CONCEPTUAL DESIGN AND LAYOUT OF AIR-COOLING CONDENSERS (ACC) HEAT SINK FOR ALFRED LFR DEMONSTRATOR REACTOR

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Abstract

In present paper a conceptual design for a state-of-the-art condensing cooling with air, an EVAPCO-BLC patent applied for the Mioveni location existing conditions and cooling requirements from ALFRED LFR demonstrator reactor, was presented. The Mioveni site is characterized by a shortage of cooling water and huge hydrological work is required to provide remote water supply. The proposed cooling system uses air-cooled condenser (ACC) technology with a "V" shaped frame, in which the fans are located at the ACC top. Introducing a deflector in the condenser, a significant improvement in cooling performance is achieved when environment temperatures are high. These types of ACC exchangers provide maximum surface area on the footprint for greater heat dissipation while providing efficient dry cooling capabilities.

Keywords: *ACC, ALFRED, LFR, EVAPCO, Air cooling condenser*

Introduction

The present work addresses a new cooling technology that provides condensation of the exhaust steam from the low-pressure casing of the ALFRED turbine via Air Cooling Condensation (ACC) cooling towers. In 2018, the US-based Evapco-BLCT company "Advanced Technology ACC" brought to market the "no CoreTM" heat exchanger, which is a new, innovative technology that pushes the limits of heat transfer in dry cooling applications.

The "no CoreTM" heat exchanger (condenser) greatly improves heat transfer coefficients over a wide range of operating conditions to reduce surface area requirements and reduce material costs.

The advanced ACC technology is centered on a modular design concept. This dry cooling concept is addressed in the conceptual design for direct air cooling of the ALFRED demonstration reactor secondary circuit [1].

Taking into account the immediate and future global concerns in the field of energy safety and water availability for the ALFRED demonstration reactor at the Mioveni site such a solution can be considered.

ALFRED (Advanced Lead Fast Reactor European Demonstrator) is a demonstration reactor for Lead Fast Reactor (LFR) technology [2] and is the main component of a unique research infrastructure to be built on the platform of the Institute for Nuclear Research (RATEN ICN) Pitesti, located in Mioveni, Arges County.

The combined effects of global population growth and expanding industrial, agricultural and commercial activities have placed increasing demands on both water and electricity.

As the developing countries advance, competition for water will increase while climate change will greatly affect water supply. Electricity and heat suppliers will become more vulnerable to water shortages, leading to power outages and significant loss of revenue.

In these conditions, many energy developers, due to lack of water location restrictions and environmental concerns decide to develop and install dry cooling systems. The selection of direct air cooling (dry) technology to be used for power plants is an economic decision frequently influenced by environmental and by local factors.

Thus, air-cooled condensers designed for industry evolved into a configuration that recognized the special needs of condensing a large volume of low-pressure steam.

We consider this new, innovative type of cooling to be a convenient technical-economic process for the ALFRED demonstration reactor secondary circuit [3] since there are no thermal and chemical pollution problems resulting from the use of coolant:
- the cooling circuit presents flexibility for any location and layout of the mounting area since the equipment requiring cooling does not need to be near a permanent cooling water supply;
- maintenance costs are reduced;
- installation is easier because the installation is modular;
- the environmental impact is lower than in the case of water-cooled condenser due to the elimination of water consumption while no chemicals are needed for water treatment.

Generalities

In the beginning, the use of dry cooling methods was sometimes the only feasible option due to the lack of water for some sites. However, the combined trends of increasing energy demand, a wider rate of shortage of water available for cooling and rising water costs, and more stringent environmental restrictions on the use of wet cooling systems have served to broaden the selection of the ACC (Air Cooling Condenser) option, both in terms of number and size of units.

The growing importance of this quite different technology for condensing and recovering steam exhausted from the turbine requires a broader understanding of the design and associated application principles involved, as well as performance monitoring techniques and cleaning methods to be applied. This was also pursued in the present work.

Air-cooled condensers (ACCs) designed for industry, have evolved into a configuration that recognized the special needs of condensing a large volume of low-pressure steam, as well as eliminating non-condensable components.

Air-cooled condensers are used for two main reasons:
- increase the efficiency of power plants;
- are a good solution compared to water-cooled towers because they do not require make-up water supply (water lost due to wind entrainment of small water droplets and evaporation) and no chemicals are needed for water treatment.

The overall efficiency of a nuclear power plant depends largely on the performance of the condenser, and the performance of the ACC depends on the ambient air temperature, fan performance and wind strength and direction.

