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Simulation and Economic Analysis of Combined Water Desalination and Power Generation from Associated Gases of Cheshmeh Khosh

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Highlights

- A novel combined desalinated water and power generation plant was used for flare gas recovery;
- The multistage flash (MSF) process is proposed as a replacement for the condenser for cooling at the steam turbine outlet;
- A novel generation plant for cogenerating power and water from associated gases is presented.

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Abstract

Flaring of gases often having a high heating value results in considerable economic and energy losses in addition to significant environmental impacts. Power generation through combined gas and steam turbine cycles may be considered as a suitable flare gas recovery process. Thermal desalination of seawater is a process that requires a considerable amount of heat; hence, it may be used in the downstream section of power generation cycles. Energy is the largest part of the cost of the water generation of all desalination processes. The energy cost of the thermal distillation of seawater is close to 50%–60% of the water generation costs. In the current study, the generation of power and desalinated water through the gas turbine cycle, steam cycle, and multistage flash (MSF) method using the flare gases of Cheshmeh Khosh is investigated. The economic parameters related to the different scenarios considered for the production of power and water are evaluated in this work. According to the economic evaluation carried out, the most economically profitable scenarios for the investigated cogeneration plant is generating as much as possible power in the steam turbine and using the remaining heat in the low-pressure outlet steam for the MSF desalination process. The results show that by increasing the steam turbine outlet pressure from 3 to 78 bar, the power generation and the water generation change from 697 to 581 MW and from 1557 to 2109 m^3/h respectively. Also, by increasing the outlet pressure of the steam turbine from 3 to 78 bar, the total capital cost increases from 1177 to $1192 million, and the operating cost changes from 117.85 to $117 million per year. Finally, the operating profit decreases from 300 to $50 million per year, and the payback period extends from 3.92 to 4.75 years.

Keywords: Associated Gas, Cheshmeh Khosh, MSF, Combined Heat and Power Generation, Operating Profit

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1. Introduction

Flaring is a usual method for the disposal of flammable waste gases in oil, gas, and petrochemical industry (Zadakbar et al. 2011). According to the World Bank reports in 2018, Iran is the third country among the top thirty flaring countries, burning 17.3 billion cubic meters of flare gases annually (Khalili-Garakani et al. 2020). The huge amount of associated and flare gases burning in oil and gas refineries in Iran is one of the most important sources of energy loss in the country. Venting of petroleum-associated gases (flare gases) to the atmosphere is one of the significant sources of greenhouse gases (GHG). The formation of SO_x and NO_x during sour gas combustion causes the emissions of air pollutants into the atmosphere (Zoeir et al. 2019). In order to prevent energy and economic losses and to mitigate environmental impacts due to flaring, flare gas recovery (FGR) methods should be considered (Kang et al. 2019). Due to the high economic value of gas condensate and liquefied petroleum gas (LPG), the recovery of the gas condensate and LPG requires a natural gas liquids (NGL) plant to separate these products before the flare gases are processed by other methods (Hamidzadeh et al. 2020). There are many methods for FGR: injection in pipelines, LNG, gas to liquids (GTL), and compressed natural gas (CNG) plants (Ghadyanlou et al. 2015); enhanced oil recovery (EOR), synthesis gas production, gasoline production (Jafari et al. 2018); and power generation (Nezhadfard et al. 2020). Increasing global water scarcity is fueling initiatives everywhere for clean water treatment, making efficient seawater desalination an attractive goal for chemical plant design. A 2015 market analysis found that the global desalination process market earned revenues of $11.66 billion, and this number is expected to reach over $19 billion by 2020 (Pouyfaucon et al. 2018). Power generation using the gas turbine cycle can be an attractive option for flare recovery. In order to prevent wasting of heat existing in the hot exhaust of gas turbine, steam turbine cycle—which has a lower operating temperature compared to the gas turbine cycle—may be used as the bottoming cycle of the gas turbine cycle for generating more power (Sayyaadi et al. 2020).

