Original Research Article

Reduction of Energy Consumption and Increase in Synthesis Compressor Efficiency in Methanol Units by Designing a Dry Cooling System

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ABSTRACT

Airflow is an effective cooling solution for industries due to its abundance and accessibility. Utilizing air-cooled condensers aims to minimize water consumption in cooling towers by alleviating the heat load on turbine condensers. In this project, we simulated the C-3001 turbine system, E-4 condenser, and cooling tower by compiling data from the Meteorology Organization and relevant design specifications. After validating the accuracy of the simulated system, we applied operational conditions. The results revealed that the E-4 condenser faced a heat load exceeding its design capacity, potentially leading to complications within the system. Considering the site's physical conditions, equipment layout, and existing piping, a location was identified for branching the steam outlet from the steam guide hood to the condenser. We determined the maximum steam output and evaluated the feasibility of branching and its effects on turbine behavior through CFD analysis. The findings of this study indicated that condensing more than 20 tons per hour of the turbine's exhaust steam was not feasible. Consequently, we designed and analyzed a new condenser system using CFD. The results showed that this design could reduce the cooling tower's makeup water consumption by 16 cubic meters per hour in the methanol unit, while also positively impacting turbine efficiency and performance. Overall, this design effectively reduces the load on the E-4 condenser, subsequently lowering the turbine's exhaust pressure and enhancing its efficiency. The innovation of this work lies in identifying a solution that decreases the makeup water required for cooling, which could serve as a significant factor in improving turbine efficiency.

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Introduction

Providing adequate cooling for process units is one of the most critical aspects of production in any complex. From a pinch analysis perspective, unit cooling revolves around balancing operational and capital costs. A common rule of thumb indicates that approximately 66% of the cooling heat load in complexes is supplied by air coolers, while the remaining 34% comes from water coolers. The preference for air coolers is primarily due to two reasons: they have low maintenance costs and relatively reasonable electricity consumption. However, in many regions, climatic conditions and temperature limitations may necessitate a significantly higher heat transfer surface area for effective cooling. Typically, the capital cost of air-cooling systems is estimated to be about four times that of water coolers. The cooling system in each complex is designed to handle the heat load in several key sections.

Cooling

Condensation

Typically, the condensation heat load in cooling networks, considering that its purpose is to dissipate the latent heat of vapors (including chemical product vapors or water vapors), is greater than the cooling heat load. Part of the condensation load in complexes is related to the condensers of C.T. turbines. In these types of turbines, approximately twice the generated power is dissipated as heat [1,2]. Concerning the large amount of heat dissipated from these types of power generators, and considering the severe reduction in water resources in recent years in various regions of the world, especially in hot and dry regions such as the Middle East and East Asian regions such as China, as well as some regions of America, the policy of replacing air instead of water has been raised for several years. According to the EPRI (Electric Power Research Institute) report in the United States, by the end of the 20th century, 2500 MWe of power was generated in this way in the United States, which experienced a 280% growth by 2004 and reached 7000 MWe in more than 60 power plants in the United States [3]. Research conducted by the same institute shows that this trend will grow even faster in the coming years, provided that the turbine efficiency drop is compensated. According to the Power-mag website, which is one of the most reputable sites for news on power plants and new technologies in them, in England, as one of the wettest regions in the world, currently, 1200 MW of power generation in the country's power plants is being produced through ACC (Air Cooled Condenser). In China, currently, 35000 MW of power is generated through condensation by ACC, and more interestingly, every month in this country, a 2300 MW or 2600 MW power plant is equipped with this technology. In Iran, recently in the Dalahoo power plant in Kermanshah province and the Haris Power Plant in Ardabil Province, ACC technology is used for condensation in power-generating turbines. Considering the continuation of the global warming phenomenon, the effect of which in many regions of the world is in the form of reduced rainfall and continued drought, in the not-too-distant future, the trend of using this technology will accelerate. However, it is necessary to mention that one of the problems of using this plan, especially in hot and dry regions, is the problem of turbine efficiency drop due to reduced heat transfer efficiency, reduced condensation rate, and increased back pressure of turbines in the hot seasons of the year [3,4]. This is why power plants in Iran have so far been built in cold regions, and the development of this technology in the southern and southwestern regions has not been well received. The efficiency of C.T. turbines depends on the final condenser pressure (S.C.). The cooler the fluid used to supply cooling to the condenser, the more efficient the condenser will be, which in turn increases the efficiency of the C.T. turbine. Therefore, the sensitivity to the supply of cooling fluid for these condensers is significantly higher. This is important because the efficiency of the turbines directly affects steam and fuel consumption, particularly in North America and European countries. Where environmental issues are very important, the priority is to increase the efficiency of the condenser under vacuum, and accordingly, extensive research has been conducted in recent years in this regard to provide economic methods to enable the use of air as a cooling fluid and compensate for the turbine efficiency drop in hot environments. It seems that air, due to its abundance and unlimited availability, is one of the best options for use as a cooling fluid in industries. The first use of air as a cooling fluid in the oil industry occurred in 1920 in the southwestern United States due to water scarcity in the region. The initial prototype of air coolers was vertical, but in the mid-1930s, the design changed from vertical to horizontal. In the initial design of horizontal coolers, the system was designed as two-pass and natural circulation. In Europe, Germany was the first country to use this system. The positive performance of air coolers caused engineers to look at this event more positively, and the first refinery based on air coolers was built in 1948 in the Texas region. Subsequently, based on the same design, in 1958 and 1960, the first refineries based on air cooling were built in Germany and England [8]. However, unfortunately, considering that air is a fluid with low capabilities to heat transfer compared to water, water is often the preferred choice for cooling and condensation in industries. The table below compares the heat transfer factors of water and air.

