THERMO-ECONOMIC ANALYSIS AND OPTIMIZATION OF THE STEAM ABSORPTION CHILLER NETWORK PLANT

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Absorption chillers are one of the most used equipment in industrial, commercial, and domestic applications. For the places where high cooling is required, they are utilized in a network to perform the cooling demand. The main objective of the current study was to find the optimum operating conditions of a network of steam absorption chillers according to energy and economic viewpoints. Firstly, energy and economic analysis and modeling of the absorption chiller network were carried out to have a deep understanding of the network and investigate the effects of operating conditions. Finally, the particle swarm optimization search algorithm was employed to find an optimum levelized total costs of the plant. The absorption chiller network plant of the Marun Petrochemical Complex in Iran was selected as a case study. To verify the simulation results, the outputs of energy modeling were compared with the measured values. The comparison with experimental results indicated that the developed model could predict the working condition of the absorption chiller network with high accuracy. The economic analysis results revealed that the levelized total costs of the plant is 1730 $/kW and the payback period is three years. The optimization findings indicated that working at optimal conditions reduces the levelized total costs of the plant by 8.5%, compared to the design condition.

Keywords: *Absorption chiller network, Energy and economic analysis, Levelized total costs, Particle swarm optimization*

1. Introduction

Absorption chillers represent an exciting alternative to the conventional vapor-compression chillers because they can supply cooling without high electrical consumption [1-3]. The mechanical compressor of a compression chiller is indeed substituted by a thermal compressor, where the refrigerant vapor at the outlet of the evaporator is first absorbed in an absorbent solution, pumped to the higher-pressure level, and then desorbed again in the generator [4, 5]. To drive this process, a lowtemperature heat source is necessary at the generator [6-9]. The absorption refrigeration cycle is gaining considerable attention because it can make fair use of low-grade waste heat for cooling demand and employ eco-friendly refrigerant [10, 11]. It is evident the uses of the thermo-economic analysis to verify the viability of the cogeneration systems have been used and applied along with different thermal plants [12, 13], aiming the best proposal to generate steam, electricity, and chilled water for the ice factory industry [14], to generate enough energy for achieving the demand of the swimming pool indoor buildings [15] or even to generate air cooling and electricity for buildings in the university [16, 17]. Since the thermo-economic analysis aims to investigate the energetic technical parameters and also the financial indices to estimate if any thermal plant would be feasibly or not [18], the needs to search for the ideal input configuration in terms of the energetic and economic domain have been mentioned in many studies on polygeneration systems, as it could be seen in the literature [19, 20]. In this context, using different technical methods to optimize the thermal systems have been applied to find the best configuration for energetic and economic efficiency using the Four E technique [21], artificial neural network [22], using the TRNSYS function to the optimization of the economic index [23], MOPSO algorithm [24] or even combining different techniques of optimization such as pessimistic and optimistic criteria [25]. Previously, Panahizadeh et al. [26] presented an analogous study using the exergetic parameters as the basis of the optimization method trying to minimize the exergy destruction by applying the particle swarm optimization algorithm; however, in the present study, we aimed to use the financial parameters such as levelized total costs, net present value, internal rate of return, and payback period as the basis of the objective function to the optimization method. Hence, the main goal of this study was to implement an optimization analysis with an energetic-economic view to find the best configuration for the network of the absorption chiller to operate efficiently. Although extensive research has been done on thermo-economic analysis of absorption chillers, insufficient research has been carried out on the absorption chiller network plant. Also, the limited thermodynamic analysis of the absorption chiller network plant has been carried out; however, to the best of the author's knowledge, no comprehensive analyses have been done in identifying the optimum operation conditions of the absorption chiller network plant. To bridge this gap, the main contributions of this state-of-the-artwork can be drawn as follows, proposing a novel computer algorithm for simultaneous thermo-economic analysis of the absorption chiller network plant, performing accurate and detailed energy and economic simulation of the mentioned plant, evaluating the influence of changing operating conditions like cooling tower water temperature and steam temperature on the levelized total costs of the absorption chiller network plant, applying the two most important economic methods of payback period (PP) and net present value (NPV) for evaluating the mentioned plant, presenting a comprehensive sensitivity analysis for investigating the effects of design parameters on assessment criteria of the plant mentioned above, and performing a particle swarm optimization search algorithm for finding the optimal levelized total costs of the stated plant.