Many researchers have discussed the environmental suggestion on process selection, the economic impacts of FGR, and the necessity to recover or remove flare gases. The cogeneration units of power and desalinated water often consist of a membrane separation unit for the separation of acid gases (Cyrus et al. 2019), a gas turbine and a steam turbine cycle for power generation, and a seawater desalination section through evaporation (Thiel et al. 2015). Rahimpour et al. also worked on flare gas recovery processes in Asalouyeh gas refineries. They considered GTL, power generation by the gas turbine, compression, and injection of the flare gases to refinery pipeline as the alternatives. Their results showed that the return on investment (ROI) was higher in the case of electricity generation compared to the two other methods (Rahimpour et al. 2012). Using energy from flaring gases for on-site wastewater treatment for the hydraulic fracturing process was investigated by Glazer et al. (2014). In 2016, the simulation and economic evaluation of the seawater desalination process using flare gases from oil platforms were carried out by Chen et al. In their work, a coupled thermal–vapor compression desalination process powered by flare gases was proposed and rigorously simulated using Aspen Plus. Their results showed that the proposed thermal process is technically viable and cost-effective at most locations (Chen et al. 2016). In 2018, seawater desalination using energy recovered from flare gases in various desalination systems was investigated by Jafari et al. In their study, the amount of energy recovered from flare gases, flare gas consumption in the thermal desalination processes, energy and electricity consumption, environmental considerations, and the volume of the water produced in different systems were evaluated (Jafari and Sarrafzadeh 2018). Al-Aboosi et al. (2018) studied and simulated an integrated approach to water–energy nexus in flare gas production. The purpose of this study was to develop a design for integrating water desalination and power plants, including multiple energy sources, the cogeneration process, and desalination technologies in treating wastewater and providing fresh water for shale gas generation. Mozammel et al. (2019) studied and simulated the integrated ejector-based FGR and desalination water in flare gas production. They developed a new process by integrating the ejector-based flare gas recovery (EFGR) process with the thermal vapor compression (TVC)-based desalination process. The results of the EFGR–TVC process are confirmed to be technically viable and economically effective under normal operating conditions. Nezhadfard et al. (2020) studied environmental–economic parameters for different power generation scenarios for flare gas recovery purposes. They investigated four power generation scenarios, including the gas turbine cycle, combined gas turbine cycle, reciprocating internal combustion engine cycle (RICE), and solid oxide fuel cell (SOFC)/gas turbine (GT) cycle in terms of economic and environmental performance for flare gas recovery purposes. Their results indicated that among the studied scenarios, RICE and SOFC/GT cycles have the best and worst economic performance respectively. Hamidzadeh et al. (2020) studied a multi-objective decision-making model of flare gas recovery in a zone with multiple flare gases and conducted the simulation of all available technologies for flare gas recovery. The optimal combinations of all the technologies were investigated by minimizing the payoff period of the total capital costs and CO_2 pollutant reduction by using the genetic algorithm (NSGA-II). By simulation and economic evaluation of the FGR technologies in MATLAB software, the final results showed that the outlet gas of the NGL plant (100% of the flare gas) is assigned to EOR (70% of the dry gas), the gas turbine (4% of the dry gas), the combined cycle power plant (26% of the dry gas), and water production (80% of the flue gases of the gas turbine). The total capital cost was $410.8 million, and the return payoff period was 1 year.

The integration of the FGR and the desalination of seawater processes for handling the generated water and power can not only monetize gas emission sources but also generate desalinated water for different usages (Heidari et al. 2016). Hence, there is a necessity to create correct management strategies for desalinated water generation in areas near oil and gas fields and to integrate wasted energy resources with the equipment for the desalination of seawater. Two main technologies are currently used in seawater desalination: thermal processes, namely MSF, multi-effect distillation (MED), and TVC and membrane processes, namely reverse osmosis (RO) and electrodialysis (ED) (Al-Karaghouli et al. 2013). Energy cost, total operating cost, equipment cost, and total capital cost are the main contributors to the water production cost of any of these processes. The energy cost is responsible for about 50% of the produced water cost. For thermal distillation processes, low-temperature heat (nearly 90% of total energy requirement) and power are required for the operation. Nonetheless, for membrane processes (RO and ED), only power is required as an energy input (Feng et al. 2019). Because a large amount of heat is wasted in the combined cycle power plant by using natural gas or flare gas (Naderi et al. 2018), in this process, thermal methods have been chosen for the desalination of seawater. The current work aims to introduce an appropriate method for FGR. In plants of the cogeneration of desalinated water and power, where the heat is supplied from the waste heat of the turbine, the energy cost will be much less (Huang et al. 2020). With the Persian Gulf seawater, MSF is a good option because fouling and other large pollutions can be separated from the feed before the distillation occurs. Additionally, MSF plants can be located near oil and gas fields and paired to their waste energy to conserve energy. In a conventional combined cycle power plant, there is a condenser for cooling at the steam turbine outlet. The innovation of this work is to use an MSF unit for the desalination of seawater instead of this condenser. Considering the trade-off between the amount of the power generated in the combined heat and power generation (CHP) plant and the volume of the desalinated water produced, a sensitivity analysis is performed based on different economic parameters; H_2S-free flare gas is used herein. The purpose of this study is to compare two scenarios for generating more power using the released heat and consuming part of the heat to produce desalinated water.

