

The possibility of strengthening the cooling system of single and double-pass steam power cooling tower facilities, including technical, chemical, economic and environmental evaluations

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ABSTRACT

In the past, certain power plants in the country utilized wet cooling systems to condense the return steam from the turbine, primarily due to factors like abundant water resources, unrestricted access to underground water reserves, and limited urban development. However, with the current water crisis and high water consumption associated with wet cooling systems, developers of thermal power plants are increasingly opting for dry cooling towers. This thesis focuses on a specific steam thermal power plant in an urban area, contemplating the transition from a wet to a dry cooling system. The transition will be analyzed from technical, economic, chemical, and environmental perspectives. Initially, the thermodynamic cycle of the steam power plant under the wet cooling system will be simulated using the ThermoFlow software version 23. Subsequently, various worldwide cooling systems will be assessed as potential replacements for the existing wet cooling system. A critical aspect of designing and modeling the cooling system involves determining the optimal temperature, which will be based on meteorological data, location-specific considerations, technical and economic factors, and simulation outcomes for each alternative. Additionally, the choice of chemical control regime for the water and steam cycle during operation will be evaluated based on the cooling system type, heat surface materials, and system equipment. Power plants have also been affected by this water shortage, resulting in reduced capacity and occasional inability to operate at maximum efficiency. As a result, power plants are increasingly using alternative cooling systems that rely less on water consumption, such as dry towers. Several power plants, including Isfahan, Hamdan, Tarasht, Bathat and Montazer Qaim, have acknowledged this issue and are taking necessary measures to resolve it. Finally, using ThermoFlow software and geothermal data, the old wet cooling tower was replaced with a new dry ACC cycle and the effect of this change on cycle and power plant performance characteristics was evaluated. Also, an environmental, chemical and economic assessment has been conducted to analyze other aspects of the proposed cycle and its feasibility.

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1. Introduction

The water demand for the cooling systems of power plants is exerting pressure on the water

supply and compromising the generation of electricity. The depletion of water resources is primarily attributed to factors such as population growth, economic development, and rising temperatures, which contribute to an increase in the demand for both water and electricity. Additionally, droughts exacerbate the situation by further reducing the availability of water.

Power plants are particularly susceptible to the adverse effects of high temperatures and the increased electricity demand for air conditioning purposes. In order to mitigate the impact of severe water scarcity, one potential solution is to relocate electricity generation to regions that are less arid. However, this approach poses challenges as it puts strain on the power grid. Depending on the magnitude and severity of the drought, the grid may struggle to compensate for the power generation lost from the offline power plants.

As previously mentioned, the cooling system of power plants consumes the largest amount of water, necessitating the replacement and resistance of the coolant system. One strategy to reduce the reliance of electricity generation on water consumption and enhance water availability for other purposes is to implement measures that minimize the water consumption of the cooling systems. These measures can include the adoption of cooling systems with lower water consumption rates, as well as considering alternative cooling technologies such as single pass, cooler, dry cooler, and hybrid cooler systems. These systems are classified based on their water consumption, capital cost, and annual expenses.

Several investigations have been carried out to minimize water consumption in power facilities. Here is an overview of various initiatives. Bracco et al [1] have employed Three distinct elementary mathematical models to forecast the stable behavior of an A-frame air cooled condenser. operational parameters have been implemented based on the information. A-frame air cooler.

Tao [2] conducted an examination of power plants performance by integrating a wet and dry cooling system under various operating conditions. In order to analyze the thermodynamic efficiency of the steam system, a specialized modeling program code is utilized. The power plant is designed to operate under

different conditions, and the behavior of the system is studied when it deviates from its intended state. This study involves altering not only the ambient temperature and relative humidity, but also several parameters associated with cooling performance. These parameters include the steam flow rate from the turbine, the load on the air cooling fans, and the number of cooling pumps. The performance of the cooling towers is thoroughly investigated.

Consequently, an optimal combination of variables is identified, enabling the system to achieve maximum power output while minimizing water consumption.

Loew [3] et al. conducted a thorough analysis of the expenses associated with upgrading cooling systems in order to mitigate the impact on water availability for coal and gas-fired combined cycle power plants in Texas. Their findings were based on the ultimate cost of decreasing water usage (in dollars per gallon of water). The outcomes of this research can be utilized to evaluate various power plants and water management approaches. This study sets itself apart from others by delving into the initial, operational, fuel costs, and maintenance of replacement cooling systems. Generally cooling systems for power plants can be categorized as shown in Fig.1.

2. Air-Cooled Condensers and Cooling Tower

Air-cooled condensers (ACC) have been utilized in various dimensions and sizes since 1930. In A-frame ACC system, two radiators are positioned at an angle (δ) with a downward slope, installing ACC cooling type A-frames. The steam passes through the passage and an axial fan generates airflow over it. The upper radiator receives the steam in the fin-tubes, where under the influence of the airflow, the saturated steam transforms into saturated liquid at the bottom of the frame. Subsequently, the condensed fluid in the condensation tank is transferred to the boiler system.

This system, known as the ACC (Air-Cooled Condenser), operates by allowing the exhaust steam to enter a series of ACC converters through pipes. These converters are cooled by air, facilitating the condensation process and the release of condensed water, which then enters the pump cycle. Typically, the converters in this system is of the delta type, and the airflow within