2. Description of the absorption chiller network plant

An absorption chiller network (ACN) includes more than one chiller that work together in a series or parallel arrangement to produce the desired cooling capacity. Apart from absorption chillers, the absorption chiller network plant (ACNP) should have also additional equipment including the main boiler, chilled water storage tank, cooling tower, cooling tower water pump, chilled water pump and air handling or heat exchangers to generate required cooling demand. In this research, the ACNP used for the cooling process in the Mono-Ethylene Glycol (MEG) factory of Marun Petrochemical Complex (M.P.C.) in Iran is selected as a case study as shown in Figure 1. The plant consists of four single effect steam absorption chillers with a cooling capacity of 4775 kW, two forced draft fan cooling towers, a storage tank, cooling tower pumps, and chilled water pump. Also, in this study, it was assumed the steam boiler produced required steam of four chillers with a capacity of 44 tons of steam per hour with 1.5 bar pressure and consumed natural gas.

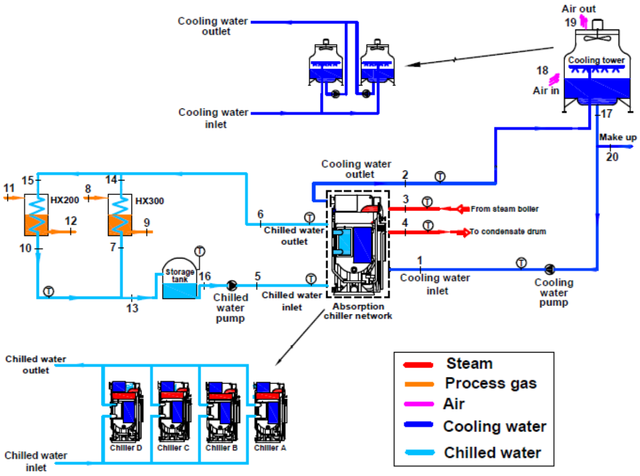


Figure 1. Schematic of the ACNP: case study

3. Thermo-economic and optimization modeling of the ACNP

This section shows the energy analysis, economic and optimization modeling of the absorption chiller network plant

3.1. The energy analysis of the absorption chiller network plant

For evaluating the performance of a system from different viewpoints, it is necessary to perform the energy analysis of the whole system. The general forms of the mass and energy balance equations for a control volume at steady state flow are expressed as follows [27]:

$$\sum_i \dot{m} - \sum_o \dot{m} = 0 \qquad \sum_i \dot{m}h - \sum_o \dot{m}h + \dot{Q} - \dot{W} = 0 \qquad (1, 2)$$

In which $\dot{m}$, h, $\dot{Q}$ and $\dot{W}$ represents the mass flow rate, specific enthalpy, heat power, and mechanical power, respectively. Also, the subscripts i and o are related to the inlet and outlet streams of the control volume. For concerned ACNP the final form of the energy balance equations for each component is described in Table 1. In the following equations, indexes 1 to 20 are stream numbers as shown in Figure 1.

Table 1. Energy balances of the ACNP

Equipment	Equation			
Boiler	$\dot{Q}_B = \eta_c \times \dot{m}_f \times LHV_f$			(3)
Cooling tower	$\dot{m}_{18}h_{18} + \dot{m}_2h_2 = \dot{m}_{19}h_{19} + \dot{m}_{17}h_{17}$	$h_{19} = (C_{Pa}T_{19} + \omega_{19}h_{g19})$	$\dot{Q}_{cooling,t} = \dot{m}_{chw} \times C_{Pw} \times (T_{chwni} - T_{chwno})$	(4,5) (6,7) (8)

