power output	303 MW	293. 6 MW	Motive steam to entrained vapor ratio	2. 05	1. 97
Natural gas thermal input	511 MW	555 MW	Distillate production (kg/s)	20. 65	21. 3
Oxygen consumption	3555 MT/day	3405MT/day	Gained output ratio (GOR)	5. 95	6. 03
Turbine outlet flow	923 Kg/s	923 Kg/s	Compression ratio (CR)	3. 562	3. 42
Turbine inlet condition	T = 1158 C, P = 300 bar	T = 1158 C, P = 300 bar	Expansion ratio ER	110. 3	113. 2
Turbine outlet condition	T = 727 C, P = 30 bar	T = 727 C, P = 30 bar	Specific heat consumption (KJ/kg)	329. 2	337. 6
Oxygen power plant	56 MW	56 MW	Motive steam temperature (C)	195	189
CO2 compression power	77 MW	86. 4 MW	Exergy efficiency (%)	9. 65	9. 3

The energy efficiency of the equipment is calculated using the Thermodynamic First law. The simulation of the Allam cycle is based on the Thermodynamic features which is given in Table 1. In this model, the compressor power, turbine, pump, heat transfer coefficient in the recuperator, net and gross efficiency of cycle and other sections are taken into consideration. In order to ensure the accuracy of simulation, the results of the simulation carried out in this study are compared with the results of the references [7,35] in Table 2.

Exergy Analysis

In order to analyze the exergy of the cycle, the first and second law of thermodynamics is used. In addition, mass, energy, and exergy balance are used in accordance with the following equations [36];

$$\sum_{i}^{0} m_{(i)} - \sum_{e}^{0} m_{(e)} = 0 \quad (1)$$

$$Q - W + \sum_{i}^{0} (m.h)_i - \sum_{e}^{0} (m.h)_e = 0 \quad (2)$$

The amount of exergy at each point of the cycle is calculated using the following equation;

$$e = (h - h_0) - T_0 (S - S_0) \quad (3)$$

In ideal gases, the amount of exergy in all points can be written based on the following equation [36];

$$ex = c_p T_0 \left[\frac{T}{T_0} - 1 - \ln\left(\frac{T}{T_0}\right) \right] + \ln\left(\frac{p}{p_0}\right)^{(k-1)/k} \quad (4)$$

After calculating the exergy of all points in the cycle, the amount of exergy destruction and efficiency can be calculated in different cycles. The equations used to calculate the exergy efficiency of various components of the power cycle are as follows;

$$EFF_{EXturbine} = \frac{W_{turbine}}{m_{combustion}.EX_{turbine} - M_1.Ex_1} \quad (5)$$

$$EFF_{comp} = M_3.\left[\frac{Ex_{comexit} - Ex_3}{W_{comp}} \right] \quad (6)$$

$$EFF_{Excombustion} = m_{combustion}.Ex\_turbine \left[\frac{EX_{turbine}}{M_9.Ex_9 + M_{13}.Ex_{13} + M_{14}.(Ex_{14} + HHV_{Methan})} \right] \quad (7)$$

The equations used to calculate the exergy destruction rate of the power cycle are as follows;

$$EX_{disturbine} = -w_{turbine} + m_{combustion}.Ex_{turbine} - M_1.Ex_1 \quad (8)$$

$$EX_{discomp} = -M_3.(Ex_{comexit} - Ex_3) + W_{comp} \quad (9)$$

$$Ex_{discombution} = M_9.Ex_9 + M_{13}.Ex_{13} + M_{14}.(Ex_{14} + HHV_{Methan}) - m_{combustion}.Ex_{turbine} \quad (10)$$

The following relationships have been used to calculate the exergy destruction of the components of the MED-TVC [35];

Thermo-compressor:
$$E_{D,ej} = M_m.\left[[h_m - h_d) - T_0.(s_m - s_d) \right] - M_{ev}.[(h_d - h_{ev}) - T_0.(s_d - s_{ev})] \quad (11)$$

Effects 1:
$$E_{D,e1} = M_s.\left[(h_s - h_{fs}) - T_0.(s_s - s_{fs}) \right] - D_1.L_1.\left(1 - \frac{T_0}{T_{v,1}}\right) - F_1.C_1.\left[(T_1 - T_f) - T_0.\ln\left(\frac{T_1}{T_f}\right) \right] \quad (12)$$

Effects 2:
$$E_{D,e2} = D_1.L_1.\left[1 - \frac{T_0}{T_{v,1}}\right] + B_1C_1.\left[\Delta T - T_0.\ln\left(\frac{T_1}{T_2}\right) \right] - D_2.L_2.\left[1 - \frac{T_0}{T_{v,2}}\right] - D_2.L_2.[1 - \frac{T_0}{T_{v,2}}] \quad (13)$$

