JEK2 Condenser Cooling Technology

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ABSTRACT

GEN energija d.o.o. is currently evaluating the construction of the second unit of the Krško Nuclear Power Plant (JEK2). The proposed site is situated west of the existing nuclear facility, nestled in the Sava River valley on the western edge of the Krško plain.

The important part of the new nuclear power plant (NPP) will be its cooling system. Because the thermal capacity of nearby Sava River is already used in full extent for cooling of the existing power plant, the new NPP will have to rely on cooling towers. Approximately two-thirds of the heat produced in the reactor of the nuclear power plant is dispersed to the environment through the cooling system, only one-third is converted into useful mechanical work via turbine. Efficient heat dispersion from the condenser is vital to maintaining the necessary enthalpy potential for turbine operation. Given the long operational lifespan of a nuclear power plant, even marginal optimizations in cooling efficiency result in significant cumulative energy gains.

Systems responsible for cooling power plants have a significant influence on spatial planning. Cooling towers occupy a considerable portion of the total plant layout, and some cooling towers can reach heights up to more than 200 meters. These systems also have an environmental impact due to their consumption and discharge of water to and from river. This is why this topic is important, even in the initiative phase and in national spatial planning.

This paper evaluates and compares various cooling solutions suitable for the condenser cooling of JEK2. Four distinct technologies—natural draft, mechanical draft, fan-assisted natural draft, and hybrid cooling towers—are identified, analysed, and compared. The study emphasizes the importance of selecting a cooling technology that aligns with both the specific technical parameters of the plant and the surrounding environmental constraints.

Keywords: *Cooling, Cooling tower, JEK2, NPP*

1 INTRODUCTION

In a nuclear power plant, approximately two-thirds of the heat generated by the nuclear reactor is dissipated through the cooling system, while only one-third is converted into useful mechanical work via the turbine. For this reason, it is logical to optimize heat dissipation, as even minor improvements contribute to primary energy savings and reduced emissions.

High-quality operation of the cooling system is facilitated by the corresponding enthalpy potential, which is limited by ambient parameters. In the case of water cooling with a wet cooling tower, the available potential is limited by the wet-bulb temperature of the ambient air. By increasing the efficiency of the cooling tower, the temperature of the cooling water approaches the wet-bulb temperature of the surrounding air, thereby indirectly improving the efficiency of the entire energy system. Efficient heat dissipation has a major impact on the overall efficiency of a nuclear power plant.

The existing Krško Nuclear Power Plant (NPP) utilizes the cooling capacity of the Sava River in combination with cooling cells. Because the cooling capacity of the Sava River is already fully utilized by the existing plant, cooling for JEK2 will depend entirely on cooling towers.

This paper covers the basics of cooling tower operation, presents various technologies currently on the market and comperes them.

2 COOLING WATER PROCESS IN NUCLEAR POWER PLANTS

2.1 The main cooling water system (CW)

The main cooling water system (CW) (Figure 1) is a non-safety system in a nuclear power plant. It is responsible for dissipating the latent heat of uncondensed steam in the condenser. The heat that needs to be dissipated to the environment is about 2/3 of the energy produced in the reactor. Although the amount of heat discharged is huge, it is useless as the steam in the condenser has low pressure and low temperature and cannot be used to produce electricity. The CW system is responsible for transferring heat from the condenser to the environment. This environment can be a river, a lake or the sea (once through cooling) or air (cooling towers).

2.2 The essential service water supply system (SW)

The essential service water supply system (Figure 1) is safety classified and must operate continuously, even during a power plant shutdown. The system is responsible for cooling the component cooling system and cooling of the boron heat regeneration system. Through the component cooling system, the SW is responsible for dissipating heat from the safety and non safety systems and equipment at all stages of the plant's operation (e.g. residual heat dissipation during cooling, etc.). The amount of heat that SW has to dissipate into the environment is much less compared to CW system. As with the CW, the heat can be discharged into various environments such as a river, lake or sea (flow cooling) or air (cooling towers, evaporation pools).