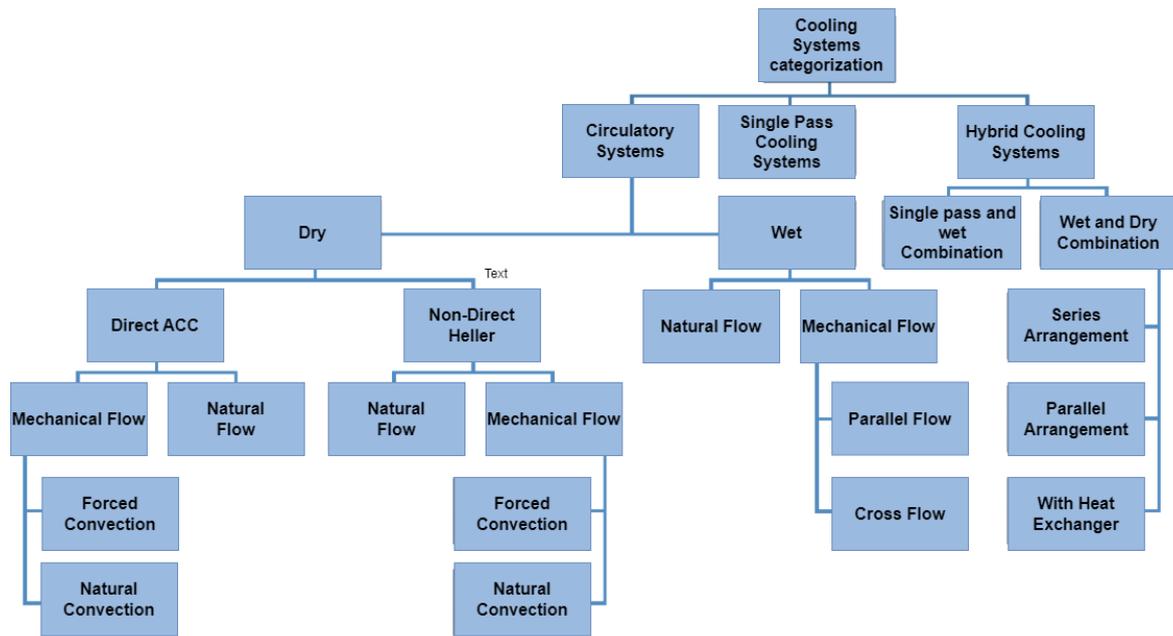


Fig.1. Categorization of power plants cooling systems

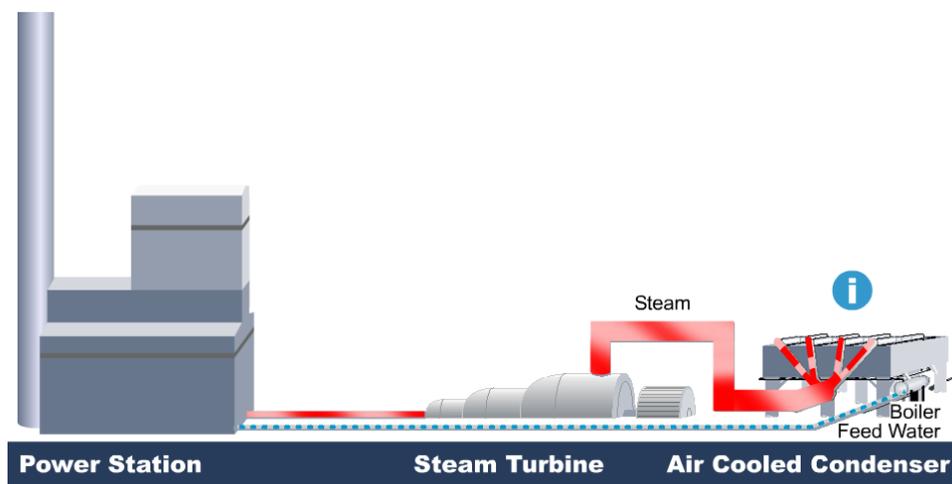
them can be either forced or natural. One drawback of this system is that the steam pipes entering the tower have low pressure, resulting in a high specific volume of steam. Consequently, the pipes used in this system are usually large and heavy. This is illustrated in Fig.1, which depicts a direct dry cooling system. However, the ACC system offers several advantages over water-cooled/wet condensers. Some of these advantages include the absence of a need for feed water, no pollution caused by blowdown, no freezing (except for the popping system and condensate water storage), absence of water

vapor plumes, no pollution in the environment and underground water, less corrosion of surfaces due to the dryness of thermal surfaces, and lower maintenance and repair costs.

Air-cooled Condensers can be categorized in three:

- Inductive Flow (V-Frame)
- Forced Flow (A-Frame)
- Natural Flow

It can be said that the A-frame type is the most common between these three types of condensers.



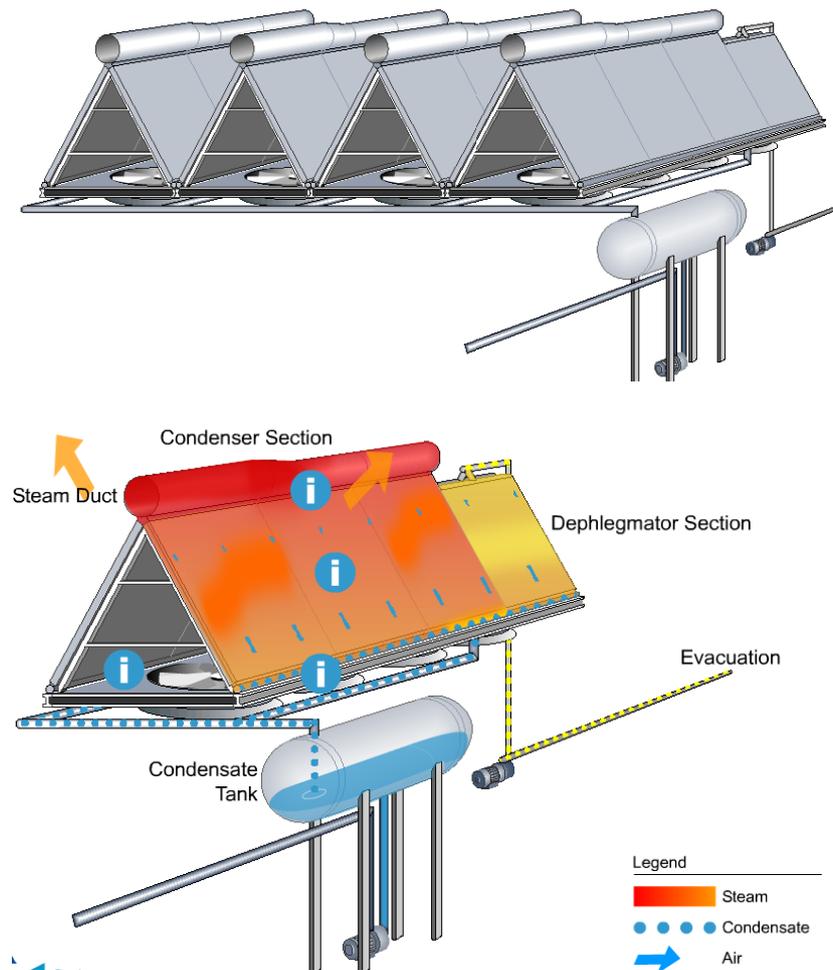


Fig.2. A-frame type ACC condenser

The advantages of air-cooled condensers over other types of condensers and cooling towers are:

- One significant benefit of employing a dry cooling systems lies in its minimal water consumption, making it a viable option in numerous water-scarce regions. In Iran, where water scarcity is prevalent across most areas, the nation's demand for water for drinking and agriculture is steadily increasing, even the relatively water-rich West regions has embraced a superior dry cooling system compared rather than other alternatives.
- These systems are capable of delivering a greater volume of air compared to other towers, resulting in the exit air from the dry tower being hotter than the air released from the same wet tower, Consequently, transporting dry warm air

to higher altitudes within the atmosphere.

