COMPARATIVE ANALYSIS OF DIFFERENT NUMERICAL SIMULATIONS OF THERMAL POLLUTION CAUSED BY THE OPERATION OF A THERMAL POWER PLANT

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Abstract: One of water pollution is heat caused by heated industrial wastewater that increases water system temperatures. In power plants and industrial manufacturers, a large amount of water is used. In this paper, the impact of thermal pollution of the Danube River caused by the operation of the Kostolac B thermal power plant B is considered. The Kostolac B thermal power plant uses a once-through condenser cooling system. It uses the water of the Danube River as cooling water. With the help of numerical simulations, the assessment of thermal pollution was performed. 2D and 3D numerical simulations in the Ansys Fluent software package have been developed. The analysis of the obtained results showed a difference in the temperatures of the Danube River at different sections downstream of the thermal power plant. The temperatures of the Danube are higher downstream from the Kostolac thermal power plant, which can be an indicator that there is thermal pollution of this thermal power plant towards the river. 2D and 3D simulations with the same initial and boundary conditions were compared to determine which numerical simulations were more suitable for use. The analysis showed that 3D simulations provide more approximate solutions to measurements read from meteorological stations. Namely, the temperatures obtained by 3D simulations coincide to a good extent with the measurements of the meteorological station located downstream of the thermal power plant.

Key words: thermal pollution, thermal power plant, environmental impact, wastewater, numerical simulation

1. INTRODUCTION

The Western Balkans is a region that is severely affected by climate change, which requires measures to reduce the negative impact on the environment. In the Republic of Serbia, most of the electricity was obtained from coal (lignite). The share of renewable energy sources in obtaining electricity is 24%, with the largest part referring to hydroelectric power plants. Obtaining electricity from the sun, wind, and biomass is with only a 4% share in the Republic of Serbia [1]. Due to the extremely high dependence on coal, the transition to clean and renewable energy sources is necessary. However, it should also strive for thermal power plants that use lignite as fuel to work as efficiently as possible and with as little negative impact on the environment as possible. Among thermal-based power generation, coal-based power plants are highest in air pollution, waste generation, water consumption, emission of mercury, greenhouse emission [2]. Taking into account the fact that the largest share of heat emissions comes from units older than 30 years, there is a motivation to gradually eliminate some of the most polluted ones shortly [3].

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Thermal-based power facilities, are critically dependent on water for cooling purposes. This enables them to maintain high production efficiencies, but also means that they use tremendous volumes of water every day. Most freshwater is used as cooling water, as much as 88% [4]. Cooling systems used in thermal power plants can be open (once-through) and closed (re-circulation) systems [5].

After the water is used in thermal power plants for the process of cooling the condenser, it is returned to natural watercourses as wastewater with elevated temperature. The addition of heated wastewater may not significantly increase the total temperature of water bodies, but it will increase the local temperature from where it is discharged. This type of pollution is called thermal water pollution. Thermal pollution is the deterioration of water quality by any process that changes the temperature of ambient water [6].

Because rising water temperatures can be dangerous to the environment, for example, the impact on fish populations, in many countries it is necessary to prepare an Environmental Impact Assessment (EIA) before building such facilities. Among many other aspects of EIA, predicting a possible increase in water temperature caused by an artificial heat source is crucial. Such predictions are usually made using numerical models [7].

To evaluate the thermal pollution effects, the ambient waters are categorized into two major zones, named near-field and far-field [8]. Near-field zone involves initial mixing (with three-dimensional thermal characteristics) which takes place in a matter of a few minutes and within a range of tens to hundreds of meters. In a far-field zone, mixing takes place in an order of days to months (due to two-dimensional thermal stratification) and within a range of tens or hundreds of kilometers [9,10]. It should be noted that, although the unsteady turbulent flow and heat transport problem in near-field natural coastal water is always strictly three-dimensional, in most engineering applications.

In this paper, a comparative analysis of 2D and 3D models of thermal pollution that occurs on the Danube River by the thermal power plant Kostolac B.

2. THERMAL POWER PLANT KOSTOLAC

TPP Kostolac is located near the town of Pozarevac. The total power of this thermal power plant is 1010MW. It consists of four units grouped as Kostolac A and Kostolac B. TPP Kostolac A consists of two units with one power 100MW and the other 210MW. TPP Kostolac B consists of two units each with 350MW [11]. Figure 1 shows the location of the Kostolac B thermal power plant, the distance from the Danube River as well as the channel of the Mlava River through which this thermal power plant is connected to the Danube. The mathematical model, based on the equations of mass and energy balance, and numerical model for the simulation of cold-end operation for this particular power plant is de-veloped, and presented in [12].