Effects:
$$E_{D,ei} = (D_{i-1} + d'_{i-1}).L_{i-1}.\left[1 - \frac{T_0}{T_{v,i-1}}\right] + B_{i-1}.C_{i-1}.\left[\Delta T - T_0.\ln\left(\frac{T_{i-1}}{T_i}\right) \right] - D_i.L_i.\left[1 - \frac{T_0}{T_{v,i}}\right] - F_i.C_i.\left[(T_i - T_f) - T_0.\ln\frac{T_i}{T_f} \right] i = 3, \ldots .n \quad (14)$$

Condenser:
$$E_{D,c} = D_n.L_n.\left(1 - \frac{T_0}{T_{v,n}}\right) - M_{sw}.C_{sw}.\left[(T_f - T_{sw}) - T_0.\ln\left(\frac{T_f}{T_{sw}}\right) \right] \quad (15)$$

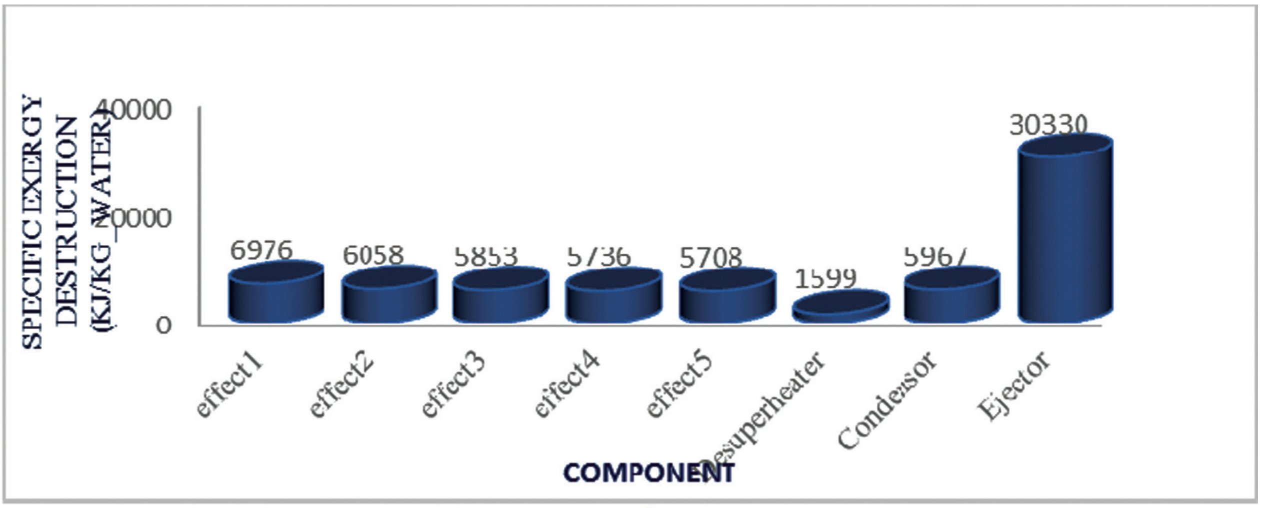
$$E_{D,de} = M_d.\left[\left(h_d - h_s\right) - T_0.\left(S_d - S_s\right)\right] - M_w.\left[\left(h_s - h_w\right) - T_0.\left(S_s - S_w\right)\right] \quad \text{Desuperheater} \quad (16)$$

EXERGY RESULTS

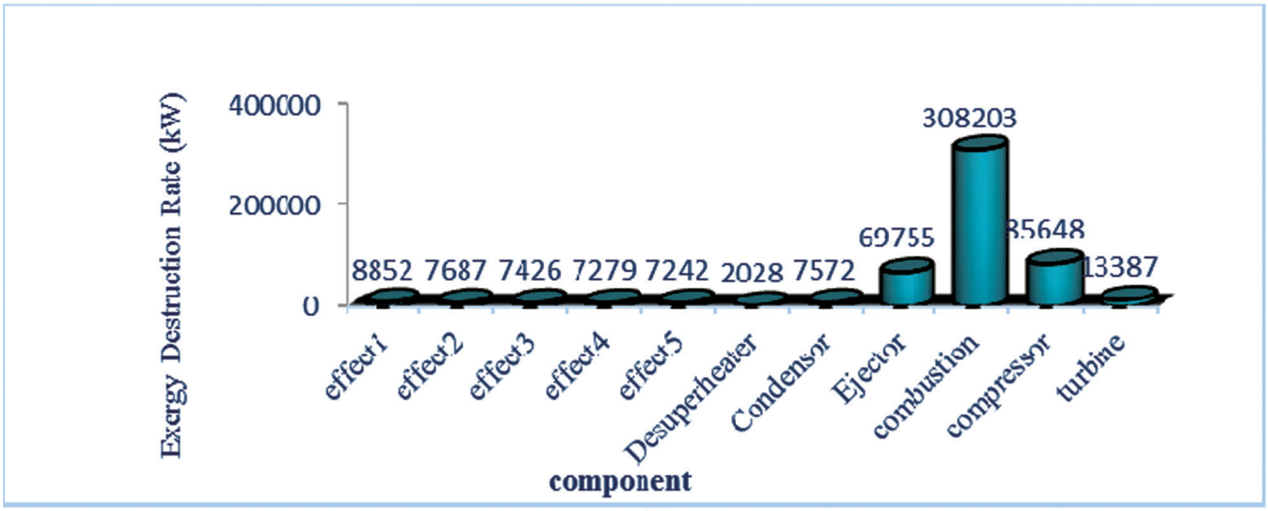
In order to analyze the thermodynamic cycle, the parameters of the MED-TVC unit are expressed in accordance with Table 3.