Table 1: Comparison of water and air properties

Row	Index	The superiority coefficient of water over air
1	Thermal conduct	23 times that of air (at 35 °C)
2	Specific heat	4 times that of air

The differences in physical properties between water and air require four times the mass and 3200 times the volume of air compared to water for a specific heat load (Table 1) [8]. Although the air has significant heat transfer issues, particularly regarding initial investment costs and land use, it presents a challenge given the decreasing availability of usable water resources. In recent years, it has become increasingly clear that replacing air with water in the cooling and condensation sections of industries will be necessary in many regions around the world, including Iran. This shift is particularly important since the temperature of the incoming air significantly impacts the performance of Air-Cooled Condensers (ACCs) [9], in 2006 [10], the effect of having an inlet air cooling system on the fan using chilled water was studied. Their study was conducted in a 170.9 MW power plant located in southern New Mexico. They showed that to achieve this goal, a chilled water reservoir with a volume of 4500 cubic meters is needed. Bracco *et al.* [11] investigated the use of ACCs in thermoelectric units such as steam power plants or combined cycles. In this study, they presented three mathematical models to investigate the effects of inlet air temperature on the fan, the presence and accumulation of non-condensable gases in the ACC tubes, and also the return of steam to the exchanger. Zhao *et al.* [12] also studied numerically the efficiency of an air cooler in a two-unit thermal power plant, each with a capacity of 135 MW, in 2009. They investigated the effect of the size and direction of local wind speed, the installation height of ACCs, and the location of the main building of the power plant. They found that the absolute pressure of the turbine increases with increasing wind speed and decreasing installation height of ACCs. The reason is that the wind, in addition to reducing the air flow rate by the fans, can transfer the output heat back to the fan inlets by circulating the flow. This improper air circulation can be due to its circulation due to the presence of the main building of the power plant near the ACCs. Kruger in 2010 [13] studied numerically the effect of the presence of a porous wall to prevent the effect of wind on the ACCs performance. The arrangement of these walls prevents the effect of the fans on the upstream of the inlet air flow to other fans. A year later, in another work [14] at the Eldorado power plant in Nevada, USA, they again investigated the effect of wind. The results show that wind speed has an unfavorable effect on the performance of fans. The model presented by them in this work, according to the authors' claim, can evaluate large ACCs. These authors, in another work in 2013 [9], studied the effect of increasing the inlet air temperature on the fans. The results for 4 different inlet temperatures show that increasing the temperature reduces the performance of the ACC and reduces the efficiency of the turbine in 2013 [15], Michael Owen designed an air-cooled condenser for a back-pressure turbine steam power plant. he utilized numerical simulations, analytical methods, and experimental results. He also assumed the flow to be incompressible. In this work, the geometrical specifications of the steam transfer pipes from the turbine to the ACCs, steam headers, condensate pipes, condensate collecting headers, and technical specifications of the fans, etc. were calculated for a steam power plant. Mishra and Arya [16], in 2015, reviewed the studies conducted in the field of using ACCs in steam power plants. The literature review shows that the presence of wind and high ambient temperature reduces the ACCs performance and consequently creates pressure at the turbine outlet and reduces its power generation. Owen and Kruger [17], in 2017, numerically simulated the steam flow in large ACC exchangers. They investigated the effect of the inlet steam pressure drop from the headers to the tubes in different geometries. Their results show that the geometry of the connection of the tubes to the header and the proper way of steam entering the ACC tubes can be effective in the distribution of steam between the ACC tubes. In 2018 [18], in a new reconstruction of the ACC, V-shaped cells were combined with induced axial flow fans, and a modified design of the new ACC was proposed for a specific wind direction. Since the thermal flow performance of air-cooled condensers (ACCs) deteriorates under wind conditions, taking measures against the adverse effects of wind on the ACC is suggested. In this study, all variables in both conventional and new ACC layouts were investigated and compared under different wind conditions. The results show that the mass flow rate of the new ACC is significantly increased compared to the conventional ACC both in the absence and presence of wind. The flow skew through the induced axial flow fans is largely suppressed, and the inlet air temperature of the new ACC is reduced, which leads to improved thermal flow performance of the ACC and reduced turbine back pressure of the power generation unit. For a conventional ACC with A-shaped condenser cells, off-axis flows and reverse flows in the condenser cells in the wind direction lead to poor aerodynamic characteristics of the axial flow fans, so the thermal flow performance of the ACCs deteriorates, and the turbine back pressure increases. However, for the new design ACCs with V-frame cells and induced axial flow fans, the thermal flow performances are excellent, and the air velocity and temperature fields, inlet air temperature, and flow velocity distribution for the axial flow fans in the proposed 90-degree wind direction are presented. Ambient winds may deteriorate the thermal flow performance of the air-cooled condenser (ACC) in power plants, so suggesting measures against the adverse effects of wind for efficient ACC operation is useful. In a work done in 2018 [19], air deflectors installed under the ACC fan platform, based on a proposed 2×300 MW ACC power plant, are proposed, and the air deflectors with different geometric parameters and tilt angles θ of 30 degrees, 45 degrees, and 60 degrees are analyzed. To improve the performance of ACCs in wind conditions, air vents are installed under the windward fans. The 45-degree tilt angle air deflectors are fundamentally superior in suppressing the adverse effects of wind, guiding airflow, and blocking ambient winds, as well as in terms of airflow conditions near the fans, compared to others. In another study