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Original scientific paper

RELATIONSHIP BETWEEN THERMAL POLLUTION AND IMPACT OF OUTLET ANGLE OF THE THERMAL DISCHARGE

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A b s t r a c t: Predicting the behavior of thermal discharges from power plants under different outlet angles of the thermal discharge was done. The operation of power plant Nikola Tesla B was considered. This power plant has a once-through cooling system and uses the Sava river as a natural water cooling system. For numerical simulation, Ansys Fluent software package was used. Five positions of the channel discharge angle were considered. A two-dimensional model was developed and the k-ε turbulence model was applied. During the analysis, the values of maximum temperatures generated by pouring the discharge channel were considered. Also, the size of the field affected by this type of pollution was observed. The obtained data as a result of numerical simulation can be used to study problems associated with the mixing of heated water discharged from thermal power plants into the river flow. With this study, it is possible to reduce the impact of thermal pollution from the power plant by selecting an adequate outlet angle for the thermal discharge channel.

Key words: thermal pollution; thermal power plant; environmental impact; waste water; numerical simulation

СООДНОС НА ТЕРМИЧКОТО ЗАГАДУВАЊЕ И ВЛИЈАНИЕТО НА ИСПУСНИОТ АГОЛ НА ТЕРМИЧКИТЕ ЕФЛУЕНТИ

А п с т р а к т: Направени се предвидувања за тоа како се однесуваат термичките ефлуенти во река добиени од термоцентрала при различни агли на испуст во реката. Во предвид беше земена работата на ТЕЦ Никола Тесла Б. Оваа термоцентрала има проточен систем на ладење и ја користи водата од реката Сава како природен воден систем за ладење. Предвидувањата се направени по пат на нумерички симулации користејќи го софтверскиот пакет Ansys Fluent. Развиен е дводимензионален нумерички модел во кој турбуленцијата е опишана преку k-ε моделот. Во текот на анализите се земени предвид вредностите на максималните температури на површината на реката добиени од испуштањето на термичките ефлуенти. Анализирани се обликот и големината на температурното поле кое се развива од овој тип на термичкото загадување. Добиените резултати од нумеричките симулации можат да се користат за анализирање на проблемите врзани со мешањето на загреаната вода што се испушта од термоцентралите во речните корита. Врз основа на оваа анализа влијанието на топлинското загадување од централата може да се намали со избор на соодветен агол на испуст на каналот за термичките ефлуенти во реката..

Клучни зборови: термичко загадување; термоцентрала; влијание врз животната средина; отпадни води; нумерички симулации

INTRODUCTION

Water is an essential component of the environment with profound implications in the emergence and sustaining of life in a given area [1]. It is necessary to control water quality and reduce water pollution. One of the water pollution is thermal pollution. Thermal pollution is discerning the quality of the water using any action which changes the temperature of the ambient water [2]. With the temperature increase, oxygen in the water is reduced thus directly affecting the ecosystem of the water source itself [3]. A common cause of thermal pollution is the use of water as a refrigerant in power plants and industrial manufacturers. There are several negative consequences of the existence of thermal pollution of water, such as:

1. *Reduction of dissolved oxygen levels in water*

The increase in water temperature is directly related to the amount of oxygen that dissolves in water. During warm periods, surface water received more heat due to reduced water velocity and higher solar penetration into the seized water. Reduced dissolved oxygen can cause direct mortality in aquatic organisms or result in subacute effects such as reduced growth and reproductive success [4, 5].

2. *Increase in toxins*

As a result, high temperatures can cause more than normal levels of organic matter, fecal bacteria, and toxic substances in waters affected by heat pollution. The resulting increase in biochemical oxygen demand (BOD) can lead to the killing of fish, and high concentrations of fecal bacteria can limit water use.

3. *Environmental impact*

Small temperature changes can affect some aquatic species. Heat pollution can cause the mass killing of plants, insects, or amphibians. However, some species, such as algae, tend to benefit from heat.

4. *Migrations*

Hot water can also cause certain types of organisms to migrate to a suitable environment that would meet their survival needs. This can result in a loss for those species that depend on them in their daily diet because their food chain is broken.

