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Selection of the most suitable cooling technology for the JEK2 project

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ABSTRACT

The existing nuclear power plant in Krško uses once through cooling with combination of cooling cells if needed. Since the cooling capacity of the Sava River is already fully utilized, JEK2 cooling will depend on cooling towers.

The paper presents the basics of cooling nuclear power plants with cooling towers, the presentation of various technologies on the market and development of computational models for evaluating mechanical and natural draft cooling towers.

Dry, wet, and hybrid cooling technologies are presented. Most nuclear facilities today are cooled by once through or wet cooling. Due to the stringent environmental requirements for once through cooling, more and more newly built power plants are cooled by wet cooling towers.

From a multitude choice of cooling technologies, three alternatives were selected that would be most suitable for cooling the JEK2 condenser: a natural draft counterflow cooling tower, an induced mechanical draft counterflow tower and a hybrid tower with wet and dry cooling. Each of these has its advantages and disadvantages.

Based on the input data for JEK2 project, empirical models developed in MS Excel were used to evaluate cooling towers for the main cooling water system (CW) and the essential water supply system (SW). The models link the dependence of JEK2 power and the required dimensions of cooling towers.

The paper also compared the operating costs (excluding maintenance costs) for cooling JEK2 with mechanical cells or a natural draft tower.

1 INTRODUCTION

In a nuclear power plant about two-thirds of the heat generated by the nuclear reactor is dissipated through the cooling system, only one-third is converted into useful mechanical work on the turbine. For this reason, it makes sense to optimize heat dissipation, as even minor improvements contribute to primary energy savings and reduced emissions. The quality operation of the cooling system is provided by the corresponding enthalpy potential, but this is limited by the ambient parameters. In the case of water cooling with a wet cooling tower, the available potential is limited by the temperature of the wet ambient air thermometer. By increasing the efficiency of the cooling tower, the temperature of the cooling water approaches the temperature of the wet bulb of the surrounding air and indirectly improves the efficiency of the energy system.

In a nuclear power plant, efficient heat dissipation with a cooling system has a major impact on the overall efficiency of the energy system. There are three types of cooling or heat dissipation from the condenser. The most efficient and cheapest solution is to cool condenser with once through water, which is usually water from a nearby river or sea. The second are wet cooling towers that take advantage of increased heat dissipation due to water evaporation. The third least effective option are dry cooling towers.

The existing nuclear power plant in Krško uses cooling capacity of Sava river in combination with cooling cells to cool its condenser. Since the cooling capacity of the Sava River is already fully utilized due to the cooling of the existing Krško NPP, JEK2 cooling will depend on cooling towers.

The paper covers the basics of cooling with cooling towers, the presentation of various technologies on the market and the description of empirical models of cooling towers for JEK2 for natural draft and for mechanical cells.

The paper also compared the operating costs (excluding maintenance costs) for cooling JEK2 with mechanical cells or a natural draft tower.

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).

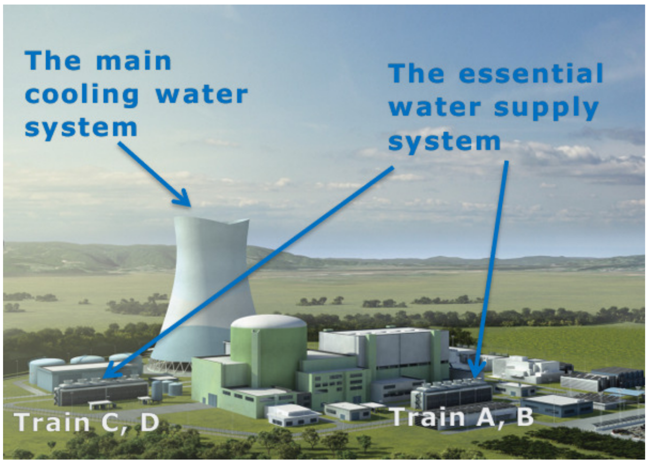

Figure 1: The main cooling water system and essential water supply system for JEK2

3 OVERVIEW OF COOLING TECHNOLOGIES

Electricity generation requires reliable access to large amounts of water, especially for cooling. Huge amount of water are used to cool the condenser in nuclear power plants and other thermal power plants. In the secondary circuit about two-thirds of the energy is lost due to the limitations of the Rankin's steam cycle converting heat into mechanical energy. If the power plant is right by the sea, a large river or a large lake, cooling can be achieved simply by a once-through cooling system, where large amount of water circulate through a condenser in one pass and dissipate heat back to the sea, lake or river. The water can be salty or sweet. An increase in temperature will result in increased evaporation. If there is not enough water for heat dissipation, then cooling can be done with a cooling tower. The most common is wet cooling, where most of the heat is dissipated by evaporation. The mechanisms of the heat transfer to the air and convection are less important. In wet cooling towers, about 3 to 5% of the water evaporates and needs to be replaced constantly. Dry cooling towers are closed loop system where heat exchangers inside cooling towers dissipate heat into air with heat transfer and convection. There is no transfer of substance.