in 2018 [20], a data-driven model for ACCs of thermal power plants based on data fitting and the SVR method was used to extract a data-based model for steam turbine back pressure from operational data to express the ACC characteristics under real operation. In this study, fan frequency, ambient temperature, wind speed, mass flow rate, and outlet steam enthalpy as the input variables based on analytical formulas have been selected. The results indicate that the data-driven model aligns well with experimental operation data across various conditions. A 2018 study [21] investigates the optimal operation strategy for an air-cooled condenser (ACC) in a large-scale 660 MW Rankine cycle power plant. In recent years, ACCs have gained significant attention due to their application in Rankine cycle-based power plants that utilize renewable (e.g., solar) and traditional (e.g., coal) heat sources in water-scarce regions. The research aims to identify the best operational strategies for air fans and the corresponding back pressure in a large-scale coal-fired ACC power plant in China while considering various conditions through precise modeling. The findings indicate that there is strong agreement between the predictions made by the established models and actual operational data across a wide range of load factors (50-100%) and ambient temperatures (10-30 °C). Furthermore, to enhance the power plant's profitability, the study provides quantitative and practical operating guidelines for air fans. In 2019 study [22], a combined layout of ACC with finned tube bundles with a linear configuration was presented to improve cooling performance. ACCs are usually arranged in an A-shape to expand the heat transfer surface, but this shape also has some known design flaws that inhibit cooling performance. To overcome this geometric defect, a combined ACC with a finned tube is proposed horizontally inside the dry cooling tower and configured linearly outside the tower. In this study, a three-dimensional CFD method is developed, and the thermal flow characteristics of the proposed ACC are analyzed and compared with two types of traditional ACCs. In addition, the effects of platform height from 5 meters to 50 meters are also investigated for the new ACC design. The results show that the new proposed ACC can significantly increase the cooling performance at wind speeds less than 9 m/s, especially in the absence of wind, compared to the conventional ACC model, with a heat transfer rate increase of nearly 20%. While at high wind speeds, the conventional ACC with vertically arranged heat exchanger bundles shows the highest cooling efficiency, so it is mostly applicable for areas with strong prevailing winds. For the new ACC, optimal platform heights are 15 meters and 40 meters at low and high wind speeds, respectively. This information can help optimize the design of ACCs in power plants. In another study conducted in 2020 [23], various configurations for A-frame air-cooled condensers for use in power plants are investigated in this study. A computational model has been developed to predict the heat transfer performance and pressure drop of a 10.67 m by 12.2 m ACC during the summer (inlet air at 30 °C and 25% relative humidity), when air-cooled systems typically perform worst. The condenser geometry modeled in this study is the A-frame condensers used in dry-cooled power plants. Each condenser unit is 12.2 m wide and has 10.67 m long carbon steel tubes to form an A-frame with a 60-degree apex angle. Steam at 7 kg/s enters each ACC and is distributed equally among all tubes. Each tube has a rounded rectangular cross-section of 190.5 × 25.4 mm and a wall thickness of 1.27 mm. In this study, parametric studies were also conducted to identify the optimal condenser geometry with plain, corrugated, and louvered fins to determine the effect of different condenser fin geometries on the overall cycle performance. While ACC designs with corrugated or louvered fins improve the overall cycle efficiency over the baseline case, it was found that reducing the plain and conventional fin spacing leads to the largest improvement in cycle efficiency (1.14% increase for the Rankine cycle, and 0.84% increase for the combined cycle). Venter *et al.* [24], in a 2021 study, numerically investigated the effect of the presence of a windbreak on the performance of ACCs. Their results show that the performance of the ACC depends on the wind speed, the position and installation height of the ACC, and also the installation position of the windbreak. Likewise, to achieve proper performance at a speed of 16 meters per second for wind-blowing, the windbreak should cover 50% or more of the wind-blowing surface. In a 2021 study [25], dynamic modeling for a coal power plant with ACC condensers in water-scarce areas was addressed to reduce water consumption. ACCs, despite their water-saving advantages, have disadvantages such as environmental sensitivity, high costs, and poor performance, which worsen the economics and flexibility of the integrated system. For efficient operation, this study presents a dynamic ACC model that is integrated with a 600 MW coal power plant to study the interactions between heat and power under different loads. The condenser is modeled in a one-dimensional way to reflect the effects of crosswind and ambient temperature disturbances, and then an operational mode for coordinating the ACC and the coal power plant is proposed, which can significantly improve the performance of the power plant. In a recent study in 2023 [26], the environmental and thermal impact of using ACC in the Kalina cycle for power generation in hot and dry regions was investigated. The Kalina cycle uses low-temperature heat sources to generate high-pressure steam to run the turbine for power generation, and since the steam at the turbine outlet has a relatively low temperature, a cool environment is required for liquefying the steam in the condenser. This study examines the environmental and economic impact of using air-cooled condensers in the Kalina cycle, considering the Tarasht steam power plant. The overall results show that the use of ACC in the Kalina dual cycle (KSC-Da) saves water consumption and reduces CO2 emissions. Therefore, it is the most suitable choice. In the upcoming research, based on scientific evidence, previous studies, and with the known specifications of the steam output from the turbine, the possibility of using ACC instead of water-cooling tower is numerically investigated, and the pressure drop of the flow from the turbine outlet to the ACC outlet is calculated for the design of an ejector that can create a specific flow rate in the path from the turbine to the ACC.

