THERMAL EFFECTS OF HYDROELECTRIC POWER STATIONS ON THE ENVIRONMENT

I. P. Safonov and A. N. Kovalenko

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The problem of "thermal contamination" of the atmosphere around active hydroelectric power stations is investigated. Using the energy and material balance equations for a steady-state incompressible liquid flow, it is shown that natural heat release from a water discharge is comparable with and, occasionally, exceeds the heat discharge of a thermal power station with an output equal to that of the HPS.

In recent years, in choosing the main directions of development of large-scale power generation, close attention has been given to ecological problems. In many cases conservative approaches are used: emissions of dust and toxic nitrogen and sulfur oxides from thermal power plants are analyzed. They can be measured and controlled relatively easily with the aid of well-established methods that have been employed by industrially developed countries for a long time. Hydroelectric power stations are considered to be the cleanest. Heat- utilizing stations (thermal power plants, atomic power plants) are, in addition, a source of "thermal contamination" of the atmosphere since more than half of the heat produced is transferred to the coolant. For HPS this factor is ignored. In our opinion, since the contribution of HPS to power generation is rather high, amounting to 20% [1], and their output can reach 5 to 6 million kW, in analyzing projects and integrated plans of developing regions, heat discharges from HPS cannot be neglected, since in some cases, in particular, in winter, they can exceed those from thermal power stations. In summer, on the contrary, active HPS usually remove thermal energy and reduce the temperature level of the environment. When the generated power is transmitted to remote areas, in particular, from Siberia to the European part, energy approximately proportional to the transmitted power is removed from the power generating region.

The above statement will be confirmed by tentative calculations, using the energy and material balances for steady-state incompressible liquid flows [2]:

$$\frac{N}{G}+\frac{\Delta P}{\rho}+\Delta(gZ)+\Delta\left(\frac{u^2}{2}\right)=\frac{Q}{G}-C_p\Delta T,\ \ G=\rho uF=\text{const.}$$

Analysis of the energy balance over a section with the difference of levels ΔZ between the initial flow section with the discharge G and the cross section where the velocity head is restored ($\Delta(u^2/2)=0$) shows that under adiabatic conditions ($Q=0$) for modern HPS with an efficiency of 90 to 96%, nearly the whole static head ($\Delta P = -\rho g\Delta Z$) is transferred to the power output (N/G).

Under natural conditions without power output ($N = 0$) the potential energy of dicharged water completely dissipates to heat, which is released ($Q_d = Gg\Delta Z = C_pG\Delta T$), increasing the system entropy ($\Delta S = C_pG\Delta T/T$) and the flow temperature proportionally to the difference of levels ($\Delta T = g\Delta ZC_p$).

It can easily be demonstrated that in such a case every 100 m of water discharge provide the water temperature rise $\Delta T = 0.23^\circ$, and operation of a HPS with a total output of $2.5\cdot10^6$ kW on a river with the circular flow rate G = 2550 ton/sec ($223\cdot10^3$ m^3/day) with the same 100-m head is equivalent to the heat power output $Q_d = 2150\cdot10^6$ kcal/h dissipated under natural conditions.

One can see that the natural heat release from a water discharge can be compared with the heat discharge of a large thermal power station with an output of 2000 to 25000 MW for the case considered. Heat removal from the steam power cycle of such a plant involves evaporation of about $G_i = Q_d/r = (2\text{-}4)\cdot10^3$ ton/h of water from the coolant, depending on the temperature head and the corresponding contribution of convection [3].

I. I. Polzunov Central Boiler and Turbine Institute Research and Production Organization, St. Petersburg, Russia. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 65, No. 1, pp. 95-97, July, 1993. Original article submitted October 24, 1991.

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Thus, a hydraulic turbine can be considered as a kind of heat engine that substitutes for natural heat scatter by waterfalls and (similarly to steam turbine plants) disturbs the temperature and evaporation regimes of the water resources used. The fact that the heat removal in this case is local and the huge water mass is concentrated in reservoirs constructed near HPS is essential for increasing the scale of such disturbances.

Extensive water surfaces and high amounts of stored water result in substantial temperature stratification over the depth (from within the wet thermometer temperature range at the surface to the temperature of the maximum density of +4°C for deep layers [1]). In summer and autumn it causes a noticeable water temperature decrease and earlier stream water freezing, while in winter the discharge of warmer water downstream gives rise to unfrozen river surfaces over several kilometers. Even in a severe Siberian, winter (in particular, in the Krasnoyarsk region) their specific area (the ratio of the water table and the circulation flow rate), calculated following [4], amounts to at least $\omega = \Omega/G = 0.35\text{-}0.4\ m^2/(m^3/day)$ with account of the decrease of the surface temperature of the discharged water from -4° to $0^{\circ}C$ (a decrease of the temperature of the medium depth from +4 to $+2^{\circ}C$). For the case considered, the active nonfrozen downstream water area is about $\omega = \Omega G = 70\text{-}78\ km^2$ and the heat flux transferred to the environment will be $Q_d = C_p G \Delta T = 18360 \cdot 10^6$ kcal/h.

In a general statement it is necessary to take account of many other factors, in particular, changes of the incident and reflected solar energy fluxes, increase of the radiative and convective heat transfer surface area, etc. These increase the scale of the impact of an HPS on convective and evaporative heat transfer to the atmosphere by about an order of magnitude as compared to the case of a "pure" power output.

It should be noted that a cascade construction of a large HPS [5] with typical parameters tentatively corresponding to those used in the present examples increases the quantitative results 4 or 5 times.

The above estimates indicate a substantial effect of HPS operation on the thermal regime in the region where the station is located. Evidently, this should affect primarily the climate of the region, which becomes warmer in winter and cooler in summer.

Corresponding changes will occur in the downstream areas too, because there the mean mass temperature of the coolant and, consequently, the heat release will change. In particular, local winter heat emissions in the downstream areas reduce the mean mass temperatures and the thermal potential of the rivers far from the zones of disturbance. This, in turn, induces relative cooling of the climate in the areas located downstream of the cascade of a hydropower plant (except for the above-mentioned local areas of heavy heat emissions). The last circumstance can make navigation very difficult in the mouths of Siberian rivers and the sea coastal waters.

No doubt, the factors discussed above also influence the formation of atmospheric phenomena, although it is extremely difficult to estimate this influence. It is manifested indirectly in the observed increase of air humidity and the total amount and frequency of atmospheric precipitation in the coastal areas of large reservoirs, in fogs, less steep diurnal and seasonal temperature variations, altered wind roses, and other factors typical of the transition from a continental to a marine climate [1]. All these can substantially complicate the ecological situation in a combination with harmful industrial emissions.

Thus, it can be concluded that in comprehensive analysis of future power construction, development of various regions in the country, simulation of global atmospheric processes, and estimation of negative effects of climatic changes, the thermal action of HPS and water structures should necessarily be taken into consideration.

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