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Research Article

Can Waste Heat of a Thermal Power Plant Be a Key for Absorption Cooling Systems?

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ABSTRACT

Waste Heat Driven Absorption Cooling Systems (WHDACS) can be simply defined as a cooling system which uses thermal fluid couples such as LiBr-H_2O or NH_3-H_2O to decrease the temperature of selected space via waste heat usage in generator. This study focuses on the use waste heat that is discharged from thermal power plants in order to meet heat load of generator used in absorption cooling systems. Yatagan thermal power plant that has 3 discharged waste heat units with 145 MWt per unit. 172°C steam temperature and 1.18bar steam pressure is examined as a case study. LiBr-H_2O ACS is designed and optimum working parameters of system elements are determined by both considering single effect of the parameter and interacted effect of the temperature and concentration ratio parameters on Coefficient of Performance (COP) and Exergetic Coefficient of Performance (EPC) of the system. Optimum values of T_1, T_2, T_4. T_5, X_w, X_s for single effect are found as; T_1=100°C. T_2=40°C. T_4=10°C for max COP 4°C for max EPC. T_5=70°C. X_w=45% and X_s=63.41%. Optimum values for interacted independent parameters are found as 100°C for T_1. 46.86°C for T_2. 9.996°C for T_4 and 70°C for T_5. 45% for X_w. 60% for X_s by using Nelder-Mead Method. It is observed that the waste heat discharged from Yatagan Thermal Power Plant is convenient to establish an absorption cooling system. Cooling potential of WHDACS is calculated 84MWt approximately for each waste heat unit.

1. Introduction

Absorption cooling system (ACS) is based on the idea of absorbing heat from a selected area (space) by using cooling fluid such as water (H_2O), ammonia (NH_3), methylamine (CH_3NH_2), methyl chloride (CH_2Cl_2). The materials which are used to transfer the absorbed heat to an absorber are lithium bromide (LiBr), water (H_2O), calcium chloride ($CaCl_2$), strontium chloride ($SrCl_2$), lithium nitrate ($LiNO_3$). Drawing heat from a selected area decreases the temperature in that space so the cooling process can achieve its main goal.

There are different types of absorption cooling systems such as, Single Staged ACS, Double and Triple Staged ACS, Triple Staged Hybrid ACS, Generator-Absorber Heat Exc. Cycles (GAX), Regenerative Absorption Cycles (RA), etc [1]. Each kind of ACS has its own goal to achieve can be used effectively in different conditions for different purposes. For instance, single staged ACSs are preferable in the market because of their quiet, low cost and no maintenance required cycle structure [2, 3].

On the other hand, energetic and exergetic analysis showed that their COP (coefficient of performance) is around 0,7. Double staged or triple staged ACSs can be more efficient than single staged ACSs with COP values more than 2 and 3 [4]. But some disadvantages follow the increase of COP values such as large installation

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area, high input temperature requirements. Therefore, numerous studies are carried on to discuss system efficiencies, requirements, different thermal fluid couples, energetic and exergetic efficiencies of entire systems or individual system elements. Lately, vast majority of studies focused on the heat source of generator and tried to answer “which energy source should drive the generator system?”

Solar energy driven ABSs are examined in literature and max. cooling loads, max COP values are calculated as well as exergetic efficiencies of system components. Results showed that most significant design parameter is outlet temperature of the solar collector, in other words inlet temperature of generator [5-15]. Some studies aimed to form a general irreversible cycle model for absorption refrigerators and endoreversible absorption refrigeration cycle model with the irreversibility of heat transfer between the working fluid and the heat reservoir [16, 17].

Also, single staged absorption cooling systems are examined in order to determine the exergy loss and driving force values in each sub system. According to the results exergetic loss in premixing process in the absorber is higher than other system components and it is suggested that reducing the flow ratio increases the premixing exergy loss in the absorber [18]. As mentioned above, high heat emission values are detected in thermodynamic processes of ACS and it is underlined that entropy, enthalpy, temperature and flow rate values should be defined as significant variables for system design [19].

ACSs can be driven by many different energy sources such as electricity, combustion tanks, some waste heat discharged from different energy sources. These systems can be designed for meeting the cooling loads of ships or big fishing vehicles [20-22]. Some studies used exhaust gas as a primary energy source for ACSs which discharge from vehicles or combustion engines with high temperature. According to the results exhaust gas driven absorption cooling systems can be a good alternative to classic compressed air-cooling systems [23, 24].

As ACS can be defined as green cooling systems there should be a measurable/quantitative scientific indicator. Therefore, Üst 2005, defined an ecological performance criterion for different energy source driven ACSs such as Carnot heat engine, gas tribunes, heat pumps and calculated optimum design parameters of system components [25, 26]. Absorption systems can be used for dehumidification, heating and cooling by driving industrial waste heat and it is presented that these systems are usable according to the energy efficiencies [27]. As seen above, numerous studies are carried on about different energy source driven ACS lately because main energy input is HEAT in generator in order to gain COOLING energy. This reverse relation highly enables the usage of solar energy as an energy source regarding high cooling load means high solar energy [6, 8-10, 12, 28].

When all studies are taken into consideration, it can be seen that there are numerous studies deal with ACSs which are triggered by various energy sources such as waste heat of a combustion engine, solar energy, boiler with auxiliary energy input etc. On the other hand, there are numerous studies deal with the reuse or recovery of waste heat discharged from energy power plants such as space heating, domestic water heating, greenhouse heating etc. In the Literature, there is a lack of studies discuss the ACSs which use waste heat of a power plant as an input energy source. In this study, it is aimed to prove that if waste heat energy discharged from power plants would be usable to trigger ACSs as an input energy source or not. In advance, the major target of this paper is to determine the optimum working/design parameters of single stage ACS triggered by waste heat energy of a power plant in order to gain max energetic and exergetic efficiencies.

2. General methods

In this study, waste heat driven absorption cooling systems (WHDACS) are examined and waste heat discharged from Yatagan Thermal Power Plant is used as a primary energy source in generator. It is aimed to draw energy between medium pressure and low-pressure turbines for cooling demand. This will also improve the energy performance of power plant [29]. The main goal is to determine whether waste heat discharged from the power plant is usable or not for ACSs. As mentioned above, different type of energy driven ACSs have some troubles such as crystallization problem or insufficient temperature level. So, there will be a discussion part including solution suggestions about probable problems in the recommended system.

2.1. System description

Waste heat driven absorption cooling system (WHDACS) used in this study is a single stage LiBr-H_2O ACS with cooling tower due to being most common system in the market. Cooling water flows through the direction of absorber in-absorber out-condenser in-condenser out-cooling tower with the temperatures 32-35 °C in absorber and 35-37.5 °C in condenser. Yatagan Thermal Power Plant of which waste heat is used to drive generator to produce superheated steam and to separate cooling fluid (water) from LiBr-H_2O solution is in Muğla. Muğla is located in the south-west district of Türkiye where the average

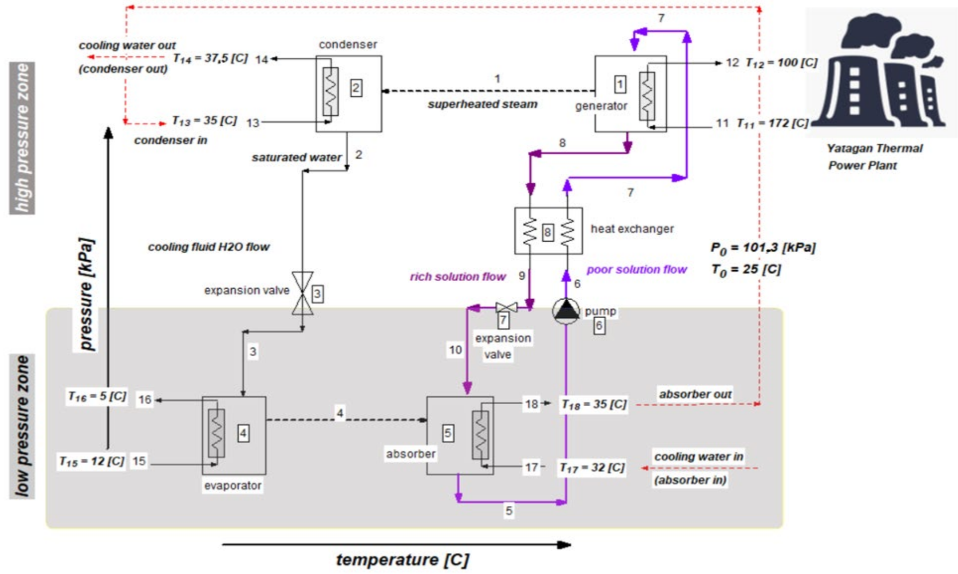


Figure 1. Schematic design of WHDACS and flow diagram

external temperature is relatively high. Thus, the external temperature and pressure values are considered as 25°C and 101.325kPa (1atm) which are used to calculate the dead state exergetic thermophysical properties such as dead state enthalpy (h_0), dead state entropy (s_0) etc. There are two pressure zones in the system which are created by the expansion valves and a pump used in cooling fluid strong solution and weak solution flow line numbered as 3-6-7 in Figure 1. Creating different pressure zones by these system elements, thermodynamic properties of the cooling fluid is getting capable of driving heat from the space.

Therefore, system element of compressor used in typical cooling/refrigeration systems which is known as high energy consumer is not needed in absorption cooling systems. That is why absorption cooling systems are much more preferable than classic compressor refrigeration systems.