Experimental

Method

Reducing water consumption in industries is one of the concerns and worries of owners of various industries such as steel, oil and gas, petrochemicals, and power plants, and each of the industries, according to their production methods and operational necessities, proposes methods. Among these, the principles of water optimization in steam power plants are simpler and more feasible because the process of electricity generation and supplying the required steam is simpler compared to the production process in refineries and petrochemical plants, and naturally, steam loss is also negligible. The major water loss in power plants is in the cooling system, which aims to condense the exhaust steam from the turbine. However, the research conducted in power plants to reduce the amount of water consumed in cooling towers also illuminates the way for other industries because the principles of power generation in power plants and other industries have a common alphabet, which is, in fact, the use of C.T. turbines.The root of all water losses in the cooling tower is related to the phenomenon of evaporation because evaporation, besides removing 1% to 2% of the circulating water in the entire cooling system, will also cause the concentration of water salts, which in itself causes the need for water disposal through blow down. Reducing the amount of evaporation requires reducing the heat load of the cooling tower and according to Equation (1) [4]:

$$E = 0.00158 * M^{\circ} * \Delta T_r \quad (1)$$

Evaporation is a function of two key parameters: the volume of circulating water and the temperature difference between the inlet and outlet water. Therefore, to reduce the amount of evaporation, it is necessary to control these two key factors. Vacuum condensers have a high volume of circulating water. On the other hand, in cooling towers, two simultaneous phenomena of mass and heat transfer occur [5], and the main cause of evaporation is, in fact, the phenomenon of mass transfer during water cooling. Therefore, to reduce the amount of evaporation, it is necessary to practically eliminate the phenomenon of mass transfer, and the cooling process should practically rely only on heat transfer, which makes the use of dry cooling or air coolers more important. However, as previously mentioned, the use of dry cooling alone in hot regions or hot seasons of the year is associated with a decrease in turbine efficiency. From Kroger's veiwpoint, there are three suitable methods for condensing the exhaust vapors from C.T. turbines:

Using a wet cooling system and S.C. exchanger

This method is the most common condensation method due to its low investment cost, and its basis is the absorption of latent heat of steam evaporation by cooling water and the dissipation of this heat in the cooling tower by two methods of simultaneous mass and heat transfer. The cooling tower has a simple structure and consists of packing, droplet traps, and fans. In industrial applications, the induced draft type is mainly used, which allows direct contact of air with water by sucking air through the packing's. This condensation method, despite its reasonable investment cost, has high operating costs, and corrosion, scaling, and bacterial growth should be regularly controlled in the system. The S.C. exchanger also has a simple structure and is made of several tube passes in direct contact with cooling water, and practically, investment costs in this section are also low. These exchangers need to remove non-condensable gases that enter the system due to air suction from the very small gaps and cracks in the turbine outlet hood and to provide turbine vacuum, some of the steam is removed from the system by an ejector or vacuum pump [6].