2. Materials and methods

Cheshmeh Khosh oil field is located in the Dasht Abbas area, Ilam province, 2 km south of Dehloran, and 5 km west of Andimeshk. The strategy to collect associated petroleum gases from the oil field began 15 years ago with the primary goal of increasing pressure to enhanced oil recovery (EOR). However, the compounds in this flare gases are much more valuable than those used for EOR. These associated gases, mainly consisting of methane (65 mol %), C_2–C_7 (31 mol %), and CO_2, H_2S, and N_2 (4 mol %), are suitable for the combined heat and power generation as well as desalinated water production (Moghadam et al. 2012). The specifications of the associated gases of Cheshmeh Khosh oil field and its treated associated gases are given in Table 1. The objective is to purify the flare gas, to separate the acidic and dangerous gas of H_2S, and to bring the concentration of these gases to a standard and acceptable level. H_2S content must be less than 4 ppm (Nourmohamadi et al. 2018) to prevent corrosion problems in the gas turbine blades and heat recovery system generator (HRSG) and inhibit SO_x emissions in the combined desalinated water and power generation process (Seidi et al. 2017). The treated flare gas for the production of heat and power in the first step enters the gas cycle power plant.

Table 1

The specifications of the associated gases of Cheshmeh Khosh oil field.

Conditions	Feed gas	Flare gas (treated)
Temperature (F)	45	55
Pressure (bar)	10	10
Molar flow (lbmol/h)	10865.767	10517.733
H_2S ppm	12761	4
Composition	mol %	mol %
Methane	0.644	0.670
Ethane	0.159	0.165
Propane	0.088	0.092
i-Butane and n-Butane	0.042	0.044
C_5–C_8	0.021	0.014
CO_2	0.021	0.000
H_2S	0.013	0.000
H_2O	0.007	0.008
N_2	0.006	0.006636

For generating steam using the hot exhaust from the gas turbine, an HRSG is used (Afshar et al. 2018). The heat generated by the CHP plant will be used to produce desalinated water from the Persian Gulf seawater. It is assumed that the seawater composition is only water and NaCl with a total dissolved solid (TDS) of 44710 mg/L. The current study selects a multistage flash distillation process. Not only is the MSF process a very suitable method, but it is also the most common method currently producing about 50%–60% of the world's desalinated water (Heidary et al. 2019).

Aspen HYSYS software v. 11 was used for this simulation. A considerable characteristic of this software is its ability to couple with other main tools such as MATLAB, PROII, Aspen Process, Economic Analyzer, Microsoft Excel, etc. Having simulated the process via Aspen HYSYS software v. 11 software, the results are linked to Aspen Process Economic Analyzer (APEA) for the purpose of economic evaluation. In the current work, the Peng–Robinson thermodynamic model is applied to the simulation of the power generation cycles (Liu et al. 2019). Peng–Robinson equation of state (PR) is a modification of the Redlich–Kwong equation of state published by Peng and Robinson in 1976 (Lopez et al. 2017). Also, electrolyte–nonrandom two-liquid (NRTL) thermodynamic model is used for the simulation of the desalination of the seawater process (Liponi et al. 2020). The electrolyte–NRTL activity coefficient model has been one of the most widely practiced engineering fluid packages for both aqueous and nonaqueous electrolyte systems (Moon et al. 2012).