Figure 1. Connection of the Kostolac thermal power plant with the Danube [13]

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In the Republic of Serbia, there are measuring stations on natural watercourses. From these measuring stations can obtain information on water temperatures, levels, and water flows. Figure 2 shows part of these stations that are currently located on the Danube.

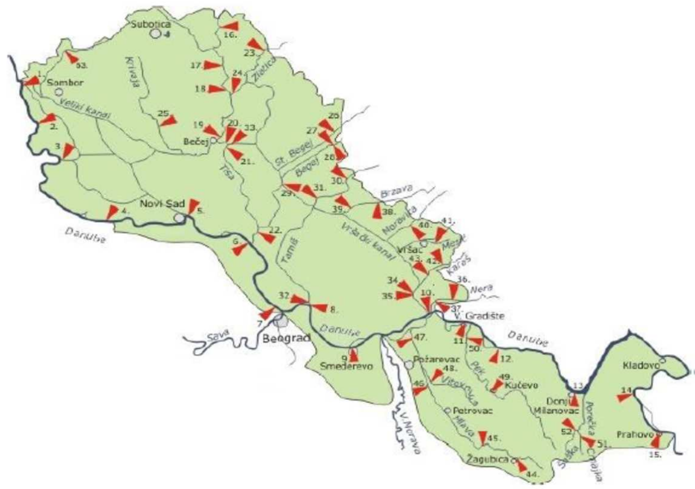

Figure 2. Part of the reporting surface water stations network in Serbia [14]

Near the Kostolac thermal power plant, there is a measuring station Smederevo which measures the characteristics of the Danube before reaching the thermal power plant, and a measuring station Veliko Gradište located downstream from the thermal power plant. Figure 3 shows the maximum Danube water temperatures read from these measuring stations upstream and downstream of the thermal power plant Kostolac B [14].

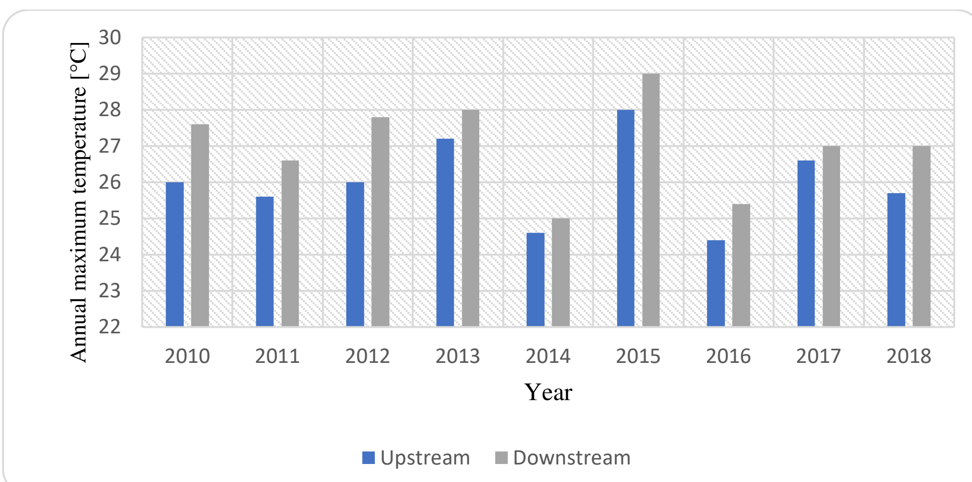

Figure 3. Annual maximum temperatures of the Danube River near the Kostolac thermal power plant

What can be noted from the diagram is that the temperatures of the Danube are higher downstream of the Kostolac thermal power plant, which can only be one of the indicators that there is thermal pollution of this thermal power plant towards the river.

The following table shows the values of the minimum water flows at the measuring station Smederevo from 2010-2019 year for summer period. The summer period is shown because it is precisely the period when the flow of water is reduced due to high temperatures and very low precipitation. These measurements were used later in the formation of the numerical model.