Using a parallel wet and dry cooling system (Figure 1)

This method, which is displayed in Figure 1, is known as the parallel wet and dry cooling system and is one of the new methods of condensation in C.T. turbines [1]. In this method, which uses both wet and dry cooling simultaneously, in addition to observing the considerations of reducing water consumption and maintaining turbine efficiency in hot seasons, the reliability factor of the system performance in critical situations is also higher [1,7]. In this system, in the hottest weather conditions, the maximum efficiency can be achieved by dividing the turbine's steam output flow between the two heat exchangers. This method has a higher initial (construction) cost compared to the other methods, but it is undoubtedly one of the best options for upgrading systems that rely only on S.C. However, it should not be forgotten that branching from the turbine outlet hood and dividing the flow between the two exchangers has its own considerations.

Using a dry cooling system (Figure 2)

The use of a dry cooling system alone is suitable for cold regions, and practically, this system alone for areas that have moderate and hot weather, in most seasons of the year, due to the decrease in the temperature difference between the ambient air and the fluid being cooled, will face a decrease in efficiency [3]. For this reason, for turbines whose performance has a special sensitivity, such as turbo compressors of catalytic units or power generators at peak load, they are not sufficient alone, and it is necessary to use an auxiliary heat transfer system.

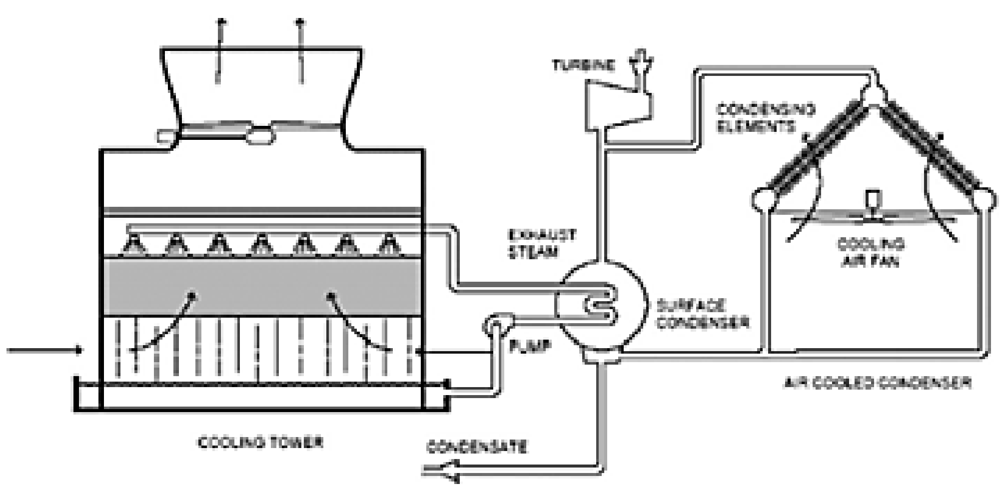

Figure 1: Parallel wet and dry.

Since 2012, the American EPRI, based on studies at the University of Stellenbosch in South Africa, has passed a plan from the basic design stages and detailed design and practical testing, based on which it is possible to eliminate the weakness of using ACCs in hot regions by the HDWD system, which is based on the simultaneous transfer of mass and heat, and to use this system in hot weather conditions that also face the problem of water shortage, as demonstrated in Figure 3.

The HDWD structure is like the ACCs structure with more than one row of tubes, one part is considered as reflux, which is practically the place for the disposal of non-condensable gases. The direction of fluid movement in these tubes is opposite to the direction of fluid movement in ordinary tubes, and their length is also shorter. Regarding ACCs that are installed in hot regions, the reflux tubes are practically assumed to be the outlet of the two-phase fluid of steam and water, and this two-phase fluid is directed to an exchanger with plain tubes. This exchanger is equipped with a droplet water spraying system, which can operate in dry and wet conditions. The two-phase fluid, after entering this exchanger, is cooled by the air flow created through the main fan (dry mode), and if this mode is not sufficient, the water spray nozzles are put into service, and the surface of the tubes, in addition to the air flow, is also cooled by water, and after cooling, the water used in the collecting trough is collected and directed to the tank, and in this way, practically the condensation process will be completed. Figure 3 illustrates an A-type example of this system.

Modeling of the Exchanger Network of the Fanavaran Methanol Unit

In this project, the goal is to create a branch from the outlet hood of the C-3001 turbine in such a way that, based on the pressure difference, the flow can be divided between the two SC and ACC exchangers. Currently, HHP steam in the C-3001 st turbo compressor is used to generate power in the compressor, and then LP steam from the turbine outlet is recovered by the E-4 exchanger. 213 T/h of HHP steam with a temperature of 512 °C and a pressure of 112 barG enters the first turbine. The turbine, with a speed of 6765 rpm and an approximate efficiency of 75%, produces power equivalent to approximately 16.8 MW. From the 213 tons of turbine outlet steam, 113 T/h of steam, on average, in the operational mode, is extracted as blow down for use in the production process and exits the turbine, and 100 T/h is directed towards the C.T turbine, which generates power equivalent to 21 MW, and after driving the C-3001 compressor, the steam is directed to the E-4 exchanger for condensation. Concerning the sensitivity of the C-3001 compressor operation in the complex, and considering that the goal is to minimize investment costs, after collecting complete design and operational information of the site and weather conditions based on the documents of the Meteorological Organization, the information of the C-3001 st turbine system and the E-4 condenser and cooling tower are analyzed based on the design conditions, simulated, and after ensuring the simulation accuracy, the operating conditions are applied in the simulation and the results are analyzed.