2.1. Simulation of combined generation units of desalinated water and power

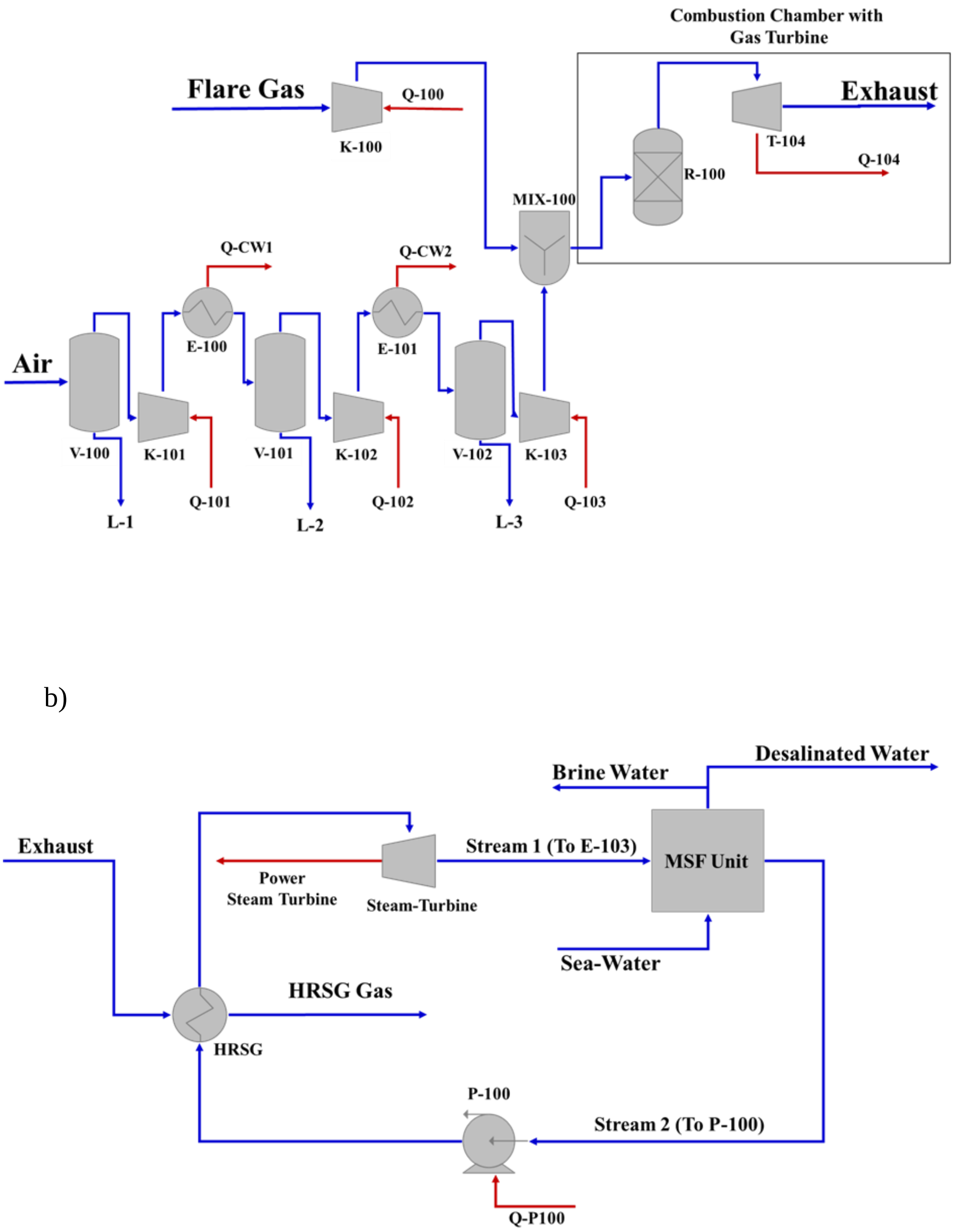
This section describes the simulation of the combined generation process of desalinated water and power. It should be noted that the flare gas sample is assumed to be sweet, and the sweetening cost is considered in the price. The working basis of a conventional gas turbine cycle is receiving fuel energy, generating power, and rejecting heat to a sink at a lower temperature. Gas turbine cycles often work based on the Joule–Brayton constant-pressure closed cycle (Khaliq et al. 2009). The Brayton cycle is one of the impressive cycles for the conversion of gas fuels to power. For further use of the heat of the hot stream of gas turbine exhaust, a bottoming cycle is usually placed downstream of the gas turbine cycle to form a combined cycle. The bottoming cycle of the combined cycle is usually a steam cycle working based on the Rankine cycle (Song et al. 2018).

Initially, the mixture of air and flare gas is compressed up to 20 bar in a compressor, and then it enters a combustion chamber. It is assumed that all of the hydrocarbons present in the flare gas sample are completely burned in the combustion chamber. Atmospheric pressure is considered for the gas turbine exhaust, which enters the HRSG to produce superheated steam (Rahimpour et al. 2012). The HRSG is made of an economizer, superheater, and evaporator. Then, the produced steam enters the steam turbine at a pressure of 85 bar. The pressure of steam leaving the steam turbine determines the amount of power generated. The low-pressure steam is condensed, and it returns to the beginning of the steam cycle (Naderi et al. 2018). The MSF units typically range from 5,000 to 35,000 m^3/day and consist of a series of stages ranging from 4 to 40 each, with successively lower temperature and pressure, which causes the flash evaporation of the hot brine followed by the condensation of freshwater (Alkaisi et al., 2017). The MSF process contains 15 flash stages in series (Mabrouk et al. 2015). Seawater is fed from the Persian Gulf Bay at a rate of 27290 m^3/h. The total dissolved solids are assumed to be 44700 mg/L of seawater. Seawater enters the process at a temperature of 35 °C. Within the multistage flash process, the seawater of the Persian Gulf is heated through a series of 15 heat exchangers (Cond-1, Cond-2, …, Cond-15) and a brine heater before entering a series of 15 evaporation chambers (Sep-1, Sep-2, …, Sep-15). After the Persian Gulf seawater exits the final heat exchanger (Cond-1), it enters a brine heater (E-103), where it is heated to the temperature necessary for the flashing process to begin. When the seawater is heated to a temperature appropriate for flashing, it enters the first evaporation chamber (V-102). Upon entering the chamber, the seawater is flashed. Some of the seawater evaporates, leaving the salt behind. The seawater that does not evaporate moves to the next stage, which operates at a higher temperature and a lower pressure, and the process is repeated. In the evaporation chambers, the seawater of the Persian Gulf flashes, and the desalinated water vapor is condensed, saved, and sent to a water treatment unit. The brine stream proceeds to the next chamber, and the process continues. The simulated MSF process fulfills different environmental, ethical, social, and health-related constraints. The brine discharged back to the sea is diluted to at most 2% above the natural background salinity as required by law so that the plant does not cause an injury to any local marine life.