Cooling systems used in thermal power plants can be open (once-through) and closed (re-circulation) systems [6]. Once-through systems use water from sources (e.g., oceans, rivers, lakes, or ponds for cooling) as a coolant and then return the water to the sources from where it was taken [7]. With a closed cooling system, the thermal power plant withdraws water, then the water circulates inside the system, where it is not returned to the water source from where it was taken.

Thermal pollution of freshwater natural watercourses due to the operation of thermal power plants is more pronounced in thermal power plants with a once-through cooling system [8]. In contrast with closed cooling systems, where almost all the heat absorbed during the steam cycle is removed via evaporation and dissipated into the atmosphere, once-through cooling involves the direct rejection of the heat back into the water body [9]. As there are several thermal power plants along one river that use water from the same river to cool condensers, the whole process of planning the construction of new thermal power plants and the use of water from the same river in a certain domain is further complicated [10]. To protect natural water courses as much as possible, certain Directives in the world determine the maximum allowed values of surface water temperature [11,12]. In the US, the maximum allowed value is 32 °C, while for EU countries, the water temperature after discharge from thermal power plants should not exceed 21.5 °C and 28 °C, i.e. it should not be higher than 1.5 °C or 3 °C concerning the temperature of the natural watercourse before withdrawal in the thermal power plant.

If the water temperature is higher than 25 ° C, it is considered dangerous for aquatic plants and certain species of fish because it leads to a decrease in oxygen and an increase in the concentration of ammonia [13]. Many countries have directives for respecting the maximum allowable temperature of natural watercourses after discharging heated water in them.

The group of authors [10] found that in the summer months, in thermal power plants that use a once-through cooling system, the river temperature warms by 9.5–10 °C. This research was done in the US. With such an increase in temperature, there is a significant impact on the living world in the river. There is a great dependence on water temperature and air temperature [14], only by the action of meteorological conditions. This dependence is 7 °C in summer while in winter it is 5 °C. The summer period is of great interest for researching the heat load because then there is a large consumption of electricity, and the water of the river itself is at a higher temperature [15].

In recent times, more and more researchers are considering the use of numerical tools in predicting and calculating the impact of thermal pollution on watercourses. River temperature management and reduction of thermal pollution are the best planned with simulation models that allow scenario assessment [16].

Numerical methods require the division of areas of interest into a large number of finite volumes or elements. Boundary conditions when solving problems by numerical methods are usually simulated to represent the actual boundaries of the problem itself. The advantages of numerical methods are the ability to display real geometry and time dependence without going to the laboratory and setting up a physical model [17].

This paper was considered a proper water channel model, applying the k-ε turbulence model, and then simulating the related velocity fields and temperature distributions on the condition of different velocities and outlet angles of the thermal discharge to provide useful theoretical support for the cooling water of the power plant can be reasonably selected and the surrounding water environment can be effectively protected.

RESULTS AND DISCUSSION

Numerical simulation of thermal pollution of the Sava river by mixing hot water from the channel that cools TPP Nikola Tesla B was done using the Ansys Fluent program. A Semi-Implicit Method for Pressure-Linked Equations (SIMPLE method) in numerical simulations is used. The geometric model and discretization mesh were created in the Gambit program. The grid consists of 58 000 elements, all of which are rectangular Quad Map. Around the walls of the river and in the part of the connection of the canal with the river, where are a mixing of water in the river itself and water from the channel, the network is additionally densified.

In this paper, the Sava river is considered together with the hot water channel coming from TPP Nikola Tesla B. The problem was considered for the summer period when due to high temperatures, the temperature of the Sava river increases, and at the same time, the river flow decreases. At the location of TPP Nikola Tesla B, the Sava river is 400 m wide. The problem of thermal pollution was considered at a length of 1 km. The hot water channel is 6m wide and 400 m long. The angle that forms the channel with the Sava river is considered for five positions. The mathematical model of thermal pollution based on Reynolds-averaged Navier-Stokes (RANS) equations were developed in [18]. The temperature of the Sava river was considered 22°C. This is the average temperature of the Sava river for the period from June to October. With the operation of a thermal power plant, the water is heated to 10°C. The results of numerical simulations are shown in Table 2.

