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Simulation and Thermodynamic Analysis of a Combined Cooling, Heating and Power (CCHP) System with Allam Power Cycle by means of a Pure Carbon Capture Approach

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ABSTRACT

In this research, using the same logic, an attempt has been made to investigate the possibility of utilizing the excess heat output of the power generation cycle to meet the heat demand of an absorption cooling production system. This study can include variables such as energy efficiency, exergy and economic and environmental variables in order to provide an acceptable basis for comparison with other schemes used in the field of simultaneous production of power, heat and cooling. It seems that due to the novelty of the cycle and the numerous environmental benefits and energy savings, as well as the existence of very little research in this field, researchers' research can provide the basis for the use of the subject on a large scale and power plant. The results of the present study,the system Allam can be used in simultaneous production systems. However, the cost of running the system is higher.

Keywords: CCHP system, Allam Power Cycle, Exergy, Exergy costing

1. INTRODUCTION

The combined cooling, heating, and power CCHP systems have the function of recovery of the waste heat to supply cooling and heat to satisfy the electrical power demand simultaneously [1]. By the other means, the trigeneration systems have advantages of high-efficiency energy transferring compared to the conventional energy systems [2]. The features of high efficiency and low emission which likely contribute significantly to reduce emissions draw a lot of attention in the recent decades. Utilizing the recovered heat is a core technology for the CCHP systems. A general point about the CCHP systems’ capacity is that the power rate lower than 1 MWe is regarded as small-scale applications. Systems with smaller capacity are called small-scale or microscale CCHP systems [3]. The small-scale and microscale CCHP systems are a popular topic as the household energy demand or small commercial applications are suitable loads for this kind of distributed energy systems and such remote loads cannot get a high-efficiency power supply in common case [4]. Adollahi discusses a multiobjective optimisation on the residential small-scale CCHP system. In this CCHP system, the energy efficiency, the total installation cost rate, and the cost rate of the environment are optimised simultaneously [5]. Another CCHP system designed for small-sale applications is presented by Maraver aiming at improving the use of biomass resources and distributed generation. In that research, the concepts of artificial thermal efficiency and the primary energy saving ratio are introduced to evaluate the designed system. The results of the research show that a small-scale CCHP plant based on biomass combustion is an efficient energy generation system [6].As distributed energy systems, combined cooling, heating, and power (CCHP) systems have become very popular in many countries[٧]Compared with the traditional separate generation energy system, a CCHP system can reduce the energy consumption evidently because it uses the waste heat from the prime movers and is located near the end user, which prevents energy waste and transmission losses [٨]. In addition, it provides a resilient electricity supply and enables a flexible dispatch of generation technologies According to the United States Department of Energy .[٩] ,employing a CCHP system can intensify energy security, improve the energy infrastructure, and contribute to the carbon reduction target [١٠]. The European Union (EU) predicted that 20% electricity load and 25% heat load of the entire EU would be provided by CCHP systems in 2030, which corresponds to 23% of the EU carbon reduction targets [١١,١٢]. The Chinese government plans to extend the application of CCHP systems: 15 million kilowatt CCHP systems should be established by 2020 [١٣] .Lots of researchers have been working on this topic to avoid excess output of electricity or heat [14]. In the CCHP systems, the waste heat is recovered for improving the system's efficiency. Besides that, it is well proven in actual operational condition that there is a potential part of waste heat which can be further extracted and transferred to useful energy by the ORC systems [15]. The idea of combining the CCHP system with ORC has been tested by many former researches. Zare combines a geothermal-driven CCHP system with the ORC system. The ORC system is used to absorb part of system internal heat for higher power output [16]. In Wang's CCHP-ORC system, the fuel consumption is reduced [17]. The ORC systems have proven that part of low-temperature heat can be transferred to available electricity [18, 19]. It is imperative that the global community implements a path to achieve significant reductions in current greenhouse gas emissions, principally CO. This resolve is set out in the COP-21 protocol [20]. At present, efforts focus on using nuclear and renewable energy sources to meet low-carbon power needs. While these are important clean energy sources, the IPCC 5th Assessment shows that a broader portfolio of low-carbon energy sources is necessary to offer the greatest chance of meeting global climate change targets. In particular, the IPCC 5th Assessment finds that climate models that do not include carbon capture and sequestration in addition to renewable and nuclear energy result in the fewest scenarios in which global temperature rise is maintained below agreed limits. Additionally, the assessment shows that scenarios without carbon capture and sequestration achieve results only with substantially higher costs [21]The Allam Cycle offers a path to a sustainable energy future by cleanly and economically employing hydrocarbon energy reserves in a process that inherently captures combustion derived CO2 for sequestration or reuse. The Allam Cycle was originally presented in Kyoto at GHGT-11. It has now reached a mature state of development and will soon be demonstrated using a pilot plant now entering the commissioning stage. Traditional power cycles, such as natural gas combined cycle (NGCC), supercritical coal cycles, and integrated gasification combined cycles (IGCC), require the addition of expensive, efficiency-reducing equipment in order to reduce and capture emissions of CO, and other pollutants. Analyses of these cycles have shown that the additional CO2 removal systems can increase the cost of electricity by 50% to 70% when capturing typically 90% of the CO, generated from hydrocarbon fuel combustion [22]. The Allam Cycle takes a novel approach to reducing emissions by employing oxy-combustion and a high-pressure supercritical CO, working fluid in a highly recuperated cycle [23]. The CO, that must be vented from the process leaves at pipeline pressure and high quality as a result of the operating conditions of the cycle, thereby mitigating the common necessity of an additional capture, clean-up, and compression system. The cycle is able to utilize a variety of hydrocarbon fuels, including natural gas, unprocessed raw and sour natural gas streams containing H2S and C02, and gasified solid fuels such as coal, oil refining residuals, and biomass. The result is a power cycle with major advantages over conventional systems that do not capture C02, attaining 59% LHV efficiency (comparable to best-in-class NGOC power plants not capturing CO2), significantly higher efficiencies than state-of-the-art coal plants, currently reaching 51% LHV, low capital costs due to the simplicity and high-pressure of the cycle; low ambient cooling requirements, depending on cooling configurations used; and virtually no air emissions, including full CD, capture. Additionally, for a small reduction in performance the Allam Cycle can run substantially water free [24, 25]The Allam Cycle has been under development for 7 years by 8 Rivers Capital. Specific development of the natural gas Allam Cycle has been undertaken by NET Power, a company owned by 8 Rivers, Exelon Generation, and CB&I. NET Power is currently building a 50 MWth natural gas demonstration power plant in La Porte, Texas, soon entering commissioning. The plant will be a fully operational, grid-connected power plant containing all key system components. Further, it will demonstrate the full operability of the cycle, including start-up, shut-down, load following, emergency operations, and partial-load operation in addition to component duration testing. In this research, due to the introduction of a new power generation cycle by Net Power Company, in which carbon dioxide is used as the operating fluid instead of air, an attempt has been made to combine this cycle, which is known as the pain cycle. the purpose of this study is Simulation and Thermodynamic Analysis of a Combined Cooling, Heating and Power (CCHP) System with Allam Power Cycle by means of a Pure Carbon Capture Approach. With an absorption cooling system, in addition to supplying the heat required by the absorption system, the carbon dioxide produced in the power generation process from traditional systems (fossil fuels) is completely absorbed and prevented from entering the environment. The cycle studied in this research is closed cycle and 100% of carbon dioxide produced in the combustion process is absorbable. The results of this study, while it can be important from an environmental point of view due to the absorption of carbon dioxide, From an energy point of view, it can also save fuel by increasing efficiency. It is important to note that in most common methods of reducing carbon emissions, the cost of electricity generated by the plant will increase significantly. But using the pain cycle without incurring significant additional costs can lead to environmental benefits. On the other hand, meeting the demand for cooling requires investment and energy consumption. The basis of the logic of combining energy systems with each other has always been considered. In this research, using the same logic, an attempt has been made to investigate the possibility of utilizing the excess heat output of the power generation cycle to meet the heat demand of an absorption cooling production system. This study can include variables such as energy efficiency, exergy and economic and environmental variables in order to provide an acceptable basis for comparison with other schemes used in the field of simultaneous production of power, heat and cooling. It seems that due to the novelty of the cycle and the numerous environmental benefits and energy savings, as well as the existence of very little research in this field, researchers' research can provide the basis for the use of the subject on a large scale and power plant.

