European Online Journal of Natural and Social Sciences 2017; www.european-science.com
Vol.6, No 3 pp. 417-429
ISSN 1805-3602

Thermodynamic Analysis and optimization of a Cooling and Power Cogeneration System using GMDH and Genetic Algorithm

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Received for publication: 08 April 2017.
Accepted for publication: 23 July 2017.

Abstract

In today's world, the demand for energy is increasing and energy conversion must be done with the lowest environmental consequences to use energy resources. The use of electrical energy in this way was very effective, and major supply sources of the world will be provided through the application of thermodynamic cycles that have been established to work in heat engines. In this regard, a Cooling and Power Cogeneration System has been examined specifically on a limited scale. This study tries to use this type of system and dual operating fluids in order to extract optimal results for these cycles. The aim of this study is finding the system performance by changing the number of selected entries (backpressure turbine, condenser temperature and super heater temperature). The proposed combined thermodynamic cycle is based on Rankine Cycle and absorption refrigeration cycle with ammonia recovery. This cycle uses a mixture of water and ammonia as the working fluid. With the proposal of the cycle and by changing the turbine inlet pressure from 18 to 32 Bar and temperature changes for condenser input from 330 to 360 degrees, as well as temperatures ranging from 400 to 500 degrees for a turbine inlet are used to study the impact of effective parameters using a thermodynamic analysis toward the reviews of turbine work and the amount of cooling and the overall efficiency using EES software in each component of the systems. The results show that change in some of these parameters causes an improvement in one of the outputs performances and destroys the other. Thus the need for a multi-objective optimization will be felt. In this regard, in order to determine the output functions, first, by changing the input parameters in the selected range, 500 data output will be created and then by using the method of grouping, numerical data will be specified in the number of output function Information based on the input. Then, by using genetic algorithms and MATLAB software, simultaneous optimization (turbine power and cooling capacity and efficiency of the system) will be done for the input Selective variables. According to the results of the optimization, it turns out that in order to achieve the system performance in the production of all three objective functions, the temperatures in system design must have the lowest level range. In addition, if there is no need to produce cold, the mentioned temperatures can be adjusted in high levels of range.

Keywords: Power, Cooling Cycles, Absorption, Group Data Method of Category, Genetic Algorithm, Optimization

Introduction

The world's major electrical energy is provided through the application of thermodynamic cycles that have been established to work in heat engines. For this purpose, there are several thermal power cycles that have been classified according to the working fluid. This category may be noted as steam power cycles and gas cycles. In steam power cycle, the gas that circulates the turbine blades is obtained from the evaporation of a liquid and in gas power cycles, such as the Brayton cycle, Working fluid is as a gas throughout the cycle. Compression refrigeration and absorption systems are the most common refrigeration systems. Compressor, condenser, evaporator and expansion valve are the main parts of a compression refrigeration cycle(A. I. Kalina, 1984).

The ideal cycle for Vapor Compression Refrigeration is shown as a cycle $(1-2-3-4-1)$ in Fig (1). Saturated steam at low pressure enters the compressor, and passes the adiabatic reversible compression process$1-2$. Then, the heat excerts at constant pressure during the process$2-3$, and working fluid will be removed from the condenser as saturated liquid. Subsequently, the process of adiabatic repression $3-4$ occurs. And then to complete the cycle, working fluid will be evaporated at constant pressure during the process$4-1$. This cycle is similar to the Rankine cycle, but it is upside down, and the only difference is that the Rankine cycle is used from expansion valve instead of the pump (A. Oliveira et al. 2002).

The deviation of this ideal cycle from the cycle of Carnot $1'-2'-3-4'-1'$ is evident in the T-S graph. The reason for the deviation is that instead of transferring the mixture of steam and liquid by a compressor in the process of $1'-2'$ based on based on the Carnot cycle, it is better that the compressor only transfer vapor. Compressing a mixture (With the reasonable flow) that has been shown with mode$1'$, and maintaining a balance between the vapor and liquid, in fact, is impossible. Because heat and mass must pass the border between phases. It is easier that the expansion process happens irreversible in an expansion valve, so that a means of expansion receives the saturated liquid, and evacuates the mixing of liquid and vapor in accordance with the process$3-4'$. With these reasons, the ideal cycle of Vapor Compression Refrigeration has been shown in Figure (1) with the cycle $1-2-3-4-1$(C. Martin and D.Y. Gosswami, 2006).