Table 1

Parameters used in the main scenarios

Scenario	Velocity channel v_1 (m/s)	Velocity Sava v_2 (m/s)	Water flow channel Q_1 (m^3/s)	Water flow the Sava Q_2 (m^3/s)	Channel temperature t1 (K)	River temperature t2 (K)
1	1	1	6.003334	400	305	295
2	2	1	12.00667	400	305	295
3	3	1	18.01000	400	305	295
4	4	1	24.01333	400	305	295
5	5	1	30.01667	400	305	295

Table 2

River temperature of the mixed water under different angles downstream the junction area

Scenario	Angle 30 (deg) dT (°C)	Angle 60 (deg) dT (°C)	Angle 90 (deg) dT (°C)	Angle 120 (deg) dT (°C)	Angle 150 (deg) dT (°C)
1	0.27791	0.29734	0.35043	1.08903	1.35245
2	0.3936	0.49922	2.07418	1.58468	1.56437
3	0.44351	0.62914	1.87699	1.8286	1.93911
4	0.46053	0.67338	2.08654	2.07335	2.41308
5	0.46495	0.70412	2.35987	2.26189	2.70783

Based on the results, it can be concluded that when the angle at which the hot water channel flows into the Sava river increases, the temperature of the river itself increases after mixing. When planning the construction of a thermal power plant, the angle of discharged channel should be planned at an angle of 30 degrees. Figure 1 presents a comparations of temperature differences at different outlet angles in the diagram. Q_1.

The following figures from 2 to 6 show the temperature fields for 30, 60, 90, 120 and 150 degrees.

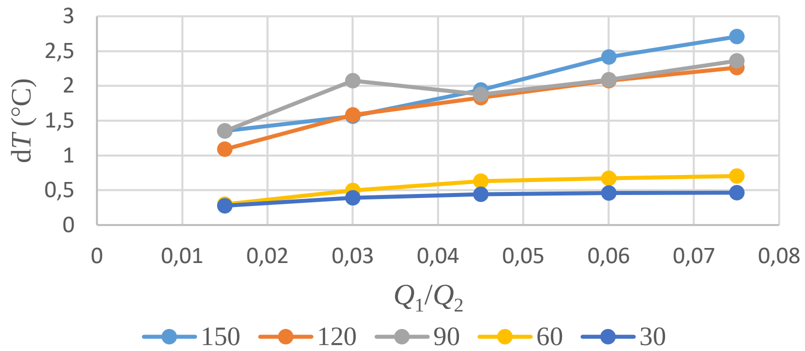

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Fig. 1. Comparations of temperature difference at different outlet angles