As shown in Fig3a, the specific exergy destruction Rate for MED-TVC unit and fig3b, exergy destruction for Allam and MED-TVC unit.

According to Fig. 3a, 3b, the greatest amount of exergy destruction rate is related to the combustion chamber due to irreversible processes and the lowest rate is related to the fifth evaporator. It is also observed that the amount of exergy destruction in the first desalination evaporator is the highest compared to other evaporators Due to high feed water temperature and feed water pressure in the first stage, and Due to the decrease in temperature and pressure in the effects, the amount of exergy destruction in each stage is less than in the previous stage. The greatest amount of exergy destruction has occurred in the combustion chamber because a large amount of exergy combustion chamber has been destroyed to heat the excess air. According to Fig. 3b, the amount of exergy destruction in the combustion chamber is the highest compared to other equipment. One of the reasons for the high exergy degradation in the combustion chamber is the high amount of irreversibility.



a)



b)

Figure 3. Specific Exergy destruction Rate for MED-TVC unit (a) and exergy destruction (b) on the Mass discharge rate of freshwater.

Fig 4 shows the exergy destruction changes per unit mass discharge rate of fresh water produced in accordance with changes in the temperature of the Compressor. According the fig 4, the specific exergy destruction in the ejector has the highest degree of destruction due to irreversible processes of mixing and expansion, while the super-heater has the least amount of it. Fig. 4 indicates the variation of specific exergy destruction in the mass discharge rate of freshwater in response to changes in the input temperature of the compressor, which is used as a source of energy for desalination. According to Fig. 4, it can be seen that an increase in the compressor inlet temperature has little effect on the exergy destruction of the fresh water unit, although the highest exergy destruction is related to the ejector and the lowest exergy destruction is related to the super-heater. In the first evaporator, compared with the second evaporator to the fifth evaporator, the amount of exergy destruction per unit mass discharge of freshwater is the highest.

Fig. 5 indicates the total destroyed exergy changes in the unit mass discharge rate of fresh water which is produced in accordance with changes in the temperature of the compressor in the desalination process. With regard to Fig. 5, it can be seen that with increasing compressor inlet temperature, the amount of exergy destruction decreases per unit mass of freshwater produced.

In Fig. 6a, it is observed that the ejector's exergy destruction rate was the highest rate. Increasing the input temperature of the compressor increases the power cycle of the exergy degeneration of the reactor. It is also observed that the amount of exergy destruction of the first evaporator is greater than that of the second to fifth evaporators, although the least exergy destruction is related to the super-heater. In Fig. 6b, the change in the amount of exergy

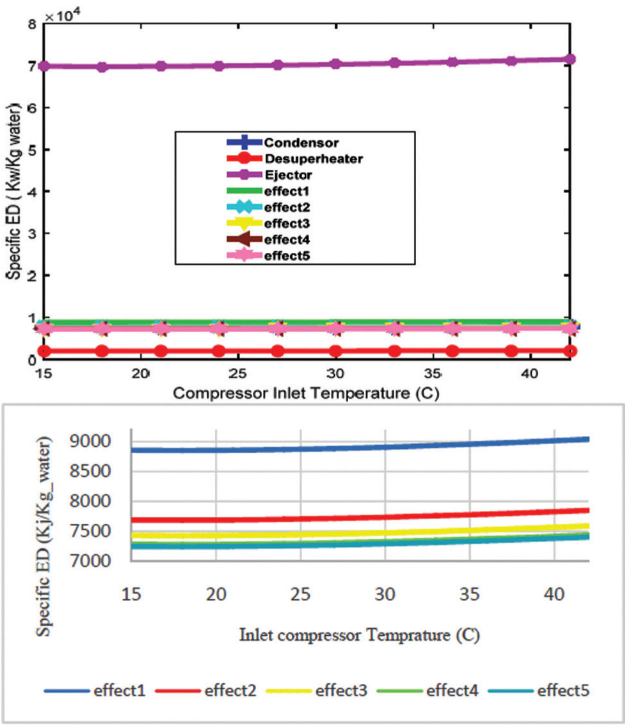


Figure 4. Exergy destruction changes per unit mass discharge rate of fresh water produced in accordance with changes in the temperature of the Compressor.

