Environmental and Thermoeconomic Study of the Impact of Using Air-Cooled Condensers in the Kalina Cycle for Power Generation in Hot and Dry Regions

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The Kalina cycle utilizes low-temperature heat sources to generate high-pressure vapor for running a turbine to produce power. Since the vapor at the turbine exit is relatively low temperature, a cool medium is required to liquefy the vapor at the condenser. This requirement imposes a practical limitation to the Kalina cycle for application in hot and dry regions. This paper studies the environmental and economic impact of using air-cooled condensers in the Kalina cycle. A dual Kalina cycle (KSC-D), the hybrid dual Kalina cycle (KSC-Dh), and the basic Kalina cycle (KSC-1) have been compared, considering Tarasht Steam Power Plant, Tehran, as a case study. Subsequently, power output, water consumption, CO_2 emission, and IRR , NPV were investigated for each case. Results show the least power output ($4346704 kWhyear^{-1}$) and the maximum power output ($5008627 kWhyear^{-1}$) belong to the basic Kalina cycle with an air-cooled condenser (KSC-1a) and the KSC-Dh cycle, respectively. Moreover, using air-cooled condensers in the dual Kalina cycle (KSC-Da) saves about $425825 \times 10^3 m^3$ of water annually. KSC-Da is the most economical and has the shortest payback time of three years. Also, for KSC-Da, the natural gas saved is 0.7765 to 1.22 $Mm^3 year^{-1}$, and the reduction in CO_2 emission is about 4378 Tons $year^{-1}$. The overall results indicate that although the KSC-Da ranks fourth in terms of power output among the different cases (producing $4564262 kWhyear^{-1}$), it is still the most viable choice regarding the impact on the environment and reducing the amount of CO_2 emissions.

keywords: *CO2 emission, Dual Kalina cycle, Heat recovery, Low-temperature, Water consumption, Water-cooled condenser*

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NOMENCLATURE

a	Air Cooled
A	Area
ACC	Air Cooled Condenser
Con	Condenser
C	Cost
C_{LO}	Loss Cost Flow
C_P	Product Cost Flow
C_F	Fuel Cost Flow
C_{in}	Yearly income
CRF	Capital Recovery Factor
$\dot{E}$	Exergy rate
Eva	Evaporator
HEX	Heat exchanger
IRR	Internal Rate of Return
$\dot{m}$ F	Mass flow rate
Mix	Mixer
NPV	Net Present Value
P	MPressure
T	Temperature
TCI	The total cost of investment
Tur	Turbine
U	Heat transfer coefficient
Val	Valve
W	Water Cooled
X	Ammonia-water mass fraction
$\dot{z}_{CI}$	Capital Investment Rate
$\dot{z}_{O\&M,j}$	Operation and Maintenance Investment Rate
B	Bottom Cycle
Ex	Exchanger

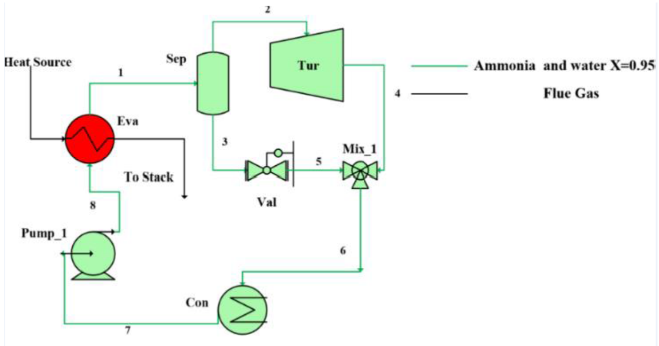

Fig. 1. The basic Kalina cycle configuration (KSC-1)

Exh	Exhaust
in	Inlet
j	Component
out	Outlet
Po	Power
T	Top Cycle
Tot	Total

1. INTRODUCTION

Power cycles with the ability to generate electricity from low-temperature heat sources have been proposed to reclaim a large portion of heat loss to the environment in power plants, which is an essential consideration regarding global warming and climate change [1].

The Kalina cycle [2], developed by Alexander Kalina in the late 1970s and early 1980s, is an advanced thermodynamic cycle that uses an ammonia-water mixture for its operation. It can convert thermal energy from a comparatively low-temperature heat source into mechanical energy. It shows promising results regarding efficiency and the mitigation of environmental issues. Also, due to its non-isothermal phase change, the ammonia-water mixture can adapt well to a liquid heat source temperature profile and reduce the exergetic losses [3]. Fig. 1 shows the basic Kalina cycle configuration.

The unique features of the Kalina cycle have attracted the attention of many researchers [4]. Zhu et al. [5] presented a modified two-pressure Kalina cycle with a heat source temperature of 400 °C and compared its performance with the basic Kalina cycle. Restrictive parameters in their study included a cooling water temperature of 25 °C, minimum turbine output steam quality of 0.85, minimum exhaust temperature of 90 °C, and maximum turbine inlet pressure of 20 MPa. The results showed that their proposed two-pressure modified Kalina cycle is more efficient due to irreversibility reduction. Still, they did not investigate the effect of environmental conditions on the proposed cycle's output power.