	$\omega = 0.622\dfrac{\varphi \times P_g}{P_{atm} - \varphi \times P_g}$	$h_{18} = (C_{Pa}T_{18} + \omega_{18}h_{g18})$	
ACN	$\dot{m}_1h_1 + \dot{m}_3h_3 + \dot{m}_5h_5 = \dot{m}_6h_6 + \dot{m}_4h_4 + \dot{m}_2h_2 + \dot{W}_{ACN}$		(9)
HX200 / HX300	$\dot{m}_{15}h_{15} + \dot{m}_{11}h_{11} = \dot{m}_{12}h_{12} + \dot{m}_{10}h_{10}$	$\dot{m}_{14}h_{14} + \dot{m}_8h_8 = \dot{m}_7h_7 + \dot{m}_9h_9$	(10) (11)
Cooling tower pump / Chilled water pump	$\dot{W}_{cwp} = \dfrac{\dot{m}_{cwni} \times g \times h_{cwp}}{\eta_{cwp}}$	$\dot{W}_{chwp} = \dfrac{\dot{m}_{chwni} \times g \times h_{chwp}}{\eta_{chwp}}$	(12) (13)
Cooling tower fan	$\dot{W}_{cwf} = \dfrac{\dot{m}_{a,i} \times \Delta P_{cwf}}{\rho_{a,i} \times \eta_{cwf}}$		(14)

The variables $\dot{Q}_B$, $\dot{m}_f$, LHV_f and η_c are boiler heat input in kW, fuel mass flow rate in kg/s, fuel lower heat value in kJ/kg and combustion efficiency, respectively. The variables $\dot{m}$, h, C_{Pa}, T, h_g, ω, P_g, P_{atm} and φ are mass flow rate in kg/s, specific enthalpy in kJ/kg, specific heat at a constant pressure of air in kJ/(kg.°C), temperature in °C, water vapor enthalpy in kJ/kg, absolute humidity in kg_{H2O}/kg_{dryair}, water saturation pressure in kPa, atmospheric pressure in kPa and the relative humidity of the air, respectively. The variables $\dot{m}_{chw}$, C_{Pw}, T_{chwni} and T_{chwno} are chilled water flow rate in kg/s, the specific heat at constant pressure of water in kJ/(kg.°C), chilled water inlet and outlet temperatures in °C, respectively. The variables $\dot{W}_{ACN}$, $\dot{W}_{cwp}$, $\dot{m}_{cwni}$, g, h_{cwp} and η_{cwp} are the input work of the absorption chiller network in kW, the input work of cooling water pump in kW, cooling water network inlet flow rate in kg/s, gravity acceleration in m/s^2, cooling water pump head in km and cooling water pump efficiency, respectively. Also, the variables $\dot{m}_{a,i}$, ΔP_{cwf}, $\rho_{a,i}$ and η_{cwf} are inlet airflow rate in kg/s, cooling tower fan pressure difference in kPa, inlet air density in kg/m^3 and cooling tower fan efficiency, respectively.

The COP_{ACN} with M chillers and The COP_{ACNP} are defined by equations 15 and 16 [26]:

$$COP_{ACN} = \frac{\dot{Q}_{Cooling,t}}{\sum_{j=1}^{M}(\dot{Q}_{GEN,j} + \dot{W}_{P,j})} \qquad COP_{ACNP} = \frac{\dot{Q}_{Cooling,t}}{\dot{Q}_B + \dot{W}_{ACNP}} \qquad (15,16)$$

Where $\dot{Q}_{Cooling,t}$, $\dot{Q}_{GEN}$, $\dot{W}_P$ and $\dot{W}_{ACNP}$ are a total cooling load of the network in kW, ACN's generators heat input in kW, ACN's pumps power input in kW, ACNP's pumps power input in kW, respectively.

3.2. Economic analysis

Economic analysis includes the estimation of different fixed and operating costs. Here, a comprehensive economic analysis is done, which involves all of the important financial variables. The fixed costs (FC) of the project include the investment costs of the system (C_{invs}) as shown in Table 2, and the costs of installing the system components and their related piping (C_{inst}). Usually, C_{inst} in the investigations is considered between 5 to 15% of C_{invs}. In this study, it was assumed 10% of C_{invs} [23].