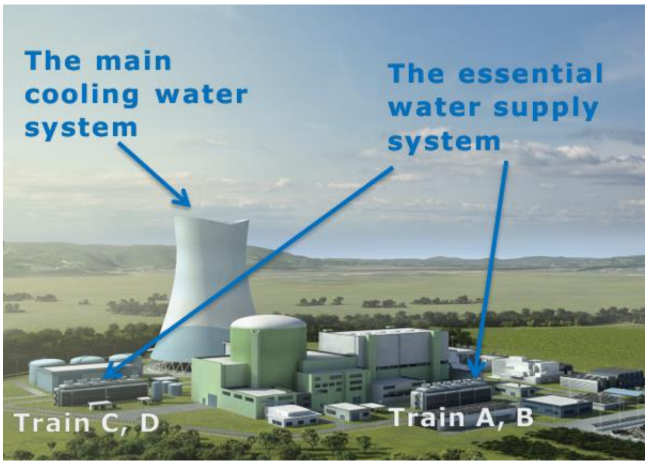

Figure 1: The main cooling water system and essential water supply system for JEK2

2.3 Classification of cooling towers

Electricity generation requires reliable access to large amounts of water, particularly for cooling purposes. Significant volumes of water are used to cool the condensers in nuclear power plants and other thermal power plants. Within the secondary circuit, approximately two-thirds of the energy is lost due to the limitations of the Rankine cycle in converting heat into mechanical energy.

If a power plant is located directly by the sea, a large river, or a large lake, cooling can be achieved via a once-through cooling system. In this setup, a large volume of water circulates through a condenser in a single pass before dissipating heat back into the water source. This water can be either saline or fresh. However, the resulting increase in water temperature leads to increased evaporation.

If sufficient water for once-through heat dissipation is unavailable, cooling can be performed using a cooling tower:

- Wet Cooling: This is the most common method, where the majority of heat is dissipated through evaporation. Heat transfer directly to the air and convection are less significant mechanisms in this process. In wet cooling towers, approximately 3% to 5% of the water evaporates and must be constantly replenished.
- Dry Cooling: These are closed-loop systems where heat exchangers inside the towers dissipate heat into the air solely through heat transfer and convection. There is no transfer of substance (water loss) in this process.

Figure 2 illustrates the classification of cooling towers according to the IAEA [1]. Although the figure displays a wide range of cooling tower types, numerous hybrid systems also exist, such as the Hybrid Tower, which utilizes both wet and dry cooling and fan assisted natural draft which combines natural and mechanical draft.