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Table 1. Minimal water flow rate for July, August, and September from 2010-2019 upstream the TPP Kostolac

Year	Minimal water flow rate [m^3/s]		
	July	August	September
2010	4110	3770	4120
2011	3200	2600	2140
2012	3250	2050	2350
2013	3050	2150	2250
2014	3600	4440	4750
2015	2950	2600	2520
2016	3610	3600	2650
2017	3150	3350	3290
2018	3420	2250	2150
2019	2710	2730	2370

3.NUMERICAL RESULTS

Numerical simulation at the junction of the river Danube and the effluent cooling water channel was made using the program ANSYS FLUENT. The boundary conditions used in this model are the input of the mass flow and temperature of the water in the Danube, mass flow, and temperature at the entrance to the effluent channel (Mlava river channel). The geometrical characteristics of the channel are given in figure 4.

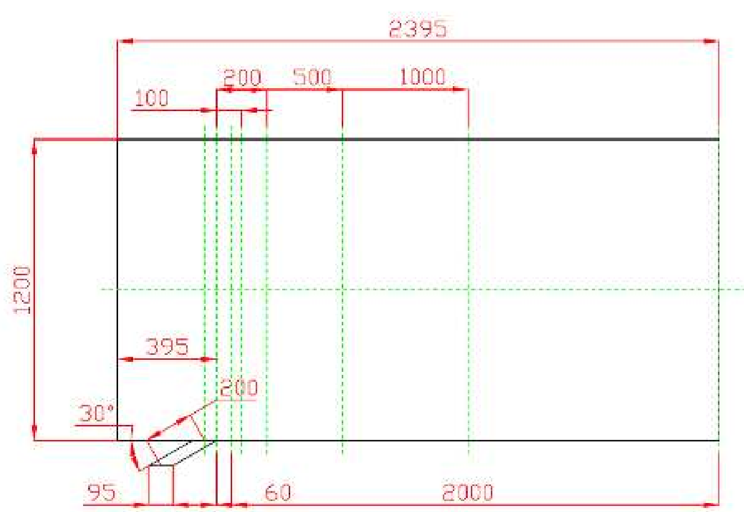

Figure 4. The geometrical characteristics of the channel

The mathematical model of thermal pollution is based on Reynolds-averaged Navier-Stokes (RANS) equations. The mathematical form of the RANS equation and the energy equation is presented in [15]. Turbulent flow is simulated using the k-ε turbulent model.

In the 3D simulation, the gravitational acceleration is taken into account. The upper plate represents the water-free surface with the adopted boundary condition "Symmetry" in order not to get

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a refund of flow or an undefined flow direction. The outlet flow of the effluent channel is taken as the "outflow" with 100% outflow conditions. A Semi-Implicit Method for Pressure-Linked Equations (SIMPLE method) in numerical simulations is used. The convergence of the results is obtained up to 10^{-8}. Presented results are obtained for atmospheric parameters and power plant operating conditions for the cases of minimum water flow rates in August. Danube flow rate was 2,880 m^3/s, while the effluent flow rate was 29.5 m^3/s. The average Danube temperature before mixing with effluent water was 27°C. Table 2 is presented the results for 2D and 3D numerical simulations of thermal pollution in the Danube River for August 2015. The effluent (in the effluent channel) enters the river at a sharp angle (around 30°) in relation to the river flow.

Table 2. Maximum temperature of the mixed water in different cross-sections downstream of junction area, for August 2015

	2D	**3D**
Section [m]	Temperature [°C]	Temperature [°C]
60	30.77	33.29
100	31.17	32.29
200	30.96	31.10
500	30.95	29.86
1000	31.12	29.10
2000	31.06	28.68

On next diagram, presented in figure 5, is shown curves of 2D and 3D numerical simulations.