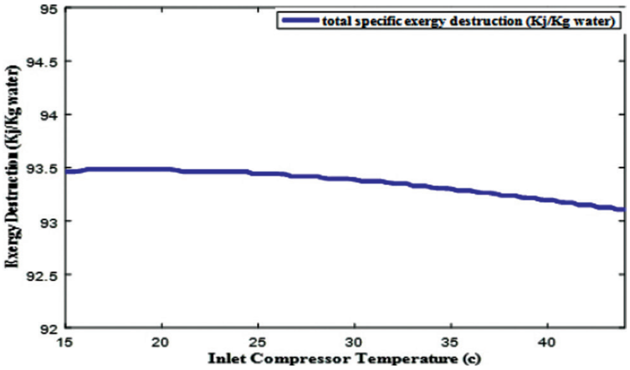


Figure 5. Total changes of exergy destruction per unit mass of fresh water produced in accordance with the temperature of the compressor.

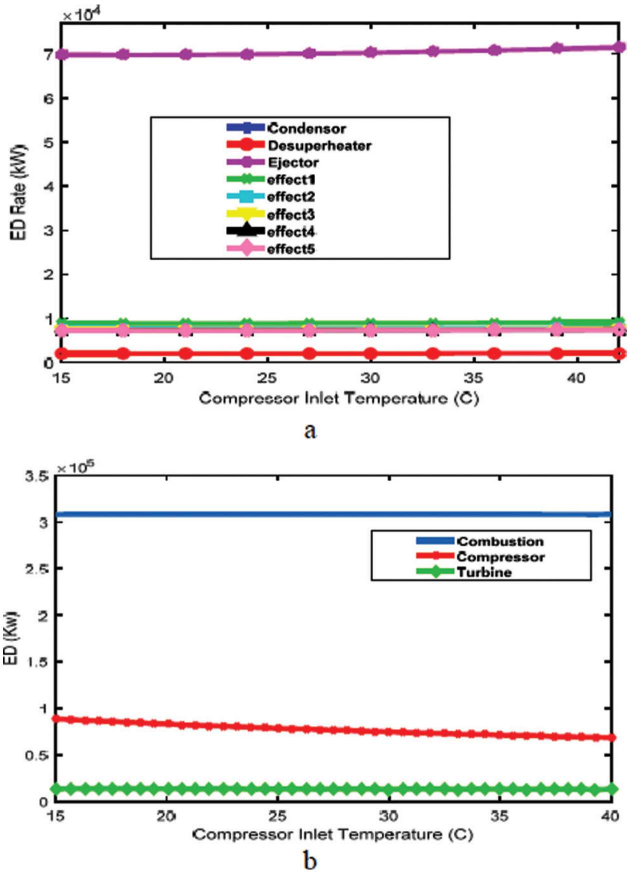


Figure 6. Exergy destruction rate based on the compressor inlet temperature in the proposed cycle.

destruction according to the compressor inlet temperature of the power cycle is shown. According to the Figure, the combustion chamber has the highest rate of exergy destruction in the power cycle and in the whole cycle. An increase in the compressor inlet temperature does not change the amount of exergy destruction in the combustion chamber, although the rate of exergy destruction in the compressor decreases with increasing compressor temperature.

In Fig. 7, the total destroyed exergy rate is shown in terms of the variation in the input temperature of the compressor. According to Fig. 7, increasing the input temperature of the compressor will decrease the total destroyed exergy of the entire proposed cycle. The reason is that the rate of exergy destruction in the turbine reduces.

Table 4 shows the amount of exergy entering the proposed cycle and the exergy consumption of all components of the proposed cycle. According to table 4, it is observed that the highest exergy is in the turbine (29%) and the lowest exergy is in the desalinization unit (7%).

Fig. 8, shows the correlation between the excess heat of the cycle and the temperature required for desalination, along with the change in mass flow rate of the cycle. According to Fig. 8 it is observed that the amount of net power, turbine power (Fig. 8a) and flow rate fuel (Fig. 8b) increases, and the amount of heat used in desalinization and exergy destruction (Fig. 8c) increases with the increase of turbine discharge. Due to the fact that all other parameters remain constant, such as the inlet temperature to the turbine and the combustion chamber, and the amount of fuel consumption, the exergy degradation in the combustion chamber increases with increasing flow rate output turbine. On the other hand, increasing the flow rate through the turbine will increase production capacity

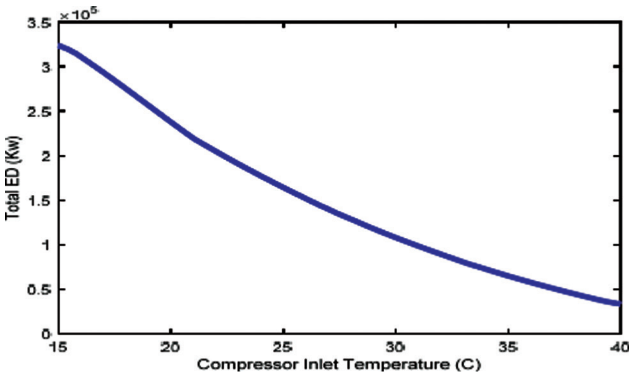


Figure 7. Total exergy destruction rate of the proposed cycle in terms of changes in the compressor inlet temperature.