2.RESEARCH BACKGROUND

To date, various researches have been done in the field of CCHP systems, some of which are mentioned below. in the article [26] proposes a stochastic-robust coordinated optimization model for CCHP micro-grid considering multi-energy operation and power trading with EMs, from the perspective of the day-ahead stage. By depicting the uncertain day-ahead and real-time clearing prices as stochastic scenarios, the objective function is constructed based on stochastic optimization and conditional value-at-risk, which is to minimize both the expected operational cost and potential risk of cost increase related to scenarios. By modeling the uncertain renewable generations as uncertainty set, the operational constraints are established based on robust optimization, which is to guarantee safe and stable operation under the worst-case realizations within uncertainty set. Through the abovementioned combination of multiple methods, the proposed model reasonably keeps both the conservativeness and computational complexity at relatively low levels. Simulations have verified the effectiveness of this model in terms of cost minimization, computational time, renewable power accommodation and risk control compared with existing methods. Furthermore, simulation results also reveal that additional benefits are brought for CCHP micro-grid by EM participations. in the article[27]a novel geothermal driven CCHP system, in which the ejector transcritical CO2 cycle is integrated with conventional Rankine cycle, is proposed (system a). The proposed system is then modified by replacing the gas cooler with an internal heat exchanger to make a more efficient CCHP system (system b). To investigate the first and second law performance of the proposed systems, thermodynamic models are developed and parametric analysis is carried out to examine the influences of design variables. The results indicated that, the gas cooler of conventional system can be replaced by an internal heat exchanger for a wide range of practical operating conditions and this replacement can improve the exergy efficiency, net output power and output cooling respectively by 30.9%, 49.1% and 75.8% at the expense of 39.1% reduction in heating output. Also a comparison is made between the two proposed systems in this work with similar systems (based on ejector transcritical CO2 cycle) proposed previously by other researchers and superiority of proposed systems in this paper is revealed and discussed.in the article [28]a conventional waste-driven combined heat and power cycle, which is the key component of many energy systems in Europe for baseload coverage of heat and electricity networks, is combined with a large-scale absorption chiller to not only create a strong yet reliable synergy between the three energy sectors of cold, heat and power, but also to improve the plant performance in terms of energy and sustainability indices. The proposed scheme is designed and thermodynamically assessed for the energy market of Denmark as the case study of this work. The results showed that the thermal and electrical efficiencies of the proposed hybrid system are better than the conventional configuration for 12% and 1.3%, respectively. In addition, the exergy efficiency, sustainability index and emission reduction of 28.58%, 1.4 and 445.935 kg-CO2/GJ are obtained for the system operating with a third-generation district heating system. Based on previous research, it can be said that CCHP systems are evolving. However, the results of previous research indicate the existence of weaknesses and strengths in this. This highlights the need for research in this area.

3.RESEARCH HYPOTHESES & QUESTIONS

This research seeks to answer the following questions based on the assumptions made below.
How can the use of carbon dioxide operating fluid increase the efficiency of the gas-fired power generation cycle?
Utilizing the heat output of this cycle in supplying the required heat of an absorption cooling system, what are the technical requirements for the design to be possible?
Is combining the pain cycle with the cooling production system environmentally and economically advantageous?
It seems that in comparison with the existing systems, combining the pain cycle with the cooling generation system will achieve the highest efficiency of the combined systems.
By simulating and applying energy engineering methods, the cycle arrangement can be designed in such a way that it can be technically combined with absorption cooling production systems.
Operation of the pain generation cycle can not only lead to 100% carbon dioxide emissions in the environment, but also have a competitive cost of electricity generation and in this regard has an advantage over other methods of carbon sequestration and storage in the industry.