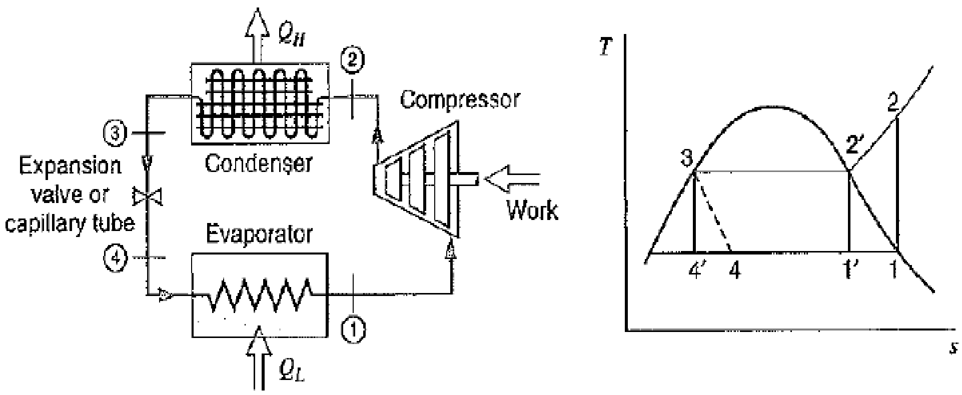

Figure 1: Cycle and graphs of T-S Ideal compression refrigeration [1]

In the vapor compression refrigeration systems, compared to steam power cycles, a diverse working fluid is used (refrigerant). In the initial refrigeration systems, vapor compression, ammonia and sulfur dioxide had of great importance. At the same time, today the main refrigerants are halogenated hydrocarbons that are known as Freon and Zhenatron. For example dichlorodiphenyl Floyrometan is known as Freon 12 and Zhenatron 12. Because in the process of heat transfer, the refrigerant changes its phase, the refrigerant pressure will be saturated pressure during the heat feeding process and heat dissipation(D. Erickson, G. Anand, I. Kyung, 2004).

In the gases, the low pressure is synonymous with large specific volume and this means that relevant equipments should be larger. Higher pressures mean smaller equipment, but this equipment should be designed in such a way that, they have resistance in the face of high pressure. Pressure should be chosen less than the critical pressure. In applications where the temperature is ultra-low, by combining two separate systems, the dual system can be used. It is desirable to use refrigerants that if other restrictions allow, the cycle has the largest coefficient of performance(D.L. Larson, 1987).

(1) In the cooling mode, the heat of stimulus should be provided by the highest temperature in the cycle (in the generator), and the effects of cooling can be observed in the lowest temperature in the evaporator. The sum of these heats exit in the intermediate temperature (condenser). According to the thermodynamic laws, this process can be done without input work. In fact, these cycles are called absorption refrigeration cycles (D.Zheng et al. 2006). In absorption cooling system, pump, generator and absorber will be replaced the compressor in the compression system. The input compression system as top-level energy (work) and in absorption system is the heat. Sources used in this system such as solar energy, are the gas turbine of gas exhaust and geothermal resources. In this type of cycles, the pump work is small. This subject has been shown in figures (2).

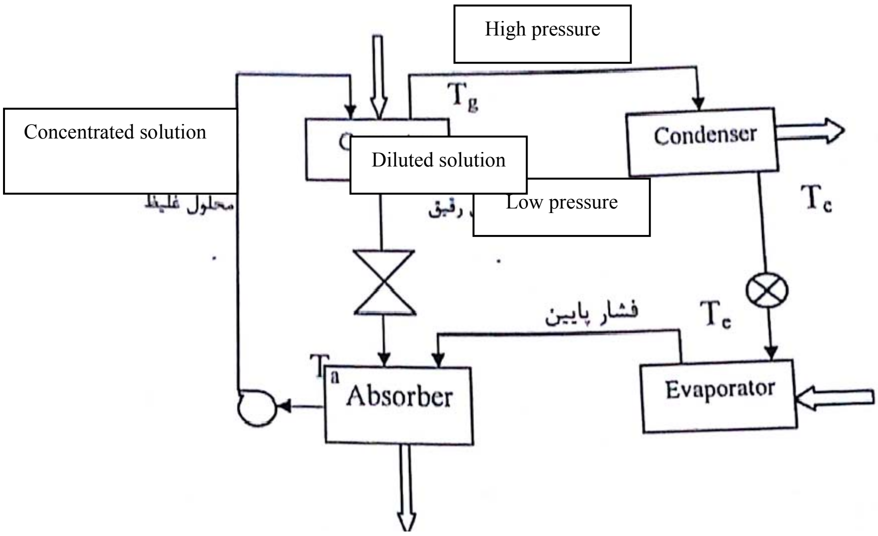

Figure 2: Original equipments of absorption refrigeration systems

By adding a heat exchanger, which exchanges the heat of input ammonia dilute solution to the separator with a concentrated solution of input ammonia to the generator and preheats it, the absorption refrigeration cycle can be significantly improved.