In this study, the direct air-cooled condenser uses dry cooling technology to remove heat from the thermal cycle of the ALFRED demonstration reactor.

The thermal loads required to be transferred, in the three operating regimes of the ALFRED secondary circuit (nominal, extreme summer, severe winter) are presented in the table below.

Table 1. Heat loads and environmental conditions for Mioveni site [4 - 6]

Environment conditions	Nominal	Extreme summer	Severe winter
Secondary cycle efficiency [%]	43.92	42.52	44.38
Heat transferred [MW]	142.4	147.1	140.2
Condenser pressure bar [a]	0.054	0.101	0.0423

The cooling towers for the ALFRED demonstration reactor have been sized for the extreme summer regime, the most demanding regime in terms of cooling performance.

In order to design the secondary circuit cooling system of the ALFRED demonstration reactor, the configuration of the site, the location of the buildings in the area where the cooling battery (consisting of towers equipped with direct air-cooled condensers) was located have been analyzed. The mounting position for the new equipment, components, routing and configuration of all piping was established according to the design requirements, codes and applicable standards.

Spatial layout using AUTOCAD PLANT 3D software was essential in establishing the piping routes and mounting positions of equipment, components and existing buildings on the RATEN ICN Pitesti platform.

Dry cooling

Dry cooling removes heat from a system by using ambient air to reject heat. Since this type of cooling is waterless, the maintenance required for such cooling equipment is greatly reduced.

Dry cooling can be used for closed circuit cooling of fluids and also for condensing steam by direct air cooling (direct air-cooled condenser towers).

Dry cooling is widely used as a method of condensing steam in a vacuum in power generation plants using an Air-Cooling Condenser (ACC) [4]. In this process, the steam evacuated under vacuum at the outlet of the low-pressure turbine casing enters a series of circular pipes (tubing) that carry the steam to the condenser battery.

The ACC cooling tower [5] directs steam through a series of finned pipes, where ambient air is forced over the fins, resulting in condensation of the discharged steam. In short, the ACC consists of ducts (to transport the steam), condenser cores (finned tube bundles) to increase heat transfer, mechanical equipment to create airflow (fans, motors and gearboxes) and ducts/tanks to collect the condensed steam.

A direct air-cooled condenser can replace a surface condenser and cooling tower system when water is not available or simply is too expensive.

Airflow and surface are essential to maximize the cooling effect of a dry cooling system. There are systems that facilitate this energy transfer by directing the process fluid through a series of finned, aluminum, high-pressure pipes. By constantly passing large amounts of air through the pipe fins, heat is rapidly removed from the system and exhausted to the atmosphere.

There are several models specifically designed to operate in 100% dry cooling mode, either closed-circuit cooling towers or direct air-cooled condensers.

In present study, the direct air-cooled condenser model was chosen. In the ALFRED cooling circuit diagram, a "V" type capacitor has been considered, the fan being mounted at the top of the capacitor (see Fig. 1).

The advantage of the V-type condensers is that they are efficient solutions requiring minimal side space to maintain air circulation and can exhaust air through maximized space.

The V-shaped air-cooled industrial condensers provide maximum surface area on the footprint for greater heat dissipation. These units maintain a low profile while providing efficient dry cooling capabilities.