Nemati et al. [6] proposed a model to compare the Kalina and Organic Rankine (ORC) cycles as heat recovery systems downstream of a CGAM cogeneration system and optimized the model. In this study, they compared the effect of some decision variables on the energy efficiency and exergy of the combined cycle and determined the turbine size for both cycles. Their results showed that the ORC cycle has higher energy efficiency and exergy than the Kalina cycle. Still, the size of the Kalina cycle turbine is smaller than the turbine in the ORC cycle. However, they did not evaluate the effect of the cooling medium temperature on the performance of the two cycles.

Wang et al. [7] numerically investigated the effect of cooling medium temperature (environmental conditions) on the Kalina cycle's thermal efficiency. They used an air-cooled condenser to maximize the impact of the ambient temperature on the cycle's performance. They changed the speed of cooling fans to control temperatures and condensing pressures. Their results showed that a composition-adjustable Kalina cycle (a Kalina cycle with a variable ammonia-water mass fraction, X) provided better power output and cycle efficiency under varying ambient temperatures. However, they did not offer a practical solution and did not evaluate the design economically.

Mehrpooya and Mousavi [8] used solar energy as the heat source for the Kalina cycle. They used conventional thermo-exergy methods to study the economics and thermodynamic features of the Kalina cycle and used the advanced thermo-exergy method to determine irreversible costs. They found that most energy degradation occurred in one of the heaters, and the highest exergy efficiency was related to the turbine. They did not provide any data regarding the effects of ambient temperature variations and cooling water temperature changes on cycle performance.

Ogriseck [9] investigated integrating the basic Kalina cycle with a combined heat and power (CHP) plant and showed the net efficiency changes of the combined cycle due to variations in cooling water temperature and the ammonia-water mass fraction. The results showed the power plant's net efficiency is 12.3% to 17.1%, and the gross efficiency ranges from 13.5% to 18.8%, with an output power of 320 to 440 kW. He also evaluated the results for five different ammonia-water mass fractions and showed that the best efficiency was for the mass fraction of 0.82 and a cooling water temperature of 5°C. However, he did not present an approach for improving cycle performance in hot and dry climates and areas with cooling water scarcity.

Akimoto et al. [10] proposed an integrated system consisting of a conventional Kalina cycle and a heat pump cycle in heat exchange with the Kalina cycle's condenser to generate electricity. Results showed using the heat pump downstream of the basic Kalina cycle improved the power generation by up to 81%, enhancing the power generation's economy for a heat source temperature above 353K. However, they did not study the effect of ambient and cooling medium temperature changes on their proposed design's efficiency and power output.

Parvathy and Varghese [11] investigated the effect of using a multi-stage steam turbine to improve the Kalina cycle performance. They examined the impact of intermediate pressure on separator temperature, vapor fraction at the exit of the low-pressure turbine, net power output, net heat input, and efficiency of the cycle parameters. They found that the efficiency of the Kalina cycle can be increased by 4.04% using a multi-stage steam turbine and intermediate reheating. This configuration does not adapt to ambient and heat source temperature changes due to the impossibility of changing the ammonia-water mass fraction in the intermediate heater against these temperature changes. Hence, they obtained their results only for the constant heat source and ambient temperature conditions.

Abam et al. [?] presented a three-item analysis including energy, exergy, and economy for their combined cycle configuration. This combined cycle included a Kalina cycle upstream and an embedded vapor absorption cooling system downstream. Their results showed that cooling and turbine output at simulation conditions were estimated to be 1077 kW and 291 kW,

respectively. However, they did not investigate the effects of changes in the cooling fluid temperature on the cycle's cooling and output power in this layout.
Mergner and Schaber [13] investigated the effect of changes in the ammonia-water mass fraction on the output power for a Kalina cycle application to produce electrical energy from geothermal energy. They found that the changes in the ammonia-water mass fraction between 85% and 92% had a minor impact on the behavior of the critical performance parameters, namely temperature, pressure, and flow rate of the evaporative heat exchanger. Still, they did not investigate the effects of the cooling fluid temperature changes on these parameters.
In the Kalina cycle, due to the thermodynamic conditions of the ammonia-water mixture, steam output from the turbine has a lower temperature but higher pressure than steam in the Rankine power cycle. Therefore, using water at a low enough temperature for the condensation process at the steam turbine outlet presents a practical limitation to the Kalina power cycle. Most studies have not addressed the effects of cooling medium temperatures in the condensation process on the Kalina power cycle, and no solution has been provided to reduce the impact.
The present work studies the environmental and economic impact of replacing water-cooled condensers with air-cooled ones in the Kalina cycle for use in hot and arid areas. Five cases have been considered and compared based on the basic Kalina cycle and dual Kalina cycle configurations. These are the dual Kalina cycles (KSC-Da, KSC-Dw) working with respectively only air and only water-cooled condensers, the basic Kalina cycles (KSC-1a, KSC-1w) using respectively only air and only water-cooled condensers and the hybrid dual Kalina cycle (KSC-Dh) working with hybrid (water-air) condensers. As a case study, a power plant (Tarasht Steam Power Plant, Tehran) has been considered to study the basic Kalina and the dual Kalina cycles. The flue gas (stack gas) from the power plant boiler is the low-temperature heat source in the two power cycles. The effects of variations in the cooling medium temperature on annual power generation have been investigated for the five cases. Subsequently, power output, water consumption, and CO2 emission were examined for each case. Also, considering the cost of using groundwater resources, the economic parameters (IRR, NPV) were calculated to compare the economy of the various cycles.