1-2 First, when the LiBr-H_2O solution in the generator is heated by the inlet heat from the Yatağan Thermal Power Plant, H_2O separates from the solution and becomes superheated vapor in flow line 1 due to its lower evaporation point than the LiBr brine. Then, the superheated vapor enters the condenser to condense into saturated water with the help of cooling water.

T_1 and T_2 are the temperature values of superheated steam and saturated water in flow line number 1-2 which has a significant impact on coefficient of performance (COP) and exergetic coefficient of performance (EPC). Therefore, T_1 and T_2 values which are set as input parameters in Engineering Equation Solver (EES) software are one of the focal points of this study. In order to provide most efficient system

conditions, T_1 and T_2 values are defined as independent variable that allows design engineer to set boundary conditions in different set values.
2-3 Saturated water which condensed to liquid state in condenser passes through expansion valve in order to decrease its pressure by isenthalpic transformation in system element 3.

3-4 Saturated water in P_{min} conditions enters to evaporator in order to absorb heat from cooling fluid that follows the flow line number 15-16 and become saturated steam due to heat transfer in evaporator. Heat transfer in evaporator decides cooling conditions. Therefore, T_4 and cooling power of evaporator (Q_{eva}) is set to be an independent parameter in the software.

4-5 Saturated steam transfers its heat loaded in evaporator to the absorber fluid that comes from generator as in the state of strong solution. All the energy drained from space passes to LiBr via H_2O. The strong solution coming from generator dilutes by mixing with water comes from evaporator and weak solution occurs in absorber. Energy and exergy flows are strictly depending on the temperature of absorber (T_5) and concentration of LiBr in weak (X_w) and strong (X_s) solution. Therefore, T_5, (X_w) and (X_s) values are set to be independent parameters in the software. In the literature, generally concentration values are considered as a specific constant value such as X_w=0.56 and X_s=0.64 [30].

5-6 After the absorber, weak solution passes through pump to increase pressure. However, power of the pump is negligible as compared to the power of other system elements, it is also set to be independent parameter in order to make accurate solutions for energetic and exergetic flow in this study. In simulations, it is observed that 3kW pump power is preferable.

6-7 After getting into high pressure zone, weak solution enters to the heat exchanger before entering generator for pre-heating in order to increase the efficiency of the system.

7-8 Weak solution concentration ratio increases due to water vaporization in generator and become strong solution after the removal of some water in superheated steam state in flow line 1.

8-9-10 Strong solution passes through heat exchanger in order to transfer its heat to weak solution and increase absorption potential. After that, strong solution enters to the expansion valve to decrease pressure and become efficient absorbent for the system in low pressure zone.

T_1-T_2-T_4-T_5 and X_w-X_s values are set to be independent parameters, simulated and iterated in order to determine the optimum values for each individual effect and simultaneous effect on COP-EPC values of the system.

2.2. Methodology

2.2.1. Thermodynamic analysis

It is assumed that, all system elements' temperature distribution is homogenous and all outlet temperature and pressure values are assumed to be same value of the system element. Pressure losses are neglected inside the system and pipeline circle.

There are 4 major system elements called generator, condenser, evaporator and absorber with pressure control elements called expansion valve and pump. All major elements are in closed loop and have energetic interaction with following flow lines. Inlet and outlet flow temperatures and pressure values are as shown in Figure 1. Environmental properties of death state conditions are taken as 101,3 kPa and 25 °C in accordance with the literature.

Also, system elements are assumed to be in adiabatic conditions. Thermodynamic analysis needs enthalpy, entropy, mass-fraction, pressure and mass-flow-rate values of the fluid in each flow point which are calculated by ESS software by using following functions;

Pressure functions;

$$P_{max}=p\_{sat}(water; T=T_2) \quad (1)$$

$$P_{min}=p\_{sat}(water; T=T_4) \quad (2)$$

Enthalpy functions in each flow point; fluid type expresses the state of fluid such as steam, water, saturated water/steam etc. and *i* presents the flow points shown in Figure.1.

h_i=enthalpy (fluid type; $T=T_i$; $P=P_i$) (3)

$(1 \leq i \leq 4 \;\&\; 11 \leq i \leq 18)$

h_i=h_LiBrH2O ($T=T_i$; $X=X_w$) $(5 \leq i \leq 7)$ (4)

h_i=h_LiBrH2O ($T=T_i$; $X=X_s$) $(8 \leq i \leq 10)$ (5)

specific heat at constant pressure functions;

c_{p-w}= cp_LiBrH2O($T=T_i$; $X=X_w$) (6)

c_{p-s}= cp_LiBrH2O($T=T_i$; $X=X_s$) (7)

Entropy functions in each flow point;

s_i=entropy (fluid type; $T=T_i$; $P=P_i$)

$(1 \leq i \leq 4 \;\&\; 11 \leq i \leq 18)$ (8)

s_i=s_LiBrH2O ($T=T_i$; $X=X_w$) $(5 \leq i \leq 7)$ (9)

s_i=s_LiBrH2O ($T=T_i$; $X=X_s$) $(8 \leq i \leq 10)$ (10)

In each flow line, exergetic flow rates that are interacted inside the system are calculated as shown in Table 1 as well as exergetic flow rates in each system elements interacted with outside flow such as cooling water or space cooling system. All system elements are interacted with both inside and outside flow which makes Exergy in and Exergy out values up. Therefore, each system elements Exergy in and out flows are calculated as;

$$\mathrm{Ex}_{in-gen} = \mathrm{Ex}_{11} - \mathrm{Ex}_{12} \quad (11)$$

$$\mathrm{Ex}_{out-gen} = (\mathrm{Ex}_{1} + \mathrm{Ex}_{8}) - \mathrm{Ex}_{7} \quad (12)$$

$$\mathrm{Ex}_{in-con} = \mathrm{Ex}_{1} - \mathrm{Ex}_{2} \quad (13)$$

$$\mathrm{Ex}_{out-con} = \mathrm{Ex}_{14} - \mathrm{Ex}_{13} \quad (14)$$

$$\mathrm{Ex}_{in-eva} = \mathrm{Ex}_{3} - \mathrm{Ex}_{4} \quad (15)$$

$$\mathrm{Ex}_{out-eva} = \mathrm{Ex}_{16} - \mathrm{Ex}_{15} \quad (16)$$

$$\mathrm{Ex}_{in-abs} = \mathrm{Ex}_{5} - (\mathrm{Ex}_{10} + \mathrm{Ex}_{4}) \quad (17)$$

$$\mathrm{Ex}_{out-abs} = \mathrm{Ex}_{18} - \mathrm{Ex}_{17} \quad (18)$$

Exergy destruction can be defined as the difference between inlet exergy, work ect. and outlet exergy, work etc. As it is assumed that all system elements are in adiabatic conditions and no heat loss occurs through the flow line borders, all system elements' exergy destruction values are calculated as;

$$\mathrm{Ex}_{des-gen} = \mathrm{Ex}_{in-gen} - \mathrm{Ex}_{out-gen} \quad (19)$$

$$\mathrm{Ex}_{des-con} = \mathrm{Ex}_{in-con} - \mathrm{Ex}_{out-con} \quad (20)$$

$$\mathrm{Ex}_{des-eva} = \mathrm{Ex}_{in-eva} - \mathrm{Ex}_{out-eva} \quad (21)$$

$$\mathrm{Ex}_{des-abs} = \mathrm{Ex}_{in-abs} - \mathrm{Ex}_{out-abs} \quad (22)$$

It is expected that Ex_{des} values display the development potential of system elements

2.2.2. Optimization principle

Optimization of system elements for different purposes is the major topic of energy engineering process. In the literature, generally studies are focused on a single and instant situation of a system flow and all system parameters are calculated according to the specified-chosen values.

Optimization procedure of EES is used to determine the optimum values of independent parameters which can be listed as Conjugate Directions Method, Direct Method, Genetic Method, Variable Metric Method, Nelder Mead Method.

Conjugate Direction Method (CDM); mostly known as Direct Search or Powell's Method which is based on to determine the max-min points of a function in series that depend on one-dimension independent variable.

Direct Method (DM); is based on to determine local max-min points in small intervals. After all local max-min points are determined in all defined intervals, the max value among all max points are set to be absolute max point and the min value among all min points are set to be absolute min point.

Genetic Method (GM); is the optimization algorithm that gives the most stable results. However, it works rather slow than other optimization methods because of having too many iterations. Genetic Method Algorithm calculates the possibility of local max-min points obtained from local small intervals to be the absolute max-min point of all defined intervals.

Variable Metric Method (VMM); is multi-dimensional state of Quadratic Approximation method. The main idea is to equate the partial differential of second order independent parameter objective function to zero.

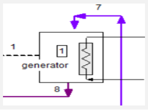
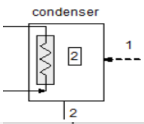
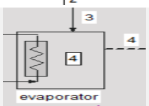
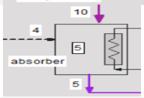
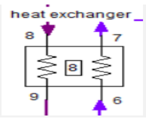
Nelder Mead Method (NMM); is found in 1965 by himself and based on to depend objective function to multi independent parameter without considering deviations in these parameters. In this algorithm (n+1) test points are used for n-dimensional space.