4. THE GOVERNING EQUATIONS OF THE PROBLEM

4.1 Entropy

Entropy is a scientific concept, as well as a measurable physical property that is most commonly associated with a state of disorder, randomness, or uncertainty. The term and the concept are used in diverse fields, from classical thermodynamics, where it was first recognized, to the microscopic description of nature in statistical physics, and to the principles of information theory. To provide a quantitative measure for the direction of spontaneous change, Clausius introduced the concept of entropy as a precise way of expressing the second law of thermodynamics. The Clausius form of the second law states that spontaneous change for an irreversible process in an isolated system (that is, one that does not exchange heat or work with its surroundings) always proceeds in the direction of increasing entropy. For example, the block of ice and the stove constitute two parts of an isolated system for which total entropy increases as the ice melts. By the Clausius definition, if an amount of heat Q flows into a large heat reservoir at temperature T above absolute zero, then the entropy increase is $\Delta S = Q/T$. This equation effectively gives an alternate definition of temperature that agrees with the usual definition. Assume that there are two heat reservoirs R1 and R2 at temperatures T1 and T2 (such as the stove and the block of ice). If an amount of heat Q flows from R1 to R2, then the net entropy change for the two reservoirs is (1)

$$\Delta s = Q\left(\frac{1}{T_2} - \frac{1}{T_1}\right) \qquad (1)$$

which is positive provided that T1 > T2. Thus, the observation that heat never flows spontaneously from cold to hot is equivalent to requiring the net entropy change to be positive for a spontaneous flow of heat. If T1 = T2, then the reservoirs are in equilibrium, no heat flows, and ΔS = 0. The condition ΔS ≥ 0 determines the maximum possible efficiency of heat engines—that is, systems such as gasoline or steam engines that can do work in a cyclic fashion. Suppose a heat engine absorbs heat Q1 from R1 and exhausts heat Q2 to R2 for each complete cycle. By conservation of energy, the work done per cycle is W = Q1 – Q2, and the net entropy change is $\Delta s = Q\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$ To make W as large as possible, Q2 should be as small as possible relative to Q1. However, Q2 cannot be zero, because this would make ΔS negative and so violate the second law. The smallest possible value of Q2 corresponds to the condition ΔS = 0, yielding $\left(\frac{Q_2}{Q_1}\right) = \frac{T_2}{T_1}$ as the fundamental equation limiting the efficiency of all heat engines. A process for which ΔS = 0 is reversible because an infinitesimal change would be sufficient to make the heat engine run backward as a refrigerator. The same reasoning can also determine the entropy change for the working substance in the heat engine, such as a gas in a cylinder with a movable piston. If the gas absorbs an incremental amount of heat dQ from a heat reservoir at temperature T and expands reversibly against the maximum possible restraining pressure P, then it does the maximum work dW = P dV, where dV is the change in volume. The internal energy of the gas might also change by an amount dU as it expands. Then by conservation of energy, dQ = dU + P dV. Because the net entropy change for the system plus reservoir is zero when maximum work is done and the entropy of the reservoir decreases by an amount dSreservoir = −dQ/T, this must be counterbalanced by an entropy increase of

$$dS_{system} = \frac{dU+PdV}{T} = \frac{dQ}{T} \qquad (2)$$

for the working gas so that dSsystem + dSreservoir = 0. For any real process, less than the maximum work would be done (because of friction, for example), and so the actual amount of heat dQ′ absorbed from the heat reservoir would be less than the maximum amount dQ. For example, the gas could be allowed to expand freely into a vacuum and do no work at all. Therefore, it can be stated that

$$dS_{system} = \frac{dU+PdV}{T} \geq \frac{d\acute{Q}}{T} \qquad (3)$$

with dQ′ = dQ in the case of maximum work corresponding to a reversible process. This equation defines Ssystem as a thermodynamic state variable, meaning that its value is completely determined by the current state of the system and not by how the system reached that state. Entropy is an extensive property in that its magnitude depends on the amount of material in the system. In one statistical interpretation of entropy, it is found that for a very large system in thermodynamic equilibrium, entropy S is proportional to the natural logarithm of a quantity Ω representing the maximum number of microscopic ways in which the macroscopic state corresponding to S can be realized; that is, $S = k \ln \Omega$, in which k is the Boltzmann constant that is related to molecular energy. All spontaneous processes are irreversible; hence, it has been said that the entropy of the universe is increasing: that is, more and more energy becomes unavailable for conversion into work. Because of this, the universe is said to be “running down.”

4.2 Exergy

In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir, reaching maximum entropy.[1] When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero. In 1848, William Thomson, 1st Baron Kelvin, asked (and immediately answered) the question Is there any principle on which an absolute thermometric scale can be founded? It appears to me that Carnot’s theory of the motive power of heat enables us to give an affirmative answer. With the benefit of the hindsight contained in equation, we are able to understand the historical impact of Kelvin's idea on physics. Kelvin suggested that the best temperature scale would describe a constant ability for a unit of temperature in the surroundings to alter the available work from Carnot's engine. From equation (3): {\displaystyle {\frac {\mathrm {d} B}{\mathrm {d} T_{R}}}=-S\qquad {\mbox{(4)}}}Rudolf Clausius recognized the presence of a proportionality constant in Kelvin's analysis and gave it the name entropy in 1865 from the Greek for "transformation" because it describes the quantity of energy lost during transformation from heat to work. The available work from a Carnot engine is at its maximum when the surroundings are at a temperature of absolute zero.

4.3 Thermoeconomic

Energy, exergy and economic analysis alone can not be the answer to the design and optimization of heating systems, a more complete discussion when considering the cost imposed by inefficiencies as well as the additional cost of correcting these inefficiencies. This is the subject of the thermoeconomic debate. Thermoeconomics provides an analytical tool not previously available through conventional thermodynamic or economic analysis. Thermoeconomics is based on the principle that the only logical basis for allocating costs due to thermodynamic inefficiencies is exergy. A complete thermoeconomic analysis includes the following steps:

- Exergy analysis
- Economic analysis
- Exergy costing
- Thermoeconomic estimates

The basis of thermoeconomic analysis is the same as thermodynamic and exergetic analysis. In this section, the economic model governing the triple production system and desalination water is introduced. Based on this economic model, the objective function of the problem is obtained, which is the cost of production of electricity unit and fresh water unit. Calculating costs in an industrial unit basically includes the following steps:

- Calculate the practical cost of products or services
- Provide basic relationships for pricing property and services

- Provide methods for allocating and controlling costs
- Provide information for decision-making and evaluation operations

The above expressions are summarized in mathematical language in relation (4), which expresses the cost balance for the whole system.

$$\dot{C}_{P,tot} = \dot{C}_{F,tot} + \dot{Z}^{CI}_{total} + \dot{Z}^{OM}_{total} \qquad (4)$$

This equation states that the cost rate associated with system production is the left-hand sentence (equal to the sum of fuel cost rates), the first right-hand sentence (and investment), the second right-hand sentence (and maintenance and operations), the third right-hand sentence (In addition, the last two sentences on the right can be written as a relation (5)

$$\dot{Z} = \dot{Z}^{CI}_{total} + \dot{Z}^{OM}_{total} \qquad (5)$$

In general, for a heating system, the following balance should be established:

The final cost of the product =Operating costs of repairs + initial cost of equipment and facilities + cost of fuel