2. METHODOLOGY

A. The various Kalina cycle cases considered

The comparison of the five cases is based on the analysis of two configurations: the basic Kalina cycle (KSC-1) and the dual Kalina cycle (KSC-D) proposed by the authors with advantageous features [14, 15].
In the basic Kalina cycle (Fig. 1), the ammonia-water mass fraction of $X = 0.95$ is obtained based on the temperature of the heat source and the maximum achievable power output. The dual Kalina cycle (Fig. 2) comprises two basic Kalina cycles; a top cycle (KSC-DT) and a bottom cycle (KSC-DB). In both configurations, the flue gas ($m = 27.46\ kgs^{-1}$ at 175°C temperature) enters the top cycle evaporator. However, in the dual Kalina cycle, the flue gas, after exchanging heat with an ammonia-water mixture of $X = 0.95$ in the top cycle, enters the evaporator in the bottom cycle and exchanges heat with an ammonia-water mixture of $X = 0.44$. The HEX_1 exchanger at

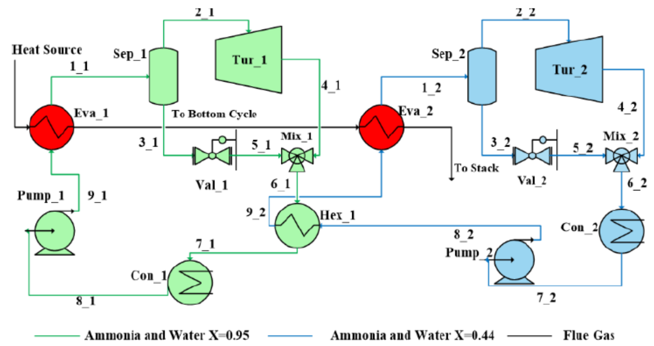

Fig. 2. The dual Kalina cycle configuration (KSC-D)

the outlet of the upstream turbine has two advantages. First, it reduces the temperature of the vapor exiting the upstream turbine through heat exchange with a cold ammonia-water mixture in the bottom cycle, which helps improve the condensation process in the top cycle condenser. Second, due to the higher temperature of the ammonia-water mixture in the top cycle, the heat exchange in the HEX_1 exchanger causes preheating of the ammonia-water mixture in the top cycle.

Fig. 3 shows the five different cases for the two configurations considered in this study. Fig. 3(a) and 3(b) show the KSC-1w and KSC-Dw cases, where cooling water, for example, from a cooling tower or groundwater, is used as a coolant for the condensation of the turbine's outlet vapor [15]. Similarly, as shown in Figs. 3(c) and 3(d), air-cooled condensers are used for the condensation of the vapor in KSC-1a and KSC-Da cases [16]. Fig. 3(e) shows the case of the dual Kalina cycle using both an air-cooled condenser and a cooling tower in a hybrid (KSC-Dh) case [17].

B. Thermodynamic equations

All equations related to mass and energy balance and thermodynamic equations for every cycle component used in each of the five cases are based on the equations used in Ref. [18].
Also, the total area of the heat exchanger is equal to the total area of the fins and the primary area, which is calculated based on the equations in Ref. [19] and Ref. [20].

C. Equations used for economic analysis

The cost of all heat exchangers, including evaporators, preheaters, and condensers for the Kalina cycle, is obtained from Eq. (1), where $C_{b,ex} = 588$ USD$ m^{-2} and $n = 0.8$ [21].

$$C_{ex} = C_{b,ex} \times (A_{Tot_{ex}})^n \quad (1)$$

The cost of equipment such as turbines and pumps is obtained from Eq. (2), where the parameter $C_{b,j}$ for pump and turbine is 1120 USD$ kW^{-1} and 4405 USD$ kW^{-1}, and the coefficient n is 0.8 and 0.7, respectively. Also, the parameter Power j is the equipment power [21].

