# Study of the Stratification Effect at the Reactor Installation in the Smolenskaya Area

**Thanh Binh Nguyen, Aleksey S. Shelegov and Igor A. Chusov**

**Abstract** This paper studies the Stratification Effect (SE) in the cooling basin for the Smolensk Nuclear Power Plant (NPP) and its dependence on the climatic condition. We investigated how climatic condition is the cause of the SE and analyzed all variations of the SE via program complex ANSYS-CFX. The obtained results were then compared to each other to assess the consequences of the possible impact of SE on the economy of the power units in its normal operation mode. The results indicate that SE happens when there is no cooling evaporation on the surface of the reservoir, moreover, air velocity greatly impact the SE, if the wind flows faster, the SE is less likely to appear, as the result, NPP has the better net efficiency.

**Keywords** Stratification effect · Smolensk NPP · NPP net efficiency

## 1 Introduction

When operating a NPP from many of its units, both main and auxiliary, it is necessary to divert a large amount of heat into the environment. The heat transferred to the environment is mainly carried out by water. For the operation of NPP, technical water supply is very important, in many ways determining the reliability and economic efficiency of the plant [1]. After discharging hot water into the environment, the warmer liquid does not mix with the cooler in the water basin—that phenomenon is called the SE. The SE possibly violates the normal operation of the NPP. In addition, the SE affects the economy of NPP. In order to assess the SE, the following works were performed for the Smolensk NPP site, located on the bank of the Desna river:

- Developing a model for the propagation of the heat flow of liquid into the water-cooling pool, taking into account the climatic conditions of the region.

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- Assessing the consequences of the possible impact of the SE in the normal operation mode of the power units on its economy.
- Executing a forecast of changes in water temperature in the river under different climatic conditions in the normal operation of power units.
- Calculating the impact of the SE on the profitability of NPP.

## 2 Climatic Condition and Hydrography of Smolensk Area

Smolensk region—the subject of the Russian Federation, is part of the Central Federal District. It borders with Moscow, Kaluga, Bryansk, Pskov and Tver regions of Russia, as well as with the Mogilyov and Vitebsk regions of Belarus. The climate of the area is temperate continental, in which:

- The average yearly temperature is in the range of [4.5, 4.8] °C.
- The wind speed in the warm period is in the range of [3, 4] m/s, in the cold period is [4, 5] m/s.
- The maximum temperature of the warmest month is July 34 °C, the minimum temperature of the coldest month is January −43 °C.
- The average annual relative humidity in Desnogorsk is 70%.

The purpose of water used in NPP is to take water resources from a river to cool the technological circuits of NPP, to compensate for irrecoverable losses and, accordingly, to generate electricity. The cooling systems of the technical water, designed to dispose unused heat for the production of electric power, represent a set of hydraulic structures, pumping stations, pipelines, and heat exchange equipment. The use of recycling water management system leads to an economical consumption of natural water.

The speed of the river flow varies depending on the season of the year. The greatest velocity during the spring high water and during the low water period, is up to 1 m/s on the rifts, and is about [0.3, 0.4] m/s on the reaches.

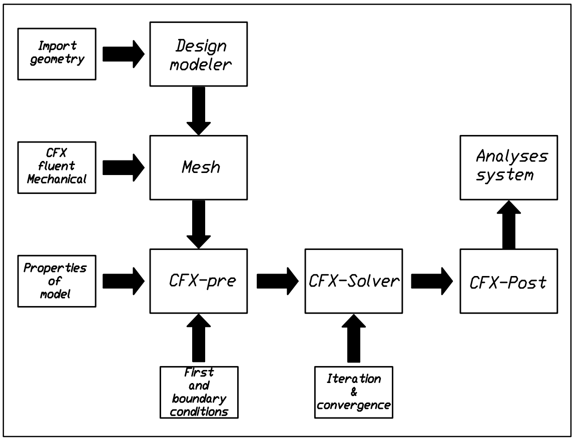



**Fig. 1** The scheme for setting and solving the problem using program ANSYS-CFX

# 3 Creating the Forecasting Model of the Smolensk NPP Area

## *3.1 Methodology*

In order to solve the problem, the program complex ANSYS-CFX[1] was used, which consists of 5 applications, between these applications there is an exchange of information flows that arise during the formulation and solution of hydrodynamic problems, the operating scheme of the complex is showed in Fig. 1.