3. Results and Discussions

3.1. Flow inside the system

EES software calculates flow parameters of the system including mass flow rate. Temperature, enthalpy and energy of system elements in each flow points in accordance with the set values of independents parameters. Independent parameters are defined as input parameters in EES program in order to allow design engineer to set suitable values for different cases which is seen in blue brackets in Figure 2.

Table 1. Mathematical model of energetic and exergetic analysis

System elements & flow lines	Diagram	Mass balance	Energy balance	Exergy flow
Generator (1)		$\dot{m}_7 = \dot{m}_1 + \dot{m}_8$ $\dot{m_{gen}} = \frac{Q_{gen}}{h_{11} - h_{12}}$	$\dot{m}_7 . h_7 = \dot{m}_1 . h_1 + \dot{m}_8 . h_8$ $\dot{q_{gen}} = F . h_8 + h_1 - (F+1) . h_7$ $Q_{gen} = \dot{q_{gen}} . \dot{m}_1$	$\psi_1 = (h_1 - h_{01}) - T_0 . (s_1 - s_{01})$ $Ex_1 = \dot{m}_1 . \psi_1$
Condenser (2)		$\dot{m}_1 = \dot{m}_2$ $\dot{m_{con}} = \frac{Q_{con}}{h_{13} - h_{14}}$	$\dot{q_{con}} = h_2 - h_1$ $Q_{con} = \dot{q_{con}} . \dot{m}_2$	$\psi_2 = (h_2 - h_{02}) - T_0 . (s_2 - s_{02})$ $Ex_2 = \dot{m}_2 . \psi_2$
Evaporator (4)		$\dot{m}_3 = \dot{m}_4$ $\dot{m_{eva}} = \frac{Q_{eva}}{h_{15} - h_{16}}$	$\dot{q_{eva}} = h_4 - h_3$ $Q_{eva} = \dot{q_{eva}} . \dot{m}_4$	$\psi_4 = (h_4 - h_{04}) - T_0 . (s_4 - s_{04})$ $Ex_4 = \dot{m}_4 . \psi_4$
Absorber (5)		$\dot{m}_5 = \dot{m}_4 + \dot{m}_{10}$ $\dot{m_{abs}} = \frac{Q_{abs}}{h_{17} - h_{18}}$	$\dot{m}_5 . h_5 = \dot{m}_4 . h_4 + \dot{m}_{10} . h_{10}$ $\dot{q_{abs}} = (F+1) . h_5 - h_4 - F . h_{10}$ $Q_{abs} = \dot{q_{abs}} . \dot{m}_4$	$\psi_5 = (h_5 - h_{05}) - T_0 . (s_5 - s_{05})$ $Ex_5 = \dot{m}_5 . \psi_5$
Expansion valve (3-7)	ISENTHALPIC FLOW	$\dot{m}_2 = \dot{m}_3$ $\dot{m}_9 = \dot{m}_{10}$	$h_2 = h_3$ $h_9 = h_{10}$	$\psi_3 = (h_3 - h_{03}) - T_0 . (s_3 - s_{03})$ $Ex_3 = \dot{m}_3 . \psi_3$
Pump (6)	$W_{in} = W_{pump}$		$\dot{m}_6 . h_6 = \dot{m}_5 . h_5 + W_{pump}$	
Heat exchanger (8)		$\eta_{ex}; efficiency$ (independent parameter)	$\eta_{ex} = \frac{T_8 - T_9}{T_8 - T_6}$ $\eta_{ex} = \frac{\dot{m}_6 . cp_w . (T_7 - T_6)}{\dot{m}_{10} . cp_s . (T_8 - T_9)}$	
Fow lines i=1 to 10			$\psi_i = (h_i - h_{0i}) - T_0 . (s_i - s_{0i})$ $Ex_i = \dot{m}_i . \psi_i$	
Flow lines i=11 to 18	$i = 11\ to\ 12$ $Ex_i = \dot{m_{gen}} . \psi_i$	$i = 13\ to\ 14$ $Ex_i = \dot{m_{con}} . \psi_i$	$i = 15\ to\ 16$ $Ex_i = \dot{m_{eva}} . \psi_i$	$i = 17\ to\ 18$ $Ex_i = \dot{m_{abs}} . \psi_i$
F - COP - EPC	$F = \frac{x_w}{x_s - x_w} = \frac{\dot{m}_{10}}{\dot{m}_1}$	$COP = \frac{Q_{eva}}{Q_{gen}}$	$EPC = \frac{\dot{m_{eva}} . (\psi_{16} - \psi_{15})}{\dot{m_{gen}} . (\psi_{11} - \psi_{12})}$	

The output of the software is compared with studies in the literature at constant values selected as

T_1=120°C, T_2=40°C, T_4=6°C and T_5=50°C as well as Q_{eva}=1500kW, X_s=64% and X_w=56% in Ref. 30.
T_1=100°C. T_2=45,8°C. T_4=5°C and T_5=40°C as well as Q_{eva}=174kW. X_s=64% and X_w=58% in Ref. 31

T_1=81,4°C T_2=37,4°C. T_4=4,7°C and T_5=37,4°C as well as Q_{eva}=35kW. X_s=63.51% and X_w=56.68% in Ref. 32.
T_1=85°C. T_2=40°C. T_4=10°C and T_5=40°C as well as Q_{eva}=50kW. X_s=59.91% and X_w=54.91% in Ref. 33. [30-33]

As seen in Table 2, most thermodynamic variables are the same or very close to be neglected the deviation but physical exergy values deviate critically at some points.

The physical exergy value is calculated by multiplying the enthalpy difference between the flow point and the dead state thermal conditions and the entropy difference between the flow point and the dead state thermal conditions by the dead state temperature in K.

It is considered that the deviation in the physical exergy values at some points is due to different dead state conditions

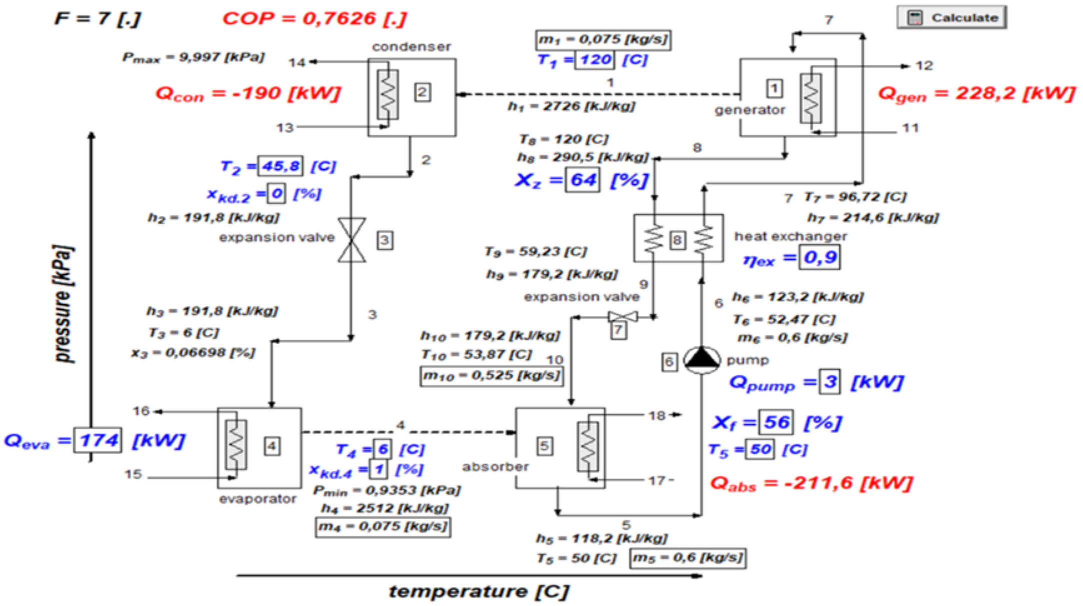


Figure 2. Energetic results and mass flow rates output of EES

Table 2. Comparison of Thermophysical Properties in each flow points calculated by EES with other studies – Validation crosscheck

Flow Points (i)		T_i [°C]	$\dot{m}_i$ [kg/s]	X_i [%]	h_i [kJ/kg]	s_i [kJ/kgK]	ψ_i [kJ/kg]
1	**EES vs Ref.30**	120	0.6398		2726		
		120	0.6399		2725		
	EES vs Ref.31	100	0.075		2687	8.449	173
		100	0.08		2687.5	8.4479	174.62
	EES vs Ref.32	81.4	0.0149		2653	8.557	105.9
		81.4	0.0149		2652	8.556	105.8
	EES vs Ref.33	85	0.0212		2659	8.511	126.2
		85	0.0212		2659	8.51	-
2	**EES vs Ref.30**	40	0.6398		167.5		
		40	0.6399		167.5		
	EES vs Ref.31	45.8	0.075		191.8	0.6491	2.903
		45.8	0.08		191.83	0.6493	2.93
	EES vs Ref.32	37.4	0.0149		156.7	0.5376	1.05
		37.4	0.0149		156.6	0.5374	0.9558
	EES vs Ref.33	40	0.0212		167.5	0.5724	1.528
		40	0.0212		167.5	0.5723	-
3	**EES vs Ref.30**	6	0.6398		167.5		
		6	0.6399		167.5		
	EES vs Ref.31	5	0.075		191.8	0.6902	-9.335
		5	0.08		191.83	0.6903	-9.28
	EES vs Ref.32	4.7	0.0149		156.7	0.5645	-6.968
		4.7	0.0149		156.6	0.5643	-7.066
	EES vs Ref.33	10	0.0212		167.5	0.5944	-5.015
		10	0.0212		167.5	0.5942	-