$$C_j = C_{b,j} \times \left(Power_j\right)^n \quad (2)$$

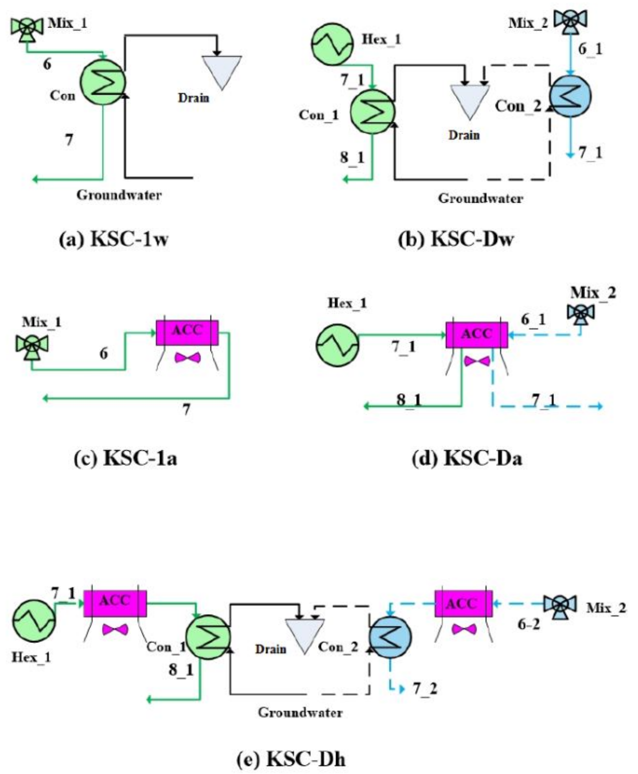

Fig. 3. The five different cases (KSC-1w, KSC-Dw, KSC-1a, KSC-Da, KSC-Dh) for the two considered configurations

Net electricity sales revenue is obtained from Eq. (3), in which $C_{E,Tur}$ is the cost rate balance of the turbine and is obtained from Eq. (4) [21].

$$C_{el} = C_{E,Tur} \times (Power_{Out})^{n} \quad \textbf{(3)}$$

$$C_{E,Tur} = (C_{F,j}\dot{E}x_{F,j} - C_{LO,j}\dot{E}x_{Lo,j} + \dot{z}_{CI,j} + \dot{z}_{O\&M,j})/\dot{E}x_{P,j} \quad \textbf{(4)}$$

For the economic analysis of the five cases, the parameters NPV, CRF, IRR, and yret are used, which are obtained from Eqs. (5) to (8) [22–24].

$$NPV = -TCI + C_{in}/CRF \quad \textbf{(5)}$$

$$CRF = \left(i_{eff}\left(1+i_{eff}\right)^{n_y} / \left(\left(1+i_{eff}\right)^{n_y} - 1\right)\right) \quad \textbf{(6)}$$

$$TCI = C_{in}/\left(IRR(1+IRR)^{n_y}/((1+IRR)^{n_y} - 1)\right) \quad \textbf{(7)}$$

$$y_{ret} = TCI/C_{in} \quad \textbf{(8)}$$

where the effective rate of return, $i_{eff} = 0.1$, and the operation period of the power plant, $n_y = 20$ years.

Fig. 4. Stacks of Tarasht Steam Power Plant

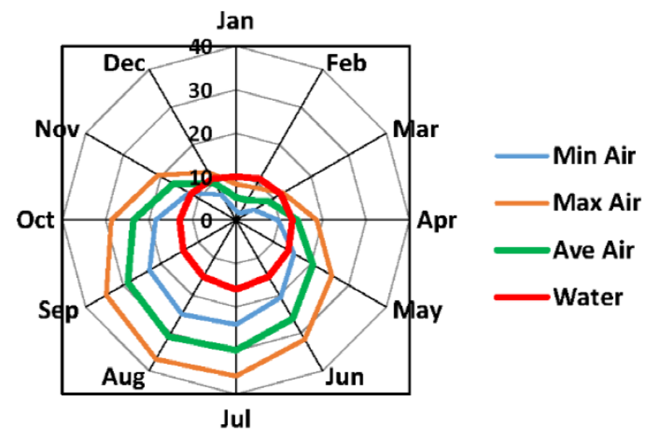

Fig. 5. Annual ambient air and groundwater temperature variations (°C) in Tehran

D. The case study

In this case study, the flue gas from the steam boiler's stacks in Tarasht Steam Power Plant (Tehran-Iran), shown in Fig. 4, was used as the driving heat source for the Kalina cycle. The minimum temperature difference in the pinch point for all the heat exchangers is 3°C.

According to their material, the heat transfer coefficient for evaporators, heat exchangers, and condensers are considered to be 0.9, 1, and 1.1 $kWm^{-2}K^{-1}$, respectively [25]. Also, the isentropic efficiency for turbines and pumps is $\eta_{Tur} = 0.88\%$ and 0.75%, respectively.