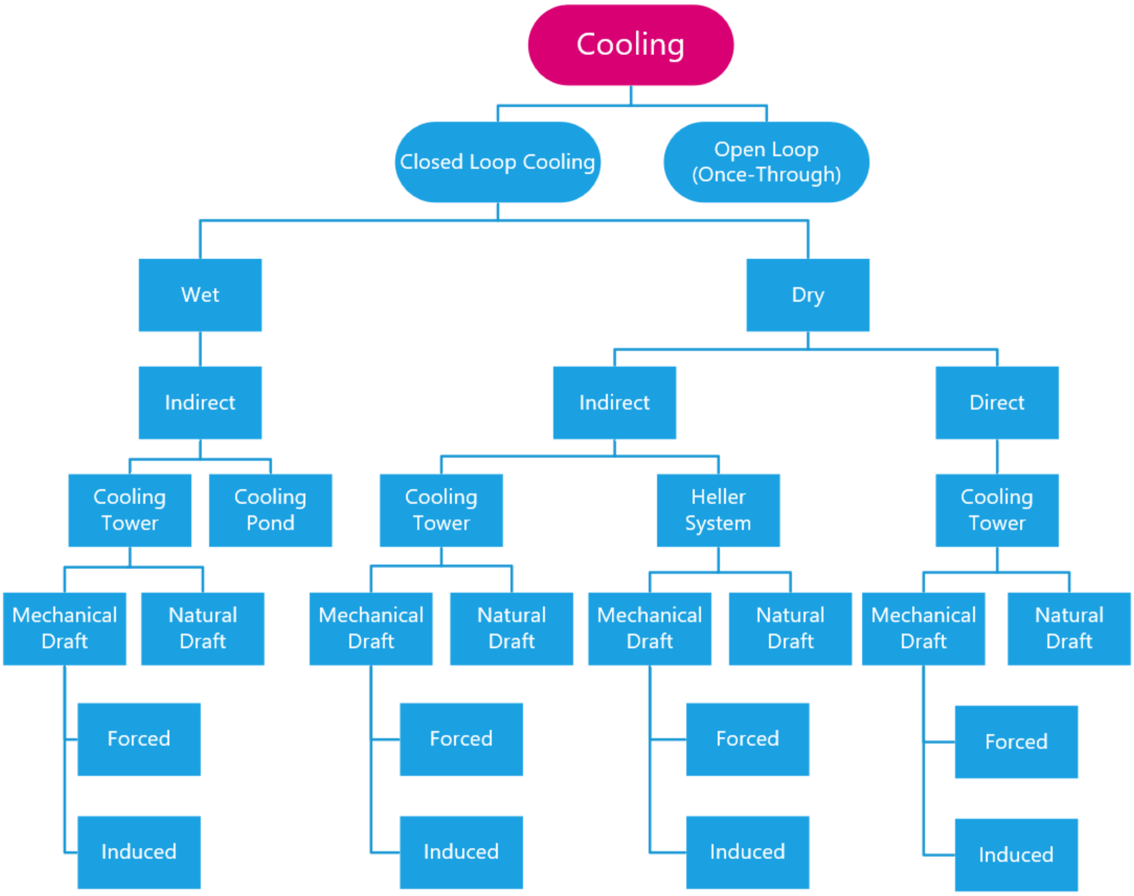

Figure 2: Classification of cooling towers according to IAEA [1]

3 SELECTION OF COOLING TOWER FOR JEK2

In theory, all technologies presented in Figure 2, apart from direct dry cooling, would be capable of cooling the new JEK2 plant. However, because efficient condenser cooling directly influences the overall efficiency of the power plant, the choice of cooling technology is critical.

The most favourable and efficient option would be once-through cooling; however, since the cooling potential of the Sava River has already been fully exploited, a cooling tower must be selected. Given that there is sufficient water available to cover evaporation losses, the next best choice is wet cooling, as it achieves higher efficiency.

GEN recognized the following technologies as the most promising for further evaluation:

- Counter-current natural draft cooling towers
- Counter-current mechanical induced draft towers
- Fan assisted natural draft cooling tower
- Hybrid towers (utilizing both wet and dry cooling)

3.1 Natural draft cooling towers

Natural draft cooling towers are common in the chemical industry and iconic in power generation (thermal and nuclear). Despite various designs, their core function remains the same: creating airflow through heat exchangers and fill media. This is achieved via buoyancy; as air inside the tower warms up, its density decreases, causing cooler, denser ambient air to displace it.

Wet towers operate as semi-open systems. Water from condensers is pumped to nozzles and sprayed over fill media, which provides a massive surface area for heat transfer and evaporation. The resulting exhaust is typically saturated water vapor (fog). Because this discharge occurs at great heights, it has minimal impact on surrounding structures.

The tower's performance fluctuates with ambient conditions, which affect the internal airflow. They are characterized by passive operation as the tower has no moving parts, low energy demand, and cost-effectiveness as these features result in minimal maintenance and operating costs.

3.2 Mechanical induced draft towers

Mechanical draft cooling towers are utilized across all industrial sectors where heat rejection is required, and like natural draft towers, they are a staple in power generation. As the name suggests, airflow is generated mechanically by fans driven by electric motors. Their primary advantage is predictable operation that remains independent of weather conditions. However, they consume significant electrical energy, which inherently reduces the overall efficiency of the power plant.

The mechanical assembly is subject to wear and tear, resulting in substantially higher maintenance costs compared to natural draft alternatives. While these towers are low-profile and cause minimal visual degradation to the landscape, they require a large physical footprint. A notable drawback is the low-altitude discharge of saturated air (plume), which can negatively impact nearby buildings and components.

3.3 Fan assisted natural draft cooling tower

This technology utilizes fans to increase airflow through the tower which is similar to natural draft but smaller. To conserve energy, some fans are deactivated when ambient temperatures drop.

Operating experience indicates that the "stack effect" is limited due to the restricted shell height and is strongest at low ambient temperatures, becoming nearly negligible as temperatures rise. Unlike natural draft towers, airflow remains relatively stable thanks to fan assistance. However, this design requires significant power and additional maintenance for mechanical components like motors and gearboxes. While the system offers some temperature control flexibility by closing specific quadrants, winter operation requires careful management to prevent uncontrolled freezing. Furthermore, the failure of a single fan can have a significant thermal impact, as it often necessitates the shutdown of an entire quadrant.

