CONCEPTUAL DESIGN AND LAYOUT OF THE COOLING TOWERS NECESSARY TO REMOVE HEAT FROM THE CONDENSER SECONDARY CIRCUIT OF THE ALFRED DEMONSTRATOR REACTOR

PROIECTUL CONCEPTUAL ȘI AMPLASAREA TURNURILOR DE RĂCIRE NECESARE PENTRU ÎNDEPĂRTAREA CĂLDURII DIN CONDENSATORUL CIRCUITULUI SECUNDAR AL REACTORULUI DEMONSTRATOR ALFRED

Iulian Pavel NITA[1], Rodica PANCEF[2]

Abstract: *In this paper it will be presented designing calculation of a cooling tower battery required to remove heat from turbine condensers from secondary circuit of ALFRED reactor. The proposed cooling system it is in closed circuit, having as final cooling agent ambient air in forced circulation, solution feasible for future layout of future ALFRED demonstrator reactor. In this paper it will be presented also layout proposal and technical solution chosen for removing heat from turbine condenser*

Keywords: ALFRED reactor, Cooling towers

Rezumat: *În cadrul lucrării se va prezenta calculul de dimensionare a unei baterii de turnuri de răcire necesare pentru răcirea condensatoarelor turbinei din circuitul secundar al reactorul ALFRED. Circuitul de răcire propus va fi un circuit închis, cu turnuri de răcire in circuit închis, având agent de răcire aerul atmosferic cu circulație forțată, soluție fezabila pentru amplasamentul viitorului reactor de demonstrație ALFRED. In cadrul lucrării se prezinta și propunerea de amplasare precum și soluția tehnica aleasă pentru răcirea condensatorului turbinei.*

Cuvinte cheie: reactor ALFRED, turnuri de răcire

1. Introduction

The scope of this paper is to design and make general layout of main equipment for cooling system of secondary circuit condenser of ALFRED demonstrator reactor.

[1] dr. eng ITP gr II, RATEN - CITON, Magurele ILFOV, ROMANIA, e-mail: nitai@router.citon.ro
[2] eng - SINGP, RATEN - CITON, Magurele ILFOV, ROMANIA, e-mail: pancefr@router.citon.ro

Many industrial processes require the elimination of heat fluxes in the environment, in order to maintain the parameters of the energy processes within the normal operating limits.

In the case of high capacity industrial energy installations, this heat elimination is usually achieved by means of a cooling water flow that takes the heat from the respective industrial installation, in our case the ALFRED turbine condenser and then gives it to the environment.

This transfer to the environment of the heat taken from the industrial process, by the cooling water, is usually achieved by means of cooling towers. Industrial water cooling is done in cooling towers in which the water gives off a certain amount of heat, reaching nominal parameters so that the water can be recycled for cooling of the respective installations.

The quality of the water used in the energy industry is of vital importance in the smooth running of the technological processes and in ensuring an adequate life of the installations.

There are cooling systems in which the water is used only once, with a single passage (open circuit cooling towers) after which the water is discharged and there are cooling processes in which the water is recirculated (closed circuit cooling towers).

Factors influencing the process of convection and evaporation cooling are the contact surface between water and air and the heat and mass exchange coefficients between water and air. The humidity of the air entering the tower influences the evaporation of the water that occurs due to the difference between the pressure of the formed vapor and the pressure of the water vapor in the air.

It is recognized that the best technical procedures for cooling a process is a complex problem, because it must be ensured that the cooling requirements of the process must be balanced, the specific factors in each case and the environmental requirements, which allows the system to be implemented only under conditions economically and technically viable.

2. Description of the activities performed within the work

2.1. ALFRED reactor condensing cooling water system

Heat absorption from the condenser is done with cooling water from cooling towers in the closed circuit. Closed-circuit cooling tower batteries are provided because the location of the ALFRED demonstration reactor does not allow for open-circuit cooling due to the lack of a permanent water source.

The following are the thermal loads required to be transferred in the three operating modes (nominal, severe summer, severe winter).