The temperature of the heat source from the steam boiler's stacks is about 175 °C. The power plant's average steam cycle efficiency is about 21%, and the average net heat value of the consumed fuel during this period was 49.675 $MJkg^{-1}$. Since the power plant under consideration is located in Tehran, the annual variations of the ambient air and groundwater temperatures in Tehran are as depicted in Fig. 5.

3. RESULTS

A determining factor for increasing the consumed recycled heat in the Kalina cycle and, therefore, the power generation

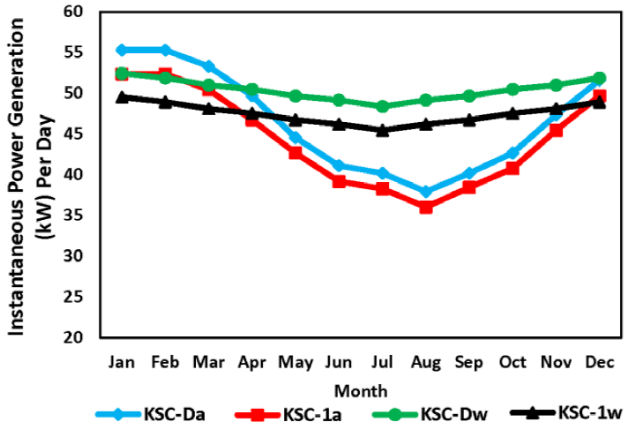

Fig. 6. The daily power generation for KSC-1a, KSC-1w, KSC-Da, and KSC-Dw, based on monthly variations of ambient air and groundwater temperatures

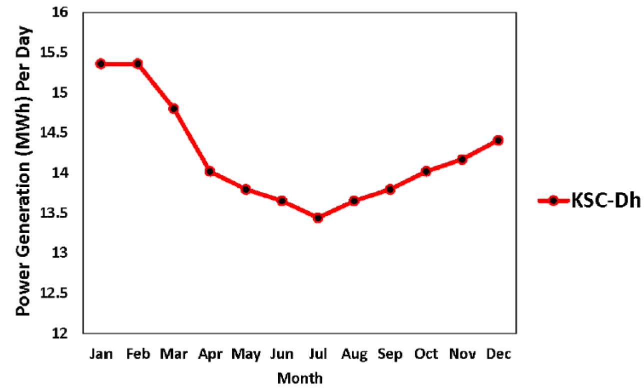

Fig. 7. The daily power generation for KSC-Dh, based on monthly variations of ambient air and groundwater temperatures

capacity of the cycle is the ammonia-water mass fraction, X. The desired mass fraction was determined by considering the changes in the ammonia-water mass fraction at 175°C using the laws of thermodynamics and mass and energy balance for both configurations.

The thermodynamic properties at different points, and power generation for all the cases (refer to Figs. 2 and 3) at a heat source temperature of 175°C, were obtained by energy and mass balances and using the library database in EES software.

Accordingly, the maximum electrical power generation capacity for the basic Kalina cycle (KSC-1) is obtained at the mass fraction of $X = 0.95$. Similarly, the maximum power output for the bottom cycle (KSC-DB) in the dual Kalina cycle configuration is obtained at the mass fraction of $X = 0.44$.

Due to the effect of coolant temperature in the condenser, the maximum power generation at a mass fraction of 0.95 for the dual Kalina cycle using ambient air as the coolant is obtained as 460,800 kWh in January. For the basic Kalina cycle, it is 436,392 kWh. While the corresponding values obtained when using groundwater resources are 437,040kWh and 412,560 kWh, respectively.

Fig. 6 depicts the average daily instantaneous power output for both configurations based on annual ambient air and groundwater temperature variations (considered as the cooling fluids). The power generation for the KSC-1a and KSC-Da cases shows a sharp decrease due to a considerable increase in the ambient air temperatures during the warmer months, the reduction being most pronounced between April to August. However, because of less annual variation in the groundwater temperature, the average daily instantaneous power generation for the KSC-1w and KSC-Dw cases, which use water-cooled condensers, follows a uniform trend.

In the hybrid case of KSC-Dh, an air-cooled condenser is used in conjunction with a water-cooled condenser. Fig. 7 shows this case's power output curve for different months. Here, for the cold months of the year, when the ambient air is cooler than the groundwater temperature, an air-cooled condenser can be used for the condensation process. However, in the hot months, when the ambient temperature is warmer than the temperature of groundwater sources, a combination of air and water can be used for the steam condensation process. This protocol can result in higher average daily instantaneous power output than other cases.

Fig. 8 compares daily power generation for the KSC-Da case with KSC-Dw, KSC-Dh, KSC-1w, and KSC-1a, based on annual ambient air and groundwater temperature variations.

As seen in Fig. 8(a), the total power generation for the KSC-Da case is 4,564,262 kWh, which is 379,961 kWh less than the total power generation for the KSC-Dw case, which is 4,944,223 kWh. In Fig. 8(b), the annual power generation for the KSC-1w is 4,656,599 kWh. Therefore, the power production for the KSC-Da case is 92,337 kWh less than KSC-1w. However, as shown in Fig. 8(c), from March to December, the power generation for the KSC-Da case is less than that of KSC-Dh (5,008,627 kWh) by an amount of 444,365 kWh, which is the most significant difference between the power generation for the KSC-Da case and other cases.

