# Thermodynamic and economic analysis of windbreak wall in dry cooling tower

**Abstract**

This research aimed to model and analysis the energy and exergy for all components of the combined cycle of the Montazer Ghaem power plant in the design conditions and to investigate the effect of using a windbreak wall on the performance of the cooling tower and the power of the combined cycle. According to the results, the most exergy destruction was in the combustion chamber and regenerative boiler, respectively. The results showed an increase in the power of the combined cycle due to the use of windbreak walls. The use of windbreak walls in three modes of one tower, two towers, and three towers was economically analyzed for 25 years. In all three plans, the net present value was positive; also, the internal interest rate and the investment payback time were above 90% and between 14 and 16 months, respectively.

**Keywords:** Dry cooling system; Windbreak wall; Energy analysis; Exergy analysis; Economic analysis

## Introduction

Over the past two decades, energy-related issues have been considered more due to energy prices and environmental problems. Therefore, analyzing power plants and finding solutions have been considered for the proper use of energy and improving processes. In our country, due to the frequency of fossil fuel sources, more attention has been directed toward thermal power plants.

In a power plant cycle, the need to use a cooling system for condensation is always accompanied by spending a significant amount of energy produced by the power plant to circulate the cooling fluid [1]. This energy consumption is about 1.4-kilowatt hours per kilowatt hour of electricity produced by the fossil fuel power plant with water cooling fluid [2]. In this study, we investigated the dry cooling system used in the Montazer Qaem power plant. Dry towers with natural suction (Heller) are one of the commonly used cooling towers in power plants. One of the disadvantages of dry cooling systems is the effect of weather conditions, especially windy conditions on thermal efficiency. Environmental conditions, including windy conditions, can reduce the total cooling capacity of the tower by more than 40%. Practically, the effect of wind blowing is not taken into account in the design of cooling towers, while in most cases this effect exists in reality [3]. Some studies have been mentioned concerning the exergy analysis of combined cycle power plants. Sihan *et al.* [4], Ameri & Ahmadi [5], and Abolnoor [6] identified the combustion chamber as the factor of exergy destruction. Many studies have been conducted on the effect of wind on the performance of cooling towers and the use of windbreak walls to reduce the wind's effects. According to Su & Po [7], the heat dissipated by the tower decreases by about 33% in windy conditions with a speed of 10 meters per second. Yang *et al.* [8] investigated the effect of pressure on the hydraulic-thermal performance of the tower using numerical analysis. Demon & Rudy [9] obtained the airflow and its temperature distribution at the bottom of a dry cooling tower during windy conditions. Bandar *et al.* [10] investigated the effects of using a windbreak wall on the mass flow rate of the input air. Al-Viked & Bahia [11] investigated the effect of 8 windbreak walls in windy conditions using numerical simulation. In this research, energy and exergy were analyzed for all components of the combined cycle of the Montazer Ghaem power plant. We investigated the effect of wind on the cooling tower and the completely combined cycle. As well as, we investigated the effect of the windbreak wall on reducing the negative effects of wind on the cooling tower and the power of the combined cycle; also, the use of the windbreak wall around the cooling tower was analyzed economically.

## Exergy analysis

The exergy analysis aimed to determine the location and system irreversibility and identify undesirable thermodynamic processes based on the determination of exergy losses, as well as to determine the most possible improvements in the system based on the concepts of inevitable and avoidable exergy losses.

## Equations

The exergy balance formula y is adjusted considering the first and second laws of thermodynamics. This formula is as follows:

$$\dot{E}x_Q + \sum_i \dot{m}_i ex_i = \dot{E}x_W + \dot{E}x_D + \sum_e \dot{m}_e ex_e \quad (1$$

In the above formula, $\dot{E}x_D$ indicates exergy destruction and $\dot{E}x_W$ indicates exergy work and $\dot{E}x_Q$ represents the heat exergy and *ex* represents the specific exergy of the input and output flow which is obtained by the following formula:

$$ex = ex_k + ex_p + ex_{ph} + ex_{ch} \quad (2$$

The following formula is used for calculation of chemical exergy fuel [12].

$$\zeta = \frac{ex_f}{LHV_f} \quad (3$$

This formula for fuel through CxHy is as follows:

$$\zeta=1.033+0.0169y/x-0.0698/x \quad (4$$

Using the above formulas, exergy analysis was conducted for the components of the combined cycle. The results of exergy analysis have been shown in Figures 1 and 2.