Table 2. Comparison of Thermophysical Properties in each flow points calculated by EES with other studies – Validation crosscheck (Continue)

	Flow Points (i)	T_i [°C]	$\dot{m}_i$ [kg/s]	X_i [%]	h_i [kJ/kg]	s_i [kJ/kgK]	ψ_i [kJ/kg]
4	EES vs Ref.30	6 6	0.6398 0.6399		2512 2512		
	EES vs Ref.31	5 5	0.075 0.08		2510 2510.6	9.025 9.0254	-176 -174.37
	EES vs Ref.32	4.7 4.7	0.0149 0.0149		2510 2509	9.033 9.031	-178.9 -178.9
	EES vs Ref.33	10 10	0.0212 0.0212		2519 2519	8.9 8.899	-129.6 -
5	EES vs Ref.30	50 50	5.119 5.119	56 56	118.2 117.7		
	EES vs Ref.31	40 40	0.801 0.8	58 58	107 105.71	0.2299 0.2395	0.6626 1.58
	EES vs Ref.32	37.4 37.4	0.1383 0.1384	56.68 56.68	95.77 95.76	0.2196 0.2195	0.4513 34.87
	EES vs Ref.33	40 40	0.2548 0.2547	54.91 54.91	94.08 94.05	0.2461 0.2461	0.6638 -
6	EES vs Ref.30	50.29 50	5.119 4.479	56 56	118.8 117.7		
	EES vs Ref.31	41.93 42	0.801 0.8	58 58	110.8 109.68	0.2419 0.2518	0.8448 1.88
	EES vs Ref.32	48.34 37.4	0.1383 0.1384	56.68 56.68	117.5 95.77	0.2884 0.2195	1.62 34.87
	EES vs Ref.33	45.79 40	0.2548 0.2547	54.91 54.91	105.9 94.06	0.2835 0.2461	1.3 -
7	EES vs Ref.30	96.05 -	5.119 -	56 -	213.1 -		
	EES vs Ref.31	82.46 85	0.801 0.8	58 58	191 195.13	0.4815 0.5027	9.656 12.57
	EES vs Ref.32	70.44 63.12	0.1383 0.1384	56.68 56.68	162 147.2	0.4226 0.3788	6.201 38.78
	EES vs Ref.33	73.67 63.31	0.2548 0.2547	54.91 54.91	163.6 141.9	0.4569 0.3937	7.343 -
8	EES vs Ref.30	120 120	4.479 4.479	64 64	290.5 284.7		
	EES vs Ref.31	100 100	0.7255 0.73	64 64	253.3 248.38	0.5299 0.5302	13.3 16.67
	EES vs Ref.32	81.4 90	0.1234 0.1236	63.51 63.51	216.2 232	0.4388 0.4829	7.559 92.55
	EES vs Ref.33	85 85	0.2335 0.2334	59.91 59.91	203.9 203.8	0.4809 0.4808	10.12 -
9	EES vs Ref.30	57.26 -	4.479 -	64 -	175.7 -		
	EES vs Ref.31	47.74 51	0.7255 0.73	64 64	158.7 159.35	0.2564 0.2765	0.2708 3.24
	EES vs Ref.32	51.64 58.44	0.1234 0.1236	63.51 63.51	162.2 174.4	0.2794 0.3168	1.079 84.5
	EES vs Ref.33	49.71 58	0.2335 0.2334	59.91 59.91	135.8 151.6	0.2806 0.3291	1.731 -

Table 2. Comparison of Thermophysical Properties in each flow points calculated by EES with other studies – Validation crosscheck (Continue)

	Flow Points (i)	T_i [°C]	$\dot{m}_i$ [kg/s]	X_i [%]	h_i [kJ/kg]	s_i [kJ/kgK]	ψ_i [kJ/kg]
10	**EES vs Ref.30**	53.87	4.479	64	175.7		
		52.68	4.479	64	284.7		
	EES vs Ref.31	47.68	0.7255	64	158.7	0.2561	3.596
		49	0.73	64	159.35	0.2655	6.52
	EES vs Ref.32	46.33	0.1234	63.51	162.2	0.2498	9.917
		51.79	0.1236	63.51	174.4	0.329	80.87
	EES vs Ref.33	45.11	0.2335	59.91	135.8	0.2534	9.863
		58	0.2334	59.91	151.6	0.3291	-

3.2. Optimization of system parameters

EES software has its embedded optimization procedure. Once the flow and energy-mass balances are coded correctly, parameter which will be optimized, set as an independent parameter. All iterations are done according to the boundary conditions of independent parameters as seen in Table 3.

Table 3. Boundary conditions of independent parameters

	Boundaries	Thermophysical State
T_1 [°C]	$100 \leq T_1 \leq 160$	Superheated steam in generator
T_2 [°C]	$40 \leq T_2 \leq 55$	Saturated water in condenser
T_4 [°C]	$4 \leq T_4 \leq 10$	Saturated steam in evaporator
T_5 [°C]	$50 \leq T_5 \leq 70$	Weak $LiBrH_2O$ solution in absorber
X_w [%]	$45 \leq X_w \leq 60$	Weak $LiBrH_2O$ solution in flow line 5-6-7
X_s [%]	$60 \leq X_s \leq 75$	Strong $LiBrH_2O$ solution in flow line 8-9-10

3.2.1. Optimization of T_1, T_2, T_4, T_5 for maximum COP and EPC

The abbreviation of T_1 which presents the temperature of generator is set as an independent variable in order to determine all thermodynamic properties of inner flow of the system. Other independent parameters T_2, T_4, T_5, X_w and X_s are set as constant values of 40°C, 6°C, 70°C, 56%, 64 % respectively. EES software run 26 iterations according to Quadratic Approximation Method and found optimum T_1 value as 100°C for maximum COP value as 0.821 and EPC value as 0.2181 shown in Figure 3.

After determining the optimum value of T_1, T_2 which presents the temperature of condenser is set as an independent parameter. T_2 oscillates in its boundary conditions between 40°C and 55°C while T_1, T_4, T_5, X_w and X_s are set as constant values of 100°C, 6°C, 70°C, 56%, 64% respectively. The optimum value of condenser temperature is found as 40°C according to Quadratic Approximation Method with 25 iterations for maximum COP value as 0.821 and EPC value as 0.2181 shown in Figure 4.

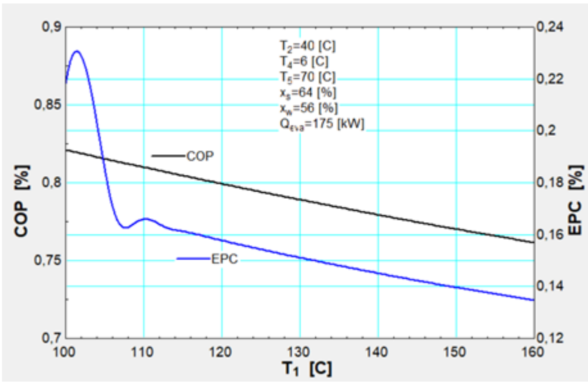


Figure 3. COP and EPC change for T_1

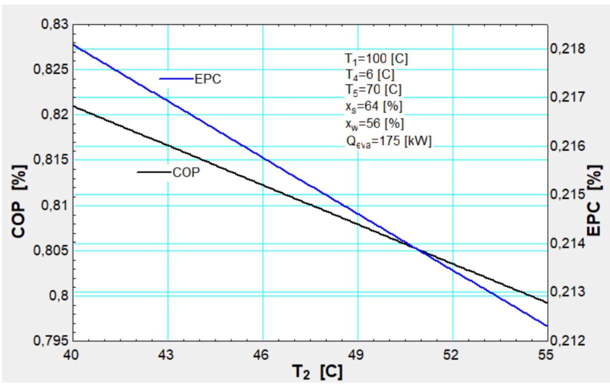


Figure 4. COP and EPC change for T_2

T_4 the value of evaporator temperature is the most significant and complicated variable that determines energetic and energetic efficiency values of the system. As seen in Figure 5. while COP is directly proportional with T_4, EPC has reverse proportion. Therefore, different optimum T_4 values are found for both maximizing COP and EPC as 10°C and 4°C. Single independent variable test which is used as Quadratic Optimization Method is not enough for maximizing both COP and EPC values because optimum T_4 value is found 10°C with max COP 0.8236 by 34 iterations and 4°C with max EPC 0.2323 by 28 iterations. So optimum value of evaporator temperature would be determined by defining all values as independent variable with two objective functions.

T_5 temperature of absorber has positive effect on both COP and EPC of the system as seen in Figure 6. Optimum value of T_5 is found 70 °C according to Quadratic Approximation Method with 0.821 COP value by making 32 iterations. The same optimum value is valid for maximum EPC of 0.2181 that is achieved by 32 iterations with same optimization method.