The cooling towers for the ALFRED demonstration reactor were sized for the severe summer regime.

Table 1. **Main values of secondary heat transfer circuit of Alfred reactor**

Environmental conditions	**Nominal**	**Severe summer**	**Severe winter**
Thermal efficiency (%)	43.92	42.52	44.38
Heat power (MW)	142.4	147.1	140.2
Condenser pressure bar (a)	0.054	0.101	0.0423

The condensation process, being a phase change process, takes place approximately isobaric-isothermal. The final pressure obtained in the condenser is dependent on the temperature of the cooling water, the amount of cooling water and the temperature differences that determine the heat transfer.

The evacuation of heat in the cooling tower takes place, on the one hand by convection between fine drops of water and the surrounding air and on the other hand, by evaporation (a small amount of water evaporates in the air). Therefore, the process involves both heat transfer and mass transfer. Thus, we can say that the cooling of the water in the towers is due to the exchange of heat and mass between the water and the outside air with which it comes in contact.

Due to the complex exchange of heat and mass between water and air, the state of the air has a complex evolution, tending towards the saturation state at the exit of the tower.

The main climatic parameters, with a special influence on the cooling tower are: ambient temperature, wet bulb temperature and air humidity.

The systems in the secondary circuit of the ALFRED demonstration reactor must be designed, manufactured and operated in accordance with the European and national regulations and standards in force or with other types of standards identified by the authorization holder and approved by the National Commission for the Control of Nuclear Activities.

Also, the ALFRED project will comply with the nuclear safety requirements regarding the design and construction of nuclear power plants, according to the European norms in force. These norms will be issued in accordance with the provisions of Law no. 111/1996 on the safe conduct, regulation, authorization and control of nuclear activities.

The fulfillment of the provisions of these norms constitutes a necessary condition for the authorization by the CNCAN (National Commission for the Control of Nuclear Activities) of the construction activities of the ALFRED demonstration reactor.

2.2. Details of the proposed conceptual project

For the cooling system of the ALFRED reactor, a preliminary technological scheme was drawn up (conceptual project phase). The cooling system of the ALFRED reactor is a new system, designed entirely within this work.

For cooling the condenser ALFRED, it was chosen the choice of a system with 10 cooling towers in closed circuit (mixing), with forced circulation, in counter current, of 15 MW each and 3 centrifugal circulating water pumps (3 x 50%), located in the Pump Station of the plant.

The proposed forced circulation cooling towers are equipped with axial fans and allow the adjustment of the cooling water temperature by varying the number of fans in operation and their speed. In this regard, we have proposed the use of cooling towers with fans with variable speed motors.

According to the proposed scheme for the cooling circuit of the ALFRED reactor, in normal operation, it is sufficient to operate two circulating water pumps to ensure the transfer of heat to be removed from the reactor.

The temperature of the cooling water supplied to the condenser will be maintained in the range (20.9°C to 32.5°C), during the operation of the ALFRED reactor, in all three regimes: nominal, severe summer and severe winter. The towers were sized to provide cooling water at 32.5°C (severe summer) at the condenser.

The flow rates of cooling water conveyed, at a temperature difference in condenser of 10°C, are the following:

- nominal speed: 3401.9 kg/s;
- severe summer regime: 3513 kg/s;
- severe winter regime: 3349.7 kg/s.

Also, the thermal load required to be transferred through the cooling towers is as follows:

- nominal capacity: 142.4 MW;
- severe summer regime: 147.1 MW;
- severe winter regime: 140.2 MW.

Cooling towers with forced draft were chosen because they provide more intense cooling than the other types of cooling towers, being equipped with cooling batteries that provide maximum cooling capacity.

Advantages of using the cooling towers chosen are: low energy consumption; low noise level due to the fact that they have the possibility to provide"low-sound" and"super low sound" fans; easy maintenance; the best solution for avoiding Legionella bacteria; energy saving - low consumption due to axial fans with variable load; Higher hydraulic load due to higher air velocity (compared to natural draft).