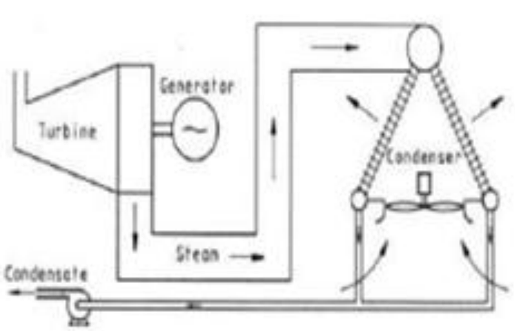

Figure 2: A.C.C system with HDWD.

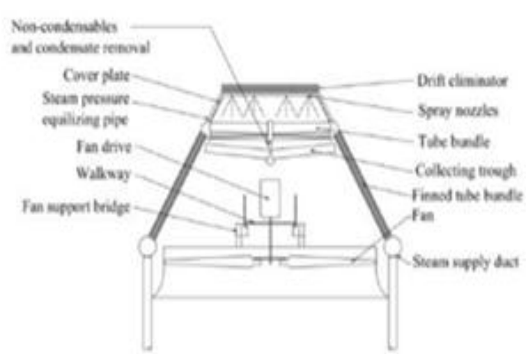

Figure 3: An example of A.C.C.

Concerning the physical conditions of the site, a location has been selected for branching the steam outlet from the steam guide hood towards the condenser. Based on the standards, the maximum steam output is determined, and the possibility of taking a branch and its effect on the turbine behavior has been investigated by CFD analysis. In the two-dimensional model, first, the ACC will be designed for the heat load of the full steam capacity, and in this design, the number of rows of the ACC, the number of tubes, and other heat transfer components of the ACC will be fully investigated. In the second part and CFD calculations, based on the available space and the possibility of branching in the turbine outlet hood section, the maximum size and obstacles in the way of piping and allowable pressure drops, the maximum achievable steam in the ACC path will be determined, and based on that, the ACC design will be updated. Based on the new design, the pressure drop inside the tubes will be fully investigated and the result will be reported. Figure 4 illustrates a power plant with a water-cooling tower, while Figure 5 depicts a power plant with an air cooler. Based on the gathered information, we have decided to use model number 2, which involves the simultaneous use of an air-cooled condenser (ACC) and a steam condenser (S.C.). The reasons for selecting this configuration are as follows:

1. Existing equipment, such as the steam condenser, will be utilized.
2. Given the sensitivity of the C-3001 compressor, choosing this arrangement minimizes the risk of equipment failure or efficiency loss associated with a parallel system.
3. During the hot season, some of the steam can be directed toward the steam condenser, which will effectively reduce both investment costs and the land area required for the installation.

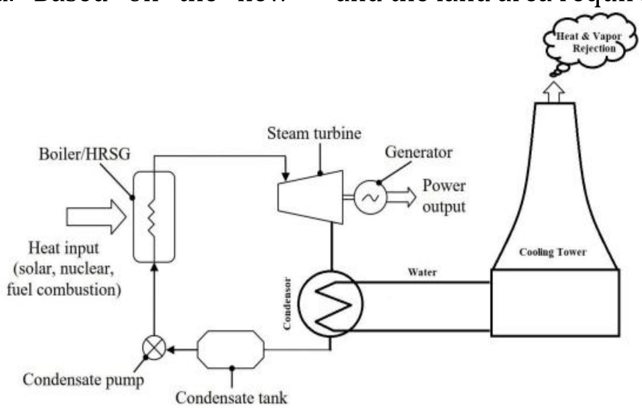

Figure 4: Power plant equipped with a water-cooling tower.

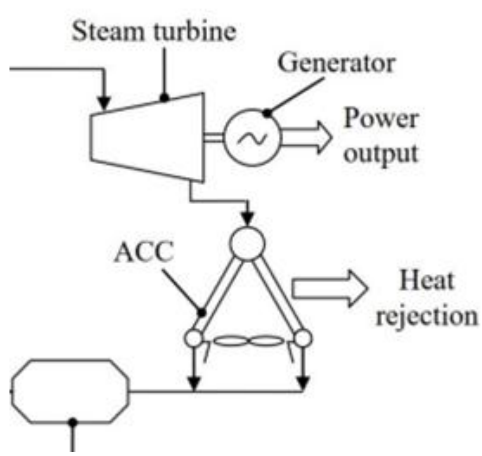

Figure 5: Power plant equipped with an air cooler.