Fig. 8(d) compares the power generation for the KSC-Da and KSC-1a cases. As shown, the KSC-1a case is the only case that generates less power than the KSC-Da case on all days of the year, and the difference between the power generation of these two cases is 217,558 kWh. The higher power generation difference from January to April is due to the better performance of the intermediate heat exchanger HEX (see Fig. 2) in the year's cold months, which helps the condensation process in the top cycle.

Fig. 9 shows the monthly power generation diagram for the five analyzed cases. Variations of power generation in different months for these cases are due to the difference in the cooling fluids used for the condensation process and the number of days each month. As shown in Fig. 9, the highest power generation for all cases occurs in the cold months of the year, namely December and January.

Heat recovery efficiency is equal to the ratio of power generation to input heat. Considering that the amount of heat input is constant and equal to 5943 kW, the changes in heat recovery efficiency for all 5 cases are shown in Fig. 10.

The natural gas saved is 1.22 $Mm^3 year^{-1}$, and the reduction in CO2 emission for the proposed configuration (KSC-Da) is about 4378 $Tonsyear^{-1}$.

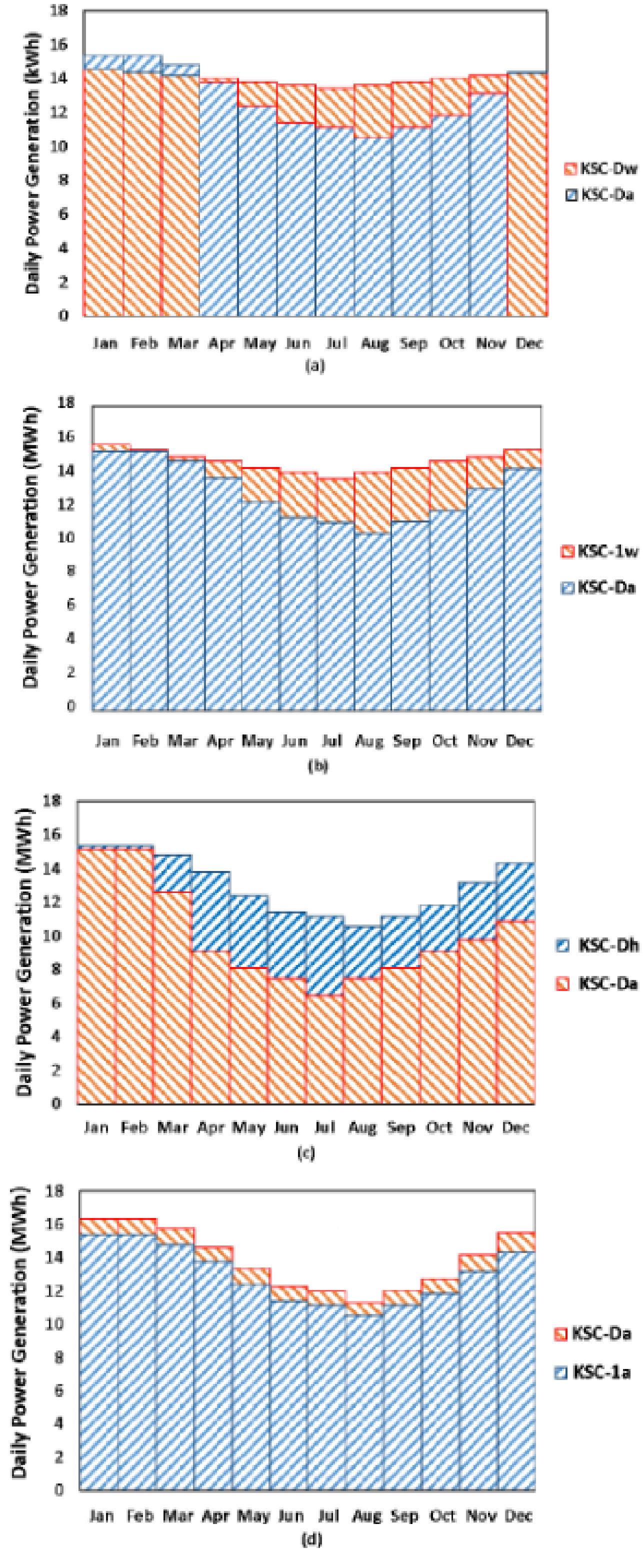

Fig. 8. Comparison of daily power generation for the KSC-Da case with other cases