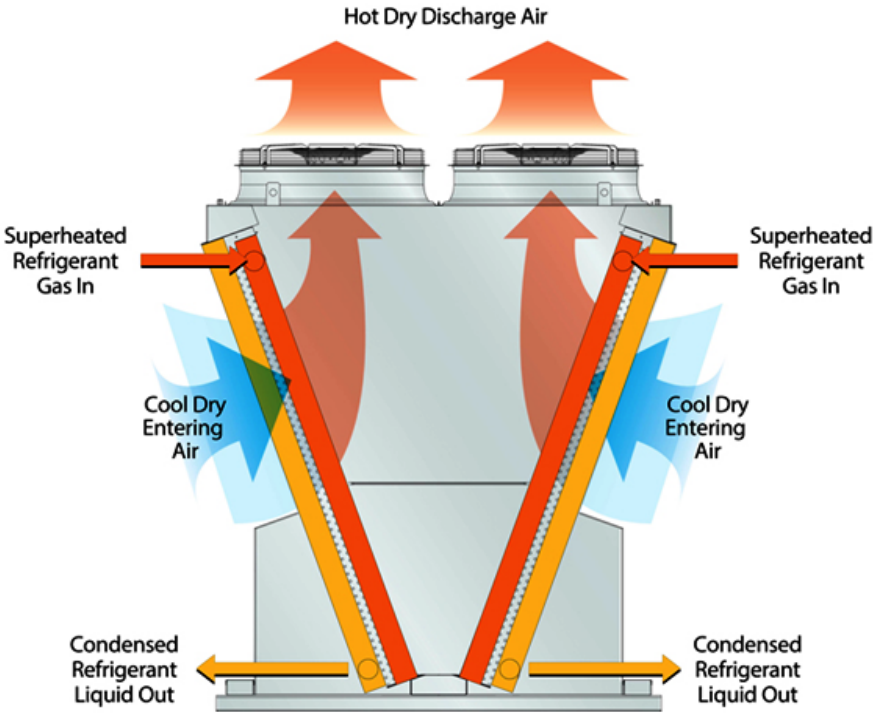


Fig. 1. "V" type ACC Condenser diagram

Obtained results

The sizing calculation for the secondary circuit cooling system of the ALFRED demonstration reactor [8] was performed taking into account the *extreme summer regime*, which is considered the most demanding regime for the secondary circuit due to the maximum thermal load to be removed and the difficult cooling conditions characterizing the summer season.

After the hydraulic sizing calculation was performed, the diameters, flow rates, pipe pressures and hydraulic loads of the condensate pumps of the circuit were obtained.

For the sizing calculation of the condensate circulation piping from the ACC cooling towers [9] to the thermal cycle in the Turbine Building, a maximum allowable velocity of 1.5 m/s was considered.

After the sizing step in which the diameters of all the pipes in the system on the condensate side were obtained, the condensate pumps were selected. Taking into account the hydraulic data of the network, the load requirement of the pumps was 10 mcl, at a flow rate of 226.58 m^3/h. Two fully redundant pumps with 100% (1+1) were chosen.

For the system operation, the NPSH available in the installation was determined resulting in a value of 12.6 m, compared to 2.68 m pump requirement, with a reserve of 9.22 m.

The basic design data used for the selection of cooling towers at the Mioveni site are the following: turbine exhaust steam flow = 65.2 kg/s; turbine exhaust steam enthalpy = 2447.2 kJ/kg; turbine steam back pressure = 101 mbar(a); total heat transfer = 147.0 MW; dry bulb temperature = 30.2 °C; steam title = 94.3%; steam temperature = 46.0 °C.

The heat load transferred by the cooling tower battery (ACC1 ÷ ACC14) has a margin of 4.6%. EVAPCO's offer, for the ACC cooling tower battery introduced in the scheme, results in a total load of 154 MW against the requirement of 147.1 MW under extreme conditions - *EXTREME SUMMER*, when all 14 ACCs with which the cooling tower battery has been equipped are in operation.

For this conceptual design, a battery consisting of 14 direct air-cooling towers arranged in three rows (two rows with 5 ACCs and one row with 4 ACCs) with forced draught (with axial fan) was chosen, where the steam coming from the turbine through the 5.3 m collector is distributed directly to the lower part of the ACC tower and then through vertical columns to the ACC condensers.

Due to the Copyright Agreement with EVAPCO, the patent owner, the computational diagram, condensate storage and pump layout, cooling tower layout, and Process and Instrumentation Diagram are available only contacting the present study first author on the email provided for correspondence, nitai@router.citon.ro.

Conclusions

The ALFRED secondary circuit direct air-cooling system plays a key role in the thermal cycling of the power plant, supplying the ACC condenser with the amount of cooling air required to remove condensation heat from the steam for all turbine and steam generator operating modes.

In the ALFRED scheme, the secondary circuit is cooled by a battery of advanced technology cooling towers with innovative condensers cooled directly by ambient air.

The proposed conceptual design ensures the total heat removal of 147.1 MW (with 4.6% reserve) from the secondary circuit of the ALFRED demonstration reactor via the ACC cooling tower battery. For this load, the fans of the cooling battery convey an air flow of 12796 m^3/s (*EXTREME SUMMER* mode).

The performance of direct air-cooled condensers decreases with increasing temperatures and in high wind conditions. In the paper, methods to improve ACC operation under the above conditions were determined.

The steam flow distribution in the direct air-cooled condenser and aspects related to the operation of the deflagrator (dry and wet/dry) were presented. To be mentioned that the dephlegmator introduction in the scheme achieves a measurable improvement in cooling performance at high ambient temperatures.