The total capacity of the steam output from the Low-pressure section of the turbine is equivalent to 90 tons per hour, and the arrangement of the condenser and ACC has been investigated. It is worth mentioning that, considering the sensitivities, the main goal is that the existing S.C. system remains and practically, due to the possibility of branching according to the available space on the outlet hood, the possibility of using both systems is provided. Concering the sensitivities and the need to describe the flow distribution between the two exchangers, the investigation of pressure drops, the investigation of heat loads, and other related issues, the design will be done based on the following two methods:

1. Design based on two-dimensional modeling with HTRI software and heat transfer formulas
2. Three-dimensional modeling and CFD description using COMSOL software.

The simulation work of the exchanger and cooling tower has been done with T.F323 software, and the reason for choosing this software as the basis of the simulation, besides the accuracy and considering all the details of the equipment for accurate simulation, is the wide range of equipment introduced by the software. The analysis was conducted for both the minimum and the maximum heat load capacities of the exchanger under the hottest temperature conditions of 52 °C and a maximum relative humidity of 30%.

The investigation of the design principles of piping and air condensers and their accessories has also been done using CFD calculations and simulation with HTRI software. CFD method has been used for ACC design and investigation of operational factors such as pressure drop in the tubes, the possibility of choking, etc. to ensure the complete thermal design and accurate investigation of the heat transfer process between steam and air, and the fluid behavior in all parts is investigated in terms of pressure drop and choking phenomena. Based on this, the maximum diameter of the pipes should be considered 812.8 mm, equivalent to 32 inches, and the maximum speed of ~20-30 m/s has been calculated to prevent the phenomenon of choking along the pipe, and considering the location of the project implementation, there will be no restrictions in terms of access to other units. The piping design principles are based on creating a maximum pressure drop of 0.02 bar and not creating choking in the path, the calculations of which have been done through CFD calculations. Two types of tubes are used in the ACC structure. The first type of tubes, which are known as condensation tubes, are responsible for almost all of the heat transfer load in the exchanger structure. These tubes connect the steam inlet header to the condensate header. The second type of tubes is dephlegmator tubes, which are used if the ACC structure has more than one row of tubes. The main purpose of considering dephlegmator in the ACCs structure is to prevent the reverse flow of steam in the tubes and, as a result, prevent the accumulation of non-condensable gases in the tubes. Due to space constraints and to maximize the use of space, the length of the tubes is selected to be 9 meters and their diameter is 31.75 mm, the diameter of the fans is 7.92 meters and the connection of the fan to the electromotor is by belt. A suitable pump is considered to transfer the collected condensate from the receiving tank to the main tank, and also an ejector, which is responsible for the initial discharge during start-up and creating a vacuum during operation, is considered. The equipment and facilities of the unit are mainly made of carbon steel. The basis of the design of this system is based on the condensation of 20 t/h of LP steam output from the turbine with a pressure of 0.26 bar and a temperature of 73.5 °C. In this project, the design of the steam and condensate water path for three ACCs has been done by analytical and numerical methods. To numerically simulate the flow and heat transfer for the steam output from the turbine to the stage of conversion to condensate water in the ACC, the governing equations are in three dimensions including the equations of continuity, momentum, k and epsilon and energy, and the equation of state. These equations have been solved using Ansys Fluent software and the computing server of Razi University. Likewise, the path design is based on the same flow rate and pressure drop, and in the second case, based on the same velocity in the pipes carrying steam from the turbine outlet to the inlet to the cooling towers and also from the turbine outlet and in the condensate pipes. Due to the high rate of steam in the pipes, the flow is compressible and turbulent. Furthermore, due to the lower cost of piping and fittings and, as a result, less pressure drop, the same velocity method was chosen for the design. Calculations were performed for the miter elbow without guide vanes and the round elbow and the miter elbow with guide vanes (Figure 6) and their effect on the pressure drop was investigated. The results showed that to avoid high-pressure drops, the miter elbow with guide vanes is more suitable for connections. The opposite figure shows the pressure drop obtained from the Moody diagram method. By creating guide vanes at the elbow, it is expected that the flow will be guided in a better way. Flow separation and the presence of vortices after the elbow are eliminated in this case. As can be seen, the guide vanes have guided the flow well. In this case, the presence of the vanes has caused the pressure drop to be converted into a frictional type, and the presence of the vanes by eliminating the vortex in the elbow causes a reduction in pressure drop compared to other elbows, this effect is visible in Figure 6.

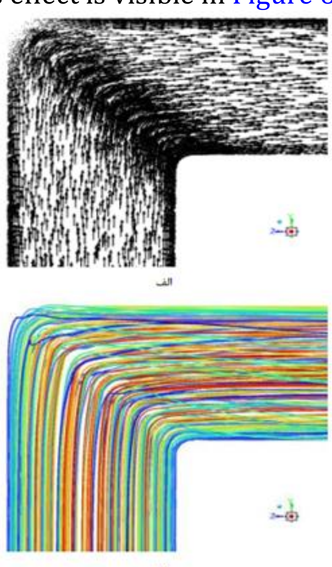

Figure 6: CFD design of elbows.