GMDH neural networks

GMDH Neural networks are a manifestation of GMDH algorithm, which are expressed in form and style of network structure.

The use of neural networks in the implementation of algorithm GMDH makes flexibility and optimization through the creation of different network structures and a background in facilitating to create computer software. Generally, the use of the networks in the algorithm makes the integration easier and makes the analysis of models reasonable or minor functions to the various ways, which leads to variation in selecting the optimum model, in order to reduce the error rate of the model and the volume and content of model mathematical function(E.D. Rogdakis & K.A. Antonopoulos, 1991).

Cycle modeling and its data based on GMDH

With the modeling that was done in the previous chapter, and the results of the model, we have examined the turbine pressure in the range of 18 to 32 bar, and condenser temperature of 330 to 360 ° C and turbine inlet temperature of 400 to 500 ° C in the cycle and have prepared 500 responds about it, at the same time by ESS, with the same distance, to be able to achieve continuous cycle functions with this data by GMDH for three variables of turbine-efficiency cycle working and the cycle cooling and to optimize these three variables for the target cycle. Finally, data obtained from Thermodynamic modeling cycle, that was obtained with EES application, converted to continuous functions in order to the integration and accurate data, with GMDH method and finally, optimize that functions, which are obtained from data and modeled variables of the cycle(F. Xu and D.Y. Gosswami, 1999).

5- Algorithm for work

Turbine-Function

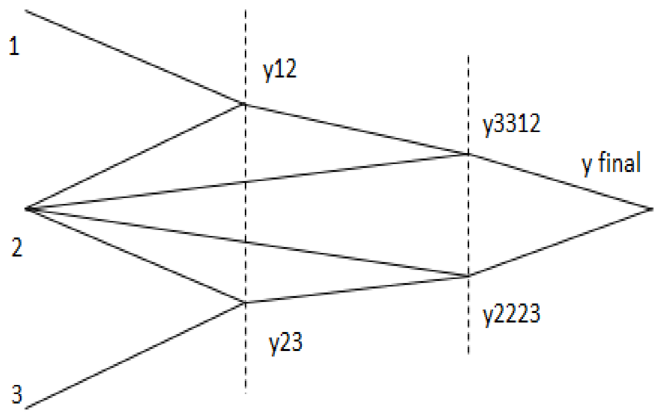

Figure 3: Algorithm for Turbine function

yfinal= -0.029578596115002+3.815942280410127*y2223-2.815248376442810*y3312-0.026911326380357*y2223^2+0.016372803101186*y3312^2+0.010534493598376*y2223*y3312

The algorithm for the ***–thermal*** η cycle efficiency

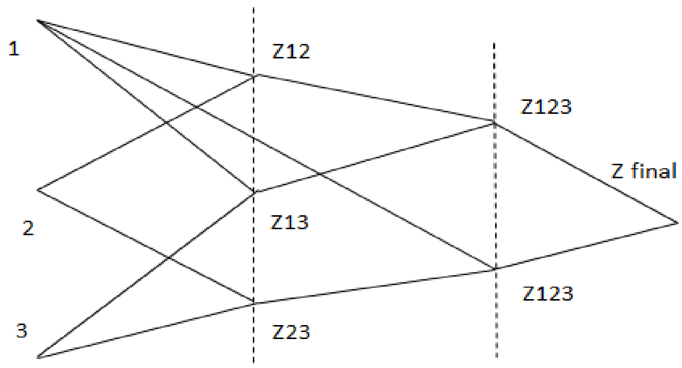

Figure 4 The algorithm for the cycle efficiency

zfinal=-0.000424834639937-1.278912251607494*z1312+2.284056791797298*z1123+3.834193742702951*z1312^2-3.842248926043794*z1123^2-0.007303325880757*z1312*z1123