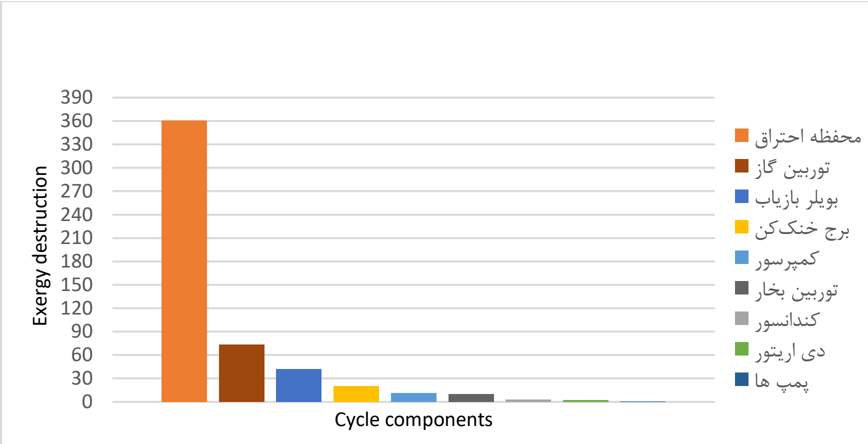


Figure 1) Exergy destruction in combined cycle components

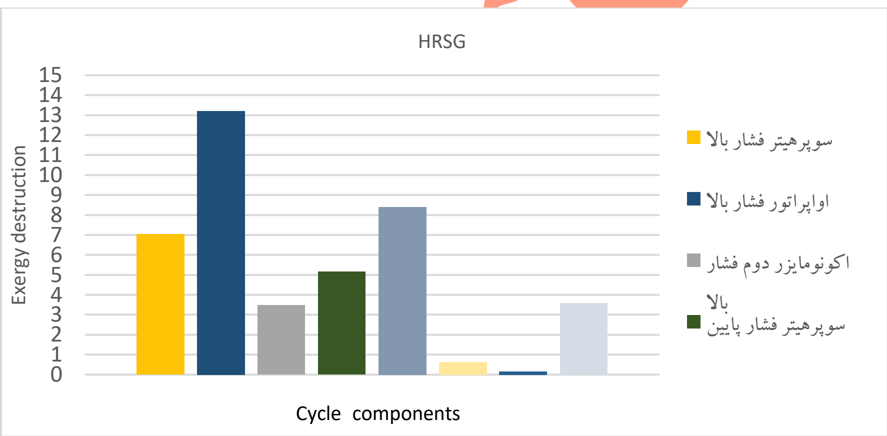


Figure 2) Exergy destruction in regenerative boiler components

According to the above graphs, the highest amount of exergy destruction in the entire combined cycle is related to the combustion chamber due to the nature of the combustion process as an irreversible chemical process. After the combustion chamber, the gas turbine and regenerative boiler have the highest exergy destruction. The sum of the exergy destruction values in the high-pressure components of the recuperator boiler is more than the exergy destruction values in the low-pressure components, which is due to the higher mass flow rate of steam in the high-pressure components.

**Analysis of wind effect on the cooling tower with and without windbreak wall**

Wind blowing causes a decreased performance of the cooling tower. Therefore, in windy conditions, the ability of the cooling tower to remove the heat of the steam cycle fluid is reduced compared to the condition without wind. The reaction of the control system in windy conditions, reducing the performance of the cooling tower, is in this way that the production power of the steam cycle must be reduced by reducing the steam mass flow rate to prevent the reduction of the condenser vacuum and the increase of its pressure, as well as the conflict of temperature and pressure at different points of the cycle.

The wind effect on thermal performance and exergy of the combined cycle power plant was modeled for different wind speeds in 20, 15, 10, and 5 m/s. Then the effect of installing the walls on the tower's performance and the output power of the power plant was evaluated by installing four walls with a "+" arrangement around the tower. The amount of heat emitted to the environment through the cooling tower was obtained by numerical simulation of the cooling tower using computational fluid dynamics methods and Fluent software in some studies [13, 14] and the mentioned information was used in this study. In this study, CFD analysis results for a tower were used. Then the same process was conducted for three towers. The additional power produced by the windbreak walls was calculated using calculating the heat dissipated from the towers in windy conditions with and without a windbreak wall for one tower and three towers mode and calculating the condenser vacuum and mass flow rate changes to maintain the condenser vacuum. Figure 3 shows the results of increasing the output power using the windbreak wall in all three combined cycle modes in the dominant wind.