Table 4. Exergy components as a percentage of total input exergy

	(%)	KW
Exergy input	100	941537
Exergy converted to power in a Turbine	29	267318
Exergy converted to power in a combustion chamber	12	123281
Exergy consumed	16	158850
In Compressors and Pumps		
Exergy entering the MED-TVC	7	73212
Exergy destruction	33	318875

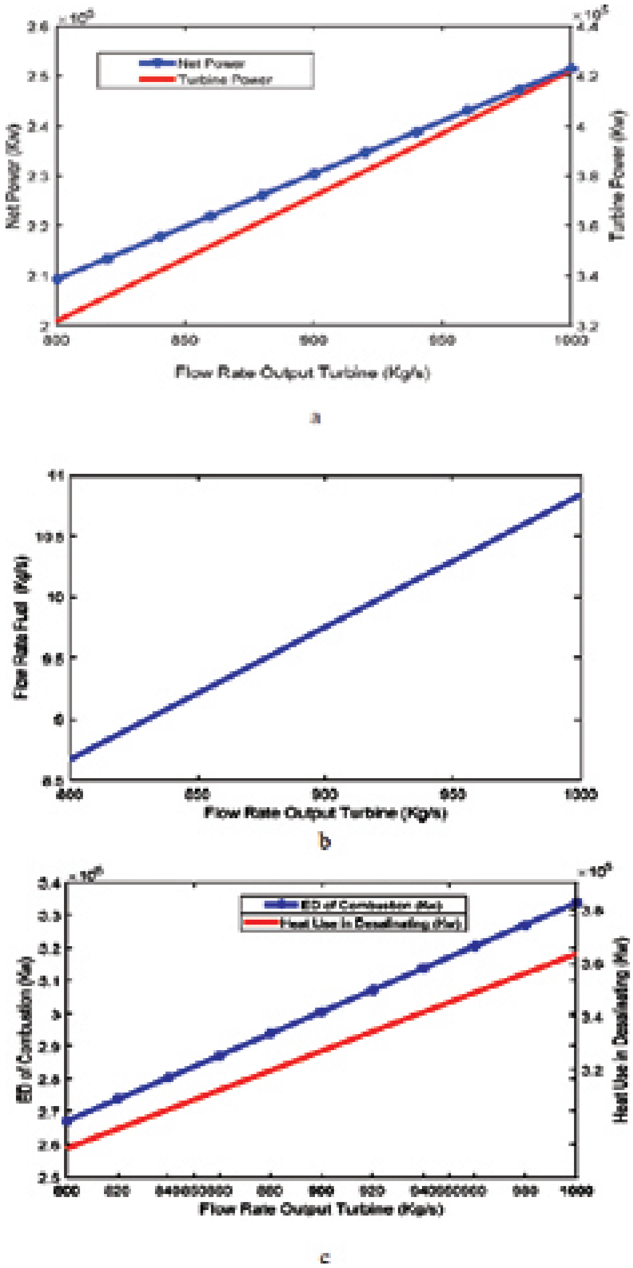
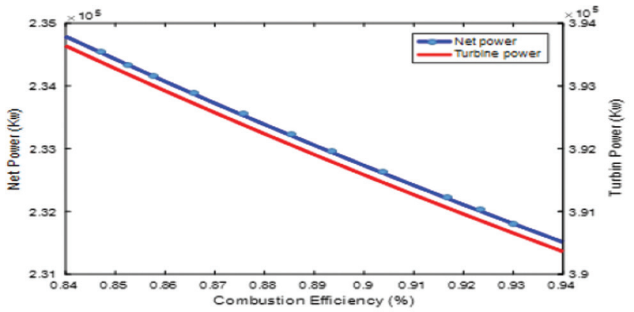
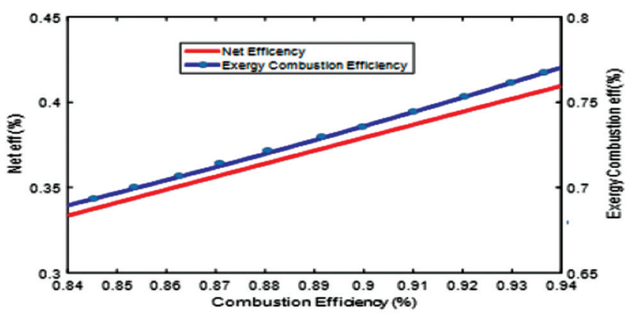


Figure 8. Estimation of the balance between the excess Heat of the cycle and the temperature required for desalination with a mass discharge change.

In Fig. 9, the effect of the change in combustion efficiency of turbines in the proposed cycle has been investigated. According to Fig. 9a, it is observed that with increasing combustion efficiency, the Turbine power and net power decrease because assumption of a constant inlet temperature to the turbine, which reduces the amount of fuel consumed and thus reduces the flow through the turbine, which leads to a reduction in output power in the turbine and cycle, while according to Fig. 9b the exergy destruction efficiency and net power increase.



a



b

Figure 9. Effect of combustion efficiency on the assumption of constant urbine inlet temperature.