The algorithm for cooling q

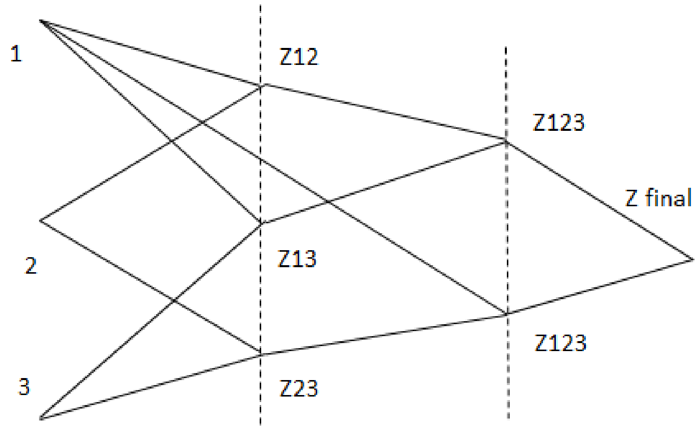

Figure 5: The algorithm for cooling

wfinal= -0.000011597178087+0.832827779089117*w1113+0.167174796517195*w1123-0.004750226775351*w1113^2+0.004779596753678*w1123^2-0.000029467946447*w1113*w1123

GMDH neural network performance validation

In the following charts, the data obtained from the software EES are modeled as neural network in MATLAB software. To do this, half of the data are used for testing and the other half was used as a training model. For each objective function, a separate model was provided in terms of selected decision-making variables, which turbine pressure ratio range changes from 32-18 and cycle condenser temperature changes from 330 to 360 ° C and turbine inlet temperature changes from 400 to 500 ° C. As can be seen, the chart (6) indicates good matching of obtained model with the input data(F. Xu et al. 2000).

Optimization

Thermodynamic cycles of power and cold generator, which use of dual Working fluid, are always concerned by engineers and researchers. In this thesis, the irreversibility resulting from heat transfer is ignored, and it is trying to explain the best performance. For this purpose, as stated, Among the input parameters or design variables, the parameters are selected that the designer has more freedom to change values. In the first stage, the objective functions will be selected. These objective functions are based on the designer's requirements, which are considered for the thermodynamic cycle of power and cold generation, output work of the turbine, cooling capacity of the cycle and total thermal efficiency of objective functions cycle. It is obvious that all of these target functions must be optimized(G. Alexis, 2007).

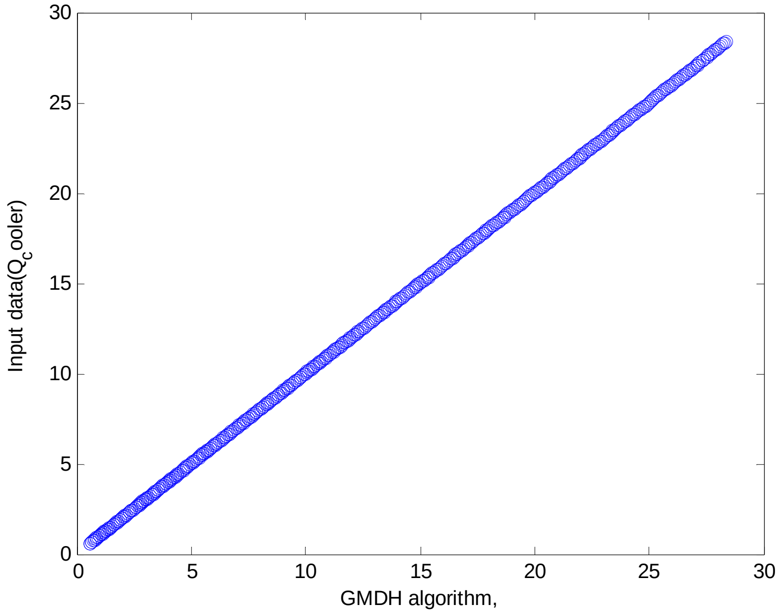

Figure 6: Input data changes with the genetic algorithms

For example, in the following formulas, x is design variables and F is objective functions

$$F_1 = F_i(x_1, x_2, \dots, x_n) \qquad\qquad i = 1,2, \dots$$

For example, if we have five objective functions, we have 5 categories of the optimized design variables, where do the objective function extremum. Here, depending on the designer's opinion that which one of objective functions is more important in the design, he uses the optimal value of the same design variables of the objective function. The advantage of this method is its simplicity and the certainty of the answers and the problem of this method is that those optimized values which make F_1 maximum, may not only make F_2 extremum, but also attribute a very far value of what the designer's goal is, and if the designer wants to select the group of answers that maximum F_2, these groups of answers make the amount of F_1 low. Since most real-world engineering problems are these kinds, it means they have multi-function that should be optimized at the same time, different methods are invented called Multi-Objective for Genetic Algorithms(G. Angelino & P.C.D. paliano, 1998).