Low-pressure steam leaving the steam turbine is used to warm seawater in the MSF process. The major advantage of the mentioned configuration is that the heat exchanger applied in the MSF process, which uses steam turbine (ST) outlet steam for warming up the seawater, acts as a condenser for the steam turbine cycle, and the water produced is pumped back to the HRSG; thus, another condenser is not required. The simulation flowsheet of the process of the combined generation of desalinated water and power is depicted in Figure 1.

By decreasing the pressure of the steam leaving the steam turbine, the amount of power generated is increased; on the other hand, the temperature of the ST outlet steam used to warm up the seawater is decreased, which results in a reduction of the produced desalinated water. Accordingly, there is a trade-off between the amount of power generated in the steam cycle and the desalinated water produced in the MSF process. In order to investigate this trade-off, the pressure in the steam turbine outlet stream is changed from 3 to 78 bar to perform a sensitivity analysis. For evaluating the economic profitability of the simulated cogeneration unit, the capital cost, the operating cost, the operating profit, and the payback period are calculated for each scenario.

a)



b)

c)

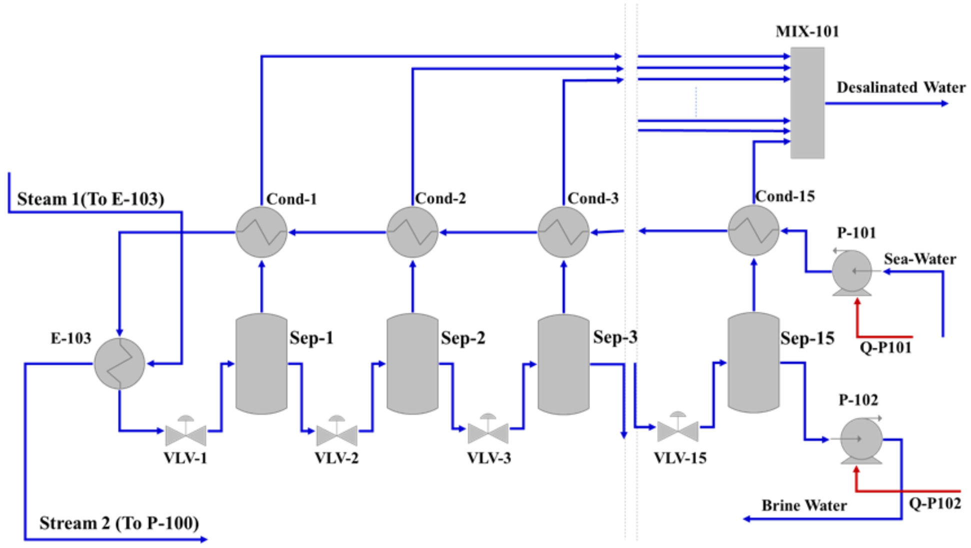


Figure 1

The simulation flowsheet: (a) and (b) combined desalinated water and power generation unit; (c) multistage flash desalination process.

The net power generation in the combined desalinated water and power generation indicates the amount of power generation in the process (the power generation in a gas turbine and steam turbine) minus the total power consumed by the process. The net power generation in this process is presented in Figure 2.

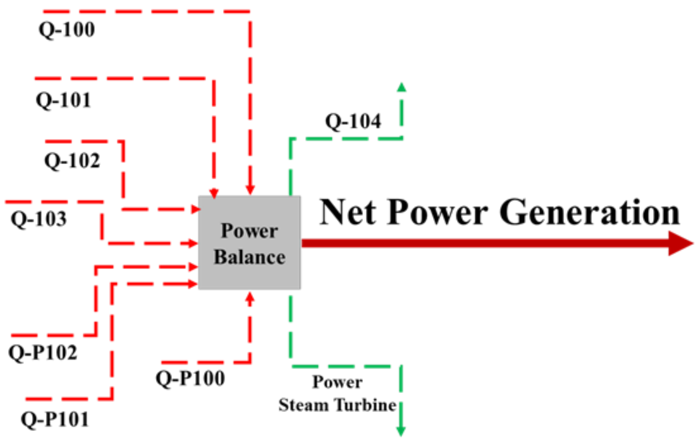


Figure 2

The net power generation in the combined desalinated water and power generation unit.