Wind walls were used to reduce the effects of increased wind intensity. Changing the shape of finned pipes from round to flat and adjusting their inclination, as well as using various pipe cleaning techniques, help to increase the heat transfer rate.

Since the ACC cooling system of the ALFRED reactor secondary circuit is located outside, measures have been taken to avoid freezing during the winter season by providing with insulation elements (including heat tracing) the equipment, piping, and automation apparatus.

The electricity consumption for driving the fan motors in the case of air cooling is 2.08 MW in comparison with 1.8 MW in the case of water cooling. The cost difference recovery from electricity consumption in case of air cooling is assured by the fact that there are no costs for make-up water consumption, sewage, chemical treatments, pump station, equipment and installation costs (ACCs are modular and have fewer components, hence a cost advantage in installation).

The ACC condenser type introduced in the proposed conceptual design offers improved maintenance and performance as well as a higher degree of standardization of the plant.

The use of this cooling type system can significantly speed up the approval of construction license for a power plant because water use issues are removed from the calculation. Shortening a project schedule (by 6 months, for example) can completely change a project's budget, leading to significant savings.

For the same amount of heat transfer, the operation of air-cooled condensers has better economics compared to the water-cooled condensers operation, due to the introduction of new generation "no Core TM" heat exchangers in the condenser scheme.

The application of the direct air-cooled condenser (ACC) concept will undoubtedly help to establish dry cooling as the preferred technology for modern power plants, in this case the ALFRED demonstration reactor.

References

[1] Bandini, G. et al. (2013) ″Safety Analysis Results of Representative DEC Accidental Transients for the ALFRED Reactor″, Int. Conf. on Fast Reactors and Related Fuel Cycles: *Safe Techn. and Sust. Scenarios* (FR13), Paris, France.
[2] Alemberti, A. et al. (2015) ″ALFRED and the Lead Technology Research Infrastructure″, European Research Reactor Conf. RRFM 2015, Bucharest, Romania.
[3] Alemberti, A., Frogheri, M., Mansani, L. (2013) ″The Lead Fast Reactor - Demonstrator (ALFRED) and ELFR Design″, Int. Conf. on Fast Reactors and Related Fuel Cycles: *Safe Techn. and Sust. Scenarios* (FR13), Paris, France.
[4] Nita, I.P., Pancef, R. (2021) ″Conceptual Design and Layout of the Cooling Towers Necessary to Remove Heat from the Condenser Secondary Circuit of the ALFRED Demonstrator Reactor″, Proc. of 15th WEC Central & Eastern Europe Energy Forum FOREN 2020, Vol. 7 (2), pp. 55-68.
[5] Nita, I.P., Pancef, R., Ivan, A. (2019) ″Designing of the main components of the secondary circuit of ALFRED reactor″, *EMERG*, Vol. 5(12), pp. 57-63.
[6] Nita, I., Pancef, R. (2019) ″Sizing of main equipment and systems from regenerative circuit of Advanced Lead Fast Reactor European Demonstrator″, Proc. of 12th Int. Conf. NUCLEAR2019, Pitesti, Romania.
[7] Ellmer, M. (2012) ″How to improve air cooler vacuum steam condensers performance in the field″, Proc. of Int. Conf. POWER-GEN Europe 2012, Techn. paper ID309.
[8] Kröger, D.G. (1996) ″Cooling Tower Performance Evaluation″, Water Research Commission, WRC Report no. 478/I/96, Pretoria, South Africa.
[9] EVAPCO ″Cooling Towers – Factory Assembled″, EVAPCO Group, www.evapco.com.
[10] Mishra, P., Arya, M. (2015) ″A Review of Literature on Air Cooled Condenser (a Heat exchanger used in Steam Power Plant)″, *Int. J. of Research in Aeronautical and Mech. Eng.*, Vol. 3(10), pp.1-8.
[11] Alemberti, A. et al. (2014) ″Lead-cooled Fast Reactor (LFR) Risk and Safety Assessment White Paper″, GenIV International Forum, RSWG White Paper.
[12] Baweja, M., Bartaria, V.N. (2013) ″A Review on Performance Analysis of Air-Cooled Condenser under Various Atmospheric Conditions″, *Int. J. of Modern Eng. Research*, Vol. 3(1), pp. 411-414.
[13] EVAPCO (2019) ″Advanced Technology ACC″, EVAPCO Proposal 19-637-41RA1 prepared for CITON Bucharest, EVAPCO Group.