3.4 Hybrid cooling towers

A hybrid cooling tower integrates both wet and dry cooling technologies to optimize performance. These systems can operate either to prioritize water conservation—potentially saving up to 10% of water annually—or to minimize the visible plume. The latter is often the primary reason for choosing a hybrid design, as it reduces the visual impact of the tower on the surrounding environment.

The process begins as water from the condenser first passes through the dry section, located in the upper part of the tower, where it is cooled by closed heat exchangers. Ambient air passing through this section warms up, which significantly lowers its relative humidity and increases its capacity to absorb moisture. The water then continues into the wet section, where it is sprayed over fill media to take advantage of the high cooling capacity provided by evaporation.

In a standard wet system, the air leaving the fill media would be supersaturated, creating a thick, visible fog. In a hybrid system, however, this moist, saturated air is mixed with the warm, dry air from the upper section before being discharged. By blending these two airflows, the overall relative humidity of the exhaust is reduced to a level where the water vapor becomes invisible, minimizing plume exhaust. This comes with its drawbacks; hybrid towers are known for their high initial investment and substantial maintenance costs

3.5 Comparing the selected cooling towers

The technologies were compered based on economic factors (construction and operating costs), footprint, operating experience, operating stability environmental impact, and visual impact (Table 1)

Table 1: Advantages and disadvantages of cooling tower types [2][3][4][5]

Natural draft cooling tower	**Induced draft cooling tower**	**Hybrid cooling tower**	**Fan assisted natural draft cooling tower**
+plume release into the upper atmospheric layers +small footprint +minimal environmental impacts +minimal maintenance requirements +minimal operating costs	+low visual impact +weather-independent operation +most coste-ffective construction	+high noise levels +large footprint +high maintenance costs +high operating costs +high energy consumption +potential for recirculation	+lower visual impact +weather-independent operation +smaller footprint
-high visual impact	-high noise levels	-high noise levels	-high noise levels

-high construction cost -weather-dependent -operation	-large footprint -high maintenance costs -high operating costs -high energy consumption -potential for recirculation -low altitude plume release	-large footprint -high construction cost -high maintenance costs -high operating costs -high energy consumption -limited operational experience	-high maintenance costs -high operating costs -high energy consumption -limited operational experience

Natural Draft Cooling Towers: From an environmental and economic perspective, this is the best choice. Although the initial installation is quite expensive, the operating costs are minimal. Since it does not require energy to create a draft through the tower, it is one of the most environmentally friendly technologies. The primary drawback is its significant height, which would alter the visual landscape of the surroundings.

Mechanical Cooling Towers (Cells): These are slightly cheaper to install than natural draft towers. However, they are characterized by high energy consumption and high operating costs. They also emit plum in lower layers of atmosphere and have an impact on surrounding microclimate.

Fan Assisted Natural Draft Cooling Towers: Are known for its small footprint and smaller visual impact as natural draft cooling towers. They combine characteristic of the ladder with the mechanical draft. However, they are expensive to build and also have big operating costs.

Hybrid Towers: These are the ideal choice when the goal is to minimize plume formation (fog); however, this comes at a high price. Hybrid towers have the most expensive construction costs and are accompanied by high operating costs.

The logical diagram for our selection of the cooling tower for JEK2 is presented in Figure 3