Figure 2 shows the classification of cooling towers according to IAEA [1]. Although the figure shows a wide range of cooling towers, there are also numerous hybrid systems, such as the Hybrid Tower, which uses both wet and dry cooling. There are several types of hybrid cooling, but only the latter is described in this paper, as it is suitable for JEK2 cooling.

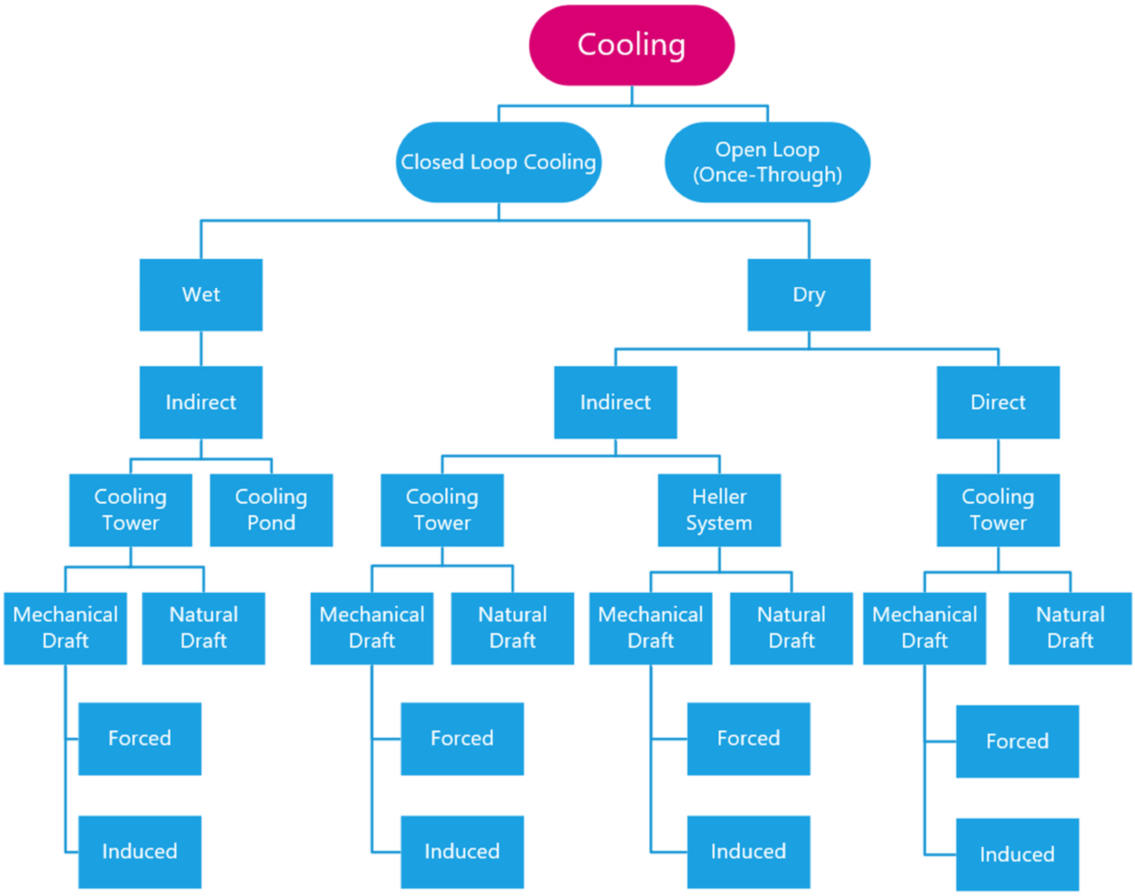

Figure 2: Classification of cooling towers according to IAEA [1]

* There are also hybrid systems that use several cooling principles: A hybrid tower that uses both wet and dry cooling or hybrid tower with a combination of mechanical and natural draft

** Wet cooling is in fact a semi-open system, because in the cooling tower water must be in direct contact with air in order to evaporate.