The pumping station will be of semi-buried type and contains 3 centrifugal circulating water pumps (3x50%) with the following flow rates Q (kg/s):

Weight = 1702 kg/s; Qmax = 2284 kg/s; Qmin = 854.7 kg/s.

The location of the semi-buried pump station was chosen to ensure optimum operating conditions of the pumps, creating a NPSH reserve in the installation, to prevent the operation of the pumps in the cavity.

The water required for filling the hydrotechnical circuit as well as the compensation of losses is made with decarbonated treated water, received from the Water Treatment Station.

Each pump takes from a 40" header (Dn 1000) on which were placed an isolation valve with a butterfly flap, a filter, ventilation, drainage and automation equipment. Also on each pipe on the pump discharge is provided with a butterfly flap retention valve, an electrically operated butterfly flap closure valve, ventilation, and drainage and automation equipment. All three pipes flow into a common 40" header.

Header G001-52" (Dn 1300), through which the hot fluid from the CD1 condenser located in the Turbine Building circulates, has an underground route at the altitude of 2,400 m, in the technological channel. On this header, in the Turbine Building, a an electrically operated closing valve MV004-52"was provided, which isolates the output from the reactor CD1. The header is further branched into two headers.

The cooling towers consist of four cooling cells, each equipped with an axial fan. Each cell has an input on the hot fluid and an output on the cold fluid (fluid resulting from the cooling process in the tower). The entry of the hot fluid in the tower is made at the elevation + 6,187m and the exit of the cold fluid from the tower is made at the elevation + 2,415m.

The inlets and outlets in / from the cooling cells are provided with a manually operated butterfly flap isolation valve.

The cooling fluid from the towers is output via two headers G004 and G005.

The outlet of each cooling cell is provided with a manually operated butterfly flap closure valve.

Both exit headers are joined in a common header G006-52" (Dn1300) which has an underground route in the technological channel (at elevation -2,400m) to the pump station.

The entrance to the pump station is made underground at the level of the header G006-52" (Dn1300).

Exit from the pump station of the header G007-52" (Dn1300), will be made apparently at the elevation + 1,171 m. Next, the route will be underground in the technological channel, until the limit of the Turbine Building.

On the header G007-52", in the Turbine Building, there was provided an electrically operated butterfly flap closure valve, through which the entrance to the condenser can be isolated.

The suction header of the pumps was provided with elements of temperature and pressure measurement. At the output of each pump, a pressure measuring element was provided on the discharge pipe and on the header that connects the Pump Station and the Turbine Building, G007 - 52", a pressure measuring element and an element were provided. flow measurement (FE001).

A preliminary list of materials containing the main components (pipes, bends, tees, reductions, releases, special parts, manual and actuated fittings, automation equipment, supports, etc.) has been prepared for the entire proposed cooling water system.

The cooling circuit will operate at nominal speed with two of the three circulation pumps provided in the scheme. In order to carry out the sizing of the cooling circuit, the most unfavorable regime was considered, namely, the severe summer regime, when the temperature and the flow of the cooling water at the condenser have the highest values.

The sizing of the system was done considering a permissible flow velocity in pipes of maximum 2.5 m/s. From the dimensioning calculation resulted both the diameters of the pipes and the flow required by the circuit pumps at the charge of the cooling towers.

For the chosen sizing regime were considered all 10 cooling towers in operation, with the corresponding isolation valves open.

For the location of the cooling towers CT001 ÷ CT010 (10x15 MW), two variants of location have been studied. One of the variants is allocated for the location of the ALFRED plant, an area of 8300 sqm and the other variant has an area of 11500 sqm. In the area chosen for the location of the battery of cooling towers CT001 ÷ CT010 the following buildings will be located: pump station, water treatment station, auxiliary building for cooling towers and laboratory.