OPTIMIZATION

Optimization of the proposed cycle aims at reducing the exergy destruction and increasing the amount of produced freshwater. For this purpose, the system has two different scenarios to optimize the cycle and are as follows. Since the genetic algorithm is one of the most powerful algorithms for optimizing systems, the researchers used this algorithm to optimize the cycle in this research [29].

Lower degrees of exergy destruction can increase the efficiency and improve the working conditions of the cycle in terms of the process. The first objective function is considered in accordance with the following equation.

$$Objective\ function = MIN\left(total\ Ex_D\right) \quad (17)$$

To optimize, the effective parameters must be selected in such a way to have the greatest impact on the cycle. Therefore, the optimization variables considered for the First scenario include: turbine inlet temperature, turbine input pressure, turbine output pressure, turbine output discharge, the temperature of the entrained steam of the desalination unit and the working temperature of the first stage in water desalination. The dependent variables selected for the power and water desalination cycle have a range of low variations but high efficiencies.

The goal of the optimization process performed in the Second scenario is to increase the amount of freshwater

Table 5. Min and Max values of optimization in the first scenario and second scenario

First scenario			**Second scenario**		
Variable	**min**	**max**	**Variable**	**min**	**max**
Turbine output discharge (Kg/s)	900	950	Input pressure of desalination unit (KPa)	810	1010
Turbine output pressure(KPa)	2000	4000	Input stream temperature of desalination unit (C)	60	70
Turbine input pressure (KPa)	2500	3500	The temperature of desalination unit in First stage(C)	175	210
Turbine inlet Temperature(C)	1100	1200	The temperature of the injected saltwater of the stages of the desalination unit(C)	25	40
Input steam pressure inthe desalination unit (K Pa)	810	1010	saltwater Inlet temperature (C)	35	55
steam inlet temperature in desalination unit (C)	175	210			
Working temperature of the First stage of desalination unit (C)	60	75			

produced, taking into account the constant conditions of the power cycle. The objective function is considered in accordance with the following equation.

$$Objective\ function = MAX\left(D_i\right) \quad (18)$$

Table 5 shows minimum and maximum values of optimization in two scenarios.

OPTIMIZATION RESULT

The dependent variables in two scenarios are shown in table 6.

A comparison between the results of the Ahmadi et al [34] and two optimization scenario is presented in Fig. 10. As showed in Fig. 10a, distillate production increased in the second scenarios because the objective function is intended to increase the freshwater production, which has led to an increase in pressure and inlet temperature to the desalination unit, but decreased in the first scenario. According to Fig. 10b, exergy input fuel in the cycle increased in first scenarios because the amount of irreversibility in the optimization of the second scenario is reduced, which leads to an increase in the exergy entering the cycle and also a decrease in the exergy degradation and decreased in Second scenarios. According to Fig. 10c, the total destroyed exergy of the whole cycle is reduced and net power efficiency is increased in two scenarios Due to the increase in turbine efficiency and desalination efficiency respectively.

Table 7 shows the overall results of the cycle function from the perspective of energy and exergy in the Ahmadi et al [34] in comparison to the performed optimizations in two different scenarios.

Given that in the first scenario the optimization is focused on reducing the exergy destruction on the Allam cycle with MED-TVC desalination, and in the second scenario the optimization is focused on increasing the fresh water produced on the MED-TVC desalination unit the results obtained in both scenarios are different. The optimization results of the first scenario, which is aimed at reducing the total exergy destruction of the proposed cycle, show that the exergy destruction of the cycle is reduced by 18% compared to the base model and by 7% in the second scenario. Similarly, regarding internal components, in the first and second scenarios, the exergy destruction rate of all components in the cycle has been reduced. In addition, in the first and second scenarios, the exergy destruction has only increased in recuperate and compressor respectively, which indicates preferable optimization performance by decreasing exergy destruction. On the other hand, a decrease in the destruction of exergy in the cycle increases the efficiency and improves the working conditions of the cycle. According table 7 the exergy destruction in recuperator in the first scenario is greater compared to the second scenario because by reducing the pressure ratio in the turbine and reducing the compressor outlet temperature with a low pressure ratio, it leads to an increase in the recovery of the recuperator exergy. In the optimization of the second scenario, due to the increase of the compressor outlet temperature, the amount of exergy degradation in the recuperator is reduced. The results of the optimization showed that the efficiency of the cycle increased by 30% in the first scenario and 13% in the second scenario. The rate of net power of the cycle has increased by 30% and 24% in the first and second scenarios, respectively. Generally, in both optimization processes, the efficiency has been improved and the amount of exergy destruction has been decreased. The performance of the first scenario, due to the objective function, which is a determinant of reduction of exergy destruction, is better than the performance of the second scenario. The results showed that the production of fresh water has increased by 22% compared to the base model,

Table 6. Values of dependent variables in two scenario

First scenario		Second scenario	
Variable	**Value**	**Variable**	**Value**
Turbine output discharge (Kg/s)	949	Input pressure of desalination unit (KPa)	984
Turbine output pressure(K Pa)	2038	stream inlet temperature of desalination unit (C)	60
Turbine input pressure (K Pa)	30743	The temperature of desalination unit in First stage(C)	175
Turbine inlet Temperature(C)	1200	The temperature of the injected saltwater of different stages of the desalination unit(C)	40
Input steam pressure of the desalination unit (K Pa)	982	saltwater inlet temperature (C)	55
The temperature of desalination unit in First stage(C)	170		
Working temperature of the First stage of desalination unit (C)	60.75		

which is due to the increase in the amount of exergy entering the desalination unit.