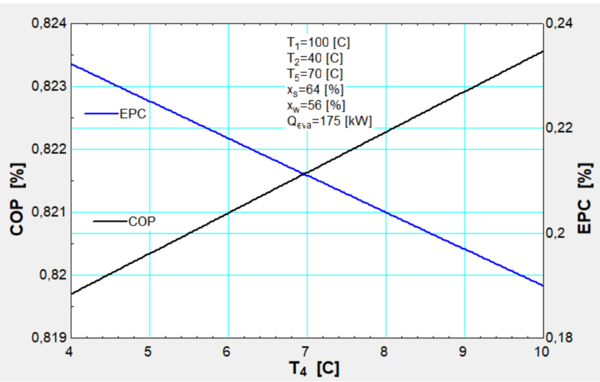


Figure 5. COP and EPC change for T_4

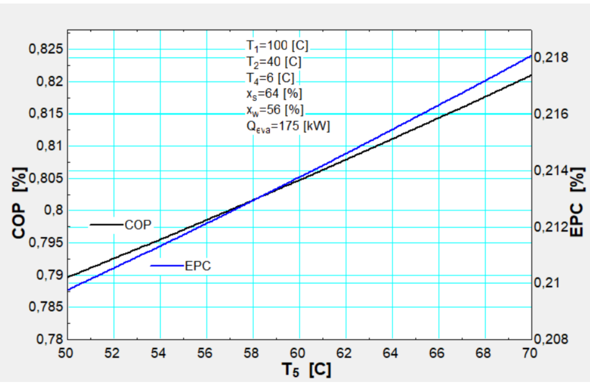


Figure 6. COP and EPC change for T_5

The boundary conditions of T_1. T_2. T_4 and T_5 has a major part for determining the optimum values. So, it is recommended that design engineer should consider the working principles and boundary conditions by absolute match with cooling purposes such as which products will be used in cooling prosses, time period of cold storage and required minimum temperature.

3.2.2. Optimization of X_w. X_s for maximum COP and EPC

Weak and strong concentration ratio values are the most significant values that creates the flow rate of system. Because it depends on the ratio of weak solution concentration to difference between strong and weak solution concentration values. Nonetheless, concentration values are very effective on determining efficiencies of the system.

Weak solution follows the flow line between 5 to 7 and once it enters into generator H_2O leaves the solution due to low vaporization point as superheated steam. Therefore, weak solution turns into strong solution due to increment in concentration value and follows flow line 8-10. While ratio of H_2O in LiBr derives between weak and strong solution ratios mass flow rates and heat transfer values change along with all thermodynamic properties. Although, Xw and Xs values are depended to temperature, pressure, composition of solution, concentration ratios are independent parameters which effects COP and EPC values of the system. T_1, T_2, T_4, T_5, X_s values are set as constant variables at 100°C, 40°C, 6°C, 70°C and 64% respectively. In the optimization proses, it is not considered how concentration ratios occur but only how they affect the COP and EPC of the system.

As seen in Figure 7, both COP and EPC values are reverse proportional with weak solution concentration value.

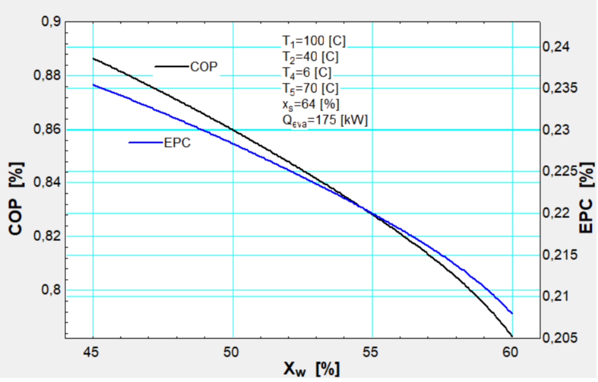


Figure 7. COP and EPC change for X_w

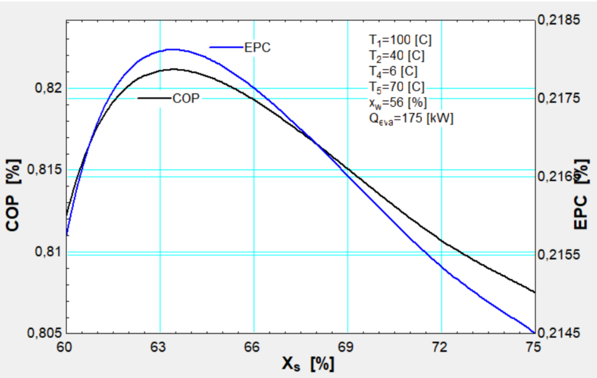


Figure 8. COP and EPC change for X_s

Weaker solution concentration means higher system efficiency. Quadratic Approximation Method calculated the optimum X_w value as 45% with 0.8863 COP and 0.2354 EPC values by making 25 iterations. As expressed above, X_w value is the most significant parameter that determines the efficiency of system and COP value reached to 0.8863 even higher than COP of the system that has optimum value of T_4 as 0.8236. Also. same results showed up for EPC value of the system even higher than EPC of the system that has optimum value of T_4 as 0.2323. The optimum X_s value is found 63.41% with 0.8211 max COP and 0.2181 max EPC by making 16 iterations as seen in Figure 8.

3.2.3. Independent variable interaction in optimization process

All temperature values are set as an independent variable that varies between its boundary conditions in order to observe the effect of all interacted independent variable on system efficiencies. Figure 9 shows the effect of independent temperature variables on COP of the system.

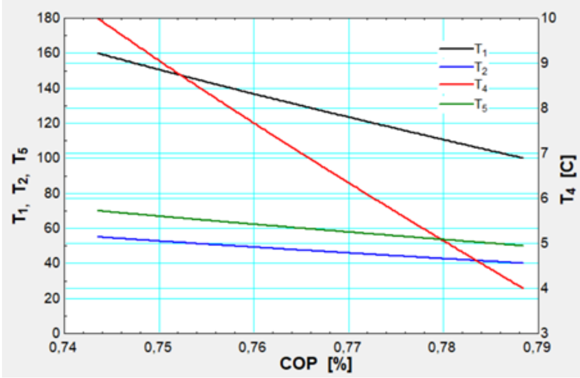


Figure 9. The effect of all independent temperature variables on COP

Figure 10 shows the correlation between EPC and independent temperature values.

After 4 independent temperature values are defined to the software and single objective function is set for both maximizing COP and EPC individually; Conjugate Directions Method (CDM) run 311 iterations for maximizing COP. Optimum T_1, T_2, T_4 and T_5 values are found as 100°C, 40°C, 10°C and 70°C respectively for max COP value of 0.8236. CDM run 123 iterations for maximizing EPC and found optimum T_1, T_2, T_4 and T_5 values as 100°C. 40°C. 4°C and 70°C with max EPC 0.2323.

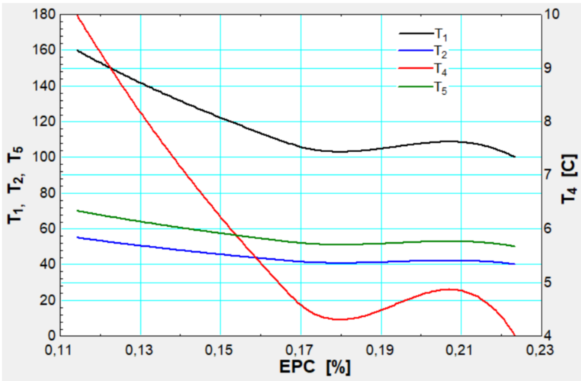


Figure 10. The effect of all independent temperature variables on EPC

According to the Variable Metric Method (VMM) optimum values of T_1, T_2, T_4 and T_5 are found as 100°C. 40°C. 4°C and 50°C respectively for maximum COP value of 0.7884 by making 36 iterations. VMM run 47 iterations for maximizing EPC and found optimum T_1, T_2, T_4 and T_5 values as 100°C, 40°C, 4°C and 50°C with max EPC 0.2234.

Nelder-Mead Method (NMM) gives more sensitive results for optimum values of T_1, T_2, T_4 and T_5 as 100°C, 40°C, 4°C and 55.77C respectively. The maximum COP value is found as 0.7969 by making 197 iterations. According to NMM for max EPC objective function optimum values of T_1, T_2, T_4 and T_5 are found as 100°C. 46.89°C, 4°C and 69.88°C respectively with max EPC 0.2294.

According to Direct Method (DM) optimum values are found as 100°C for T_1, 40.01°C for T_2, 9.996°C for T_4 and 70°C for T_5 with max COP 0.8235 by making over 1000 iterations. DM found the optimum values of T_1, T_2, T_4 and T_5 as 100°C, 40°C, 4.01°C and 70°C respectively when objective function is set for max EPC. Max EPC value is found as 0.2323.

Genetic Method (GM) run over 1100 iterations and found 100°C for optimum T_1, 40.26°C for optimum T_2, 9.764°C for optimum T_4 and 70°C for optimum T_5 with max COP value of 0.823. When objective function is set for maximizing EPC optimum values of T_1, T_2, T_4 and T_5 are found as 102.6°C, 40.33°C, 4.026°C and 69.96°C respectively with max EPC 0.2311. Weak solution and strong solution concentration ratios are reverse proportional with both energetic and exergetic efficiency of the system as seen on Figure 11 and Figure 12. The lower concentration ratio means higher efficiency.