In optimization process, the aim is finding the minimum or maximum of a function. For this purpose, to find the optimal value of objective functions, the design variables must be formulated under optimization as a mathematical expression. The formulation process begins by introducing a set of variables, which determines system performance that are called design variables. So, after determining the values of these variables, the optimum design of the System will be determined. The most important step in a complete formulation is determining the system design varaibles. Another point is that the design variables of the systems will be independent as much as possible(J.D. Maloney & R. C. Robertson).

Optimization of design variables with an objective function

In optimizing, we need initial values for the combined cycle parameters of power and cold generation with water and ammonia Working fluid.

$T_{absorber} = 280\ K$ $T_{superheater} = 410\ K$ $T_{boiler} = 400\ K$
$T_{condenser} = 360\ K$ $P_{low} = 2\ bar$ $P_{high} = 25\ bar$ $x_a = 0.5$

Among the above parameters, that all are independent from each other, As noted above, 3 parameters of $P_{turbine}$,$T_{superheater}$ and $T_{condenser}$ which are respectively turbine inlet pressure, Superheaters temperature and the temperature of the condenser, were considered as design variables. These parameters were chosen because they are able to be changed. For example, by changing the turbine inlet pressure, the amount of output work will change. Also by increasing the temperature of Superheaters, the amount of generating cold reduces in cooler. But in parameters$T_{absorber}$ ‘ T_{boiler} and x_a due to structural limitations of materials and operating conditions of the cycle, these changes cannot be made(J.S. Arora, 1989).

By selecting the above items, as design variables, important output parameters of the cycle are considered as objective functions. These objective functions are the work output of the turbine, cooling capacity of the cycle, total thermal efficiency of the cycle. Relationships related to the objective functions are described in the relevant chapters in detail (K.E. Herold et al. 1989).

Optimization with an objective function for combined cycle with Working fluidity of water and ammonia for the form which ammonia mass fraction is $x_a = 0.5$, is done with one, two and three design variables. The results of optimization with one variable input and two fixed inputs obtained for different objective functions were compared with results of functional diagrams obtained from the cycle thermodynamic analysis, which was done in previous seasons. The comparisons are shown in the table (1). According to the values in this table, the verification of obtaining values is confirmed by genetic algorithm(K. Takeshita et al. 2005).

The results of optimization with two variable inputs and one fixed input, for different objective functions and for the mass fraction of ammonia $x_a = 0.5$ were presented in the table (2). In addition, the comparison of this part results with the table (1), just confirms the values. For example, the amount of output power of the proposed cycle with two input variables and one fixed input is $T_{condenser} = 360K$,$W_t = 115.4\ kw/kg$ which the pressure of the turbine was $P_{turbine} = 18\ bar$and the superheater temperature was$T_{superheater} = 500\ K$ (N. Srinivas , K. Deb, 1994).

Also in the state of one variable input and two fixed inputs ($T_{condenser} = 360K$ and$T_{superheater} = 410\ K$), the amount of output power of the mentioned combined cycle is $W_t = 92.56\ Kw/kg$, that in the pressure of the turbine, it is $P_{turbine} = 18\ bar$. Single objective optimization results with three variable inputs are shown in table (3) for an ammonia mass fraction$x_a = 0.5$. As can be seen, the optimal amount of output power is $W_t = 131.6\ Kw/kg$which is obtained in input values of ($P_{turbine} = 18.04\ bar$,$T_{condenser} = 400K$ and$T_{superheater} = 500\ K$)(C.A. Coello, A.D. Christiansen, 2000).

By comparing these amounts with the results of table (1) for the above objective function (output power) that is $W_t = 92.56\ Kw/kg$, it is clear that this answer is very close to the answer obtained in three variable inputs. Thus, the correct answers will be cleared. In the tables below, the objective functions are, the output powerW_t, thermal efficiency of the cycle $Efficiency$and cycle cooling capacity$Cooling\ Capacity$ and design variables, pressure of the turbine$P_{turbine}$, condenser temperatures$T_{condenser}$ and the superheater temperature$T_{superheater}$(N. Zhang, N. Lior, 2007).