The space occupied by the cooling tower batteries and the buildings that serve them (circulating water pump station and auxiliary building for cooling towers), is as follows:

- Batteries cooling tower with forced draft: 70 x 22 (m);
- Water pumping station: 31 x 22 (m);
- Auxiliary building of the cooling towers: 20 x 20 (m).

Following the study of the two site variants, the variant with the larger surface was developed that was developed in the work at the conceptual project level. The reason for choosing this variant was for the efficient and correct operation of the cooling towers that require large amounts of air and in this regard, an adequate distance between the cooling towers and between the battery of cooling towers and the adjacent buildings must be ensured.

An equally important consideration when installing the battery of cooling towers is that the recirculation of hot air is minimal.

Also, at the location, the speed and direction of the wind were taken into account. In the area proposed for the location of the cooling towers, the frequency of the occurrence of the wind has an approximately "circular" distribution, with a slightly intensified frequency in the E and E-N-E direction.

In this regard, the cooling towers were located so that at high wind speeds, the amount of heat released in the form of vapors would not be directed to the important buildings on the ALFRED platform or to the Nuclear Research Institute.

Last but not least, the variant with the larger available surface was chosen to ensure the space needed for maintenance of the cooling batteries and the installation of the access platforms.

The selected process instrumentation will be adequate to allow the entire cooling system to be put into operation and properly operated in all operating situations.

The risk aspects of the ALFRED condenser cooling system refer to possible leaks and microbiological contamination. In this regard, preventive maintenance and monitoring are effective measures to prevent leakage as well as microbiological contamination.

As a recommendation, operators can opt for a remote control to monitor the operating parameters of the cooling towers and to use an automatic dosing device to maintain water quality.

2.3. Required industrial water for cooling circuit

The maximum water flow required to cool the condenser in the secondary circuit ALFRED, in severe summer regime is 3513 kg/s.

It can be ensured from the industrial water catchment circuit, the added care flow covering the losses of water by evaporation, the losses of water by entraining fine water paints to the flow of air introduced in turn and the amount of water needed to protect and protect the physical and chemical hold property of Kris (by purge).

The water flow required to ensure a temperature difference of 10°C in the inlet water temperature in cooling bends and the temperature output of the cooling towers is approximately 2.85% of the total flow of 3513 kg/s, so approximately 100 kg/s.

For the demonstration reactor ALFRED, the water supply source for industrial purposes or constitutes the Târgului river, the main prize Clucereasa.

2.4. Cooling capacity control at units equipped with axial fans

The best way to control the cooling tower's capacity is to use a frequency converter to power the fan motor. This method allows a precise capacity adjustment by changing the fan speed, allowing for loads close to the required installation.

The system can operate for long periods of time with fan speeds below 50% if the cooling load requirement drops or the outside temperature drops.

2.5. Management of ice deposits of cooling towers equipped with axial fans

In more severe weather conditions the use of defrost management is indicated. This is achieved by starting the fans at half capacity but with the reverse direction of rotation, during which the circulation pumps operate maintaining a constant flow of water through the cooling tower unit. By this method, the melting of ice deposits in the cooling tower is achieved, with the help of the hot air flow that crosses the unit in the opposite direction. For this it must be taken into account that the fans must be switched off and on to allow the water temperature to rise. In order to achieve this defrosting method, it is necessary for the drive motors to be in two stages, with the possibility of changing the direction of rotation or to be equipped with frequency converters, ensuring the possibility of adjusting the load as presented above.