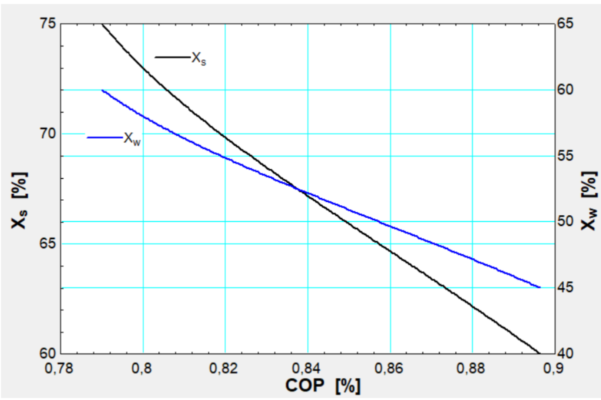


Figure 11. The effect of all independent concentration variables on COP

However, it must be mentioned that if X_w or X_s values keep decreasing at some critical point, absorption prosses fails due to low concentration ratio. The absorbent material is LiBr in the system, the more concentration ratio means higher absorption of heat that is absorbed from cooling space in evaporator. In addition to the fact, flow ratio "F" decreases by difference between X_s and X_w. Concentration ratios can be decreased to some critical point in order maximize energetic and exergetic efficiencies without failing the absorption prosses and causing low flow ratio. Therefore, boundary conditions are crucial to determine the optimum value.

The optimum weak and strong solution concentration ratios are calculated by defining both ratio as an independent parameter and two single objective functions are used one for maximizing COP and the other for maximizing EPC. Five different optimization methods are used same as temperature values as shown in Table 4.

Optimum values of concentration values are found much more rigid and stable than temperature values in each optimization method.

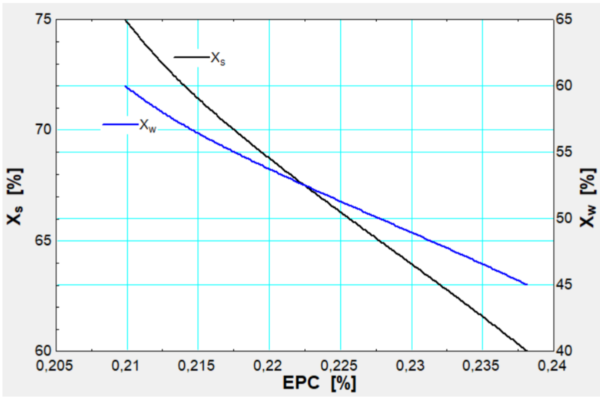


Figure 12. The effect of all independent concentration variables on EPC

Table 4. Optimum concentration ratios (X_w-X_s) with different optimization methods

		X_w	X_s
Conjugate Directions Method	**Value**	45 %	60 %
	COP	0.8964	0.8964
	EPC	0.2381	0.2381
	Iterations	156	69
Variable Metric Method	**Value**	45%	60%
	COP	0.8964	0.8964
	EPC	0.2381	0.2381
	Iterations	15	15
Nelder-Mead Method	**Value**	45%	60%
	COP	0.8964	0.8964
	EPC	0.2381	0.2381
	Iterations	12	12
Direct Method	**Value**	45%	60%
	COP	0.8961	0.8964
	EPC	0.2381	0.238
	Iterations	550	550
Genetic Method	**Value**	45%	60%
	COP	0.8964	0.8964
	EPC	0.2381	0.2381
	Iterations	1111	1111

3.3. Energy and exergy flow in the system

WHDACS used in this study feeds by the waste heat discharged from Yatagan Thermal Power Plant. Thus, superheated waste steam should be drawn between the flow lines mid-pressure line and low-pressure line at staged turbines.

Superheated steam flow between mid-pressure and low-pressure flow line is 1.18Bar, 172°C and 145MWt total thermal energy [34]

All independent parameters are set as an independent parameter in the software and iterated 10 steps in boundary conditions. While T_1 oscillates between 100-160°C, T_2 between 40-55°C, T_4 between 4-10°C, T_5 between 50-70°C, X_w between 45-60%, X_s between 60-75% and Q_{eva} is set to constant value of 175kW, power of entire system elements, mass flow rates and system efficiencies are as shown in Table 5.

For instance, while all independent parameters are in their lowest level, system efficiencies are at the highest level and it is vice versa for the highest level of independent parameters. The most dramatic and interesting fall is in EPC value in Run-2 from 0.245 to 0.1827 just one step further from the optimum values of the independent parameters.

Therefore, it is observed that optimum values of generator temperature, condenser temperature, evaporator temperature, absorber temperature, weak and strong solution concentration ratios are significant over system efficiencies.

Also, these are significant over mass flow rate in weak solution flow line and strong solution flow line which can be describe as absorbent flow line. On the other hand, in cooling flow line which is followed by cooling fluid H_2O from 1 to 4 till mixing with the absorbent LiBr, mass flow rate is relatively constant, small changes occur while independent parameters oscillate between their boundary values.

That's why evaporator power is set to a constant value which is considered as 175W in order to make it easy to compare with the results found in literature. However, power of evaporator is the main output of the system and should be considered according to cooling requirements.
So, power of evaporator is set to be independent parameter between 50 to 500 kW while other independent parameters are set to their optimum values in order to see how mass flow rate and power of system elements such as absorber and condenser changes.

As seen in Figure 13. mass flow rates except $\dot{m}_1$ and power of condenser and absorber increases dramatically. It should be expressed that negative value in power of absorber and condenser shows the direction of energy flow not the quantitative value.

Table 5. Mass flow rate and power of system elements in different values of independent parameters (10 iterations in boundary conditions)

	COP	EPC	$\dot{m}_1$	$\dot{m}_5$	$\dot{m}_{10}$	Q_{abs}	Q_{con}	Q_{gen}	$\boldsymbol{T_1}$	$\boldsymbol{T_2}$	$\boldsymbol{T_4}$	$\boldsymbol{T_5}$	$\boldsymbol{X_w}$	$\boldsymbol{X_s}$
Run-1	0.865	0.245	0.0748	0.2243	0.2991	-190.6	-188.4	202.4	**100**	**40**	**4**	**50**	**45**	**60**
Run-2	0.848	0.183	0.0750	0.2332	0.3081	-193.6	-189.3	206.4	**106.7**	**41.67**	**4.667**	**52.22**	**46.67**	**61.67**
Run-3	0.831	0.171	0.0751	0.2421	0.3172	-196.9	-190.2	210.5	**113.3**	**43.33**	**5.333**	**54.44**	**48.33**	**63.33**
Run-4	0.815	0.161	0.0753	0.2511	0.3264	-200.2	-191.1	214.8	**120**	**45**	**6**	**56.67**	**50**	**65**
Run-5	0.798	0.151	0.0755	0.2601	0.3356	-203.7	-192	219.2	**126.7**	**46.67**	**6.667**	**58.89**	**51.67**	**66.67**
Run-6	0.783	0.142	0.0757	0.2691	0.3448	-207.1	-192.9	223.6	**133.3**	**48.33**	**7.333**	**61.11**	**53.33**	**68.33**
Run-7	0.768	0.134	0.0759	0.2782	0.3541	-210.4	-193.8	227.9	**140**	**50**	**8**	**63.33**	**55**	**70**
Run-8	0.754	0.126	0.0761	0.2874	0.3635	-213.3	-194.7	232.2	**146.7**	**51.67**	**8.667**	**65.56**	**56.67**	**71.67**
Run-9	0.741	0.119	0.0763	0.2966	0.3728	-215.8	-195.7	236.3	**153.3**	**53.33**	**9.333**	**67.78**	**58.33**	**73.33**
Run-10	0.728	0.112	0.0765	0.3058	0.3823	-217.6	-196.6	240.5	**160**	**55**	**10**	**70**	**60**	**75**

Mass flow rate is critical parameter while designing and sizing system elements. High mass flow rates are undesirable because of the difficulties to control the flow and high-power requirements in the circulation-flow line. It should be examined that how power of evaporator effects the power of generator which is the energy input system element and COP and EPC before determining the optimum evaporator power.

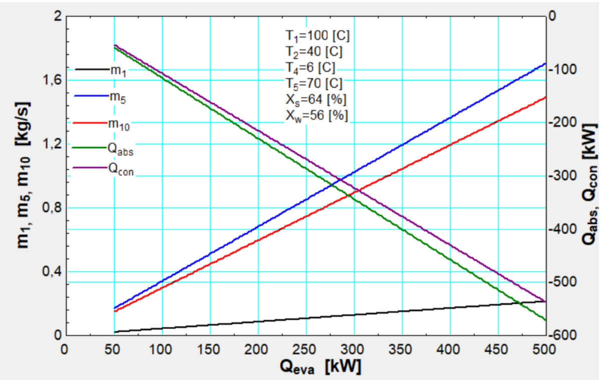


Figure 13. The effect of Q_{eva} on mass flow rate and Q_{abs}-Q_{con}

Figure 14 shows that power of the evaporator has significant effect on power of generator but not on system efficiencies.

Therefore, while determining the optimum value of evaporator power, the main determinant should be mass flow rates. Waste heat discharged from Yatagan Thermal Power Plant is quite high enough to feed all generator requirements but mass flow rates are getting above the critical point of 1kg/s when Q_{eva} exceeds over 300kW.