Optimization of design variables with two objective functions

In this section, by using mathematical functions obtained from modeling and genetic algorithms, the best values will be determined for the three objective functions, which include the work output of the turbine, cooling capacity and thermal efficiency. It means, the input variables will be elected in such a way that for three objective functions in conflict with each other, the proper values are found. It is clear that in this case, the respondent is a design vector that is located between the point of maximum output power, the highest cooling capacity and thermal efficiency. In addition, with one getting better, the other one becomes worse. The following figures show the chart of the Pareto front for optimal points where interval values are most output work of the turbine, cooling capacity and thermal efficiency of the models obtained in the previous step(N.Y. Babcock & Wilcox company, 1978).

Table 1: Results of genetic algorithm method and Functional diagrams of combined cycle with one variable input

combined cycle	$18 \le P_{turbine} \le 32$, $T_{superheater} = 410k$, $T_{condenser} = 360k$		$410 \le T_{superheater} \le 500$, $P_{turbine} = 18\ bar$, $T_{condenser} = 360k$		$360 \le T_{condenser} \le 400$, $P_{turbine} = 18\ bar$, $T_{superheater} = 410k$	
The results of genetic algorithm	$P_{turbine}$	18	$T_{superheater}$	500	$T_{condenser}$	400
	$W_{Turbine}$	92.56	$W_{Turbine}$	115.4	$W_{Turbine}$	111.5
The results of functional diagrams cycle	$P_{turbine}$	18	$T_{superheater}$	500	$T_{condenser}$	400
	$W_{Turbine}$	92.56	$W_{Turbine}$	115.4	$W_{Turbine}$	111.5
The results of genetic algorithm	$P_{turbine}$	26.18	$T_{superheater}$	410	$T_{condenser}$	360
	$Cooling$	17.98	$Cooling$	5.743	$Cooling$	5.743
The results of functional diagrams cycle	$P_{turbine}$	32	$T_{superheater}$	410	$T_{condenser}$	360
	$Cooling$	12.91	$Cooling$	5.743	$Cooling$	5.743
The results of genetic algorithm	$P_{turbine}$	32	$T_{superheater}$	500	$T_{condenser}$	400
	$\eta_{Thermal}$	0.2301	$\eta_{Thermal}$	0.1553	$\eta_{Thermal}$	0.1767
The results of functional diagrams cycle	$P_{turbine}$	32	$T_{superheater}$	500	$T_{condenser}$	400
	$\eta_{Thermal}$	0.230	$\eta_{Thermal}$	0.1553	$\eta_{Thermal}$	0.1767

Table 2: The results of single-objective optimization with genetic algorithm method with two variable inputs

combined cycle	$18 \le P_{turbine} \le 32$ $410 \le T_{superheater} \le 500$ $T_{condenser} = 360k$		$410 \le T_{superheater} \le 500$ $360 \le T_{condenser} \le 400$ $P_{turbine} = 18bar$		$360 \le T_{condenser} \le 400$ $18 \le P_{turbine} \le 32$ $T_{superheater} = 410k$	
The results of genetic algorithm for power turbine	$P_{turbine}$	18	$T_{superheater}$	500	$T_{condenser}$	400
	$T_{superheater}$	500	$T_{condenser}$	400	$P_{turbine}$	18.01
	$W_{Turbine}$	115.4	$W_{Turbine}$	131.9	$W_{Turbine}$	111.4
The results of genetic algorithms for heat capacity	$P_{turbine}$	25.95	$T_{superheater}$	410	$T_{condenser}$	360
	$T_{superheater}$	410	$T_{condenser}$	360	$P_{turbine}$	26.14
	$Cooling$	17.96	$Cooling$	5.743	$Cooling$	17.98
The results of genetic algorithm for thermal efficiency	$P_{turbine}$	32	$T_{superheater}$	500	$T_{condenser}$	372
	$T_{superheater}$	410	$T_{condenser}$	400	$P_{turbine}$	32
	$\eta_{Thermal}$	0.2301	$\eta_{Thermal}$	0.1871	$\eta_{Thermal}$	0.236

Table 3: The results of single-objective optimization with genetic algorithm method with three variable inputs