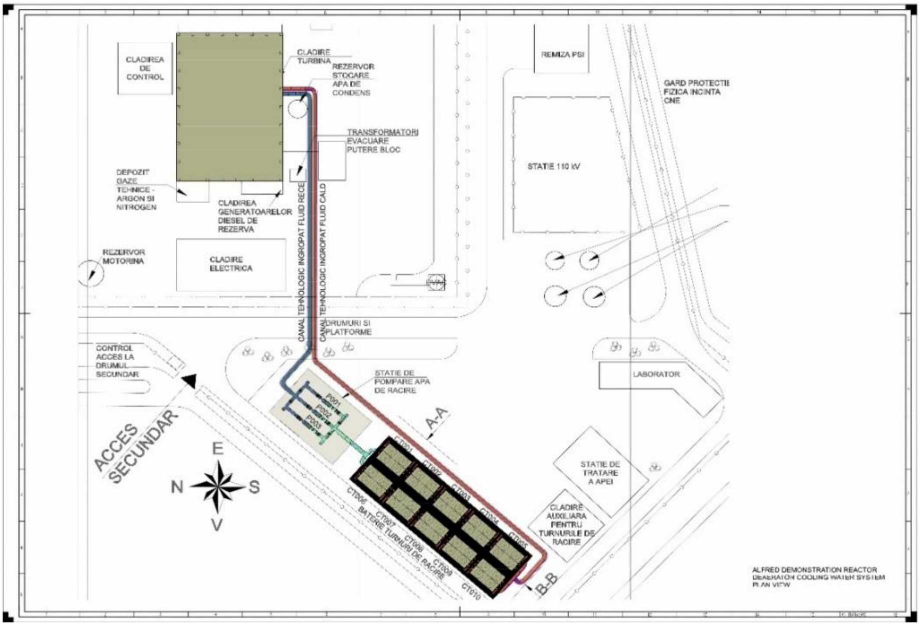

Figure 1. AFRED Demonstrator reactor Deaerator cooling water system Plan View

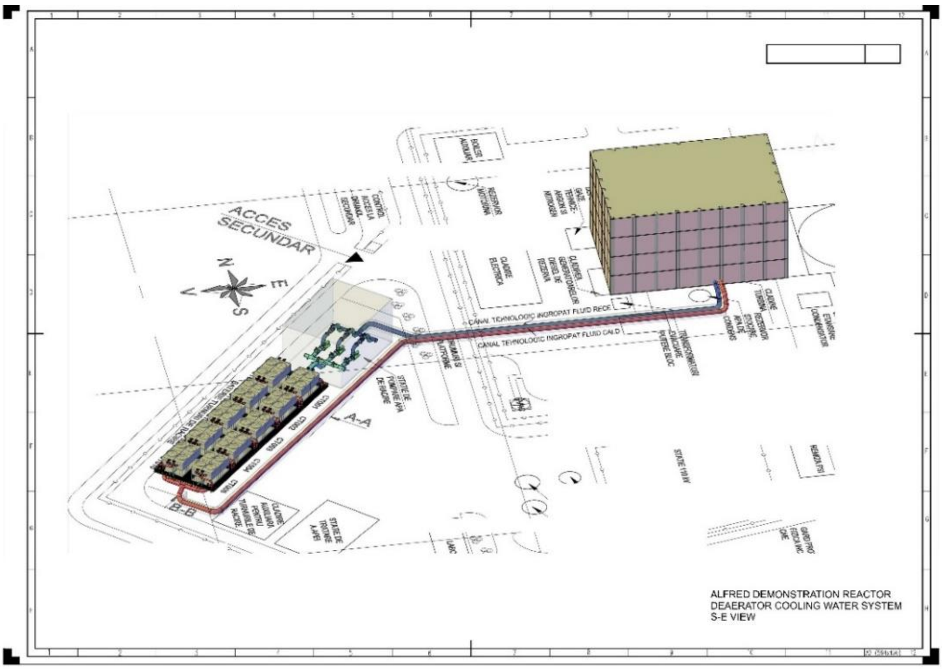

Figure 2. AFRED Demonstrator reactor Deaerator cooling water system S-E View

In the case of the Alfred reactor we proposed the variant with frequency converters.

The defrost cycle should be included in the automatic system for controlling the water-cooling process.

3. Obtained results

In order to analyze the behavior of the cooling system in the proposed configuration, a hydraulic calculation of the whole system was performed under the adverse cooling regime, severe summer.