Considering the costs of the raw materials and utilities and the price of the produced products, the operating profit for the cases simulated here can be calculated as the difference between the total income from selling the products and the costs of the raw materials and utilities used in the process. The price of the raw materials, utilities, and products in the current study is listed in Table 2. It should be noted that the required electricity for the compressors and the pumps is supplied using the power generated in the plant. Hence, the net power generation considering the power consumption in the compressors and the pumps is used in the economic evaluation. By dividing the total capital cost by the operating profit, the payback period is calculated.

Table 2

The unit price of the feed, the utilities, and the products.

Utility/Product	Unit	Unit price
Sweet flare gas	\$/kg	0.06847
Desalinated water	\$/m^3	1.76
Cooling water	\$/kg	4.44×10^{-6}
Power	\$/MWh	56.88

3. Results and discussion

This study performed the simulation and economic analysis of combined desalinated water and power generation from associated gases of the Cheshmeh Khosh oil field utilizing Aspen HYSYS software v.11 and APEA software v. 11. The purpose of the economic analysis is to determine the most profitable economic option between the generation of the maximum power from the CHP unit and the production of the desalinated water. The specifications of the treated flare gas stream, the air, the exhaust gas, and the wastewater outlet from the air compression stage are tabulated in Table 3. As presented in Table 4, 956 and 89.85 MW of power was generated in the gas and steam turbine respectively. Further, 372.6, 2.726, and 1.80 MW was consumed for the air compressors, the treated flare gas compressor, and the pump respectively. Therefore, at this capacity of the treated flare gas, the designed combined cycle power plant generates 669 MW of net power. The process flow diagram (PFD) configuration of a combined cycle power plant in Aspen HYSYS software and the simulation results were compared with the works of Rahimpour et al. (2012) and Okullo et al. (2018) for validation; the results were in very close agreement.

Table 3

The specification of the treated flare gas, the air, the exhaust, and the wastewater in the combined cycle power plant.

Conditions	Flare gas (treated)	Air	Exhaust	L-1	L-2	L-3
Temperature (°C)	45	30	565	25	35	35
Pressure (bar)	10	1	1	1	3	9
Volume flow (m^3/day)	285,000	80,710,000	231,800,000	9025	739.4	718
Mass flow (ton/day)	2,766	102,100	94,330	9091	739.3	718
H_2S ppm	4	-	-	-	-	-
Composition	mol %	mol %	mol %	mol %	mol %	mol %
Methane	0.670	0.00	0.00	0.00	0.00	0.00
Ethane	0.165	0.00	0.00	0.00	0.00	0.00
Propane	0.092	0.00	0.00	0.00	0.00	0.00
Butane	0.044	0.00	0.00	0.00	0.00	0.00
C_5–C_8	0.014	0.00	0.00	0.00	0.00	0.00
CO_2	0.000	0.00	0.054	0.00	0.00	0.00
H_2S	0.000	0.00	0.0011	1.00	1.00	1.00
H_2O	0.008	0.10	0.094	0.00	0.00	0.00
N_2	0.007	0.69	0.74	0.00	0.00	0.00
NO	-	0.00	0.00	0.00	0.00	0.00
O_2	0.00	0.21	0.11	0.00	0.00	0.00

Table 4

The generation and consumption of power in the combined cycle power plant.

Generation or consumption of heat and power	Value (MW)
Power consumption of feed compressor	2.726
Power consumption of air compressors	372.6
Power generation of gas turbine	956
Power consumption of pump	1.80
Power generation of gas turbine	89.85
Net power generation in the GT system	668.72

Table 5 presents the distillate and brine mass flow rate, the salinity, the temperature, and the saturation pressure at different MSF stages in the suggested MSF configuration. In the MSF stages, the flashing brine flow rate decreases while passing through stages 1–15 due to evaporation; however, the brine salinity increases. Also, as listed in Table 5, the seawater enters the MSF unit at a mass flow rate of 647,900 ton/day and a TDS of 44.7 g/L, and the brine stream is returned to the sea at a flow rate of 592910 ton/day and a TDS of 45.3 g/L. The PFD configuration of an MSF process in Aspen HYSYS software and the simulation results were compared with the works of Mabrouk et al. (2015) and Dhiantravan et al. (2020) for validation; the results were in very close agreement.

Table 5

The specification of each stage of the MSF process.