4.4 Exergy costing

Exergy is a cost basis in a heating system, meaning that for each of the exergy currents in the system, a cost is allocated per unit of exergy, and the total exergy current is converted into a cost current. You have found a coefficient, (kW since exergy is calculated from the material and energy dimension or energy rate) for example to be able to convert this dimension to the cost rate. This process is called exergy costing. In this process, a cost is associated with an exergy. Such as the exergy current of the input or output material or the working current or heat input or output to / from the system. These statements are found in Relationships (6 to9).

$$\dot{C}_i = c_i \dot{E}_i = c_i(\dot{m}_i e_i)$$
$$\dot{C}_e = c_e \dot{E}_e = c_e(\dot{m}_e e_e)$$
$$\dot{C}_w = c_w \dot{W}$$
$$\dot{C}_q = c_q \dot{E}_q$$

Where C'i, C'e, C'w and C'q are the average costs per unit of exergy (e.g. $ / GJ). (Are m from the system as a relation (10) summary k so the equilibrium equation of costs, for system components for example for the component.

$$\sum_e \dot{C}_{e,k} + \dot{C}_{w,k} = \dot{C}_{q,k} + \sum_i \dot{C}_{i,k} + \dot{Z}_k \qquad (10)$$

C'w,k : Is positive if the component k work.
C'q,k : Is positive If heat transfer k done.
C'i,k : Corresponds to the input mass flows of the desired component.
C'e,k : Corresponds to the output mass flows of the desired component.

The exergy equilibrium equation is generally obtained by opening the relation (10) in the form of relation (11).

$$\sum_{e}(c_e\,\dot{E}_e)_k + c_{w,k}\dot{W}_k = c_{q,k}\dot{E}_{q,k} + \sum_{i}(c_i\dot{E}_e)_k + \dot{Z}_k \tag{11}$$

It is calculated from thermodynamic analysis and exergy analysis and finally from the equation (11) of the system product price with E'i, E'e, E'w ,W knowing the price of fuel entering the system.

4.5 Auxiliary Costing Equation

Solving the cost equation for systems with more than one product requires one or more auxiliary equations in addition to the equation of equilibrium, known as cost auxiliary equations. In the next step, fuel and production must be determined. The determination of fuel and product depends on the type of flows and the purpose of using these flows in the desired component. This is usually divided into two categories.

Definition of fuel and product based on the difference in exergy at the entrance and exit

Sometimes the exergy exchanges in the system are of the type of physical exergy, usually in such cases the exergy difference between the entry and exit of one stream is considered as fuel or the difference of exergy in the entry and exit of another stream as a product. For example, in a heat exchanger, we operate according to Table 1.

Table 1: Definition of fuel and product in a heat exchanger

object			
Mode 1) Cold flow heating		Mode 2) cooling hot stream	
product	E'ce - E'ci	product	E'hi - E'he
fuel	E'hi - E'he	fuel	E'ce - E'ci

Definition of fuel and product based on exergy values at system input and output

This method is generally used to determine fuel and product when the exergy exchanges are chemical. That is, the sum of input exergies is considered as fuel and the sum of output exergies is considered as product. That is, in writing exergy equations, one should always pay attention to the purpose of using that component in the system.

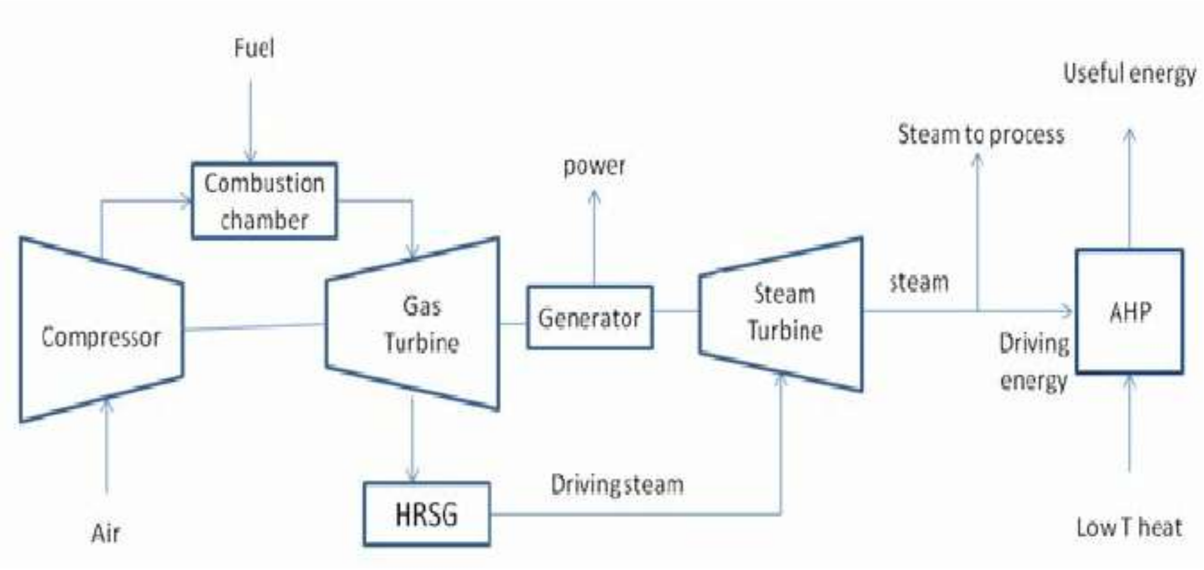
The efficiency is an important and useful metric to evaluate how well a system performs. In CCHP systems for data centers, four efficiencies are commonly used: the efficiency of power generation, pgu, the COP of absorption chillers, COPabs, overall system efficiency, overall, and effective electric efficiency, εEE. They are defined by Eqs. (1)–(4). pgu = Eload elec Qng (1) COPabs = Qabs cooling Qrec (2) overall = Eload elec + Qrec Qng (3) εEE = Eload elec Qng − (Qabs cooling/(COPconv × elec)) (4) where Eload elec is the power load excluding the power used for electrical chillers in data centers; also the electricity output from PGUs in CCHP systems (kWh); Qng is fuel input to PGUs in CCHP systems (kWh); Qabs cooling is cooling energy produced by absorption chillers in CCHP systems (kWh); Qrec is the heat recovered in HRUs (kWh); COPconv is the COP of electrical chillers in conventional system, 4 as assumed [21]; and elec is the average efficiency of power generation across USA, 34.7% as assumed [22]. The efficiency of power generation and the COP of absorption chillers are indicators of performance at equipmentlevel. The overall system efficiency is defined as the percentage of energy in original fuel source that is effectively used for both electricity and useful thermal energy generation according to EPA [1]. However, it is not adequate alone since quality of electricity and thermal energy is different but is considered equally in the definition. Therefore, effective electric efficiency is used to account for different quality of electricity and thermal energy. This measure expresses CCHP efficiency as the ratio of net electrical output to net fuel consumption, where net fuel consumption excludes the portion of fuel that goes to producing cooling energy [1]. 2.3. E3 Performance measures 2.3.1. Energy performance measure One unit of certain form of energy is not directly comparable to one unit of another form of energy consumed on site because some forms of energy are raw fuels while the others are converted fuel or energy such as electricity and steam. Furthermore, raw fuels received on site have different amount of losses during the processes of transmission, storage, and distribution. It is necessary to convert allthe forms of energy consumed on site to equivalent units of raw fuel as a uniform platform to compare all forms of energy. The equivalent units of raw fuel are called primary energy. Primary energy is an energy form found in nature that has not been subjected to any conversion or transformation process. Therefore, the primary energy consumption is calculated by multiplying the total amount of certain form of energy consumed on site by its primary energy conversion rate, which considers the losses during conversion, transmission, storage, and distribution. Thus the primary energy was used as the basis for energy performance assessment. In data centers, the primary energy consumption by conventional energy systems and gas turbine CCHP systems can be expressed by Eqs. (5) and (6) accordingly. PEconv = Eload elec + Qload cooling COPconv · pecrelec (5) PECCHP = Qng · pecrng + Qelec cooling COPconv · pecrelec (6) where Qload cooling is the cooling load in data centers (kWh); Qelec cooling is the cooling energy generated by electrical chillers in CCHP systems (kWh); pecrelec is primary energy conversion rate for electricity; and pecrng is the primary energy conversion rate for natural gas. To compare the energy performance between conventional systems and CCHP systems, Primary Energy Reduction Ratio (PERR) was used as the energy performance measure. The PERR is the percentage of the primary energy reduction to the primary energy consumed by conventional system as expressed in Eq. (7). A negative PERR indicates that a CCHP system consumes more primary energy thanthe corresponding conventional system, and vice versa. PERR = PEconv − PECCHP PEconv × 100%