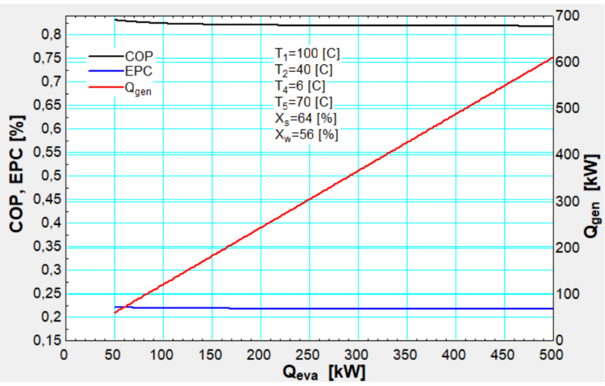


Figure 14. The effect of Q_{eva} on COP-EPC and Q_{gen}

Thus, optimum evaporator power should be considered around 300 kW in this case scenario. Figure 15 shows the effect of generator temperature on exergy flows in flow lines 1-7-8-9-10 and exergy destruction in system elements. The exergy flow in the flow lines increases depending on the generator temperature. While the exergy destruction values in the condenser, evaporator and absorber system elements remain relatively constant, exergy destruction in the generator increases significantly. Especially, between 100-110°C exergy destruction in generator increases exponentially and linear rise follows after 110°C. Therefore, selection of T_1 close to 100°C helps to reduce exergy destruction in generator.

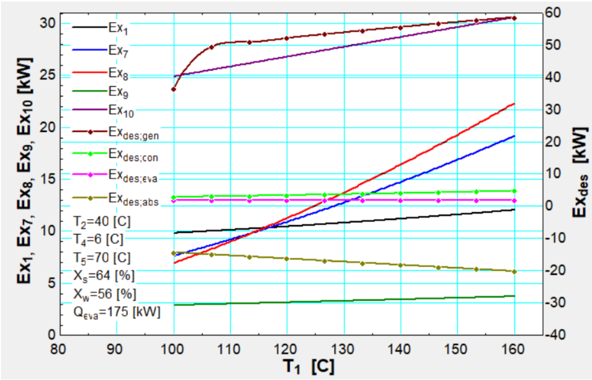


Figure 15. The effect of T_1 on exergy flow in related flow lines and exergy destruction in system elements.

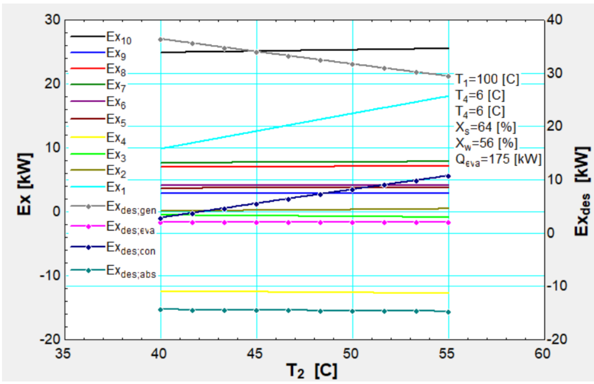


Figure 16. The effect of T_2 on exergy flow in related flow lines and exergy destruction in system elements.

Exergy flows in flow lines 2-3-4-5-6-7-8-9 increases slightly by condenser temperature while exergy flow in flow line 1 and 10 increases at high rate as seen in Figure 16. Exergy destruction in condenser is reversely proportional with condenser temperature. Exergy destruction decreases in generator by temperature of condenser increases.

Temperature of evaporator decreases the exergy flow in flow line 10 and increases exergy flow in flow line 4 and exergy destruction in absorber while it slightly decreases exergy destruction in evaporator as seen in Figure 17.

It is observed that energetic change in exergy flow in flow lines except 4 and exergy destruction except absorber is not significant. Temperature of absorber is significant for both exergy flow in flow lines of absorbent flow and exergy destruction of system elements as seen in Figure 18. engineer while designing or sizing absorber unit in particular.

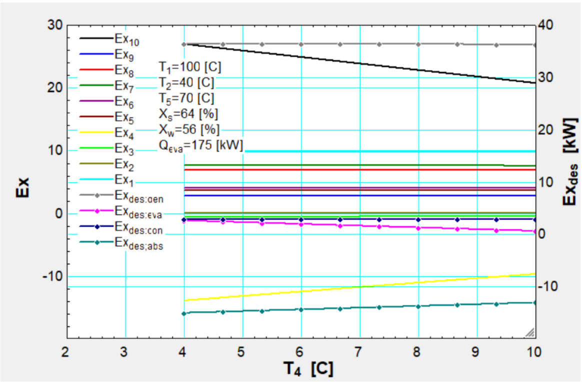


Figure 17. The effect of T_4 on exergy flow in related flow lines and exergy destruction in system elements.

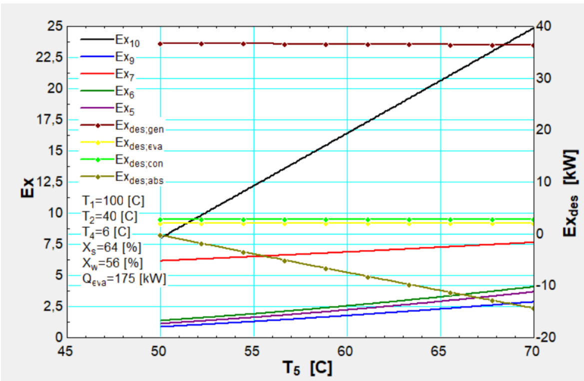


Figure 18. The effect of T5 on exergy flow in related flow lines and exergy destruction in system elements

Concentration ratio of weak solution is significant over exergy flow in flow lines especially 7-8-10 and exergy destruction in absorber. As seen in Figure 19 exergy destruction in absorber is exponentially reverse proportional with the concentration ratio of weak solution while exergy flow in flow line 7-8-10 are exponentially increasing by the weak solution concentration ratio.

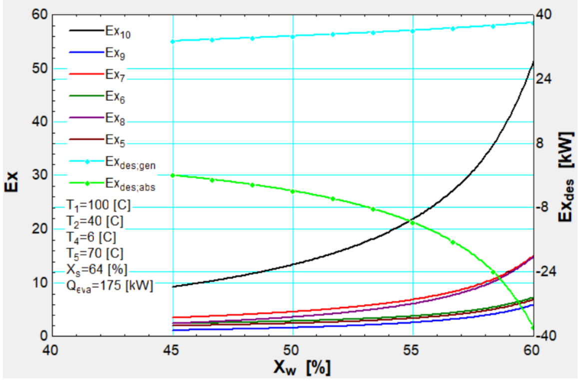


Figure 19. The effect of X_w on exergy flow in related flow lines and exergy destruction in system elements

Exergy flow in flow lines 5 to 10 is reversely proportional by concentration ratio of strong solution and it is observed that decrement is getting higher after 68%. Also, exergy destruction in absorber and generator exponentially increases after 68%. Therefore 68% of strong solution concentration ratio is critical point for both max exergy flow in flow lines and min exergy destruction in system elements as seen in Figure 20.

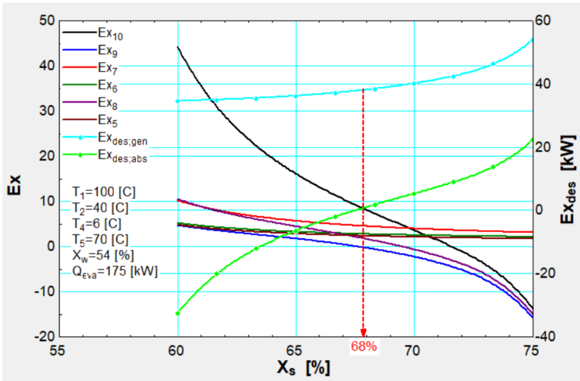


Figure 20. The effect of X_s on exergy flow in related flow lines and exergy destruction in system elements

Exergy destruction values in each system element, physical and total exergy values in each flow line and mass flow rate values at optimum conditions of system elements can be seen in Figure 21.

3.4. Potential of WHDACS fed by Yatagan thermal power plant

Thermal power of flow line between mid-pressure and low-pressure turbine flow line is 145 MWt and mass flow rate is much greater than mass flow rate of superheated steam needed by generator. Therefore, steam flow from power plant to ACS should be divided to parallel flow lines which can be arranged by distribution center as seen in Figure. 22. Each flow line is designed to feed an individual ACS by the help of appropriate pumps to ensure the proper circulation.

WHDACSs COP values are around 0.7 and in some particular conditions it can be reached to 0.82 and all optimum conditions are discussed earlier.