Table 8 shows compares the results of this study in tow scenarios with other studies, including Ahmadi et al the authors of this article.

According to Table 8, it can be seen that the optimization done in the first scenario is more efficiency than other researches done on the Allam cycle. Also, the amount of fresh water produced in the second scenario had a better performance compared to other studies.

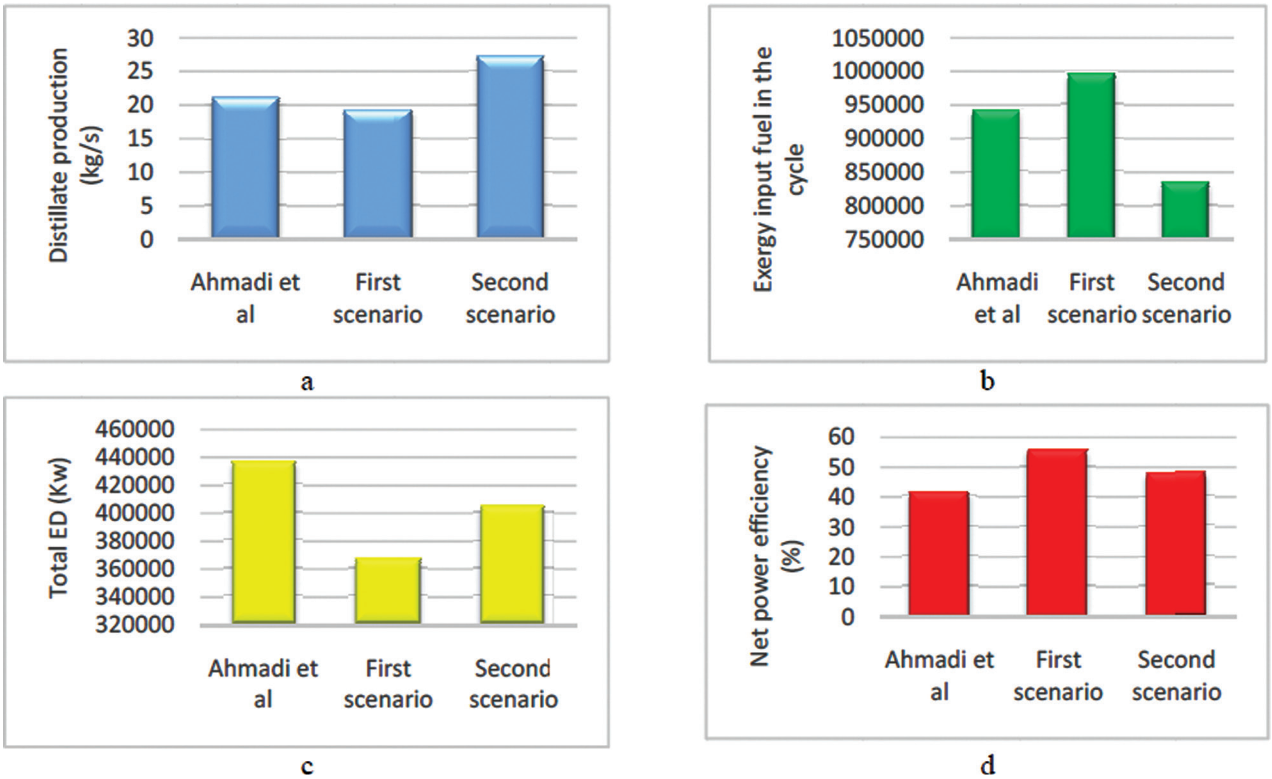


Figure 10. A comparison between the base state and optimization states of (a) Distillate production, (b) exergy input fuel in the cycle, (c) Total exergy destruction and (d) Net power efficiency.