- The dry cooling towers are more efficient in humid areas.
- Dry cooling tower can work more silently compared to wet cooling towers.

3. Meteorological data of the studied power plant

The analyzed power plant is the martyr Montazer-Ghaem power plant located near the Shahryar geological station. So, for the purpose of this study, the data from this station will be considered for the power plant.

3.1. Analysis of ambient temperature

As Shown on Fig.3, the ambient temperature of 20°C was the most frequent temperature throughout a year and the average of temperature was 17°C. Also, maximum and minimum temperature was 42.1°C and -13.8°C respectively.

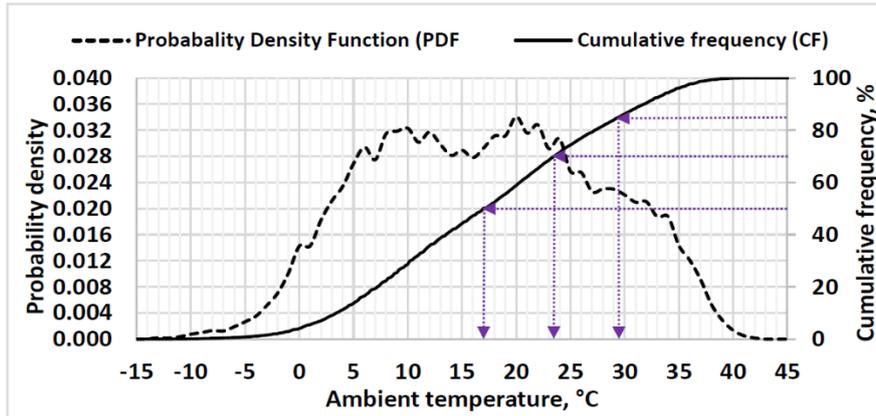


Fig.3. Air temperature distribution for a whole year [4]

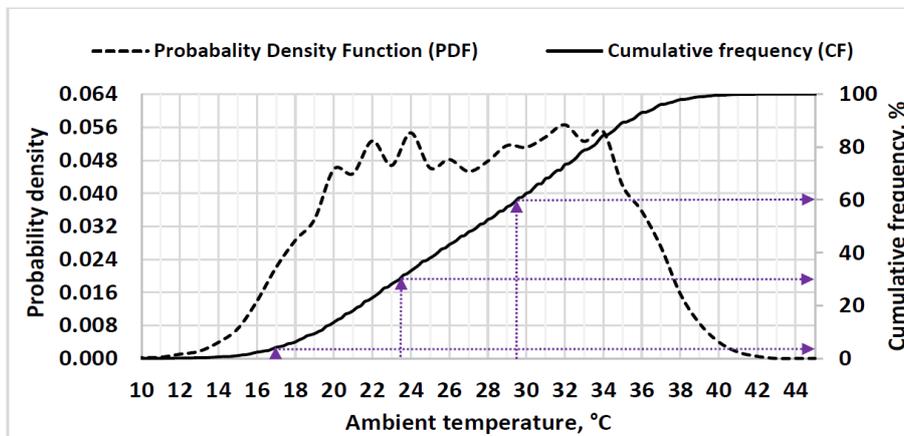


Fig. 4. air temperature distribution for hot months [4]

Since the ACC systems are adversely affected by ambient temperature, the hot months of a year are of utmost importance for prediction of performance of these systems.

3.2. Wind Speed and direction analysis

As illustrated in Fig.5, average wind speed throughout a year is 3.2 m/s and a wind speed of

0.8 m/s is the most frequent case. Maximum recorded wind speed by the station was 20 m/s. In order to gain a better understanding of the wind regime of the region wind speeds will be categorized in wind classes and the distribution is analyzed. Referring to Fig.6, wind classes ranging from 2 to 4 m/s speeds were the most common case in the region. Winds ranging from

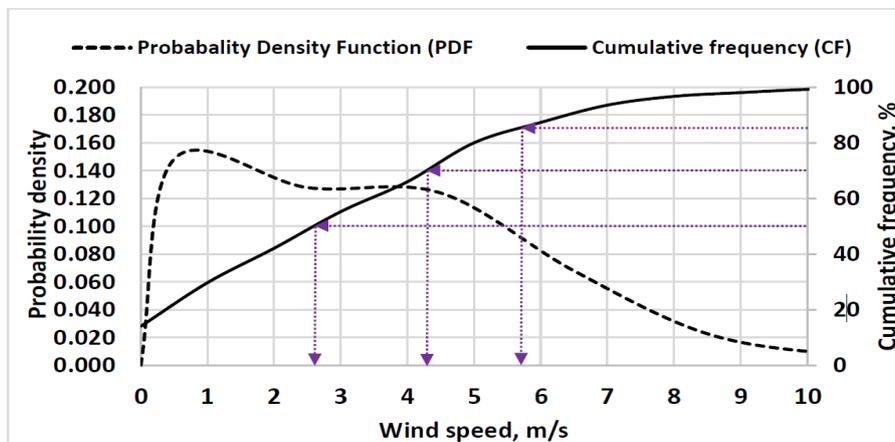


Fig.5. Wind speed distribution for whole year [4]

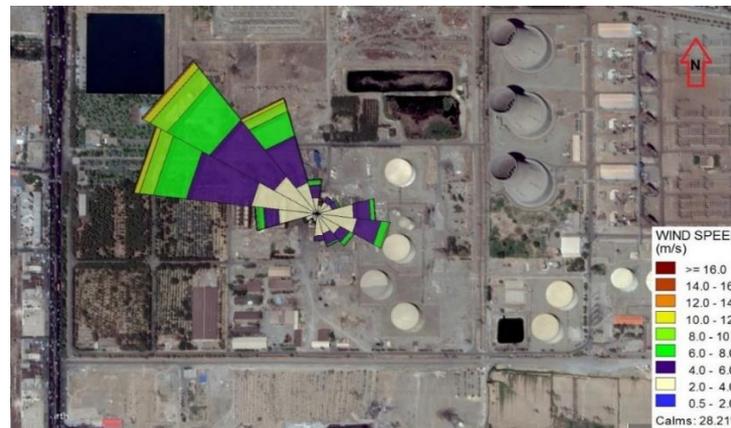
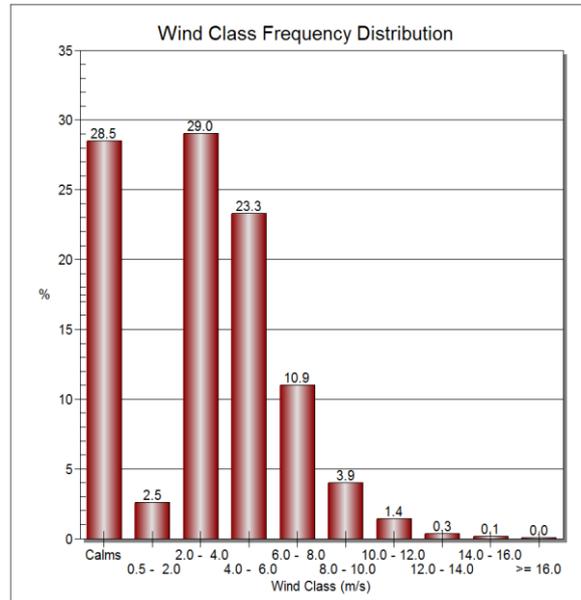


Fig.6. Wind speed distribution (classified) for whole year

0.5 to 2 m/s are very unlikely (2% probability). So, it can be concluded that the ACC system will be dealing with calm wind regime.