Stage	Temperature (°C)	Pressure (bar)	Flashing salinity (g/L)	Distillate flow rate (ton/day)	Total distillate flow rate (ton/day)	Brine flow rate (ton/day)
1	115.2	1.81	44.80	9500	9500	638400
2	114.8	1.66	44.80	3500	13000	634900
3	112.2	1.52	44.90	3500	16500	631400
4	109.3	1.38	44.95	3400	19900	628000
5	106.6	1.26	45.05	3400	23300	624600
6	104.1	1.15	45.10	3300	26600	621300
7	101	1.04	45.10	3300	29900	618000
8	98.28	0.94	45.20	3200	33100	614800
9	95.52	0.85	45.30	3200	36300	611600
10	92.85	0.77	45.30	3200	39500	608400
11	89.93	0.69	45.35	3100	42600	605300
12	87.14	0.62	45.40	3100	45700	602200
13	84	0.54	45.40	3100	48800	599100
14	78	0.48	45.50	3100	51900	596000
15	70	0.40	45.50	3090	54990	592910

These diagrams indicate that by increasing the steam turbine outlet pressure from 3 to 78 bar, the power generation declines from 697 to 581 MW, but the desalinated water production rises from 1557 to 2109 m^3/h. The amounts of the net power generated and the desalinated water produced in the simulated cogeneration units are delineated in Figure 3. It is obvious that as the power generation decreases due to increasing the pressure in the ST outlet, the amount of the produced desalinated water increases.

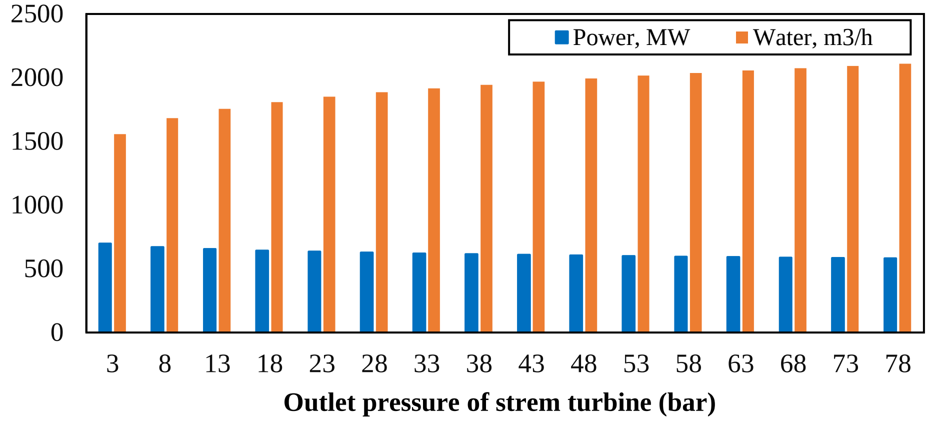


Figure 3

The amount of generated power and produced desalinated water in different simulated cases with different pressures in the steam turbine outlet.

The effects of increasing steam turbine outlet pressure on the capital cost and the operating cost are illustrated in Figure 4. This figure indicates that by increasing the steam turbine outlet pressure from 3 to 78 bar, the capital cost rises from 1177 to $1192 million, but the operating cost decreases from 117.85 to $117 million per year. The reason for the increase in the capital cost with enlarging the pressure is the increase in the steam turbine power. Raising the pressure also increases the amount of the produced desalinated water, and thus the capacity of the MSF unit, thereby increasing the capital cost.

The effects of increasing the steam turbine outlet pressure on the operating profit and the payback period are depicted in Figure 5. It indicates that by increasing the steam turbine outlet pressure from 3 to 78 bar, the operating profit changes from 300 to $251 million per year, and the payback period extends from 3.92 to 4.75 years. From the results obtained for the case study, we can conclude that by increasing the steam turbine outlet pressure, the operating profit decreases, and the payback period extends. Thus, the most economically profitable scenario for the investigated cogeneration plant is to generate as much as possible power in the steam turbine and use the remaining heat in the low-pressure outlet steam for the MSF desalination process.