Following the hydraulic calculation, the entire cooling water system was dimensioned and the diameters, flow rates, pressures of all pipes and hydraulic loads of the circulating water pumps were obtained. Being a system that carries water at a relatively low temperature, the flow through the system pipes has been dimensioned for a speed of 2.5 m/s.

After the dimensioning step, the circulating water pumps were chosen, resulting in a required pumping height of 15 mcf at a flow rate of 1757 kg/s for the severe summer regime.

Also, the sizing of the cooling towers was performed and the required additional water flow was calculated to compensate for the losses by evaporation, purge and losses resulting from the fine droplets of water by the air flow introduced into the tower with the axial fans positioned at the side. top of the towers. The addition water flow rate for the entire cooling battery resulting from the calculation is around 100 kg/s (around 10 kg/s per tower).

The basic design data used for choosing the cooling towers for the Mioveni site were: ambient temperature 37°C; wet bulb temperature 18°C; relative humidity 60% - 77%.

The thermal load transferred by the cooling tower battery has a reserve of 3.5%, from the calculation resulting in a total of 152.3 MW as against the 147.1 MW requirement.

Also, the air flow through the tower was calculated and a value of 332.5 m^3/s was calculated.

The pumping station has been chosen as a semi-buried type and contains 3 circulating water pumps (3x50%), with a semi-open rotor, in a single step, with a nominal flow of 1757 kg/s.

The location of the semi-buried pump station was chosen to ensure optimum operating conditions of the pumps, creating an NPSH reserve in the installation, to prevent the operation of the pumps in the cavity.

Following the hydraulic calculation, all the data necessary to dimension the installation were obtained, namely: pipe diameters, flow rates, pressures, as well as pump flow rate and pump height.

Following the calculation made, the NPSH available in the plant was determined resulting in a value of 11.8 m, compared to 5.1 m the required pump.

Thus, a reserve of 6.7 m results. From the hydraulic data of the network, the load requirement of the 15 mcl pumps resulted, at a flow rate of 1757 kg/s.

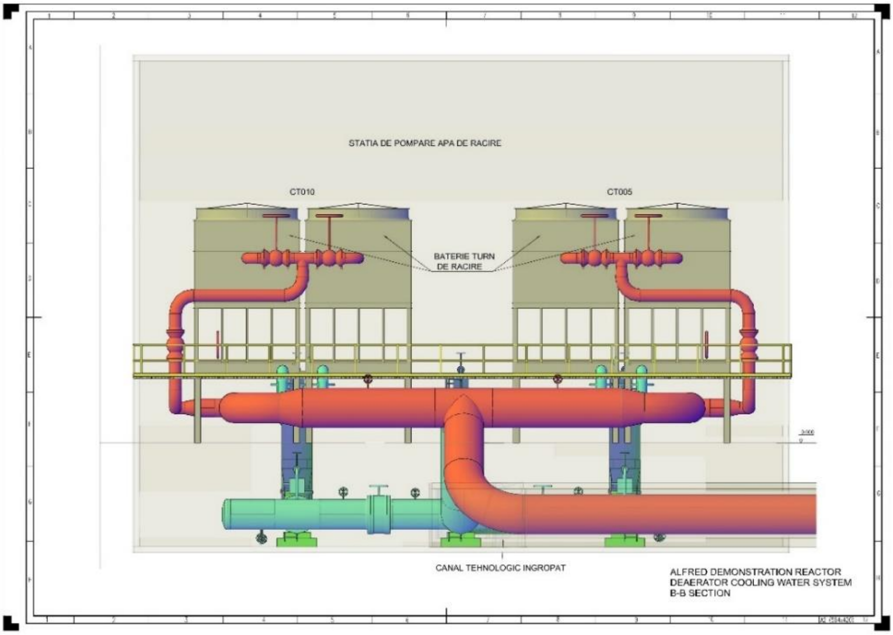

Figure 3. AFRED Demonstrator reactor Deaerator cooling water system - Pump Station B-B Section

