Heat Supply for the Power-Biological Complex from TPP and NPP

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Abstract. This work is devoted to the problem of utilization of waste heat from condensers of thermal power plants and nuclear power plants. The waste heat of the condensers of TPPs and NPPs, together with the circulating water, enters the environment, causing its thermal pollution. The use of this heat in an energy-biological complex, for example, in fisheries, increases their efficiency and solves an environmental problem. Compared to ordinary ponds, this energy complex has an almost year-round increase in biomass and accelerated maturation of producers. The article presents a developed methodology that makes it possible to assess the effectiveness of such a fishery. Calculations using this method were carried out for a fish farm raising sturgeons on the basis of the waste heat of a nuclear power plant with a VVER-1200 reactor and a K-1200-6.8/50 turbine

1. Introduction

For Russia with its cold climate (70% of the territory belongs to the regions of the North and equivalent regions), the prospect of using low-potential waste heat from energy facilities is very relevant. The existing experience of creating fish farms on waste waters of power plants shows their economic efficiency.

On the territory of our country, due to natural and climatic conditions, a large share of products in commercial fish farming falls on the summer. Winter in some fish breeding areas lasts 200-210 days. In the best case, the growth of fish stops, the fish lose weight. An alternative option for fish farming is warm waste water from thermal power plants and nuclear power plants [1].

2. Thermal emissions from TPPs and NPPs

2.1. Types of thermal emissions from TPPs and NPPs

The efficiency of modern nuclear power plants is approximately 30-35%. Most of the heat energy (65-70%) is emitted into the environment.

Part of the heat from the TPP enters the environment through the turbine condensers. At NPPs, all waste heat enters the environment through the turbine condensers, its amount is 1.7 times more than at TPPs [2]. Together with the circulating water, it is sent either to the cooling pond or to the atmosphere through the cooling towers. Let us now consider in more detail the situation with thermal pollution of nuclear power plants.
Nuclear power plants use for cooling cooling towers and cooling ponds. The flow rate of water cooling the turbine condensers is approximately 50 m$^3$/s per 1000 MW of electrical power, and its temperature should not increase by more than 10$^\circ$C. To remove such an amount of heat, it is necessary to have a surface area of the cooling reservoir of 10$^{-12}$ km$^2$ per 1000 MW, while the amount of water going for evaporation reaches 30 $\cdot$ 10$^6$ m$^3$/y.

2.2. Environmental damage from thermal pollution of waste heat from TPPs and NPPs

Economic losses are associated with the lack of utilization of a significant part of the generated energy. The release of heat through cooling systems causes economic damage in the region. Thermal pollution of the cooling reservoir changes the natural status of its ecosystem. The cooling ponds of nuclear power plants in Russia are mainly natural water systems. They should be subject to all environmental requirements for the protection of natural waters from pollution, including thermal pollution. The evaporation of large amounts of water changes the climate in the region, which leads to various consequences: increased corrosion of wires and equipment, icing and fog, deterioration of public health, etc.

When increasing the capacity of a nuclear power plant or building a new unit, it is necessary to take into account the already existing ecosystem in the area of the nuclear power plant. An increase in thermal power will require the adoption of additional measures to remove heat from the station:
1) Increase the area of the cooling reservoir (find a new one, build a dam).
2) Build new cooling towers.
3) Switch to a combined cooling system (cooling towers and cooling pond).
4) Find consumers of heat from nuclear power plants (for example, fish farming or agriculture) [4-9].

Waste waters of TPPs have a large complex of chemical pollution. The waste water from the nuclear power plant is practically clean. This increases their potential for use in the production of clean food.

3. Features of the use of cooling ponds

The One of the new areas of industrial fish farming is fish farming using waste water from thermal power plants [10].

The heated water of the TPP is discharged into cooling ponds or natural reservoirs. This water is used for growing fish in cage farms, basin farms, energy biocomplexes, fish hatcheries for raising producers.

3.1. Types of cooling ponds

The area of such reservoirs is 31-7100 hectares. Compared to conventional ponds, they are characterized by a longer period of optimal water temperature for fish. The growing season is extended by 90-120 days. The food supply in them is much higher in comparison with ponds. Variants of using cooling ponds: pond, lake.