5.RESEARCH METHOD

In this research, the proposed cycle is simulated in Cycle-Tempo software .Cycle-Tempo is a flow sheeting for the thermodynamic analysis and optimization of energy conversion systems. It is suited for: conventional power plants, compression refrigeration and cooling systems; unconventional energy systems like: solar ORC power plants, tri-generation systems, absorption-cooling and refrigeration systems, fuel cells, Kalina-cycle power plants, scCO2 -turbine power plants, IGCC power plants, etc. Cycle-Tempo is one of the few software packages that allows for exergy analysis. Then the output is considered as the input of another model that is modeled in order to simulate an absorption cooling system in the same way and the operating conditions of the studied cooling system are calculated. Then, from the methods of engineering economics, the economic estimation of the proposed system and its environmental advantages will be evaluated. At the end of the verification, the results will be done with samples done in Net Power Company and other related researches. Other thermodynamic analyzes have also been performed in EES software.

6. SYSTEM SIMULATION

In this research, due to the introduction of a new power generation cycle by Net Power Company, in which carbon dioxide is used as the operating fluid instead of air, an attempt has been made to combine this cycle, which is known as the pain cycle. With an absorption cooling system, in addition to supplying the heat required by the absorption system, the carbon dioxide produced in the power generation process from traditional systems (fossil fuels) is completely absorbed and prevented from entering the environment. The cycle studied in this research is closed cycle and 100% of carbon dioxide produced in the combustion process is absorbable. The results of this study can be important from an environmental point of view due to the absorption of carbon dioxide. Tables 1 and 2 show the specifications of the CCHP bicycle separately.



Figures 3: Cchp system

Table 2: Parameter of optimal model CCHP

Parameter	Symbol	Value	Unit
Coefficient of performance of absorption chiller	COP_{abch}	1.3	-
Coefficient of performance of electric chiller	COP_{ech}	4	-
Heat efficiency of absorption chiller	η_{abch}	0.8	-
Heat efficiency of boiler	η_b	0.85	-
Electrical efficiency of separation production	η_e^{sp}	10.35	-
system	η_{grid}	0.92	-

Efficiency of grid	η_{rec}	10.8	-
Utilization efficiency of residual heat	P_{ng}	0.295	yuan/kWh
the natural gas price	P_e	0.9	yuan/kWh
the electricity price	A_{abch}	1500	yuan/kWh
Unit price of absorption chiller Unit price of electric chiller	A_{ech}	950	yuan/kWh
Unit price of boiler	A_b	200	yuan/kWh
Unit price of engine	$A_{e,\text{engine}}$	4000	yuan/kWh
Unit price of turbine	$A_{e,turbine}$	5000	yuan/kWh
Additional cost factor of absorption chiller	U_{abch}	0.25	-
Additional cost factor of electric chiller	U_{ech}	0.15	-
Additional cost factor of boiler	U_b	0.2	-
Additional cost factor of PGU	U_e	0.25	-
CO2 emission conversion factor of natural gas	$\mu_{co2,f}$	220	g/kWh
CO2 emission conversion factor of electricity	$\mu_{co2,e}$	968	g/kWh
Time step-size	t	1	h
Life cycle	n	20	year
Benchmark interest rate	i	0.08	-

Allam Cycle uses carbon dioxide as a high-pressure, high-pressure Brighton cycle fluid with a unique turbine that operates at an input pressure in the range of 200 to 400 bar and a compression ratio of 6 to 12 bar. Cyclic combustion chamber damper cycle that burns the fuel with pure oxygen at high pressure to provide high pressure feeder for rotating the turbine. In the cycle (1) the general dermatology of the elm cycle has shown that in this cycle the turbine outlet gas enters the recuperator with a temperature of 727 degrees Celsius and a pressure of 30 degrees enters the recuperator and exits at a temperature of 43 degrees Celsius. This current loses its moisture before entering the compressor in the dehumidifier installed in the cycle and a pressure of 29 bar and a temperature of 17 degrees Celsius enters the compressor. Part of the compressor outlet gas flow out of the cycle for sale and the rest of the cycle flow enters the recuperator and turbine seps through two different routes. The first part of the flow enters the recuperator directly through the circulation pump with a pressure of 310 and the other part of the flow from the turkey comes to the desired pressure through the oxygen pump. And runs preheated using the turbine output current. Oxygen reacts with oxidation at the inlet to the turbine and a mixture of inlet gas enters the turbine at a temperature of 1150 ° C. Table 3 shows the input characteristics of the various components of the Elam cycle with natural gas.