3.3. Relative humidity analysis

As for relative humidity, the average for hot months of the year is 34.5%.

4. System setup and input data

Wet cooling towers are currently being utilized to cool the four units of 156 Megawatts in the steam cycle of the MontazerGhaem power plant. These cooling cycles are essential for the operation of the system.

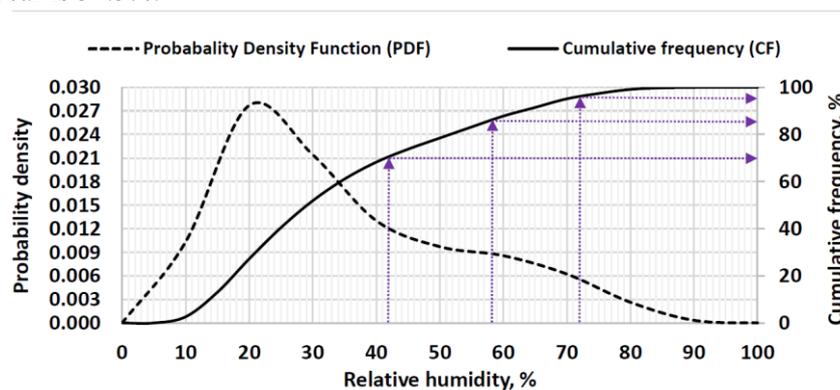


Fig.7. Relative humidity distribution for a whole year

However, one significant drawback of this cooling system is its high water consumption. The schematic diagram of the steam cycle for the power plant is presented in Fig.8.

4.1. Boiler

The boiler of the plant is manufactured by Combustion Engineering Co. with a rated capacity of 1100000 pounds per hour of steam. The steam can be superheated to 1875 psig and 1005°F.

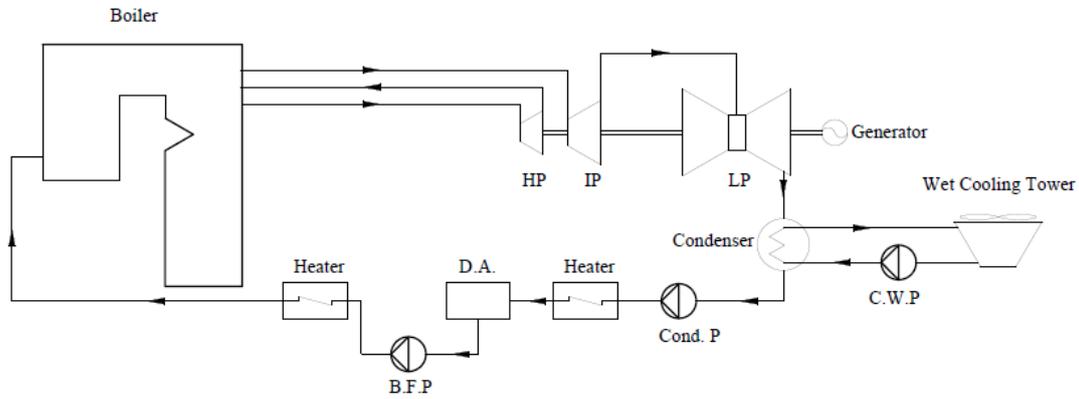


Fig.8. Schematic of the studied power plant

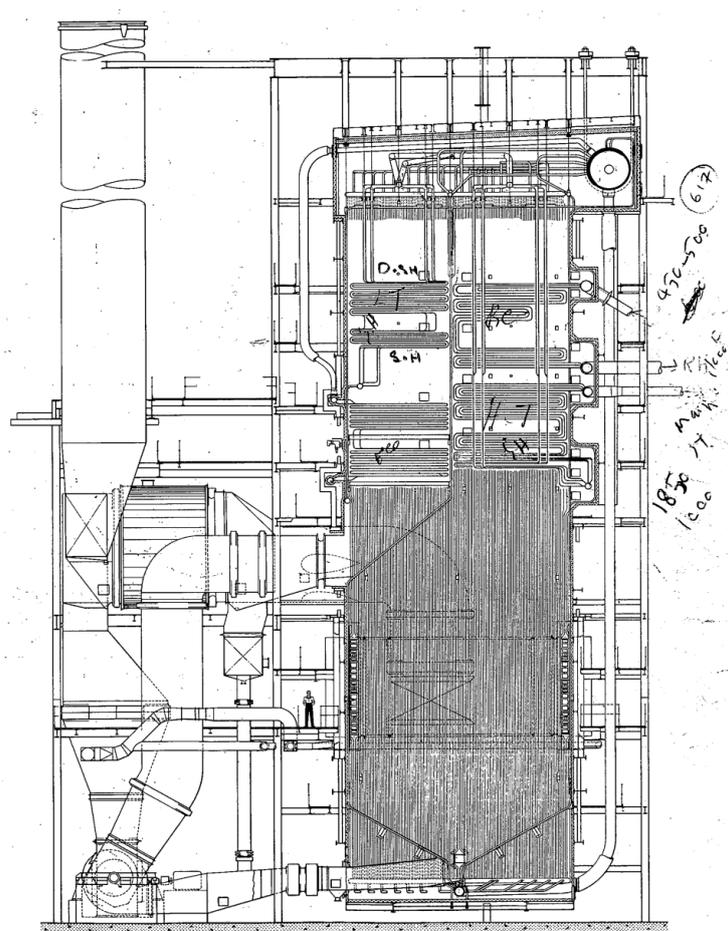


Fig.9. Schematic of the Boiler of the power plant

4.2. Boiler Feed Water Pump

The BFW pump for the plant is manufactured by Pacific Pumps Co. with a rated speed of 3000 RPM and rated capacity and head of 1340 gallons and 5500 feet respectively. The pump is a BB5 API type pump with 11 stages.