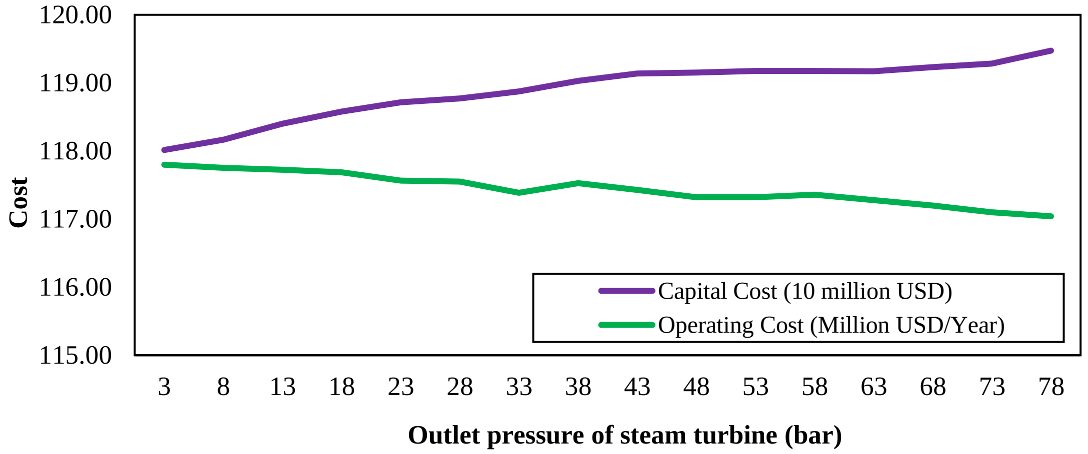


Figure 4

The effects of increasing the steam turbine outlet pressure on the capital cost and the operating cost.

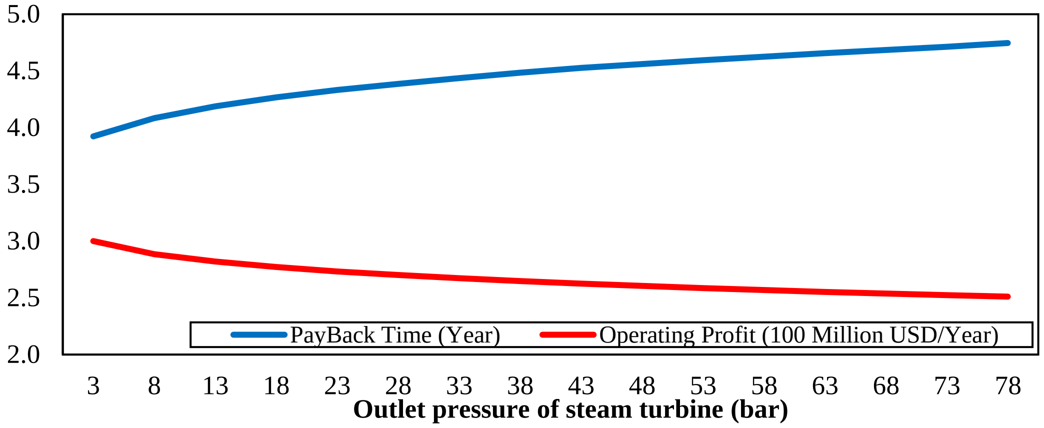


Figure 5

The effects of increasing the steam turbine outlet pressure on the operating profit and the payback period.

4. Conclusions

In order to mitigate the major environmental problems and economic loss due to burning considerable amounts of flare and associated gases, flare gas recovery processes should be taken into consideration. The cogeneration plant of power generation and seawater desalination can be considered as a suitable process for flare gas recovery. The simulations carried out on the cogeneration plant of power generation and seawater desalination indicate that by reducing the steam turbine outlet pressure, the power generated in the steam cycle increases; thus, the volume of the desalinated water produced in the multistage flash process is reduced. From the economic evaluations performed on the different simulated cases, it can be deduced that the best possible option for achieving the highest economic profitability is to generate power in the steam turbine as much as possible and use the heat remaining in the steam turbine outlet steam for the desalination process. An important advantage of the proposed configuration is that the heat exchanger applied in the MSF process, which uses steam turbine outlet steam to warm up the seawater, acts as a condenser, and the water produced is pumped back to the HRSG used in the steam cycle. The economic evaluations indicate that a payback period of less than four years can be achieved for the cogeneration plant by using a suitable configuration. The results of this study demonstrate that by increasing the steam turbine outlet pressure from 3 to 78 bar, power generation and water production change from 697 to 581 MW and from 1557 to 2109 m^3/h respectively. In addition, by increasing the outlet pressure of the steam turbine from 3 to 78 bar, the total capital cost rises from 1177 to $1192 million, and the operating cost declines from 117.85 to $117 million per year. Finally, the operating profit decreases from 300 to $50 million per year, and the payback period extends from 3.92 to 4.75 years.

Nomenclature

APEA	Aspen Process Economic Analyzer
CHP	Combined heat and power generation
CNG	Compressed natural gas
ED	Electrodialysis
EOR	Enhance oil recovery
FGR	Flare gas recovery
GHG	Greenhouse gases

GTL	Gas to liquids
HRSG	Heat recovery steam generator
LPG	Liquefied petroleum gas
MED	Multi-effect distillation
MSF	Multistage flash
NGL	Natural gas liquid
NRTL	Nonrandom two-liquid
PR	Peng–Robinson
RO	Reverse osmosis
TDS	Total dissolved solid

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