$18 \le P_{turbine} \le 32$		$18 \le P_{turbine} \le 32$		$18 \le P_{turbine} \le 32$	
$410 \le T_{superheater} \le 500$		$410 \le T_{superheater} \le 500$		$410 \le T_{superheater} \le 500$	
$360 \le T_{condenser} \le 400$		$360 \le T_{condenser} \le 400$		$360 \le T_{condenser} \le 400$	
$P_{turbine}$	18.04	$P_{turbine}$	26.4	$P_{turbine}$	32
$T_{superheater}$	500	$T_{superheater}$	410	$T_{superheater}$	410
$T_{condenser}$	400	$T_{condenser}$	360	$T_{condenser}$	371.8
$W_{Turbine}$	1316	$Cooling$	17.94	$\eta_{Thermal}$	0.236

In the diagram (7), a Pareto chart of turbines work, cooling capacity is presented. The horizontal axis is turbines work and Vertical axis is cycle cooling capacity. While the work output of the turbine increases from $W_{turbin} = 80$ until $W_{turbin} = 102$, the Cooling capacity reduces from 29.3 to 25.5. As well as to increase the thermal capacity from 0.13 to0.215, according to Figure (8), it is necessary to reduce the cooling capacity from 25.8 to 5. On the other hand, as shown (9), the increase of thermal efficiency from 0.135 to 0.215 leads to the reduction of turbines work from $W_{turbin} = 102$ to $W_{turbin} = 70$. However, these points do not have any superiority to each others. and according to the designer's opinion, each of them can be placed as cycle performance basis(O.J. Demuth, 1984).

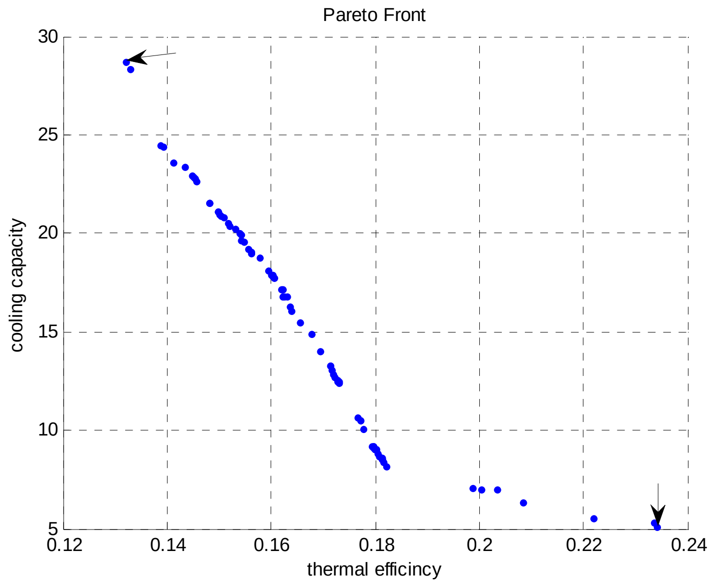

Figure 7: Heat output beam-cooling capacity graph

Optimization results

Figure 7 shows the optimum points without superiority in the form of the Pareto chart in thermal efficiency page and cooling capacity and it is observed that the process of the chart is downward, regardless of odd points and improving one function is in order to reduce another function. Single points also represent part of Pareto charts, that have the highest work and thermal efficiency, but the amounts of cooling in these areas is very low and even zero. And in zero conditions, turbine exit temperature is higher than ambient temperature and the cycle acts like power system. Since the purpose of applying this system is putting all three objective functions available, the main focus will be on the cooling sections, but according to the operating conditions and the purpose of using the system, if only power generation is considered, the values in this point, can be used to achieve the best working conditions of the system.

Figures 8 and 9 show the optimum values portrayed in the pages of output power - thermal efficiency and output power - cooling capacity. Due to continuouse and closeness of related sectors in graphs, it can be seen that these functions will have oppositional behavior. Therefore, the increase of one, will reduce the other. It should be noted that this type of behavior in the values happens in the case of cooling. According to these charts, point A represents the conditions that the cooling capacity and thermal efficiency are the highest, but the work of the turbine is allocated the minimum amounts. In addition, point B indicates the position where the work of the turbine will have its maximum value, but the cooling capacity and thermal efficiency has the lowest amount. The point at which all three functions are in the best position can be the point C(S. Vijayaraghavan, D.Y. Goswami, 2003).