4.3. Turbine

The turbine is manufactured by General Electric (GE) with 6 extraction lines. The turbine is 24 stages. The first stages are impulse type and the last stages are reaction. The rated power of turbine is 156250 kW.



Fig.10. BFW pump of power plant

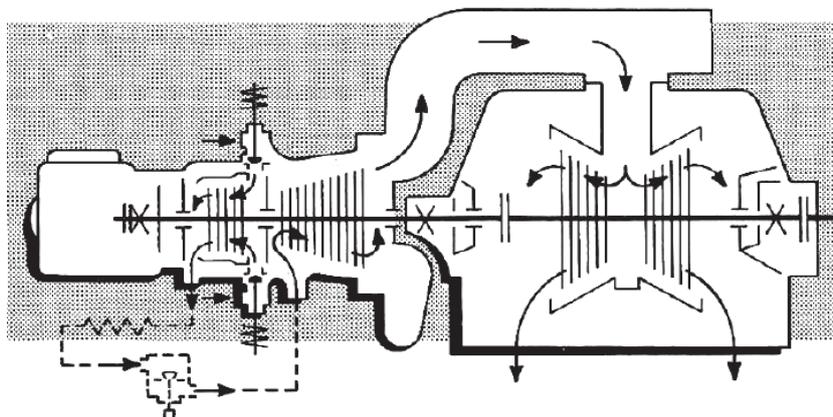


Fig.11. Turbine of power plant

The simulated cycle is shown in Fig. 14 and the resulting data from a simulation of the cycle in order to validate the results are presented in Table 1.

As can be seen in Fig. 1, simulation results are in good accordance with the actual data of the power plant.

The novelty of this present research as stated earlier, is to augment the power plant cycle via the replacement of a wet cooling tower by a dry cooling tower. Some assumptions regarding the modeling of the ACC system:

1. The minimum permissible pressure of the condenser is 0.6 bar and the

maximum permissible pressure is 0.16 bar more than the turbine alarm set pressure.

2. Increasing off-design temperature will increase the pressure of the condenser. Since the maximum pressure of the condenser has been set based on item no.1 the pressure will be limited to this number by derating.
3. Inlet temperature can be between 18 to 26°C which will be the optimum range for sizing and cost of the condenser.

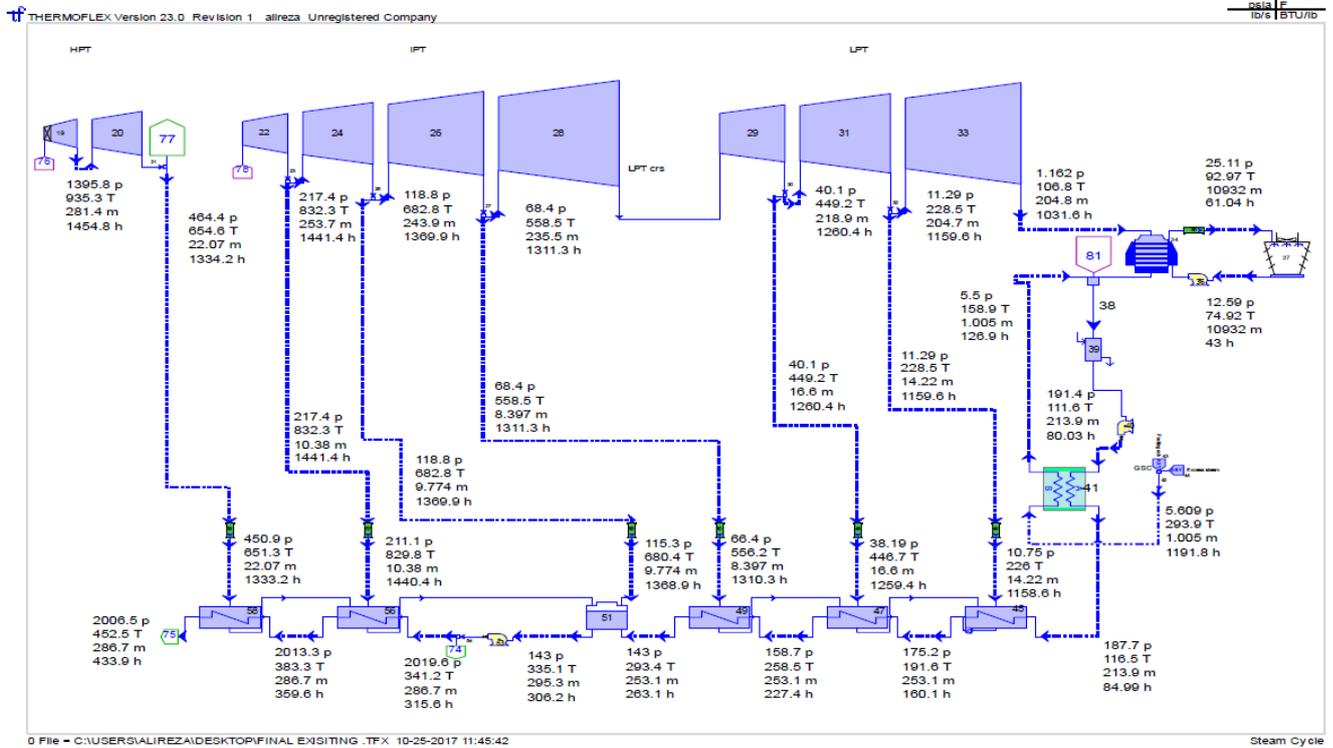


Fig.14. Simulated cycle of the power plant in Thermoflow

Table 1. Validation of simulation and actual cycle data

	Simulation	Actual cycle	Error (%)
Turbine outlet steam mass flow rate (lb/h)	725600	743700	2.43
Condenser heat rejection (BTU/h)	700.2E6	725.9E6	3.54
Boiler inlet temperature (°F)	451.5	452.1	0.13
Boiler efficiency (HHV) (%)	84.85	85.79	1.1
Efficiency of cycle (%)	37.8	37.14	1.78
Water mass flow rate of cooling tower (m ³ /h)	16500	17000	2.94

The proposed system is then simulated using ThermoFlow and the illustration of the proposed cycle can be seen in Fig. 15.

The results of the simulation of the ACC condenser for different design temperatures and pressures are presented in tables below.