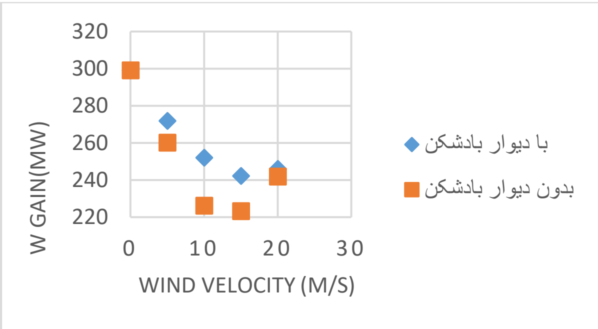


**Figure 3)** Total production power of three combined cycle units in windy conditions with and without windbreak wall in 30 degree wind

In order to present a precise analysis, we need to check meteorological data regarding the direction and time of wind blowing. The time of wind blowing in different directions was extracted from meteorological data and used for economic analysis.

**Economic analysis**

Economic analysis and determination of important economic criteria are one of the parameters for decision-making to implement a project. In order to economic analysis of the windbreak wall construction around the tower, its total costs and incomes must be calculated and evaluated according to the interest and inflation rates. The cost of project implementation, depending on the type of plan, mostly includes an initial investment with little maintenance cost. The income of the project implementation is equal to the total income from the sale of extra electricity produced compared to the state of non-implementation of the plan.

In this research, three plans have been examined:
Plan 1: Use of windbreak wall for tower number 1
Plan 2: use of windbreak wall for towers 1 and 3
Plan 3: use of windbreak wall for 3 towers
The income obtained from electricity sales, which represents the excess power produced and the total hours of wind blowing for each speed throughout the year, was calculated by 700 rials based on the price of each kilowatt-hour of electricity produced by combined cycle power plants.
The additional power produced based on the hours and direction of the wind blowing was extracted from the meteorological information (Tables 1, 2, and 3).

**Table 1)** Total annual income of the windbreak wall design of tower No. 1

| **Angle** | **Modified net power** (MWh) | **Income** (million Rials) |
|---|---|---|
| **0** | 1494.18 | 1045.926 |
| **30** | 6905.44 | 4833.808 |
| **60** | 6554.37 | 6588.059 |
| **90** | 2464.06 | 1724.824 |

| Annual income | | 12192.635 |
|---|---|---|

**Table 2)** Total annual income of the windbreak wall design of tower No. 2

| **Angle** | **Modified net power** (MWh) | **Income** (million Rials) |
|---|---|---|
| **0** | 378.24 | 364.768 |
| **30** | 6698.01 | 6488.607 |
| **60** | 6398.8 | 4479.160 |
| **90** | 1277.7 | 894.390 |
| **Annual income** | | 10326.925 |

**Table 3)** The total annual income of the windbreak wall design of tower No. 3

| **Angle** | **Modified net power** (MWh) | **Income** (million Rials) |
|---|---|---|
| **0** | 638.63 | 447.041 |
| **30** | 6514.70 | 4560.290 |
| **60** | 6457.34 | 4520.138 |
| **90** | 1254.41 | 878.087 |
| **Annual income** | | 10405.556 |

The next step is to calculate the costs of wall building. The costs were calculated in two parts of wall and foundation construction. In the foundation section, these costs include lean concrete, 300 concrete grade, Longitudinal, and transverse two-layer reinforcements, and molding. The summary of the financial processes of the windbreak wall design for each of the combined cycle towers is according to Tables 4 to 6.

**Table 4)** Summary of the financial processes of the plan 1

| **Type of expense or income** | **expense or income (million rial)** |
|---|---|
| **Raw materials, construction and installation of windbreak wall for cooling tower number 1** | 11014.344 |
| **Annual repair and maintenance** | 550.717 |
| **Unpredicted initial cost** | 550.717 |
| **Annual income from the sale of excess electricity** | 12192.635 |

**Table 5)** Summary of the financial processes of the plan 2

| **Type of expense or income** | **expense or income (million rial)** |
|---|---|
| **Raw materials, construction and installation of windbreak wall for cooling tower number 1 and 3** | 22028.688 |
| **Annual repair and maintenance** | 1101.434 |
| **Unpredicted initial cost** | 1101.434 |
| **Annual income from the sale of excess electricity** | 22519.560 |

**Table 6)** Summary of the financial processes of the plan 3

| **Type of expense or income** | **expense or income (million rial)** |
|---|---|
| **Raw materials, construction and installation of windbreak wall for cooling tower number 3** | 33043.032 |
| **Annual repair and maintenance** | 1652.151 |
| **Unpredicted initial cost** | 1652.151 |
| **Annual income from the sale of excess electricity** | 32925.116 |