4 SELECTION OF COOLING TOWER FOR JEK2

There are no direct answers as to which technology is the best choice for the new nuclear power plant in Krško JEK2. Basically, all the technologies presented in Figure 2 would be suitable except direct dry cooling. However, with efficient cooling of the condenser, we directly influence the efficiency of the power plant, so the choice of cooling is very important. The most favorable and efficient option for cooling the condenser would be once-through cooling, but since the cooling potential of the Sava River has already been exploited, a cooling tower has to be chosen. Given that there is enough water available to cover evaporation losses, the next best choice is wet cooling. Wet cooling achieves more efficient cooling. The findings of this paper are that countercurrent natural-draft cooling towers, countercurrent mechanical induced draft towers, and hybrid towers with wet and dry cooling are the best choices for JEK2. The same findings can be found in study made by SPX [2]. Each of these has its advantages and disadvantages as presented in Figure 3. What they all have in common is that they are countercurrent with film fills (packings), that create the largest transfer surface. The final selection will have to be made based on the economic aspect (construction and operation costs), the impact on the environment and visual impact.

From an environmental and economic point of view, the best choice would be a counter-current cooling tower on natural draft. Although its installation is quite expensive, its operation is almost free. As it does not need any energy for enabling draft through the tower it is also one of the most environmental friendly technologies. The main problem is its size or height that would change the image of the surroundings. The next alternative is the installation of countercurrent towers with induced mechanical draft - cells. These are slightly cheaper compared to natural draft, but in addition to high energy consumption, they also have high operating costs. The hybrid tower with wet and dry cooling is the right choice when we want to avoid producing fog, which has a high price. Such a tower has by far the most expensive construction, and at the same time it is accompanied by high operating costs. A summary of the advantages and disadvantages of these cooling towers is presented in Figure 3.

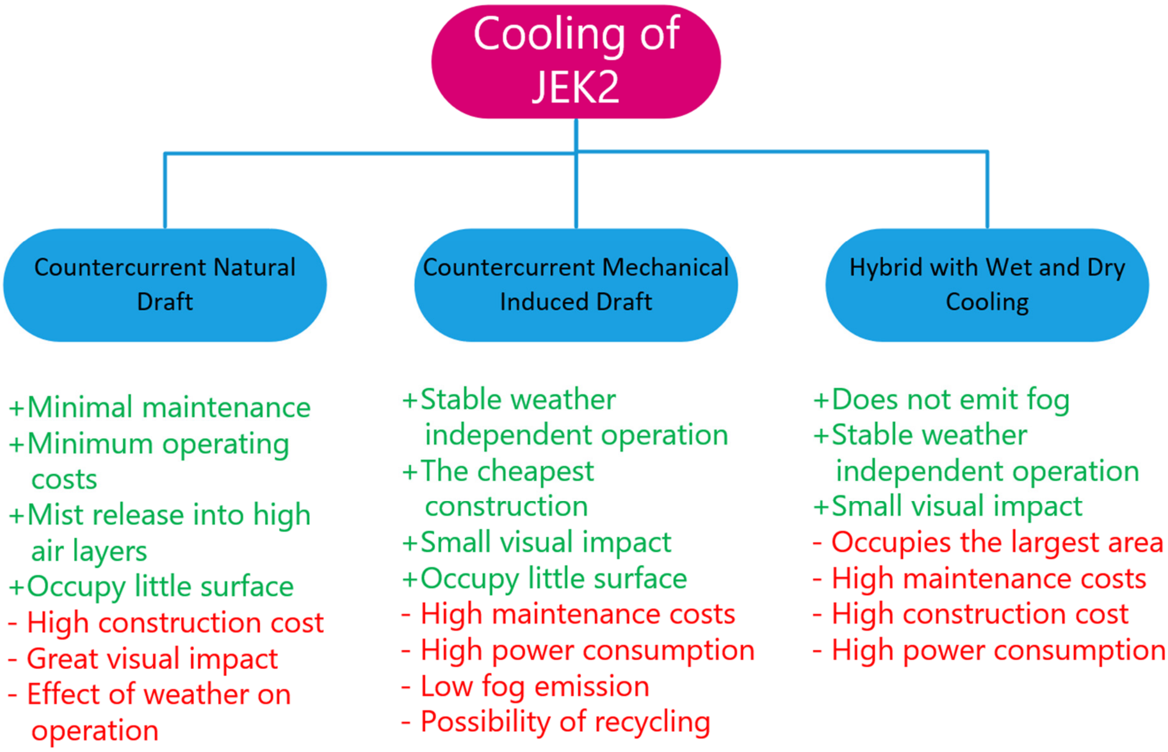

Figure 3: Advantages and disadvantages of the proposed cooling towers for JEK2

The best choice for cooling the SW system is a counter current tower with induced mechanical draft - cells. A good alternative represents cooling ponds, the operation of which is much less prone to failure. However, they occupy a lot of space, which is not in abundance at the location in Krško.