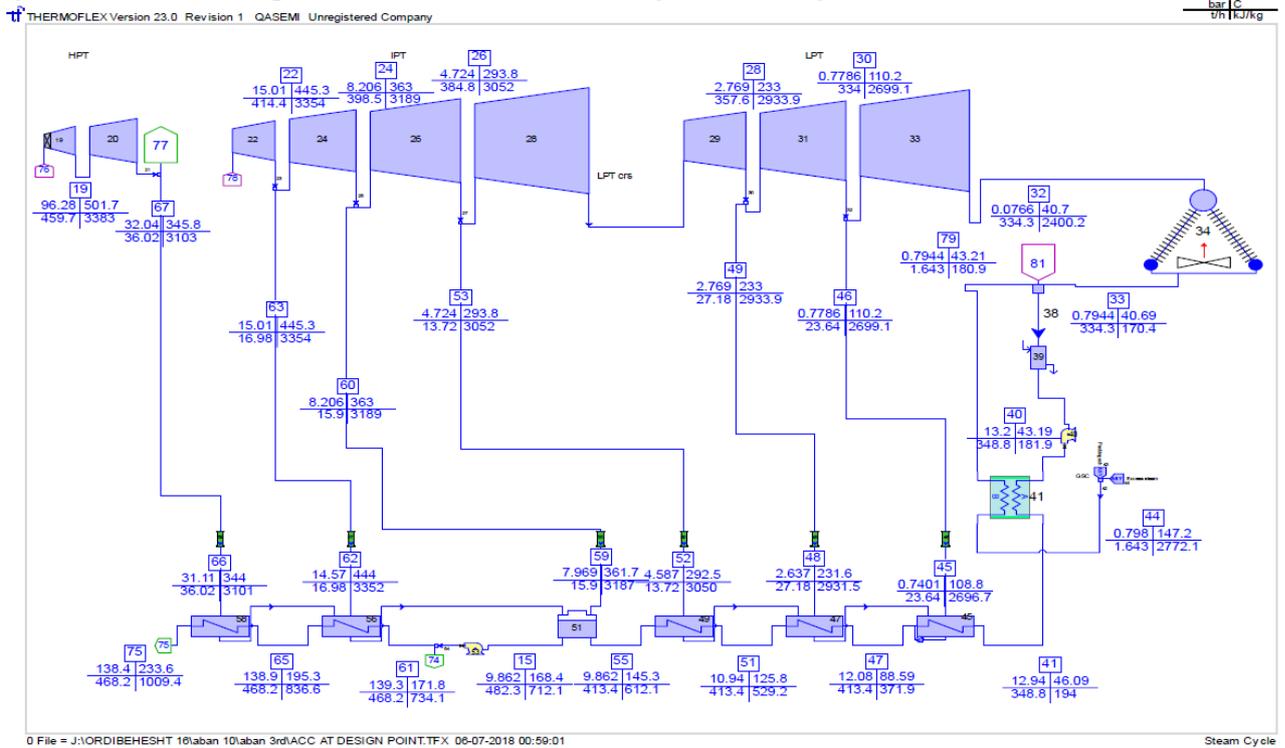


Fig. 15. Simulated proposed ACC cycle of the power plant in ThermoFlow

Table 2. design temperature of 16°C and design pressure of 0.08 bar

Design temperature (°C)	16	18	22	25	26	28	30	32	35	40
Pressure (bar)	0.08	0.1	0.11	0.13	0.14	0.16	0.16	0.16	0.16	0.16
Nominal Power (MW)	140.6	138.4	137	134.8	134	132.4	120.1	107.7	897.9	578.8
Net Capacity (MW)	133.3	131	129.7	127.5	126.7	125	113.1	100.9	833.3	520
Efficiency (%)	34.97	34.48	34.16	33.58	33.41	33.02	32.1	32.1	30.72	27.01

Table 3. design temperature of 22°C and design pressure of 0.08 bar

Design temperature (°C)	22	24	26	28	30	32	35	40
Pressure (bar)	0.08	0.0898	0.1	0.11122	0.1253	0.1397	0.16	0.16
Nominal Power (MW)	140433	139417	138258	136953	135504	134016	131576	86530
Net Capacity (MW)	132640	131620	130457	129146	127694	126201	123750	79663
Efficiency (%)	34.91	34.68	34.42	34.08	33.75	33.39	32.75	30.29

Table 4. design temperature of 26°C and design pressure of 0.08 bar

Design temperature (°C)	26.5	30	35	40	41	42	43
Pressure (bar)	0.08	0.0972	0.1273	0.16	0.16	0.16	0.16
Nominal Power (MW)	140283	138451	135166	131298	119385	108774	98523
Net Capacity (MW)	131983	130058	126757	122781	111289	100899	90834
Efficiency (%)	34.77	34.39	33.57	32.57	32.29	31.77	31

The results show that increasing the working temperature of the condenser can lead to an increase in condenser pressure. Also, an optimization of investment cost and turbine output power has been conducted and the results are provided in Fig. 16.

As per Fig. 16 since there is no optimized option (design point) no conclusion can be

made. In this regard, other parameters such as fan number can be considered.

Considering Fig. 17, two design numbers of fans 24 and 28 are the optimized number of fans for the cooling tower. Other performance characteristic parameters of the cycle can be calculated based on this. Condenser heat rejection can be seen in Fig. 18.

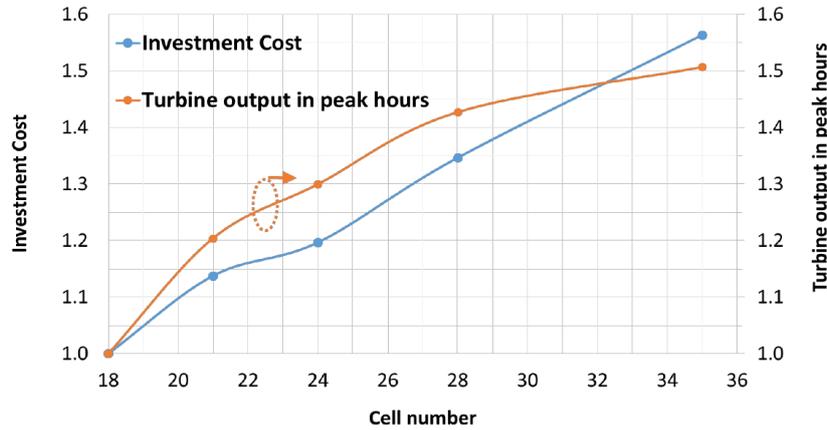


Fig. 16. Results of proposed cycle optimization for turbine output power and investment cost