The economic criteria used in the financial analysis of this project are the net present value (NPV), the internal interest rate, and the payback period (PP) of the project. The net present value of the inflated financial process is calculated using the following formula:

$$k_0=a\left(\frac{\left(1-\frac{1+f}{1+i_f}\right)^n \frac{1+f}{1+i_f}}{1-\frac{1+f}{1+i_f}}\right) \qquad (5$$

In the above formula, *a* is the uniform annual income without considering the inflation effect and *if* is the apparent rate, which is actually the minimum absorbing rate after inflation calculated by the following formula:

$$i_f=i+f+if \qquad (6$$

In this formula, *i* is the minimum absorption rate and *f* is the inflation rate. The economic analysis is conducted based on the interest rate of 16.6% and the inflation rate of 16.47%. Also, the life of the project in this analysis is 25 years.
The payback period was used as the second criterion of economic analysis. The value of n is calculated by solving the following equation reflecting the capital payback time.

$$\sum_{j=1}^{n} \frac{S_j - C_j}{(i+1)^j} - I_0 = 0 \qquad (7$$

*SJ* is the sales value at time *j*, *Cj* is the cost value at time *j* and *I0* is the initial investment. The third economic criterion is the domestic interest rate. The effective interest rate of an investment is defined as the internal rate of interest (IRR).
This discount rate makes the net present value of the plan zero. Indeed, it represents the percentage of annual interest resulting from investing in an economic project.

$$\sum_{j=1}^{n} \frac{S_j - C_j}{(r+1)^j} - I_0 = 0 \qquad (8$$

If the calculated interest rate of *r* is more than the minimum interest rate of *i* (which is usually the average interest rate in the central bank), the investment will be profitable. The calculated values for the net present value of the plans are shown in Tables 7 to 9.

**Table 7)** Current value of project financial processes for project 1

| Type of expense or income | Current value (million Rials) |
|---|---|
| Initial investment | 11565.061 |
| Result of annual expenses and income | 68603.493 |
| Net present value (NPV) | 57038.432 |

**Table 8)** Present value of project financial processes for plan 2

| Type of expense or income | Current value (million Rials) |
|---|---|
| Initial investment | 23130.122 |
| Result of annual expenses and income | 126212.730 |
| Net present value (NPV) | 103082.608 |

**Table 9)** Present value of project financial processes for plan 3

| Type of expense or income | Current value (million Rials) |
|---|---|
| Initial investment | 34695.183 |
| Result of annual expenses and income | 184285.324 |
| Net present value (NPV) | 149590.141 |

As shown in the above tables, the net present value are positive, which indicates the profitability of the plans.

## Conclusion

The windbreak wall is used to reduce the wind's negative effects. The effect of using a windbreak wall in a combined cycle power plant was analyzed from an exergy and economic point of view. The results can be summarized as follows:
According to the exergy analysis of all components of the combined cycle power plant, it was found that the combustion chamber has the largest share of exergy destruction, due to the combustion process nature and the irreversible chemical reaction in the combustion process. The highest exergy

destruction was observed in the combustion chamber, gas turbine, regenerative boiler, and cooling tower, respectively. A windbreak wall has a positive effect on the steam cycle; however, it does not affect the gas cycle. In the steam cycle, the increase in the flow rate of air sucked by the tower in windy conditions improves its performance and the production power by the steam cycle also increases. According to the economic analysis of the windbreak wall for three modes of 1, 2, and 3 towers for 25 years, the net present value is positive. Also, the internal interest rate and the investment payback time are above 90% and between 14 and 16 months, respectively

**Table 8)** Glossary

| | |
|---|---|
| Uniform annual income, IRR | a |
| Cost, IRR | C |
| kJ/kg, Exergy | ex |
| Exergy rate, kW | $\dot{E}x$ |
| Inflation rate | f |
| Interest rate | i |
| Apparent rate | $i_f$ |
| Investment, IRR | I |
| Net present value, IRR | k |
| Low heating value, kJ/kg | LHV |
| flow rate, kg/s | $\dot{m}$ |
| Domestic interest rate | r |
| Sell, IRR | S |
| Temperature, K | T |
| Subtitle | |
| Chemical | ch |
| Destruction | D |
| Output | e |
| Fuel | f |
| Input | i |
| Year | J |
| Kinetic | k |
| Mix | mix |
| Environment | o |
| Primitive | 0 |
| Physical | ph |
| Potential | p |
| Heat | Q |
| Work | W |