5 EMPIRICAL MODELS FOR DETERMINING COOLING TOWER DIMENSIONS

Based on the data for JEK2, we have developed empirical models with good accuracy that connect the dependence of JEK2 power with the required dimensions of cooling towers.

5.1 Empirical model for mechanical cells

The calculation for mechanical cells is made by the Merkel method. The procedure is made for calculating heat performance of a countercurrent cooling towers with induced draft [3]. The towers have fill made in the form of pleated sheet metal. Input data for the calculation were obtained from the SPX study [2]. Generally, there are five parts of the calculation: calculation of enthalpies, calculation of the Merkel integral, calculation of fill, calculation of the pressure drop in the cooling tower and finally the choice of cooling towers based on the mass flow of water per square meter of fill. Due to the complexity of the model, the calculation procedures are not shown in detail in this paper.

5.2 Empirical model for natural draft cooling tower

The calculation for natural draft cooling tower is made according to procedure described in [4]. The procedure is made for calculating heat performance of a natural draft cooling tower with hyperbolic shape and wet cooling. Dimensions, shape and ambient conditions are input for calculation of heat dissipation of cooling tower. The presented calculation of the cooling tower on natural draft takes place iteratively. It is necessary to assume certain parameters at the beginning in order to start calculation (the state of the air in the cooling tower above the fill - temperature, pressure, humidity and enthalpy ratio; the pressure at the tower outlet and the mass flow of moist air through the fill). Generally, there are three parts of the calculation: energy equation (Merkel number), transfer equation (Chebyshev integral) and draft equation. These equations give new values to assumed parameters and the process is iteratively repeated until the assumed parameters are equal to calculated parameters.

6 OPERATING COSTS

The paper also shows the operating costs (excluding maintenance costs) for the mechanical cells and natural draft tower.

For the operation of mechanical cells, electricity is used to operate the fans and pumps to raise the cooling water above cooling fill. Total estimated annual operating cost (excluding other maintenance costs) of mechanical cells is 3.876.283 EUR. The calculation with input data is shown in the Table 1.

Table 1: Estimated annual operating costs of mechanical cells for the 1100 MW reactor

Mechanical cells		
Fan power consumption	**Unit**	**CW**
Total installed fan power	kW	5600
Average annual workload (estimated)	%	0,75
Average fan operating time	hours	8300
Estimated price of electricity	EUR/kWh	0,05
Fan operating costs	**EUR**	**1.743.000 €**
Pump power consumption	**Unit**	**CW**
Pumping height	m	12
Cooling water flow	m3/s	39,3
Pump power (calculated)	kW	5140,44
Average pump operating time	hours	8300
Estimated price of electricity	EUR/kWh	0,05
Average annual workload (estimated)	%	100%
Pumps operating costs	**EUR**	**2.133.283 €**
Total annual operating costs	**EUR**	**3.876.283 €**

To operate the natural draft tower, electricity is used to run the pumps that raise the cooling water above the cooling fill. The total estimated annual cost of operating the natural draft tower is EUR 2.840.758. The calculation with input data is shown in the Table 2.

Table 2: Estimated annual operating costs of natural draft tower for the 1100 MW reactor

AP1000 - Natural draft tower		
Fan power consumption	**Unit**	**CW**
Pumping height	m	16
Cooling water flow	m3/s	39,3
Pump power (calculated)	kW	6845,2
Average pump operating time	hours	8300
Estimated price of electricity	EUR/kWh	0,05
Average annual workload (estimated)	%	100%
Total annual operating costs	**EUR**	**2.840.758 €**

In the case of the 1100 MW reactor, we estimate that approximately 3,9 million EUR of electricity is used annually for cooling with mechanical cells, and approximately 2,9 million EUR for cooling with the natural draft tower. The annual difference in electricity consumption is therefore approximately 1 million EUR in favor of the natural draft tower. For final economical evaluation other maintenance and investment costs would have to be calculated.

7 CONCLUSION

Since the cooling potential of Sava river is already used for cooling existing nuclear power plant in Krško, cooling towers have to be built for cooling JEK 2. Various technologies are on the market, but wet cooling towers offer the best performance. The findings of this paper are that countercurrent natural-draft cooling towers, countercurrent mechanical induced draft towers, and hybrid towers with wet and dry cooling are most suitable for cooling JEK2 condenser. Countercurrent mechanical induced draft towers are the best choice for cooling of essential service water system. Each of these has its advantages and disadvantages. What they all have in common is that they are countercurrent, are film fill type and exploit evaporation. The final choice of JEK2 cooling will depend on the economic aspect (construction and operation costs), the impact on the environment and visual impact.

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