Table 2. Cost functions of various components of the ACNP

System Equipment	Cost Function	Ref.	System Equipment	Cost Function	Ref.
Absorption chiller	Z_{AC} =122.2 ($/kW)	[36]	Pump	$Z_P = 705.48 \times \dot{W}_P^{0.71}(1 + \frac{0.2}{1-\eta_p})$ ($)	[28]
Storage tank	Z_{ST} =290 ($/m^3$)	[35]	Boiler	Z_B=Ton of Steam×6500 ($)	[29]
Cooling Tower	$Z_{CT} = 746.749 \times \dot{m}_{CT}^{0.71} \times \Delta T_{CT}^{0.57}(T_{i,CT} - T_{o,CT})^{-0.9924} \times (0.022T_{wb,o} + 0.39)^{2.447}$ ($)				[28]

The operating cost (OC) of the system consist of the operating and maintenance cost ($C_{O\&M}$), fuel and electricity cost ($C_{f\&e}$) ,and the environmental cost due to the penalty of the pollutant emissions (C_{env}). $\dot{W}_{Net}$and N are the plant's desired net produced power in kW and plant's expected lifetime in the year, respectively. Levelized total costs of the plant during the considered lifetime, defined as below equation in $/kW [20]:

$$LTC = \frac{\text{Total costs during system lifetime}}{\text{Net produced power}} = \frac{FC + (OC \times N)}{\dot{W}_{Net}} \quad (17)$$

$$C_{invs} = \sum_{j=1}^{m} Z_j \qquad C_{f\&e} = \left(z_f \times \dot{m}_f \times LHV_f\right) \times 3600 \times t_{year} + \left(z_e \times \dot{W}_{elc}\right) \times t_{year} \quad (18, 19)$$

$$FC = C_{invs} + C_{inst} \qquad OC = C_{O\&M} + C_{f\&e} + C_{env} \quad (20, 21)$$

In the above equations z_f, z_e, $\dot{W}_{elc}$ and t_{year} are fuel price in 10^{-6}×($/GJ), electricity price $/kWh, electricity consumption in kW and total working hours of the system each year, respectively. The CO_2 emission penalty cost of the ACNP related to electric and fuel consumption and calculated by the following equation [34]:

$$C_{env} = Z_{env} \times (\dot{m}_{CO_2,f} \times 3600 + \mu_{CO_2,e} \times \dot{W}_{elc}) \times t_{year} \quad (22)$$

In the above equation Z_{env} and $\mu_{CO_2,e}$ are environmental tax factor and emission conversion factor for electricity consumption from grid which are 0.024 $/$kg_{CO_2}$ [21] and 0.571 kg_{co2}/kWh [33]. Also, the variable $\dot{m}_{CO_2,f}$ is a CO_2 flow rate and calculated by using natural gas combustion relation in kg_{CO2}/s. After completion of the plant's economic assessment, the economic reliability of the plant is evaluated through two important standard methods of Payback Period (PP) and Net Present Value (NPV). Based on the definition, the PP is expressed as the length of time which takes to return all of the investment costs [2].The amount of NPV at the end of the system's lifetime is calculated based on below equation [11].

$$PP = \frac{FC}{AS} \text{ and } NPV = -(FC \times IF_0 \times RDF_0) + \sum_{i=1}^{N}(AS \times IF_i \times RDF_i) \quad (23, 24)$$

In which, the annual net saving money (AS), the inflation factor (IF_i) and the real discount factor (RDF_i) are defined as the following equations [20].

$$AS = AI - OC \qquad IF_i = \left(1 + \frac{R}{100}\right)^{-i} \qquad RDF_i = \left(1 + \frac{RIR}{100}\right)^{-i} \quad (25, 26, 27)$$

Where AI is the total annual income of the plant, R is the rate of inflation, DR is discount rate and $RIR = DR - R$ is the real interest rate. Also, i stands for the i-th year during the plant's lifetime and IRR is an internal rate of return [20].

$$NPV = 0 = \sum_{i=1}^{N} \frac{\text{Net cash flow}}{(1 + IRR)^i} - FC \quad (28)$$

In the economic analysis of the plant if:

NPV >0 and IRR>DR, the plant investment is feasible. (29, 30)

3.3. Single objective optimization

Particle Swarm Optimization (PSO) algorithm has been used to search for optimal values of decision variables of the concerned study. According to the set of benchmark test problems, it has been shown that the PSO searching algorithm adopts in terms of both speed and memory requirements has superior computational efficiency rather than a genetic algorithm (GA) in finding the global optimal solution. PSO algorithm does not need evolution operators such as crossover and mutation which are necessary for the GA algorithm. The parameters used for optimization in MATLAB by the

PSO algorithm in this study are shown in Table 3. The maximum number of iterations, the function tolerance, and the maximum number of stall iterations were used as a stopping criterion of MATLAB code. Inertia weight was used to define the percent of exploration (the ability to generate new solutions) and exploitation (the ability to utilize current solutions) in the searching algorithm. Self and social coefficients show the personal and global learning factors related to the self-cognitive experience of particle and particle ability to learn from global. A swarm size is the number of particles in the studied swarm.