Here is the translation of the provided text into fluent, scientific English, with the references integrated appropriately:

The results also show that the designed path has created equal flow rates, i.e. 1.592 kg/s, for each of the three air-cooled condensers and approximately equal pressure drops in all three paths. Due to the existence of standard sizes for the pipes and the impossibility of selecting the diameters obtained from the calculations, the pressure drops in the different paths are not exactly equal, but they have the least difference from each other. Due to the space constraints of the site and the strength of the steam outlet duct sheet from the turbine, one or three outlets with a diameter of 61 cm are considered. For the two locations being considered for the installation of the ACCs (three units), calculations have been performed for two different scenarios. One location is near the turbines, while the other is situated farther away. Initially, calculations were conducted for the location close to the turbines, and subsequently, the calculations were repeated for the more distant location. It was decided to transfer the entire outlet flow from the turbine to the ACCs through three branches. However, with the identification of problems such as choking for the entire flow rate and also the limitation of the branch size that can be created in the turbine outlet duct, it was decided that about one-sixth of the total flow rate would be transferred to the ACCs. Calculations for the first location were done with three branches and different flow rates, but calculations for the second location were done with one branch and one-sixth of the flow rate for all three ACCs. According to the results, for a location farther from the turbine neighborhood, the total flow rate is equal to 19 tons per hour using one branch (to reduce piping costs) for all three ACCs. The final results were fixed for the farther location, and the numerical simulation was done in three stages:

1- Transfer of steam output from the turbine from the beginning of the branch to the beginning of the air cooler and its header.

2- Inside the finned tubes, which, by passing air over them, condensation takes place inside them.

3- Condensate water collecting header.

Conclusion

The study of the project of using an air condenser or dry condenser in Fanavaran Petrochemical was carried out to reduce the consumption of makeup water by reducing the amount of evaporation in the cooling tower of the methanol unit. In the first stage, after operational data collection, site visits, and analysis of the region's weather conditions, the simulation of the operating and design conditions of the cooling tower, E-4 condenser, and C-3001 turbine was done. It was very high accuracy compared to the unit documents. As well as examining the conditions of the complex in terms of the possibility of installing an air cooler condenser, an air condenser was designed along with all accessories such as a condensate transfer pump, condensate receiving tank, piping, etc., and the relevant documents were issued by IPS, NIOEC, HEI, and ASME standards. The important and noteworthy point of this study is that the existing E-4 condenser is currently unable to condense the input steam volume due to the decrease in heat capacity, which is based on the HEI standard, which explicitly states the steam quality at the turbine outlet of 0.85, and this will reduce the efficiency of the turbine.

This decrease in efficiency has caused a much larger volume of steam to be consumed to supply the compressor power, which, in addition to creating additional costs, has also caused the following problems:

1- The higher temperature of the water leaving the E-4 condenser is not only causing faster scaling in the condenser but has also significantly increased the heat load on the cooling tower. As a result, there has been an uptick in the consumption of makeup water.

2- The entry of an excessive volume of LP steam into the condenser and the low efficiency of the E-4 condenser have reduced the condensation rate, which has resulted in a decrease in the steam velocity in the turbine outlet hood and the steam complex, which can lead to a decrease in turbine efficiency. In this regard, it is necessary to mention that the steam exiting from the mentioned turbine in all seasons due to the mentioned defects is always between 5 and 9 degrees Celsius in a supersaturated state, one of the reasons for which may be the inefficiency of the condenser.

If the proposed air condenser is installed and put into operation, it will reduce the flow of low-pressure (LP) steam entering the E-4 condenser by 20 tons per hour. This reduction will enhance the efficiency and performance of the turbine. In addition, it will significantly slow down the scaling process. By minimizing scaling, overall efficiency of the condenser will improve, resulting in a lower heat load.

have a significant effect on reducing the amount of makeup water by 140,000 cubic meters per year. This project, according to the initial assessment done in the summer of 1401, will cost approximately one hundred and forty billion Rials, which, considering the positive effects on the following, seems to be a completely logical investment:

1- Reducing water consumption
2- Improving turbine efficiency
3- Improving E-4 condenser efficiency
4- Reducing repair cost

It is important to note that in the coming years, due to the decrease in rainfall on the one hand and the high costs of energy carriers on the other hand, most large companies will be forced, apart from the methods of the past decades to reduce operating costs, to turn to the implementation of new projects such as the project presented to improve the conditions. The decrease in efficiency has caused a much larger volume of steam to be consumed to supply the compressor power, which, besides creating additional costs, has caused the temperature of the water exiting the E-4 condenser to rise, which as a result causes faster and more scaling in the condenser. The heat load of the cooling tower has also increased significantly, and this has led to increased consumption of makeup water. In total, this project can help to reduce the load on the E-4 condenser and, as a result, the turbine outlet pressure and increase turbine efficiency.

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