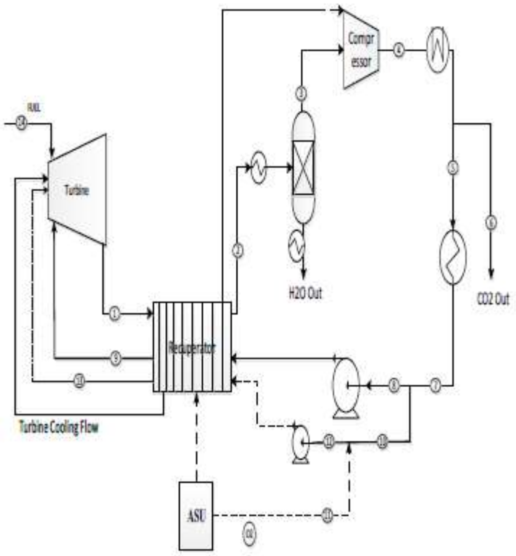
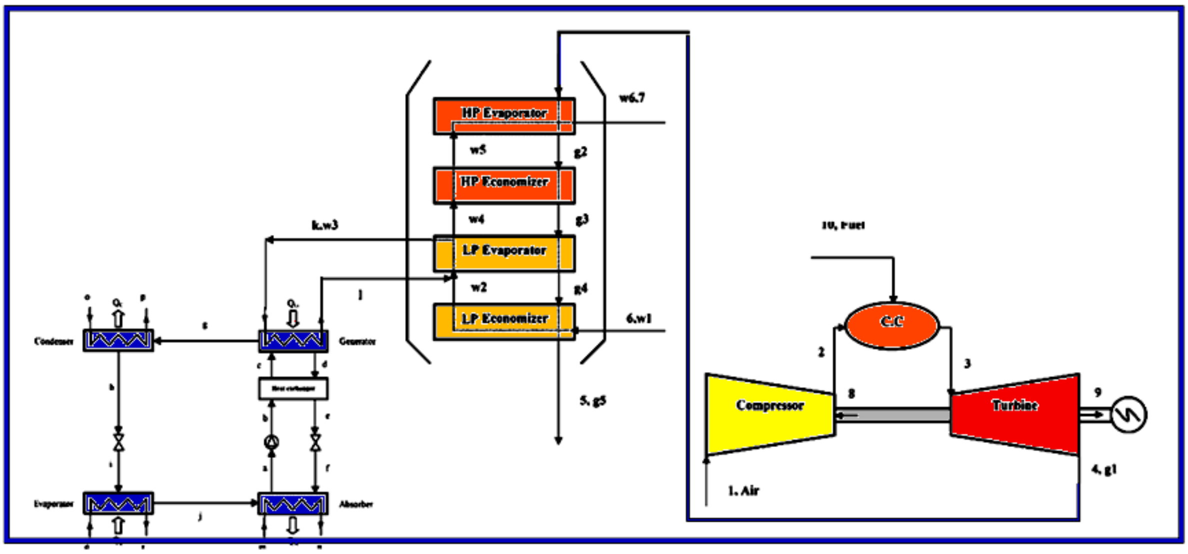


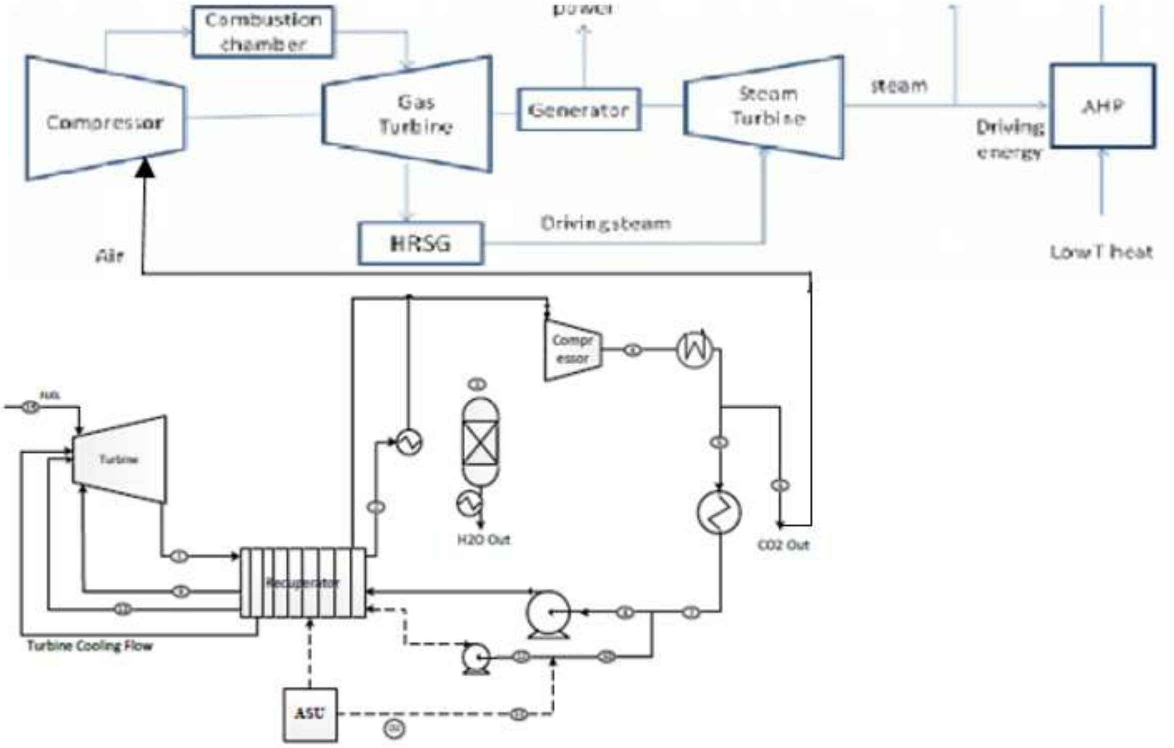
Fig 3: General schematic of the Alam cycle with natural gas fuel