Table 3. Parameters used for optimization in MATLAB for PSO algorithm

Parameter	Value	Parameter	Value
Function tolerance	10^{-4}	Maximum number of stall iterations	250
Inertia weight	0.6	Self and social learning coefficients	1.1
Swarm size	100	Maximum number of iterations	1800

4. Results and discussions

This section first deals with the comparison between the experimental and numerical results to show the accuracy of the modeling developed. Then, presents the economic analysis results and the optimization values find for the ACNP.

4.1. Verification of the modeling results

The operating data of the concerned ACNP on June 10th, 2017, were measured with an infra-red thermometer (uncertainty ±0.1 °C); ultrasonic mass flow meter (uncertainty ±22 kg/s) and a digital multimeter (uncertainty ±1 kW) are listed in Table 4. For numerical results validation, the outlet chilled water temperature of the case study ACN was recorded in Table 5 at different temperatures of the inlet cooling tower water. These values compared with the values calculated by numerical code while the steam temperature and the inlet chilled water temperature of the ACN were the same.

Table 4. Data measured on the site

Parameter	Value	Unit	Parameter	Value	Unit
The chilled water inlet temperature	16.8	°C	Steam outlet temperature (generator)	95	°C
The chilled water outlet temperature	10.2	°C	Steam flow rate	12	kg/s
Chilled water flow rate	672	kg/s	Steam inlet temperature (generator)	145	°C
Cooling water inlet temperature (absorber)	35	°C	Cooling tower air flow rate	520	Nm^3/s
Cooling water outlet temperature (condenser)	43	°C	Each cooling tower fan power consumption	90	kW
Cooling water flow rate	1398	kg/s	Each cooling tower pump power consumption	485	kW
Each absorption chiller pumps power consumption	8.9	kW	Chilled water pump power consumption	216	kW

The comparison was made considering the experiment values as can be seen in Table 5, the highest relative error between the numerical and experimental results was around 5% and the lowest one was less than 2%., which proves that the developed model was accurate. The relative errors can be attributed to the following facts as simplified assumptions underlying the thermodynamic model, chiller’s solution heat exchanger efficiency was considered 58% in the numerical code, which may not be in the experimental case of this value, non-consideration of the fouling factor of heat exchangers of chillers in the numerical study, used constant UA product along with the operating conditions in the simulation and the thermodynamic analysis was considered as global, that it does not take into account all the phenomena in the process.

Table 5. Comparison of numerical and experimental values of the ACNP

T_{cwni}(°C)	Num. (°C)	Exp.(°C)	Diff. (%)
35	10.06	10.2	1.37
36	10.12	10.6	4.53
37	10.24	10.8	5.19

4.2. Energy analysis results

Table 6 presented all the important thermodynamic properties of streams in the cycle, by using the computer code written in the Engineering Equations Solver (EES) for a typical working day of concerned ACNP. This energy balance helps to have comprehensive analysis and investigate the effects of key criteria for the ACNP.

Table 6. Thermodynamics properties at each point for the ACNP

Point (i)	T_i (°C)	P_i (kPa)	m_i (kg/s)	h_i (kJ/kg)	Point (i)	T_i (°C)	P_i (kPa)	m_i (kg/s)	h_i (kJ/kg)
1	35	608	1384	147.1	11	37	1447.9	400.1	152.5
2	41.1	506.6	1384	172.6	12	32	1346.6	400.1	131.7
3	145	148.9	8.96	2762.4	13	15.5	506.6	672	63.4
4	95	101.3	8.96	398	14	10	506.6	336	42.5
5	15	608	672	63.5	15	10	506.6	336	42.5
6	10	506.6	672	42.5	16	15	506.6	672	63.4
7	15	506.6	336	63.4	17	35	506.6	1364	147
8	25	49.6	179	105	18	43.5	101	520	71
9	15.7	44.7	179	65.7	19	40	101.3	520	144.7
10	15.9	506.6	336	67.2	20	25	506.6	20	105

By using the values of Table 6 and Eq. (16), the coefficient of performance of the ACNP was equal to 61.2%.