Table 7. Optimization results for two scenarios

Variable	Unit	Ahmadi et al [34]	First scenario		Second scenario	
		Value	Value	Compare with base model (%)	Value	Compare with base model (%)
Net cycle power	KW	231745	333911	30	307985	24
Total Exergy destruction	KW	435770	366570	−18	404413	−7
Net power efficiency	%	41. 33	59. 51	30	48. 04	13
Exergy input fuel in the cycle	KW	941533	994584	5	833894	−12
Distillate production	Kg/min	1269	1160	−9	1631	22
Input energy to MED-TVC	KW	335473	310855	−7	373597	10
Exergy destruction of the Turbine	KW	13388	10678	−25	11203	−19
Exergy destruction of the Compressor	KW	85648	59470	−44	113814	24
Exergy Destruction of the Recuperate	KW	28710	42008	31	21587	−33
Exergy Destruction in Evaporator of MED-TVC unit	KW	38486	18824	−104	38832	0.08
Exergy Destruction in MED-TVC	KW	123616	103432	−19	142925	13

Table 8. Comparison between the results obtained from Tow scenario and other studies

	First scenario	second scenarios	Ahmadi et al [34]	Zhu et al [30]	Chan et al [37]	Rodriguez et al [29]
Net power efficiency (%)	59. 51	48. 04	41. 33	43.64	49.32	53.9

	First scenario	second scenarios	Ahmadi et al [34]	Khorshidi et al [35]
Distillate production (Kg/s)	19.33	27.18	21.15	24.01

CONCLUSION

In this paper, a hybrid cycle composed of the MED-TVC Desalination and Allam cycle is proposed for the production of electricity and water desalination in the Kish Island. Allam cycle is used to generate electricity needed to produce electricity as well as to supply energy for the desalination plant. Based on the energy analysis carried out in this research, it is found that the greatest amount of energy wastage is in the compressor. Therefore, the compressor is utilized as a source of energy for desalinating water, and the other points in the Allam cycle have no thermal value needed for heat recovery. We analyzed the proposed cycle performance from the perspectives of energy and exergy. The results of this research showed that using the wasted energy from the Allam cycle can produce 1269 (Kg/min) fresh water with MED-TVC desalination. The results of the exergy analysis of the proposed cycle showed that by increasing the compressor inlet temperature and increasing the combustion chamber efficiency in the Allam cycle, the total exergy destruction can be reduced, in addition; the greatest amount of exergy destruction occurs in the combustion chamber and the highest exergy rate in the turbine was used for generation. The results of optimization with genetic algorithm showed that the total exergy destruction of the cycle decreased (compared with the base state) by 18% in the first scenario and by 7% in the second scenario. As a result, the amount of exergy destruction decreased and the cycle efficiency increased. Also, the amount of freshwater produced in optimization process of the second scenario increased by 22%.

Future Works

The purpose of this research is to show how an MED-TVC desalination unit with Allam cycle is combined and examining the propose cycle from energy and exergy analysis. This article is a base research and this research is an introduction to future research. In the next step, for improving the performance of the cycle and to identify the major energy-consuming equipment and the amount of electrical energy consumed in the system, we will try to Exergoeconomic, Exergoenvironmental analysis and multi objective optimization of the cycle in order to increase efficiency of cycle; increase production capacity and reduced environmental impacts.

NOMENCLATURE

B	Brine flow rate (kg/s)
BPE	Boiling point elevation (C)
C	Specific heat capacity of water (kJ/kgK)
CR	Compression ratio
D_i	Distillate (kg)
d_i	Flash vapor flow rate (kg/s)
E	Exergy
$EFF_{EXturbine}$	exergy efficiency of turbine,%
EFF_{comp}	exergy efficiency of compressor,%
ED_i	Exergy destruction rate of component (kW)
ED_t	Total exergy destruction rate (kW)
E_{SD}	Specific exergy destruction (kJ/kg)
ER	Expansion ratio
F_i	Feed water flow rate (kg/s)
GOR	Gain output ratio
h_d	Enthalpy of the discharge steam (kJ/kg)
h_{fs}	Saturated liquid enthalpy (kJ/kg)
h_{ev}	Enthalpy of the Entrained vapor (kJ/kg)
h_m	Motive steam enthalpy (kJ/kg)
h_s	Input steam enthalpy to first effect (kJ/kg)
h_w	Enthalpy of Spray water (kJ/kg)
h_0	Environment state enthalpy (kJ/kg)
L	Latent heat (kJ/kg)
M_c	Condenser vapor flow rate (kg/s)
M_{cw}	Cooling water flow rate (kg/s)
M_d	Discharge steam flow rate (kg/s)
M_{ev}	Entrained vapor flow rate (kg/s)
M_m	Motive steam flow rate (kg/s)
M_s	Input steam flow rate to first effect (kg/s)
M_{sw}	Seawater flow rate (kg/s)
n	Number of effects
P	Pressure (Kpa)
P_d	Discharged vapor pressure (kPa)

P_{ev}	Entrained vapor pressure (kPa)
P_m	Motive steam pressure (kPa)
P_s	Input steam pressure to first effect (kPa)
T_t	Discharge steam temperature (C)
T_{ev}	Entrained vapor temperature (C)
T_r	Feed water temperature (C)
T_i	Effect temperature (C)
T_m	Motive steam temperature (C)
T_s	Input steam temperature to first effect (C)
T_{sw}	Seawater temperature (C)
$T_{v,i}$	Output vapor temperature from effect (C)
T_0	Dead state temperature (K)
$W_{turbine}$	Power of turbine (KW)
W_{comp}	Power of compressor (KW)

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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