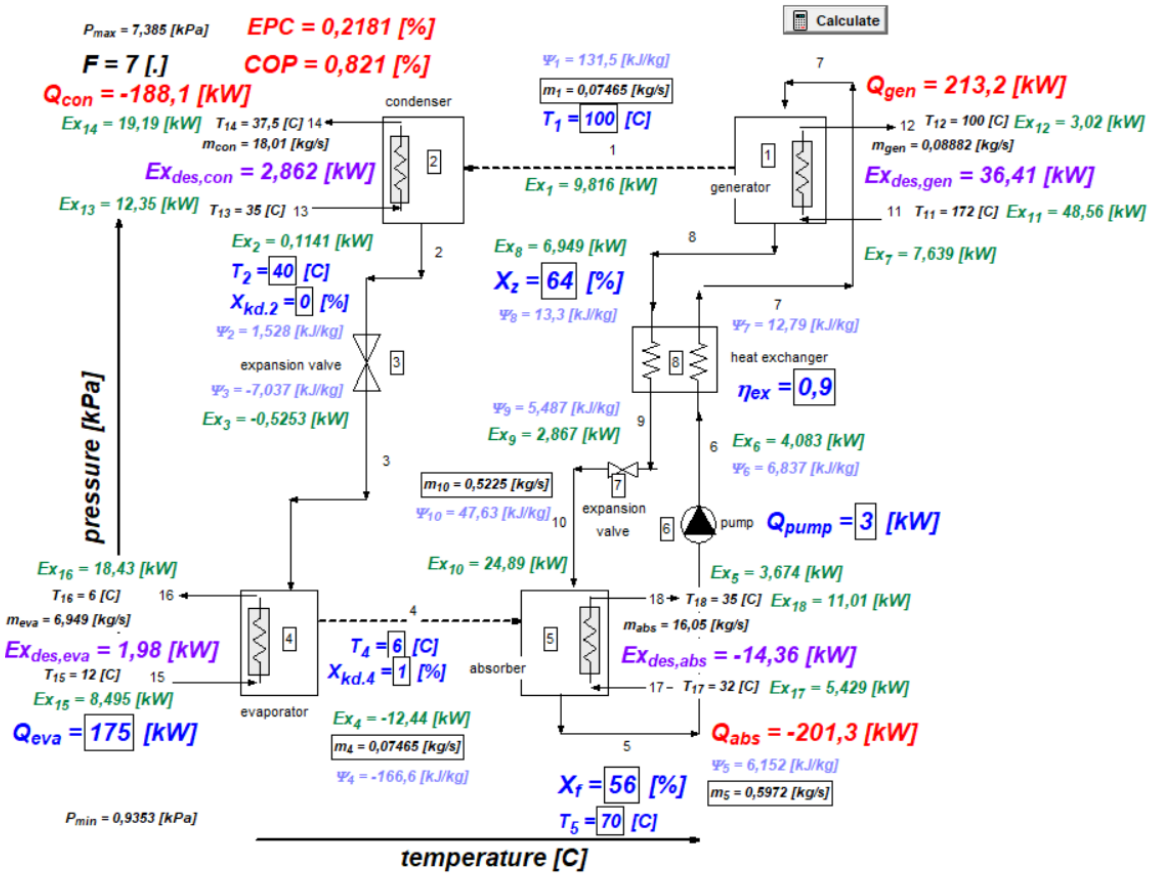


Figure 21. Exergy destruction in system elements and flow lines

It is necessary to add distribution center as shown in Figure 22, between Yatagan Thermal Power Plant and each ACS which means more energy loss will occur due to distribution flow lines, plumbing components and even means more pressure loss due to plumbing corners, valves, turbulent flow and pumps. All energy loss is assumed to be 15%. These mentioned losses depend on distribution line position, length, material, number and properties of plumbing elements [34, 35]. Since, the optimum ACS is 300 kW, the number of parallel flow lines would reach 280. If the power of evaporator considered as 400kW number of parallel flow lines would reach 210, parallel flow

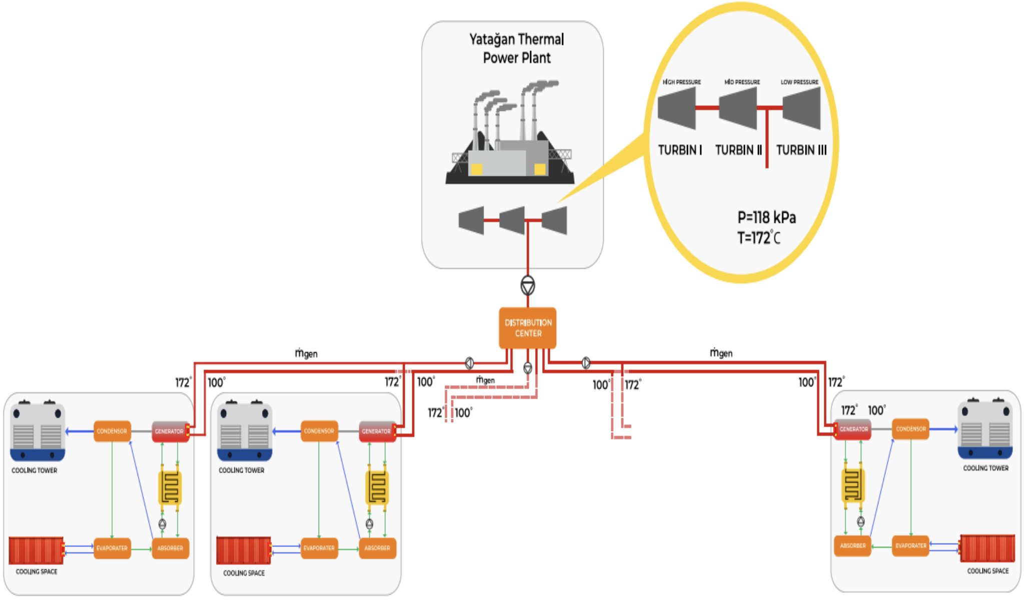


Figure 22. Schematic presentation of superheated steam distribution taken from Yatagan Thermal Power Plant

lines would reach 340 if power of the evaporator designed as 250kW. Either way cooling potential reaches 84MWt approximately.

It can be defined that total exergy flow in ACS applications is composed of kinetic, potential, physical and chemical exergy due to lack of any other energy input source such as electrical, nuclear etc. Kinetic and potential exergy is neglectable in ACS because work against gravity or kinetic exergy change is quite small when it is compared with other exergy flow values [36, 37].

It is same for chemical exergy flow in both cooling cycle and absorption cycle [38, 39]. In fact, chemical exergy potential $\mu_i$calculation method is coded to the software and the results are examined, It is observed that chemical exergy flow can be neglected, even “0” in cooling cycle. Therefore, the main component for exergy flow in ACS is physical exergy which is dependent to enthalpy and entropy difference between flow point conditions and dead state thermophysical properties.

The key part is to determine the dead state conditions in order to find exact exergy in flow lines or system elements. As it is discussed in the study made by [36]. There are different approaches for determining the dead state conditions. It is underlined that in most studies, dead state conditions are taken as the conditions of surrounding environment. But in the mentioned study, this generalization is criticized for being some system elements are not interacted directly to the surrounding environment which the fluid cannot be in equilibrium with. Therefore, it is suggested that system elements should be divided into subsystems considering different surrounding environment. In this study, dead state conditions are taken as ambient conditions for Mugla city regarding cooling cycle flows though evaporator, condenser and absorber with cooling tower. Only few system elements are surrounded by other system elements and this is not significant over the total energy and exergy flow between flow lines.

To avoid the conflict, it is best recommended that exergy destruction parameters provide more precise outputs for exergetic cycle of system than exergy values of flow line and system elements. Exergy destruction in generator is greater than exergy destruction in absorber, condenser and evaporator respectively as seen in Figure 21. This course is same as the exergy destruction values in the Literature [36, 40, 41]. If exergy destruction defined as improvement potential of system element, it is certain that generator is the most developable system element in this case.

4. Conclusion

In this paper, energy and exergy analyses are carried out for single stage LiBr-H_2O ACS with cooling tower by using EES program. Energetic and exergetic performance of single stage LiBr-H_2O ACS is analyzed in order to determine whether waste heat of Yatagan Thermal Power Plant is convenient to drive selected absorption cooling system or not. It is seen that T_1, T_2, T_4, T_5, X_w, X_s parameters are the most important parameters determining the system efficiency.

At first, T_1, T_2, T_4, T_5, X_w, X_s are set as independent parameters and single effect of each independent parameter on COP and EPC is found while other independent parameters are set to a constant (optimum) value.
Optimum values of T_1, T_2, T_4, T_5, X_w, X_s are found as; T_1=100°C. T_2=40°C. T_4=10°C for max COP 4°C for max EPC. T_5=70°C. X_w=45% and X_s=63.41 %.

Then, all independent temperature parameters and concentration ratios are interacted with each other in order to find more accurate optimum parameters. Five different optimization processes are used and found; 100°C for T_1, 46.86°C for T_2, 9.996°C for T_4 and 70°C for T_5, 45% for X_w,60% for X_s by using Nelder-Mead Method.

Evaporator power is examined as an independent parameter to observe the effect on other system elements and mass flow rates. 300kW evaporator power is the optimum power for ACS driven by waste heat discharged from Yatagan Thermal Power Plant.

If analysis redone by changing the prospect for min exergy destruction perspective, selection of T_1 close to 100°C helps to reduce exergy destruction in generator.
Also, 68% of strong solution concentration ratio (X_s) is a critical point for max exergy flow and min exergy destruction in system elements.
Exergy destruction in generator is greater than exergy destruction in absorber, condenser and evaporator.

WHDACS would be preferable for cold storage especially for local products.
As a result, waste heat of Yatagan Thermal Power Plant is a convenient source for ACS especially for the kind that uses LiBr-H_2O. All results showed that ACS driven by waste heat of Yatagan Thermal Power Plant has similar efficiency, mass flow rate and power values with the system results presented in the literature which are driven by other energy sources. This means Yatagan Thermal Power Plant carries out sufficient thermodynamic properties to drive ACS. It is observed that WHDACS are preferable for cold storage especially for local products that need cold storage.

For further motivation, there are so many questions waiting to be answered such as if ACS which uses different fluid couples are more congruent with waste heat of Thermal Power Plants or not. What is the potential of countries for WHDACS? How does WHDACS contribute to eliminate the foreign dependency in energy for especially developing countries?

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Authors' Contribution
In the study carried out, Author 1 under the headings of evaluation of the results obtained, arrangement of the text and examination of the results, the author 2 under the titles of forming the idea, making the design, performing the numerical analysis and literature review.

The Declaration of Conflict of Interest/ Common Interest
No conflict of interest or common interest has been declared by authors.

The Declaration of Ethics Committee Approval
This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics
Authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this

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