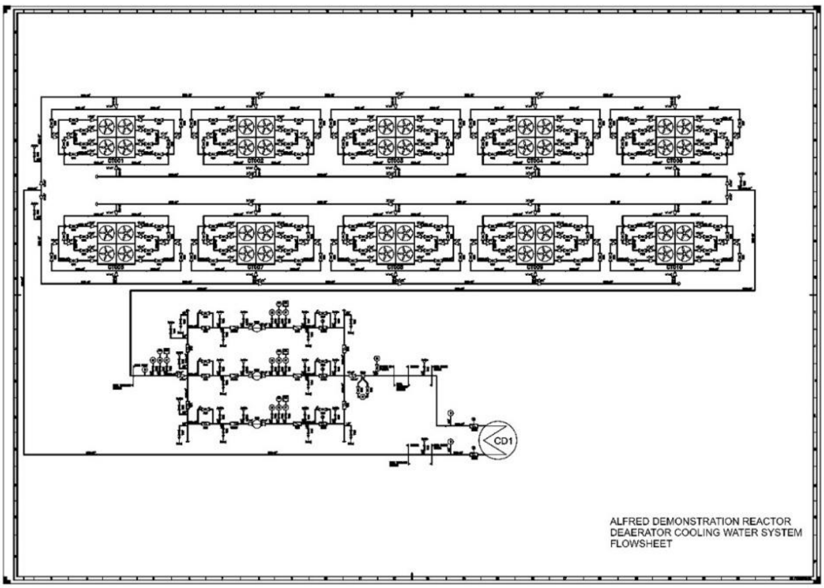

Figure 4. AFRED Demonstrator reactor Deaerator cooling water system - FLOWSHEET

4. Conclusions

This paper is part of the strategic direction regarding the support activities for the realization of studies, conceptual projects for the LFR, in particular for the ALFRED demonstrator reactor.

The cooling system of the ALFRED reactor is a new system, designed entirely within this work.

For the design of the cooling system of the demonstration reactor condenser ALFRED analyzed the terrain configuration, the position of the buildings in the area where the cooling battery location was proposed and the mounting position was established for the new equipment, components, route and configuration of all pipes, according to design requirements, codes and applicable standards.

General layout coordination in AUTOCAD PLANT 3D (figure 1, 2 and 3) was essential in establishing pipelines and mounting positions for equipment, components as well as buildings serving the cooling system, namely: Pump Station, Auxiliary Cooling Tower Building and Water Treatment Station.

The cooling water system of the ALFRED condenser is located on the ICN Pitesti platform, in a forested area, at an altitude of 445 m, where the number of days with high wind speeds is reduced.

The towers have been placed in such a way that the air flow in and out of the tower does not encounter obstacles that can lead to the phenomenon of air recirculation. In this regard, the wind direction has been taken into account, which has the slightly intensified frequency of occurrence from the E direction (7.6%) and E-N-E (8.2%).

The industrial water necessary for the normal running of the cooling process will be provided by the Clucereasa hydro node, supplied with water from the Târgului River.

The water required for filling the hydrotechnical circuit as well as the compensation of losses is made with decarbonated treated water, received from the Water Treatment Station.

A conceptual technological scheme of the condenser cooling system (figure 4) for the ALFRED demonstration reactor turbine has been proposed and important parameters have been calculated: pressure, flow, enthalpy, velocity in all pipelines of the system.

The pipes of the system have dimensions between 1/2"÷ 52". Most pipes are apparently mounted but there are two 52"headers that are mounted underground, in the technological channel. One header transports the hot fluid from the steam turbine condenser until it enters the cooling tower battery and another header carries the cold fluid, from the Pump Station to the CD1 reactor located in the Turbine Building.

In order to analyze the behavior of the cooling system in the proposed configuration, a hydraulic calculation of the entire system was performed under the adverse cooling regime - severe summer.

Also, the sizing of the cooling towers was performed and the required additional water flow was calculated to compensate for the losses by evaporation, purge and losses resulting from the fine droplets of water by the air flow introduced into the tower with the axial fans positioned at the top of the towers.