4.3. Economic analysis results

In this section as shown in Table 7, the investment or capital cost of the ACNP was calculated by using the equations in Table 2 and Eq. (18). In this study, the operating and maintenance cost ($C_{O\&M}$) is assumed to be 6% of the plant's investment cost [18]. N is considered to be 20 years for the ACNP. The price of natural gas and interest rate is supposed to be 0.222 ($/GJ) [30, 34] and 14%, respectively [31]. The inflation rate, real interest rate, price of buying electricity, and t_{year} are considered 5%, 18%, 0.018 ($/kWh) [34] and 7000 (hour/year), respectively.

Table 7. The investment cost for each equipment of the ACNP

Component	Cost ($)	Component	Cost ($)
Absorption chillers	2334020	Storage tank	130500
Cooling Towers	205586	Cooling tower pumps	62156
Boiler	286000	Chilled water pump	28734
		Total	3046996

Since ACNP produces cooling, $\dot{W}_{Net}$ is plant cooling capacity and calculated by using Eq. (8). For the annual income (AI) calculation of the ACNP, the case study plant has been considered. If the chilled water temperature increases 1°C, the EO production of the MEG factory according to afield data in the Marun petrochemical company reduces 112 kg/hr and the MEG production reduces 145.6 kg/hr, as well. Therefore, by considering 560 $/(ton of MEG) [32], 7000 hr/year working time for the plant and 5 °C chilled water temperature decrement, the annual income will be AI= (145.6×7000×5×560)/1000=2853760 $/year. The operation cost and LTC of the ACNP according to used data from Table 6 are reported in Table 8.

C_{invs}=3046996 $ C_{inst}=0.1×3046996=304700 $ FC_{ACNP}= C_{invs}+ C_{inst}=3351696 $

Table 8. Main modeling outputs for the ACNP

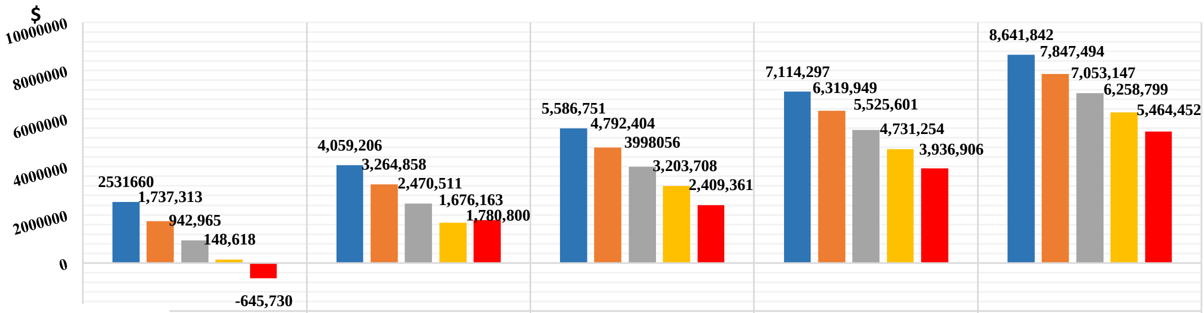
Parameter	Value	Unit
OC_{ACNP}	1484000	$/year
LTC_{ACNP}	1730	$/ kW

The cash flow (cost over the useful life of the plant) of the ACNP which compromised the NPV and IRR economic indices is shown in Table 9. The row related to the cumulative cash flow in this Table shows that for the first two years of working plant the income does not meet the investment cost. From the third year the cash flow becomes positive, so, ACNP's payback period is three years. Also, the results of the NPV and IRR economic indices verify that the plant investment is feasible. The sensitivity analysis of economic indices concerning cost and income are shown in Figures 2 and 3. As can be seen in these Figures the IRR economic index is more sensitive to change in the income and cost of the ACNP. In the most pessimistic scenario, where the revenue is 20% lower than the estimated value and the costs 20% higher than the initial calculation of the ACNP, the NPV and IRR are not economically justified because the NPV is negative, but in other cases it is feasible. During the absorption chiller network operation, changing the thermodynamic conditions of the inlet variables such as the cooling tower water temperature, steam temperature, and chilled water temperature affect the chillers operating parameters and LTC_{ACNP}.