## *3.2 Model of the Calculated Area*

For the numerical modeling of the Smolensk NPP and the Desna River, the task of external flow around the buildings of the NPP site was designed to develop a solid vector model of the site, accurate to the main production buildings. In our case, the enclosing space in the 6-kilometer zone of NPP area was considered. The solid model of Smolensk NPP area is shown in Fig. 2 with a scale of 1:10 and consists of 2 domains:

- Aerial area with a height of 20 m;
- Water area with a depth of 1 m.

[1]The license of the ANSYS simulation belongs to Obninsk Institute for Nuclear Power Engineering of the National Research Nuclear University MEPhI & authors are permitted to utilize the method for solving the problem in this paper.

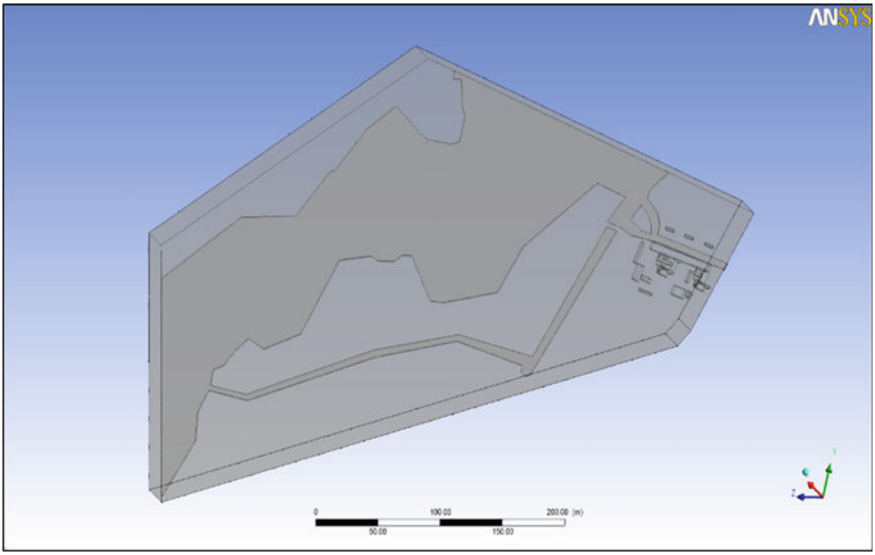



Fig. 2 The calculating model of the area

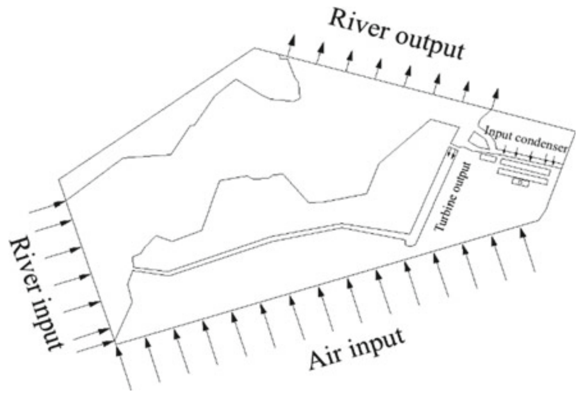
## 3.3 Boundary Conditions and First Conditions

Figure 3 indicates the boundary conditions of the problem, which illustrates the flow direction of the river, and the air. The picture also illustrates locations, where the hot water is disposed, and where the recycling water is inputed for the main condensers.

Next, we implied the first conditions based on the climate data, environment data and technical parameters of the Smolensk NPP:

- Air velocity $v_{air} = [0, 5]$ m/s, river flow velocity $v_{river} = 0.4$ m/s;

Fig. 3 Boundary conditions



- Water temperature at the outlet of the turbine is T = 35 °C, the temperature inside the river $T_{river}$ = 15 °C, air temperature: $T_{air}$ = {10, 15} °C;
- Intensity of evaporation of the water in the basin is $I_{evapor.river} = 10^{-9}$ g/s.
- Cooling water flow rate for K-10120 type capacitor $G_{turbine}$ = 23,000 kg/s, Smolensk NPP has 3 working units, so we get G = 69,000 kg/s, the model with a scale of 1:10, thus $G_{model}$ = 6900 kg/s.

# 4 Results and Discussion

In this section, we considered all of the possible variations of the SE by including various air velocity and two heat transfer methods—convection and cooling evaporation.

## *4.1 First Case—Heat Transfer by Convection*

The first case provided variants, in which the velocity of the fluid flow was 0.4 m/s, the velocities of the air flow were {0.5, 1, 2, 3, 4, 5} m/s with convective heat transfer and evaporation was neglected. The obtained results of all variations in the first case are showed in Fig. 4.