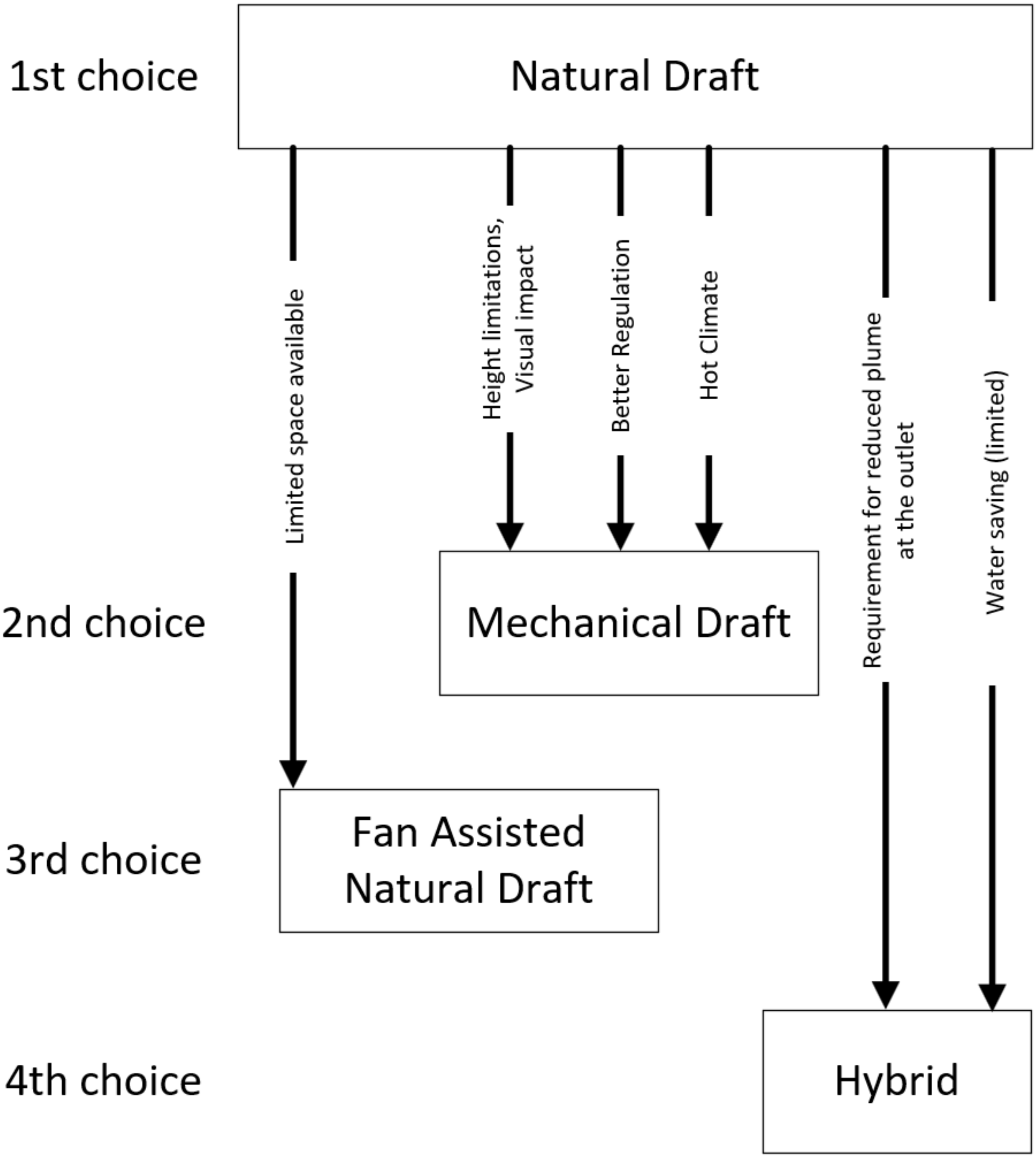

Figure 3: Logical diagram for GEN selection of the JEK2 cooling tower [5]

4 CONCLUSION

From a wide range of cooling technologies, we have selected the most suitable options for the JEK2 condenser cooling: a natural draft cooling tower, induced mechanical draft towers (cells), a fan-assisted natural draft tower, and a circular hybrid tower. Each of these options presents its own set of advantages and disadvantages. A common feature of all selected technologies is their counter-flow design and the use of film fill media to maximize the heat transfer surface area.

The final selection of the most appropriate technology depends primarily on economic factors, such as construction and operating costs, as well as the environmental, footprint, operational experience and visual impact on the landscape. Based on the comparison, the natural draft cooling tower is the optimal choice for JEK2 nuclear power plant, characterized by its long operational lifespan. The second most suitable option is mechanical induced draft cells. While fan-assisted natural draft towers are an interesting solution when space is limited, circular hybrid towers are relevant when the goal is to reduce visible water vapor or minimize water consumption. However, these latter two options are significantly more expensive, offer very limited operational experience, and present challenges regarding noise levels.

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