Table 2: Parameter of optimal model CCHP

Parameter		Base Case	Variation	Reference
Turbine Inlet Temperature (ISO)	%	1150	±0	[47]
Turbine Inlet Pressure	%	300	±0	[47]
Turbine Pressure Ratio	%	0.1	±0	[47]
Combustor R-1, Outlet Temperature	%	1300	±100	[46]
Combustor R-1, Pressure Drop	%	1.6	±0	[47]
Combustor R-1, Heat Loss	%	1	±0	[58]
Oxygen Purity	%	99.5	±0	[47]
Excess Oxygen	%	2	±0	[24]
O2 Fraction (Molar) after Dilution	%	22.5	±7.5	[47]
Pump P-1, Efficiency	%	75	±5	[58]
Pump P-1, Mechanical Efficiency	%	98	±0	[58]
Compressor C-1-C-4, Polytropic Efficiency	%	80	±5	[58]
Compressor C-1-C-4, Mechanical Efficiency	%	98	±0	[58]
Motor Efficency	%	98	±0	[58]
Generator G-1, Efficiency	%	99	±0	[58]
Heat Exchanger E-1, E-2, Pinch Temperature Difference	%	7.5	±2.5	[58]
Heat Exchanger E-1, E-2, Pressure Drop (gas)	%	2	±0	[58]
Heat Exchanger E-1, E-2, Pressure Drop (liquid)	%	4	±0	[58]

Heat Exchanger E-3, Pinch Temperature Difference	%	3	±2	[60,61]
Heat Exchanger E-3, Pressure Drop	%	2	±0	[58]
Separator V-1, Pressure Drop	%	2	±0	[58]
Cooling Water Range	%	11	±0	[58]
Cooling Tower Fan Power Demand	%	197.5	±0	[65]
ASU, Specific Power Demand	%	250	±50	[66,67]
CO2 Purification, Specific Power Demand	%	50	±25	[67]





7. RESULTS

Figure 4 shows the cost of the proposed system and the current system in different months of the year. According to this chart, in all months of the year, the cost of the proposed system is about 28% less than the current system. Table 4 shows the results of thermodynamic analysis of two types of systems, which according to the results shown, it is clear that the proposed hybrid system has higher conditions and characteristics than the existing system.

Table 3 : Input specifications of different components of the Alum cycle

No	Temperature (°C)	Pressure (bar)	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

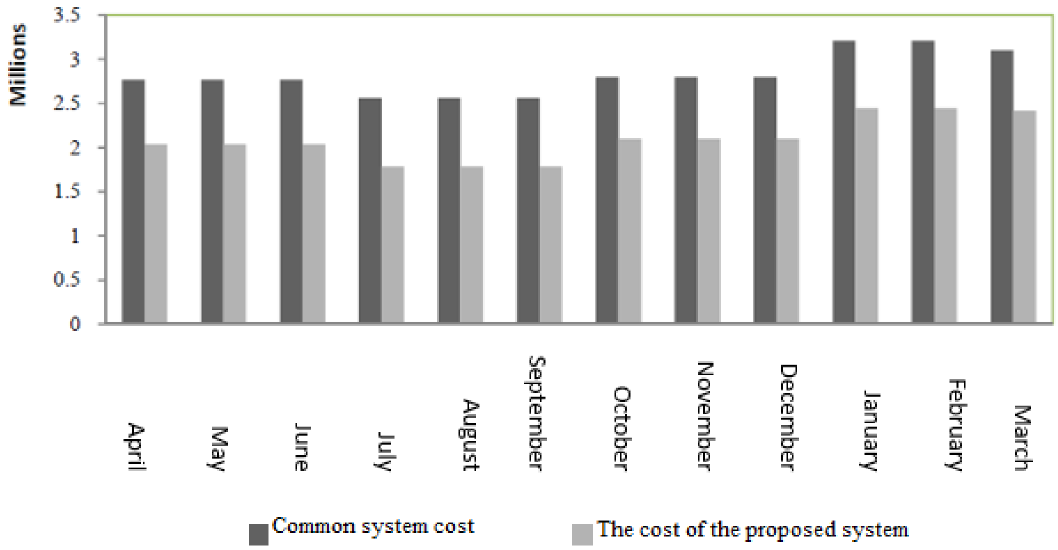


Fig 4: Proposed system cost chart and common system

Table 4 : Results of thermodynamic analysis

	Cchp	proposed hybrid system
Electrical energy demand (kWh)	113.14	58.92
Heat demand (kWh)	173.77	14.44
Cooling demand (kWh)	87.13	48.9
Electrical energy generated by the engine (kWh)	61.49	130.63
Energy supplied by electrical energy storage (kWh)	20.04	12.61
Energy supplied by the heating storage unit (kwh)	38.52	47.31
System capacity enhancement (%)	47.01	64.15
Engine operation time (h)	11.53	9.46
Energy consumption amount (kWh)	214.23	148.93
Overall efficiency (%)	34.92	56.53
Efficiency enhancement (%)	8.98	22.35
CO2(KWH/KG)	50	0

Figure 5 also shows the power consumption ratio relative to the turbine output power. According to this diagram in the proposed hybrid system, increasing the turbine output has no effect on the amount of turbine energy consumption and turbine consumption has been constant.

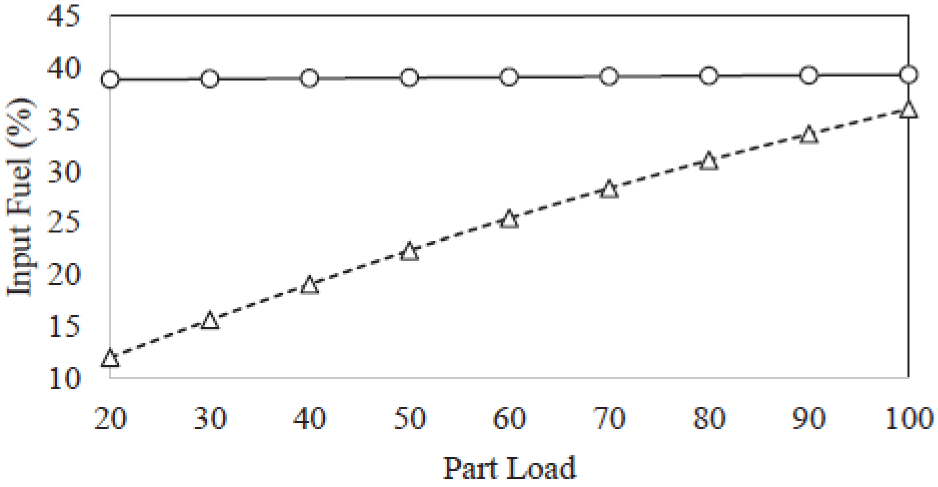


Fig5. Technical parameters of turbine in terms of part load operation

Figures 5 and 6 show the degree of exergy degradation in the two common systems and the proposed hybrid system, respectively. By comparing these two graphs, it can be concluded that the amount of exergy degradation in the proposed system is much less.