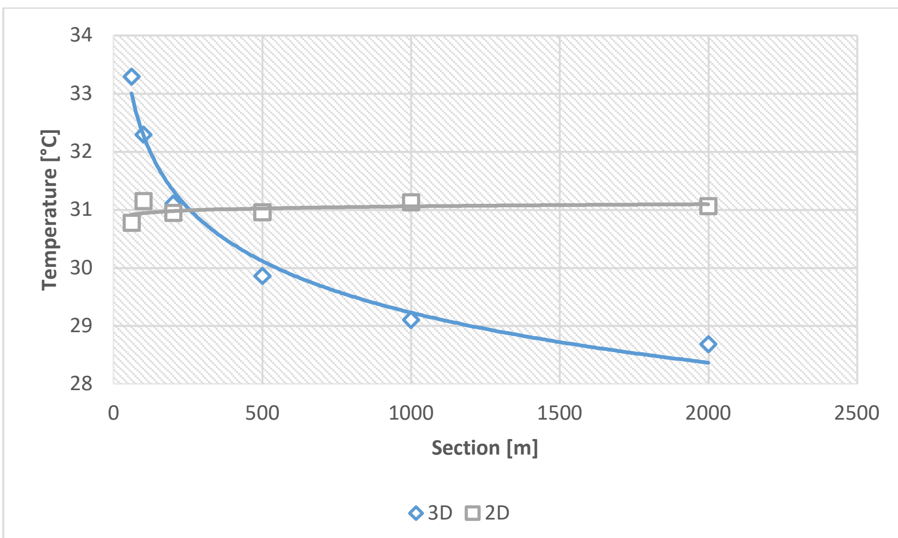

Figure 5. Presentation of numerical results

During the 2D simulations, the results of raising the temperature of the Danube River is 4 °C at a distance of 2 km were obtained. Using 3D numerical simulations, the temperature rise of the Danube is 1 ° C for the same distance. If compare the obtained values with the values shown in Figure 4, it can be established that the solutions obtained by 3D simulations are closer to the measurements from the measuring stations downstream from the thermal power plant. Increasing the temperature by just 1 ° C or 2 ° C can adversely affect wildlife in rivers because the increase is deadly to some species and can affect their growth and reproduction [16].

On the figure 6 is presented results of 3D numerical simulation for August 2015.

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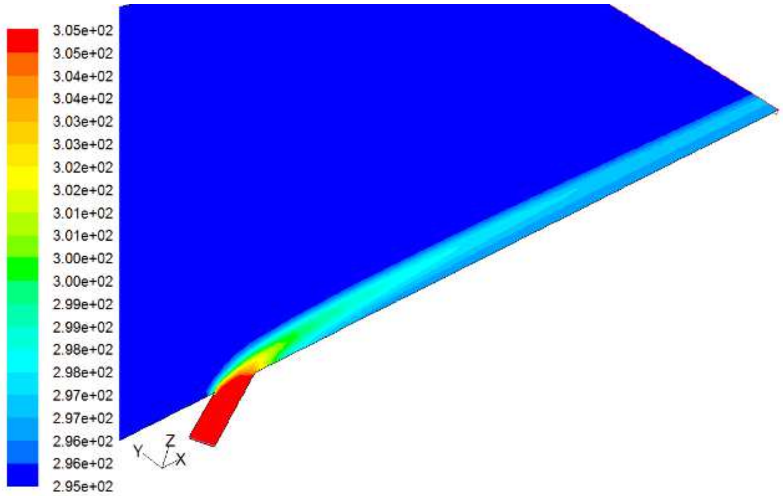

Figure 9. Temperature change on the water surface, August 2015

Figure 9 show the contours of temperature distribution on the Danube River for August 2015. It is obvious that with increasing discharge rates from the water discharge channel, the contaminated water area also increases.

4.CONCLUSION

The influence of initial conditions on the prediction of the increase of river temperature below the point of release of heated water for a designed power plant has been analysed in this study. The temperature of the Danube River, downstream of the Kostolac thermal power plant, increases by about 1 ° C. As the Danube is a river of high flow and capacity, this kind of thermal pollution does not greatly affect the river ecosystem.

This analysis of thermal pollution confirmed that by using 3D simulations, results are approximately the same as the measurements on the river itself. By using 3D simulations, the temperature picture of thermal pollution is complete. The reason for this is using the depth of the river in the calculation. The temperature distribution is taking into account depth, and not only by the upper surface of the river, as is the case when we use 2D simulations.

Further plan for analysing the thermal pollution of rivers by thermal power plants in the Republic of Serbia, will become down to analysing the impact of this type of pollution on the Sava River. Namely, the Sava has a smaller capacity concerning the Danube River, and there are Nikola Tesla thermal power plants on it, which have a larger capacity than the Kostolac thermal power plant. Heat pollution is expected to be more pronounced on the smaller river.

This analysis confirmed the claim that in near-field zones it is necessary to apply 3D simulations to obtain more accurate solutions.

ACKNOWLEDGMENT

This research was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract No. 451-03-9/2021-14/200109)"

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