3.2. Features of coolers

Small coolers are used as feeding ponds for the summer rearing of marketable fish. A distinctive feature of coolers is the impossibility of draining them in autumn. Fish are caught with active fishing gear with the maximum removal of their biomass. Coolers are stocked again in spring. Stocking density is calculated based on the natural food base.

3.3. Limitations on intensification measures and temperature

Application of intensification measures (fish feeding, fertilization) can lead to increased development of phytoplankton, pollution of the reservoir with soluble organic matter.

When organizing fishery on small coolers, it is taken into account that the water temperature in the bottom layers is not higher than 25 $^\circ$C.

The temperature requirements for different types of fish are different. For the main fish breeding object, heat-loving carp, the most favorable water temperature for its growth is 23-33C. This water temperature in the central zone of our country is observed only in July and August. Clary catfish only
live in warm water. If the temperature is below 15 °C, it will not survive. Trout, on the other hand, perishes at temperatures above 21 °C. It is necessary to set the cage lines so that the catfish live in a warm shallow water, and the sturgeon and trout - at the bottom, where the coldest water is [2].

In large reservoirs, an even temperature regime and a hydrochemical structure. To adjust the parameters, cleaning and disinfection installations, oxygen generators are used. It is necessary to clean the bottom of silt and algae, monitor the amount of vegetation in the reservoir [10-13].

3.3.1. Features of large chillers. Higher temperatures reduce the food supply for these chillers. The lake method is used in large coolers. In this case, the directional formation of the ichthyofauna is carried out. In some cases, juveniles of farmed fish are released into the cooler. In large reservoirs, there are areas with sufficient water temperature for some cold-water fish. The cultivation of herbivorous fish is especially important, due to which there is a decrease in the volume of phytoplankton and higher aquatic vegetation. Unlike small coolers, large ones capture only the annual increase in fish biomass. In pond farms, carp becomes sexually mature in the 3-5th year of life, depending on climatic conditions.

3.3.2. Formation of livestock in pond farms. Producers of herbivorous fish in pond conditions also have a long period of maturity. Under the conditions of warm waters, their accelerated maturation occurs. It is especially important to obtain breeders from herbivorous fish in the 1st-2nd fish breeding zones. Accelerated production of producers contributes to the formation of broodstock in pond farms.

4. Scheme of heat supply for fishery from TPP and NPP

4.1. Types of live fish plants
Live fish plants are the most promising way of using the warm waters of a thermal power plant, which can be applied to any water supply system of a power plant, regardless of its geographical location. The plant is a system of pools in which marketable fish (carp, trout) are grown in compacted plantings, a large flow of warm water and intensive feeding with artificial feed.

Live fish plants can be of a closed type, that is, indoors, and open. It is better to build only open-type factories, since in winter they use waste heat with insignificant heat transfer, and are also more economical in construction.

4.2. Pool arrangement
Taking into account the technology of fish farming and industrial construction methods, reinforced concrete pools of various sizes and depths of up to 1.5 m are designed. The total area of the pools depends on the amount of circulating water and ranges from 0.5 to 3-4 hectares. To locate a plant with all auxiliary services, a plot of land must exceed the area of the pools by 6-8 times and be from 5 to 25 hectares (when growing the same amount of fish in fish farms of the usual type, 80-100 times more land is required).

Pools are placed in parallel rows of 14-26 pieces, between which passages are made for serving fish. Warm water, depending on the terrain, is supplied to the live fish plant from the discharge communications of the TPP and NPP by gravity or with the help of a pumping station. The amount of water required for a fish factory is determined at the rate of 2 l/s per 1 centner of fish [14].

Cooling ponds are used where there is sufficient land to accommodate them, as an alternative to cooling towers or to discharge heated water into a nearby river or coastal bay (“through-cooling”). Figure 1 a and b shows the schemes of heat supply for the fishery with the use of a cooling tower and without a cooling tower.

4.3. Scheme of heat supply for a fishery with a cooling tower
In the heat supply scheme for a fish farm with a cooling tower (Figure 1a), part of the heated waste water after the condenser enters the fish farm, then into the cooling tower together with the main water
flow. In summer, water does not come from a condenser, but from a river or other natural or artificial reservoir.

4.4. **Fish farm heat supply scheme without cooling tower**

In the heat supply scheme for a fish farm without a cooling tower (Figure 1b), part of the heated waste water after the condenser enters the fish farm, then into the river, or another natural body of water, or into the cooling pond together with the main water flow. In summer, water also comes not from a condenser, but from a river or other natural or artificial reservoir.