Table 9. The cash flow of the ACNP

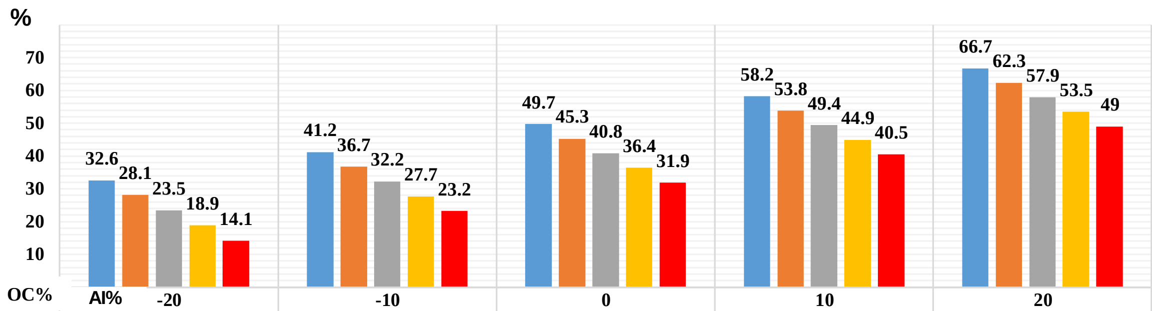
Year	0	1	2	3	5	10	20
Investment cost (FC)	3351696						
Operation cost (OC)		1484000	1484000	1484000	1484000	1484000	1484000
Cash out	3351696	1484000	1484000	1484000	1484000	1484000	1484000
Annual income (AI)	0	2853760	2853760	2853760	2853760	2853760	2853760
Salvage							486882
Cash in	0	2853760	2853760	2853760	2853760	2853760	2853760
Net cash flow	-3351696	1369760	1369760	1369760	1369760	1369760	1369760
Cumulative cash flow	-3351696	-1981936	-612176	757584	3497104	10345904	24530386
DR				18%			
NPV				3998056 $			
IRR				40.8%			

Figure 4a demonstrates the variation of the outlet chilled water temperature and LTC_{ACNP} with network inlet steam temperature. As observed, an increase in the network inlet steam temperature increases the heat transfer rate in the chiller's generator and leads to the higher separation of the refrigerant from LiBr/H_2O solution and higher generator pressure. These two factors cause more refrigerant to be condensed in the condenser and sent to the chiller evaporator for spraying, which reduces the outlet chilled water temperature of the network to setpoint temperature (10 °C). Also increasing the steam temperature due to the increased cooling capacity, reduces the LTC of the plant. Figure 4b provides the variation of the LTC of the plant and outlet chilled water temperature to the inlet cooling water temperature of the network. As shown, decreasing the cooling water temperature decreases the network outlet chilled water temperature and LTC of the plant due to increasing the cooling capacity of it.



OC% \ AI%	-20	-10	0	10	20
-20	2531660	4,059,206	5,586,751	7,114,297	8,641,842
-10	1,737,313	3,264,858	4,792,404	6,319,949	7,847,494
0	942,965	2,470,511	3998056	5,525,601	7,053,147
10	148,618	1,676,163	3,203,708	4,731,254	6,258,799
20	-645,730	1,780,800	2,409,361	3,936,906	5,464,452

Figure 2. The NPV economic index sensibility analysis for the ACNP ($)



OC% \ AI%	-20	-10	0	10	20
-20	32.6	41.2	49.7	58.2	66.7
-10	28.1	36.7	45.3	53.8	62.3
0	23.5	32.2	40.8	49.4	57.9
10	18.9	27.7	36.4	44.9	53.5
20	14.1	23.2	31.9	40.5	49