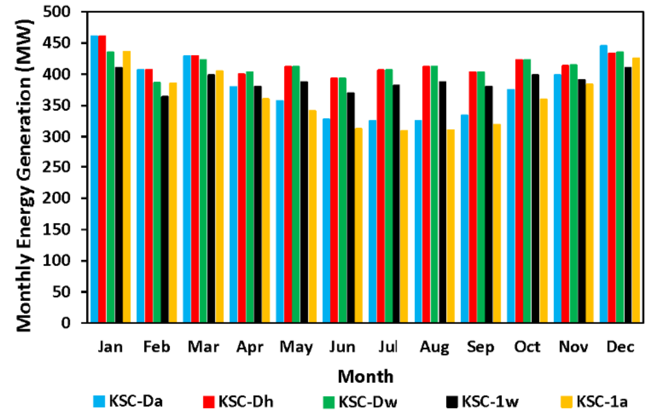

Fig. 9. Monthly power production considering the monthly variations of ambient air and groundwater temperatures

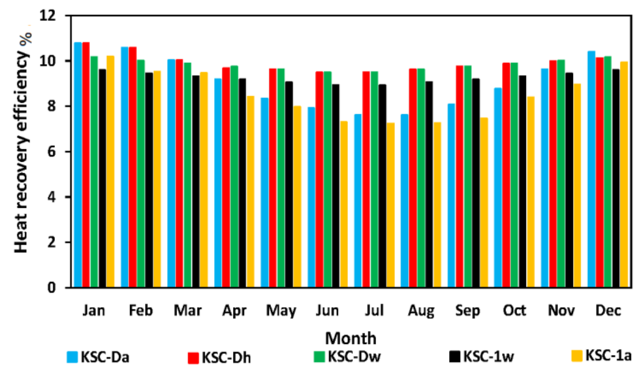

Fig. 10. Monthly changes in heat recovery efficiency

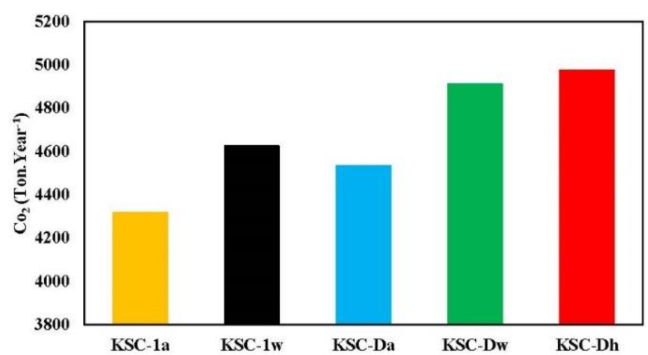

Fig. 11. The annual reduction in CO2 emission for the five cases

Considering that the efficiency of the upstream steam cycle is 21%, the amount of CO2 emission reduction for each of the five cases is as depicted in Fig. 11. As shown, case KSC-Dh has the highest annual decrease in CO2 emissions, and the KSC-1a case has the lowest CO2 emissions among the five studied cases. Moreover, the KSC-Da case is also in fourth place regarding the reduction of CO2 emission.

Fig. 12 shows the monthly water consumption for the three cases, KSC-Dw, KSC-1w, and KSC-Dh. The area under the curve is equal to the annual water consumption for each case, amounting to 425825×10^3, 191514×10^3, and $71921 \times 10^3 m^3$ for KSC-Dw, KSC-1w, and KSC-Dh, respectively. Therefore, it may be concluded that by changing the cooling fluid in the condenser

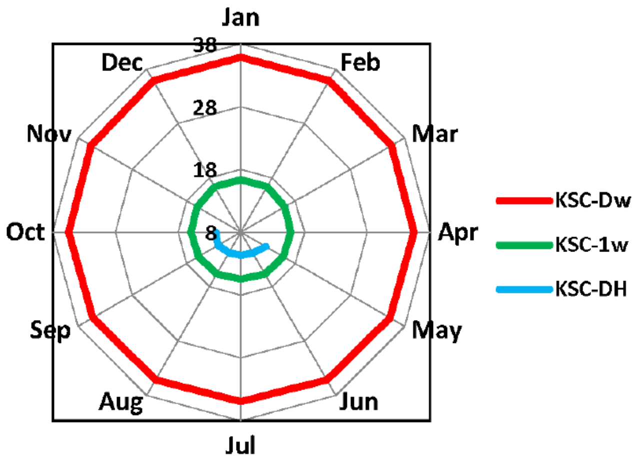

Fig.12. Monthly water consumption (10^6 m^3) for KSC-Dw, KSC-1w, and KSC-DH cases

Fig. 12. Monthly water consumption ($10^6 m^3$) for KSC-Dw, KSC-1w, and KSC-DH cases

Table 1. Mass flow rate for cooling fluid

Case	Water(kgs^{-1})	Air(kgs^{-1})
KSC-1w	189.2	—
KSC-1a	—	463.54
KSC-Da	—	596.28
KSC-Dw	243.38	—
KSC-Dh	92.48	369.7

from water to air for the dual Kalina cycle (KSC-D), the water consumption can be reduced by an amount of 425825 × $10^3 m^3$.