**Figure 1.** Schemes of heat supply for fisheries. a) with a cooling tower; b) without cooling tower

1 - condenser; 2 - fisheries; 3 - river or other natural body of water; 4 - circulation pump; 5 - cooling tower.

5. **Methodology for calculating the heat supply system for the fishery from the condensers of the turbines of TPP and NPP**

5.1. **Space Temperature graphs of the heat supply system for the fishery from TPP and NPP**

To assess the efficiency of using waste heat from TPPs and NPPs for a given area of the fishery, the following variants of the temperature graphs of the heat supply system for the fishery (for sturgeons) were taken into account [15-19]:
1) autumn-spring 27/17°C;
2) winter 27/7°C.

5.2. **Necessary equipment for fisheries**

To ensure optimal conditions for growing various types of fish, it is necessary to provide a water supply installation with the following equipment: pumps, pools, aerators, nitrate filter, biological filter, fittings, drains and pipes, automatic feeders, a device for disinfection, measuring sensors for different tasks.

For storage and processing of finished products, it is necessary to have refrigeration, smoking and other equipment [20].

5.3. **Fisheries capex**

Investment in fish farming is equal to:

\[ K = k \cdot F \]  

Here \( k \) - is the specific capital investments in fisheries, rub./m²; \( F \) - is the total surface area of fisheries basins, m².
5.4. Annual costs of operating a fishery
The annual costs of operating a fishery are determined by:

\[ C = C_d + C_m + C_w \]  

(2)

where \( C_d \) - depreciation charges, amounting to 10% of capital investments in fisheries, mln.rub./y; \( C_m \) - maintenance costs, amounting to 10% of depreciation charges, mln.rub./y; \( C_w \) - costs of wages, mln.rub./y.

5.5. The amount of heat consumed by the fishery
The thermal power of the fish farm heat supply system is:

\[ q = \alpha \cdot (t_w - t_a) \cdot F + k \cdot (t_w - t_g) \cdot F_f \]  

(3)

Here \( \alpha \) - is the coefficient of heat transfer from water in a reservoir to atmospheric air, W/(m\(^2\)°C); \( t_w \) - is the water temperature in the reservoir, °C; \( t_a \) - is the temperature of the atmospheric air, °C; \( k \) - is the coefficient of heat transfer from water in the reservoir to the ground, °C; \( F_f \) - area of reservoir fences, m\(^2\).

The required amount of heat is determined by the following formula:

\[ Q = q_{s-a} \cdot \tau_{s-a} + q_w \cdot \tau_w \]  

(4)

where \( q_{s-a} \) , \( q_w \) - thermal power during spring-autumn and winter, MW; \( \tau_{s-a} \), \( \tau_w \) - duration of the heating period during spring-autumn and winter, h/y.

5.6. Initial data and calculation results according to the developed methodology
According to the developed methodology, calculations were carried out to assess the efficiency of heat supply to the fishery on the basis of the waste heat of NPPs with VVER-1200 and K-1200-6.8 / 50 turbine.

| Initial data for calculation according to the developed methodology | Designation | Dimension | The value of the quantity |
|---|---|---|---|
| Pond area | F | ha | 1.0 |
| Specific investment in fisheries | k\(s\) | rub/m\(^2\) | 33000 |
| Thermal power consumed by fisheries | q | MW | 2.46 | 4.08 |
| Heating duration | \( \tau \) | h/y | 4320 | 2160 |
| Temperature head | \( \Delta t \) | °C | 10 | 20 |
| The amount of consumed heat | Q | Gcal | 9137.35 | 7577.64 |
| Fisheries annual costs | C | mln. rub./y | 106.8 |
| Project results | R | mln. rub./y | 250.0 |
| Discounted payback period | \( \tau_{pp} \) | y | 2.3 |

Calculations have shown that for the third year of operation, the annual net income will be positive.

6. Conclusions
The analysis of calculations according to the developed methodology showed that the use of waste heat from TPPs and NPPs for heat supply to fish farms is very effective. In addition to solving the environmental problem with thermal pollution, it allows to increase the efficiency of the fish industry due to the year-round increase in the mass of fish and the accelerated receipt of producers. Calculations
showed that the discounted payback period of the project based on the use of waste heat from the NPP was 2.3 years.

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