Figure 3. The IRR economic index sensibility analysis for the ACNP (%)

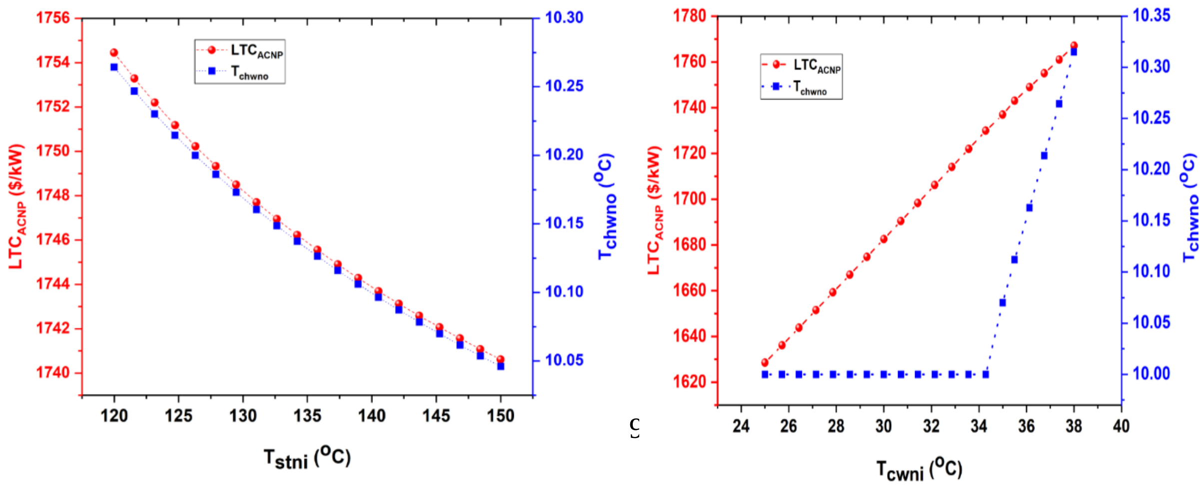


Figure 4.a) The behavior of LTC_{ACNP} and T_{chwno} by changing the inlet network steam temperature (T_{chwni}=16.8 °C, T_{cwni}=35 °C, η_{SHX}=0.58), b) The behavior of LTC_{ACNP} and T_{chwno} by changing inlet network cooling temperature (T_{chwni}=16.8°C, Tstni=145 °C, η_{SHX}=0.58)

4.4. Optimization of the ACNP

In the present study to optimize the ACNP by PSO algorithm needs to be linked EES with MATLAB™ and used the parameters of the PSO algorithm are shown in Table 3. This optimization is done to minimize the LTC of the plant. The range of allowable values for decision variables and the optimum value of those which are obtained by using the PSO algorithm are listed in Table 10.

Table 10. Range of decision variables and their optimal values in the ACNP

Decision variable	Range of variation	Optimal value
Steam inlet temperature (°C)	120-150	149.5
Cooling water inlet temperature (°C)	25-38	25
Chilled water outlet temperature (°C)	10-11	10
Solution heat exchanger efficiency (-)	0.5-0.7	0.7
Steam control valve opening (%)	50-100%	84
LTC_{ACNP} ($/kW)	1500-1800	1583

5. Conclusion

This study was carried out to find the optimal operating conditions of an ACNP based on energy and economic analysis. A high accuracy computer code was developed to predict the performance of the ACNP and investigate the effects of various parameters. To verify the developed code, the ACNP of the Marun Petrochemical Complex was selected as a case study. The comparison between the modeling results and experimental values showed good accuracy of the developed model. Based on the present investigation, some conclusions can be drawn as cited below:

- An increase in the ACN inlet steam temperature decreases the ACN outlet chilled water temperature and the LTC of the plant. Reduction in the ACN inlet cooling water temperature decreases the LTC of the plant too.
- The optimization of the ACNP by using the PSO optimization algorithm shows that the cooling water inlet temperature has a more significant effect on the LTC of the plant rather than the steam inlet temperature. The PSO optimization algorithm results demonstrate that working at optimal condition reduces the LTC of the plant 8.5%, rather than design condition.

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