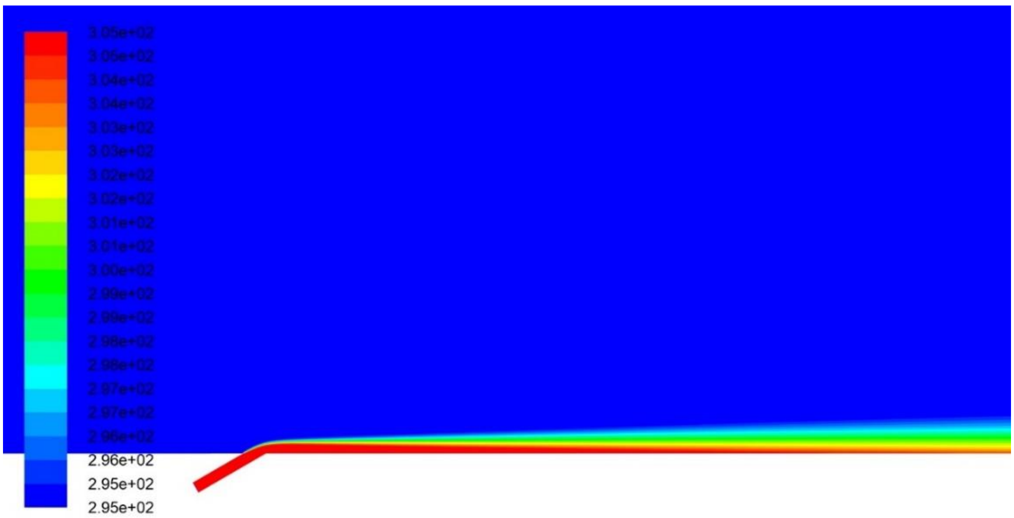

Fig. 2. Temperature contours for 30 degrees

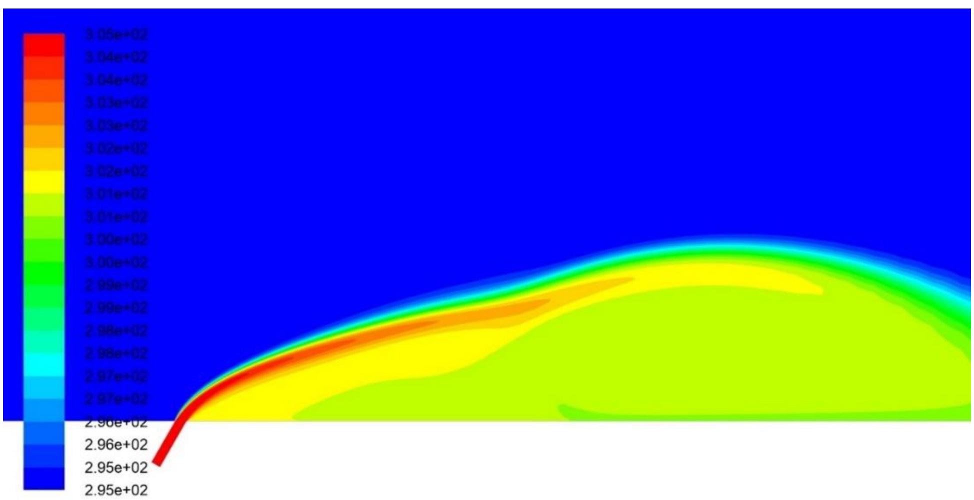

Fig. 3. Temperature contours for 60 degrees

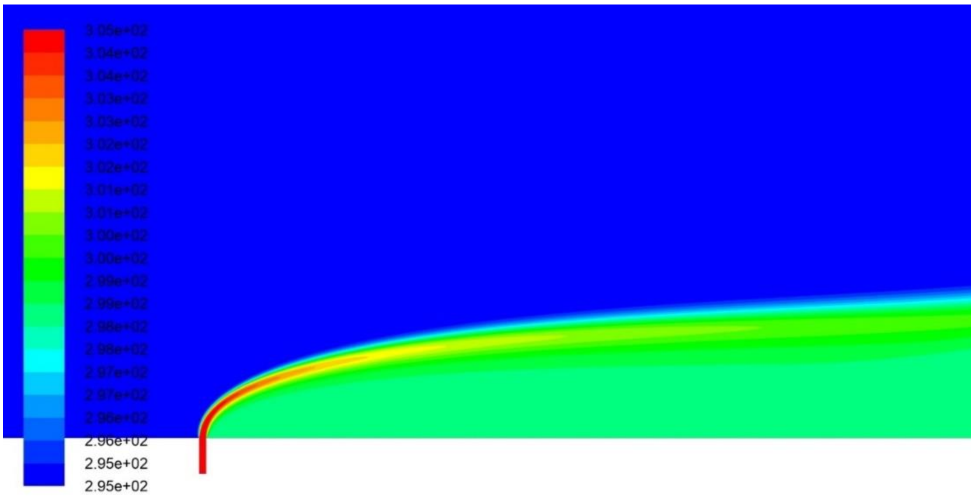

Fig. 4. Temperature contours for 90 degrees

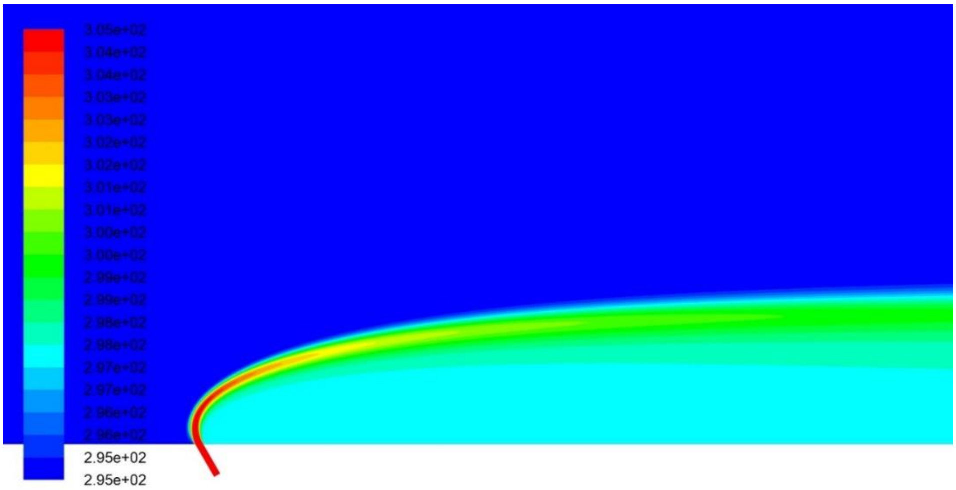

Fig. 5. Temperature contours for 120 degrees

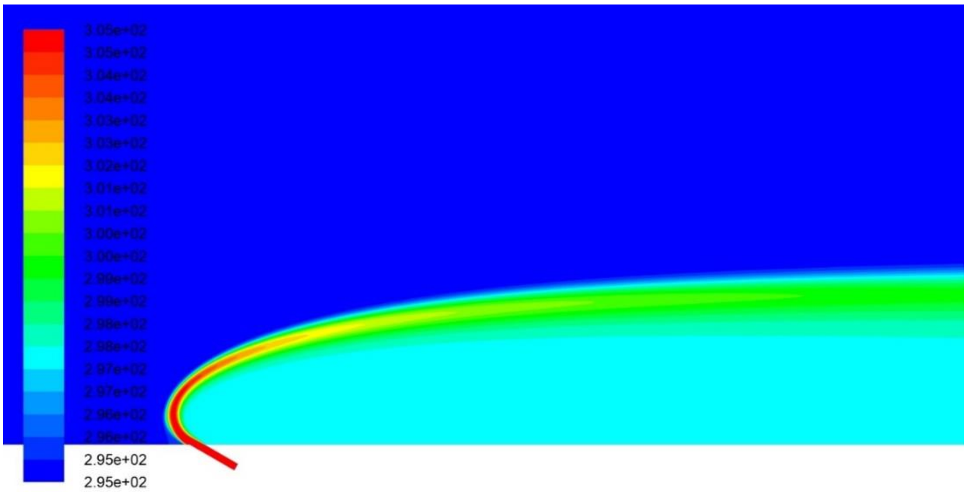

Fig. 6. Temperature contours for 150 degrees

An example of the inflow channel of hot water into the Sava river is shown when it is located on the bank of the river. The numerical simulations led to the conclusion that thermal pollution occurs along the bank itself if the inflow channel has a sharper angle. When it comes to an angle that is greater than

90 degrees, it was concluded that in that case there is local thermal pollution in the wider area of the river. By comparing the temperature fields, the analysis showed that thermal pollution is more pronounced when the angle of the channel with hot water is greater.

CONCLUSION

The dependence of thermal pollution and the outlet angle of the hot water channel is analyzed in this paper. The Nikola Tesla B thermal power plant was used as a reference model. This thermal power plant uses the water of the Sava river as a cooling medium. An increase in the temperature of the Sava river to a distance of 1 km downstream of the power plant was considered. The Ansys Fluent software package was used to obtain numerical simulations

The temperature field is gained in this paper by numerically simulating the thermal discharge with a two-dimensional model. The results show that the temperature range is related to the outlet angle and velocity of water in the channel. Specifically, the temperature range enlarges when velocity increases. Also, as the outlet angle increases, the thermal pollution becomes more pronounced. With the increase of the outlet angle, higher temperatures of the Sava river are obtained, and the temperature zone is also more affected. Namely, at an angle of 30 degrees, thermal pollution occurs only along the right bank of the river, while at an angle of 150 degrees, pollution occurs towards the middle of the river width.

Numerical simulations of thermal pollution of rivers are a very reliable and useful tool for analyzing the distribution of temperatures, velocities, and zones of mixing of two streams of water.

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