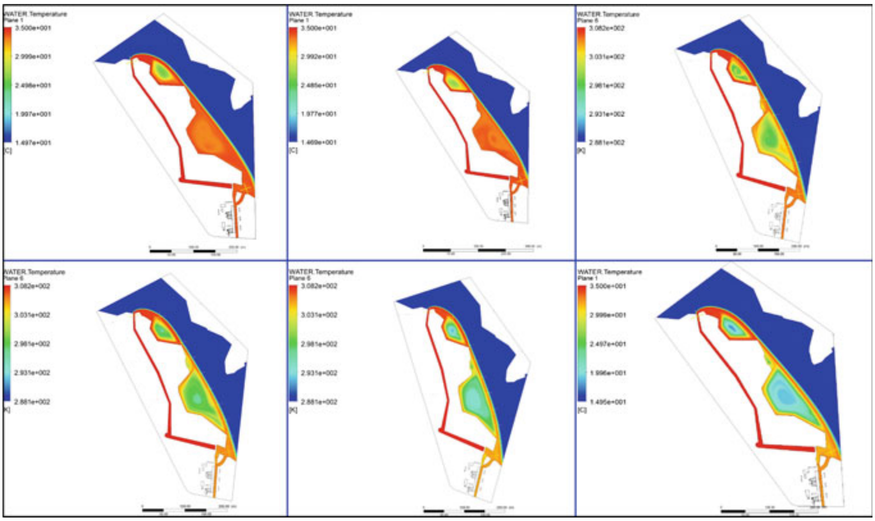


**Fig. 4** The SE with the air velocity $v_{air}$ was 0.5, 1, 2 m/s on the first row & 3, 4, 5 m/s on second row respectively

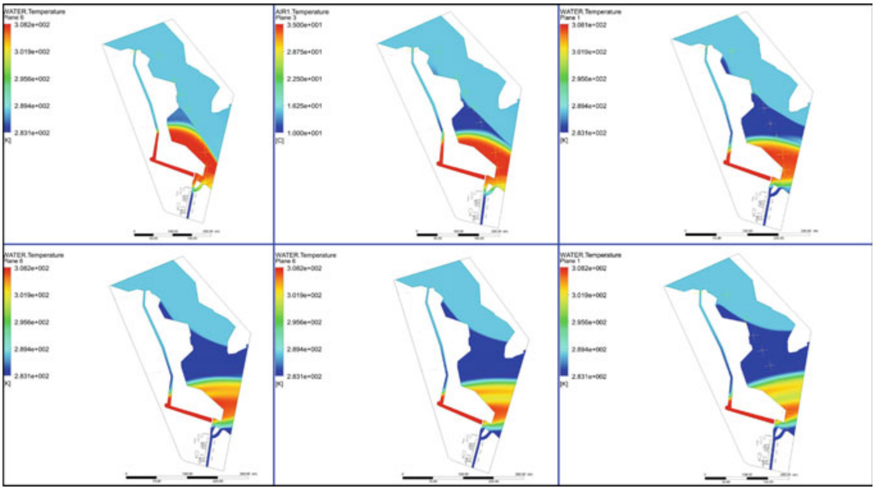


**Fig. 5** The effect with the air velocity $v_{air}$ was 0.5, 1, 2 m/s on the first row & 3, 4, 5 m/s on second row respectively

### *4.2 Second Case—Heat Transfer by Cooling Evaporation*

Next, with the same procedure, the second case provided calculating variants, in which the velocity of the fluid flow was 0.4 m/s, the velocities of the air flow were {0.5, 1, 2, 3, 4, 5} m/s with heat transferred by cooling evaporation (intensity of evaporation to the surface of the river is $10^{-9}$ g/s). The obtained results are showed in Fig. 5.

Figure 4 shows how the air velocity effects the SE. Based on the color shown, there are changes in water temperature correspond with the changes of the air velocity, the faster the air flows the less likely SE to appear. Based on the color change shown in Fig. 5, it is worth noting that if cooling evaporation happens, the SE has yet to be appeared, on the other hand, if heat is only transferred by convection, the SE will occur, another words, the more evaporated water the better heat transferred from the reservoir. However, the process of evaporation heavily depends on the climatic conditions of the area such as the wind and the humidity. For instance, if the humidity is close to saturation (90–95%), the water barely evaporates, water contains a vast amount of heat, as the result, the SE takes place.