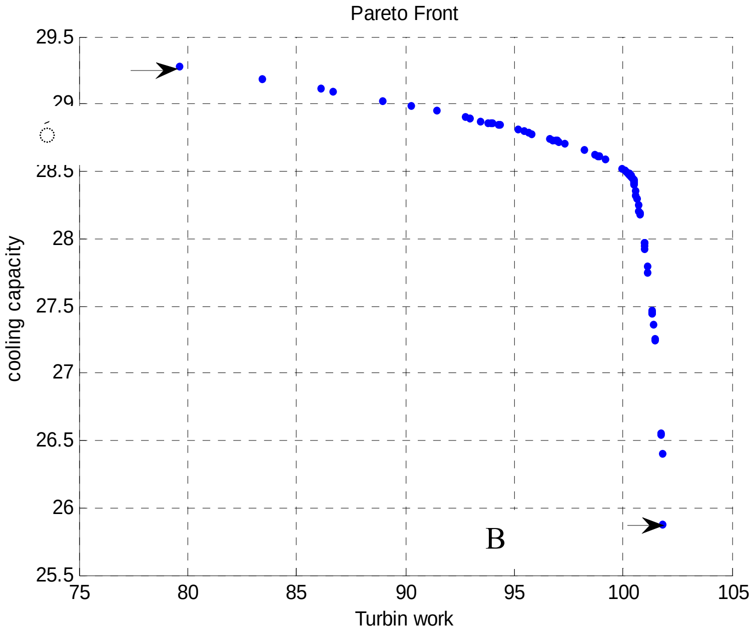

Figure 8: Chart of turbine output power beam -cooling capacity

According to these results, it can be referred, to achieve the maximum available cooling, it is required to design in such a way that the design variables about temperature will be in the lowest presented interval value. In addition, this is while that in order to optimum conditions of the system by removing the cooling function, the corresponding temperatures must allocate the maximum range of the interval. These points include part of Pareto charts that there will be no cooling capacity.

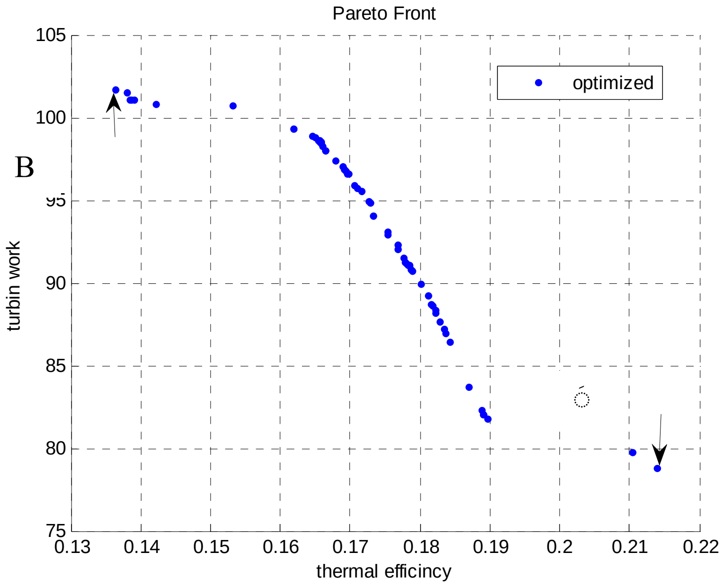

Figure 9: Chart of thermal capacity beam - output work of the turbine

Conclusion

In this study, assuming a thermodynamic cycle of power and cold generator that was used Dual water-ammonia Working fluid. In the beginning, we have explained the absorption refrigeration cycle and common components of an absorption cycle were introduced. Since the cycle Working fluid is a mixture of water and ammonia. Some of the ammonia features of the physical, chemical and structural are described and a review of ammonia synthesis process was carried out.

For modeling the mentioned thermodynamic cycle, the thermodynamic characteristics must be specified in different stages of cycle Working fluid. Therefore, Gibbs free energy functions were used for pure substance and its combination with the dew point temperature and bubble point for the material in equilibrium. The advantages of method Gibbs are described and to ensure the accuracy of the values obtained with the software EES that uses Gibbs free energy functions to calculate the thermodynamic properties of the fluid mixture, was used to compare the Enthalpy and entropy of the fluid with its experimental values and was presented in the form of graphs.

Then the performance of the cycle was done by using the software EES and its thermodynamic analysis and the results were studied by presenting graphs. In the following, a brief description of the genetic algorithm was presented and several methods of optimization were proposed and since the cycle, performance was better by using liquid water - ammonia, and the optimization of the cycle behavior was done under this Working fluid. The Turbine inlet pressure, superheater temperature and condenser temperatures were examined as design variables and output power with three objective functions and the results were presented in the form of a Pareto chart.

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