The choice of a battery consisting of 10 cooling towers of 15 MW each, in closed circuit (mixing), with forced circulation, with countercurrent circulation, in which the hot water coming from the condenser is distributed directly at the top of the tower, by spraying and coming into contact with the air blown through the tower, the air being sucked in at the bottom thus ensuring its cooling by evaporation of a certain amount of water.

The cooling towers with forced circulation are equipped with axial fans and allow the adjustment of the cooling water temperature by varying the number of fans in operation and their speed. In this regard, we have proposed the use of cooling towers with fans equipped with variable speed motors. These variable speed engines are very efficient and are also used in very cold periods, at negative temperatures, for defrosting cooling towers.

These cooling towers have the following advantages:

- low noise level because they have the possibility of providing "low-sound" fans that reduce the noise level by 4-7 db (A) and "super low sound" that reduce the noise level with 9 ÷ 15 db (A);

- easy maintenance; the best solution for avoiding Legionella bacteria; energy saving - low consumption due to axial fans;

- Higher hydraulic load compared to natural draft towers, due to the higher air speed.

Each tower is composed of 4 cooling cells, each cell having a fan of 45 kW.

The pumping station was chosen as a semi-buried type and contains 3 centrifugal circulating water pumps (3x50%), with a semi-open rotor, in a single step, with a nominal flow rate of 1757 kg/s.

In this conceptual project, the installation of the battery of cooling towers, of the pump station in which the main equipment and components with the related automation, as well as of the routes of the two headers were made: the hot fluid and the cold fluid. For these routes were prepared: preliminary lists of materials, preliminary data sheets for all components and equipment in the scheme, 3D location plans (plan views and sections), hydraulic calculation of sizing of the whole system and thermal calculation for battery sizing cooling towers.

For the dimensioning of the cooling towers, we used relations from the specialized literature that were solved with the calculation program MATHCAD13 and for the dimensioning of the routes and the choice of the pumps, the calculation code PIPENET 1.9 was used.

The input data for the secondary circuit of the ALFRED demonstration reactor were extracted from the paper [1].

Following the hydraulic analysis for the configuration of the cooling system, the new system provides design parameters for the cooling water at the turbine condenser (CD1), on the secondary side of the ALFRED boiler, in the most severe operating regime, namely, severe summer.

Also described in the project were:

- the location of the ALFRED demonstration reactor and the CD1 condenser cooling water system;

- the design requirements for the new cooling system and for the interface systems of the CD1 reactor have been established;

- the requirements regarding integrated control and prevention of the environment; description of the main equipment and components was made;

- normal and abnormal operating regimes have been described; the basic operating sequences of the cooling towers CT001 ÷ CT010 have been described;

- described the method of controlling the cooling capacity of the towers, the treatment and water chemistry, the control of the biological contamination of the water, the freezing protection of the entire cooling system and the management of ice deposition on the cooling towers equipped with axial fans;

- an interface chapter of the cooling system was prepared with the other systems in the secondary circuit ALFRED; described the air quality and the wind regime in the cooling system installation area (Mioveni);

- a preliminary list of equipment, components and fittings was prepared, the calculation hypotheses, the methods of analysis of the calculation schemes and the calculation methods used were described.

From the calculation we can conclude that the cooling water system of the condenser of the secondary circuit ALFRED, in the proposed location variant, fulfills its performance indicators when operating in severe summer regime, in this case the cooling fluid flow (3513 kg/s), when the maximum temperature of the cooled fluid is 32.5°C and the temperature difference in the condenser is 10°C.

The proposed conceptual design for the cooling system ensures the total evacuation of the amount of heat of 147.1 MW, from the condenser of the secondary circuit of the ALFRED demonstration reactor, in the severe summer regime.

The final conclusion of this paper is that the cooling requirements are met, using 100kg/s cooling water, thus ensuring the appropriate technological conditions for the operation of the secondary circuit of the ALFRED demonstration reactor.

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