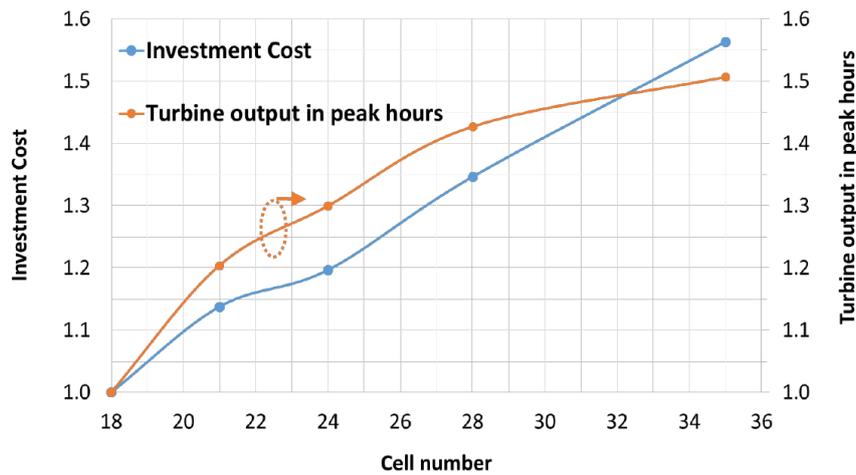


Fig.17. Results of proposed cycle optimization for fan number of cooling tower

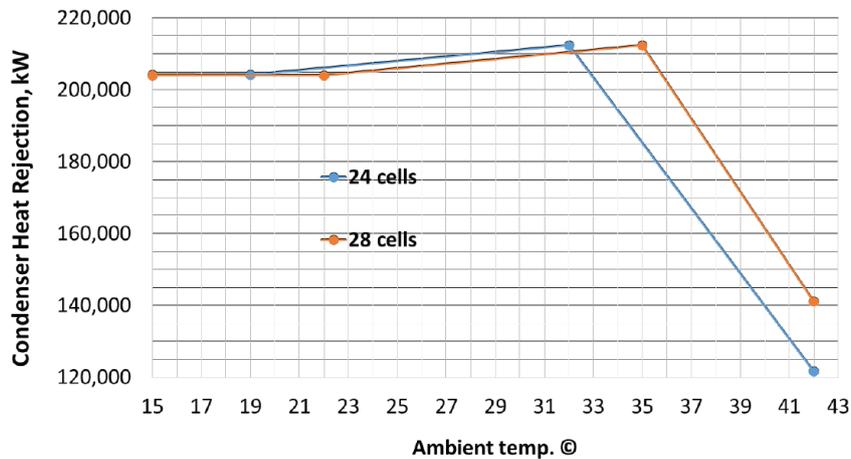


Fig.18. Results of condenser heat rejected

Also, the result for turbine deaerating during three hot months of the year can be seen in Fig. 19.

The specification of the designed ACC system and general dimensions of the systems are specified in Table 5.

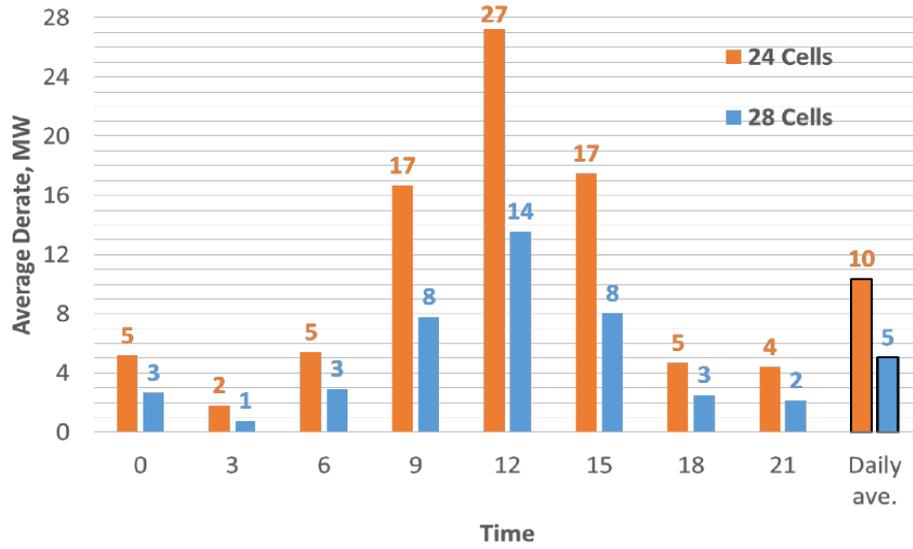


Fig.19. Results of average deaerating of the turbine during three hot months of the year

Table 5. Design specification of the ACC system

Tube arrangement	In line	Fin thickness (mm)	0.3
Tube material	Galvanized CS	Fin spacing (mm)	2.009
Number of tubes per row	208	Fin pitch (1/meter)	433.1
Tube length (m)	9.748	Inlet face velocity (m/s)	2.231
Fin material	Aluminum	Pressure drop (millibar)	0.8463
Fin height (mm)	19	Overall heat transfer coefficient (W/m ² C)	718.4
Fin effectiveness	0.8371		

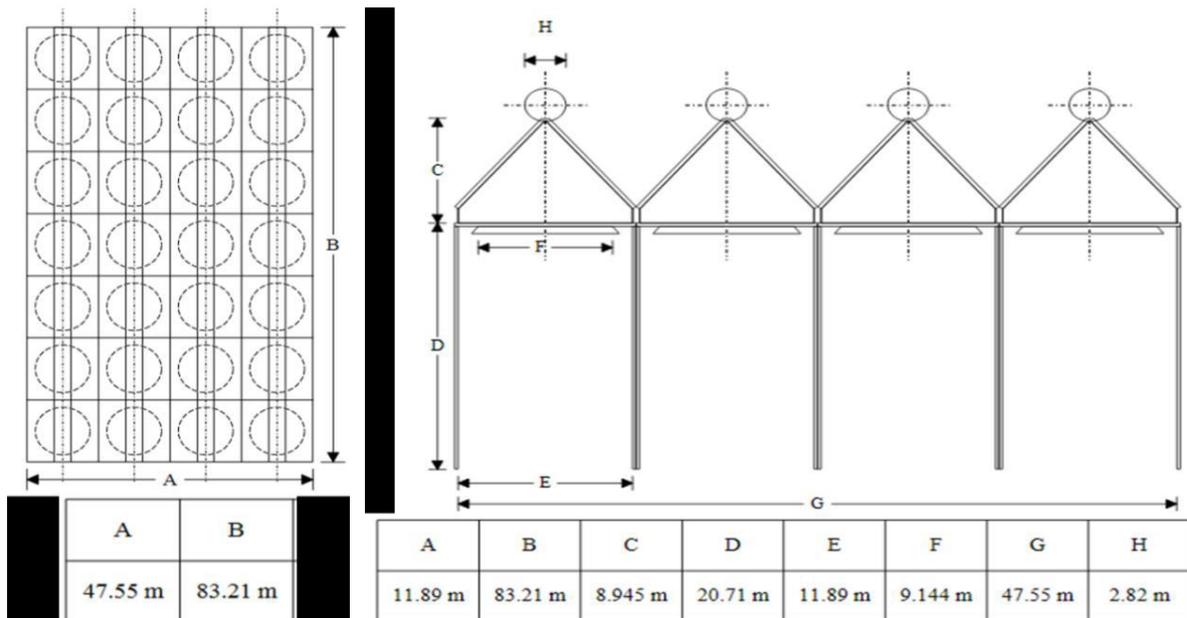


Fig.20. The general dimension of the ACC system

Now that the new ACC cooling cycle has been developed for the power plant and its design and off-design conditions and performance have been evaluated, other aspects of the proposed cycle, such as; economical, chemical and environmental aspects can be evaluated and compared to the previous wet cycle. As can be seen in Fig. 21 the level of underground levels around the power plant has dwindled in recent years.