Also, the water and air flow rates used in the wet and dry cooling systems are determined in Table 1. As shown, the highest water consumption is for cycle KSC-Dw (243.38kgs^{-1}), and the highest amount of air required is for cycle KSC-1a (596.28kgs^{-1}).

The total monthly electricity generation in Fig.9 equals each case's annual electricity production values. Therefore, the annual sales income for each case can be calculated by taking into account the rate of 0.12 $USD\$kWh^{-1}$ of electricity sales [26]. Also, considering that the cost of water consumption from groundwater sources for condensation for KSC-Dw, KSC-1w, and KSC-Dh cases is 0.009 $USD\$m^{-3}$ [27] and using equations (5), (6), the TCI, IRR, and NPV values for each item in Table 1 have been calculated. These values are calculated based on the maximum power generation for all cases in January.
However, as shown in Table 2, the Total Cost of Investment (TCI) has increased due to increased costs of condenser construction and operating costs resulting from groundwater use in the KSC-Dh case. Therefore, the payback period for the KSC-Da case is three years, 0.7 years less than the KSC-Dh case.

These results show that considering Tehran's climatic conditions, using an air-cooled condenser instead of a wet cooling tower is more economically justified. Also, due to limited

Table 2. Economic parameters for 5 cases

Parameter case	IRR (%)	NPV (1000 $USD\$$)	TCI (1000 $USD\$$)	C_{in} (1000 $USD\$$)	Y_{ret}	A_{Con} (m^2)
KSC-1w	24.2	1013	520.3	126.9	4.1	443.3
KSC-1a	17.08	469.6	677.3	120.95	5.6	1081.6
KSC-Da	33.4	1773	806.8	268.93	3	1150.5
KSC-Dw	27.04	1230	623.2	168.43	3.7	469.6
KSC-Dh	22.09	855.3	916.9	208.39	4.4	891.8

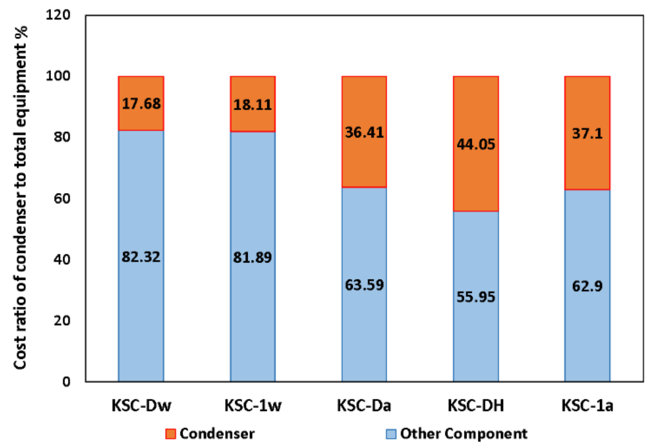

Fig. 13. Cost ratio of the condenser to the total equipment cost for the five cases

groundwater resources and the problem of land subsidence in this city, the adverse effects on the environment will be reduced. Fig. 13 shows each part's cost percentage in the total equipment costs for the five cases. As shown, the ratio of condenser cost in the KSC-Dh case is higher than in other cases. However, the payback time for the KSC-Da case is shorter than the other cases. The highest cost ratio for the condenser to the total equipment cost is related to the KSC-Dh case, which is about 44.1%.

4. CONCLUSIONS

This paper presents the environmental and economic impact of replacing water-cooled condensers with air-cooled ones in the Kalina cycle for use in hot and arid areas. The results can be summarized as follows:

- KSC-1a cycle has the least power output ($4,346,704 kWhyear^{-1}$), while the maximum power output ($5,008,627 kWhyear^{-1}$) belongs to the KSC-Dh cycle.
- Changing the condenser cooling fluid from water to air in the KSC-Da cycle can save about 425825 × $10^3 m^3$ of water annually compared to the KSC-Dw cycle.
- KSC-Da cycle is the most desirable option in terms of cost, and with an NPV of 1773,000 USD$, it has the shortest payback time of 3 years.
- The parameter IRR is 33.04% for KSC-Da, 6% higher than the KSC-Dh case, which is in second place.

- The overall results indicate that although the KSC-Da ranks fourth in terms of power output among the different cases (producing $4564262 kWhyear^{-1}$), it is still the most viable choice regarding the impact on the environment and reduces the amount of CO2 emissions significantly. It also impacts water consumption (saving about $425825 \times 10^3 m^3$ of water annually). Therefore, considering the problems caused by climate change, which have led to the reduction of freshwater resources, and the increase in greenhouse gas emissions, the dual Kalina cycle with air-cooled condensers (KSC-Da) is recommended to improve these conditions.

- The results have significant environmental implications for applying the Kalina cycle in areas with little or no groundwater resources or hot and dry regions of the country to generate power from low-temperature heat sources.

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