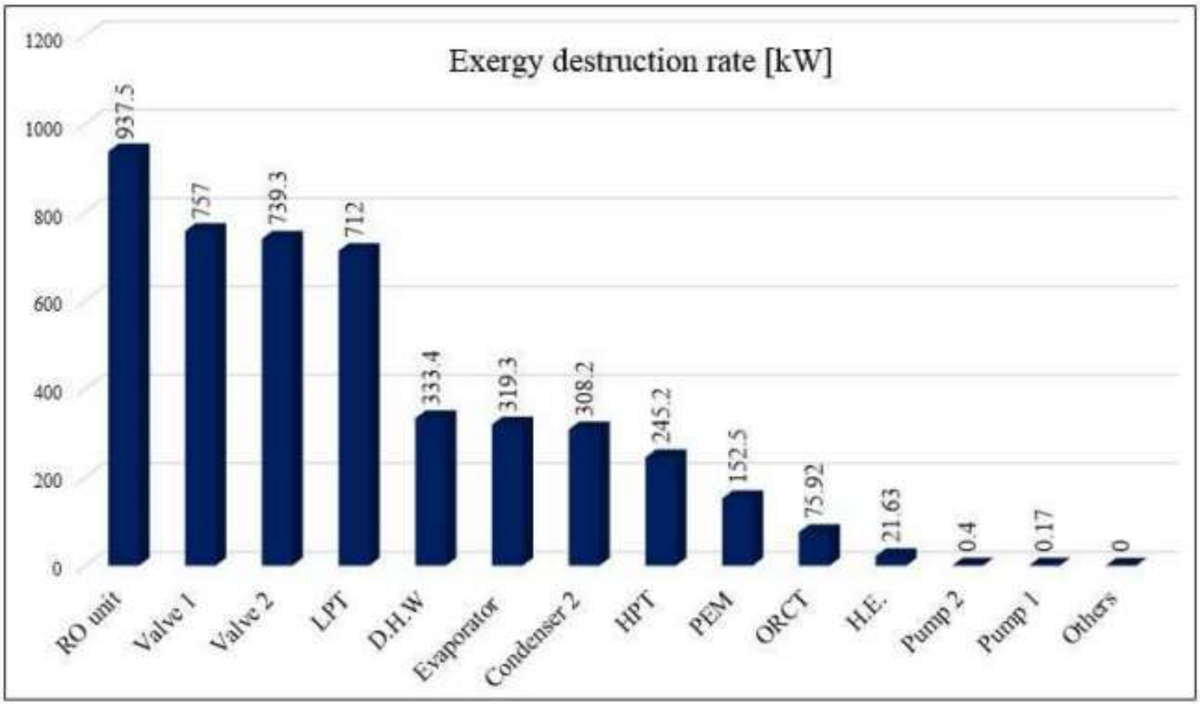


Fig6: exergy degradation in common systems

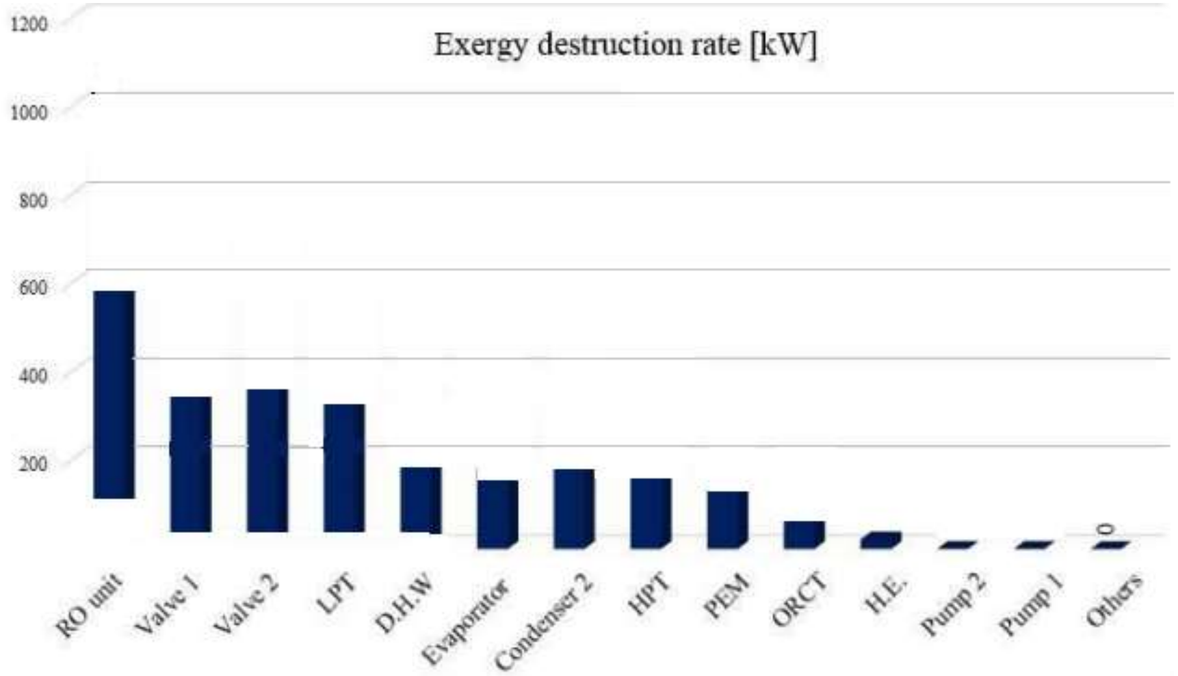


Fig6: exergy degradation in proposed hybrid system

Variable	unit	CCHP	proposed hybrid system
Net work cycle	KW	231745	333911
Total exergy degeneration	KW	435770	366570
Net cycle efficiency	%	41/33	59/55
Gross cycle efficiency	%	69/68	81/34
Exergy fuel cycle input	KW	941533	994584
The amount of water produced	M3	1269	588/8
Turbine work	KW	390596	456107
Compressor work	KW	139594	108187
Work of pumps	KW	19256	14009

8. CONCLUSION

The results of the present study can be expressed in several headings:

According to the obtained results, the system Allam can be used in simultaneous production systems

The proposed system is common in terms of air pollution despite the cchp system

The proposed system is cost-effective. However, the cost of running the system is higher.

The efficiency of the proposed cycle is higher than the efficiency of the conventional cycle

The amount of exergy degradation in the proposed system is less than the amount of exergy degradation in the conventional system

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