## 5 Processing the Calculated Results

Several points were set in the river and temperature at each point were measured, an average value of which was then computed. Comparison of the average temperatures of two cases correspond with different air velocities is shown in Fig. 6.

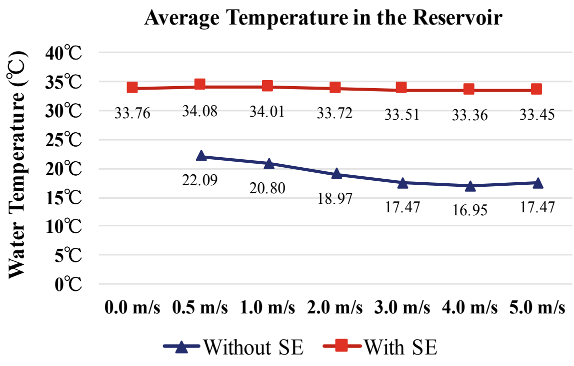



**Fig. 6** Average water temperature in the river in two cases

Next, the temperatures at the entrance of main condensers of the NPP complex was measured correspond with different air velocities, result of which is shown in Fig. 7.

The water used for condensing the post-turbine vapor plays an importance role in defining the efficiency of the power units. The cooler water input into the condenser, the better efficiency the NPP gets [2, 3]. In order to determine the impact of the SE on the economics of the NPP, we gathered a column chart, which shows the comparison of the net efficiency in normal condition and in the SE (shown in Fig. 8).

The graph shows that overall the NPP without the SE has better net efficiency than the NPP with the SE. Without SE, net efficiency barely depends on the air velocity, on the other hand, with the SE, the air velocity greatly impacts the NPP net efficiency.

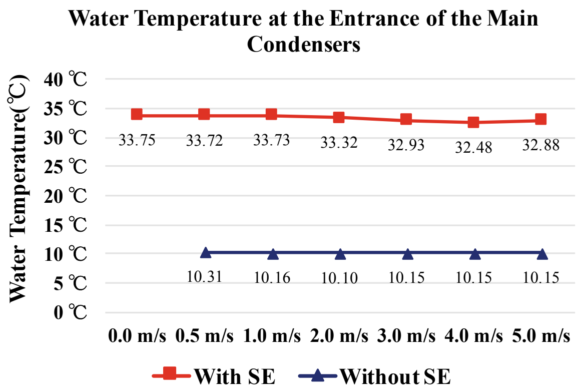



**Fig. 7** Water temperature at the entrance of the main condensers

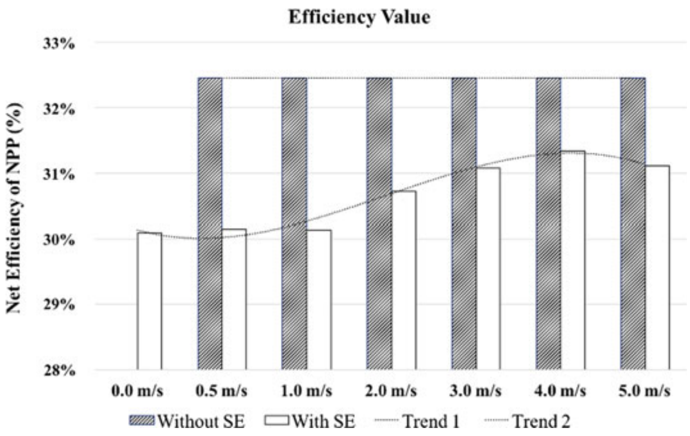



**Fig. 8** The net efficiency comparison of the NPP in normal condition and in the SE

## 6 Conclusion

The fluid stratification is common effect that we come across on a daily basis such as SE in water tanks, pools, basin, sea etc. This study has revealed how the climate would be a factor of the SE,[2] and the impact of the SE on the profitability of NPP. When looking at the bigger scenario, different parts of the world with diverse climates, SE would occur in various way. The places for construction NPP should be researched carefully and have appropriate climatic conditions to reduce the impact of the SE, moreover, a desired profitability is achieved.

This study has unwrapped the preliminary version of the SE, however, it has created the foundation for further researches of the SE such as the SE between fluid layers of the cooling pools, the intensity of evaporation of the water surface of cooling basin, research the SE in various climatic conditions, etc.

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[2]In this study, the dependence of the SE on the wind was considered.