This depletion of underground water is mainly caused by the water consumption of the power plant's wet cooling tower. This decline in underground water level can lead to land subsidence. As for the new proposed cycle since water consumption is greatly reduced this incline can be much less steep.

Chemical analysis of the water produced by the power plant will lead to the conclusion that the blowdown of the cooling towers is the main

contributor to the chemical contamination of the power plant wastewater.

Analyzing the economical aspects of this augmentation it can be calculated that for temperatures higher than 35°C the power plant will see a minor setback in net produced power.

As per Fig. 22, considering 435 rials per kWh it can be said that for each steam unit, 13.5 billion rials of loss will be imposed on the plant. However, this loss can be covered by the amount of water saved. Based on the permit given to the plant 7237 cubic meters of water can be used annually from the underground water levels. Considering 10000 rials per cubic meter of water for each 4 of the steam unit, the amount of 15.6 billion rials will be saved, which will cover the initial loss of the power plant caused by a decrease in power production.

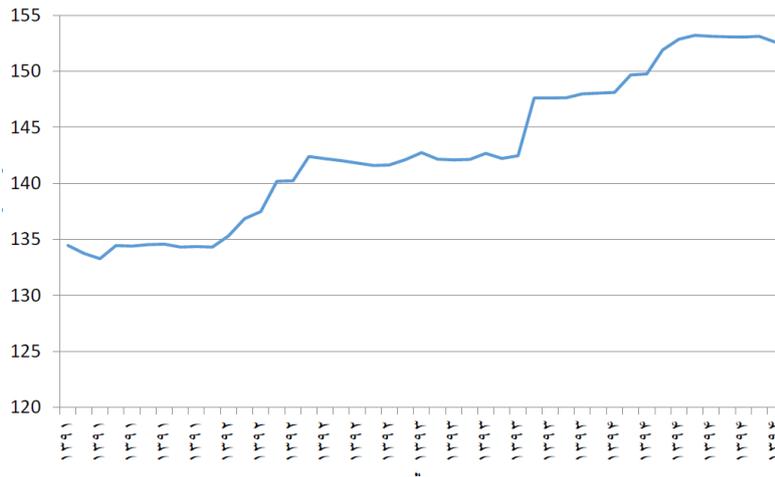


Fig. 21. Level of underground water levels near the power plant

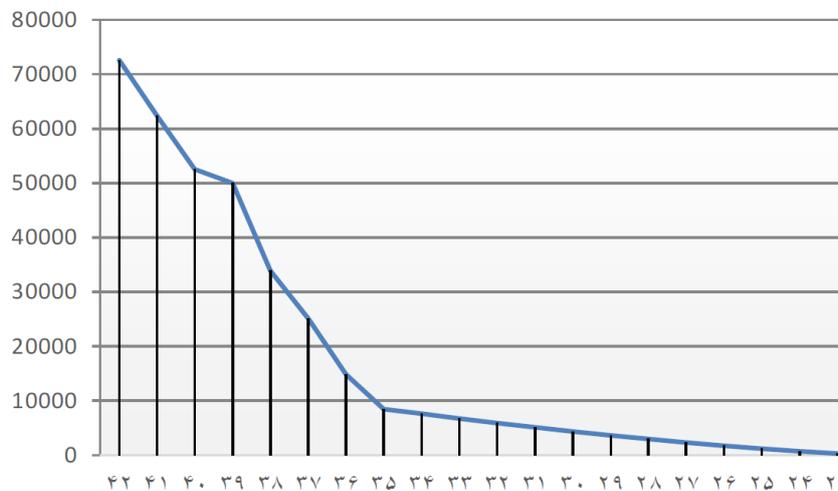


Fig.22. produced power deduction in different temperatures in the new ACC cycle

5. Conclusions

Arid and semi-arid countries are currently grappling with water scarcity issues, which has prompted them to seek out alternative water resources. However, it is equally crucial to focus on conserving the existing water resources. One significant source of waste in older steam power plants is the wet cooling towers. These towers contribute to the depletion of groundwater resources, which have been significantly reduced in recent years due to climate change and unprecedented agricultural yields. This has raised concerns about the well-being of human life. Power plants have also been affected by this water shortage, resulting in reduced capacity and occasional inability to operate at peak efficiency. Consequently, power plants are increasingly adopting alternative cooling systems that rely less on water usage, such as dry towers. Several power plants, including Isfahan, Hamdan, Tarasht, Bethat, and MontazerGhaem, have acknowledged this issue and are taking steps to address it. The MontazerGhaem Power Plant, in particular, has recognized the importance of environmental considerations and has implemented measures to address this problem. The first step in repairing or replacing cooling towers at the plant involves conducting a feasibility study. Additionally, the project aims to assess the impact and feasibility of the proposed scheme on the functioning of the power plant's units, particularly the boiler room. To achieve this, this article utilized meteorological data from the nearest urban site to the power plant to determine the parameters that influence the choice of cooling system. Furthermore, this article will provide detailed information on the technical specifications of the power plant and its equipment, using records and statistics from the manufacturer.

At last, using Thermoflow software and geothermal data, the old wet cooling tower was replaced with the new dry ACC cycle and the impact of this alteration on cycle and power plant performance characteristics was evaluated. Also, an environmental, chemical and economic assessment has been conducted to analyze other aspects of the proposed cycle and its feasibility.

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- [12] اسکندری ف، قلیچ زاده ج، بیاناتی، تبدیل سیستم خنک کاری تر به حالت دوگانه در نیروگاه شهید مفتاح همدان با استفاده از برج خشک جریان اجباری. هفدهمین کنفرانس سالانه بین‌المللی مهندسی مکانیک. اردیبهشت ۱۳۸۸؛ دانشگاه تهران